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AN OPERATIONAL RESEARCH INVESTIGATION OF THE ICE-DETECTION CAPABILITY AND UTILITY OF THE SURFACE CONDITION ANALYZER (SCAN) SYSTEM AND ITS APPLICABILITY TO NAVY-WIDE USE

by

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Prepared for:

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During 1978, Calspan Corporation conducted an independent research investigation of the basic principles and operational performance of the Surface Condition Analyzer system (SCAN)^{TM*} in the detection of icing conditions on runway surfaces and its applicability to Navy-wide use. The results and conclusions derived from this investigation were formulated from data and information garnered from the following sources: site visits and interviews at civil and Naval airfields where SCAN is installed; visits

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CONT

and discussions at the manufacturer's plant; strip-chart records of actual SCAN-output signals, correlated with visual inspection of runway and sensor surfaces, runway traction, and display terminal readouts, obtained during a two-week operational performance study at Keflavik NAS; study of the manufacturer's drawings and schematics; review of the literature on snow and ice removal and control (SIRC) operations and economic analyses of these procedures as impacted by SCAN; and climatological analyses. The principal conclusion was that, while SCAN will not supplant routine personal inspection of runways, SCAN's ability to provide, on occasion, advance warning of hazardous icing conditions coupled with its surface temperature information (used for more effective chemical application) makes it well worth the investment costs.

PREFACE

The evaluation of the Surface Condition Analyzer (SCAN) system and opinions regarding the system presented in this report were formulated on information gathered primarily during early 1978. Information acquired at that time included users' opinions which were likely based on several years' experience with early versions of the system. Since its inception, the manufacturer has continued development of the system, adding "improvements" and replacing sensors in existing systems at no cost to the owners. Since early 1978, sensors and processing electronics have been replaced at four civil airfields, and initial reports indicate improved reliability.

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ACKNOWLEDGEMENTS

The authors are indebted to a great number personnel in the Air Operations, Field Maintenance and Accounting Departments of the visited airfields for their time and cooperation in the interviews and inspections conducted during this effort. In particular, we acknowledge the outstanding hospitality, cooperation and assistance of Fire Department and Naval Weather Service personnel at Keflavik: Sveinn Eiriksson, Fire Chief; Halldor Halldorsson, Runway Inspections and Arresting Gear Officer; and Cdr. Thomas Nelson, Officer-in-Charge, Naval Weather Service. We also wish to acknowledge the thoughtful and helpful advise provided by Roland J. Pilié, Head of the Environmental Sciences Department at Calspan, throughout the many phases of this effort. The manuscript was typed by Mrs. Marilyn Handley and Mrs. Linda Branden.

Section 1

INTRODUCTION AND SUMMARY

During the past year under Contract No. N00014-78-C-0284 from the Office of Naval Research, Calspan Corporation has been conducting an operational research investigation into the feasibility of utilizing the Surface Condition Analyzer (SCAN)* system as an indicator of airport runway conditions with respect to icing and/or hydroplaning situations. The principal tasks of this effort are as follows:

(1) Investigate the basic principles of the SCAN system and provide independent opinions regarding the conceptual design and electronic and mechanical engineering.

(2) Evaluate the overall performance and applicability of Navy-wide use of the SCAN system for runway ice control.

(3) Evaluate the potential applicability of a system capable of monitoring runway water depth and relating those measurements to runway traction.

The manufacturer now has separate configurations of the SCAN system--one for ice detection and one for water-depth measurement. Currently, only the ice detection system is commercially available, and systems of from 1 to 4 sensors have been installed at the following airfields**: Keflavik NAS, Scott AFB, Trenton (Ontario) CFB, Anchorage, Cincinnati, Detroit, Indianapolis and Kansas City. (Approximately 10 additional civil airports in the U.S. are planning procurement of ice detection systems.) The results of an operational research evaluation of the ice-detection system are presented in this report. Evaluation of the water-depth measurement capability and its potential utility will be provided under separate cover.

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*Manufactured by Surface Systems, Inc., St. Louis, MO 63144.

**SCAN systems have also been delivered to Chicago (O'Hare) and Pittsburgh, but these systems are not yet fully operational.

The overall evaluation of the performance, utility and applicability of the SCAN system to Navy-wide implementation encompassed four general areas of investigation: (1) study of the basic operating principles, conceptual design and electronic and mechanical engineering of the system; (2) investigation of the system's operational performance; (3) analyses of the economics of SCAN ownership vs. snow and ice removal and control (SIRC) practices impacted by SCAN; and (4) climatological review of Naval installations. The results and conclusions derived from this investigation, as summarized below, were formulated from data and information garnered from the following sources: site visits and interviews at civil and Naval airfields where SCAN is installed; visits and discussions at the manufacturer's plant; strip-chart records of actual SCAN-output signals, correlated with visual inspection of runway and sensor surfaces, runway traction, and display terminal readouts, obtained during a two-week study at Keflavik NAS; study of the manufacturer's drawings and schematics; review of the literature on SIRC operations and economic analyses of these procedures as impacted by SCAN; and climatological analyses.

Briefly summarizing, the principal findings of this investigation are as follows: (a) the SCAN system is designed and constructed to good commercial practice and could be made to meet military specifications with a minimum of effort; (b) the radiation color, surface roughness and porosity of the sensors provide only a fair approximation of the runway surface and may give rise to false alarms and erroneous indications of surface condition; (c) there is no doubt that the sensor can detect the presence of water/ice and provide a reliable measure of surface temperature; (d) for at least the one sensor that was monitored, SCAN was incapable of detecting the phase of water/ice on the runway; surface temperature was used to define water phase; (e) in terms of SIRC operations, surface temperature is the only information unique to SCAN; SIRC personnel make constant personal inspections of runway surface conditions, keeping abreast of current and forecast weather conditions; (f) unfavorable experience with false alarms and erroneous indications, coupled with the SIRC supervisor's preemptory knowledge of runway surface conditions, have rendered the surface-condition readouts untrusted, generally unnecessary for most icing situations, and generally unused at many airfields visited even though on occasion the SCAN system does provide information on icing conditions which are unexpected and otherwise undetected by SIRC personnel; (g) surface temperature data supplied by SCAN can be an important guide in the efficient and timely application of ice-control chemicals, and this information is utilized in some SIRC operations; (h) in terms of economics at 1978 prices, the SCAN system can be cost effective; the economics of airport availability and safety were not within the scope of this evaluation but could easily exceed the cost of SCAN ownership.

In short, for snow and ice control on an airfield runway, the SCAN system is usually used as an expensive, albeit cost-effective and important, thermometer. Utilized to its fullest potential, SCAN surface temperature information could effect significant savings in costs associated with ice-control chemicals and improved airport availability and safety at airfields where significant quantities of ice-control chemicals are employed.

The SCAN system will not supplant the need for frequent visual and traction-measurement inspection of runway surfaces; however, it can on occasion provide advance warning of hazardous icing conditions, thereby enhancing airfield safety and availability.

Within the body of this report, detailed discussions of the engineering, performance and economics of the SCAN ice-detection system are provided in Sections 4, 5 and 6, respectively. Climatology considerations are discussed in Section 7, and a brief review of the literature on SIRC practices is provided in Section 3. An Executive Summary, incorporating the principal conclusions and recommendations derived from this investigation, is presented in Section 2. Additional background information is provided in Appendices A, B and C.

Section 2

EXECUTIVE SUMMARY
and
RECOMMENDATIONS

During 1978, Calspan Corporation conducted a research investigation of the basic principles and operational performance of the Surface Condition Analyzer system (SCAN)^{TM*} in the detection of icing conditions on runway surfaces and its applicability to Navy-wide use. The results and conclusions derived from this investigation, as summarized below, were formulated from data and information garnered from the following sources: site visits and interviews at civil and Naval airfields both where SCAN is installed and where SCAN is not used; visits and discussions at the manufacturer's plant; strip-chart records of actual SCAN-output signals, correlated with visual inspection of runway and sensor surfaces, runway traction, and display terminal readouts, obtained during a two-week operational performance study at Keflavik NAS; study of the manufacturer's drawings and schematics; review of the literature on snow and ice removal and control (SIRC) operations and economic analyses of these procedures as impacted by SCAN; and climatological analyses.

2.1 Background

The SCAN system consists of three separate components: (1) a number of sensors; (2) remote processing units (RPU), and (3) a display terminal. The sensors, imbedded flush with the runways are connected to the RPU's by a cable, while information may be transmitted from the RPU's to the display terminal by either cable or radio telemetry.

The sensor unit is an epoxy, hockey-puck-shaped disk (∿5 inches in diameter and 1.1 inches thick) which is mounted flush with the runway surface and comprised of three separate components: (1) a thermistor for surface

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*Manufactured by Surface Systems, Inc., St. Louis, Mo. 63144 temperature measurements; (2) two metal strips exposed on the surface for conductivity measurements; and, (3) a proprietary configuration which measures, via a capacitance measurement, the permittivity of the space above the sensor. The design basis for these measurements is the dependence of measured values of permittivity and conductivity on the presence and phase, respectively, of water on the surface of the sensor. According to the manufacturer, measurements of permittivity detect the presence of water, ice, or snow on the sensor, and the phase of the water is determined by conductivity measurements. Since the presence of chemicals can significantly affect these measurements (e.g., pure water has very low conductivity while tap water typically has a high conductivity) each system is "calibrated" for the most likely aqueous chemical solution it will encounter in actual operation.

The information gathered by the sensors is processed at the respective RPU's and relayed to the display terminal which is generally located in a Fire House or Maintenance building. The information presented by the display terminal consists of a five digit display showing air temperature (obtained from one thermistor mounted in the air generally near the building containing the display terminal), runway surface temperature, and the identifying number of the sensor currently being monitored. Four prominent display lights indicating the discrete state of the runway surface are mounted above the five digit display. These lights display either: (1) CLEAR (dry); (2) WET; (3) ALERT; or (4) HAZARD (ice).

2.2 Conclusions and Recommendations

The SCAN system is designed and constructed to good commercial practice and could be made to meet military specifications with a minimum of effort. Installation, however, is haphazard probably as a result of improper installation procedures by airfield maintenance personnel and, therefore, should be performed by SSI personnel. In addition, the radiation color, surface roughness and porosity of the sensors provide only a fair approximation of the runway surface and could be improved to more closely match the runway surface.

An apparent drift in the electronics between the RPU and display terminal, for the one sensor monitored at Keflavik, caused displayed temperature to read ~4°C warmer than actual sensed surface temperature -- a potentially serious, but correctable, error for effective and timely implementation of anti-icing strategy.

As advertised, the SCAN ice-detection system measures surface temperature, permittivity of the space immediately above the sensor (for detecting the presence of ice, snow or water), and conductivity between two electrodes on the surface of the sensor (supposedly for distinguishing the liquid from the ice phase). There is no doubt that the permittivity sensor can detect the presence of water and ice except in situations of very light, low density snow or frost. However, for the one sensor monitored at Keflavik, the distinction between liquid water and ice was based solely on surface temperature (sensed, not displayed) even though the conductivity sensor appeared to be functioning properly. Logic circuitry in the system apparently neglects the conductivity data.

Of 16 SCAN-related, runway-condition events identified during two weeks at Keflavik, 25% were false alarms, 25% were failures to detect or warn of hazardous runway conditions, 19% were correct indications of wet runways, and 25% were proper indications of icing conditions. For two of the four detected icing events, the SCAN system provided advance warnings which prompted runway inspection and SIRC activities, thereby enhancing airfield safety.

The information displayed by the SCAN system (i.e., surface condition and temperature) is utilized to a greater or less extent at various airfields depending on SIRC strategy, severity of weather, demand on SIRC operations, and past experience with the SCAN system. In terms of SIRC operations, surface temperature is the only data unique to the SCAN system, and it is generally used. Personnel in charge of SIRC keep abreast of weather (both current and forecast) and make routine, first-hand inspections of runway surface conditions; they generally know current weather and what to expect in the immediate future. At the airfields where SCAN is installed, the condition indicators are not used unless they indicate unexpectedly; but even then false alarms and discrepancies between actual and indicated surface condition have lead to distrust of the indications. However, an unexpected indication of ALERT or HAZARD will generally prompt a personal inspection of the runways.

Surface temperature data supplied by SCAN, if accurate, can be an important guide in the efficient and timely application of ice control chemicals and are used to some extent by SIRC personnel. However, the forecast capability of the trend in surface temperature is not utilized to its fullest potential.

In terms of economics, airport availability and safety considerations, the proper application of chemicals is the key element to SCAN utility and cost effectiveness. Mechanical procedures are dependent on meteorological conditions and are not significantly impacted by SCAN. The costs of chemical application are dependent on the size of runway to be treated and the costs of the chemical themselves. For anti-icing a 10000 ft runway, one application of urea costs ∿$800, while one application of UCAR costs ∿$2500 (at 1978 prices); chemical costs for de-icing are 3 to 5 times greater. Thus, for a 10000 ft runway using UCAR, the annual cost of a 3-sensor SCAN system would be matched by the costs involved in the failure to anti-ice in a timely manner on only one occasion. For a similar airfield using urea, the costs involved in failure to anti-ice on only 6 occasions would equal the annual amortized cost of SCAN. Savings from avoiding unnecessary (surface temperature > 32°F) or ineffective (surface temperature < 18°F) applications of chemicals, if avoided 6 and 10 times, respectively for UCAR and urea, would match the annual cost of SCAN ownership. The economics of safety and airport availability were not within the scope of this evaluation but could easily exceed the cost of SCAN ownership.

In summary, the SCAN system is capable of providing, on occasion, some advance warning of hazardous icing conditions, thereby enhancing airfield safety and availability. More often, however, the precursor meteorological conditions which ultimately give rise to icing events will result in false alarms from the SCAN system. Since a false alarm results only in an unnecessary personal inspection of runways by SIRC personnel who are already on duty and in view of the costs involved in damage to even one aircraft, the information provided by

SCAN for these infrequent unexpected events, regardless of the frequency of false alarms, is well worth the investment costs of a SCAN system at airfields subject to frequent icing conditions and servicing of high performance aircraft. The SCAN system, however, will not supplant the need for frequent visual and traction-measurement inspection of runway surfaces.

A limited climatological study was conducted to determine which, if any, Naval Air Stations could potentially benefit, based on weather considerations, from a SCAN system. Of 76 Naval installations, 10 were found which experienced > 0.1 inches of snow on each of more than 10 days during the winter (December through March) and at least one winter month in which mean minimum temperature was < 32°F. These Naval installations and their mean winter season temperatures are as follows: Adak, Alaska (34°F); Brunswick, Maine (25°F); Glenview, Illinois (28°F); Lakehurst, New Jersey (35°F); Keflavik, Iceland (33°F); Misawa (Honshu Is.), Japan (32°F); Quonset Point, Rhode Island (33°F); South Weymouth, Mass. (30°F); and two Antarctic stations (-15°F in the Southern Hemisphere winter). Approximately half of these airfields experience snowfalls exceeding 1.5 inches fewer than 10 times per year. Without additional experience with the SCAN system, it does not seem appropriate to consider installation at airfields with less severe weather conditions than these.

More detailed climatologies for Adak, Brunswick and Keflavik revealed the following: the percentage of winter season observations with precipitation at temperatures ≤ 32°F is 9%, 9% and 7%, respectively, for the 3 stations; and for precipitation at temperatures > 32°F, the percentages are 27, 8, and 18%, respectively. These data suggest that Adak is wetter and warmer than Keflavik and that Brunswick is dryer and colder than Keflavik. In addition, a runway-freezing model (i.e., precipitation at air temperatures > 32°F and subsequent cooling to below 32°F) based on data obtained during the visit to Keflavik suggests that the seasonal number of runway freezing events after precipitation is similar for both Brunswick and Keflavik (ie., with upper limits of 16 and 21, respectively). Data are not available for Adak. These data suggest that runway freezing may be as important for SIRC activities as is snowfall, and this was certainly true during our observations at Keflavik. Thus, from climatological considerations alone, it appears that, given sufficient aircraft activity, it would be cost effective to install SCAN systems at the three airfields of greatest interest to Navy and perhaps at the other five airfields listed above.

Finally, the utilization and need of even a perfectly-functioning SCAN system is dependent on the mission and other safety considerations at individual airfields. Particular Navy interest centers on Adak and Brunswick. Interviews with operations personnel at these airfields indicate that their requirements for SIRC activity are significantly less stringent than at Keflavik, which is on a constant "alert" status with high performance aircraft. At Brunswick and Adak, flights can frequently be scheduled around serious runway icing conditions. Further, the primary traffic at these two airfields involves P-3 aircraft which can perform effectively and safely with significant snow accumulation on the runway. In addition, Adak currently uses no chemical for ice control, and Brunswick estimates annual costs for chemicals at only $12000. Brunswick and Adak, therefore, currently have little need for such a system. In times of military alert, when the strategic importance of these airfields is increased, such a system could affect a significant improvement in airfield availability and safety (as well as reduced costs for ice control chemicals).

We are not familiar enough with the missions of the other five airfields listed above to be able to make firm recommendations.

Section 3

LITERATURE REVIEW OF RUNWAY TRACTION MANAGEMENT UNDER ICING CONDITIONS

3.1 Introduction

Any amount of moisture, frozen or unfrozen, on a runway surface can be critical to the manageability and safety of aircraft. At speeds where the pilot can still control the aircraft through manipulations of the thrust, flaps and rudder, tire traction is not critical. However, below a critical airspeed which is dependent upon aircraft type as well as crosswind conditions, it is essential that tire traction be sufficient to allow the pilot to direct and stop the aircraft. With more modern aircraft, this critical speed has climbed higher, requiring that runway surfaces be in better condition (i.e., modern aircraft are more susceptible to loss of control on icy or wet runways). Airport managers, both civilian and military, have responded to this need by an escalation in the use of expensive and sophisticated snow and ice removal and control (SIRC) equipment as well as the use of chemicals.

In an effort to minimize the expense involved with SIRC operations, many airport managers are installing ice detector sensors in the runway surface. It is their belief (as well as being heavily advertised by manufacturers) that the application of expensive chemicals may be averted in several instances per year when they would otherwise have been applied for conditions outside their operational range.

3.2 Measurements of Runway Surface Conditions

- Traction

Measurements of the runway surface condition (i.e. effective traction coefficient) are of particular importance in ascertaining the immediate need for SIRC operations as well as a quantitative criterion for determining that SIRC operations have been effective and are no longer necessary. Friction measuring devices which are incorporated into ground vehicles or towed behind them at preselected speeds represent the most common method for characterizing the condition of runway surfaces. Two studies (Horne and Tanner, 1968*; and Sugg, 1968**) jointly funded by NASA and the British Ministry provide extensive information on available devices of this type. Unfortunately, none of the devices has been accepted as a standard means of assessing the conditions of a runway surface. As a result of the use of different types of devices (if any) at various airports or Naval Air Stations, pilots are faced with quantitative information which may or may not be consistent with that provided at other airports.

A comparison of runway traction coefficients (as measured by MU-Meters and Tapley devices) with runway condition (RCR) as measured by a James Brake Decelerometer, along with equivalent braking action and increased stopping distances for F-4 aircraft, is provided below:

Traction Coefficient vs. RCR

MU-Meter Value	Tapley Value	Equivalent RCR	Braking Action	Approx. increased stopping distance for F-4's
≥0.40	≥66	≥20	Good	10%
0.39-0.36	54-63	16-19	Good-Fair	15%
0.35-0.30	36-51	10-15	Fair	46%
0.29-0.26	25-32	6-9	Fair-Poor	75%
≤ 0.25	≤ 22	≤ 5	Poor	100%

- Ice Detectors

The two most important factors that determine critical runway surface conditions are surface temperature and the presence of moisture. The surface

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*Horne, W.B., and J.A. Tanner, 1968, "Joint NASA-British Ministry of Technology Skid Correlation Study: Results from American Vehicles," Pavement Grooving and Traction Studies, NASA SP-5073.

**Sugg, R.W., 1968, "Joint NASA-British Ministry of Technology Skid Correlation Study: Results from British Vehicles," Pavement Grooving and Traction Studies, NASA SP-5073.

temperature is generally measured with a thermistor buried slightly beneath the runway surface. Techniques used to detect moisture are less general and may consist of measurements of conductance, capacitance, temperature changes, humidity, or optical properties of the runway surface. If it were not difficult enough to determine the presence or state of moisture under ideal conditions, the problem is often significantly compounded by dirt and oils and by the use of chemicals whose concentration can directly affect any or all of the above measurements.

A study performed for the Federal Highway Administration (Glauz et al, 1971*) surveyed some 22 devices which were developed for the prediction or detection of ice, snow, or frost. Of these 22 devices, it was determined that six of the devices merited further evaluation. The report discussed the design of each device as well as their inherent limitations. In this context, it presented an excellent overview of the ice detection systems and the tribulations inherent in such an evaluation.

3.3 Procedures (Techniques) for the Removal of Snow and Ice on Runways

Airport personnel can attempt to alleviate the symptons of snow and ice on a runway surface by one of four basic techniques: mechanical removal of the snow and ice; application of abrasives; application of chemicals; or, heating of the runway surface. The use of any of these four possible actions is governed by: (1) availability of equipment and manpower; (2) availability of abrasives and chemicals; and, (3) the priorities of SIRC operations.

Most airports and Naval Air Stations have established standard operations procedures (SOP) for SIRC operations. These SOP include routine runway inspections whose frequency is generally dependent upon the current weather forecast. In the event that snow or freezing precipitation begins, the crews respond in an organized manner to maintain an open runway. Generally, the organized attack on snow and ice follows a written procedure specifically

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*Glauz, W.D., 1971, "An Ice and Snow Detection Warning System Feasibility Study," Meteorology Research Incorporated Report No. 3394-E.

outlining the methods, individual equipment and equipment teams which should be used to optimize results. Published procedures (such as Tighe, et al, 1971*; and AFM 91-14**) are available to recommend SIRC strategy for a variety of runway priority-type situations. The Navy does not have a standard manual with recommended SIRC strategy, and, consequently, SIRC techniques vary widely amongst Naval Air Stations.

Most airports which experience significant snow during the winter season have at least a token force of SIRC equipment. Such equipment collections may range from one pick-up-propelled snow plow to a fleet of snow blowers, plows, graders, sanders, and brooms. Although the economics of SIRC operations are certainly a prime factor in determining the quantity as well as quality of SIRC equipment, safety considerations and priorities of the airport are also important. For example, if an airport is unconcerned about closing for an indefinite period, SIRC equipment is kept at a minimum. At Naval Air Stations, the strategic mission and type of aircraft served are prime considerations in the intensity of SIRC operations.

Probably the most common method, and in many cases the most effective, of SIRC operations is mechanical removal. Of the SIRC annual budget at every airport, the cost of manpower and equipment is by far the largest single expense. For a light snow covering, brooms are sufficient, but for heavy snow, plows and snow blowers may be necessary to open runways. The amount and type of equipment required by a particular airport or Naval Air Station is dependent upon annual snow fall amounts and the mission or importance of the airfield. The tremendous expense resulting from the closing of a large commercial airport often leads to an abundance of SIRC equipment. Likewise, Naval Air Stations which provide a vital defense role may devote significantly more money and effort to SIRC than a less strategic Naval Air Station.

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*Tighe, D.J., L.A. Garland, and J.C. Caird, 1971, "An Analysis of Airport Snow Removal and Ice Control," Federal Aviation Administration Report No. RD-71-20.

**Airfield and Base Snow and Ice Removal and Control, 1971, Air Force Manual No. 91-14.

The use of abrasives (i.e., sand or grit) is generally held to a minimum in view of the potential damage resulting from ingestion by jet engines. As a result, their use is generally restricted to ramps and taxiways.

Chemicals are experiencing ever increasing usage in SIRC operations. In their most obvious application, chemicals are applied to melt existing ice or packed snow on the runways (de-icing). This type of application is reserved for frozen precipitation which is not easily removed by brooming; the melting action of the chemicals creates pools of liquid on the runway which efficiently collect blowing snow and can potentially magnify an existing problem. The usefullness of the chemical to melt frozen precipitation is limited to temperatures greater than the freezing point of an aqueous solution of the respective chemical. Since runway surface temperatures are not commonly available, estimates of the runway surface temperature are generally based on the measured air temperature. Consequently, it is possible that costly chemical may be applied when it will be totally ineffective.

Chemicals may also be applied prior to a precipitation event to prevent expected precipitation from freezing or sticking to a below freezing runway surface (anti-icing). Such applications are less frequent than de-icing since runway surface temperature is generally unknown and the probability of predicted precipitation completely missing the runway is finite. On the other hand, anti-icing can be attractive because significantly less chemical is required to prevent icing than to eliminate an existing icing problem.

Two types of chemicals are currently employed at airports -- urea and ethylene glycol-urea (UCAR). The former is usually dispensed as a solid material (pellet or powder), the latter as a liquid. The selection of one or the other chemical (where both are available) is a function of the surface temperature and, in the case of urea, wind conditions. Urea can be employed when the surface temperature is above -9.4°C (15°F). At lower surface temperatures, the urea-water mixture will form an undesirable gel. Urea application is not practical when wind conditions cause the urea to be swept off the runway. UCAR can be effective when surface temperatures are as low as -18°C (0°F). Its application as a liquid is largely unaffected by wind conditions.

The economics of the use of chemicals (whose cost per application on one runway may run in excess of $3000) can lead to the justification of very expensive runway surveillance systems. Probably the best indication of the need of an expensive runway surveillance system is the annual budget for chemicals. It is reasonable to expect a savings of a few applications of chemicals from improved runway surveillance, and if the monetary savings can cover the amortized cost of the surveillance system, it is probably a good investment. However, it is also possible that increased surveillance of the runway may result in the application of chemicals when they would otherwise not have been applied. While there will exist an increased level of safety, it may or may not be observable and the cost of chemicals will increase. The result could be a negative return on the surveillance system.

Runways which are warmed by a heating system located beneath the runway surface provide the ultimate in SIRC. Such systems literally melt snow and ice from the runway surface. The primary disadvantage to these systems is cost. They require a tremendous investment for installation and consume enormous amounts of energy to heat the runway surface. It is possible that such systems would be economically feasible in locations where there exists a very cheap energy source (e.g., geothermal energy).

Section 4

CONCEPTUAL DESIGN AND ENGINEERING EVALUATION

The Surface Condition Analyzer (SCAN)^{tm} is an instrumentation system for indicating and, to some extent, predicting the tractive properties of an airport runway*. It comprises sensors imbedded in the runway, an air temperature sensor, a readout and control console, and equipment for communicating the sensor readings to the readout. A number of circuits serve to interpret the sensor readings and to generate outputs that are of immediate interest to airfield snow and ice control operations, e.g., readouts like WET, HAZARD (Ice), ALERT or DRY (Clear). The current SCAN 7000 system and its predecessor which also included a water-depth sensing capability are pictured in reproductions of manufacturer's literature in Figures 1 and 2, respectively. In this Section, a general description and limited functional analysis of the SCAN 7000 system as it existed in early 1978 is presented. (The manual for SCAN 7000, including circuit diagrams, is reproduced in Appendix A.) Reference is made to certain earlier or proposed configurations, where appropriate.

4.1 Sensors

Four parameters are measured by the SCAN sensors: Air temperature, which can be taken almost anywhere on the airport; the temperature just below the runway surface; the electrical conductivity at the surface; and a measure of the permittivity (dielectric constant) of the region immediately above the surface. Temperatures are measured with thermistors that typically yield

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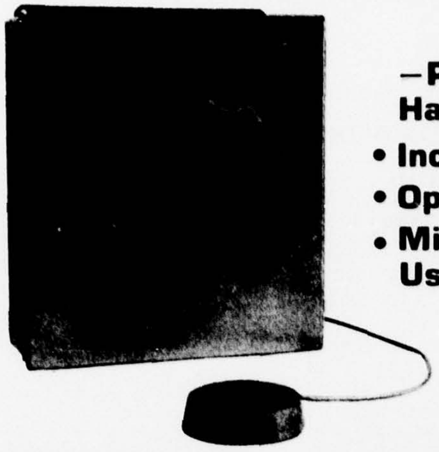
*Or, in related application, the slipperyness of highway surfaces. The device is manufactured by Surface Systems, Inc. (SSI) of St. Louis, MO, and we wish to acknowledge the cooperation of SSI in supplying some of the information and figures used here.

SCAN® 7000

Highway Condition Surveillance System



—Real Time Monitoring of Hazardous Conditions

- **Increase Safety**
- **Optimize Manpower**
- **Minimize Salt Usage**

Highway departments are finding it more of a necessity to maintain careful and instantaneous surveillance of bridge decks, tunnels and roadways during winter because of increased traffic, continuing emphasis on highway safety, higher maintenance costs and the need to minimize the use of salt.

Surface Systems, Inc. now has available its new SCAN® 7000 Series highway condition surveillance system. The system includes a A) remote processor unit (RPU) and roadway sensor; B) display monitor; C) radio telemetry link (not shown).

The system displays on its monitor air *temperature, surface temperature and* surface conditions of "clear", "wet", "alert" or "ice" of a bridge deck, tunnel or roadway at distances up to approximately 50 miles via the SCAN® telemetry system. Telephone lines can be used in place of *the telemetry system if desired with no* interface equipment required. The system also includes a relay to operate motorist warning signs at the sensor location if desired. A "system operate" relay is also included to alert maintenance if the system has become inoperative.

Easy Installation

The sensor is easy to install in bridge deck or roadway because of its small size — 127 mm (5") diameter x 29 mm (1⅛") deep. A concrete saw or core drill can be used to cut the hole for the sensor. Any acceptable epoxy based adhesive can be used to set the sensor head permanently in the pavement. The remote processor unit can be located up to 150 meters (492 feet) from the sensor. Input power, telemetry transmitter or telephone line and warning sign circuit is then brought into this unit. It is recommended the sensor head be located between the wheel tracks in the least traveled lane.

Simple Alignment

Alignment is simple. All test signals for "tune up" are built into the remote processor unit. A voltmeter and small screwdriver are all that is required. Warm weather testing of sensor, logic, telemetry/telephone line and monitor is accomplished by a single switch.

Reliable Operation

Sensor in pavement senses surface temperature and surface condition. These signals are processed in the remote *processor unit near the sensor and then* transmitted via telemetry or telephone line to the display monitor. Air temperature is sampled by a sensor located near the display monitor. The monitor displays surface and air temperature in digital form. Surface conditions of "clear", "wet", "alert" or "ice" are displayed by colored lights. The conditions of "Clear" and "wet" need no explanation. The "alert" condition indicates a hazardous situation is *beginning to occur* caused by two possible conditions: 1) light frost *beginning to form* but not thick enough to affect traction; 2) solution of water and salt just beginning to freeze which is generally in advance of actual freezing on the pavement. This is accomplished by a sensing element on the sensor surface operating at a lower temperature than the pavement. "Ice" indicates that a hazardous situation *exists* caused by heavy frost, frozen packed snow or ice. There is an audible alarm on the monitor that actuates for conditions of "alert" or "ice". The monitor has the capability of continuously monitoring up to five sensors in sequence.

Low Maintenance

Other than a simple annual inspection during the summer to test the sensor, logic, telemetry/telephone lines and monitor, there is no maintenance required.

How the System Works

The system detects surface conditions by measuring the capacitance and conductance of the precipitant on the sensor head. With this method, a heated sensor is eliminated and therefore reliability greatly improved since the system is not melting or evaporating what it is intended to detect. Surface temperature is also measured by a high accuracy thermistor in the sensor head.

Information from the sensor is processed in the remote processor unit and is coded onto a 1,000 hz tone for radio telemetry *or telephone line transmission to the* monitor. The display monitor is designed to operate with a maximum of an 18 db telephone line loss with an input level into the line at the sensor location of 0 db. No interface equipment is required for data transmission. The SCAN® radio telemetry system consists of an FCC type accepted one watt or 25 watt output transmitter and a matched receiver. The system operates in the 150 Mhz to 175 Mhz band. At the monitor, the 1,000 hz modulated tone is decoded and the information is displayed by colored lights for surface condition and LED digital displays for surface temperature. The monitor will sequentially display information from one through five sensors with a sampling time of approximately 10 seconds per sensor. An audible tone alarm is included for the conditions of "alert" or "ice". This alarm can be de-activated on the front of the monitor panel.

The total system has been engineered to *minimize the effects of lightning*. The system has been designed to operate in the presence of all types of highway ice control chemicals.

Surface Surveillance systems for highways and airports are our principal business. SCAN® systems are operating on highways and airfields throughout North America and Europe. Names and addresses of highway departments using these systems are available upon request.

This system is protected under U.S. Patent Nos. 3873927 and 3882381. Other U.S. and foreign patents are pending.

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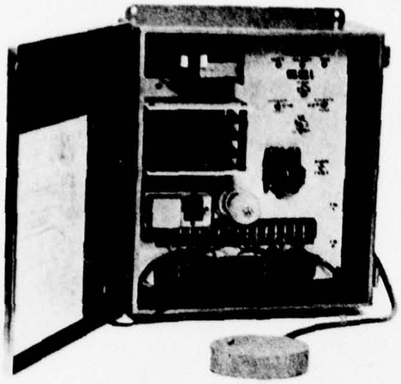
p.o. box 9927, saint louis, missouri 63122/(314) 822-2678

Figure 1

SCAN™ System

Runway Weather Surveillance System



- **Accurate**
- **Reliable**
- **Continuous Monitoring**
- **Ice Warning**
- **Hydroplaning Warning**

With the high cost of runway downtime and ice-control chemicals and the continuing emphasis on aviation safety, airport managements are realizing *the need to continuously monitor* runway surface conditions. This is particularly true during winter weather and periods of heavy rain.

Surface Systems, Inc. has developed and fully tested a complete runway weather surveillance system called the Surface Condition ANalyzer (SCAN™) *system. The heart of the system is* a single, rugged, unheated sensor.

The system displays on its monitors, air temperature, surface temperature, surface condition (clear, wet, alert or ice) and critical water depth for hydroplaning. This information can be displayed for one through five locations on a single runway or combination of runways.

Having available this information permits airport management to reduce considerably ice-control chemical usage and to know immediately when a hydroplaning hazard exist on a runway.

The SCAN™ system was developed in 1972 and has been tested and proven in continuous use at a number of airports in the United States and Canada.

Installation

The sensor is easy to install in Runway because of its small size—127 mm (5″) diameter x 29 mm (1⅛″) deep. A concrete saw or core drill can be used to cut the hole for the sensor. Any acceptable epoxy based adhesive can be used to set the sensor head permanently in the pavement. The remote processor unit can be located up to 150 meters (492 feet) from the sensor. Input power, and signal lines are then brought into this unit. It is recommended the sensor head be located approximately 12 m (40′) from runway center line.

Alignment

Alignment is simple. All test signals for "tune up" are built into the remote processor unit. A voltmeter and small screwdriver are all that is required. Testing of sensor, logic, signal lines and monitor is accomplished by a single switch.

Operation

Sensor in pavement senses surface temperature, surface condition and water depth. *These signals are processed in* the remote processor unit near the runway and then transmitted via signal lines to the display monitor. Air temperature is sampled by a sensor located near the display monitor. The monitors display surface and air temperature in digital form. Surface conditions of "clear", "wet", "alert", "ice" and critical water depth are displayed by colored lights. The conditions of "clear" and "wet" need no explanation. "Alert" indicates a solution of water and chemical just beginning to freeze. This is generally in advance of actual freezing on the runway. It is accomplished by a sensing element on the sensor operating at a slightly lower temperature than the pavement. "Ice" indicates frozen, packed snow or ice. There are audible alarms on the monitors that actuate for conditions of "alert", "ice" or critical water depth. The critical water depth as determined by research programs of NASA and FAA is between 1.3mm (.05″) and 2.5mm (.1″). The hydroplaning alarm can be set within the range of 0 to 5mm (.2″) of of water depth. The monitors have the capability of continuously monitoring up to five sensors in sequence.

Maintenance

Other than a simple annual inspection to test the sensor, logic, telephone lines and monitor, there is no maintenance required.

How the System Works

The system detects surface conditions by measuring the capacitance and conductance of the precipitant on the sensor head. With this method, a heated sensor is eliminated and therefore reliability greatly improved since the system is not melting or evaporating what it is intended to detect. Surface temperature is also measured by a high accuracy thermistor in the sensor head.

The information from the sensor is processed in the remote processing unit in which an output is connected to a signal line for surface condition ("clear" "wet", "alert" or "ice") and surface temperature. A separate signal line is required for water depth information. No interface equipment is required for data transmission; it is included in the remote processing unit and the display monitors. At the monitor end, the signals are decoded and the information displayed by colored lights for surface condition and critical water depth. LED displays are used for surface temperature and air temperature. The runway condition-temperature monitor will sequentially display information from one through five sensors with a sampling time of approximately 10 seconds per sensor. The water depth monitor displays information from each connected sensor instantly and simultaneously. Audible tone alarms are included for the conditions of "alert", "ice" or critical water depth. These alarms can be de-activated on the front of the monitor panels.

The total system has been engineered to minimize the effects of lightning. The system has been designed to perform in the presence of all types of runway ice control chemicals such as ethylene glycol, alcohols and Urea. This is accomplished by a compensation circuit that is activated by the *presence of* chemicals on the sensor head through the measurements of capacitance and conductance.

The system is modular in that it can be used as a runway condition-temperature system only, a water depth alarm system only or both as pictured above.

SSI™ developed this system in 1972. Weather surveillance systems are our principal business. Names and addresses of airports using these systems are available upon request.

This system is protected under U.S. Patent Nos. 3873927 and 3882381. Other U.S. and foreign patents are pending.

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Figure 2

a quite reproducible temperature-dependent output with a scale of a few tenths of a volt per degree Celsius. The primary sensors of the SCAN device, i.e., for runway surface temperature, permittivity and conductivity, are imbedded in an epoxy, hockey-puck-shaped disk which is mounted flush with the runway surface.

The permittivity of the space immediately above the runway surface is measured with an AC bridge circuit, applied across a proprietary sensor configuration encapsulated in the sensor. It is reasonably certain that Figures 3 and 4 provide an adequate representation of the actual sensor arrangement. A test plate (P1 in Figure 3) is mounted near the runway surface and above a guard plate (P2). A voltage follower senses the potential on the test plate and applies the same potential to the guard plate. The capacity from the test plate to the ground below the sensor and the electric field in that space is effectively removed by this stratagem. If the guard plate has the shape of a bowl, as shown in Figure 3, the electric field above the test plate is substantially vertical and passes through the plane of the runway surface. The capacity ($C_{A\infty}$) of the plate in air or vacuum (in pico farads) is very approximately

$$C_{A\infty} \approx r$$

with respect to a charge at infinity, where r is the radius of the plate (in centimeters).

As shown in Figure 4, a generator of alternating current can be connected to the test plate (point A) via a small capacitor (C_T). The plate potential can be measured conveniently at the output of the voltage follower (point B). If C_T is chosen approximately equal to $C_{A\infty}$, the voltage out of the follower is about one-half of the generator voltage (e_g), the same as on the centertap of the bridge next to the equivalent circuit of the sensor head. An AC voltmeter (shown for simplicity as a bridge rectifier and meter) would read zero under this condition. If a dielectric material is now heaped on the test plate, its capacity will increase, because it may be thought of as

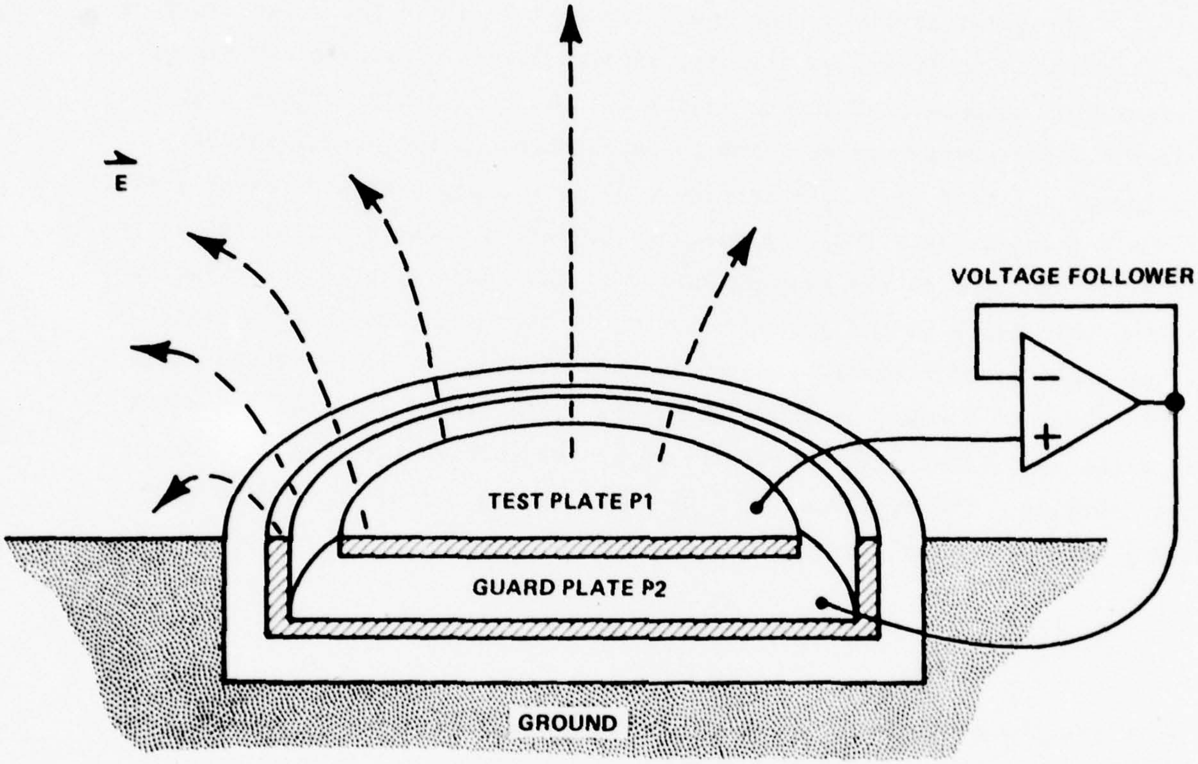


Figure 3 INFERRED CONFIGURATION OF PERMITTIVITY SENSOR

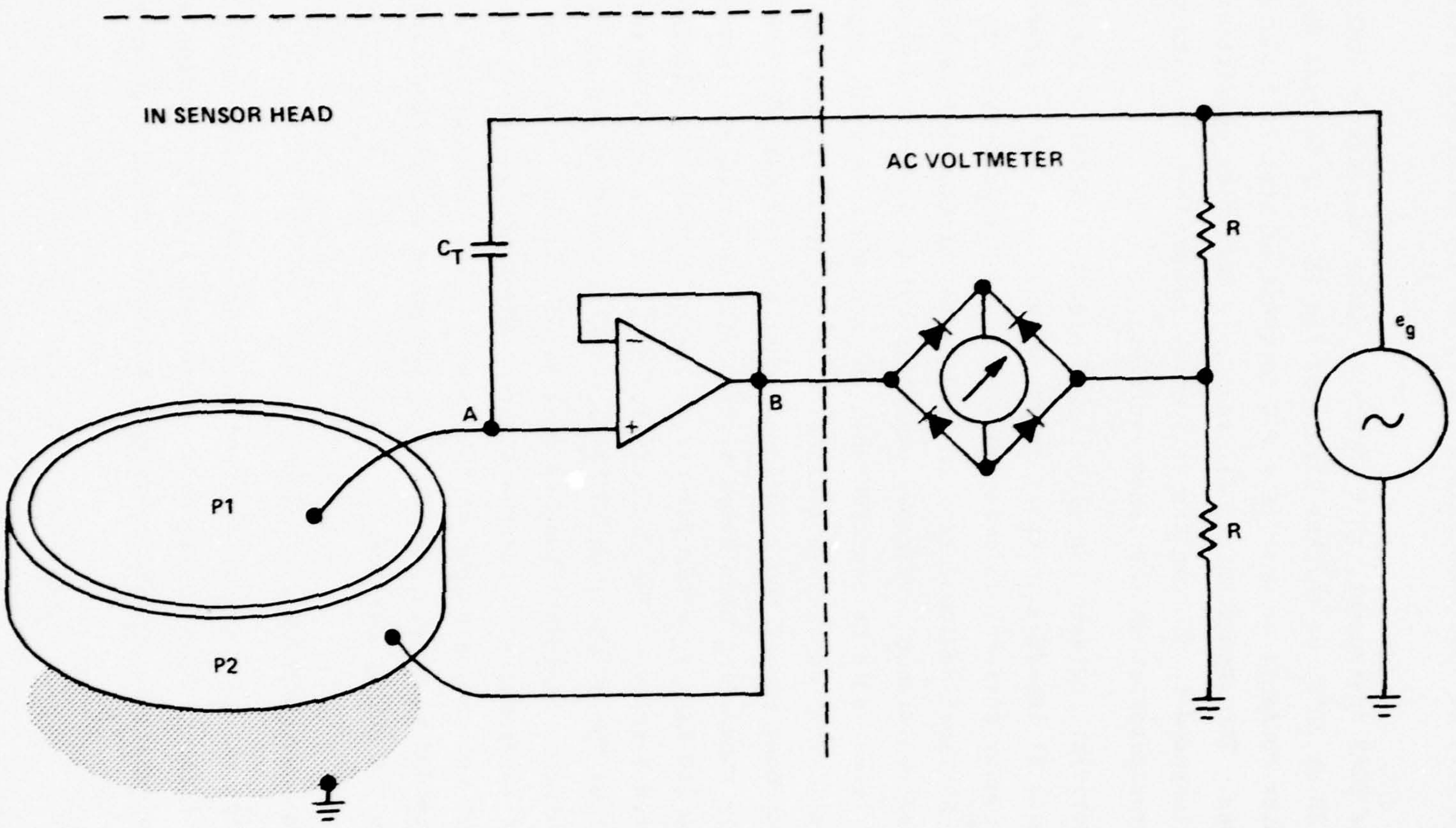


Figure 4 REPRESENTATIVE CIRCUIT FOR MEASURING PERMITTIVITY

being half immersed in the dielectric. The $C_{A\infty}$ bridge arm having increased, the voltage at B will be less than half of (e_g), and the meter will indicate a voltage.

In the SCAN instrument, thin layers of water (dielectric constant, K = 88 at 0°C, 80 at 20°C) or thicker layers of ice (K = 1.2 to near 80, depending on water content) or snow (K = 1.0 to those of ice) will cause equal indications. The capacitance (C2) sensor, by measuring permittivity, is, therefore, intended to discern the existence, rather than the kind and condition, of precipitation on the runway surface.

Conductivity, between two slab-shaped stainless steel or Monel 400 electrodes (Figure 5) imbedded in epoxy except on one face that is placed flush with the runway surface, is measured with an AC bridge similar to that provided in the National Semiconductor LM 1830 Fluid Detector Integrated Circuit. Reduced resistance (increased conductivity) between the exposed stainless steel lines would be expected when the surface is wetted, especially by an electrolyte. This changeable resistance is compared with a fixed resistor that may have one of two values, a higher one (27 KΩ) for the relatively poorly conducting urea-based electrolytes observed at airports or a lower value (10 KΩ) resistor for use in the chloride-based electrolytes observed on salted highways. The conductivity of solid ice would be very near zero, while that of "pure" water would be very low compared to the conductivity of water containing contaminants such as de-icing chemicals. A voltage (called C1) that increases with the resistance between the stainless steel probes appears at the analog output of this sensor. The conductivity sensor is obviously intended to provide a measure of the phase and/or condition of precipitation on the runway surface.

4.2 System Configuration

Ideally, the four signals derived from the SCAN sensors could be utilized in the fashion shown in Figure 6. Here each signal, function or combination of signals, is applied to as many threshold circuits as necessary

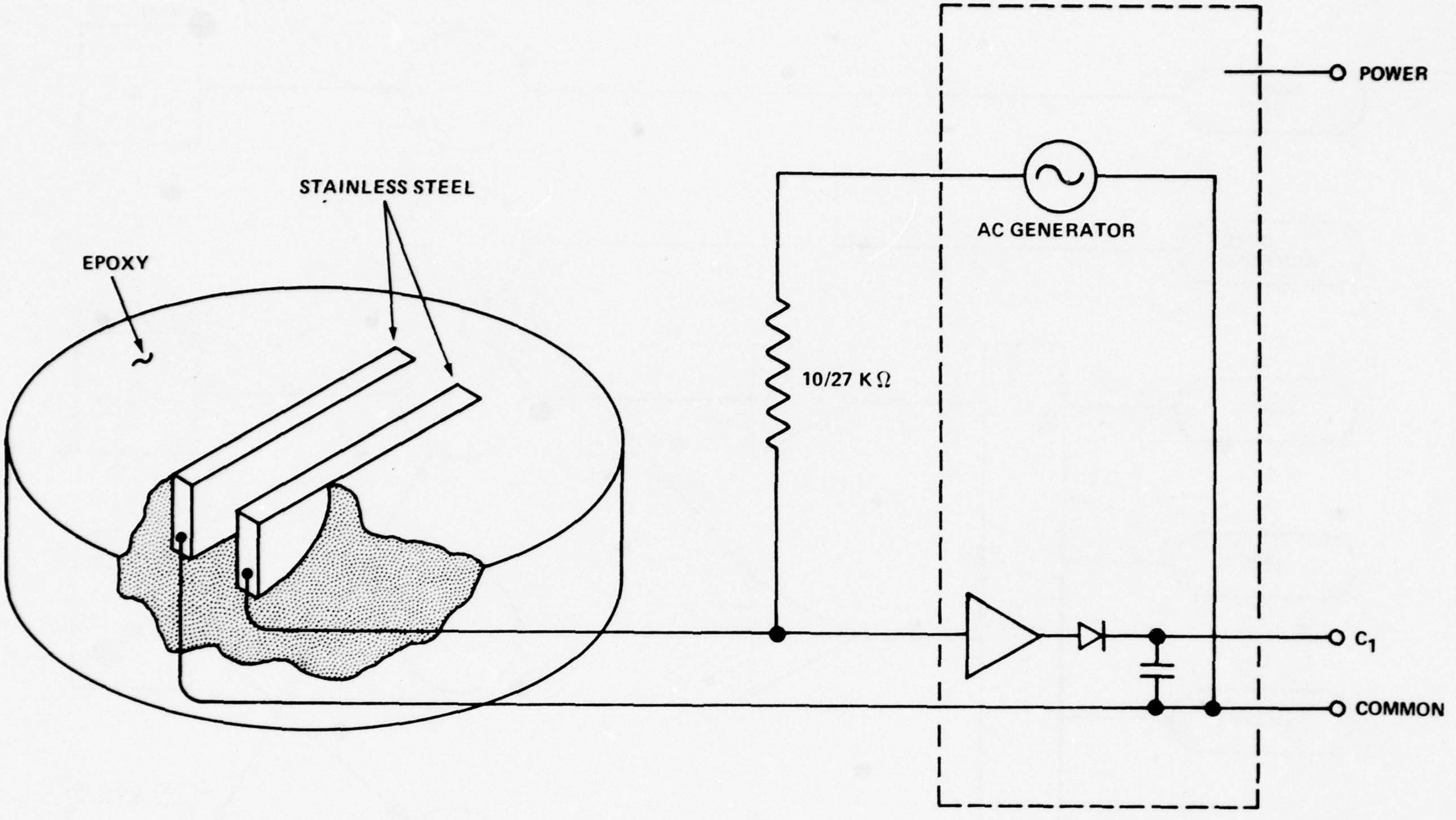


Figure 5 CONDUCTIVITY SENSOR

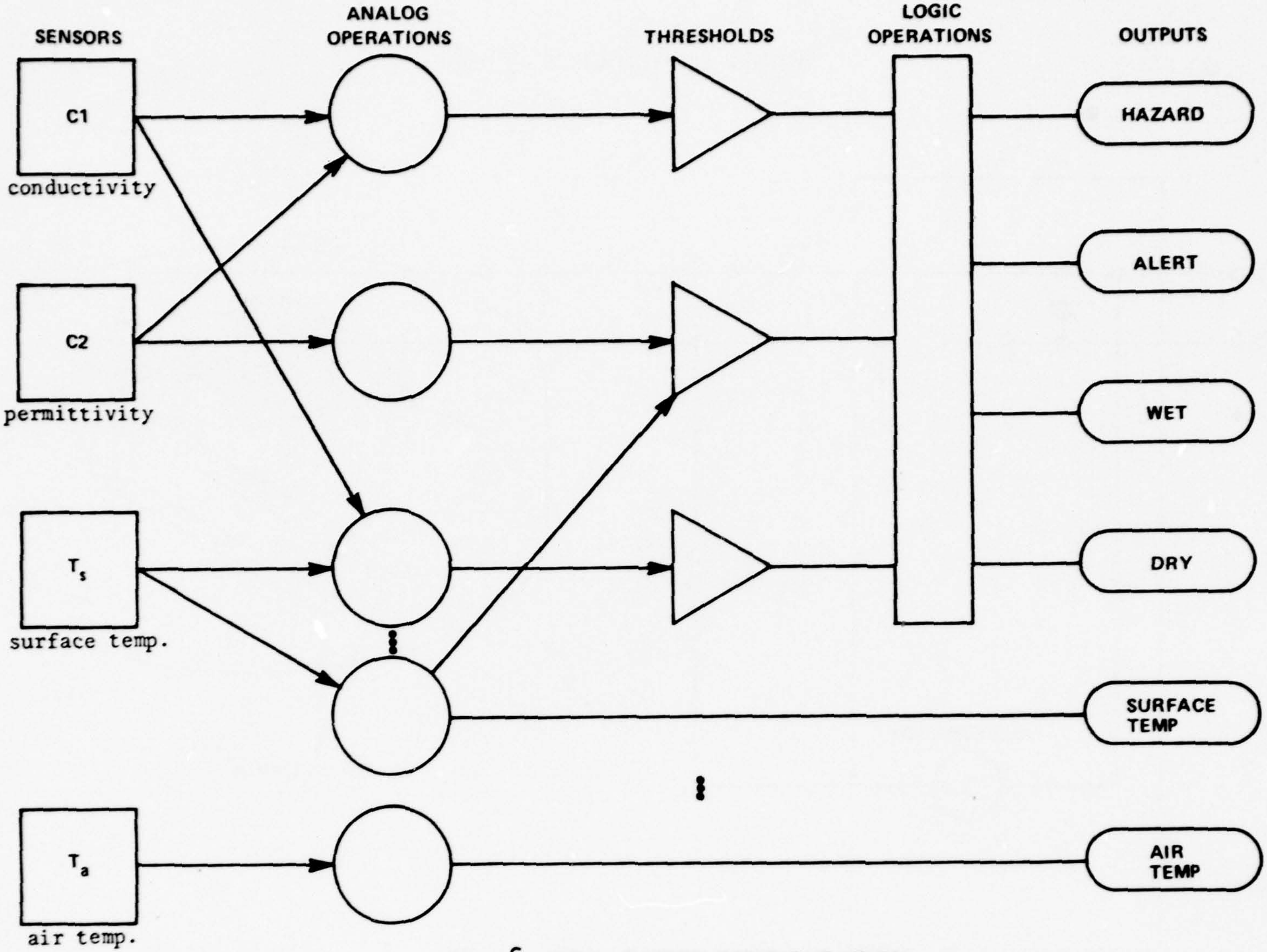


Figure 6 IDEAL SYSTEM CONFIGURATION

to define a reasonable set of conditions. For an example, one might define a simple threshold, at 0°C (32° F) applied to the runway surface temperature (T_S). Temperatures above this threshold, a priori, would be expected to be conducive to melting of frozen water. An excessive negative time rate of change ($\dot{T}_S$) of voltage might similarly be detected in order to warn of an impending freeze, or $\dot{T}_S$ might be divided by T_S (in °C) and thresholded to warn of the freeze only when it is expected in a given time.

The various thresholded, or logic signals corresponding to certain conditions might then be applied to logic circuits that identify those combinations of conditions that are of interest to or concern the airport operator. For example, the signal described above as indicating that a freeze is expected in X minutes could be AND-gated with the precipitation signal and applied to the ALERT display. In this fashion the operator could be properly warned if a wet runway was about to freeze but would not need to concern himself with a drop of temperature through 0°C when the runway is dry.

Finally, the various system states, from sensor outputs to output indications, could be filtered, sampled at certain times, checked for consistency over a certain interval, or otherwise modified as a function of time. For example, one might not issue an ALERT until it persists at least for a minute.

Practically, there are advantages to combining some of the functions that are shown neatly separated in the scheme of Figure 6. The entire processing sequence soon may be combined in a microprocessor, according to recent indications from Surface Systems, Inc. In the past, as experience was gained, various improvements were made to existing circuits and a certain amount of overlapping occurred between analog processing and logic circuits. Time dependent processes were, however, largely confined to a separate circuit segment that drives the output indicators. The current system configuration is discussed further in following sections.

4.3 Signal Processing

Surface temperature (T_S) and precipitation (C2) sensors together would provide fairly adequate indications of runway surface condition if precipitation reliably melted at 0°C. However, the efforts of airport operators to keep runways clear at subfreezing temperatures with chemicals result in complications for the instrument designer. Since there is a significant difference between the AC electric conductivity of frozen and melted precipitation, particularly where electrolytes are present, the surface conductivity (C1) measured between the stainless steel slabs (Figure 5) assumes great importance in deciding whether the runway surface is wet or ice-covered. Unfortunately, this sensor responds to conditions immediately above the surface; a sheet of ice above a layer of water is likely to be treated as water, rather than ice.

In the SCAN 7000 equipment, the surface conductivity (C1) is applied to two threshold circuits, one set at the conductivity value that approximately corresponds to thin slush, i.e., a mixture of water and a little ice, and one that would be observed in thick slush just about to freeze. The "slush" condition (it is not identified as such in the apparatus) is associated with the ALERT output of SCAN.

An additional subcondition (called "intermediate ice") is defined in a narrow conductivity region between the "slush" condition and the low conductivity of ice. The "intermediate ice" (abbreviated "intermediate" below) condition may be thought of as a mechanism to distinguish between an imminent freeze or thaw without measuring a time-rate-of-change; if the sequence "water", "slush", "intermediate", "ice" is observed, the output moves along the sequence WET, ALERT, HAZARD. If the sequence "ice", "intermediate", "slush", "water" is observed, output indications are HAZARD, WET, i.e., the ALERT state is skipped if "intermediate" is encountered before "slush" since an "alert" of improving conditions is not believed to be necessary.

Some implementations of the logic procedure sketched above involve feedback around linear circuits, thresholds and combinatorial logic (Drawing No. 20-7100, Appendix A, is attached for reference on the next page). This procedure is generally subject to the possibility of lock-up, i.e., the existence of a stable output condition or state under specific circumstances, that cannot be removed (reset) as the input states (or signals) vary over their normal range. One can usually escape from this type of trap by turning power to the system off and back on. A system that didn't enter a reasonable state in response to this procedure is presumably defective.

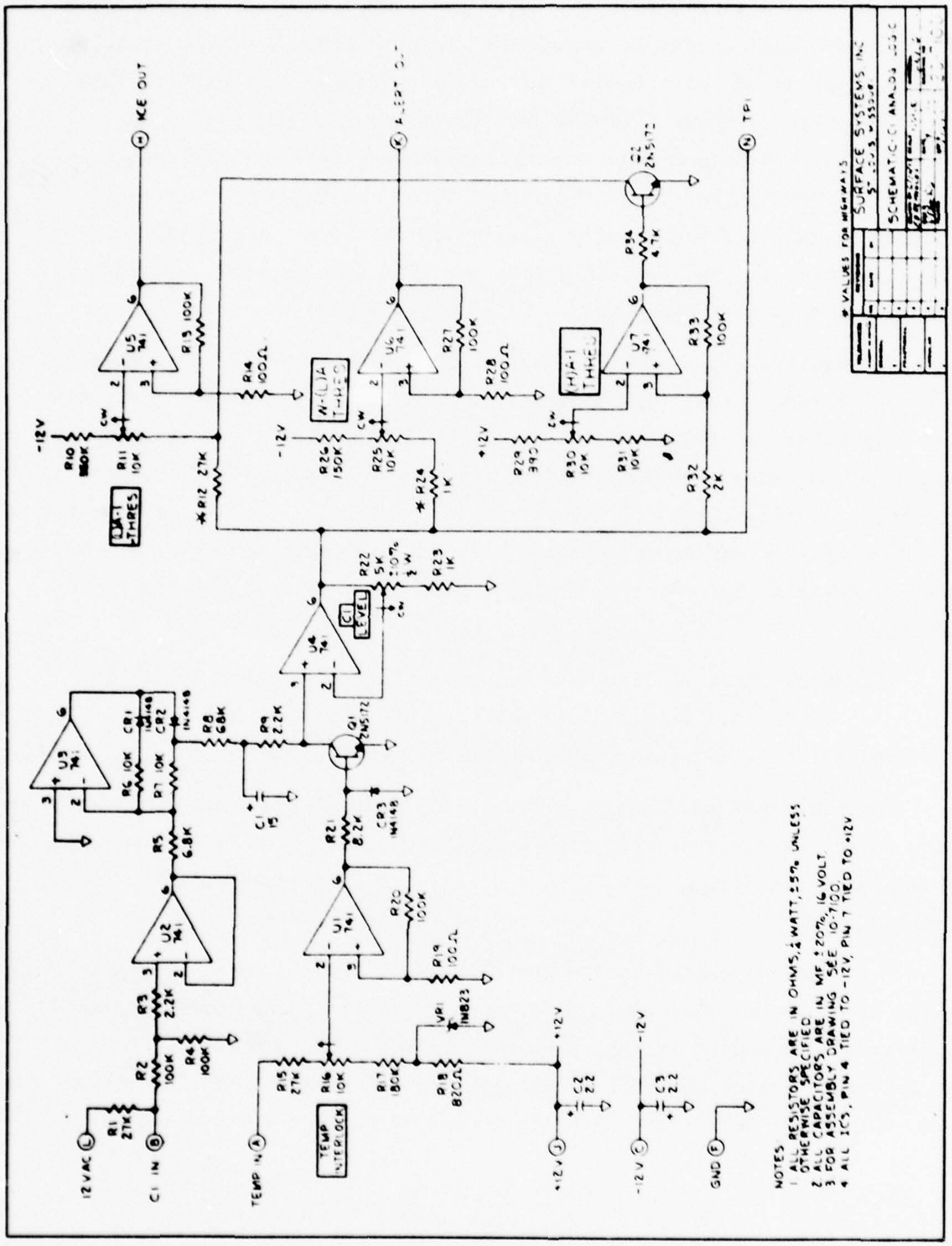
Temperature (T_S) and precipitation (C2) signals are used to gate out unlikely indications. Ice, represented by a HAZARD display, is not indicated when the temperature is above about 1°C (33F). A DRY output is generated when the precipitation sensor detects nothing above the test plate. It is conceivable that very light, fluffy snow having a dielectric constant of almost 1.0, the same as air, may be accompanied by a DRY display. Each of these system idiosyncrasies was observed during a site visit at Keflavik NAS (Section 5).

Air temperature is displayed but not utilized in logic decisions.

4.4 Installation and Interconnection of System Components

The processes involved in transferring information from the remote processor units, that are more or less associated with the runway sensors, to display monitors and system installation details are discussed in the following.

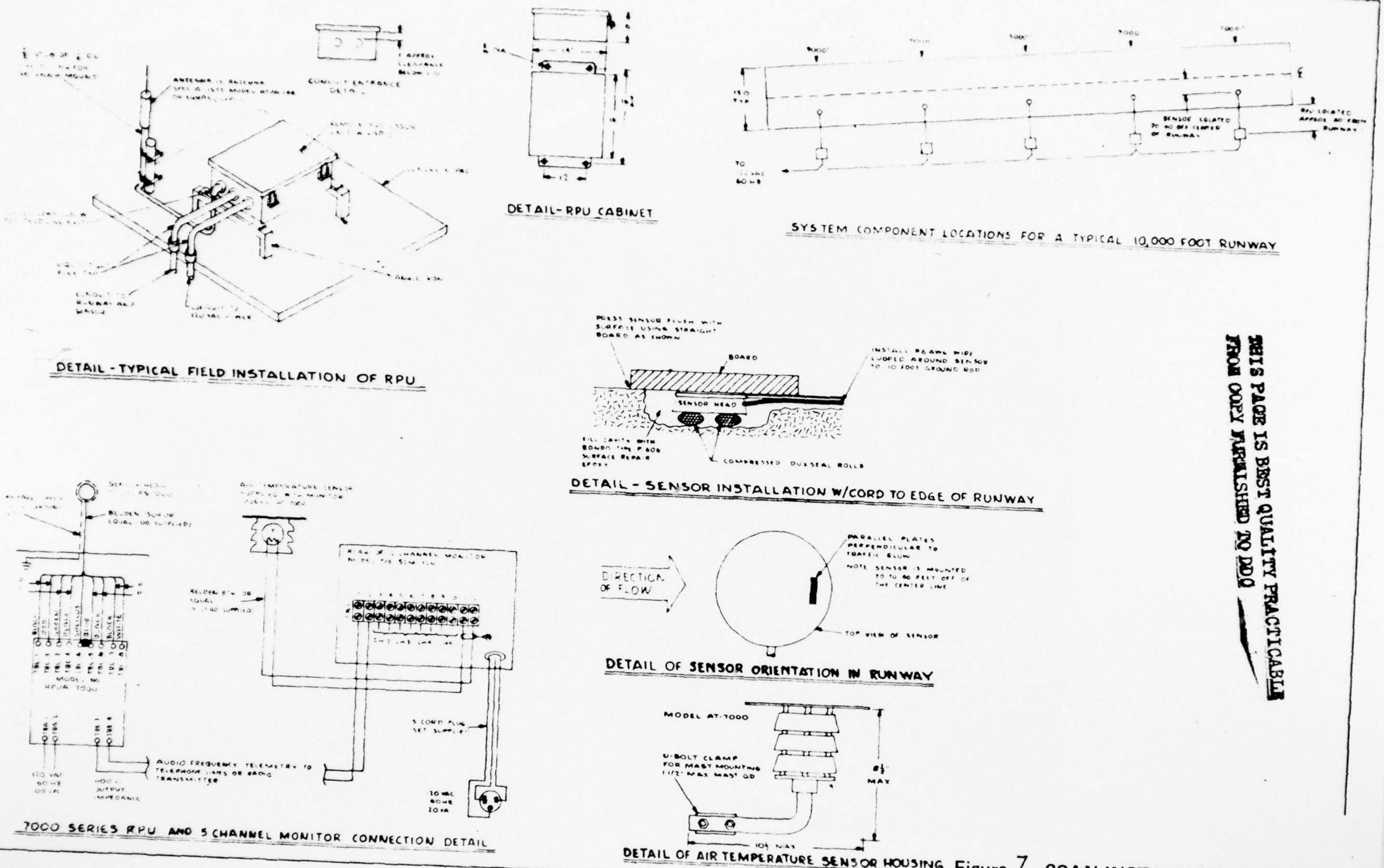
The sensors mounted in the runway are embedded in epoxy plastic. The sensor assembly has the approximate appearance of a hockey puck (Figure 7) and is secured in a cavity in the runway by casting epoxy around it. A typical sensor installation is shown in Figure 8. During the casting operation, its surface is kept flush with the runway surface by a board that



NOTES
1 ALL RESISTORS ARE IN OHMS, 1/4 WATT, ±5% UNLESS OTHERWISE SPECIFIED
2 ALL CAPACITORS ARE IN MF ±20%, 16 VOLT
3 FOR ASSEMBLY DRAWING SEE 10-7100.
4 ALL ICS, PIN 4 TIED TO -12V, PIN 7 TIED TO +12V

(Figure courtesy of SSI)

(Drawing No. 20-7100, from Appendix A)



DETAIL - TYPICAL FIELD INSTALLATION OF RPU

DETAIL-RPU CABINET

SYSTEM COMPONENT LOCATIONS FOR A TYPICAL 10,000 FOOT RUNWAY

DETAIL - SENSOR INSTALLATION W/CORD TO EDGE OF RUNWAY

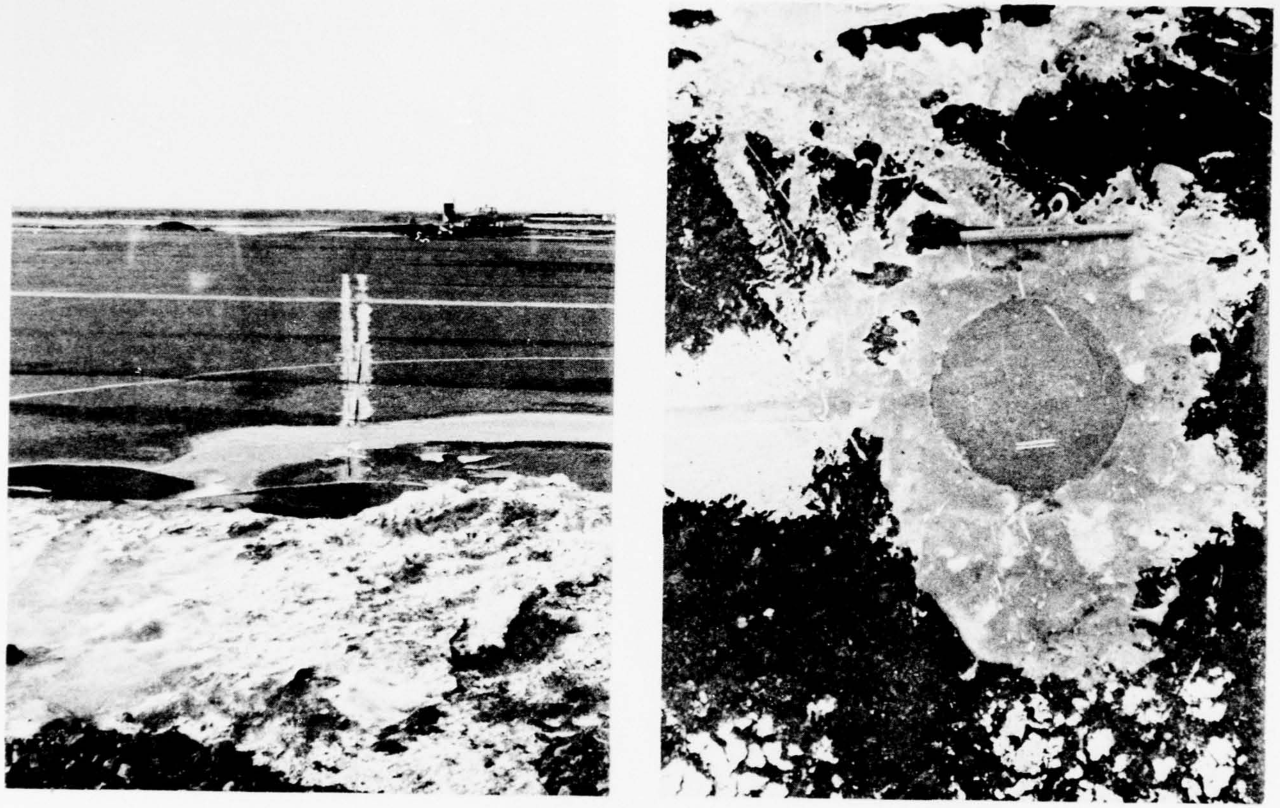
DETAIL OF SENSOR ORIENTATION IN RUNWAY

7000 SERIES RPU AND 5 CHANNEL MONITOR CONNECTION DETAIL

DETAIL OF AIR TEMPERATURE SENSOR HOUSING

Figure 7 SCAN INSTALLATION DETAILS

(Figure courtesy of SSI)



a) VIEW SHOWING EPOXIED CUT IN RUNWAY

b) TOP VIEW OF SENSOR IMBEDDED IN RUNWAY

Figure 8 PHOTOGRAPH OF NAS KEFLAVIK SENSOR INSTALLATION resists the pressure exerted by rubber balls or rollers compressed below the sensor puck (Figure 7, Detail-Sensor Installation W/Cord to Edge of Runway). Wires from the sensor are run in a narrow, epoxy-filled cut in the runway to its edge (Figure 8a).

In older versions of SCAN, permittivity (C2) was measured at a frequency of 200 kHz - to cause sufficient current to flow in the small capacity of P1 (Figure 4). At this high frequency, an amplifier was needed at a distance of about 8 meters from the sensor puck. The amplifier package (80 x 100 x 180 mm) was buried after being spliced into a polyvinyl chloride (PVC) covered cable. An adjustment screw on the package was sealed with silicone rubber (RTV). It is believed that hosing (capillary transport of water in the gap created by compression of PVC under hydrostatic pressure (Figure 9)) caused moisture damage to these amplifiers. They have since become obsolete, and a 5 kHz signal has replaced the 200 kHz bridge generator. It now proves practical to run cables up to 150 meters from the sensor but runs of 25 ± 5 meters are preferred (Figure 7, System Component Locations for a Typical 10,000 Foot Runway).

A Remote Processor Unit (RPU) is placed at the end of the sensor cable (Figure 7, Detail-Typical Field Installation of RPU). It provides power to and receives signals from the sensor puck, receives 120 V AC power from power lines, and communicates runway condition data to display monitors, either by radio links or wires (typically buried). (See Figure 7, 7000 Series RPU and 5 Channel Monitor Connection Detail, and Figure 10, RPU Block Diagram.) The RPU contains most of the processing circuits discussed earlier in Section 4.3. Further details of the RPU are provided in the following Section, "Construction of System Components".

Communication from one or more Remote Processor Units (RPU) to a display monitor can be carried either over buried wires or radio links. SSI has configured the system with parallel channels from each RPU to a Display

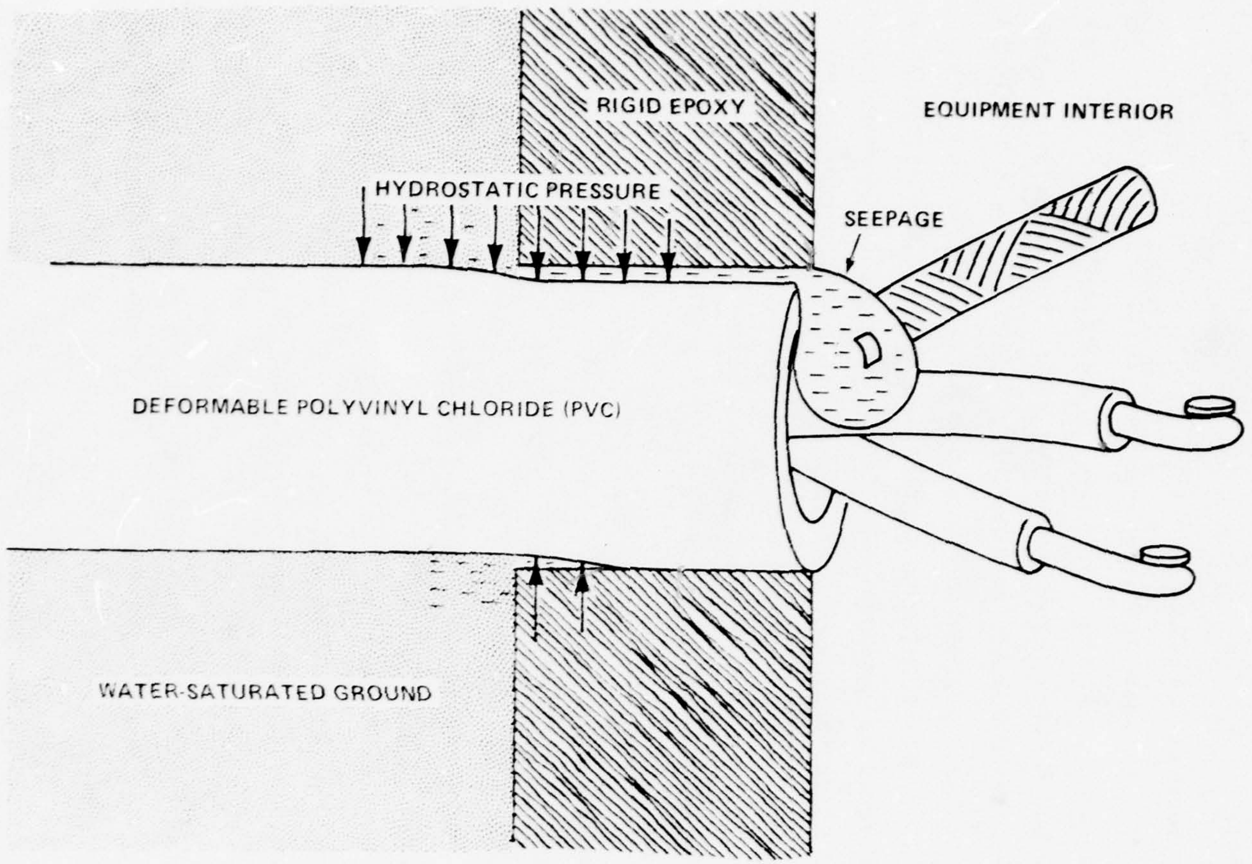


Figure 9 LEAKAGE DUE TO THE HOSING MECHANISM

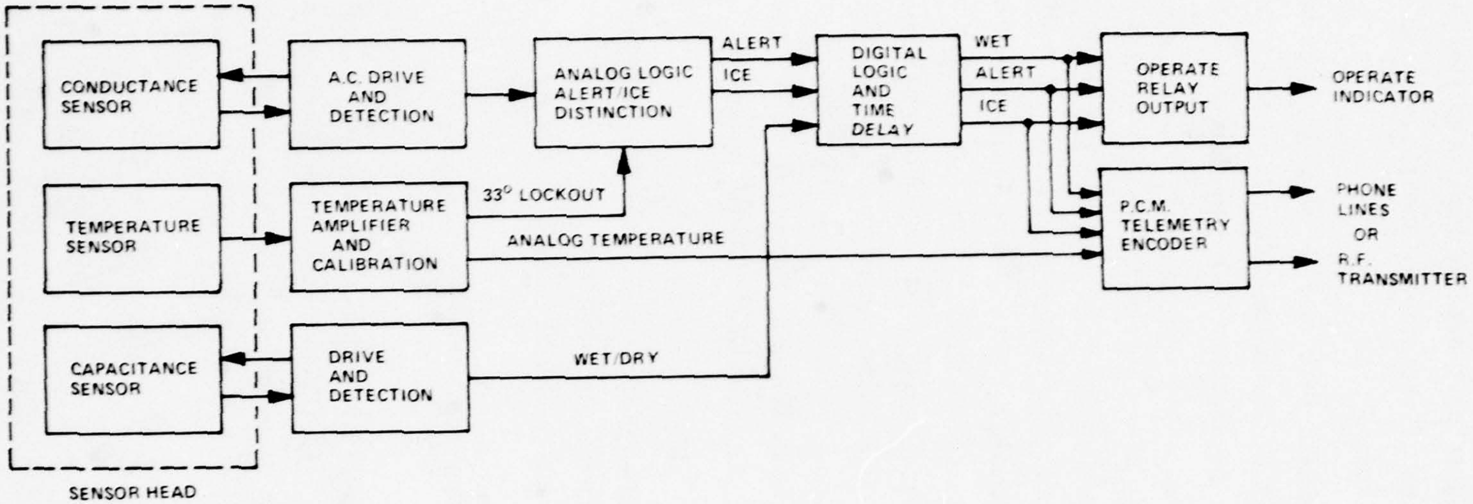


Figure 10 R.P.U. BLOCK DIAGRAM

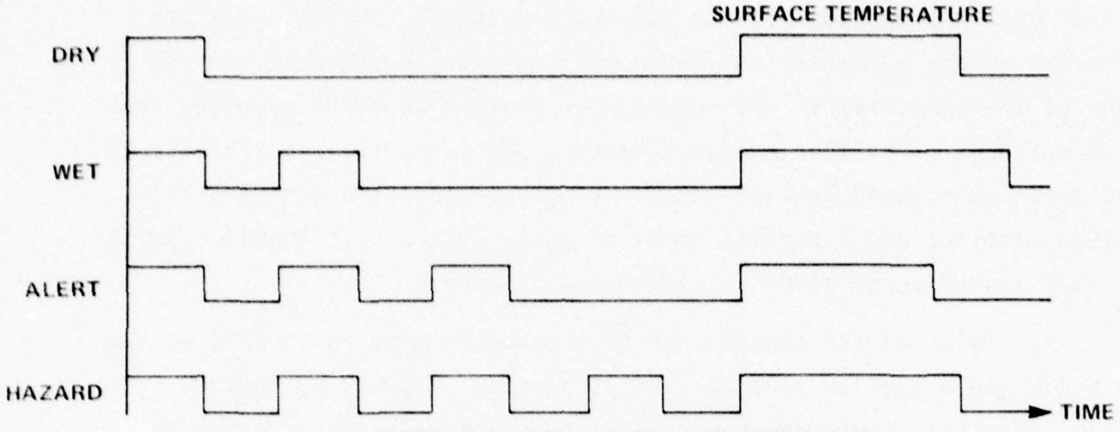
Monitor (DM). Up to four additional Display Monitors, that are to be installed within a hundred meters or so of the primary monitor, can be connected to a common radio receiver by wires.

Parallel data channels from various RPUs are typically provided by radio frequency diversity, i.e., by using radio frequency channels (details are discussed in Section 4.5). One display (DM) can monitor up to five channels or RPU's using up to five receivers. Up to five RPU's can also be wired to one Multiplex Radio (or Hard Wire) System that encodes the signals in the form of up to five audio frequencies that are frequency-shift-keyed (FSK) to convey information. When only one channel is carried on a wire (or radio), the audio signalling frequency is 1 kHz; a five channel system uses frequencies of 340 ± 20 Hz, 517 ± 32 Hz, 1050 ± 70 Hz, 2140 ± 90 Hz and 3250 ± 120 Hz. The message format (Figure 11) consists of one short burst of 1 kHz tone for the single channel system (or a shift to the upper or "mark" frequency, e.g., from 320 to 360 Hz, for the multichannel FSK system) whenever DRY is to be signalled, two bursts or shifts for WET, three for ALERT, and four for HAZARD, followed in each case by an extended shift whose duration is proportional to surface temperature.

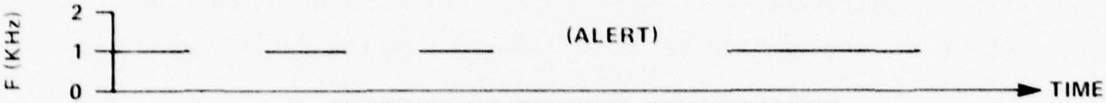
The air temperature sensor can be conveniently mounted near a Display Monitor on the airport. It is usually directly wired to the display (Figure 7, 7000 Series RPU and 5 Channel Monitor Connection Detail).

4.5 Construction of System Components

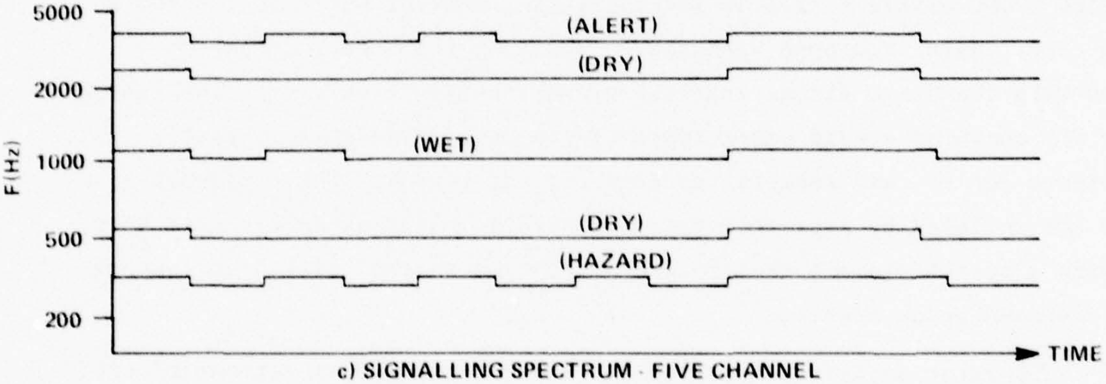
The sensor puck of the SCAN system is a cylinder 30 mm high and 130 mm in diameter (1.1 x 5 inches) made of cast epoxy. Two configurations exist: One is suitable for the three-sensor arrangement discussed in Sections 4.1-4.4, while the other is "configured to facilitate measurement of water layers involved in hydroplaning problems." Recently, it was found that



a) REPRESENTATIONS OF OUTPUT CONDITIONS



b) SIGNALLING SPECTRUM - SINGLE CHANNEL



c) SIGNALLING SPECTRUM - FIVE CHANNEL

Figure 11 MESSAGE FORMAT

roughening or grooving of the sensor puck in approximately the same pattern as exhibited by a concrete surface results in sensor outputs that are more consistent with observations on the surrounding runway surface. Further improvements in ice and water adhesion qualities and consequently in the response of the permittivity and conductance sensors would be expected from improved matching of surface energy, texture, and porosity. Possibilities that could be considered include sandblasting, coatings containing silica or silicon carbide, and a surface layer of epoxy with a salt (NaCl) crystal filler that leaves pores after it is leached in water.

The color of the sensor puck is reasonably matched to that of the runway to obtain a similar albedo, i.e., a similar response to thermal radiation. However, there are two possible sources of error in matching only the visible reflectivity/absorbtivity of the surface; both the absorbtion of the significant fraction of solar illumination in the near infrared spectrum and reradiation of 300°K radiation in the far infrared are ignored.

The remote processing unit (RPU) has dimensions of approximately 400 x 300 x 400 mm (16 x 12 x 16 inches) with a door or hatch on the 400 x 400 mm face. Being equipped with rubber seals on the hatch, it may be mounted with the hinge either vertical or horizontal (Figure 7). The inside of the RPU contains a base panel supporting a power transformer, fuse, convenience outlet, and sockets for four circuit boards. These circuit boards are enclosed by a plastic cover which also contains an extruded heat sink with a heater element that is energized by a thermal switch at temperatures near and below freezing.

Operator adjustments are provided for setting calibrations of the sensor. A set of five switches permits one to:

a. Replace surface temperature thermistors with fixed resistors simulating -16.7°C (2°F) and +0.5°C (33°F);

b. Eliminate a long delay for quicker testing;

c. Open the conductivity sensor circuit;

d. Replace the permittivity signal with an adjustable voltage set by a potentiometer.

These operator controls seem adequate for routine maintenance. Points on the plug-in circuit boards seem sufficiently accessible to allow more extensive maintenance in the field, except in inclement weather, when a temporary cover over the RPU would be needed.

Sensor output voltages can be monitored on a terminal board (D). Typical ranges are -5 to +5 V DC for temperature, 0 to 10 V DC for C1 (stainless steel conductivity probe) with maximum voltage for an open circuit or zero conductivity, and 0.5 to 2 V DC for C2 (the permittivity sensor) with voltage increasing with increasing capacity.

In terms of military specifications, the thermal environment of this unit presents special problems; It is neither as severe as the conventional -55°C to +125°C aircraft environment nor as benign as the 0°C to 50°C shipboard condition. Specification of the more severe, aircraft environment could prove counterproductive in forcing a construction style that would lead to maintenance difficulties. Specifically, some allowance must be made for condensation. If the unit is hermetically sealed and filled with a dry gas or equipped with a desiccator, it must be refilled (or resupplied with desiccant) when opened for maintenance. If it is allowed to "breath" extensively, dust and other contaminants may be introduced from aircraft prop or jet blast. The combination of limited breathing with a heater, that was chosen by the manufacturer, while probably not acceptable under the letter of military specifications, is probably the best compromise that meets their spirit.

Most components used in the RPU are available in versions that operate over the full aircraft temperature range. Such MIL-SPEC versions should be specified for military applications, even with the heater, to allow continued operation of the system if the heater should fail under conditions where moisture is not a problem. A few potentiometers, two mylar capacitors, and an aluminum electrolytic capacitor may not have MIL-SPEC equivalents with similar dimensions. These components would likely be satisfactory over all but the top end (80°C to 125°C) of the temperature range. Since this condition is not likely to be encountered on an airfield, a waiver of specification for these components appears justified.

Wired connections between the RPU and the Display Monitor, according to SSI, are normally installed by a local contractor, and their characteristics are not specified completely by SSI. In at least one installation, at Kansas City International Airport, rodents have disrupted these connections. Wires entering and leaving the SSI units are shunted by metal oxide varistors that protect the electronics against lightening-induced surges in excess of 36 volts. Recent trends indicate that radio systems, costing a few thousand dollars (competitive with wired systems) and easier to maintain, are supplanting wired systems.

Radio links comprise transmitters, antennas, and receivers. The transmitters are Repco Model 810-041, available in power outputs of from 400 mw to 25 watts. The final output stage is thermally protected against high VSWR in the event that the antenna is disconnected or shorted. This may not be the best solution for high VSWR because, under these conditions, the output transistor may be damaged by excessively high temperature. In the event of high VSWR, an immediate shutdown feature should be incorporated.

A more satisfactory method of preventing transmitter failure because of high VSWR is to monitor SWR with a bridge circuit that would shut down the R.F. drive to the output transistor. This drive would then be proportional to antenna mismatch and prevent overloading of the output stage. Another method would be to place a 3 DB pad in the output line. This would prevent the SWR from exceeding 2:1 under any conditions. This method will reduce the output power to half, but that is easy to make up in antenna gain or a higher power transmitter.

The receiver is a Repco Model 810-055. It is a double conversion, crystal controlled receiver with a final I.F. frequently of 455 KHZ. The band width is 16.5 KHZ at 3 DB and 24.7 KHZ at 60 DB. The sensitivity is 0.5 microvolts for 20 DB quieting. The telemetering frequencies that are used are spaced 6.25 KHZ*. With a receiver band width of 16.5 KHZ, transmitters operating on adjacent frequencies would cause interference.

The transmitters and receivers, manufactured by Repco (Orlando, FL) are Type Accepted in accordance with FCC Rules and Regulations, Part 21, 81, 89, 91, 93 and 95. Non-military, U.S. Government Services use certain of their equipment to which a federal stock number (FSN) has been assigned. However, the equipment carrying a FSN is not now used in the SCAN system.

The antennas employed in the SCAN system are Antenna Specialists Model ASP 244. This type of antenna is designed primarily for private citizen use on monitor receivers rather than for commercial or industrial use. There are several types of antennas that are used in the public safety, business and industrial services that are of better construction. These include those manufactured by Phelps-Dodge, Motorola, Sinclair Radio Labs, and Communications Products. They are of fiberglass construction and less affected by adverse weather conditions. These antennas are available with 5-6 DB gain which could compensate for reduced transmitter output.

Packaging of radio-frequency components--which present special problems to the designer because of the possibility of undesired oscillations, impedance mismatch, signal leakage and the like -- is not subject to the type of standardization that is currently practiced in the computer industry, for example, and anticipated in military specifications. Some degree of standardization for VHF circuits has been achieved in the industry serving the business

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*Federal Communications Commission, Rules and Regulations, Vol 5, Part 91, Paragraph 91.554, Dec. 1974.

and amateur radio market. Subassemblies, e.g., mixers, amplifiers, and transmitter modules, designed for this market may be obtained in packages that can be assembled in fairly random fashion to form transmitters, receivers and similar functional units with minimal problems. Certain subassemblies designed for the military market, in contrast, have been found to be incompatible with each other and unsuitable for assembly on relatively simple substrates, e.g., printed circuit (PC) boards. Since the military units' superior resistance to shock, vibration, and temperature extremes are not required in the SCAN system, the quality of the business/amateur grade of RF units used in SCAN is quite adequate.

A typical receiver comprises 8 modules or subassemblies on a circuit board, which, with its power supply has dimensions of about 250 x 225 x 100 mm (10 x 9 x 4 inches). A transmitter unit may be accommodated in a 100 x 125 x 75 mm (4 x 5 x 3 inch) shielded package mounted in a housing similar to that of an RPU, together with its multiplex encoder. The latter comprises 2 to 5 PC boards each with 2 integrated circuits (FSK generators), 2 transistors, 2 potentiometers and various resistors and capacitors.

A 5 channel monitor or display is housed in a container measuring 250 x 250 x 160 mm (10 x 10 x 6.5 inches).(See Figure 1.) Centrally located on the 160 mm high, 250 mm wide front face of the monitor are 2 two-digit, light-emitting diode (LED) readouts for air and surface temperature and one single-digit LED readout that indicates which channel's data are being displayed. The channels to be displayed are picked by setting up to five switches mounted next to the LED displays to the "up" positions. Four condition indicator lights labelled DRY, WET, ALERT, HAZARD, (or in older units, CLEAR, WET, ALERT, ICE) are mounted in that order and in a horizontal row across the top of the display face. That condition indicator is lit which is appropriate to the channel being sequentially sampled and whose number will appear simultaneously on the single-digit LED readout. Across the bottom, from left to right, is an illuminated pushbutton switch that enables an audible alarm accompanying the ALERT indication, the SSI Company logo and identification, and an illuminated power switch.

4.6 Conclusions

The SCAN system with two exceptions noted below was found to be designed and constructed to good commercial practice. It could be configured to meet any reasonable military specifications with a minimum of effort. The following exceptions to this judgement are noted:

1. Since we had no access to detailed descriptions of the C2 (permittivity) sensor, we were not in a position to evaluate details of its operation. From our background knowledge of such sensors, we conclude, however, that the SSI sensor performs as well as is possible and does not merit criticism.
2. There is a possibility of lockup, that might have been glossed over if there had not been indications (see Section 5) that lockup occurs in the field. The cure for this problem is fairly straightforward, as outlined in Section 4.3, and could be implemented without imparing the general excellence of the SCAN design.

These conclusions, regarding the design and construction of the SCAN equipment, are not intended as judgements of the adequacy of the sensed signals, or their processing, for the purpose of managing runway snow and ice control.

Section 5

PERFORMANCE EVALUATION

5.1 Introduction

The major task in the overall evaluation of the SCAN system's applicability to Navy-wide implementation was the determination of its actual operational performance in the detection of runway icing conditions. To this end, site visits were conducted to the eight airfields where SCAN systems currently in operation: Anchorage International, Greater Cincinnati, Detroit Metropolitan, Indianapolis International, Kansas City International, Keflavik Naval Air Station (Iceland), Scott Air Force Base (Illinois) and Trenton Canadian Forces Base (Ontario, Canada). In addition, visits were made to Brunswick Naval Air Station (Maine) and Greater Buffalo International, and telephone interviews were conducted with personnel at Adak Naval Air Station (Alaska) and Niagara Falls Airport.

The purpose of the aforementioned site visits was to acquire information on SCAN utilization and performance as related to snow and ice control (SIRC) procedures and strategies and associated costs for labor, materials and equipment. The site visits entailed interviews with operations, maintenance and accounting personnel and, in some instances, inspection of the SCAN installation and SIRC equipment. An extended visit was conducted at the Keflavik Naval Air Station to acquire first-hand information on SCAN performance during icing events.

A detailed presentation of the information collected at each of the visited airfields is provided in Appendix B. The salient aspects of the SCAN installation and implementation of SCAN-provided information at each of the sites, as well as actual performance data acquired during the Keflavik visit are discussed in this Section. Conclusions regarding the operational performance of the SCAN system and its utilization are provided at the end of the Section.

5.2 The Installation and Performance of the SCAN System at Keflavik Naval Air Station, Iceland

An extended site visit was conducted from 21 February to 10 March 1978 at the U.S. Naval Air Station, Keflavik, Iceland (USNASKEF) to obtain more detailed information on the actual performance of a SCAN system and its potential impact on Naval airfield operations. In addition to interviews and record-gathering tasks, recorders were set-up to monitor SCAN output signals, a log of SCAN surface-condition-indications was initiated, and Calspan personnel conducted runway and SCAN sensor inspections when events warranted. The SCAN installation at USNASKEF and its operational performance during the period 23 February - 10 March 1978 are discussed in detail in this Section.

5.2.1 SIRC Operations and the SCAN Installation at Keflavik

Snow and ice control (and the SCAN system) at USNASKEF is the responsibility of the Fire Department under administration from the Air Operations Officer. These duties were transferred to the Fire Department in September 1975 and consist of inspection and maintenance to insure safe braking conditions on all aircraft-used pavements. (Routine runway inspection duties were added at the request and expense of the U.S. Air Force 57th TIS.) Prior to the Fire Department's current role, snow removal was handled by the equivalent of the Base Motor Pool and consisted primarily of brooming and plowing, with apparently not-very-satisfactory results. Absolutely no chemicals were used, while sand was the primary agent used in ice control. Now, chemicals (urea) are used, and the runways are routinely inspected by a Runway Inspection Officer four times daily and constantly during times of alert. These inspections assist personnel of SIRC Operations, headed by the "Snow King," in determining a course (or continuation) of action. All the Fire Department and SIRC personnel are civilian Icelanders.

The airfield at USNASKEF is comprised of two main perpendicular runways (03-21 and 12-30) and two shorter cross runways (07-25 and 34-16) as depicted in Figure 12. The SCAN system, installed at USNASKEF in September 1976, consists of four runway surface sensors located* respectively at the approach ends of the

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*The sensors are implanted ∿40 ft (12m) from the runway centerline.

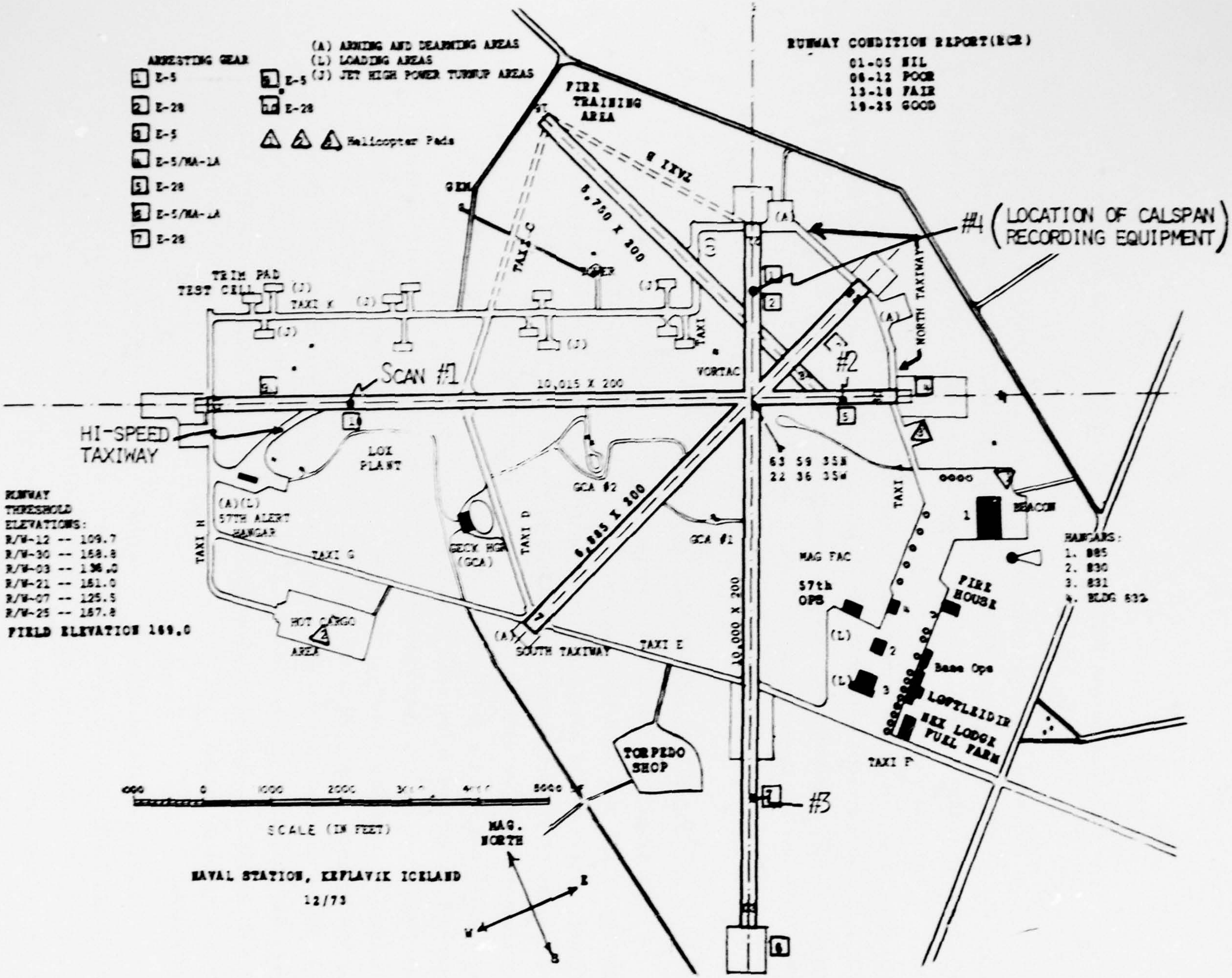


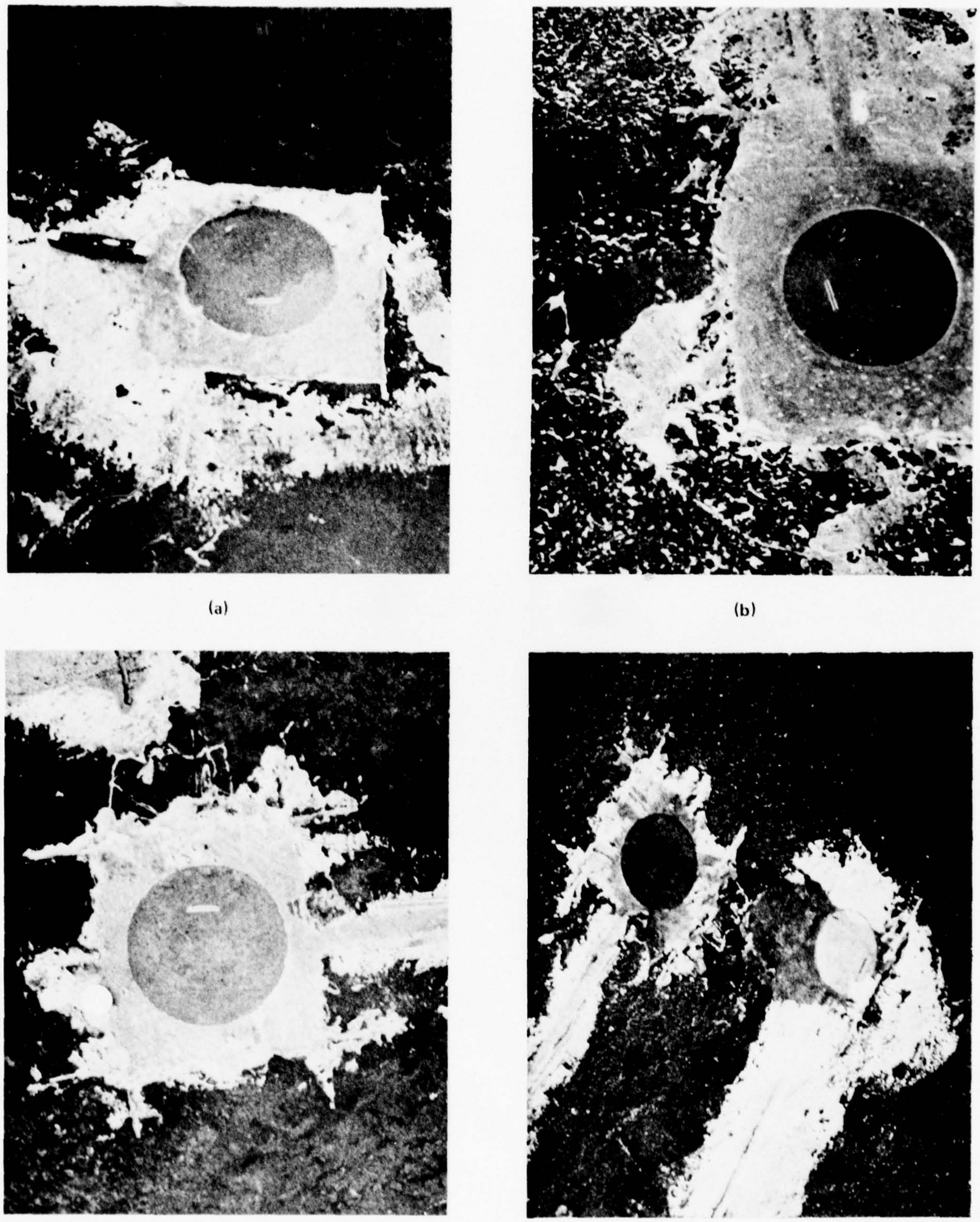
Figure 12: SCHEMATIC LAYOUT OF KEFLAVIK NAS SHOWING LOCATION OF SCAN SENSORS ON THE RUNWAYS

two main runways, two readout stations (at the Fire Department Communications Center and at SIRC Operations Building) and two air temperature sensors located on the roofs of the respective readout-station buildings. A photograph of the runway installation of SCAN sensor #3 is shown in Figure 8 (Section 4). (The two stripes leading onto the runway shown in Figure 8a are the epoxied cuts in the runway surface for the cable runs from the old and new SCAN sensor heads.)

Additional photographs of the SCAN installation at USNASKEF are shown in Figures 13 and 14. Figures 13a and d show views of SCAN sensors #1 and #4, respectively, when both sensors were indicating WET during the drizzle event of 6 March. Figure 13b shows the snow-filled depressions of the runway aggregate around sensor #2 when it was indicating HAZARD during the blowing snow situation of 28 February 1978. Figure 13d shows a view of the old and new sensor #4 at Keflavik. The older sensor, at the right of the photograph was much lighter in color. The darker color of the newer sensor (at the left of the photograph) represents an attempt by the manufacturer to more closely match the radiation color of the runway surface.

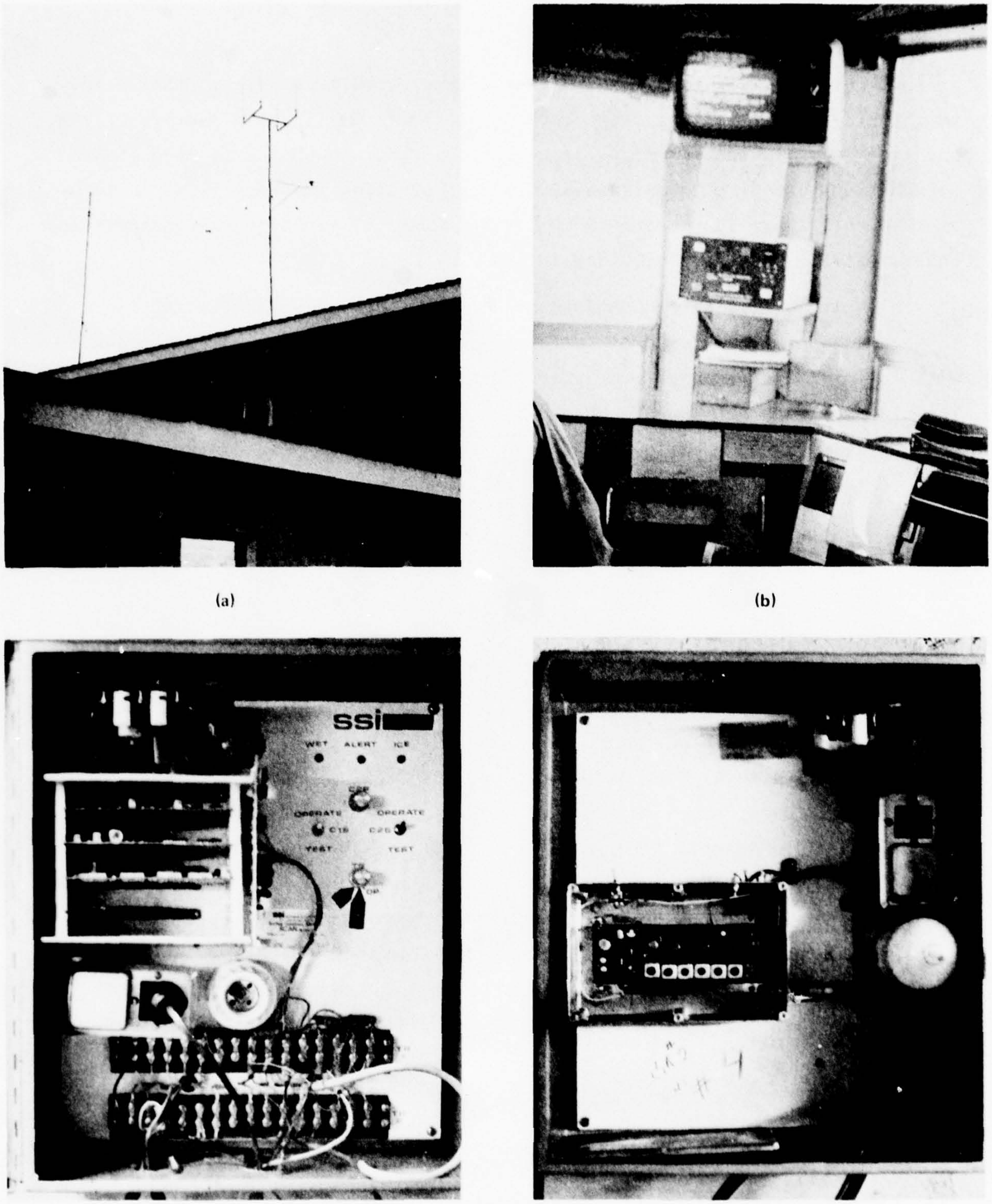
Figure 14 provides photographs of other components of the SCAN system installed at USNASKEF. Figures 14c and d show, respectively, views of the remote processing unit (RPU) and transmitter electronics for sensor #4, located in an underground bunker housing the arresting gear mechanism. Figure 14a shows the radio telemetry receiving antenna and air temperature sensor on the roof of the Fire House. Figure 14b shows the display terminal (approximately centered in the photograph) located in a prominent position in the Fire Department's Communications Center.

Personnel at the Fire Department Communications Center constantly monitor the SCAN readouts (one monitor which cycles through the outputs from the four sensors) and alert the runway inspector when WET, ALERT or HAZARD(ice) conditions occur. In the event of these conditions, the inspector makes a visual and traction measurement inspection of all runway surfaces. In the


(a) (b)

(c) (d)

Figure 13 VIEWS OF SCAN SENSOR INSTALLATIONS AT KEFLAVIK



(a) (b)

(c) (d)

Figure 14 VIEWS OF SCAN SYSTEM COMPONENTS INSTALLED AT KEFLAVIK case of obviously dry conditions (false alarms or early warning), they simply use braking ability of a pickup truck to provide a qualitative measure of runway traction. If ice, frost or snow is suspected, a MU-Meter is used (towed behind truck) to give "quantitative" runway condition readings (RCR) in terms of MU-Meter data. The relationship between MU-Meter traction coefficients and equivalent RCR values is provided in Section 3.

It appears that SCAN data are used as back-up or additional input to visual inspection of runway surfaces at Keflavik. (After initial trouble with false alarms and erronous indications, they have apparently adjusted the electronics to compensate for most of these problems.) For stable (i.e., unchanging) weather conditions, whether blowing snow or clear skies with high frost potential, routine runway inspections suffice; however, a pilot braking report or a SCAN indication of reduced traction would initiate an immediate runway inspection. Once icing or snow conditions are recognized, SCAN surface indications are no longer monitored. If runway traction has deteriorated below acceptable limits, then SCAN surface temperature information is used to determine a course of action, i.e., the application of urea, brooming, etc.

Urea is used sparingly (for financial reasons @ ~$13/100 lb bag) at USNASKEF and only when necessary to melt hardened ice. As at Buffalo, it is not as effective in high winds (typical at USNASKEF) or temperatures lower than ~20°F. (Here, the SCAN temperature data apparently provide considerable guidance.) As a general rule, they do not anti-ice, either as a matter of strategy or as a result of a lack of weather situations which lend themselves to anti-icing. However, urea was observed (applied to the Hi-Speed Taxiway prior to our arrival) to provide continued melting action during the night (on snow melt which daily runs across that area and would freeze at night) through at least the initial six days of the visit.

5.2.2 Discussion and Summary of SCAN Performance and Weather Events at Keflavik During the Period 22 February to 10 March 1978

In order to objectively decipher the actual performance and utilization of the SCAN system, Calspan personnel attempted to maintain around-the-clock surveillance of runway conditions, SCAN surface-condition indications and SIRC activities during the site visit at Keflavik. Fire Department personnel graciously offered to keep an hourly log of SCAN-measured surface conditions and temperature as read from the display terminal. However due to frequent crew changes, the logs were not complete and covered only 15-20 hr for some of the days. (Similar logs have been kept in the past.) In addition, Calspan personnel kept abreast of current weather and potential runway icing developments and accompanied the Runway Inspection Officer on numerous inspections of runway surfaces and SCAN sensors.

A recording system was installed at SCAN sensor #4 to directly monitor the surface condition (C_1 and C_2 signals discussed in Section 4) and temperature output signals. Access to the appropriate signals was acquired on the terminal strips of the RPU (see Figure 14c). Rustrak recorders were set-up to record the three output signals continuously from 22 February to 10 March 1978. (A problem with sensitivity on the temperature recording system was not remedied until mid-day on 27 February; hence, recorded temperature data were not available prior to that time.)

Time histories of the data acquired during the 16 days of observation at USNASKEF are provided in Figures 15-19. The strip-chart records for the C_1 (conductivity), C_2 (capacitance) and surface temperature signals are reproduced in Figures 15, 16 and 17, respectively. (The data presented in Figures 15 and 16 are not to be interpreted as output voltages of the sensor; they are simply relative deflections on a strip-chart record. Temperature data in Figure 17 are absolute values calibrated with the system's internal calibration.) Figures 15 and 16 are annotated with the surface condition indications as read from the display terminal and recorded in the hourly log. (The periods for which the log was maintained is indicated by the dotted line.) Hourly temperature data, as recorded (in the logs) from the display terminal, are plotted in Figure 18. For completeness, hourly air temperature data

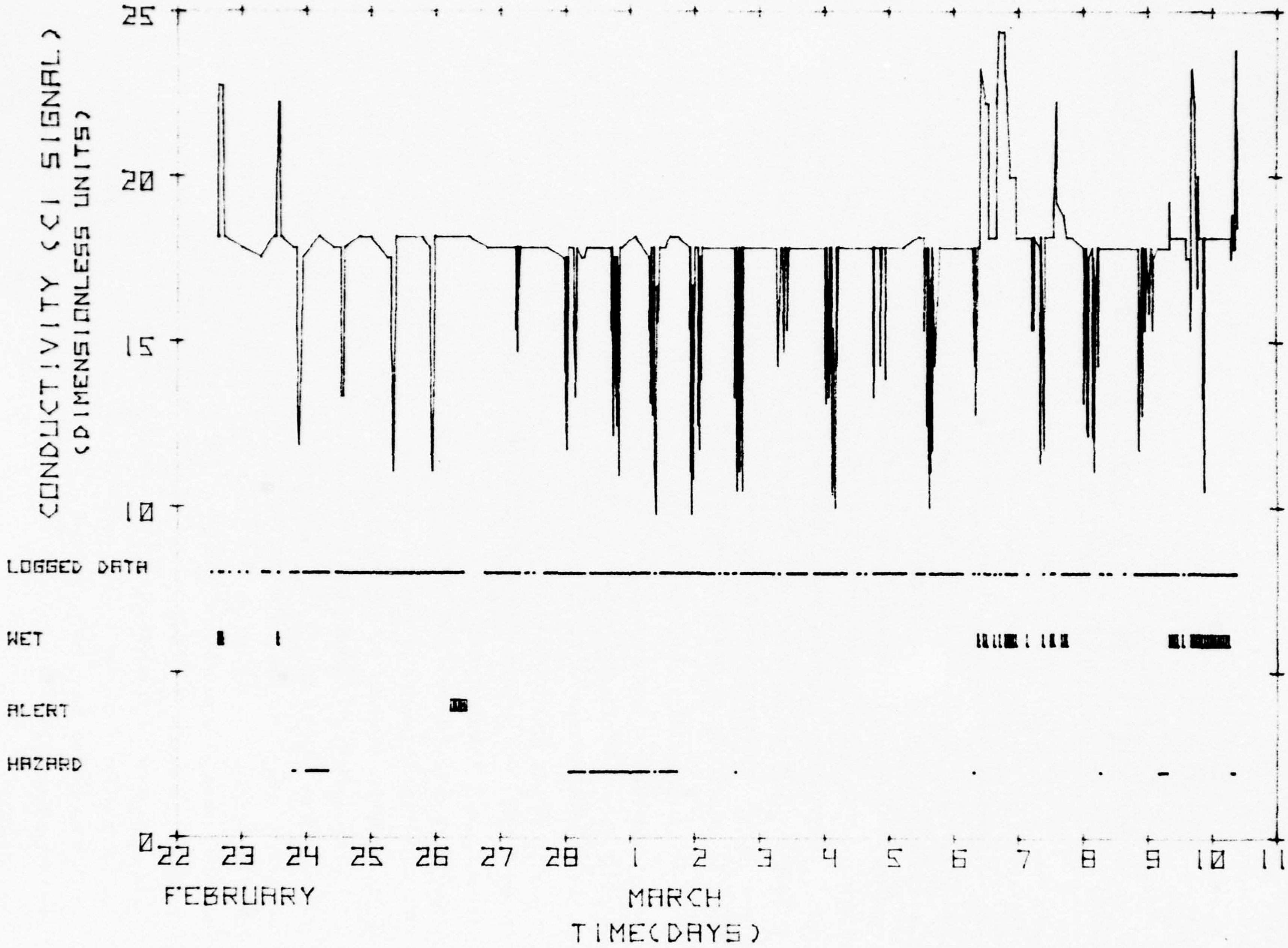


Figure 15: RECORD OF THE CONDUCTIVITY SIGNAL OF SCAN #4 AT KEFLAVIK, 22 FEBRUARY-10 MARCH 1978

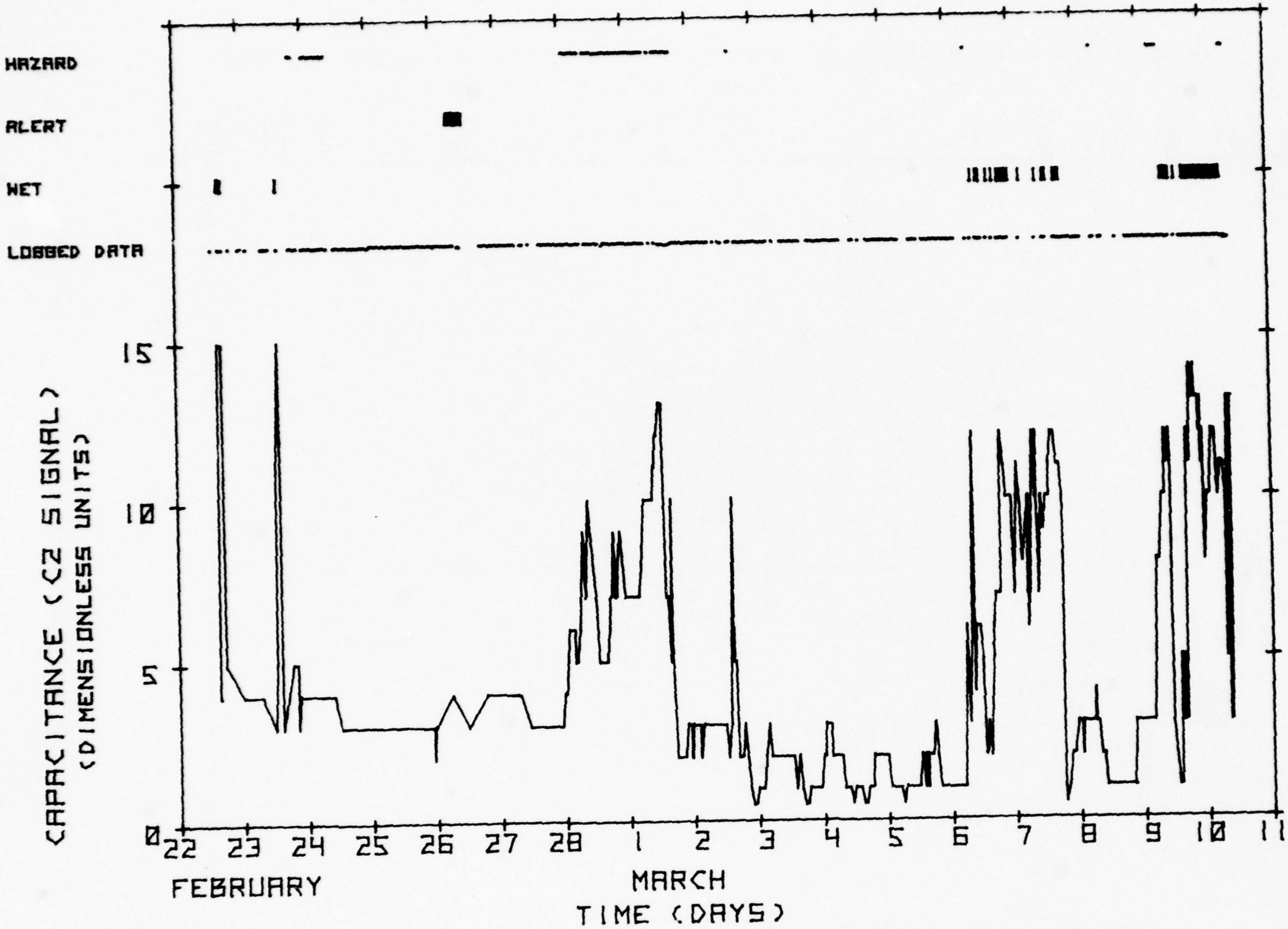


Figure 16: RECORD OF THE CAPACITANCE SIGNAL OF SCAN #4 AT KEFLAVIK, 22 FEBRUARY-10 MARCH 1978

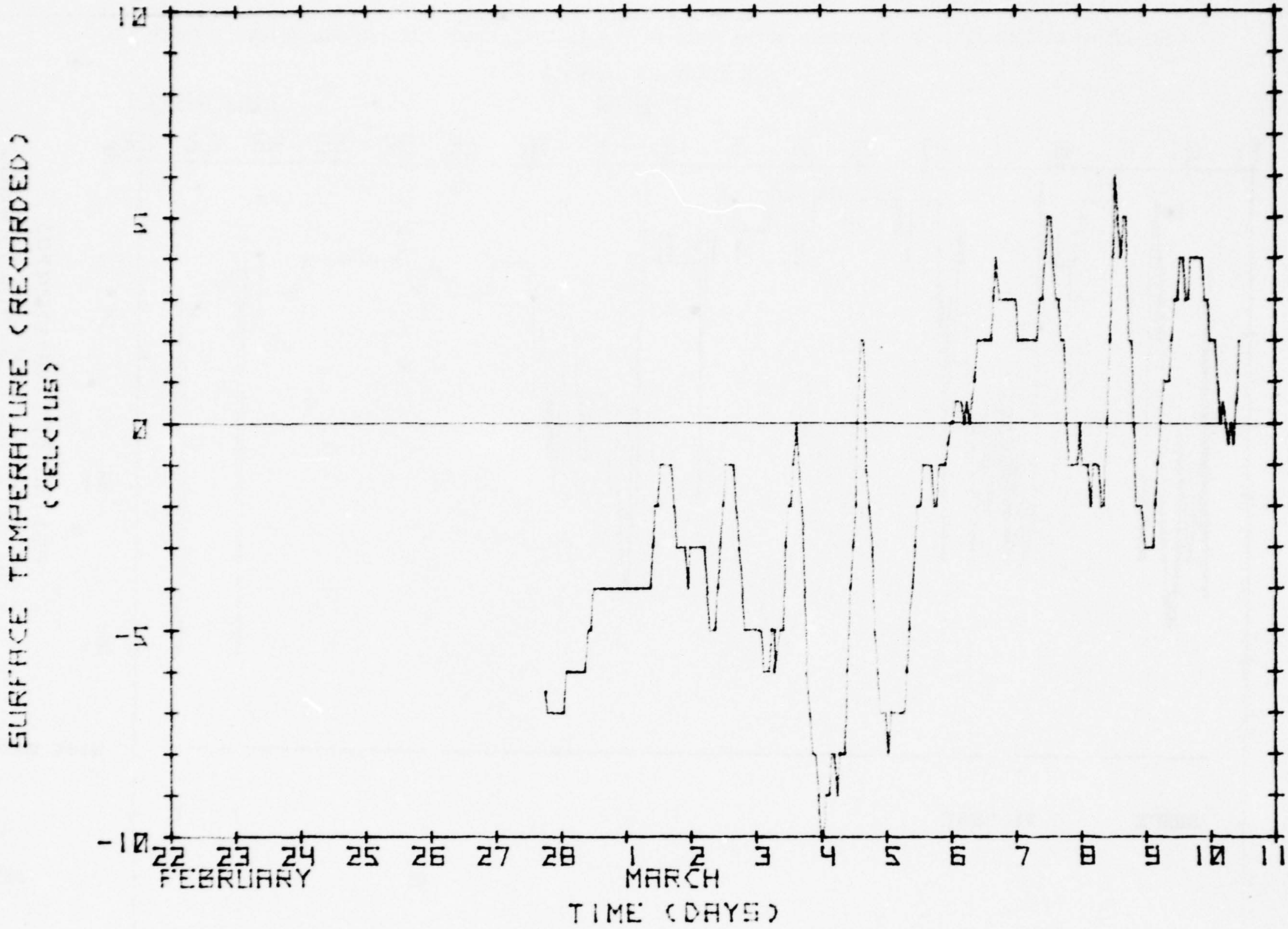


Figure 17: RECORD OF SURFACE TEMPERATURE RECORDED AT THE REMOTE PROCESSING UNIT OF SCAN #4

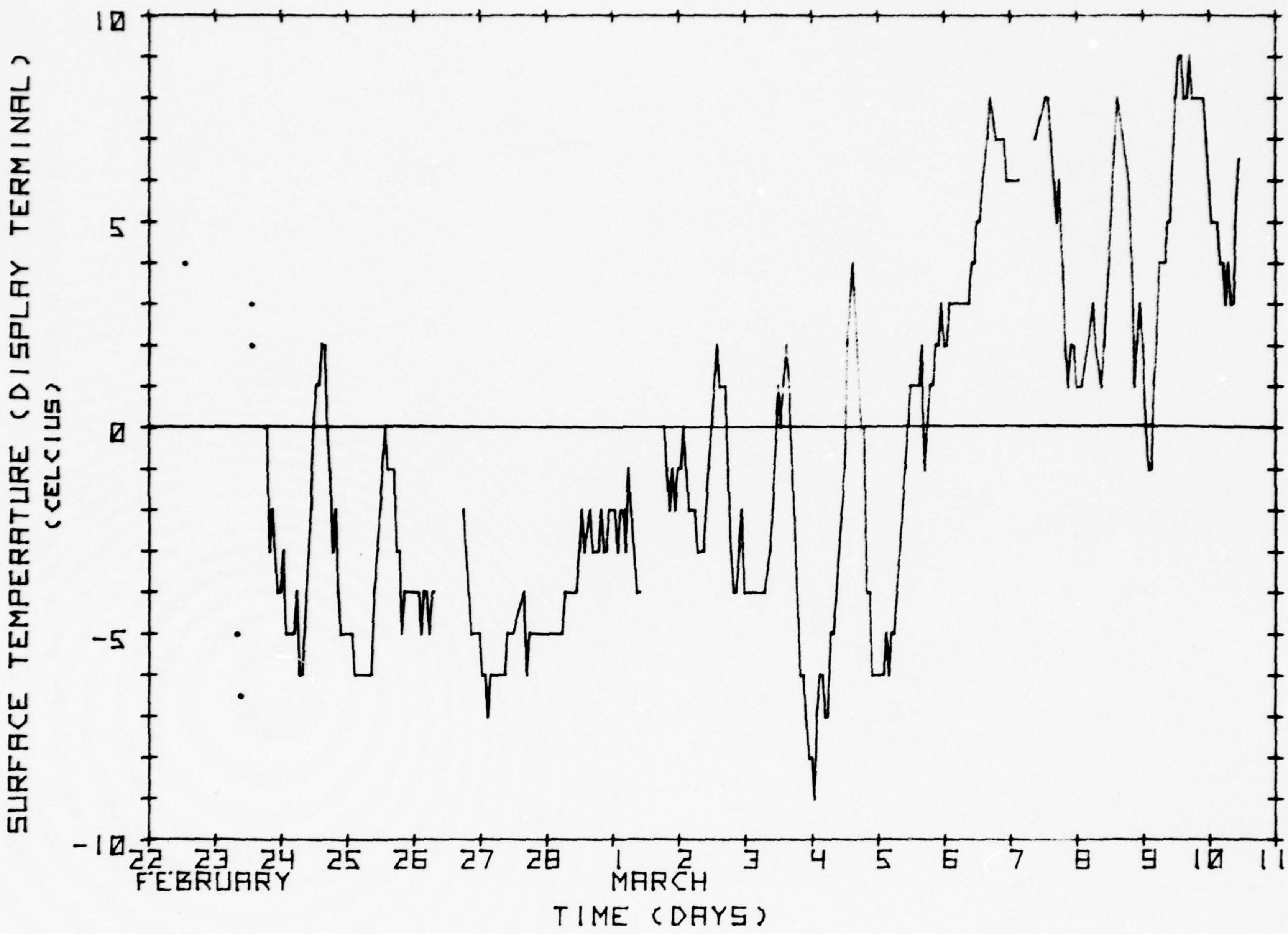


Figure 18: RECORD OF SURFACE TEMPERATURE RECORDED FROM THE DISPLAY TERMINAL FOR SCAN #4

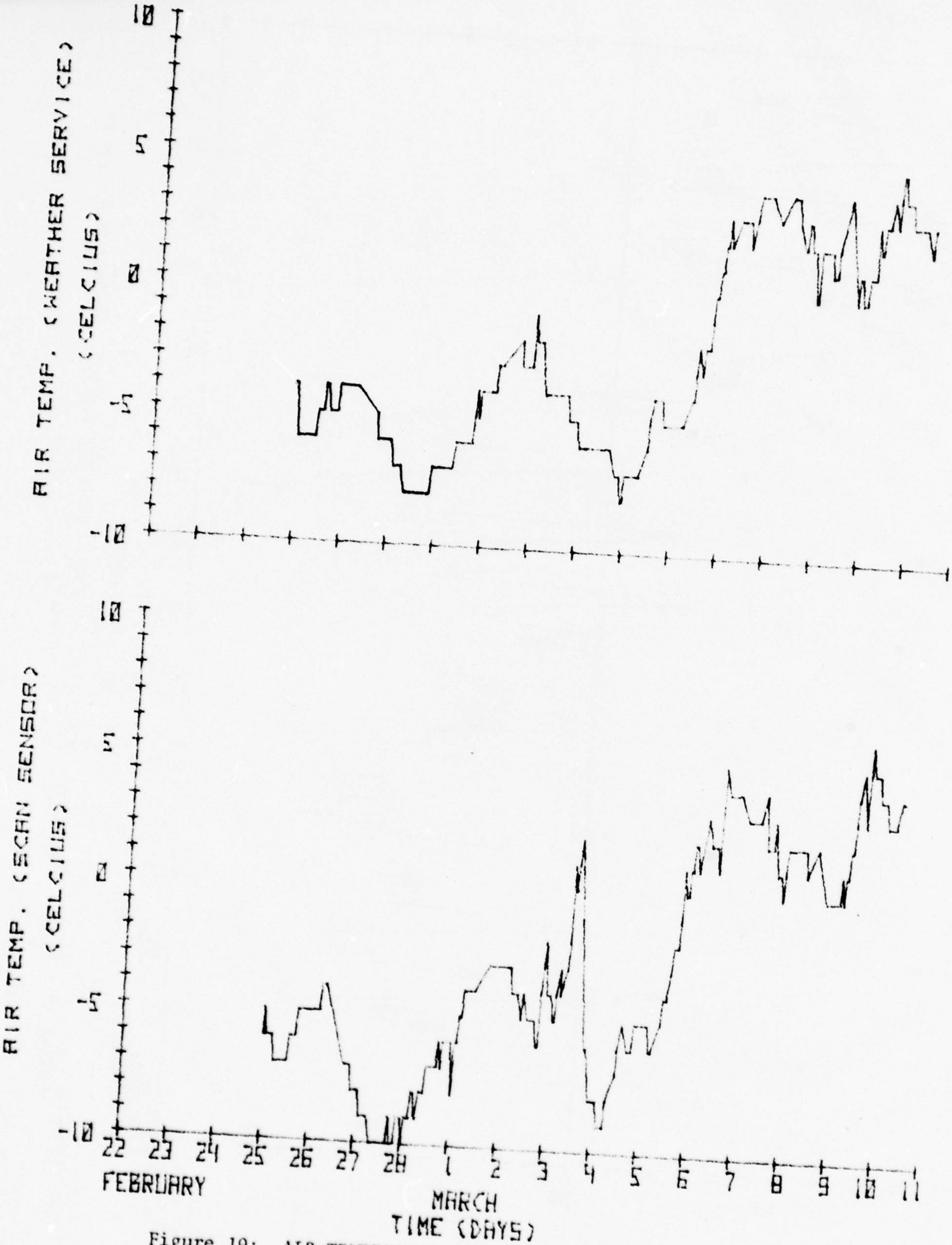


Figure 19: AIR TEMPERATURE RECORDS FROM THE SCAN SENSOR AND THE NAVAL WEATHER SERVICE

measured by the SCAN system are compared with similar hourly observations reported by the Naval Weather Service in Figure 19. (Dewpoint and wind speed data from the Naval Weather Service Records are provided in Appendix B.) The time marks on these figures refer to the 0000 hour (GMT and Local) of the indicated days.

During the 16 days of observation at USNASKEF, a total of 16 "operational", weather-related SCAN events were identified as follows chronologically:

1. A heavy frost on the morning of 23 February, which covered the sensors and runways with 1-2 mm of loose frost and lowered runway traction to poor*, went completely undetected by the SCAN system;
2. On the morning of 24 February, the SCAN system indicated icing conditions, but frost or ice was not visually detected and a reduction from good runway traction did not occur;
3. On the morning of 26 February, SCAN again gave a warning (ALERT) of potential icing conditions, but ice was not visually detected and a reduction in runway traction from good did not occur;
4. On the morning of 28 February, an already recognized condition of snow and blowing snow caused the SCAN system to indicate icing conditions, but runway traction did not measurably deteriorate and remained good;
5. Later on 28 February at mid-day, while all sensors continued to indicate HAZARD, increased snowfall intensity caused a reduction in traction to only fair on some portions of the runways, and the SCAN indication was proper;
6. In the late afternoon of 1 March, the melting (by intermittent sunshine) and refreezing of light blowing snow caused a reduction in runway traction from good to fair-to-poor, but all sensors indicated CLEAR;

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*Measured values of runway traction which indicate a braking action of less than good are sufficient to prompt snow and ice control (SIRC) activities at USNASKEF. See Section 3 for a definition of runway-braking-action terms.

7. A tire track of snow on sensor #4, judged to be ∿50-75% of the coverage of a similar track shown in Figure 21, went undetected for at least 17 hr on 2 March;

8. During the morning of 2 March, accumulations of blowing snow reduced runway traction to only fair; but SCAN sensors remained relatively snow-free, indicating CLEAR;

9. Melting of accumulated snow at mid-day on 2 March, which caused a reduction in runway traction from good to only fair, was properly indicated by the SCAN system, prompting SIRC activities;

10. In the presence of light snow showers on the afternoon of 5 March, two SCAN sensors (not #4) went to HAZARD and ALERT, respectively, but measured runway traction remained good;

11. Light rain and drizzle on the morning of 6 March was readily detected by all four SCAN sensors; however, surface temperature at sensor #4 was < 0°C, and #4 incorrectly indicated HAZARD until surface temperature increased above 0C; no evidence of ice was visually detected on runway surfaces;

12. Light drizzle again occurred on the afternoon of 6 March, and all sensors instantly responded, properly indicating WET (surface temperature was >0C);

13. On the evening of 7 March, radiational cooling of wet runways caused freezing of runway surfaces and a reduction of traction to poor and fair-to-poor; however, premature drying of SCAN sensor surfaces prevented detection of the hazardous condition and the sensors remained in the CLEAR condition;

14. On the morning of 9 March, a frost event occurred which reduced runway traction to below acceptable values; several of the SCAN sensors provided advance warning of the impending hazardous condition and no doubt prompted runway inspection and control measures;

15. On the afternoon of 9 March, the SCAN sensors instantly registered WET when light rain showers began;

16. On the morning of 10 March, several SCAN sensors provided early warning of impending freezing of wet runways; the warnings by SCAN

prompted SIRC activities which were not initially sufficient to prevent a reduction in runway traction to poor.

Of the 16 events described above, 4 (25%) were false indications, and SCAN failed to detect or warn of hazardous conditions on 4 (25%) additional occasions. (An additional failure, to detect a tire track across the sensor, was also observed.) On 3 occasions (19%), the SCAN system properly and instantly responded to rain (although one sensor on one occasion improperly reported HAZARD. On 4 other occasions (25%) SCAN properly detected hazardous icing conditions. For two of those icing events, the SCAN system provided advance warnings which prompted runway inspection and SIRC activities, thereby enhancing airfield safety.

It appears that the SCAN surface condition information was used as back-up or additional input to visual inspection of runway surfaces at USNASKEF. For the obvious conditions of snow, blowing snow or warm rain, the SCAN system was referred to infrequently. The constant presence of a RW inspector on the runways with a MU-Meter provided the information needed to direct SIRC operations. When bad spots were observed on the runways, SIRC personnel were notified and soon had swept or plowed the area. SCAN proved most useful in providing indications or warnings of unexpected events such as freezing of wet runways and frost formation. Any unexpected indication of ALERT or HAZARD was sufficient to prompt a runway inspection, and surface temperature data was occasionally used to guide application of chemicals. However, false alarms and missed events, such as the frost of 23 February, have lead to a certain degree of distrust of the system.

Central to the SCAN system's high rate of false alarms and inability to detect certain hazardous icing conditions appears to be the sensors' lack of representativeness of the surface characteristics and thermal properties of the runway surface. During meteorological situations involving snow, icing or frost, sensor surfaces were generally not visually representative of runway surfaces, even though the sensors typically responded (ie., increased capacitance shown in Figure 16) to the general meteorological event. The SCAN system repeatably detected significant quantities of snow, ice and water, but for small quantities, low density, or broken coverage of snow or ice on the sensor surface, the SCAN indications could not be predicted from observation of sensor surfaces. On several occasions, differences in the wetness of the sensor and runway surfaces, apparently resulting from differences in porosity of the respective materials and premature drying of sensor surfaces, precluded the detection of freezing runways. False alarms (ALERT or HAZARD indications) typically occurred at night, when radiation to the sky apparently cooled sensor surfaces to temperatures lower than those of the runway and approaching the dewpoint temperature, thereby causing frost or ice deposition on the sensors.

The logic involved in the SCAN system's determination of surface condition is readily apparent from a review of the data presented in Figures 15-18. It is obvious that a surface condition other than CLEAR (dry) was indicated whenever the capacitance signal (Figure 16) increased a certain amount above the baseline value. It is equally obvious, from a comparison of Figures 16, 17 and 18, that HAZARD signals (as opposed to WET, with a high value of capacitance) were generated when recorded surface temperature (Figure 17) was 0°C (32F) or lower (e.g., on the mornings of 3, 6, 8, 9 and 10 March). The conductivity probe, while capable of detecting water (both tap and rain; e.g., see 22, 23 February and 6 and 7 March on Figure 15), apparently played no role in signal processing. Therefore, for sensor #4 at Keflavik during the period 22 February-10 March 1978, the capacitance signal determined the presence of water on the sensor, and surface temperature was used to determine the phase of the water.

A potentially serious problem, involving drift of the displayed surface temperature data was observed during the latter 11 days of observations at Keflavik. The temperature data recorded at the RPU are considered reasonably accurate by these authors, as freezing events typically occurred when surface temperature was ∿0°C and frost deposition on the sensor apparently began when the sensor temperature neared the dewpoint temperature. However, displayed temperature, which was ∿1C greater than recorded temperature on 27 February, was reading ∿4C warmer than actual, recorded temperature by 10 March. (Surface temperatures displayed from all four sensors differed, at any given time, by up to 4 degrees C throughout the 16 days of observations.) If the displayed surface temperature data were to be utilized for the timely application of chemicals, as in anti-icing strategy, serious and costly errors could arise as a result of erroneous temperature information. (See Section 6 for details.)

Hourly data from the SCAN air temperature sensor and similar data from the Naval Weather Service records are compared in Figure 19. Given the differences in exposure of the two instruments, the air temperature data exhibit reasonably good agreement.

Finally, a SCAN performance problem observed on several occasions during our observations at Keflavik was the locking or sticking of a sensor in the HAZARD indication even though runways were dry and temperatures were well above freezing. Personnel at Keflavik overcame this problem by disconnecting power from the sensor and RPU. After restoring power to the unit, it would display correctly.

5.2.3 Detailed Discussion of SCAN Performance at Keflavik, 22 February-10 March 1978

In the following discussion, a chronological narrative of significant weather-, SIRC- and SCAN-related events which occurred during the 16 days of observation at USNASKEF is provided. Visual observations obtained through direct runway inspection, weather events and SIRC activities are described and referenced to SCAN output data presented in Figures 15-19 and supporting information provided in Figures 12-14. Locations of the SCAN sensors, runways and taxiways referenced in the discussion may be found in Figure 12.

- 22-23 February 1978

Weather during the initial six days of the site visit was dominated by increasing interaction between the "Greenland High" to the northwest and the "Polar Front" which was located considerably south of Iceland. The week's weather began (mid-day, 22 Feb.) with uncommonly sunny (for there, that time of year), warm (daytime 36F(2C), nighttime 30F(-1C); T-Td ∿2F), light wind conditions (NE @ 5 kt). During the week, the Greenland High built while the Polar Front shifted northward; the pressure gradient tightened, and northeasterly winds picked up to 35 kt (daytime), advecting-in gradually colder and drier air; but skys remained sunny. By 25 February, daytime temperature was ~24F(-4.5C), nighttime was 21F(-6C), Td was ~17F(-8C). From 21 through 26 February, no precipitation events occurred at USNASKEF, and hence no precipitation related ice-detection events were observed.

The recording system at SCAN sensor #4 was installed on the afternoon of 22 February, and, as an initial test, the sensor was splashed with water to depth of ~0.5 mm from ~1530-1700 GMT. The response of the conductivity and capacitance sensors to the layer of water can be seen in the spikes in Figures 15 and 16, respectively. On the following afternoon (23 Feb.) at ~1400, an attempt was made to calibrate the surface temperature probe* of #4 by creating a puddle of water ~10 mm deep over the sensor and measuring the temperature of the water with a thermometer. Again, note the spikes in the records shown in Figure 15 and 16 on the afternoon of 23 February. In both tests (ie., on the afternoons of 22 and 23 Feb.) the SCAN sensor responded to the presence of a substantial layer of water, measuring, as expected, increases in both capacitance and conductivity.

In the interval between the two aforementioned tests of Sensor #4, ie., on the morning of 23 February, a "heavy" frost event occurred and went completely undetected by the SCAN system. The frost occurred as a result of radiational cooling of runway surfaces under clear nocturnal skys, with a dewpoint depression of only 2°F(1.1°C). Initial frost formation was noted at ~1930 GMT on 22 February, but a runway inspection showed MU-Meter traction coefficients (TC) of (60/60/60)** (see Section 3 for an explanation) for the respective thirds of the runway length. Subsequent checks of runway (RW) conditions at 2300 and 0200 GMT (23 Feb.) showed a gradual thickening of the

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*The calibrations indicated that displayed surface temperature was within ±0.4°C of water bath temperature.

**The numbers refer to averages over respective portions of the runway, in this case thirds; > 40 is <u>good</u> runway traction, 36-39 is <u>good-to-fair</u>, 30-35 is <u>fair</u>, 26-29 is <u>fair-to-poor</u>, and < 25 is <u>poor</u>.

still light frost and runway TC of (60/60/60). However, by 0740/23 Feb., a heavy frost, fluffy like a light dusting of snow, covered the runways to a depth of 1-2 mm. Traction on RW12 was measured at (28/29/26/21), the latter reading near SCAN sensor #2. Based on these observations and previous experience, brooming was immediately initiated. At 0800, after one pass by the brooms down the center of the runway, traction on RW 30 was (36/36/46/44/31/22), the latter two readings on the as yet unbroomed portion of the RW near SCAN #1. The unswept South Taxiway showed TC of (29/32/28). SCAN #3, vicinity TC (17/19/17), was covered with 0.5 mm of frost and indicating -6C, CLEAR; SCAN 4 had 1.5-2 mm of frost, TC (28), and was indicating -5C, CLEAR. The brooms continued sweeping, working from the center to the RW edges. At 0842, traction on RW12 was (36/40/38/40) after one complete broom pass.

On the Hi-Speed Taxiway, the area which had been previously treated with 22 bags of urea (on 21 Feb.) was wet but adjoined abruptly by solid, thick frost at the edge of the untreated runway. The following MU-Meter traction data was acquired:

	Readings Off Strip Chart	Computed Average
Over urea-treated area	45/43	38
Over untreated area	28	27

The data indicate that had the frost event been predicted (dewpoint and surface temperature information), anti-icing measures could have prevented reduction of traction coefficients below ∿40.

Because of the possibility of continued frost deposition, the brooms are kept working in this type of situation until solar radiation becomes effective in warming runway surfaces. (Sunrise was at ∿0905.) By 0950, traction in the center portion of RW03 was (70/62), while the frost covered (now partially melted) edges were (8/25/29). At 1012 GMT, traction on the broomed portion of RW12 was (50/58/62/55/40), with frost reforming at the latter end. At 1020, even though most of the runway had been swept bare, SCAN #4 was covered with 1-1.5 mm of "loose" frost and was still indicating CLEAR.

Throughout the above described frost event, during which runway traction dropped below MU-Meter values of 30 (indicating fair-to-poor and poor braking action), all four SCAN sensors remained in the CLEAR-condition readout on the display terminal. Inspection of Figures 15 and 16 also shows that no increases in either capacitance or conductivity occurred during the period. Hence, SCAN was unable to detect this type of frost event, probably as a result of the frost's low density.

- 23-24 February 1978

By the evening of 23 February, the air had cooled and dried (dewpoint depression was 5-6°F (∿3°C)) and the winds freshened sufficiently that not the merest hint of frost was detected on exposed surfaces. However, beginning at 1830 GMT and for the reminder of the night until 0900, SCAN #4 displayed HAZARD signals. Beginning at midnight, #3 indicated ALERT for the remainder of the night. (Sensors #1 and 2 remained in the CLEAR condition throughout the event.)

Inspection of the sensor heads revealed a very thin film of dense ice/frost (black ice?) totally different from the frost of the previous morning; yet, runway traction was measured at (60/60/60) all night. Frost was not detected on other surfaces such as automobiles. The ice film, and HAZARD warning, was removed by wiping the sensor surface vigorously with a rag (in one instance a wire brush), or by warming the sensor with our hands. The condition usually then remained stable for ∿1 hr, when the HAZARD indication would come on again.

The records reproduced in Figures 15 and 16 reveal that the capacitance signal increased slightly, barely registering the presence of the thin ice film on the surface of sensor #4. Such thin films of ice on the sensor, which caused no obvious reduction in runway traction and which may be the result of differences in radiation color and thermal properties of the sensor head and runway surface, may be the cause of some of the "false alarms" experienced at Keflavik and elsewhere (see Appendix B).

The conductivity record (Figure 15) for the night of 23-24 February shows the initial observation of a series of almost daily periods of apparent reduced conductivity. A total of 19 such episodes are evident in the record, ranging in duration from 1.5 to 5.5 hr and averaging 3.75 hr. The episodes of reduced conductivity were statistically well-distributed throughout the day, with 26% occurring during the first 6 hours of the day, 26% during the second quarter, 21% during the third quarter, and 26% during the fourth quarter of the day. Inspection of these records, as well as weather and SIRC activity records, revealed that the indications were neither diurnal in nature nor related to any weather or SIRC event. We have not been able to attribute these periods of "reduced conductivity" to anything other than electrical "noise" in the circuitry of the SCAN conductivity probe.

No further precipitation, icing or HAZARD events occurred through 25 February.

- 26 February 1978

On the morning of 26 February, sensor #4 went to ALERT and remained in that status from 0700 through 1000 GMT; all other sensors reported CLEAR through the period. Skys were 60% overcast, air temperature was -3.5, dewpoint was -7.0°C, SCAN #4 surface temperature was -4°C, and runway traction was (60/60/60) throughout the period and for the remainder of the day. Figure 16 shows a slight increase in capacitance at the time, but Figure 15 shows no response of the conductivity probe. There was no obvious meteorological cause, or reduced traction event, to warrant ALERT status at that time. It is likely that this indication was either the result of a very minute film of frost or ice on the sensor surface or an electronic problem producing an indication that was not consistent with measured traction coefficients.

- 27 February-1 March 1978

Intermittant, light snow showers began after 0700 GMT on 27 February and continued throughout the day. With surface temperatures of ∿-6C, snow did not stick to the runways, runway traction remained (60/60/60), and all SCAN sensors reported CLEAR throughout the day.

By ∿2000 snow flurry activity had become more continuous (visibility ∿7 mi), and, at 2010, SCAN sensor #2 went to ALERT status; all other sensors reported CLEAR and runway traction was (60/60/60) through midnight. Inspection of the sensor revealed no obvious ice, snow or water and wiping the sensor with a rag at ∿2015 did not affect the indication. Similar wiping of the sensor at 2300 GMT briefly changed the sensor indication from ALERT to CLEAR, but the sensor went back to ALERT by midnight. As expected, no increases in capacitance or conductivity at sensor #4 were observed.

By 0100 on 28 February, prolonged snow flurry activity and more intense blowing snow (visibilities were approximately 1 mi) resulted in traces of snow on runway surfaces. Sensor #1 was indicating CLEAR, while #'s 2 and 3 were indicating ALERT and #4 was reporting HAZARD. Runway traction remained (60/60/60) and SCAN sensor readings continued this way until near sunrise (∿0845), with the exception of SCAN #3 which went back to CLEAR between 0400 and 0600. Inspection of the capacitance data in Figure 16 shows a dramatic increase in capacitance at the exact time sensor #4 indicated HAZARD. An increase in conductivity was not observed, although such an increase was not necessarily expected since the conductivity of ice is significantly less than that of water and not much greater than that of air. Through the early morning hours, recorded surface temperature (Figure 17) was -6C while displayed surface temperature was reported at -5C.

During this time, visibility remained generally less than one mile. All runways were clear and dry except for the east end of runway 12-30 (near sensor #1), which had patches of light snow over about 50% of its area. This was probably due to the previous heavy use of urea traditionally on this part of the runway. Any excess that might have still been around could have caused some melting and eventual sticking and buildup of snow. During this time there was no observable buildup of ice or snow on any of the sensors. By 0715 continued blowing snow accompanied by flurries began to accumulate; sensor #'s 1 and 3 were showing ALERTs and #'s 2 and 4 were indicating HAZARD, but runway traction remained (60/60/60). SCAN #4 continued to show an increase in capacitance (Figure 16) apparently indicating the presence of material on the sensor.

Heavy, blowing snow continued throughout the morning. Traction on RW03-21 was (52/49/55) at 0845, and sensor #3 went to HAZARD at 0900. At 0930, traction on RW30-12 was (30/55/55/52), and traction on the Hi-Speed Taxiway was (32); brooming of the runways was initiated. At 1000, traction on RW03-21 was (30/37/48/60) and by 1100 GMT was (54/56/46/56). At 1115, sensor #1 went to CLEAR, but all other sensors continued to indicate HAZARD. Figure 13b shows a view of sensor #2, and the freshly broomed runway surface surrounding it, when it was indicating HAZARD.

The afternoon brought continued blowing snow and flurries with near zero visibility at times. Once the condition of dry, blowing snow was recognized, frequent runway inspections were used to determine the runway condition. The SCAN display was no longer monitored. At no time was urea applied to the runway; brushes took care of any accumulated snow. At 1330 traction on RW03-21 was (65/58/58) and on RW30-12 was (35/48/50); on the Hi-Speed Taxiway where snow was accumulating on the wet, urea-melt, traction was (30).

Snow flurry activity and blowing snow conditions continued, but diminished with decreasing winds, through the following day (1 March) until ceasing abruptly at ∿1800 GMT on 1 March. All sensors continued to indicate HAZARD through 1700 with the exception of #3 which went to WET at 1100 and eventually to CLEAR by 1700 GMT. At 1800 all sensors went to CLEAR for the remainder of the day. Simultaneously with the change in surface condition from HAZARD to CLEAR, the capacitance signal at #4 (Figure 16) dropped back to a new, lower baseline value. For sensor #4, throughout this entire 40 hr snow and blowing snow event, the capacitance signal remained above a baseline value, surface temperature remained below freezing, and indicated surface condition remained on HAZARD; no increase in conductivity was registered during the period. During the 40 hr period, the sensors appeared to be covered with thin films of ice and were certainly not covered with loose snow.

By 1800 on 1 March, there was sufficient sunshine to melt a very fine film of the light snow on the runway, despite the fact that air temperatures only reached a high of about -4°C. (Displayed surface temperatures ranged from -0.5 (#4) to -2.0C; recorded surface temperature for #4, shown in Figure 17, indicated -1.0C.) The melting (and refreezing?)resulted in low values of runway traction (25/30/33) at 1800, but the SCAN sensors all indicated CLEAR. (The low TC values were quickly raised by brooming.) It is likely that the observed inconsistency between surface conditions and sensor indications was due to differences in surface characteristics and thermal properties of the sensors and runway surface.

At 1830, with the capacitance signal of #4 at a baseline value and all sensors indicating CLEAR, a tire track of compressed snow was observed running across the surface of sensor #4. The amount of snow on the sensor surface was judged to be ~50-75% of that of a similar tire-track-on-sensor shown at the bottom of Figure 21. The tire imprint remained on the sensor surface through at least 1130 GMT on 2 March, and, at no time during the period, did the sensor register HAZARD.

- 2 March 1978

Very windy conditions continued through the day, causing blowing snow to continually move across the runways. In the afternoon, skies cleared somewhat allowing intermittent sunshine. Air temperature remained about -5°C throughout the day.

Much effort was required of the SIRC crews to prevent accumulation of blowing snow on wet spots (where urea was present) or drifts on the runway. Runway inspection and SIRC equipment left extensive compressed snow tracks on the runways which added to traction reduction. These tracks were removed with plow blades. In addition, at the downwind end of the runway where aircraft frequently sat awaiting clearance to depart, the hot exhaust of the jet engines caused melting and subsequent ice film formation. This portion of the runway became very slick, with traction coefficients of (30) being observed.

During the morning, a discrepancy developed between SCAN sensor readings and the actual conditions of the surfaces of the runways and sensors. All sensors were showing clear, but traction coefficients were down quite low, indicating only fair and fair-to-poor braking action. At 0730, TC's on RW30-12 and PW03-21 were (30/40/38/36) and (30/31/34), respectively; at 0945, RW03-21 was (31/29/32); and at ~1100 GMT, RW12-30 was (36/39/35) while RW03-21 was (39/33/42). When examined, the sensor surfaces were covered with thin ice and snow films (of < 0.5 mm thickness). Yet neither the capacitance signal nor display terminal gave any evidence or warning of lowered traction. (Brooming and plowing were continued to alleviate the low-traction conditions.)

At mid-day on 2 March, traction on RW03-21 was (43/44/51), but traction gradually lowered to values in the low 30's. Sensor #1 went to ALERT at 1230 and to HAZARD by 1300; sensor #2 indicated ALERT at 1350. By 1425, and until about 1600, sensors #1, 2 and 4 were indicating HAZARD; sensor #3 remained in the CLEAR condition thoughout the period. The HAZARD indicated by #4 corresponded to an increase in the capacitance signal as can be seen in Figure 16; an increase in conductivity was not observed. These indications occurred as surface temperatures climbed to about zero degrees Celcius, while air temperature remained at ~-5C. SCAN surface temperature recorded (Figure 17) at the RPU indicated a maximum of -1C at the time (~1400 GMT) that display temperature (Figure 18) was indicating a maximum of +2C. Inspection of sensors at ~1545 revealed the following: sensor #1, reading CLEAR at the time, was ~20% covered with small patches of ice and snow; sensor #2, indicating HAZARD, was ~50% covered with drops of ice and patches of snow; sensor #4 had slightly less snow and ice coverage than #2 and was, at the time fluctuating between HAZARD and CLEAR; and sensor #3 was reading CLEAR and looked free of ice and snow.

The above described SCAN indications, which correlated well with mu-meter measurements of traction coefficients decreasing from ~40 to less than 30 after ~1230 GMT, were sufficient to prompt SIRC activities (traction measurements and brooming). It appears that the reduced traction and warnings from SCAN were due to melting, by intermittent afternoon sunshine, of a thin surface film of the dry snow which was present on the runway. While the dry snow represented no hazard, the thin film of water resulted in a very slick surface as well as apparently enough density to be detected by the sensors.

It appears that the sensitivity of SCAN to ice or snow is dependent upon snow density; i.e., SCAN apparently will not detect very dry, light snow until substantial amounts have accumulated. (Brooming soon brought RCRs back up to acceptable values. Good traction was confirmed by two aircraft (727 and DC-8) in reports of good braking conditions upon landing.)

- 3-4 March 1978

On 3 March, weather continued cold (air temperature ∿-6C all day) and windy (north-northwest at 20 kts) with intermittent, light snow showers. Early morning surface temperatures of ∿-5 warmed to 0°C (display terminal reading was +2C) during mid-afternoon. Dry blowing snow did not effect runway traction which remained good at (58/60/57) throughout the day. SCAN sensors all indicated CLEAR over this period, and no excursions of the conductivity or capacitance signals (Figures 15 and 16, respectively) were observed.

Sunny and cold weather predominated through the day on 4 March, with mid-afternoon temperatures of ∿-5C; *winds were generally easterly at* < 10 kts. Runways were dry and bare and all SCAN sensors reported CLEAR throughout the day.

A minor increase in capacitance at #4 was observed during the hours 0100 to 0300 on 4 March (see Figure 16) when surface temperature (Figures 17 and 18) reached minimum values, possibly signaling initial frost deposition. At 0100 recorded and displayed surface temperatures were -10C and -9C, respectively, while dewpoint (Appendix B) was -11C; at 0200 recorded and displayed surface temperatures were -9C and -7C, respectively, while dewpoint was -9.4C. At 0400, surface temperatures were -8 and -6C, respectively, while dewpoint was -8.9C. Increasing cloud cover after 0200 apparently reduced radiational cooling of the sensor surface, preventing further development of frost. The capacitance signal then went back to baseline values.

- 5 March 1978

The weather throughout the morning was cloudy with winds generally from the ENE at about 10-15 kts. A large low pressure system, located southwest of the island, began to influence the weather later that afternoon and evening. Brief, intermittent snow showers passed through during the afternoon, and winds increased to 20 kts. Later that evening, winds became very gusty, and wet snow showers mixed with rain occurred as air temperatures increased to above freezing after 2100 GMT.

Runway inspections at 0730 and 1430 showed all sensors and runway surfaces to be clear and traction was reported as (60/60/60). Light snow began at 1650, and by 1700, sensor #1 went to ALERT. At 1730 sensor #2 went to HAZARD, but #'s 3 and 4 remained in the CLEAR condition. At 1730 traction on RW30-12 was (56/64/59). Inspection of the sensors at ~1745 revealed that #2 had a few, tiny flakes of snow (< 1 mm diameter) on its surface, that #4 had even fewer snow flakes on its surface and that #1 appeared completely free of snow. (The photograph of sensor #3, shown in Figure 8b, was taken at 1800 GMT.)

The gradually warming runway surfaces were causing snow flakes to stick to these surfaces. At 1720, sensor #2 was indicating a surface temp of +2C, while all other sensors were registering below freezing temperatures. The warmer surface at #2 could have caused sticking and melting of snow which tripped the HAZARD alarm, while the snow was being blown from the cooler surfaces of the other sensors.

By 2000 hours, all sensors were again reporting CLEAR. Sensors 3 and 4 reported CLEAR for the entire day on 5 March, no increase in conductivity was observed, and only a minor increase in capacitance occurred between 1700 and 2000 GMT for #4.

- 6-7 March 1978

Light rain and drizzle, which began at ~0600 on 6 March, fell almost continuously (except for the period 0950-1520 on 6 March) during 6 and 7 March. The SCAN system apparently responded quickly to small traces of liquid water on the sensor surfaces and remained displaying WET indications for the better part of two days. (Wet or damp runways are not particularly hazardous at Keflavik since typical traction coefficients of about (55) are measured with the MU-Meter.)

Drizzle began at 0555 GMT on 6 March and the capacitance signal (Figure 16) at #4 immediately began to increase. Prior to 0400, surface condition was reported CLEAR by all sensors; by 0700, #2 was indicating WET, #'s 1 and 3 were indicating ALERT, and #4 was indicating HAZARD. (Logged display-terminal data are not available for the period 0400 to 0600.) At 0700, displayed surface temperatures were as follows: sensor #1, +2C; #2, +4C; #3, +2C; and #4 (Figure 18), +3C. By 0900, sensors #1, 3 and 4 were indicating WET, and #2 was indicating HAZARD. At 0945, #2 went to WET, and all sensors indicated WET through 1200 GMT.

The HAZARD indication by sensor #4 at 0700 and 0800 apparently stemmed from the surface temperature actually being sensed. Comparison of recorded and displayed surface temperature data for the period 0400 to 0800 (shown in Figures 17 and 18, respectively) reveals that, while the display terminal indicated +3C, actual surface temperature was being sensed at ∿0°C at the RPU. By 0900 RPU-recorded temperature (Figure 17) went above 0.5C and sensor #4 went from HAZARD to WET. No evidence of icing was detected on runway surfaces. Differences in the thermal properties of the sensor and runway aggregate may account for differences in surface temperature and, hence, sensed condition.

At 0950 the drizzle stopped, and, at 1200, sensor #'s 1 and 2 went to CLEAR; at 1230, #'s 3 and 4 went to CLEAR. Note that the capacitance signal (Figure 16) dropped to near baseline values between 1200 and 1400 GMT. During the period 1000 to ∿1230, the conductivity signal (Figure 15) increased to values approximating those observed on 22 and 23 February when the system was being tested with water. A photograph of sensor #4, taken at 1145 GMT when it was indicating WET and showing it speckled and covered ∿60% by water, is provided in Figure 13c. At the time of the photograph, the capacitance signal was 5 units (compared to a baseline of 2 or 3 and a maximum of 13 registered at 0800), and the conductivity signal was at near maximum value. As shown by the photograph, it apparently didn't require much water on the surface of the sensor to produce increases in capacitance and conductivity.

Light drizzle began again at 1530 on 6 March and continued, accompanied by fog, through ∿1650 on 7 March. The capacitance signal for #4 immediately (within minutes) increased to above baseline values (and continued to increase as water accumulated on the sensor), and all sensors went to WET; these conditions continued through ∿1800 GMT on 7 March. Approximately one hour after drizzle began (at 1630, 6 March) and as water accumulated on the sensor, the conductivity signal abruptly increased from baseline to near maximum values. (A photograph of sensor #1 (Figure 13a) at 1655 on 6 March shows the sensor ∿85% covered with a thin film of water.) The increase in conductivity was observed through ∿2330 GMT, when drizzle intensity decreased and the signal went back to baseline values. At all times during this 26 hr period, air temperatures and surface temperatures (both displayed and recorded) remained above freezing, and traction on RW12 was reported as (57/59/53).

The low pressure system responsible for the weather of 6 March continued to dominate the morning and early afternoon weather of 7 March, contributing the continued light drizzle and fog discussed in the preceding paragraph. Temperatures during the morning remained around 4°C. With the arrival of a cold front at 1400 GMT, winds shifted to WSW at 15 to 20 kts, and temperatures slowly began to drop. By 1900 hours, roadways began to ice up under clearing skies. Convective cells, moving in from the WSW, brought a couple of isolated graupel/snow episodes in the evening. Winds diminished late that evening to < 10 kts.

Runways were wet throughout the morning and most of the afternoon, with good traction (57/59/53) reported for all runways. Both the capacitance and conductivity signals peaked during a period of heavier rainfall at ∿1400. With the end of precipitation (∿1650 GMT), clearing skys, lowering humidity and windy conditions, surfaces began to dry. At 1720, sensor #1 went to CLEAR, and, by 1900, sensors #2 and 4 went to CLEAR; #3 remained WET through 2000. The capacitance signal of #4 dropped to baseline values at 1820.

By 1900, recorded surface temperature (#4, Figure 17) dropped to 0°C (display temperature was +4C), and, by 2000 (and thereafter), recorded surface temperature was -1C. Also at 1900 (∿ sunset), while the sensors were dry, pools of water on the still wet runway surfaces were observed to be freezing, apparently a result of radiative cooling of exposed surfaces. At 1915, traction was measured on RW30-12 at (47/45/47) and on RW03-21 at (47/30/19), and brooming was initiated. At 1940, traction on RW30-12 was

(25/29/27). At 1955, a Navy P-3 landed after being advised of poor runway traction. Using only minimal braking and turboprops to decelerate, the pilot reported that he was satisfied with the landing surface.

Inspection of the sensors at around 2000 GMT revealed the following: at 1950, #1 was indicating CLEAR and had a few unfrozen wet spots on its surface, while the runway surface surrounding the sensor was frozen and slick; at 2000, sensor #2 was indicating CLEAR and was covered with a thin film of ice and a few spots of frozen droplets; (sensors #1 and 3 went to ALERT at 2005); at 2010, sensor #4 was indicating CLEAR but was covered ∿30% by frozen droplets, while traction on the surrounding runway was measured at (23); at 2020, ice coverage on #3 was similar to that previously observed on #4, and measured traction was (23/27/29) on RW21-03 and (49/41/35) on RW12-30. The capacitance signal of #4 remained at baseline values during the period 1820 to 2330. Apparently the SCAN system was unable to detect this freezing period because all sensors were dry, while the RW surrounding each sensor was becoming icy and hazardous. The inconsistencies between the indications displayed by SCAN and the actual runway conditions again point to the problem of different surface characteristics of the sensor vs. the runway.

By 2300, all sensors were indicating CLEAR. At 2330, traction on RW30-12 was fair (32/34/38) with snow coverage of ∿30-40%, while sensor #2 had a small snow drift across one corner. At 2340, a small snow drift was also observed on sensor #1. At 2345, RW03-21 was ∿50% covered with snow and traction was measured at (36/38/35); sensor #4, on that runway appeared to be free of ice and snow. At 2350, a small drift of snow was observed over the interface between the runway and sensor #3. At midnight, sensor #1 went to WET, while all other sensors remained CLEAR. Displayed surface temperature for #'s 1 and 4 was +1C, while recorded temperature for #4 was -1C. It appeared that brooming activities had smeared snow or ice on sensor #1.

- 8 March 1978

With continued brooming and a cessation of snow flurry activity, runway conditions gradually improved though the early morning hours of 8 March. Traction on RW30-12 went from (33/38/40) at 0020 GMT to (53/56/52) by

0740. All sensors remained CLEAR through the night, with the exception of #4 which briefly indicated HAZARD at 0600. The HAZARD indication was attributed to brooming and residual snow left on the sensor. From Figure 16, it is obvious that the HAZARD indication corresponded to a brief increase in capacitance (from 3 to 4 units) at a time when recorded surface temperature was -1C. (Displayed surface temperature for #4 was +3.)

Through the remainder of the day intermittently sunny skys and warm temperatures (∿+3C) combined to dry runways. Traction was typically (65/65/65), all sensors indicated CLEAR and surface temperatures climbed to +5C (recorded) and +8C (displayed). During the afternoon the capacitance signal of #4 dropped to a new, lower baseline value of 0.5.

By late evening, radiational cooling had dropped surface temperatures to near freezing. Between 2000 and 2100, recorded surface temperature for #4 dropped from 0°C to -2C (displayed temperature from +4C to +1C), and capacitance increased slightly (to 3) from the baseline of 0.5. By 2300, sensor #2 went to HAZARD and remained in that condition through 0600; at the time, sensor #2 was displaying a surface temperature of 0°C. Evidently, sensor #2 and the capacitance signal for #4 (#4 remained CLEAR until 0400) were indicating the initial formation of frost which reduced runway traction early on the morning of 9 March.

- 9 March 1978

The frost event, which began late on 8 March, continued to develop through the early morning on 9 March. Sensors #3 and 4 went to HAZARD by 0400, while sensor #1 went to ALERT at that time. (Sensor #2 had been indicating HAZARD since 2300.) In this instance, the capacitance signal for #4 didn't begin to increase above its previous value until 0445. At 0400, recorded and display temperatures for sensor #4 were -2C and +1C, respectively; at 0500, -1C and +2C, respectively. Frost accumulation, and, apparently, warnings by the SCAN system, were sufficient to prompt brooming activities at 0400.

Increasing air temperatures ahead of a frontal passage caused gradual warming of runway surfaces. By 0600, recorded and displayed temperatures for #4 were 0°C and 4°C, respectively; by 0800, surface temperatures were +1C and +4C, respectively. Sensor #3 went to ALERT at 0500 and to WET at 0600; #2 went to WET at 0700; #4 went to WET at 0800*; and #1, which had been indicating ALERT since 0400, went to WET at 0900. Drying continued, and, by 1145, the capacitance signal of #4 dropped to baseline values. Sensors #2 and 3 went to CLEAR at 1355, but sensors #1 and 4 did't read CLEAR until ∿1500. (At 1445 sensor #1 was observed to have a few tiny streaks of water on its surface.)

- 9-10 March 1978

A light drizzle shower was reported at 1353 GMT, and the capacitance signal for #4 increased above baseline for a short period at 1435. Precipitation occurred again at 1554, when light rain and drizzle again developed and continued intermittently for the remainder of the day. All SCAN sensors, including #4, were indicating CLEAR at 1500 and reporting WET at 1600. Thereafter, all sensors reported continuously WET through the remainder of the day and into early morning on 10 March. At 1700, both the capacitance and conductivity signals went to maximum values. The conductivity signal went back to baseline at 1920, but the capacitance signal remained at high values until late on the morning of 10 March. Throughout the period 1300-2300 on 9 March, recorded and displayed surface temperatures (sensor #4) remained above freezing at ∿4C and ∿8C, respectively.

At 2330, precipitation ended, and skys began to clear. Radiational cooling caused the surfaces of the wet runways to cool, and, by 0600 on 10 March, recorded surface temperature was 0°C; displayed surface temperature was +3C, and air temperature was +3C. By 0700, recorded surface temperature for #4 was -0.5C while a high value of capacitance was being observed. At ∿0645, sensor #1 went to ALERT and #4 went to HAZARD, corresponding roughly to the time at which recorded surface temperature at #4 dropped below freezing.

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*At 0755, a lock-up problem was suspected at sensor #4, since it was reading HAZARD and surface temperatures were above freezing. To remedy the situation, the sensor was momentarily unplugged at the RPU, and the sensor immediately went to WET (at 0800). The lockup and sticking in the HAZARD indication apparently occurs frequently with warming temperatures after icing conditions.

SIRC personnel, as well as both Calspan personnel, were skeptical that significant runway icing would occur, but a truck was sent out to apply urea to RW03-21 for ice prevention. (Unfortunately, the truck broke down after applying only a light coating of urea to the middle of the active runway.) Some 30 to 60 minutes after SCAN had warned of runway icing, all runways were covered with ice. At 0745 sensor #1 was covered with slush; at 0800 traction on RW03-21 was (47/19/19), and sensor #3 was indicating WET and was covered with slush to a depth of ∿2 mm. At 0815 traction on taxiways was ∿(15); and by 0820 traction on RW21-03 was (09/08). (A C-130 landed at this time and reported good braking action, but the pilot used reverse-pitch-props and not brakes for decelerating.) By 0845, traction, beginning to improve, was measured at ∿(18) on RW21-03. Sensor #4, which was covered with a thin layer of ice and registering a high capacitance signal, was reporting CLEAR at 0855. (Measured surface temperature was -0.5C and displayed surface temperature was +3C.) Traction on RW21-03 was (18/33/55) at 0855 and (30/45/52) at 0900. The rising sun quickly aided in warming the runways, and all sensors except #2 were indicating WET by 0930. (The capacitance signal of #4 dropped to near baseline values briefly for the period 0915-0945.) Recorded surface temperature at sensor #4 was 0°C at 0930, +0.5C at 1000, and +2C at 1100 GMT.

Data acquisition at Keflavik was terminated at 1100 GMT on 10 March 1978.

The event of 10 March described in the preceding discussion, as well as the frost event on the morning of 9 March, were the sole instances observed during the site visit to USNASKEF in which the SCAN system provided useful predictive information. The necessary information was supplied at the display monitor, despite the fact that the sensor output signals were not being interpreted correctly. At the initial indication of icing by the SCAN system on 10 March, a light layer of urea was applied to the active runway. Additional urea would have been applied at that time, except for the malfunction of the urea spreader, and probably would have prevented the very hazardous runway conditions which subsequently occurred. In this instance, the SCAN system appeared to supply unique and valuable information which aided SIRC personnel and enhanced airport safety.

5.3 Discussion and Summary of SCAN Performance and Utilization at Other Airfields

As previously discussed, short site visits were conducted to all airfields where SCAN systems were known to be operating* to acquire information on the utilization and performance of the respective SCAN systems. The site visits were conducted during late Winter 1978, and a detailed presentation of the information acquired is provided in Appendix B. SCAN utilization and performance, as determined through interviews with operations and maintenance personnel and inspection of SCAN installations at each of these locations, is summarized in this Section.

During late Winter 1978, SCAN systems were in operation at the following airfields: Anchorage International Airport (2 sensors), Greater Cincinnati Airport (2 sensors), Detroit Metropolitan Airport (1 sensor), Indianapolis International Airport (1 sensor), Kansas City International Airport (3 sensors), Keflavik Naval Air Station (Iceland) (4 sensors), Scott Air Force Base (Illinois) (3 sensors), and Canadian Forces Base (Trenton, Ontario) (3 sensors). At these airfields, SCAN sensors are nominally mounted flush with the runway surface, and signals are transmitted from nearby remote processing units (RPU) to a display terminal typically located in a field maintenance office.

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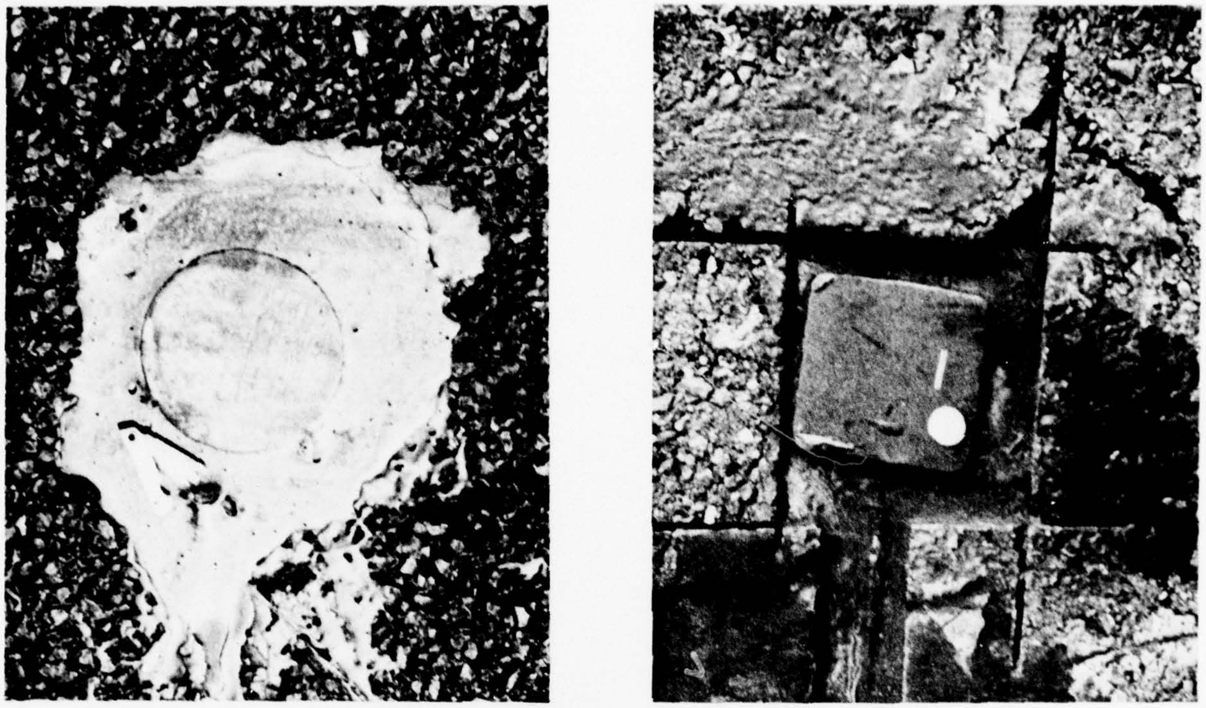
*Since Spring 1978, a 3-sensor system was delivered and installed at O'Hare (Chicago), and a 1-sensor system (with 7 additional sensors on order) was delivered to Pittsburgh. In addition, the manufacturer has installed, free of charge, new sensors (with a new capacitance-probe configuration) and new RPU's at Anchorage, Cincinnati, Indianapolis and Kansas City and plans to do so at Keflavik during Summer 1979. (Initial indications from the above 4 airfields suggest that the new sensors provide more correct surface condition reports.) Orders for SCAN systems have been placed by St. Louis' Lambert Field (5 sensors), Newburgh, N.Y. (5 sensors), and Glasgow and Edinburgh, Scotland (2 sensors, each). At least 10 other airfields are contemplating purchase of ice detection systems during 1979, including Anchorage and Detroit, both of which plan to add additional sensors to their existing SCAN systems. (The foregoing information was supplied by the manufacturer in February 1979.)

Signal transmission is via radio telemetry at Cincinnati and Keflavik and by underground cable at all other locations. At Anchorage and Detroit, existing FAA cable runs (encased in conduit) are used for the SCAN system; but all others, including the early Keflavik installation, used direct-buried cables. A considerable amount of trouble (including rodent damage, water seepage and damage by heavy equipment) has been experienced with the underground cable systems at Kansas City, Scott AFB and previously at Keflavik. In view of expense of burying cables, which can exceed the purchase price of a SCAN system, radio telemetry of SCAN data is recommend if FAA conduit lines are not available.

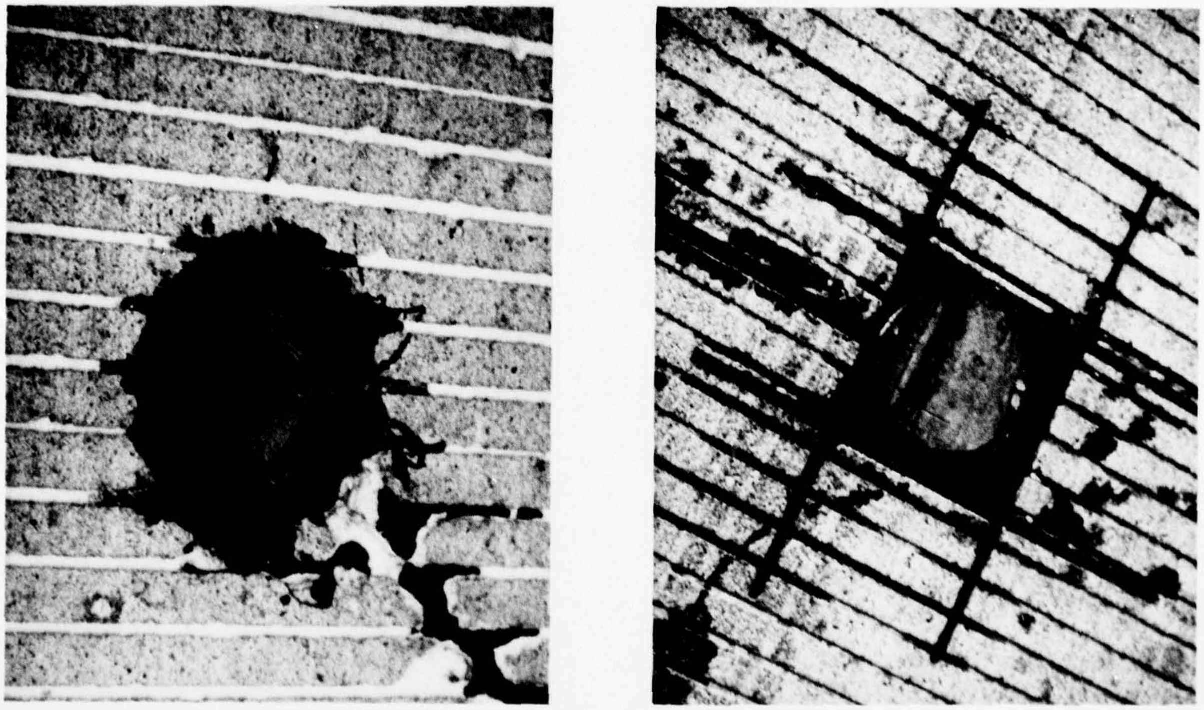
Sensor installation appears haphazard, probably as a result of improper installation procedures by airport maintenance personnel, and sensors do not always match the color and roughness characteristics of the runway surface. Figures 20a-d provide views of typical sensor implacements at Scott AFB, Anchorage, Cincinnati, and Detroit, respectively. Note, for example, the extremely rough runway surface surrounding the sensor in Figure 20a, the major depression (allowing accumulation of water and ice/snow) around the square (obsolete version) sensor in Figure 20b, the overly darkened (tar covered) sensor in Figure 20b, and the partially tar-covered sensor in Figure 20c. These types of mismatch of sensor and runway surface characteristics are no doubt responsible for much of the observed discrepancy in "surface condition" between the runway and sensor surfaces.

The information displayed by the SCAN system (ie., surface condition and temperature) is utilized to a greater or less extent at various airfields depending on SIRC strategy, severity of weather, demand on SIRC operations and past experience with the SCAN system. In terms of SIRC operations, surface temperature is the only data unique to the SCAN system. Personnel in charge of SIRC operations keep abreast of weather (both current and forecast) and make routine, first-hand inspections of runway surface conditions; they generally know current weather and what to expect in the immediate future. At the airfields where SCAN is installed, the surface condition indicators are not used unless they indicate unexpectedly; but



a) SCOTT AFB

b) ANCHORAGE



c) CINCINNATI

d) DETROIT

Figure 20 VIEWS OF SCAN SENSOR INSTALLATIONS AT FOUR AIRFIELDS even then, false alarms and discrepancies between actual and indicated surface condition have personnel distrustful of the indications. Surface temperature data supplied by SCAN can be an important guide in the efficient and timely application of ice control chemicals and are used to some extent by SIRC personnel. However, the forecast capability of the trend in surface temperature is not utilized to its maximum potential. The general viewpoint of SIRC personnel concerning the SCAN system is that "it is only a tool and should be viewed as such."

In terms of economics, airport availability and safety considerations, the proper and timely application of chemicals is the key element to SCAN utility. Mechanical procedures are dependent on meteorological conditions and are not significantly impacted by SCAN. The annual costs of chemical application are dependent on the severity of weather, the areas of runway to be treated and the costs of the chemicals themselves. For anti-icing a 10000 ft runway, one application of urea costs ∿$500-$1000, while one application of Ucar costs $2000-$3000 (at 1978 prices); chemical costs for de-icing are 2 to 4 times greater. Annual expenses for chemicals range from $10000-$20000 for Scott, Cincinnati, Trenton and Brunswick NAS to > $60000 for Anchorage, Detroit and Indianapolis. Keflavik NAS and Kansas City fall between those values, while Adak NAS uses no chemicals.

5.3.1 Scan Utilization and SIRC Strategy at Individual Airfields

The following is a summary of the information provided in Appendix B.

- Anchorage International Airport, Alaska (5 April 1978)

A 2-sensor SCAN system was installed at Anchorage (AIA) prior to the winter of 1973-1974. The two sensors, one at the touchdown point and one near the taxiway exit, are mounted on runway 06R about 50 ft from the center line of the runway. Neither of the two sensors (obsolete square shape) appeared to be flush with the runway surface and large depressions in the epoxy surrounding the sensors (see Figure 20b) likely compromised their functional operation. (One of the sensors had recently been dislodged by a grader.) Both sensors except for the conductivity probes were covered with a layer of flat-black colored tar.

This particular SCAN system was one of the early units produced by SSI and was essentially a prototype. The system has proven unreliable, inconsistent, and often erroneous, especially for surface freezing conditions. AIA personnel noted that the primary benefits of SCAN are derived from runway surface temperature measurements, but that "reliable indications of surface condition would be a welcomed and useful luxury." As at other airports, the runway surface temperature measurements are used to determine the necessity or utility of applying urea. Occasionally, certain ice conditions occur which do not require control measures. According to AIA personnel, "ice at -20%F provides (relatively) very good traction," and hence, "an airport such as Fairbanks which experiences extreme cold doesn't need the SCAN system."

Urea, the primary chemical used at AIA, is bought by the truckload (not in bags) directly from a plant located ∿150 miles away. After snow removal operations, urea is applied for final clean-up to achieve a dry runway; residual urea is then counted on to help during the next snow situation. AIA first experimented with urea in 1968, using 50-60 tons that winter. In the winter (1972-1973) prior to SCAN installation, they used ∿800 tons of urea, however, there were many instances in which it was not effective. The next winter, with SCAN providing surface temperature data, they used only 550 tons; @ $145/ton, they attributed a savings of ∿$30K in urea alone to the SCAN system. An application to the main runway requires ∿3.5 tons, while both runways and taxiways might require as much as 10 tons ($1500).

The strategy at AIA is to keep the runways dry. During winter months, runways are inspected at least once per shift by the foreman and more frequently as conditions demand. A mu-meter and/or Tapley device are used when runway conditions appear to be deteriorating, and RCR's are immediately reported by radio to the tower. Weather forecasts for AIA are obtained a minimum of once/shift by telephone from the National Weather Service in downtown Anchorage, but the forecasts are not used for detailed, advance planning. The following anecdote relative to SIRC operations and use of the SCAN system was offered:

In the midst of a recent 5 inch snowfall, surface temperature was 31°F and sunshine was expected; so instead of using urea and brooms, they simply used rubber bladed plows and allowed the sun to melt residual snow. The savings attributable to good surface temperature data are thus well illustrated.

- Greater Cincinnati Airport, Kentucky (1 March 1978)

Cincinnati (GCA) has two SCAN sensors. The first sensor (#1) was installed in September 1976; and the second, because they were pleased with performance of the first, was installed in February 1977. One sensor (#2) is imbedded in concrete (see Figure 20c) at the intersection of RW 18-36 and 27L-9R while SCAN #1 is imbedded in asphalt near the touchdown zone of RW18.

The primary ice/snow control strategy at GCA is preventative control, since "anti-icing is much easier and less costly than is de-icing." They anticipate conditions based on Weather Service forecasts and, depending on visually detected icing/snow and/or SCAN readouts (primarily surface temperature), they initiate control measures. Personnel at GCA are pleased with the SCAN system, "especially the surface temperature measurement." It provides guidance, and they are certain that "it has saved many applications of chemicals this winter that otherwise would have been needlessly wasted."

The only chemical used at GCA is liquid UCAR, and it is applied (and then brushed away) only at temperature >15°F. A typical application on one runway requires ∿1000 gallons of UCAR (@ $2.60/gal). (Annual expenses for UCAR are ∿$20000.) In the case of sub-freezing temperatures (both air and surface) and a forecast for freezing rain (apparently a common occurrence there), the procedure is to put UCAR on the RW to prevent ice from bonding to the surface. Later, additional chemical is used as needed to break up accumulated ice. (For snow, they simply plow or use a combination broom and blower called a Snow Blaster.)

Runway inspections are normally made three times daily -- at dawn, at noon and at dusk. If a HAZARD warning is indicated, an inspection is immediately initiated. (Occasional false HAZARD warnings are experienced. Inspection of sensors, in this case, usually reveals a thin layer of frost or ice. To restore sensor reading to normal, they use a little warm water and dry with a rag. False alarms are apparently not a major problem.)

During the early morning hours prior to the site visit and interviews, the Cincinnati area experienced a light snowfall (∿1/2 inch). Circumstances, therefore, provided an opportunity to witness snow removal operations and the performance of the SCAN system. During the period of observation from 0910 to 0950, air temperature was ∿-5C, surface temperate was ∿-3C, and both sensors were indicating HAZARD. Brooming began at ∿0830 EST, and at 0923, the author was invited to inspect the runways and SCAN sensor heads. Several photos of the brooming operation (between 0930 and 0945) are provided in Figure 21. The Snow Blasters in staggered-tandem were witnessed to completely clear, in one pass, a swath equal to ∿2/5 the runway width. They did a superb job, and it is certain that runway traction was nearly (60/60/60). However, each of the SCAN sensors was covered with residual amounts of snow and tire tracks (as shown in Figure 21) and thus were still reading HAZARD but now (at 0950) incorrectly in terms of general runway conditions.

- Detroit Metropolitan Airport, Michigan (6 March 1978)

Detroit (DMA) has one SCAN sensor located ∿35 feet off the centerline of RW21R-03L, near the midpoint of the runway length. DMA purchased the SCAN system in 1974 on a "trial basis," and SSI replaced the old sensor free of charge in the Fall of 1976, ostensibly to provide a more representative radiation color. They had a lot of false-alarm problems with the old sensor but have had only one incident (that DMA personnel could remember) with the new sensor (reading WET when it should have been CLEAR). The SCAN sensor is imbedded in concrete (see Figure 20d), where the runway is grooved in the cross-RW direction. They plan to purchase two additional sensors (for the approach ends of RW21R-03L) and are currently looking into radio telemetry.

The SCAN system was originally bought to be "calibrated for local conditions and to thereby increase the lead time" in advance of icing conditions. The readout is in an office where it could be monitored on a 24-hour, 3 shift basis. In bad weather, they monitor the system constantly keeping track of trends in surface and air temperature as well as runway

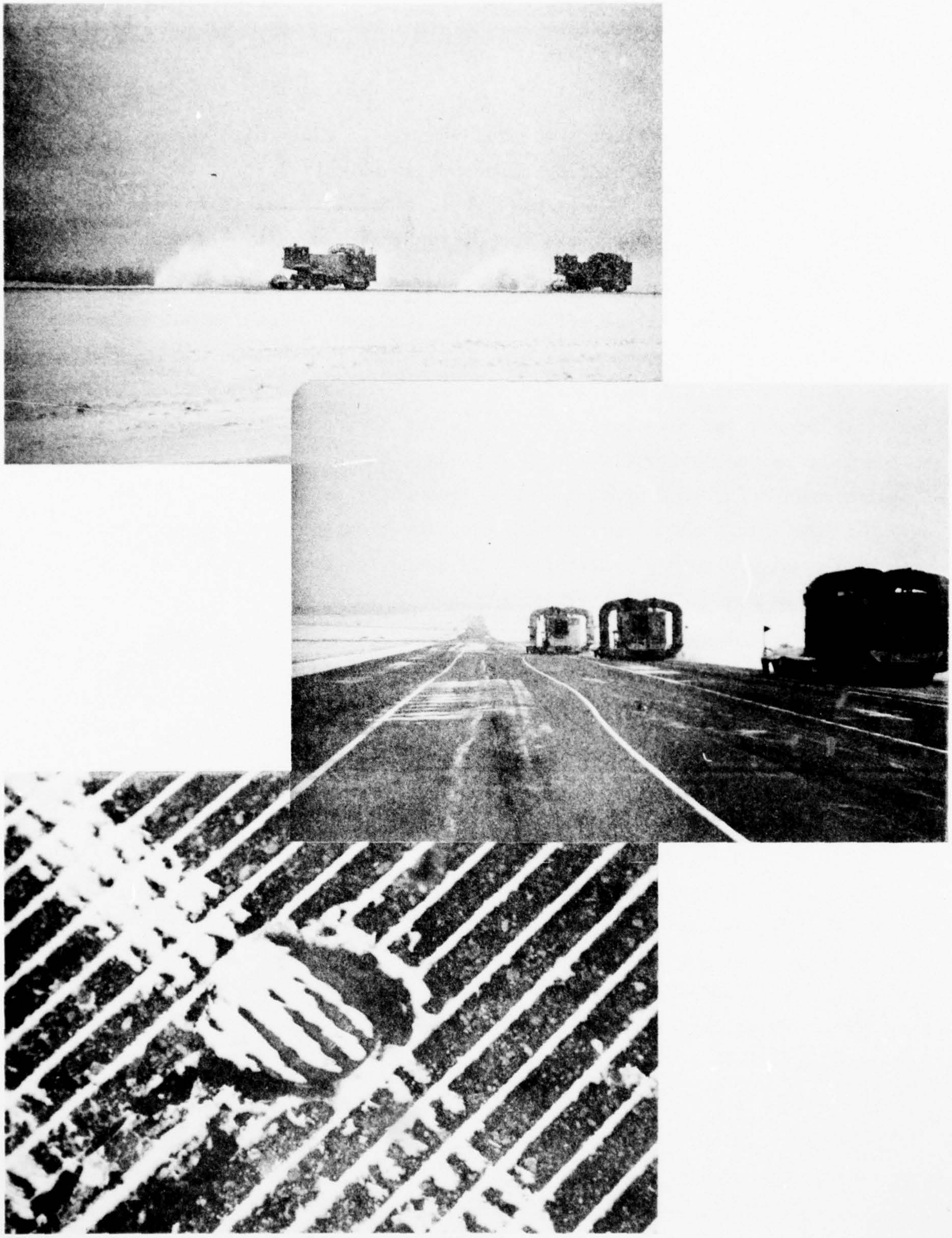


Figure 21 VIEWS OF A SNOW REMOVAL OPERATION AND SCAN SENSOR WITH TIRE TRACK AT CINCINNATI

conditions in order to implement control measures. (They also employ a private weather service to provide forecasts of potential icing conditions and surface temperature.) DMA thinks "it is a fairly valuable instrument" and they obviously think they make use of the runway condition readouts.

UCAR is the ice control chemical used at DMA, and, for ice conditions >1/8-1/4 inch, they might use ∿3000 gallons (@ $2.55/gallon) on one runway. (Annual expenses for chemicals are ∿$60000.) They pretty-much use manufacturer's recommendations for UCAR application rates (a function of condition, ice depth and temperature) and have installed a metering device on the tank truck to help adhere to manufacturer's specifications. Runways are inspected once/shift, 3 shifts/day during good weather and as frequently as every 15-20 minutes during storm conditions. During suspected low traction conditions, a MU-Meter is used to measure runway traction and to gauge ice control progress. If traction is in the low (20's), they continue control operations; if (35) or greater, they feel traction is good and they cease control measures. When a pilot calls in nil-braking conditions, the runway is closed; if inspection of the runway indicates traction (>30), then they reopen.

- <u>Indianapolis International Airport, Indiana</u> (16 February 1978)

Indianapolis (IIA) was one of the first purchasers of the SCAN system. The original unit was essentially a prototype and has been modified extensively by SSI at no charge. Due to their involvement in the development of the device, personnel at IIA are familiar with its operation and apparently rely heavily on it for decision-making concerning snow and ice control operations. The one SCAN sensor at IIA is installed on that part of the main runway which typically experiences the worst icing conditions. Since IAA was essentially a development site for SCAN, the system was quite unreliable during the first two winter seasons. After modification by SSI, it has apparently performed well, requiring only periodic routine calibrations.

Indianapolis used both urea and UCAR to combat snow and ice. For runway surface temperatures >15°F, urea is used, while UCAR is used for surface temperatures < 15°F and for anti-icing operations. It was estimated that urea usage had dropped from 300-350 tons/year before the SCAN system to about 200 tons/year; and, likewise, UCAR purchases had dropped from 15-20000 gallons/year to about 12,000 gallons/year after installation of the SCAN system. IIA personnel estimated that ~$100,000 (in chemicals) has been saved as a result of the surface temperature data provided by SCAN.

While IIA could supply no records to support claims of such dramatic savings because of the SCAN system, a specific snow storm was described in which the runway temperature never dropped below freezing. Since it was known that the snow would not bond to the warm runway, no chemicals were applied, and the brooms readily removed the snow. The estimated savings in urea for one runway in this situation was $2700.

SIRC personnel at IIA are devout proponents of the SCAN system. They argued that, even in the absence of possible monetary savings, the system was worth the investment price because of the increased safety which resulted from the additional information provided by the SCAN system.

- Kansas City International Airport, Kansas (2 March 1978)

Kansas City (KCIA) has 3 SCAN sensors installed in the main runway, RW 19-01. The SCAN sensors were, at the time, inoperative (and had been for a large fraction of the time since installation 3-4 years ago) due to rodent problems with their buried-cable data-links.

At KCIA, both urea and UCAR are used for runway ice control. With respect to usage of urea vs. UCAR, the more expensive UCAR is reserved for runways and urea is used on taxiways. Urea is not used at temperatures < 15°F; but they have no temperature minimums for UCAR. Urea is used primarily in clean-up operations after runway plowing for snow removal and during periods of repeated freeze-thaw cycles.

KCIA personnel are concerned about the expense of UCAR applications (~1000 gal per runway @ $2.80/gal) and, hence, use it sparingly. Since the runways are grooved, it runs in the grooves and is wasted. With rain, it becomes diluted quickly and runs off. Thus, in freezing rain situations, they usually allow a crust to develop before applying UCAR. (Annual expenses

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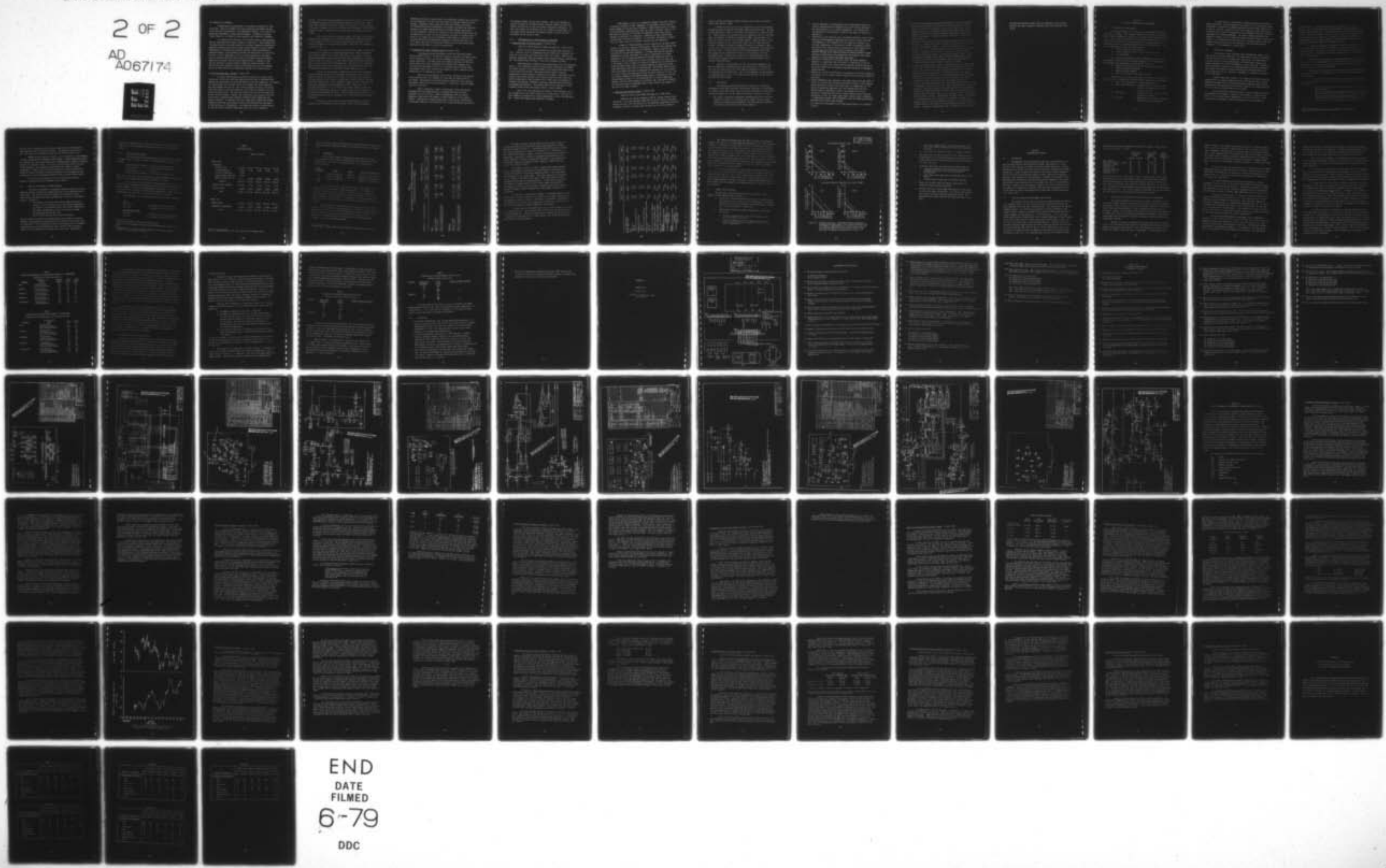

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for chemicals are ~$30000.)

During periods of bad weather, the runways are inspected at least every hour. They use a MU-Meter for these inspections and report the data to the Tower for dissemination. The information, however, is not used by the Maintenance Department to gauge control progress. Cessation of ice/snow control operations is based on visual inspection and inspector's judgement.

As indicated, KCIA has had a lot of trouble (mostly cable problems) with the SCAN system, but "when it works, it works well." They remarked that "the major benefit of the SCAN system is its surface temperature measurement." Operations personnel generally know what runway conditions are, but surface temperature in conjunction with weather forecasts allows some measure of planning/strategy. KCIA personnel said that the SCAN system "is a good tool, but only a tool", adding that it will be nearly impossible to make much sense of economics data (for KCIA) because of differing control strategies depending on personnel mood and storm characteristics. Apparently, they are very reluctant to apply chemicals (UCAR) for economic reasons. The sensors "have been especially useful in determining the need for chemicals, but as yet there have been no identifiable savings in ice control costs."

- Scott Air Force Base, Illinois (7 April 1978)

A 3-sensor SCAN system was installed at SAFB in the Fall of 1976. Initial cost of the unit with three sensors was $32K with an additional $31K required for installation of the buried cable by a private contractor. The sensors are located about 8 ft from the center of the runway, but sensor positions have been changed twice by SSI. Due to the accidental cutting of the buried cable data-link by a civilian contractor, the system was inoperative for the entire 1976-1977 winter. The cable was spliced, and the unit was operational for the 1977/1978 winter; however, due to moisture in the cables, two of the three sensors frequently gave erroneous readings of both temperature and surface condition. In addition, there was a systematic problem with surface condition indications which appears to have been minimized with adjustments to the SCAN logic by SSI personnel. The impression relayed by SAFB personnel is that the surface condition indications are still not of acceptable quality. The system being inoperative for the entirety of the first winter and frequently giving erroneous readings throughout the past winter have drastically reduced the confidence of most base personnel in the usefulness of the unit; although, they do have confidence in and make use of the surface temperature data. Maintenance for the system has been supplied courtesy of SSI.

Urea is the only chemical used at SAFB; ~2000 bags (100 lb/bag) of urea were used in the winter of 76-77 and ~3000 bags (@ $6/bag) were used in the winter of 77-78; no data are available for previous years. Base personnel thought that no appreciable savings in urea had been realized as a result of SCAN.

A James Brake Decelerometer is used to measure runway traction for field condition reports and to guide SIRC operations. RCR's are measured every 1000 ft within 25 ft of and on both sides of the runway centerline. During precipitation weather, they use SCAN surface temperature as a guide for use of the J.B. device (i.e., when surface temperature drops below 33°F). RCR's are also used to guide SIRC operations. They also use the alarm and hazard signals of the SCAN system because "it (the SCAN system) assists in assuring that they have up-to-the-minute runway condition reports."

The mission requirements at SAFB are very limited and primarily involve training, medical and VIP transport support; hence they have little nighttime traffic and minimal alert status. As a result, their snow/ice control strategy is very casual, a prime deadline being ~0630 when aircraft departures usually begin. During nighttime snowfalls, they simply plow and broom and, depending on surface temperature (SCAN), apply urea. They only plow the middle 50 ft of the 150 ft wide runways because of the type of aircraft served there; plowing is accomplished in two 12 ft swaths on either side of the runway centerline. Surface temperature from SCAN is used to determine the best time for applying urea in time for the 0630 aircraft operations.

The Air Force bought and installed the SCAN system at Scott to evaluate it for the Military Airlift Command. Due to the discontinuous operation of the unit (a point which will undoubtedly influence the conclusions of the evaluation), the unit will not receive as thorough evaluation as was planned. Apparently, their report will make the following conclusions: (1) SCAN provides unique measurements (if somewhat unreliable and frequently erroneous) of runway surface conditions and runway surface temperature; (2) data supplied by SCAN may be a useful aid in planning SIRC operations and the application of urea; (3) the mild winters and light air traffic (most of which are not urgent and can be delayed) at SAFB combine to minimize the economic feasibility and functional usefulness of SCAN at SAFB; and, (4) it is likely that some Air Force bases further north of SAFB would benefit sufficiently from SCAN to justify its acquisition.

- <u>Canadian Forces Base, Trenton, Ontario</u> (29 March 1978)

The Canadian Forces Base-Trenton (CFBT) has three SCAN sensors and two readout stations. The present sensors are located 6 ft from the edge of the RW and hence are in an area not thoroughly cleaned during ice/snow control operations. The SCAN system was originally purchased in 1975 on a "trial basis," but sensor installation was delayed until November 1977. The system CFBT purchased in 1975 is the original version which has since been modified three times (and the water depth electronics removed) by the manufacturer as he upgraded the system.

Urea is the only chemical used at CFBT. If there is any question of the need for urea, it is applied, at least down the center strip of the runway. One application including the main runway and access taxiways and requires three tons of urea (@ $175/ton). Yearly urea usage has ranged from ∿45 to ∿90 tons.

CFBT is conducting a limited "evaluation" of the SCAN system's performance for the Canadian Forces; at present CFBT does not hold a favorable view of the system. CFBT's disenchantment with the system apparently stems from their attempts to make maximum use of the readout signals. Problems with nonrepresentativeness, false alarms, nonindication of hazardous conditions, and differences in temperature signals read off the two separate readout stations have occurred. Their early attempts at complete reliance on the runway surface condition signals were met with failure, and they now use only the surface temperature information. No doubt the location of the SCAN sensors (6 ft from the runway edge) in an area where control operations are marginal played a role in the poor performance of the system at CFBT.

5.3.2 SIRC Operations at NAS Brunswick and NAS Adak

- Brunswick Naval Air Station, Maine (17 March 1978)

Naval Air Station Brunswick (NASB) does not have a SCAN system.

NASB is base for three permanent and two part-time squadrons of P-3's. There are 36 P-3's permanently based at NASB, with a potential for about 54; P-3's account for about 90% of their air traffic. NASB has two parallel, nongrooved, 8000 foot runways and an inactive shorter, perpendicular RW. The inboard runway (01R-19L) is the main instrumented runway.

SIRC operations at NASB are the responsibility of the Air Operations Officer. He is briefed on expected meteorological conditions by the NWSED and relays forecasts of icing/snow weather to the Public Works Officer who in turn alerts the Sea Bees. When precipitation begins or falling temperatures indicate potential freezing of wet runways, the Weather Service contacts Public Works personnel who actually perform the SIRC operations. RCR's are measured by Tower personnel with a James Brake Decelerometer at irregular and sometimes infrequent intervals, depending upon availability of equipment and personnel. The measured RCR's are not available to SIRC personnel (Public Works) for gauging snow/ice control progress.

Urea is the only chemical used at NASB in SIRC operations, and it was introduced only last winter (1976-77) on a trial basis. Five tons of urea (∿\$800) are required for a typical application to one of the 8000 foot RW's. Annual urea expenses are estimated at ∿\$12000.

NASB weather is said to be completely different from that occurring at Portland (∿30 miles to SW). Apparently "a cold pocket occurs along the coastal margin all the way south to Boston." NASB frequently gets 1-2 inches of snow followed by freezing rain, which can result in several inches of ice. They figure on plowing ice and snow ∿10 times/year; light snows require sweeping an additional six times/year. (NASB has not been closed during the past eight years due to weather.) In the winter, the ground is usually cold, and, hence, snow on the runway is usually dry and nonmelting.

A number of NASB personnel, with the exception of the Public Works Officer, are anxious to acquire a SCAN system. They feel that anything that will help improve SIRC operations is worthwhile. Those in favor of the system voiced the following arguments: (1) SCAN would provide continuous information on runway conditions to be used in conjunction with runway inspections; (2) the unique measurement of surface temperature would be available to aid in predictions of runway freezing, the use of urea, and in the summer, better estimates of runway air temperatures for estimation of available engine thrust; and, (3) advanced warning of icing which would allow anti-icing rather than de-icing measures. The Weather Officer would like to have RCRs every hour, but manpower and equipment are not available to do this--"SCAN could provide this data for hourly reports" he said. The P.W. officer suggested that NWSED personnel mount a thermometer on the RW and periodically refer to it for determinations of surface temperature. Further, since the SIRC strategy is to maintain dry, clean RW's he doubted the need for a means of measuring runway icing; "because snow removal is more of an art than a science."

- Adak Naval Air Station, Alaska (22 March 1978)

Naval Air Station Adak (NASA) does not have a SCAN system.

NASA has two crowned, ungrooved, 7000 ft, asphalt runways (05-23 and 08-26). As at NAS Brunswick, about 90% of the air traffic using NASA runways are P-3's, with the majority of the remainder being propeller-driven transports (C-130's). Because these aircraft can use reverse propeller pitch to provide deceleration during landings, there seems to be minimal concern about RCR's at NASA.

Within the last year or so the responsibility for SIRC operations at NASA have been transferred from Public Works to Air Operations. The goal of SIRC operations at Adak is to maintain a maximum of 0.75 inches of snow/ice. SIRC operations are performed with five snowblowers and five roll-over plows; no chemicals or brooms are employed at NASA. The procedure is to plow ice or snow to within 3/4" of runway surface. When the banks of snow resulting from plowing get sufficiently large, they are blown from the runways. According to Weather Detachment personnel, the weather at NASA is such that the snow from major snowstorms is rarely ever on the ground for more than a day. A typical winter storm at NASA apparently begins with mixed snow and rain eventually turning to rain which melts all of the accumulated snow. Aircraft patrol activities at NASA apparently can be delayed until acceptable runway conditions are achieved, whether due to nature or SIRC operations.

Officers of Public Works, the VP's (P-3 patrol squadrons), and NWSED at Adak have recommended against the acquisition of a SCAN system. They feel that snow and ice are such temporary problems that there is no justification for the expenditure. Their casual approach to SIRC operations is undoubtedly due, in part, to relaxed mission objectives and the type of aircraft billeted at Adak.

5.4 Conclusions

The following principal conclusions regarding the operational performance of the SCAN system were derived from interviews and inspections at airfields where SCAN systems were in operation and from an extended field evaluation conducted at the U.S. Naval Air Station at Keflavik, Iceland:

1. The sensors' capacitance measurement repeatably detected significant quantities of water, ice and snow; but for broken coverage, small quantities and low density snow/frost, the SCAN indications could not be predicted from observation of sensor surfaces.

2. Given an indication of precipitation by the capacitance signal, the sensor's measured surface temperature was used to define the phase of the precipitation (ie., at surface temperature < 0°C, HAZARD (ice) was indicated); the conductivity probe did not appear to function as advertised.
3. Differences in the radiation color and thermal properties of the sensor epoxy and runway aggregate apparently give rise on certain occasions to differences in the temperature of the respective surfaces; e.g., nocturnal temperatures of the sensor's surface are apparently colder than those of the runway surface, giving rise to frost deposition or freezing events on the sensor before occurring on the runway. (Advance freezing on the sensor provides an advance warning of runway freezing as advertised by the manufacturer but probably, more often, results in a false alarm of hazardous conditions).
4. Differences in porosity of the sensor epoxy and runway aggregate (probably in conjunction with differences in temperature of the two surfaces) in certain wet runway situations permits premature drying of the sensor surface and, on occasion, precludes detection of subsequent runway freezing.
5. Probably as a result of differences in temperature and surface roughness, the sensors were not always visually representative of general runway ice conditions.
6. Surface temperature data recorded at the remote processing unit (RPU) of sensor #4 at Keflavik is considered reasonably accurate, since freezing events typically occurred on the sensor when its temperature was ∿0°C and frost deposition began when the sensor temperature neared the ambient dewpoint temperature; however, an apparent drift in the electronics between the RPU and the display terminal caused displayed temperature to read ∿4°C warmer than actual, sensed surface temperature -- a potentially serious, but correctable, error for effective and timely implementation of anti-icing strategy.
7. Air temperature measurements by the SCAN sensor appear to be reasonably accurate.

8. Sensor installation appears haphazard (probably as a result of improper installation procedures by airfield maintenance personnel), with some sensors not mounted flush with the runway, depressions around sensors allowing water/ice to accumulate, and mismatched surface color and roughness characteristics, and is probably responsible for much of the observed discrepancy in "surface conditions" between the runway and sensor surfaces.

9. Because of installation costs and subsequent problems with buried-cable data-links, it appears that radio telemetry (in the absence of existing/available underground conduits) is worth the investment costs.

10. Because it is the job of SIRC personnel, they are generally well-informed on runway conditions and both current and forecast weather; during icing/snow conditions, runways are constantly inspected; hence, except for unexpected weather events, surface condition indications by SCAN are rarely referred to by SIRC personnel; however an unexpected ALERT or HAZARD indication usually prompts a runway inspection.

11. In terms of SIRC operations, surface temperature is the only data unique to the SCAN system; almost without exception, SCAN surface temperature data are used for the effective and timely application of ice control chemicals; however, the forecast capability of the trend in surface temperature is not utilized to its maximum potential; where these temperature data are accurate (unlike sensor #4 at Keflavik), they effect substantial savings in more effective application of chemicals.

12. Finally, the utility and need of even a perfectly-functioning SCAN system is dependent on the mission and other safety considerations at individual airfields. Interviews with operations personnel at Adak and Brunswick indicate that their requirements for SIRC activity are significantly less stringent than at Keflavik, which is on a constant "alert" status with high performance aircraft. At Brunswick and Adak, flights can frequently be scheduled around serious runway icing conditions. Further, the primary traffic at these two airfields involves P-3 aircraft which can perform effectively and safely with significant snow accumulation on the runway. In addition, Adak currently uses no chemical for ice control,

and Brunswick estimates annual costs for chemicals at only $12,000. Brunswick and Adak, therefore, currently have little need for such a system.

Section 6

COST-BENEFIT ANALYSIS OF SCAN OWNERSHIP

6.1 Introduction and Background

In general usage, 2 or 3 SCAN sensors are imbedded at selected locations in a runway. Most airports, however, have at least two runways. Thus, a normal complement of sensors at an airport would be of the order of 3 to 5. All sensors are connected to a centrally located monitor, either by hard wire or radio system, and the monitor is designed to provide sequential displays of information relayed from each of the sensors. The basic information provided by the SCAN system is:

1. Surface temperature of the runway
2. Surface condition ("dry", "wet", "alert" or "ice")
3. Air temperature.

The information generated by SCAN is designed to assist in the maintenance of runways during wintertime conditions. The claims made by the developers and manufacturer of SCAN are that it will:

1. Improve the efficiency of the use of ice-control chemicals
2. Reduce equipment and manhours
3. Minimize runway downtime
4. Improve the safety of the runway operation.

Basic snow and ice control and removal operations (summarized from Sections 3 and 5) encompass the following general conditions and procedures:

1. Up to 4" of loose snow -- brooming and blowing;
2. Heavy snow or more snow-- plowing followed by brooming and blowing, and depending on circumstances, de-icing;
3. Anti-icing -- application of ice-control chemicals followed by brooming;
4. De-icing -- application of ice-control chemicals followed by plowing/brooming.

In this section, a cost-benefit, breakeven analysis of SCAN ownership is presented. For the purpose of the analysis, it is assumed that runway maintenance is performed by competent personnel and that runway downtime is to be kept at a minimum. Implicit in the first assumption is that SCAN information which can be readily ascertained by visual inspection does not contribute significantly to runway maintenance. The second assumption provides that immediate, remedial action is taken when runway conditions begin to deteriorate. Finally, it is assumed that the SCAN system is in working condition and that comparable meteorological data are available to the operating personnel irrespective of the presence of a SCAN system.

6.2 Preliminary Assessment

As previously noted, the three basic informational outputs of the SCAN system are surface temperature, air temperature and surface condition. Only the first data item is unique to the SCAN system. Air temperature is available either by on-site measurements or meteorological reports, and surface conditions are readily determined by visual inspection. Mechanical runway maintenance actions must be implemented whenever conditions demand. Such actions are dictated by extant meteorological conditions which are visually apparent and are, therefore, independent of information provided by the SCAN system.

Surface temperature, however, is an important consideration in the application of ice-control chemicals for anti-icing and de-icing. Surface temperature together with existing meteorological conditions and forecasts determine when the application of ice-control chemicals is warranted and the type of ice-control chemical which can be applied.

The application of chemicals for anti-icing is designed to prevent ice formation on the runways. Conditions which result in icing are rain, sleet or wet snow with surface temperatures at or below 0°C (32°F). With higher surface temperatures, runway maintenance can be accomplished by plowing/brooming. At below freezing surface temperatures, ice-control chemicals must be applied for anti-icing followed by plowing/brooming. If, however, chemical anti-icing is not performed initially in a timely fashion, ice will form on the runways. When this occurs, chemical de-icing followed by plowing/brooming is required. It should be noted that significantly larger amounts of ice-control chemicals are required for de-icing than for anti-icing, making the operation considerably costlier.

Two types of chemicals are generally employed at airports -- urea and ethylene glycol-urea (UCAR). The former is usually dispensed as a solid material (powder), the latter as a liquid. The selection of one or the other chemical* is a function of the surface temperature and, in the case of urea, wind conditions.

Urea can be employed when the surface temperature is above -9.4°C (15°F). At lower surface temperatures, the urea-water mixture will form an undesirable gel. Urea application is not practical when wind conditions cause the urea to be swept off the runway.

Ethylene glycol-urea can be effective when surface temperatures are as low as -18°C (0°F). Its application as a liquid is largely unaffected by wind conditions.

It is concluded from the preceding discussion that the principal potential contributions of the SCAN system to runway maintenance during winter conditions are:

1. Prevent the application of ice-control chemicals for anti-icing when not necessary
2. Prevent the application of ice-control chemicals for anti-icing or de-icing when ineffective because of low surface temperature
3. Indicate the application of ice-control chemicals for anti-icing, thereby eliminating the need for subsequent de-icing
4. Aid in the selection of the proper ice-control chemical

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[*] Both chemicals are not necessarily available at all airports.

The last item is considered to be of lesser importance since many airports stock only one type of ice-control chemical. Its potential significance is due to the large cost difference between urea and ethylene glycol-urea.

Another potential benefit of SCAN is in the reduction in the frequency of runway inspection and concomitant labor savings. Airport maintenance personnel, however, have direct responsibility for maintaining the runways in operable condition and aircraft safety. As a result, they will most likely continue to make frequent visual inspections rather than rely largely on sensor information. Finally, there is no data from which it can be inferred that mechanical runway maintenance actions as measured by the frequency and type of operation, will be significantly different with or without SCAN in place.

In the section following, the areas in which major potential benefits of SCAN may accrue are examined in more detail.

6.3 Analysis of Economics of SCAN Ownership

The analysis conducted is a parametric breakeven analyses in which potential benefits (savings) are compared with the cost of ownership of the SCAN system. Four areas of potential benefits were identified earlier. These actually represent only three considerations in terms of cost benefit analysis. These are:

1. The prevention of ice-control chemical application either because it is not necessary due to warm surface temperatures <u>or</u> because it is ineffective due to low surface temperatures.
2. The timely implementation of anti-icing action, thereby precluding the need for de-icing.
3. Assist in the selection of ice-control chemicals.

Note that potential benefits are essentially the same whether ice-control chemicals are <u>not</u> applied because they are not needed or because they would be ineffective. The third potential benefit listed applies only to airports at which both ice-control chemicals are used. In part, the ice-control chemical selection problem is included in the first area. Specifically, what will be addressed here is the use of the lower cost rather than the higher cost ice-control chemical when the former can provide effective results.

6.3.1 Costs and Cost Factors*

SCAN system capital and annual costs incorporating 1 to 5 runway-embedded sensors are shown in Table 1. The following cost factors are applied:

Installation and Checkout....10% of basic equipment cost
Initial Spares...............15% of basic equipment cost
Amortization.................5 years - 8%
Operation and Maintenance....15% of basic equipment cost

Thus, for 1 to 5 sensor systems, capital costs range from \$20,000 to \$49,000; annual costs (including amortization) from \$6,500 to \$16,000.

Urea costs can range from \$180 to about \$300 per metric ton (\$165 - \$270/short ton) depending on the location of an airport relative to a primary source of supply. The cost of ethylene glycol-urea (UCAR) can vary from \$0.70 to \$1.05 per liter (\$2.60 - \$4.00/gallon depending on airport location). Transportation can represent a significant cost for both chemicals.

Representative rates of application for the ice-control chemicals are:

Urea	
Anti-icing	2.9 kg/100 m^2 (6 lb/1,000 ft^2)**
De-icing	7.3 kg/100 m^2 (15 lb/1,000 ft^2)**
Ethylene Glycol-Urea	
Anti-icing	1.3 l/100 m^2 (0.33 gal/1,000 ft^2)***
De-icing	8.1 l/100 m^2 (2.0 gal/1,000 ft^2)***

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[*] All monetary figures are based on mid-1978 prices.

[**] Discussion with personnel at Buffalo Greater International Airport, 10 May 1978

[***] UCAR Runway De-icer, Union Carbide Corporation, Functional Chemicals, 270 Park Avenue, New York, NY 10017.

TABLE 1

SCAN SYSTEM COSTS

	Number of Sensors				
	1	2	3	4	5
CAPITAL COST					
EQUIPMENT*					
Sensor System	$ 5,400	$10,800	$16,200	$21,600	$27,000
5 Channel Monitor	5,800	5,800	5,800	5,800	5,800
25 Watt RF Amplifier	2,300				
Single Channel Radio Rec.	2,300				
Multiplex Radio System		5,400	5,600	5,900	6,100
Subtotal	$15,800	$22,000	$27,600	$33,300	$38,900
INSTALLATION & CHECKOUT	$ 1,600	2,200	2,800	3,300	3,900
INITIAL SPARES	2,400	3,300	4,100	5,000	5,800
Total	$19,800	$27,500	$34,500	$41,600	$48,600
ANNUAL COST					
AMORTIZATION	$ 4,950	$ 6,880	$ 8,600	$10,400	$12,150
OPERATION & MAINTENANCE	1,580	2,200	2,800	3,300	3,900
Total	$ 6,530	$ 9,080	$11,400	$13,700	$16,050

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*Source: Surface Systems, Inc., St. Louis, MO, 15 February 1978.

Actual ice-control chemical applications can vary depending on runway surface and meteorological conditions extant at the airports at the time of application.

6.3.2 Evaluation

Three airport runway configurations, designated as A, B and C, are considered in the evaluation. Runway dimensions, expressed in length of runway and runway area to be maintained free of ice and snow are presented below.

Runway Designation	Length	Width	Area to be Maintained
A	2,590 m (8,500 ft)	(100 ft)	78,970 m^2 (850,000 ft^2)
B	3,050 m (10,000 ft)	(150 ft)	139,350 m^2 (1,500,000 ft^2)
C* (A+B)	5,640 m (18,500 ft)		218,320 m^2 (2,350,000 ft^2)

Table 2 presents anti-icing and de-icing costs and quantities per application for the postulated runway configurations. Cost bounds were previously specified for the chemicals. The lower costs are employed to compute the costs listed in the "local" columns; the higher costs for the "remote" columns. This designation is appropriate since transportation costs have a significant impact on the costs of ice-control chemicals at a particular location.

Anti-icing and de-icing operations with chemicals can be extremely costly. Costs for anti-icing range from $400 to $3,000 for a single application; comparable de-icing costs are considerably higher, varying between $1,000 and $18,600. Potential savings which can accrue by not applying chemicals when unnecessary or ineffective and/or by timely anti-icing (thus precluding subsequent de-icing) are readily apparent.

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*Configuration C assumes airport has one short (A) and one long (B) runway.

TABLE 2

COSTS AND QUANTITIES OF ICE-CONTROL CHEMICALS/APPLICATION FOR ANTI-ICING AND DE-ICING OF RUNWAYS

Chemical Ice-Control Application	Runway Configuration					
	A		B		C	
	Local	Remote	Local	Remote	Local	Remote
Cost						
Anti-ice (urea)	$ 410	$ 690	$ 730	$ 1,210	$ 1,140	$ 1,900
De-ice (urea)	1,040	1,730	1,830	3,050	2,870	4,780
Anti-ice (ethylene glycol-urea)	720	1,080	1,270	1,900	1,990	2,980
De-ice (ethylene glycol-urea)	4,480	6,720	7,900	11,850	12,380	18,570
Quantity						
Anti-ice (urea)	2.3 t (2.5 s.ton)		4.0 t (4.5 s.ton)		6.3 t (7.0 s.ton)	
De-ice (urea)	5.8 t (6.4 s.ton)		10.2 t (11.3 s.ton)		16 t (17.7 s.ton)	
Anti-ice (ethylene glycol-urea)	1,030 l (270 gal)		1,810 l (480 gal)		2,840 l (750 gal)	
De-ice (ethylene glycol-urea)	6,400 l (1,690 gal)		11,290 l (2,980 gal)		17,690 l (4,670 gal)	

The number of anti-icing, de-icing, and anti-icing in lieu of de-icing operations which yield costs equal to the annual cost of SCAN ownership are shown in Table 3. A two-sensor SCAN installation is assumed for runway configuration A, three for B and five for C. These data, in fact, indicate the number of times a year the SCAN system must prevent the unnecessary, ineffective, untimely or inappropriate application of ice-control chemicals to achieve cost-benefit equivalency. The quantities of ice-control chemicals represented by these numbers of applications are shown at the bottom of Table 3.

For example, consider a "remote" airport with runway configuration B. Approximately 9 applications of urea which were unnecessary or ineffective because of low surface temperature entail a cost equivalent to the annual cost of a SCAN system. Cost parity would also be attained if, as a result of the SCAN system, about 6 anti-icing operations were implemented which made de-icing unnecessary. As seen from the analysis, the number of "misapplications" of ice-control chemicals which SCAN must prevent in order to pay for itself is generally quite small, particularly at "remote" airport locations where large runway areas must be maintained.

An indicator of the potential number of "missapplications" is the quantity of ice-control chemicals used annually at an airport compared with the quantities listed in Table 3. The larger the difference, the greater is the likelihood of an error in the application of chemicals, particularly if the locality experiences frequent temperature fluctuations.

Various types of "misapplications" of ice-control chemicals can occur at a particular site. The most likely are believed to be the application of anti-icing chemicals, either when unnecessary or ineffective and the failure to apply anti-icing chemicals in a timely manner, thus requiring subsequent, more costly de-icing operations.

TABLE 3

BREAKEVEN ANALYSIS: NUMBER OF ANNUAL ANTI-ICING, DE-ICING AND ANTI-ICING IN LIEU OF DE-ICING OPERATIONS EQUIVALENT TO COST OF SCAN OWNERSHIP

	Runway Configuration					
	A		B		C	
	Local	Remote	Local	Remote	Local	Remote
No. of SCAN Sensors	2	2	3	3	5	5
Annual SCAN Cost	$9,080	$9,080	$11,400	$11,400	$16,050	$16,050
Urea						
Anti-ice	22.1	13.2	15.6	9.4	14.1	8.4
De-ice	8.7	5.2	6.2	3.7	5.6	3.4
Anti-ice in lieu of de-ice	14.4	8.7	10.4	6.2	9.3	5.6
Ethylene Glycol-Urea						
Anti-ice	12.6	8.4	9.0	6.0	8.1	5.4
De-ice	2.0	1.4	1.4	1.0	1.3	0.9
Anti-ice in lieu of de-ice	2.4	1.6	1.7	1.1	1.5	1.0
Urea in Lieu of Ethylene Glycol-Urea						
Anti-ice	29.3	23.3	21.1	16.5	18.9	14.9
De-ice	2.6	1.8	1.9	1.3	1.7	1.2
Quantity of Ice-Control Chemicals						
Urea (metric tons/short tons)	51/55	32/34	63/70	38/42	89/99	54/59
Ethylene Glycol-Urea (cu.m/gal)	12.9/ 3,400	8.8/ 2,300	16.0/ 4,200	11.1/ 2,900	23.0/ 6,100	15.6/ 4,100
Urea in Lieu of Ethylene Glycol-Urea						
Anti-ice						
Ethylene Glycol-Urea Saved (cu m/gal)	30.2/ 7,900	24.0/ 6,300	38.1/ 10,100	29.9/ 7,900	53.7/ 14,200	42.3/ 11,200
Δ Urea Expended (metric tons/ short tons)	67/73	54/58	84/93	66/74	119/132	94/104
De-ice						
Ethylene Glycol-Urea Saved (cu m/gal)	16.6/ 4,400	11.5/ 3,000	21.5/ 5,700	14.7/ 3,900	30.0/ 7,900	21.2/ 5,600
Δ Urea Expended (metric tons/ short tons)	15/17	10/12	19/21	13/15	27/30	19/21

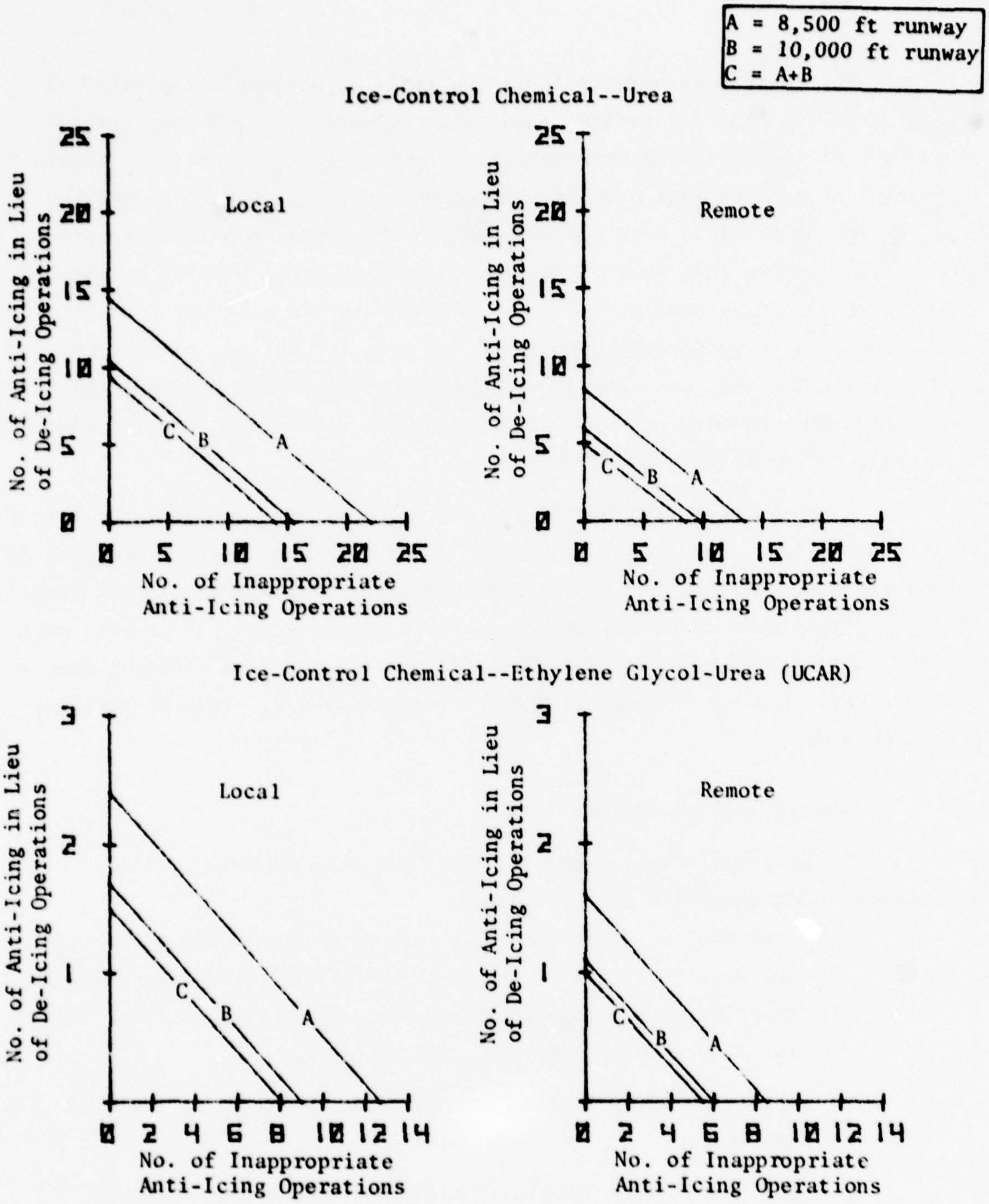
The trade-offs between these two types of actions are plotted in Figure 22 for the two ice-control chemicals presently in use. Any combination of numbers of inappropriate applications of anti-icing chemicals and timely anti-icing operations that preclude subsequent de-icing operations obtained from the curves yields a cost saving equal to the annual SCAN system cost. For example, assume that urea is the ice-control chemical used at a "local" airport with a runway configuration A. The SCAN system will pay for itself if it prevents the inappropriate application of urea for anti-icing 22 times each year. Similarly, cost equivalency is obtained if five inappropriate anti-icing operations are prevented and on eleven occasions anti-icing is performed which eliminates de-icing requirements.

It is evident from Figure 22 that a SCAN system will pay for itself if it can, in fact, preclude the "misapplication" of ice-control chemicals on relatively few occasions. This is particularly true at airports where large runway surfaces must be maintained free of ice and snow and the on-site cost of ice-control chemicals is high. Obviously, a limited SCAN installation, i.e., fewer sensors than are assumed in the foregoing analysis, would be even more cost effective.

6.4 Summary and Conclusions

The principal conclusions derived from an evaluation of the economics of SCAN ownership are as follows:

1. Acquisition, operation and maintenance costs of a SCAN system are relatively low. Annual costs (mid-1978 prices), including amortization of capital investment, range from $9,000 - $16,000 for 2 to 5 sensor systems, respectively.
2. The principal potential economic contributions of the SCAN system are
    a. Prevent the application of ice control chemicals for anti-icing when not necessary
    b. Prevent the application of ice-control chemicals for anti-icing or de-icing when ineffective because of low surface temperature


Ice-Control Chemical--Urea

Ice-Control Chemical--Ethylene Glycol-Urea (UCAR)

Figure 22: Breakeven Analysis: Trade-offs Between the Number of Inappropriate Applications of Ice-Control Chemicals and the Number of Implementations of Anti-Icing in Lieu of De-Icing Which Will Pay for the Annual Cost of SCAN Ownership for Runway Configurations A, B and C.

c. Indicate the application of ice-control chemicals for anti-icing, thereby eliminating the need for subsequent de-icing

d. Aid in the selection of the proper ice-control chemical

3. The SCAN system, in order to pay for itself, must prevent the misapplication of ice-control chemicals and/or provide for the timely application of ice-control chemicals only a relatively few times each year.

4. Conditions which favor utilization of the SCAN system are

   a. Frequent fluctuations in surface and air temperatures around and below 0°C (32°F) in the pressence of precipitation

   b. Large runway areas which must be maintained free of snow and ice

   c. Frequent usage of high-cost, ice-control chemicals

5. There is no evidence that SCAN impacts significantly on mechanical runway clearance operations.

6. The SCAN system may provide additional benefits in the areas of safety and runway availability. The value of such benefits could easily exceed the SCAN ownership cost, however, the quantification of these benefits was beyond the scope of this study.

Section 7
CLIMATOLOGICAL STUDIES

7.1 Introduction

The purpose of the climatological study was to determine which, if any, Naval Air Stations could potentially benefit from addition of a SCAN system to their snow and ice removal and control (SIRC) operations. The approach was multi-faceted with three different types of climatological analyses carried out. First, by applying criteria to the station climatic summaries, the set of Naval Air Stations was reduced to those stations which would experience a high frequency of SIRC operations. Secondly, the character of the SIRC problem as a function of climate was examined by preparing a bi-variate distribution of precipitation type versus temperature for five representative stations. Thirdly, the climatological frequency of freezing of precipitation on a runway was examined as a possible index from which to judge the need for a SCAN system to improve SIRC operations for other than frozen precipitation (ie., snow) events.

7.2 Naval Air Stations with Frequent SIRC Problems

The complete set of Naval Air Stations was obtained from the station list contained in the U.S. Navy and Marine Corps Meteorological Station climatic Summaries (1975) and cross referenced with a list provided by the contract technical monitor. Two criteria were applied to the data contained in the station climatic summaries to determine those stations which would experience a high frequency of SIRC operations. The criteria were: (1) at least one winter month (December through March) with a minimum temperature below freezing, and (2), 10 or more days per winter with snowfall greater than 0.1 inch. Of the total 76 stations only 12 satisfied both criteria. Of these, one is not associated with the administration of airport facilities and one is run by the Air Force (Selfridge AFB, Detroit, Mich.). Of the remaining 10, two are in the Antarctic (Hallett Station and McMurdo) where highly specialized landing procedures are utilized. The remaining eight stations are listed below with their mean winter season temperature, snowfall and number of days with snowfall > 0.1 inch and > 1.5 inch:

	Mean Winter Snowfall Days		Extreme Winter Snowfall Amounts		Mean Winter Temperature
	> 0.1 in	> 1.5 in	Min	Max	(°F)
Adak, Alaska	59	16	75	196	34
Misawa AB, Honshu I., Japan	53	21	-- 110 ---		32
Keflavik, Iceland	36	13	55	178	33
Brunswick, Me.	28	15	74	203	25
Glenview, Ill.	22	8	36	119	28
South Weymouth, Ma.	22	9	48	129	30
Quonset Pt., R.I.	15	8	35	118	33
Lakehurst, N.J.	13	4	23	103	35

All eight stations are located north of 40N. Two have ocean climates (Adak and Keflavik); one has a continental climate at the Great Lakes (Glenview); and the remaining five (four in the United States) have the climate of the east coast of continents. (The number of snowfall days with > 1.5 inches of snow is probably a good approximation of the annual number of SIRC operations days involving snow -- e.g., in the interview at Brunswick NAS, it was learned that they plan on ∿16 snow-related SIRC operations per winter.)

7.3 Bi-Variate Distributions of Precipitation Type vs Temperature

The proposed approach was to obtain bi-variate climatologies for at least five climatic regions into which the set of Naval Air Stations could be categorized. Initial analysis of the station climatic summaries indicated that three climate types would suffice: ocean, continental, and east coast of continent. However, as the program evolved and site interviews were conducted, it became clear that five bi-variate climatologies were needed. Consequently climatologies were run for Adak, Keflavik, Brunswick, Anchorage (Alaska), and Indianapolis (Indiana).

Keflavik was chosen to represent the ocean climate and also because it was a site for which the most data on an installed SCAN system was available. Because of particular Navy interest in the site, Brunswick was chosen to represent the climate of the east coast of continents. In the interview with

Adak personnel, it was learned that frozen precipitation frequently either melted as it fell (because air temperature was above freezing) or melted because temperatures rose above 32°F relatively soon after precipitation fell. Thus, it was suggested that SIRC operations at Adak had few problems, although the station climatic analysis indicated a potential problem since Adak had essentially the same mean winter temperature as Keflavik and more snowfall days. The bi-variate climatology for Adak was prepared to examine this situation.

In the site interview at Anchorage, it was indicated that the runway temperature feature of the SCAN system was useful to SIRC operations in indicating when the temperature was below 18°F so that urea application was no longer effective. A bi-variate distribution was prepared for Anchorage to investigate this impression.

The fifth climatology was prepared for Indianapolis, Indiana. Indianapolis was one of the sites visited and provided a continental climate distinctly south and inland of Anchorage. In addition it provided a climate for comparison with the coastal climate at Brunswick and was close enough to the Great Lakes so that its climate might approximate that of Glenview, Ill.

All special climatologies (i.e. those not routinely available from National Climatic Center at Asheville, N.C.) were prepared from the hourly observation series available from Asheville. These data were supplied by Asheville on magnetic tape in a format called Tape Data Family-14. In order to prepare the climatology from these series of observations, the tape had to be converted into a workable format. This conversion was done at Calspan for all five stations. In addition, computer programs were written to process the converted tapes and prepare the desired climatologies.

The bi-variate distributions were prepared for the temperature categories ≥ 37°F, 36°-35°, 34°-33°, 32°-31°, 30°-18°, and < 18°F and for the available precipitation categories of none, rain, rain squall, snow, snow showers, freezing rain, freezing drizzle, and sleet. The complete, detailed distributions are included in Appendix C. For purposes of this discussion only certain portions of the distributions are presented. The temperature categories were chosen to delineate the occurrence of frozen precipitation; thus the fine resolution near freezing. In addition, the break point at 18°F was included in order to investigate the precipitation and temperature behavior around the temperature below which urea ceases to be effective.

Table 4 shows the frequency of precipitation for the five stations for the indicated temperature categories. The stations are listed in order of decreasing number of observations of precipitation in the normalized winter season (2904 hours).

First consider Keflavik where the SCAN system has been in operation for a few years and where SIRC operations are frequent. In Table 5, 72% of Keflavik's winter precipitation occurs above 32°F, showing the oceanic climate of this high latitude station. However, 74% of the snow and snow showers occur with temperatures below 32°F indicating the need for frequent SIRC operations.

For Adak, note that 75% of Adak's winter precipitation occurs with temperatures above freezing, showing, as for Keflavik, the oceanic climate of this high latitude station. Almost 47% of Adak's snow and snow showers also occur at air temperatures above freezing. In addition, 63% of Adak's non-precipitation observations are above freezing. Thus, with almost half of the snowfall occurring at above freezing temperatures and with a 2/3 chance that subsequent non-precipitation hours will be above freezing, the claim that snowfall has a high probabilility of either melting as it falls or melting subsequent to precipitation ending is suported. The number of SIRC operations at Adak will likely be fewer than at Keflavik.

As shown by the data, Anchorage has an entirely different climate than either Adak or Keflavik; i.e., (in Table 4) only 12% of its winter season is above 32°F. This percentage continues to hold when the breakdown between precipitation and non-precipitation is taken into account (Table 5). Thus the SIRC operation at Anchorage is mainly concerned with precipitation that occurs at below freezing temperatures. Approximately 40% of the precipitation below freezing takes place at temperatures < 18°F, and, even when the precipitation stops, the temperature is below 18°F 56% of the time. Thus, claims of monetary savings, resulting from knowledge of surface temperature at Anchorage, are supported by this climatology.

TABLE 4

BI-VARIATE DISTRIBUTION OF PRECIPITATION EVENTS VS. TEMPERATURE

Percentage of Total Observations

Station	Precipitation Event	Seasonal Totals	Total > 32°F	Total ≤ 32°F
Adak	Precipitation	37	27	10
	Non-Precipitation	63	40	23
Keflavik	Precipitation	25	18	7
	Non-Precipitation	75	39	36
Anchorage	Precipitation	18	3	15
	Non-Precipitation	82	9	73
Brunswick	Precipitation	17	8	9
	Non-Precipitation	83	26	57
Indianapolis	Precipitation	20	11	9
	Non-Precipitation	80	39	41

TABLE 5

DISTRIBUTION OF PRECIPITATION EVENTS VS. TEMPERATURE

Percentages of Precipitation Event Total Observations

Station	Precipitation Event	> 32°F	≤ 32°F
Adak	Precipitation	75	25
	Non-Precipitation	63	37
	Snow and Snow Showers	47	53
Keflavik	Precipitation	72	28
	Non-Precipitation	52	48
	Snow and Snow Showers	26	74
Anchorage	Precipitation	17	83
	Non-Precipitation	11	89
	Snow and Snow Showers	12	88
Brunswick	Precipitation	47	53
	Non-Precipitation	30	70
	Snow and Snow Showers	14	86
Indianapolis	Precipitation	53	47
	Non-Precipitation	51	49
	Snow and Snow Showers	12	88

The continental influence at Brunswick, like Anchorage, is reflected in its precipitation frequency, with precipitation occurring during only about 20% of the winter observations. The impact of the maritime climate is seen in that 34% of the time the temperature is above 32°F, a greater percentage than at Anchorage and less than that at either Adak or Keflavik. In Table 4, Brunswick's precipitation is equally divided between above and below freezing temperatures, again reflecting the coastal location. However of the snow and snow showers precipitation type, 86% occurs below freezing. This fact, coupled with a high percentage (70%) of the non-precipitation hours being below 32°F, suggests that Brunswick's SIRC operations are mostly concerned with snowfall. However the combination of 47% of the precipitation occurring at above freezing temperatures and the 70% of non-precipitating observations occurring at below freezing suggests the possibility of previous precipitation freezing on runway surfaces.

The continental influence at Indianapolis is obvious; it has precipitation during only about 20% of the winter as at Anchorage and Brunswick (Table 4). However, its lower latitude and the influence of both the Great Lakes and the Gulf of Mexico can be seen in the equal amount of time that air temperature is above and below freezing. This equal distribution is maintained in both the precipitation and non-precipitation categories (Table 5). However, for the snow and snow shower precipitation type, 88% occurs at below freezing, similar to that at Brunswick. On the other hand, with 50% of the hours being above freezing, it appears there is a smaller likelihood at Indianapolis of previous precipitation freezing on the runway.

7.4 Climatology of Runway Freezing Events

The approach in this climatology was to determine under what deteriorated runway-traction conditions due to ice does the SCAN system provide runway condition information that is not otherwise available. An analysis of weather-related SCAN events which occurred during our visit to Keflavik, Iceland (see Section 5) indicated that the subsequent freezing of previous precipitation lying on the runway was a common occurrence. A model was developed based on the sequence of meteorological events which produced the observed conditions of "runway freezing."

To model the runway freezing event we reviewed the data acquired during the site visit at Keflavik. During the period 25 February to 10 March 1978, two runway freezing events occurred, on 7 March and 10 March. In both cases, meteorological data were obtained from the Federal Meteorological Form 1-10 Surface Weather Observation *(formerly called the WBAN form)* and compared to the SCAN observations of surface temperature (Figure 17, Section 5). The analysis revealed that precipitation occurred in the four hours before runway freezing occurred and that, when runway freezing occurred, air temperature dropped below 36°F and surface temperature dropped to 32°F or below. In addition, total sky cover went to less than 5/10 coverage.

Using the above information, we constructed a model for a sequence of WBAN-recorded meteorological conditions which described runway freezing conditions:

1) The WBAN air temperature must cross a threshold.
2) The WBAN air temperature must be at or above the threshold for the four hours before it crosses the threshold, and must remain below the threshold for four hours after it crosses the threshold. The four hour criteria was designed to eliminate situations when the temperature fluctuates around the threshold temperature.
3) The total sky cover went to less than 5/10's cover for the hour, and subsequent hour, at which the temperature threshold was crossed.

As a test, this model was run for both Keflavik and Brunswick on the winter season data contained on the converted climatological data tapes. It was decided to run the model for a range of crossover temperatures, i.e., 36°, 34° and 32°F.

The results of the model runs are shown in Table 6. Brunswick had a total record length of 68970 hours and Keflavik had 68208 hours. With a winter season of 121 days, or 2904 hours, each record had approximately 24 winter seasons. For all three threshold temperatures and assuming model criteria, Brunswick has on the average 1.3 occurrences of runway freezing per winter season and Keflavik has one event every two winter seasons. Thus, with these model criteria, runway freezing is a rather rare event at both stations. In view of the two events witnessed at Keflavik during our two-week site visit, the estimated climatological frequency seemed too small. The conclusion was reached that some of the meteorological criteria which defined the runway freezing event must be relatively infrequent, and thus the conditional probability of all the criteria together was very low.

TABLE 6

Climatology of Probable Runway Freezing Events

With Total Sky Cover Less Than 5/10's

	Temperature Threshold	Total Events	Events Per Winter Season
Keflavik	36	5	
	34	4	
	32	2	
		11	0.5
Brunswick	36	10	
	34	9	
	32	13	
		32	1.3

A test with a four hour time interval for 34°F threshold at Keflavik produced one less occurrence of runway freezing than did the eight-hour-window criteria. It was then concluded that the total sky cover criterian might be the most restrictive, and it was decided to process the climatological record for all temperature crossovers for the three threshold temperatures regardless of sky cover. The results are shown in Table 7.

When the events are normalized to a winter season, Keflavik has, as an upper limit, ∿21 events per winter; Brunswick has ∿16. With 121 days in a season, the average frequency of occurrence is one event per every six days at Keflavik and one event per every 7.6 days at Brunswick, in good agreement with the observed frequency of such events during our visit to Keflavik (i.e., one per 8 days).

TABLE 7

Climatology of Probable Runway Freezing Events Without Regard to Sky Cover

Keflavik	Temperature Threshold	Total Events	Events Per Winter Season
	36	163	
	34	177	
	32	136	
		476	21
Brunswick	36	112	
	34	127	
	32	146	
		385	16

Within the scope of this effort, it was not possible to perform these analyses for Adak. But, with the substantially warmer temperatures experienced there, it is likely that the frequency of such runway freezing events is lower than those of Brunswick and Keflavik.

7.5 Conclusions

1. Of 76 Naval installations, only 12 were found which experience > 0.1 inches of snow on each of more than 10 days during the winter (December through March) and at least one winter month in which mean minimum temperature is < 32°F. For administrative reasons, four of those stations are eliminated from consideration.
2. Of the remaining eight installations -- Adak, Brunswick, Glenview, Keflavik, Lakehurst, Misawa, Quonset Point, and South Weymouth -- approximately half experience snowfalls exceeding 1.5 inches fewer than 10 times per winter. Without additional experience with the SCAN system, it does not seem appropriate to consider its implementation at airfields with less severe winter weather than these eight.
3. More detailed climatologies for Brunswick, Adak and Keflavik suggest that, in terms of the number of required SIRC operations, the stations are similar. Further, wet-runway-freezing events may be as important for SIRC activities as is snowfall.

4. Thus from climatological considerations alone, SCAN systems could be useful at the three airfields of greatest interest to the Navy and perhaps at the other five airfields listed above.

APPENDIX A

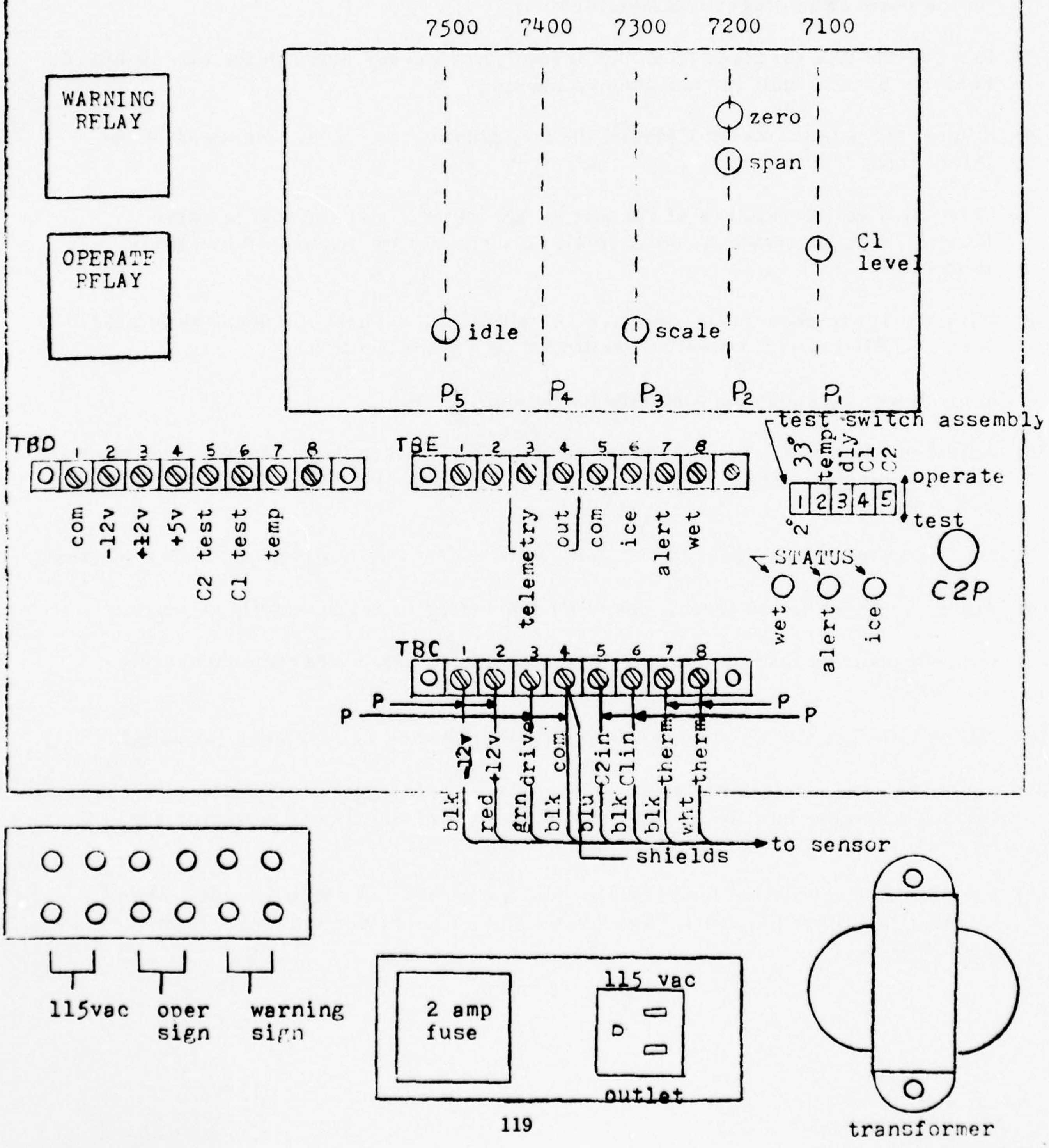
Manual For

SCAN 7000

REMOTE PROCESSOR UNIT
RPU-7000

SURFACE SYSTEMS INC.
ST. LOUIS, MISSOURI

RPU-7000	
drg. no. 7000	date 6-1-77
scale	drawn g.w
chkd gw	appvd g.w



ALIGNMENT PROCEDURE

1) To align the system the following are required:

   A) Small screwdriver
   B) A voltmeter (VM)

2) With the fuse removed, connect the sensor, power and telemetry as shown on the connection diagram inside the door.

3) Remove the five (5) plugs from the screwdriver access holes in the circuit board holder - housing unit (do not remove housing).

4) Rotate test potentiometer C2P and the five pots on the circuit boards CCW to their stops.

5) Place all five (5) switches of the test switch assembly in the test position (down). It is advisable to use a small screwdriver or pencil to move these switches.

6) With Vm set to read on the negative 10 volt scale, connect the negative (black) lead to TBD-1 and the positive (red) lead to TBD-5 (C_2 test).

7) Apply power by screwing fuse into its holder.

8) Adjust pot C2P CW, Vm should swing through 0 volts and into the positive range. Change polarity. Set the voltage at +1.50 volts and the "ice" status light should come on.

9) Set Vm range to read positive 10 volts and connect positive lead to TBD-6 (C_1 test).

10) Adjust C_1 level pot on circuit board P1 CW until Vm reads exactly 10 volts.

11) Connect positive lead of Vm to TBD-7 (temp). It should read approximately 2.5 volts.

12) Adjust zero pot CW on circuit board P2 until it reads exactly zero (0) volts.

13) Set Vm function switch for negative range and push switch no. 1 of the test switch assembly into the 33° position (up). Vm should read approximately -2.5 volts.

14) Disconnect Vm positive lead, change function to read positive 10 volts, then connect to TBD-6 (C_1 test). Vm should be on 0 volts and the "wet" light should be on.

15) Adjust span pot on circuit board CW until the voltage changes from 0 to +10.0 volts and the status lights change from "wet" to "ice". Repeat this adjustment several times to set the threshold as closely as possible where the lights just change from "ice" to "wet" (not "wet" to "ice"). Check this function by switching back and forth between 2 and 33 (switch no. 1) on the test switch assembly. "Wet" light should be on in 33 position and "ice" in the 2 position. Leave switch in 33 position.

16) With a display monitor connected across terminals TBE-3 and TBE-4 (by jumper, telephone line or radio link) adjust scale pot on circuit board P3 CW until the surface temperature display indicates 33. Note: turn the pot and wait a few seconds for the logic in the monitor to display the new surface temperature. Also the "wet" (blue) light on the monitor should be on.

17) Move switch #1 to the 2 position (down); the status light on the monitor should go to "ice" and surface temperature indicate approximately 2.

18) Place switch #2 in the operate position (up). The surface temperature of the sensor should now be displayed. (Status lights will indicate "ice" if sensor temperature is below 32°F and "wet" if above 32°F.)

19) Set Vm on negative and the 5 volt scale. Move switch #5 of the test switch assembly to the operate position (up) and connect positive lead to TBD-5 (C_2 test).

20) Adjust idle pot on circuit board P5 in the CW direction. The voltage will go in the positive direction and through 0 volts. Change Vm to indicate positive voltages and set idle pot at 0.5 volts. The "clear" light on the monitor should be on and all the lights on the RPU panel off.

21) Place hand or water on sensor head. Vm should increase to between 1.5 and 2.5 volts. The "wet" light should come on on the monitor and RPU panel if the surface temperature is above 32°F.

22) Dry off sensor head, then:

A) switch #1 in 33 position (up)
B) switch #2 in test position (down)
C) switch #3 in test position (down)
D) switch #4 in test position (down)
E) switch #5 in test position (down)

23) Monitor should indicate "wet" and 33 degrees. Move C2P pot CW to 3.0 volts. Monitor should indicate -99 and all lights off (RPU "wet" status light will still be on).

24) Move C2P CCW until Vm reads 0.10 volts. The monitor should still indicate -99 and all lights off (all lights on the RPU panel will now be off).

25) Move C2P to 0.5 volts. The monitor should now display 33 degrees and "clear". (All lights off on RPU.) This completes the test of the encoder shut down circuit.

26) A) Switch #1 in 33 position (up)
B) Switch #2 in operate position (up)
C) Switch #3 in operate position (up)
D) Switch #4 in operate position (up)
E) Switch #5 in test position (down)

The "clear" light should be on. Rotate C2P CW until the Vm reads 1.5 volts. Note that it takes approximately one (1) minute for status to change from "clear" to "wet" (if above 32°F). This is the delay circuit.

27) Place all switches in operate position (up) and leave C2P pot at its last setting. Vm should read 0.50 volts if the sensor head is dry.

28) This completes the alignment and the system is now in the operate mode.

RPU 7000
ALIGNMENT PROCEDURE
DEGREES CELSIUS

1) To align the system the following are required:

   A) Small screwdriver
   B) A voltmeter (VM)

2) With the fuse removed, connect the sensor, power and telemetry as shown on the connection diagram inside the door.

3) Remove the five (5) plugs from the screwdriver access holes in the circuit board holder - housing unit (do not remove housing).

4) Rotate test potentiometer C2P and the five pots on the circuit boards CCW to their stops.

5) Place all five (5) switches of the test switch assembly in the test position (down). It is advisable to use a small screwdriver or pencil to move these switches.

6) With Vm set to read on the negative 10 volt scale, connect the negative (black) lead to TBD-1 and the positive (red) lead to TBD-5 (C_2 test).

7) Apply power by screwing fuse into its holder.

8) Adjust pot C2P CW, Vm should swing through 0 volts and into the positive range. Change polarity. Set the voltage at +1.50 volts and the "ice" status light should come on.

9) Set Vm range to read positive 10 volts and connect positive lead to TBD-6 (C_1 Test).

10) Adjust C_1 level pot on circuit board P1 CW until Vm reads exactly 10 volts.

11) Connect positive lead of Vm to TBD-7 (temp). It should read approximately 2.5 volts.

12) Adjust zero pot CW on circuit board P2 until it reads exactly zero (0) volts.

13) Set Vm function switch for negative range and push switch no. 1 of the test switch assembly into the 1° position (up). Vm should read approximately -2.5 volts.

14) Disconnect Vm positive lead, change function to read positive 10 volts, then connect to TBD-6 (C_1 test). Vm should be on 0 volts and the "wet" light should be on.

15) Adjust span pot on circuit board CW until the voltage changes from 0 to +10.0 volts and the status lights change from "wet" to "ice". Repeat this adjustment several times to set the threshold as closely as possible where the lights just change from "ice" to "wet" (not "wet" to "ice"). Check this function by switching back and forth between -17° and 1° (switch no. 1) on the test switch assembly. "Wet" light should be on in 1° position and "ice" in the -17° position. Leave switch in 1° position.

16) With a display monitor connected across terminals TBE-3 and TBE-4 (by jumper, telephone line or radio link) adjust scale pot on circuit board P3 CW until the surface temperature display indicates 1°. Note: turn the pot and wait a few seconds for the logic in the monitor to display the new surface temperature. Also the "wet" (blue) light on the monitor should be on.

17) Move switch #1 to the 2 position (down); the status light on the monitor should go to "ice" and surface temperature indicate approximately 2.

18) Place switch #2 in the operate position (up). The surface temperature of the sensor should now be displayed. (Status lights will indicate "ice" if sensor temperature is below 0°C and "wet" if above 0°C.)

19) Set Vm on negative and the 5 volt scale. Move switch #5 of the test switch assembly to the operate position (up) and connect positive lead to TBD-5 (C_2 test).

20) Adjust idle pot on circuit board P5 in the CW direction. The voltage will go in the positive direction and through 0 volts. Change Vm to indicate positive voltages and set idle pot at 0.5 volts. The "clear" light on the monitor should be on and all the lights on the RPU panel off.

21) Place hand or water on sensor head. Vm should increase to between 1.5 and 2.5 volts. The "wet" light should come on on the monitor and RPU panel if the surface temperature is above 0°C.

22) Dry off sensor head, then:

A) switch #1 in 1° position (up)
B) switch #2 in test position (down)
C) switch #3 in test position (down)
D) switch #4 in test position (down)
E) switch #5 in test position (down)

23) Monitor should indicate "wet" and 1 degree. Move C2P pot CW to 3.0 volts. Monitor should indicate -99 and all lights off (RPU "wet" status light will still be on).

24) Move C2P CCW until Vm reads 0 volts. The monitor should still indicate -99 and all lights off (all lights on the RPU panel will now be off).

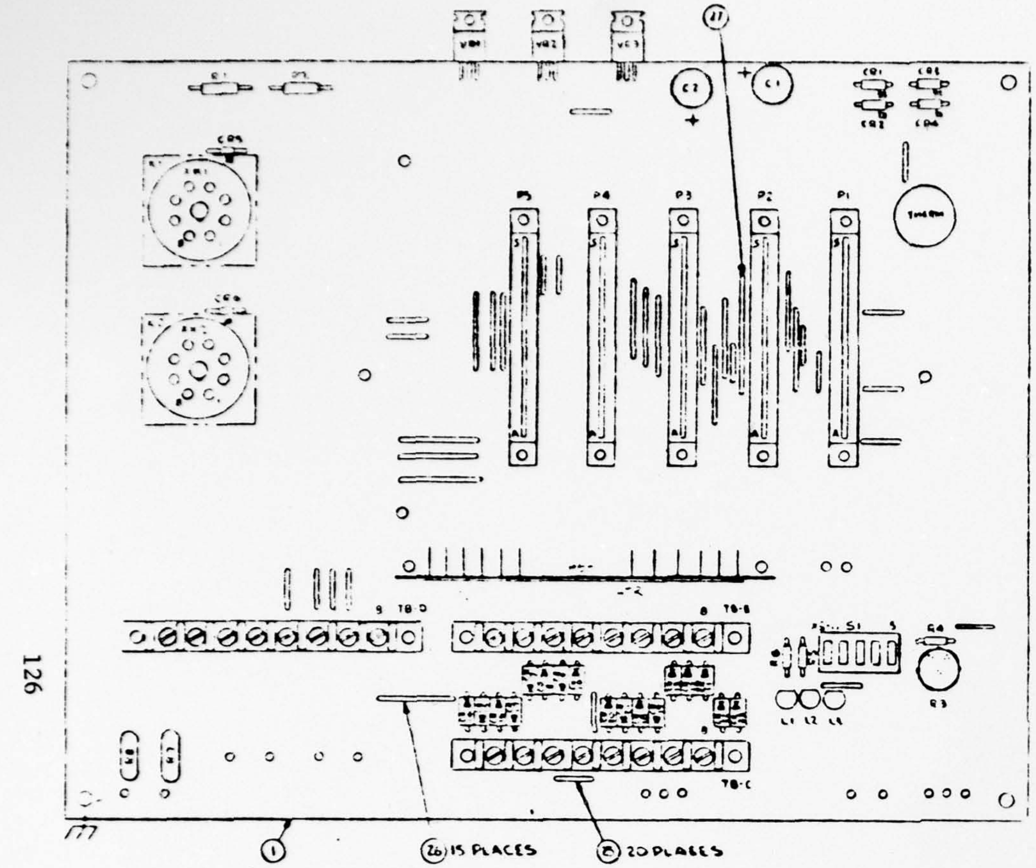
25) Move C2P to 0.5 volts. The monitor should now display 1 degree and "clear" (all lights off on RPU). This completes the test of the encoder shut down circuit.

26) A) Switch #1 in 1^o position (up)
    B) Switch #2 in operate position (up)
    C) Switch #3 in operate position (up)
    D) Switch #4 in operate position (up)
    E) Switch #5 in test position (down)

The "clear" light should be on. Rotate C2P CW until the Vm reads 1.5 volts. Note that it takes approximately one (1) minute for status to change from "clear" to "wet" (if above 0^oC). This is the delay circuit.

27) Place all switches in operate position (up) and leave C2P pot at its last setting. Vm should read 0.50 volts if the sensor head is dry.

28) This completes the alignment and the system is now in the operate mode.

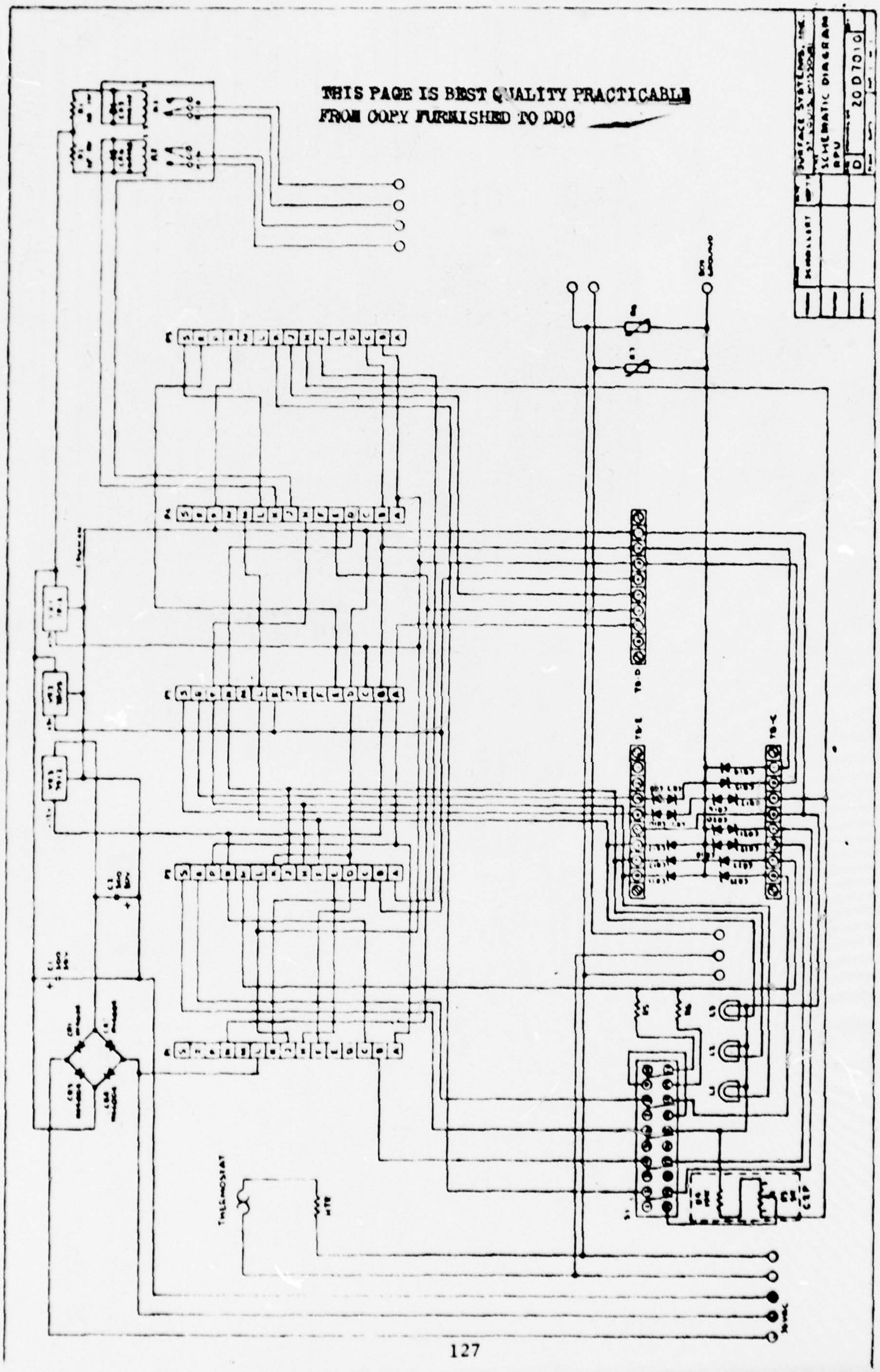


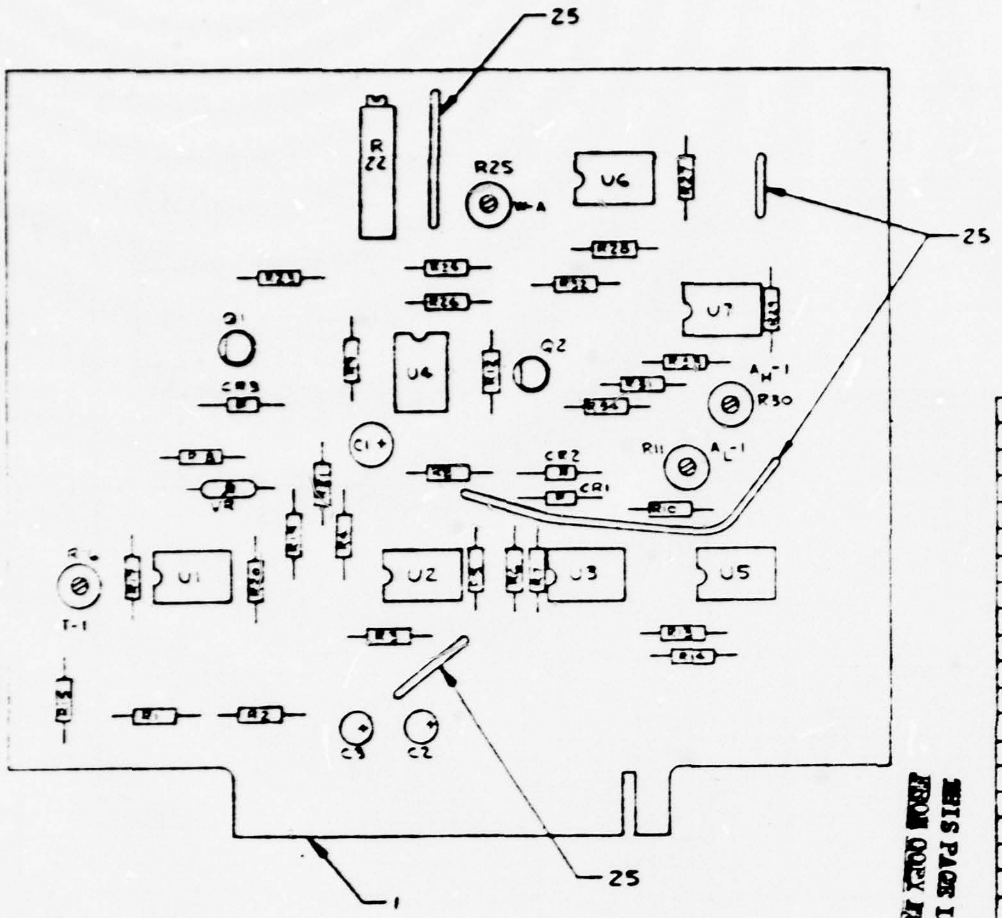
QTY	REFERENCE DESIGNATION	ITEM	DESCRIPTION	MFR	PART NO.
1	[illegible]	2[illegible]	[illegible]	[illegible]	
	R6	20	RESISTOR .43K ±5% 1/4W		
1		27	JUMPER 1.50 CENTER		
15		26	JUMPER 1.00 CENTER		
20		25	JUMPER .50 CENTER		
1	THERM	24	THERMOSTAT	[illegible]	TI
1	HTR	23	HEATER	WATLOW [illegible]	
1	VR3	22	TRANSISTOR		2N7912
1	VR2	21	TRANSISTOR		2N7805
1	VR1	20	TRANSISTOR		2N7912
3	TB-C,-D,-E	19	TERMINAL	TRW 3-170-2	
1	S1	18	SWITCH, DIP	AMP 435728I	
2	R7,R8	17	VARISTOR	GENERAL ELECTRIC	V130LA10A
1	R5	16	RESISTOR 12.1K ±5% 1/4W		
1	R4	15	RESISTOR 15K ±5% 1/4W		
1	R3	14	POTENTIOMETER 5K	ALLEN BRADLEY	YC-502M
2	R1,R2	13	RESISTOR 68 ±5% 1W		
5	P1 THRU P5	12	CONNECTOR	CINCH 50-15B-10	
1	HS-1	11	HEAT RADIATOR	WAKEFIELD 623-K	
1	XS-1	10	SWITCH SOCKET	AMP 5B3000-2	
3	L1,L2,L3	9	LAMP, LED	LITRONIX RLC 200	
1	K1	8	RELAY	P&B KRP5D	
2	XK1, XK2	7	SOCKET	AMPHENOL 78-SBW-125	
2	C1, C2	6	CAPACITOR 470μF 50V	MALLORY VTT 470K25	
2	CR10, CR19	5	SUPPRESSOR	GENERAL SEMI.	KTE-36
10	CR7 THRU CR17, CR20 THRU CR23	4	SUPPRESSOR	GENERAL SEMICONDUCTOR INDUSTRIES, INC	KTE-15
2	CR5, CR6	3	DIODE		1N4148
4	CR1 THRU CR4	2	DIODE		1N4004
1		1	BOARD, PC		7010

	NAME	DATE	
DRAWN	SCHALLERT	SEP 77	SURFACE SYSTEMS, INC. ST LOUIS, MISSOURI
CHECKED	JKW	OCT 77	TITLE ASSY, P.C. - RPU MOTHER BOARD
APPROVED	Rogers	OCT 77	SIZE C · DRAWING NO. 10C7010 · REV 0
			SCALE · SHT 1 OF 1

NOTES

1. COMPONENTS NOT IDENTIFIED BY ITEM NUMBER ON THE ASSEMBLY ARE IDENTIFIED BY REFERENCE DESIGNATIONS IN THE PARTS LIST.
2. REFERENCE DESIGNATIONS ARE FOR REFERENCE ONLY AND ARE NOT MARKED ON PART
3. FOR SCHEMATIC DIAGRAM, SEE DRAWING NUMBER 20D7010.


SURFACE SYSTEMS, INC.
ST. LOUIS, MISSOURI
SCHEMATIC DIAGRAM
BPU
D
20D7010
THERMOSTAT
TB-D
TB-E
TB-C
CR1
CR2
CR3
CR4



NOTES:
1 PIN 1 IDENTIFIED BY NOTCH ON IC.
2 COMPONENTS NOT IDENTIFIED BY ITEM NUMBERS ON THE ASSEMBLY ARE IDENTIFIED BY REF DESIG IN THE PARTS LIST
3 REF DESIG ARE FOR REFERENCE ONLY AND ARE NOT MARKED ON PART
4 FOR SCHEMATIC DIAGRAM SEE 20-7100

QTY -1	REF DESIG	ITEM NO.	DESCRIPTION	MANUFACTURER / PART NO.
4	R12,24,27,15		SEE DWG 20-7100	
1	R29	26	RESISTOR, ¼W, 390, ±5%	
AS REQD		25	WIRE, COPPER SOLID TIN COATED INSULATED	22 AWG
1	R22	24	POTENTIOMETER, ½W, 5K, ±10%	SPECTROL 43W502
4	R11,R16,R25,R30	23	POTENTIOMETER, ¼W, 10K, ±5%	SPECTROL 62-1-1-103
1	R34	22	RESISTOR, ¼W, 4.7K, ±5%	
1	R32	21	RESISTOR, ¼W, 2K, ±5%	
1	R26	20	RESISTOR, ¼W, 150K, ±5%	
2	R23,	19	RESISTOR, ¼W, 1K, ±5%	
1	R21	18	RESISTOR, ¼W, 8.2K, ±5%	
1	R18	17	RESISTOR, ¼W, 820, ±5%	
1	R17,	16	RESISTOR, ¼W, 180K, ±5%	
3	R14,R19,R28	15	RESISTOR, ¼W, 100, ±5%	
1	R10	14	RESISTOR, ¼W, , ±5% SEE DWG 20-7100	
1	R8	13	RESISTOR, ¼W, 68K, ±5%	
3	R6, R7, R31	12	RESISTOR, ¼W, 10K, ±5%	
1	R5	11	RESISTOR, ¼W, 6.8K, ±5%	
2	R3, R9	10	RESISTOR, ¼W, 2.2K, ±5%	
6	R2,4,13,20, 33	9	RESISTOR, ¼W, 100K, ±5%	
3	R1	8	RESISTOR, ¼W, 27K, ±5%	
2	C2, C3	7	CAPACITOR, 2.2MF, ±20%, 16V	KEMET T392A225M016AS
1	C1	6	CAPACITOR, 15 MF, ±20%, 16V	KEMET T392C156M016AS
1	VR1	5	DIODE	1N823
3	CR1,CR2,CR3	4	DIODE	1N4148
2	Q1, Q2	3	TRANSISTOR	2N5172
7	U1 THRU U7	2	INT CKT, 8 PIN DIP	741
1		1	PC BOARD	30-7100

SURFACE SYSTEMS, INC
ST LOUIS, MISSOURI

ASSY, P.C-C1 ANALOG LOGIC

NONE

REV 1

10-7100

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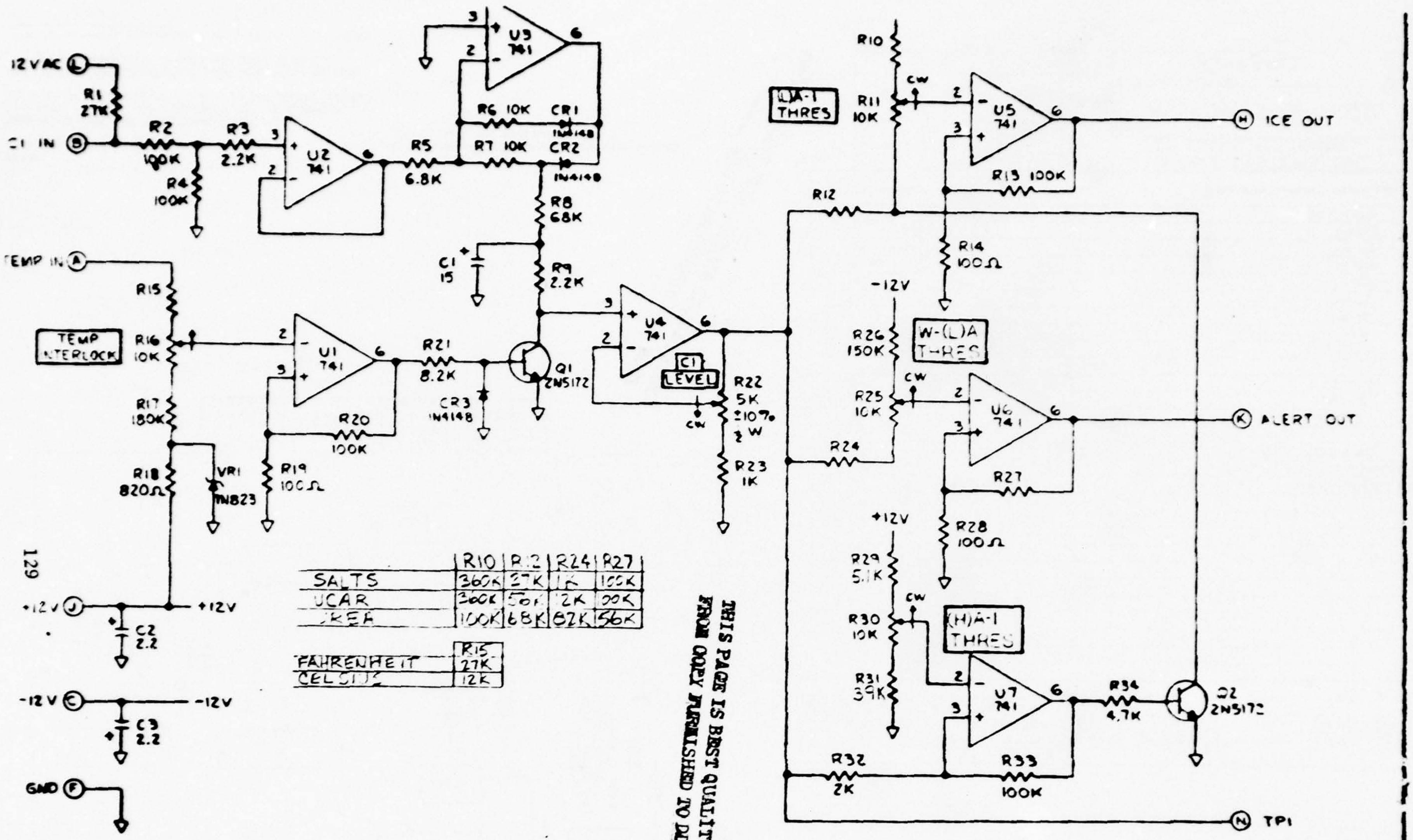
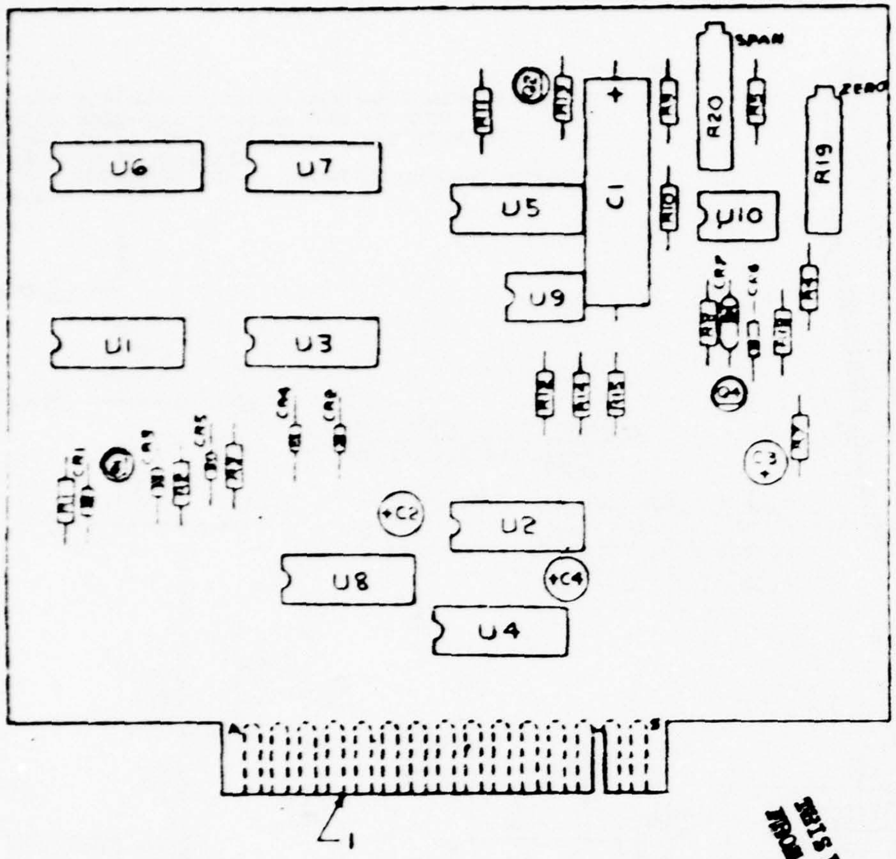


	R10	R12	R24	R27
SALTS	360K	27K	1K	100K
UCAR	360K	50K	12K	100K
UREA	100K	68K	82K	56K

	R15
FAHRENHEIT	27K
CELSIUS	12K

NOTES:
1. ALL RESISTORS ARE IN OHMS, ¼ WATT, ±5% UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITORS ARE IN MF ±20%, 16 VOLT.
3. FOR ASSEMBLY DRAWING SEE 10-7100.
4. ALL ICS, PIN 4 TIED TO -12V, PIN 7 TIED TO +12V

SURFACE SYSTEMS, INC
ST. LOUIS, MISSOURI
SCHEMATIC-C1 ANALOG LOGIC

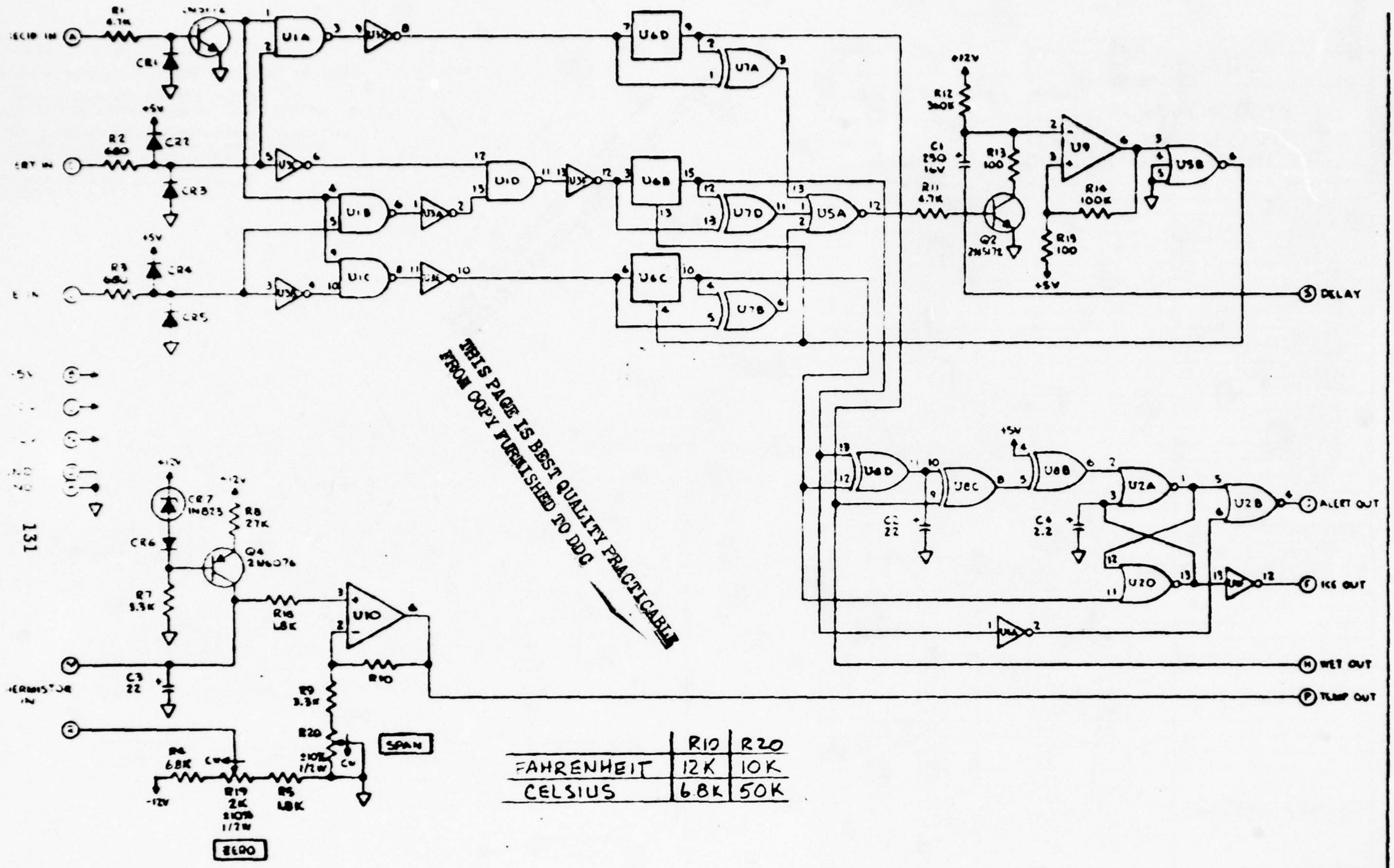


QTY -1	REF DESIG	ITEM	DESCRIPTION	MANUFACTURER / PART NO.
1	R20	32	POTENTIOMETER, SEE DWG 20-7200	SPECTROL 43P-103
1	R19	31	POTENTIOMETER, 2K	SPECTROL 43P-202
2	R9, R18	30	RESISTOR, 1.8K, 1/4W, 5%	
		29		
		28		
1	R14	27	RESISTOR, 100K, 1/4W, 5%	
2	R13, R15	26	100Ω	
1	R12	25	360K	
1	R10	24	SEE DWG 20-7200	
1	R8	23	27K	
		22		
2	R7, R5	21	3.3K	
1	R4	20	68K	
2	R2, R3	19	680Ω	
2	R1, R11	18	RESISTOR, 4.7K, 1/4W, 5%	
1	C4	17	CAPACITOR, 2.2 µF.	KEMET T392A225M016AS
2	C2, C3	16	CAPACITOR, 22 µF.	KEMET T392D226M016AS
1	C1	15	CAPACITOR, 250 µF, 16V	SPRAGUE TE-1164.5
		14		
1	CR7	13	DIODE	1N823
6	CR1-CR6	12	DIODE	1N4148
1	Q4	11	TRANSISTOR	2N6076
		10		
2	Q1, Q2	9	TRANSISTOR	2N5172
2	U9, U10	8	INT CKT	741
2	U7, U8	7		7486
1	U6	6		7475
1	U5	5		7427
2	U3, U4	4		7404
1	U2	3		7402
1	U1	2	INT CKT	7400
1		1	BOARD, PC	30-7200

	NAME	DATE	
DRAWN	C. R.	5-76	SURFACE SYSTEMS, INC. ST. LOUIS, MISSOURI
CHECKED	Rogers	4/1/77	TITLE ASSY, PC - TEMP LOGIC
APPROVAL	Rogers	4/21/77	SIZE C DRAWING NO. 10-7200 REV 1
			SCALE 2:1 SHT 1 OF 1

NOTES:

1. PIN 1 IDENTIFIED BY NOTCH ON IC.
2. COMPONENTS NOT IDENTIFIED BY ITEM NUMBER ON THE ASSEMBLY ARE IDENTIFIED BY REFERENCE DESIGNATIONS IN THE PARTS LIST.
3. REFERENCE DESIGNATIONS ARE FOR REFERENCE ONLY AND ARE NOT MARKED ON PART.
4. FOR SCHEMATIC DIAGRAM, SEE DWG NO. 20-7200
5. REFERENCE DESIGNATIONS NOT USED: Q3, R6, R16 AND R17.



	R10	R20
FAHRENHEIT	12K	10K
CELSIUS	6.8K	50K

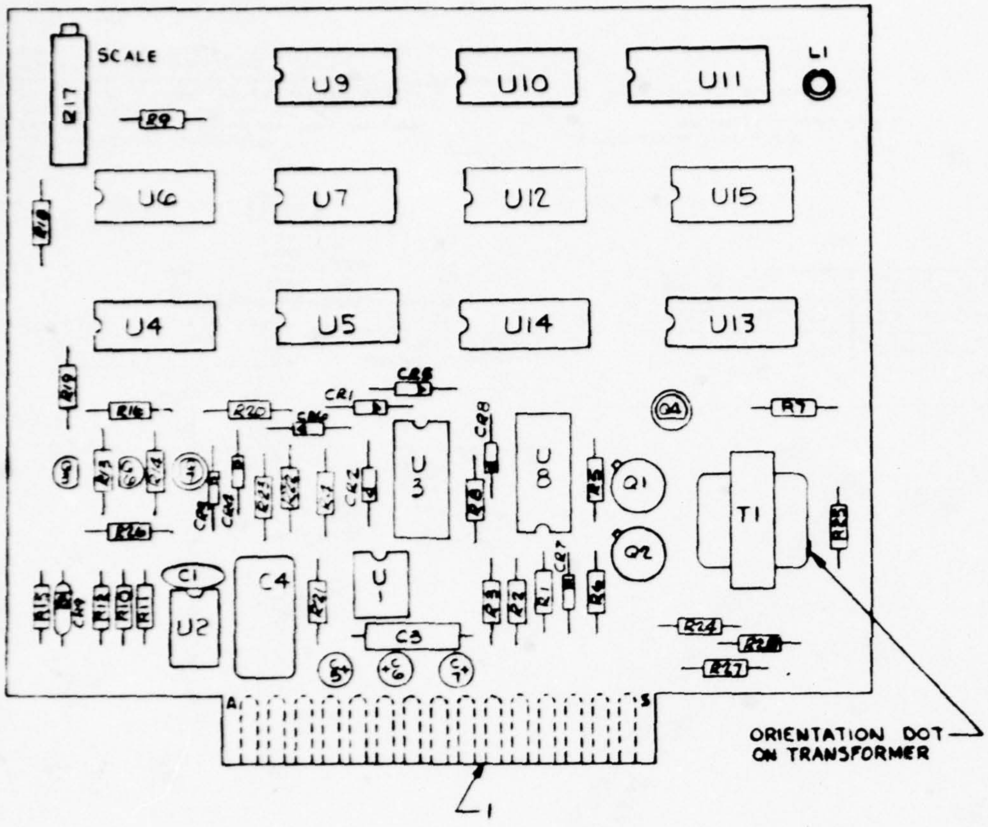
NOTES:
1. UNLESS OTHERWISE SPECIFIED:
a. ALL RESISTORS ARE IN OHMS, 1/4W, 25%.
b. ALL CAPACITORS ARE IN MF
c. ALL DIODES ARE 1N4148 UNLESS NOTED.
d. PIN 7 (GND) AND PIN 14 (+5V) FOR U1 THRU U5, U7 AND U8;
PIN 5 (+5V) AND PIN 12 (GND) FOR U6;
PIN 4 (-12V) AND PIN 7 (+12V) FOR U9 AND U10.

2. IC TYPES ARE AS FOLLOWS:
U1-7400 U3,U4-7404 U6-7475 U9,U10-741
U2-7402 U5-7427 U7,U8-7486

3. REF DESIG NOT USED:
Q3, R6, R16 AND R17

4. THIS DRAWING CONJUNCTION WITH 10-7200.

—	SCHALLERT	AUG 76	SURFACE SYSTEMS, INC. ST LOUIS, MISSOURI
—	J. O. Rogers	10/8/77	SCHEMATIC- TEMP LOGIC
—	J. Rogers	10/21/77	C · 20-7200 · 1



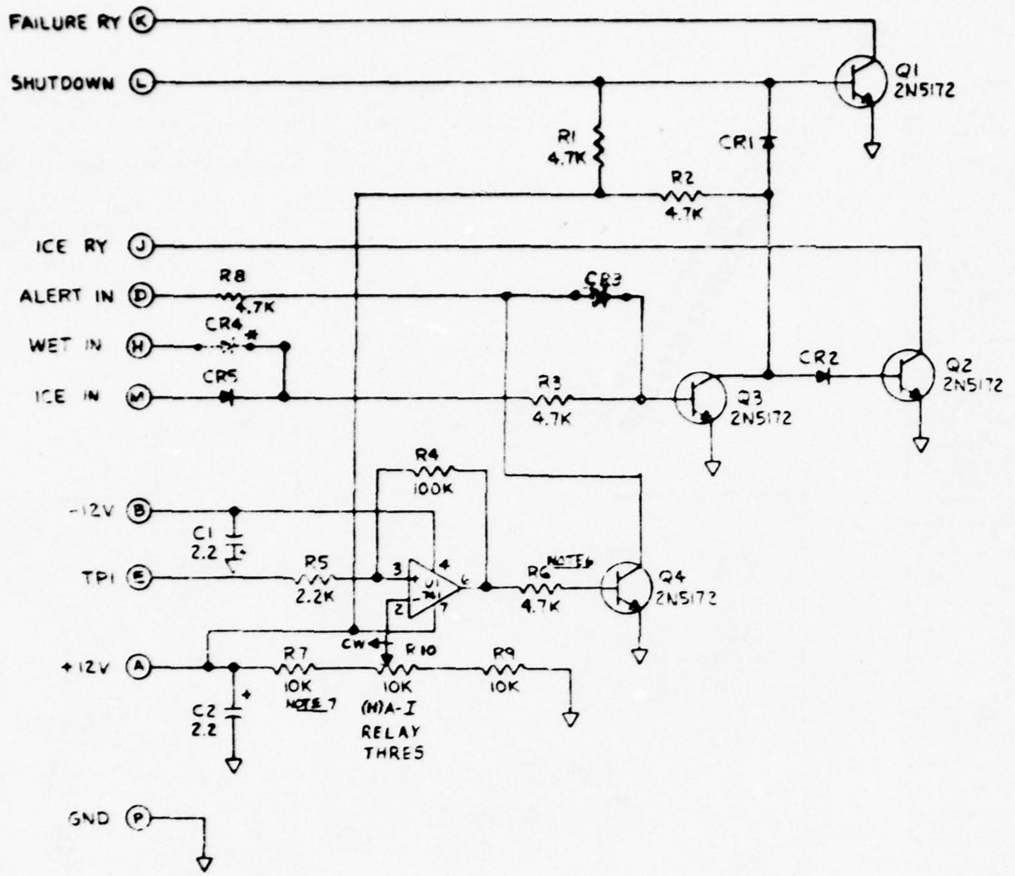
ORIENTATION DOT ON TRANSFORMER

QTY -1	REF DESIG	ITEM	DESCRIPTION	MFG	PART NO.
2	R28, R27	48	RESISTOR, 270Ω, 1/4W, 5%		
1	L1	47	DIODE, LIGHT EMITTING	LITRONICS	RLC-200
2	R5, R6	46	RESISTOR, 6.8K, 1/4W, 5%		
1	R25	45	RESISTOR, 1.2K, 1/4W, 5%		
1	R24	44	47Ω		
1	R22	43	100K		
1	R21	42	100Ω		
		41			
1	R19	40	267K, 1/8W, 1%		
1	R18	39	RESISTOR, 453K, 1/8W, 1%		
1	R17	38	POTENTIOMETER, 100K	SPECTROL	43W-104
1	R16	37	RESISTOR, 3.9K, 1/4W, 5%		
1	R15	36	2.2K		
1	R14	35	18K		
2	R13, R20	34	1MEG, 1/4W, 5%		
1	R12	33	34.8K, 1/8W, 1%		
1	R11	32	6.04K, 1/8W, 1%		
1	R10	31	5.11K, 1/8W, 1%		
1	R9	30	5.6K, 1/4W, 5%		
1	R8	29	330Ω		
1	R7	28	820Ω		
2	R4, R23	27	1.5K, 1/4W, 5%		
1	R3	26	20K, 1/8W, 1%		
3	R1, R2, R26	25	RESISTOR, 4.7K, 1/4W, 5%		
1	T1	24	TRANSFORMER-500Ω/150Ω		TARC-38
3	C5, C6, C7	23	CAPACITOR, 4.7uf, 35V	KEMET	T3928475M016AS
1	C4	22	.68uf, 100V	ITT-GB	PMT/2R
1	C3	21	.01uf, 200V	SPRAGUE	192P10392
		20			
1	C1	19	CAPACITOR, 100pf, 1KV	CRL	DD-101
1	CR9	18	DIODE		1N823
8	CR1-CR8	17	DIODE		1N4148
1	Q7	16	TRANSISTOR		2N6076
2	Q4, Q6	15			2N5172
1	Q3	14			2N4303
2	Q1, Q2	13	TRANSISTOR		2N3053
1	U14	12	INT CKT	TI	SN7420
1	U12	11			SN7404
1	U11	10			SN7442
3	U8, U9, U10	9			SN7490
		8			
2	U7, U13	7			SN7410
3	U5, U6, U15	6			SN7400
1	U4	5			SN7402
1	U3	4		TI	SN7473
1	U2	3		SIGNETICS	308N
1	U1	2	INT CKT	RCA	1458-3
1		1	BOARD, PC		30-7300

	NAME	DATE	
DRAWN	C. R	5-76	SURFACE SYSTEMS, INC., ST. LOUIS, MISSOURI
CHECK	J. O. Rogers	4/1/77	TITLE ASSY, PC-ENCODER
APPROVAL	Jo Rogers	4/1/77	SIZE C · DRAWING NO. 10-7300 · REV 0 SCALE 2:1 · SHT 1 OF 1

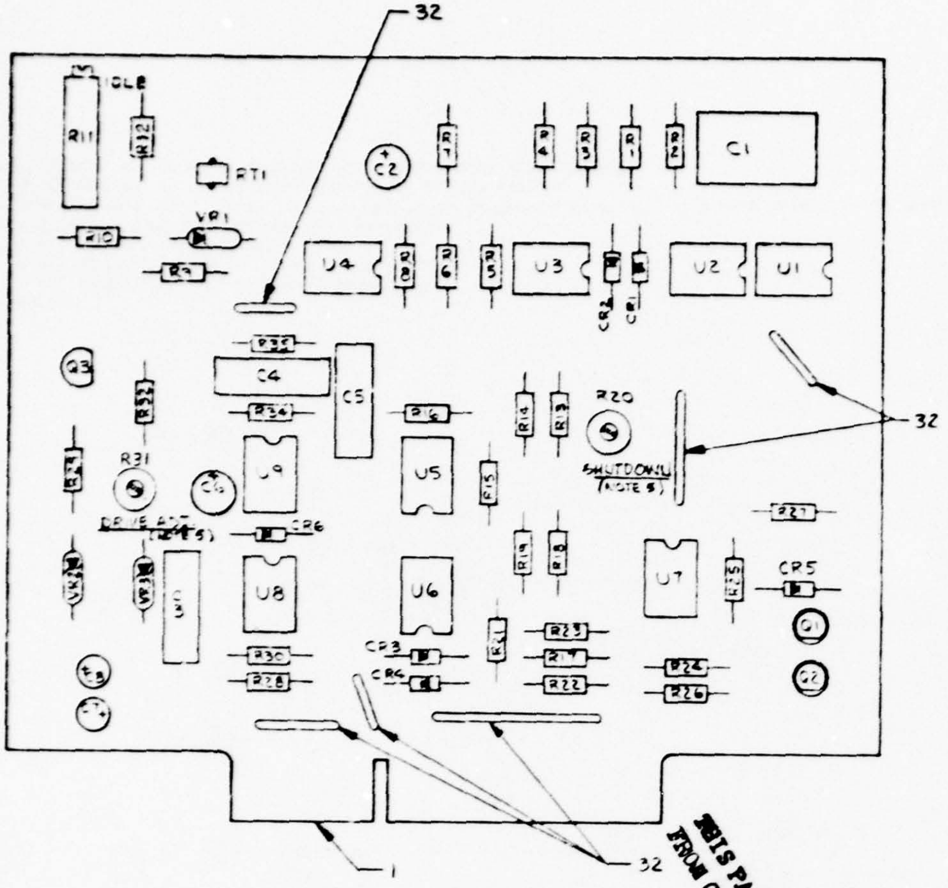
8210031205

NOTES:
1. PIN 1 IDENTIFY BY NOTCH ON IC.
2. COMPONENTS NOT IDENTIFIED BY ITEM NUMBER ON THE ASSEMBLY ARE IDENTIFIED BY REFERENCE DESIGNATIONS IN THE PARTS LIST.
3. REFERENCE DESIGNATIONS ARE FOR REFERENCE ONLY AND ARE NOT MARKED ON PART.
4. FOR SCHEMATIC DIAGRAM, SEE DWG NO. 20-7300.
5. REF DES NOT USED: C2, Q5



NOTES:
1. ALL RESISTORS ARE IN OHMS, ¼ WATT, ±5%
2. ALL CAPACITORS ARE IN MF, ±20%, 16 VOLT.
3. ALL DIODES ARE 1N4148.
4. FOR ASSEMBLY DRAWING SEE 10-7400.
5. * CR4 NORMALLY NOT INSTALLED, WHEN INSTALLED ENABLES WARNING RELAY IN WET MODE
6. REMOVE R6 TO ENABLE WARNING RLY IN HIGH ALERT MODE
7. SHORT R7 TO MAKE WARNING RELAY THRESHOLD ADJUSTABLE

SURFACE SYSTEMS, INC
ST LOUIS, MISSOURI
SCHEMATIC - RELAY DRIVER
ED REYNOLDS
NONE
TOLERANCES
REVISIONS



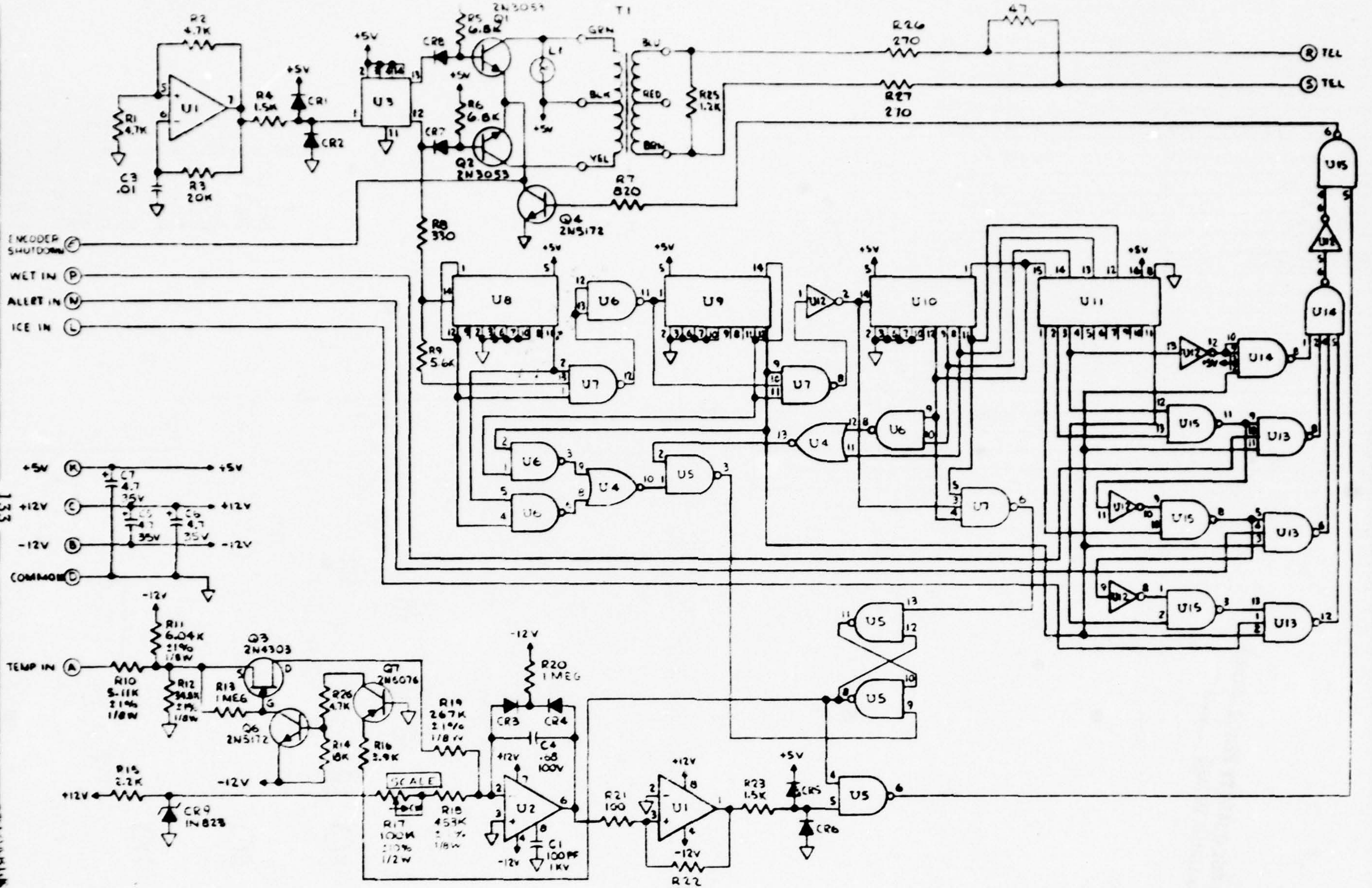
NOTES:
1. PIN 1 IDENTIFIED BY NOTCH ON IC.
2. COMPONENTS NOT IDENTIFIED BY ITEM NUMBERS ON THE ASSEMBLY ARE IDENTIFIED BY REF DESIG IN THE PARTS LIST.
3. REF DESIG ARE FOR REFERENCE ONLY AND ARE NOT MARKED ON THE PART.
4. FOR SCHEMATIC DIAGRAM SEE 20-7500.
5. THESE CONTROLS HAVE BEEN PRESET AT THE FACTORY AND SHOULD NOT BE FIELD ADJUSTED

QTY -1	REF DESIG	ITEM NO.	DESCRIPTION	MANUFACTURER & PART NO.
1	R10	33	RESISTOR, ¼W, 12.1K ±1%	RN55D1212F
AS REQD		32	WIRE, COPPER, SOLID, TIN COATED, INSULATED	22 AWG
1	R20	31	POTENTIOMETER, ½W, 5K ±5%	SPECTROL 62-1-7-502
1	R11	30	POTENTIOMETER, ½W, 2K ±10%	SPECTROL 43W202
1	R34	29	RESISTOR, ¼W, 100K ±5%	
1	R32	28	RESISTOR, ¼W, 1 MEG ±5%	
1	R31	27	POTENTIOMETER, ½W, 10K ±10%	SPECTROL 62-1-1-103
		26		
1	R29	25	RESISTOR, ¼W, 390K ±5%	
1	R28	24	RESISTOR, ¼W, 4.7K ±5%	
2	R26, R35	23	RESISTOR, ¼W, 470 ±5%	
2	R21, R27	22	RESISTOR, ¼W, 2K ±5%	
6	R17, 18, 19, 23, 24, 25	21	RESISTOR, ¼W, 3.9K ±5%	
1	R16	20	RESISTOR, ¼W, 68K ±5%	
3	R15, R22, R9	19	RESISTOR, ¼W, 1K ±5%	
2	R14, R30	18	RESISTOR, ¼W, 15K ±5%	
1	R13	17	RESISTOR, ¼W, 1.1K ±5%	
1	R12	16	RESISTOR, ¼W, 1K ±1%	RN55D1001F
1	R8	15	RESISTOR, ¼W, 48.7K ±1%	RN55C4871F
3	R4, R6, R7	14	RESISTOR, ¼W, 5.11K ±1%	RN55D5111F
4	R1, 2, 3, 5	13	RESISTOR, ¼W, 10K ±1%	RN55D1002F
1	RT1	12	THERMISTOR	FENWAL KB25J1
2	C7, C8	11	CAPACITOR, 2.2MF, ±20%, 16V	KEMET T392A225M016AS
3	C3, C4, C5	10	CAPACITOR, .0051, 500V	SPRAGUE MWC-512
2	C2, C6	9	CAPACITOR, 15MF, ±20%, 16V	KEMET T392C156M016AS
1	C1	8	CAPACITOR, .1 MF	MEPCO C280AH/A100KC4
3	VR1, 2, 3	7	DIODE, ZENER	1N823
6	CR1 THRU CR6	6	DIODE	1N4148
1	Q3	5	TRANSISTOR	2N4303
2	Q1, Q2	4	TRANSISTOR	2N5172
2	U2, U3	3	INT CKT	RCA CA3140E
7	U1, U4 THRU U9	2	INT CKT, 8 PIN DIP	741
1		1	P.C. BOARD	30-7500

SURFACE SYSTEMS INC
ST. LOUIS MISSOURI

ASSEMBLY P.C. -
SENSOR DRIVER/DETECTOR

SCALE 2/1



NOTES

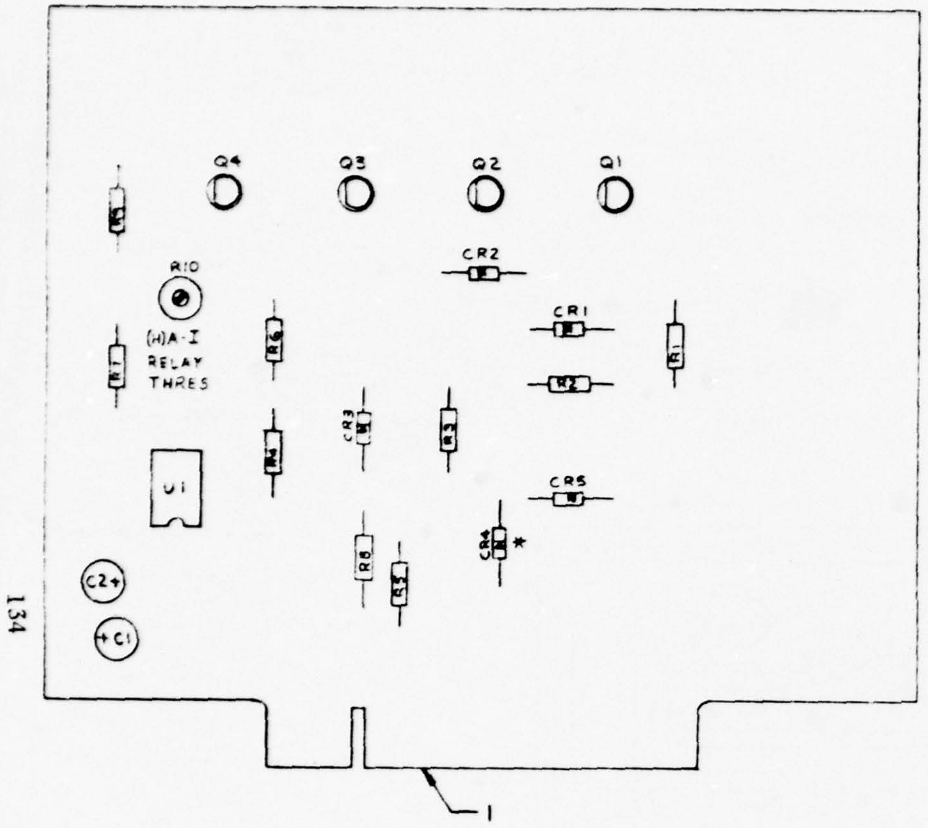
1. UNLESS OTHERWISE SPECIFIED:
   - a. ALL RESISTORS ARE IN OHMS, 1/4W, ±5%
   - b. ALL CAPACITORS ARE IN μF
   - c. ALL DIODES ARE IN4148
   - d. ALL IC PIN 7 COMMON AND PIN 14 +5V EXCEPT FOR U1, U2, U3, U8, U9, U10 AND U11.

2. IC TYPES ARE AS FOLLOWS:

U1-1458-3	U4-7402	U8,U9-5490	U12-7404
U2-309N	U5,U6,U15-7400	U10-7490	U14-7420
U3-7474	U7,U13-7410	U11-7442	

3. REF DES NOT USED C2, CR7, CR11, Q5.
4. FOR ASSY SEE 10-7300.

	NAME	DATE	
DRAWN	SCHALLERT	JUN76	SURFACE SYSTEMS, INC ST. LOUIS, MISSOURI
CHECKED	Rogers	12/21/77	TITLE SCHEMATIC- ENCODER A
APPR'VD	Rogers	12/21/77	SIZE C · DRAWING NO. 20-7300 · REV 0 SCALE — · SHT 1 OF 1



NOTES:
1. PIN 1 IDENTIFIED BY NOTCH ON IC.
2. COMPONENTS NOT IDENTIFIED BY ITEM NUMBERS ON THE ASSEMBLY ARE IDENTIFIED BY REF DESIG IN THE PARTS LIST.
3. REF DESIG ARE FOR REFERENCE ONLY AND ARE NOT MARKED ON PART.
4. FOR SCHEMATIC DIAGRAM SEE 20-7400.
* 5. CR4 NORMALLY REMOVED

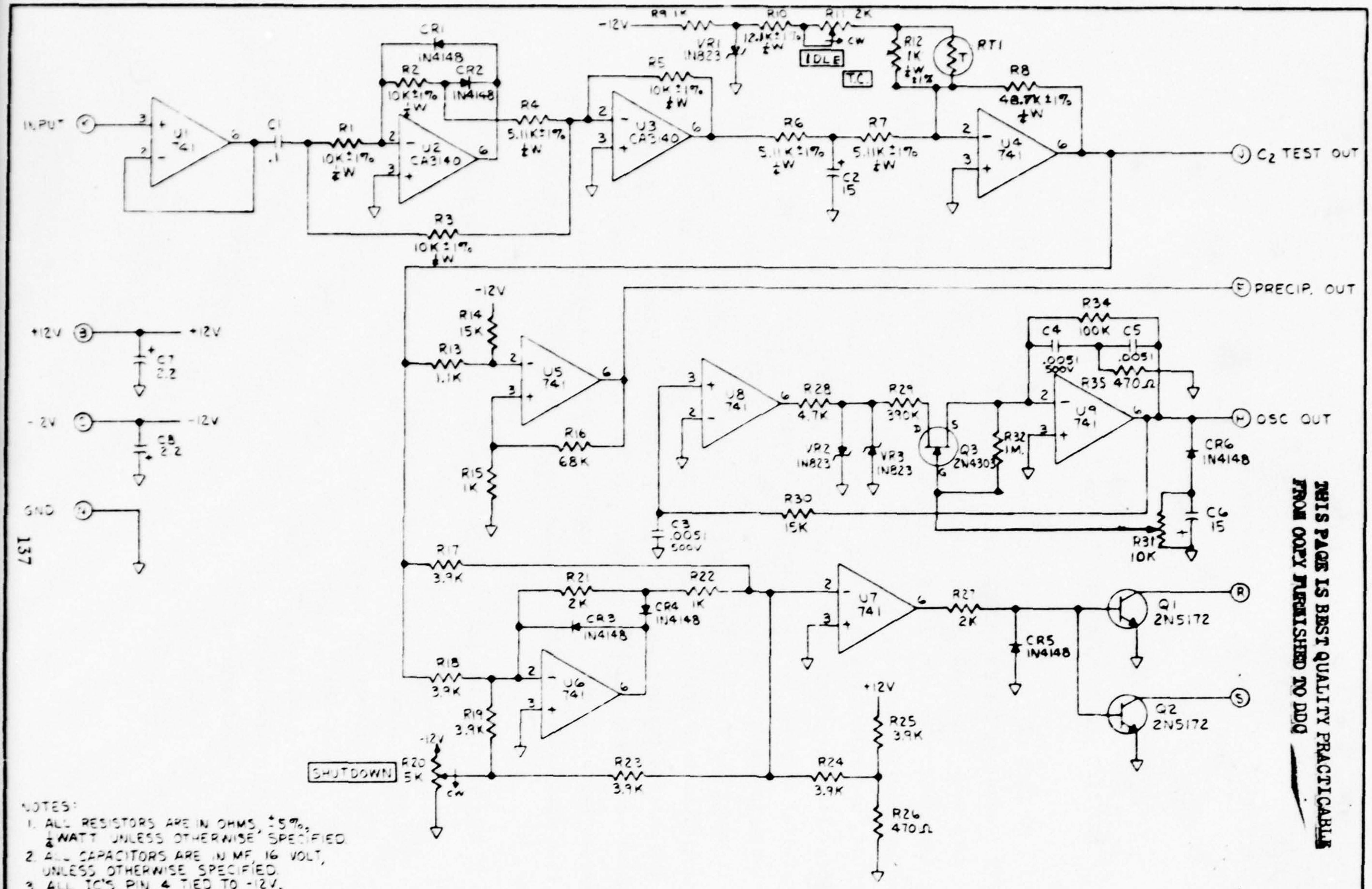
1	R10	10	POTENTIOMETER, 10K, ¾ W	SPECTROL 62-1-1-103
2	R7, R9	9	RESISTOR, ¼ W, 10K ±5%	
1	R5	8	RESISTOR, ¼ W, 2.2K ±5%	
1	R4	7	RESISTOR, ¼ W, 100K ±5%	
5	R1, R2, R3, R6, R8	6	RESISTOR, ¼ W, 4.7K ±5%	
2	C1, C2	5	CAPACITOR, 2.2 MF, 16 VOLT	KEMET T392A225M016AS
4	CR1 THRU CR5	4	DIODE	1N4148
4	Q1 THRU Q4	3	TRANSISTOR	2N5172
1	U1	2	INT CKT, 8 PIN DIP	741
1		1	P.C BOARD	30-7400
QTY -1	REF DESIG	ITEM NO.	DESCRIPTION	MANUFACTURER & PART NO.

TOLERANCES
DECIMAL
FRACTIONAL
ANGULAR
REVISIONS

SURFACE SYSTEMS, INC.
ST. LOUIS, MISSOURI

ASSY, P.C. -RELAY DRIVER

REV. D
10-7400



NOTES:
1. ALL RESISTORS ARE IN OHMS, ±5%, ¼ WATT UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITORS ARE IN MF, 16 VOLT, UNLESS OTHERWISE SPECIFIED.
3. ALL IC'S PIN 4 TIED TO -12V, PIN 7 TIED TO +12V.
4. FOR ASSEMBLY DRAWING SEE 10-7500.

SURFACE SYSTEMS INC
ST. LOUIS, MISSOURI
SCHEMATIC
SENSOR DRIVER/DETECTOR
NONE

APPENDIX B

DETAILED SUMMARIES OF INFORMATION GATHERED DURING SITE VISITS

As part of the effort to evaluate the operational performance of the SCAN system and its potential impact on runway snow and ice control, site visits were conducted to a number of airfields, both where SCAN is and is not installed. The purpose of these site visits was to acquire information on SCAN utilization and performance, snow and ice control procedures and strategies, and associated costs for labor, material and equipment. The following airfields, where SCAN systems are installed, were visited: Anchorage International Airport, Greater Cincinnati Airport, Detroit Metropolitan Airport, Indianapolis International Airport, Kansas City International Airport, Keflavik Naval Air Station (Iceland), Scott Air Force Base (Illinois), and Canadian Forces Base (Trenton, Ontario). Visits were also made to Brunswick Naval Air Station (Maine) and to Buffalo International Airport. Telephone interviews were conducted with personnel at Adak Naval Air Station (Alaska) and Niagara Falls Airport. The information acquired during these interviews, along with paraphrased quotes, are provided in narrative format in this section.

For brevity, the following abbreviations are used in the text:

RW	- runway
SIRC	- snow and ice removal and control
RCR	- runway condition report
MM	- MU-Meter reading
J. B.	- James Brake Decelerometer
specs	- specifications
info	- information
sfc	- surface
SSI	- Surface Systems, Inc.

Anchorage International Airport, Alaska (5 April 1978)

Anchorage International (AIA) has two, parallel, asphalt, ungrooved runways which are perpendicular to prevailing winter winds: RW06R-24L, 10,900 feet; and RW06L-24R, 10,600 feet. Daily air traffic averages about 100 landings per day for aircraft over 6000 lb gross weight with higher traffic occurring in summer months.

The SCAN system was installed at AIA prior to the 1973-1974 winter at a total cost of $12-13K. Two sensors, one at the touchdown point and one near the taxiway exit, are mounted on runway 06R about 50 ft from the center line of the runway. Neither of the two sensors (obsolete square shape) appeared to be flush with the runway surface, and large depressions (see Figure 20b) in the epoxy surrounding the sensors likely compromised their functional operation. (One of the sensors had recently been dislodged by a grader.) Both sensors except for the conductivity probes are covered with a layer of flat-black colored tar. The information from these sensors is relayed through established FAA ground cables to a single monitor located in the maintenance building. A shielded air temperature sensor is mounted about 5 feet off the ground, ∿30 feet from the corner of the Maintenance building.

This particular SCAN system was one of the early units produced by SSI and was essentially a prototype. The system has proven unreliable, inconsistent, and often erroneous, especially for surface freezing conditions. AIA personnel noted that the primary benefits of SCAN are derived from runway surface temperature measurements, but that reliable indications of surface condition would be a welcomed and useful luxury. As at other airports, the runway surface temperature measurements are used to determine the necessity or utility of applying urea. Occasionally, certain ice conditions occur which do not require control measures. According to AIA personnel, "ice at -20°F provides (relatively) very good traction," and hence, "an airport such as Fairbanks which experiences extreme cold doesn't need the SCAN system."

Despite the problems AIA has experienced with SCAN, AIA personnel are sufficiently convinced of its usefulness that they are in the process of procuring a new system with radio telemetry. The main runway (06R) is to be resurfaced during June 1978 and AIA hopes to secure the new system and install the sensors in the runway prior to the resurfacing. It is planned that the sensors be covered and protected from the resurfacing material; after resurfacing is completed, the new surfacing material would be ground down around the SCAN sensor, leaving it in a bowl-shaped depression in the runway.

Field Maintenance at AIA runs SIRC operations and only has to please the airline companies. In SIRC matters, the Field Maintenance Supervisor provides general supervision to a crew of 25 equipment operators and 3 foremen. (In the summer the crew is reduced to 15 operators and 3 foremen.) The 25 man crew is split into 3 staggered shifts (∿5 men plus foreman) for 7 day/week operation. When necessary, extra personnel are called in on overtime at double pay. The youngest foreman has 6 years experience, the oldest has 20 years; the youngest equipment operator has 5 years experience. The foremen make all snow removal decisions.

Urea is the primary chemical used at AIA, although 20,000 gallons of UCAR (@ $5-6/gal) is kept on hand. (They "try not to use UCAR; it is used only when necessary and has not been used during the past two winters." AIA has a 3,000 gallon tanker with a 30 foot spray bar for UCAR.) Urea is bought by the truckload (not in bags) directly from a plant located ∿150 miles away. After snow removal operations, urea is applied for final clean-up to achieve a dry runway; residual urea is then counted on to help during the next snow situation. AIA first experimented with urea in 1968, using 50-60 tons that winter. In the winter (1972-1973) prior to SCAN installation, they used ∿800 tons of urea, however, there were many instances in which it did not work. The next winter, with SCAN providing surface temperature data, they used only 550 tons; @ $145/ton, they attributed a savings of ∿$30K in urea alone to the SCAN system. An application to the main runway (06R-24L) uses ∿3.5 tons, while both runways and taxiways might require as much as 10 tons ($1500).

Sand is occasionally used at AIA and is stored indoors at a temperature of ∿40-50°F. The sand is to FAA specs (all particles < 1/8 inch). However, "if you are heating sand, it means you have ice on the runway which you want it to penetrate; we would rather not have ice in the first place," according to AIA personnel.

AIA has 6 brooms (5 Sicards and 1 Snow Blast B61A), 3 blowers, 6 graders, 3 push dozers, 4 dump trucks (2 for urea and 2 for sand), and 1 tanker for ucar. All equipment is kept indoors, as is both sand and urea. The Sicard brooms use ∿8 gallons of diesel (@ $.35/gallon) per hour, and bristles last ∿125 hours. The brooms are used for ∿1000 hours each winter. In FY77 (July 1976-June 1977), snow removal costs were $1,472,300, plus $848,600 in equipment operating costs (budget was $2,580,000).

The strategy at AIA is to keep runways dry. Weather forecasts for AIA are obtained a minimum of once/shift by telephone from the National Weather Service in downtown Anchorage, but the forecasts are not used for detailed, advance planning. The following anecdote relative to SIRC operations and use of the SCAN system was offered: In the midst of a recent 5 inch snowfall, surface temperature was 31°F and sunshine was expected; so instead of using urea and Sicard brooms at an operational cost of $100/hour, they simply used rubber bladed plows. In addition, the time required to clear the runways was reduced by 40% of that required when brooms are used. According to AIA, "most snow-belt airports have a people problem, not a snow problem. Snow/ice control is much simpler than most people make it."

Runway conditions are quantitatively determined at AIA by a MU-meter and/or a Tapley (a British device apparently similar to the James Brake Decelerometer). A series of comparison measurements at AIA have shown that the two devices agree very well for traction coefficients >30 (actually 0.30); below 30, the Tapley consistently yields slightly higher values. While the MU-Meter appears to be the most widely accepted device for determinations of runway traction coefficient, the Japanese pilots using AIA demand that a Tapley also be used.

During winter months, runways are inspected at least once per shift by the foreman and more frequently as conditions demand. The mu-meter and/or Tapley are used when runway conditions appear to be deteriorating, and RCR's are immediately reported by radio to the tower. An official notification is subsequently submitted to airport security and is processed through the appropriate channels. Based upon these reports, individual airlines make independent decisions concerning usage of AIA runways (except for an SIRC foreman report of nil braking which closes the airport). The current Field Maintenance Supervisor proudly stated that there have been no diversions of aircraft due to runway surface conditions during his tenure at AIA ($\sim$8 years). In fact, Elmandorf Air Force Base, located just to the north of Anchorage, occasionally has to divert aircraft to AIA despite the fact that Elmandorf has more SIRC equipment.

Greater Cincinnati Airport, Kentucky (1 March 1978)

The Greater Cincinnati Airport (GCA) has three grooved runways: RW 18-36, 9500 feet; RW 27L-9R, 7800 feet; and RW 27R-9L, 5500 feet. GCA has two SCAN sensors, one readout station located in the Fire Department's communications office, and a remote alarm buzzer in the Fire Department's wardroom. Data transmission is via radio telemetry. The first sensor (#1) was installed in September 1976; and the second, because they were pleased with performance of the first, was installed in February 1977. One sensor (#2) is imbedded in concrete (see Figure 20c) at the intersection of RW 18-36 and 27L-9R while SCAN 1 is imbedded in asphalt near the touchdown zone of RW18. The remote processing and radio telemetry electronics boxes lay, horizontal in the grass, ∿10-30 feet off the edges of the RW.

The primary ice/snow control strategy at GCA is preventative control, since "anti-icing is much easier and less costly than is de-icing." They anticipate conditions based on Weather Service forecasts and, depending on visually detected icing/snow and/or SCAN readouts (primarily sfc temperature), they initiate control measures.

In the event of ice at temperature < 15°F, heated sand is dispensed from seven trucks, all equipped with front-end plows and sand spreaders. The sand is kept in a heated building (heating coils in the floor provide a temperature of ∿95°F at the bottom of the sandpile) with a capacity for 500 tons. The sand is mixed with UCAR before dispensing by spraying ∿50 gallons of UCAR over each truck load.

The only chemical used at GCA is liquid UCAR, and it is applied (and then brushed away) only at temperature >15°F. A typical application on one RW requires ∿1000 gallons of UCAR (@ $2.60/gal). In the case of sub-freezing temperatures (both air and surface) and a forecast for freezing rain (apparently a common occurrence there), the procedure is to put UCAR on the RW to prevent ice from bonding to the surface. Later, additional chemical is used as needed to break up accumulated ice. Snow is simply broomed off the RW. (GCA apparently does not experience the type of frost observed at Keflavik.) Obviously the SCAN sfc temperature data provide considerable guidance, and "cost savings are realized by reducing the number of UCAR applications to only those beneficial times" as a result of SCAN. Runway inspections are normally made three times daily -- at dawn, at noon and at dusk. If a HAZARD warning is indicated, an inspection is immediately initiated. (Occasional false HAZARD warnings are experienced. Inspection of sensors, in this case, usually reveals a thin layer of frost or ice. To restore sensor reading to normal, they use a little warm water and dry with a rag. False alarms are apparently not a major problem.)

When snowfall rates are <1 inch/hour, snow and ice control at GCA is normally accomplished between flights; therefore, airport operations are not significantly affected by control operations. It is claimed that "3 Snow Blasters in tandem can clear the 5500 foot RW in 20 minutes"; and that they "can clear 2-6 inches of snow from the 9500 foot RW in 45 minutes."

Traction measurements, per se, are not made at GCA, although some thought has been given to acquiring a device. Since these devices are relatively new and most commercial pilots are unfamiliar with the meaning of the data, GCA is waiting until this type of measurement gains general acceptance and until the best of the traction measuring devices is proven. At present, they use pilot reports and update reported conditions as necessary.

GCA has only one field maintenance crew (13 personnel) who are subject to call any time and may work many hours overtime until the RW situation is stabilized. The crew members are fed overtime meals and are required to keep time slips which detail daily activities (including both regular and overtime hours for snow removal operations). The cost of labor for snow removal in calendar 1976 was $12,474. (Actual overtime hours are not known but are estimated to account for ∿70% of the labor costs.) For the first half of calendar 1977, snow removal labor amounted to $27,382. In November-December 1977, 592 overtime hours and an estimated 250 regular time hours were accrued during snow removal operations, for a total calendar 1977 labor cost of $35,500. Costs of materials, overtime meals and contracted services for snow removal and ice control in calendar years 1976 and 1977 amounted to $18,859 and $64,555, respectively.

The Field Maintenance Department operates a fleet of specialty vehicles and equipment as follows:

> 4 Snow Blasters Type B-16A (a combination front-end broom and air blast), 2 blowers, 1 Sicard (towed) broom, 7 trucks equipped with front-end plows and rear spreader boxes (sand), and 1 Tank truck with 2300 gallon capacity and a 30 foot spray bar for spreading UCAR.

During the early morning hours prior to the site visit and interview, the Cincinnati area experienced a light snowfall (∿1/2 inch). Circumstances, therefore, provided an opportunity to witness snow removal operations and the performance of the SCAN system. The following SCAN data were recorded during the period of observation:

TIME	SCAN Sensor	Air Temperature	SFC Temperature	Condition
0910	#1	22F	26F	HAZARD
	2	22	24	HAZARD
0922	1	22	26	HAZARD
	2	22	26	HAZARD
0950	1	24	28	HAZARD
	2	24	28	HAZARD

Brooming began at ∿0830 EST. At 0923, I was invited to inspect the runways and SCAN sensor heads. I took several photos of the brooming operation (between 0930 and 0945). I witnessed the Snow Blasters in staggered-tandem completely clearing, in one pass, a swath equal to ∿2/5 the runway width (see Figure 18). They really did a superb job, and I am certain that RW traction was nearly MM (60/60/60). However, each of the SCAN sensors was covered with residual amounts of snow (see Figure 21) and thus were still reading HAZARD but now (at 0950) incorrectly in terms of general RW conditions. I also took close-up photos of the sensor heads. (The head which has the tar-fill around it is #2 (Figure 20c), imbedded in concrete at the intersection of RW36 and 9R).

Personnel at GCA are pleased with the SCAN system, "especially the sfc temperature measurement." It provides guidance, and they are certain that "it has saved many applications of chemicals this winter" (∿8) that otherwise would have been needlessly wasted. However, "it is only a tool and should be viewed as such."

Detroit Metropolitan Airport, Michigan (6 March 1978)

Snow and ice control at Detroit Metropolitan Airport (DMA) is the responsibility of the Maintenance Department, but requests for control operations, runway inspections, the SCAN system, and Tower liaison are handled by the Operations Department. DMA has four runways (21R-03L, 10,500 feet; 21C-03C, 8,500 feet; 21L-03R, 10,000 feet; and 09-27, 8,700 feet) and one SCAN sensor located ∿35 feet off the centerline of RW21R-03L, near the midpoint of the runway length. The SCAN signal is fed to the read-out station in the Operations Office via underground cable (3,000 feet) encased in conduit. (Only a short portion is direct-buried.) DMA purchased the SCAN system in 1974 on a "trial basis," and SSI replaced the old sensor free of charge in the Fall of 1976, ostensibly to provide a more representative radiation color. They had a lot of false-alarm problems with the old sensor but have had only one incident that DMA personnel remember with the new sensor (reading WET when it should have been CLEAR). The SCAN sensor is imbedded in concrete (see Figure 20d), where the runway is grooved in the cross-RW direction. They plan to eventually purchase two additional sensors (for the approach ends of RW21R-03L), and they are currently looking into radio telemetry.

The SCAN system was originally bought to be "calibrated for local conditions and to thereby increase the lead time" in advance of icing conditions. The readout is in an office where it could be monitored on a 24-hour, 3 shift basis nearly constantly. In bad weather, they monitor the system constantly keeping track of trends in sfc and air temperature as well as RW conditions in order to implement control measures. (They also employ a private weather service to provide forecasts of potential icing conditions and surface temperature.) DMA thinks "it is a fairly valuable instrument" and they obviously think they make use of the RW condition readouts.

UCAR is the ice control chemical used at DMA. They use a 3000 gallon tanker, and for ice conditions >1/8-1/4 inch, they might use all of it on one RW (@ $2.55/gallon). They pretty-much use manufacturer's recommendations for UCAR application rates (a function of condition, ice depth and temperature) and have installed a metering device on the tank truck to help adhere to manufacturer's specs. In addition, they use sand as a "last resort, if it is snowing and nil braking conditions are reported." They use dry sand (previously heated) which must meet FAA and Airline specs. for grain size. They have indoor storage facilities for the sand, with a capacity of 2,600 tons.

Runways are inspected once/shift, 3 shifts/day during good weather and as frequently as every 15-20 minutes during storm conditions. During suspected low traction conditions, they use a MU-Meter (they have two). The MM is run by the Operations Department, and the data (averaged over respective thirds of the RW) are transmitted to the Tower and to a radio service which broadcasts pilot weather information. The MM data are used to gauge RW ice control progress; if MM is in low 20's, they continue control operations; if 35 or greater, they feel traction is good and they cease control measures. When a pilot calls in nil-braking conditions, the RW is closed; if inspection of the RW indicates MM 30, then they reopen. They run the MM at any speed, but usually try for 35 mph, and claim that "it is more accurate than the James Brake device".

The weather at DMA during Winter 1977-1978 "hasn't been warmer than 32F in a long time, and thus they haven't really needed the SCAN system this Winter". DMA apparently "gets a lot of freezing rain, but not this Winter." They strive to complete all clearing operations within 1.5 hours, but do not always make it. They can clear a RW in 20 minutes, but RW access and taxiways take much more time. "On the average, it takes 1.5-2 hours to remove 2 inches of dry powdery snow; longer if wet snow."

DMA has 32 maintenance personnel but finds it difficult to "muster 19 to break into shifts for long-duration, snow control operations." They "feed'em and sleep'em on the job". Personnel are paid straight-thru meal times, rather than reimbursed for meal costs.

Total snow-removal/ice-control costs for FY77 (1 December 1976-30 November 1977) were $189,000, including $90,000 for contracted snow removal on aprons, but not including equipment costs. For runway snow and ice control, DMA employs 5 plows, 4 blowers, 3 brooms, 2 spreaders, and 1 tanker.

Indianapolis International Airport, Indiana (16 February 1978)

Indianapolis International (IIA) was one of the first purchasers of the SCAN system. The original unit was essentially a prototype and has been modified extensively by SSI at no charge. Due to their involvement in the development of the device, personnel at IIA are familiar with its operation and apparently rely heavily on it for decision-making concerning snow and ice control operations. IIA personnel estimated that ∿$100K has been saved as a result of the use of the device and apparently were instrumental in convincing the Naval Air Station at Keflavik, Iceland, of the need for such a device.

IIA has two 10,000 ft commercial runways and one 3,500 ft runway for private aircraft. Its 250 flight operations per day classify it as a medium hub airport. The one SCAN sensor at IIA is installed in that part of the RW which typically experiences the worst icing conditions. Since IAA was essentially a development site for SCAN, the system was quite unreliable during the first two winter seasons. After modification by SSI, it has performed well, requiring only routine periodic calibrations.

While IAA could supply no records to support claims of such dramatic savings because of the SCAN system, a specific snow storm was described in which the RW temperature never dropped below freezing. Since it was known that the snow would not bond to the warm runway, no chemicals were applied and the brooms readily removed the snow. The cost of applying urea to one RW was estimated to be $2700. Apparently, air temperatures do not have to be greater than freezing for RW surface temperatures to be above freezing. On the day of the visit, the sky was heavily overcast and the temperature was 24°F, while a RW surface temperature of 34°F (SCAN reading) was observed.

Indianapolis uses both urea (a granulated solid) and UCAR (a liquid) to combat snow and ice. For RW surface temperatures greater than 15°F, the urea is used; while UCAR is used for RW surface temperatures less than 15°F and for anti-icing operations. The urea is spread by a sander much like we commonly see on the highways around Buffalo. A 10,000 gallon tank truck with special extended booms is used to lay the UCAR over the entire RW in only one pass. Mr. Powers stated that urea usage had dropped from 300-350 tons/year before the SCAN system to about 200 tons/year and, likewise, UCAR purchases had dropped from 15-20 thousand gallons/year to about 12,000 gallons/year after installation of the SCAN system. Only a minimal amount of sand is used on the RWs since it can be extremely harmful to jet engines.

SIRC personnel at IIA are devout proponents of the SCAN system. They argued that, even in the absence of possible monetary savings, the system was worth the investment price because of the increased safety which resulted from the additional information provided by the SCAN system.

Kansas City International Airport, Kansas (2 March 1978)

Kansas City International (KCIA) has two runways (19-01 and 09-27) and 3 SCAN sensors installed in the main runway, RW 19-01. The SCAN sensors are currently inoperative (and I gather they have been for a large fraction of the time since installation 3-4 years ago) due to rodent problems with their buried-cable data-links. Snow/ice control (and the SCAN system) is the responsibility of the Field Maintenance Department.

At KCIA, both urea and UCAR, as well as "heated" sand, are used for runway ice control; salt and $CaCl_2$ are used on road- and walkways. With respect to usage of urea vs. UCAR, the more expensive UCAR is reserved for runways and urea is used on taxiways. Urea is not used at temperatures $<15°F$; but they have no temperature minimums for UCAR. Urea is used primarily in clean-up operations after runway plowing for snow removal and during periods of repeated freeze-thaw cycle.

KCIA personnel are concerned about the expense of UCAR applications ($\sim$1000 gal per runway @ $2.80/gal) and, hence, use it sparingly. Since the runways are grooved, it runs in the grooves and is wasted. With rain, it becomes diluted quickly and runs off. Thus, in freezing rain situations, they usually allow a crust to develop before applying UCAR.

In the situation of deep snow, they just keep plowing -- "it is just a waste of chemicals to apply them" in that situation. After snow has stopped and plowing has been completed, they apply "heated" sand, occasionally mixing urea with it. The sand is heated (hot) when it is delivered by the contractor, but it is stored outdoors. They still call it "heated" sand. Chemicals are also stored outdoors.

During periods of bad weather, the runways are inspected at least every hour. They use a MU-Meter (and a James Brake Decelerometer when the MU-Meter is inoperative) for these inspections and report the data to the Tower for dissemination. The information, however, is not used by the Maintenance Department to gauge control progress. Cessation of ice/snow control operations is based on visual inspection and inspector's judgement.

The following data for snow and ice control expenditures for the past four fiscal years (1 May-30 April) were provided:

SNOW/ICE CONTROL EXPENSES

	Total Labor $	Total Labor Hours	(Sand, Chem.) Materials	Contract Snow Removal
3/4 FY 77-78 (thru Jan. 1978)	$12,937	1843.2	$17,012	$9,000
FY '76-77	24,475	3512.5	31,755	0
FY 75-76	15,111	2377.8	16,482	0
FY 74-75	27,016	4483.5	37,419	0

These figures are limited exclusively to control operations for runways and taxiways. As of December 1977, the Maintenance Department had 48 full-time employees; 13 of which are clerical and supervisory personnel. The remaining 35 are divided into 2 12-hour shifts for snow removal operations. It was estimated that ∿50% of the labor costs are overtime.

Vehicles used for snow/ice control at KCIA include: 11 plows, 6 brooms, 5 blowers and one tanker. Total depreciation on all runway-involved vehicles in FY 76-77 was $76,518. (Two sweepers are now fully depreciated; Sicard brooms are depreciated over eight years; snow plows over ten years.) Vehicle fuel costs for FY 76-77 were as follows: $53,000 (119,140 gal) regular gas; $2,926 (5,650 gal) Diesel; and $760 propane.

As indicated, KCIA has had a lot of trouble (mostly cable problems) with the SCAN system, but "when it works, it works well." They remarked that "the major benefit of the SCAN system is its sfc temperature measurement." Operations personnel generally know what RW conditions are, but sfc temperature in conjunction with weather forecasts allows some measure of planning/strategy. KCIA personnel said that the SCAN system "is a good tool, but only a tool", adding that "it will be nearly impossible to make much sense of economics data (for KCIA) because of differing control strategies depending on personnel mood and storm characteristics." Apparently, they are very reluctant to apply chemicals (UCAR) for economic reasons. The sensors "have been especially useful in determining the need for chemicals, but as yet there have been no identifiable savings in ice control costs."

KCIA is planning to purchase a radio telemetry link for the approach zone of RW19-01 later in 1978 at a cost of ∿$6K (including a new sfc sensor). Eventually, they will replace all three sensors on RW19-01 and add one to RW27-09.

Keflavik Naval Air Station, Iceland (21 February-10 March 1978)

Snow and ice control (and the SCAN system) at the U.S. Naval Air Station, Keflavik (USNASKEF) is the responsibility of the Fire Department under administration from the Air Operations Officer. These duties were transferred to the Fire Department in September 1975 and consist of inspection and maintenance to insure safe braking conditions on all aircraft-used pavements. (Routine runway inspection duties were added at the request and expense of the U.S. Air Force 57th TIS.) Prior to the Fire Department's current role snow removal was handled by the equivalent of the Base Motor Pool and consisted primarily of brooming and plowing, with apparently not-very-satisfactory results. Absolutely no chemicals were used, while sand was the primary agent used in ice control. Now, chemicals are used extensively and the runways are routinely inspected (Runway Inspection Officer) four times daily and constantly during times of alert. These inspections assist personnel of Snow and Ice Removal and Control (SIRC) Operations, headed by the "Snow King," in determining a course (or continuation) of action. All the Fire Department personnel are civilian Icelanders; they work a 24 hour shift and then get two days off (except for supervisory personnel).

The Chief of the Fire Department is responsible for the current, successful SIRC strategy employed at USNASKEF. When assigned the responsibility for snow and ice control, he apparently attended snow-control symposia and reviewed the literature on state-of-the-art control measures before designing and implementing his own control strategy. He implemented the use of urea and was largely responsible for acquisition of the SCAN system. He and personnel of the Fire Department are dedicated, beyond words, to the responsibility entrusted to them. There is no doubt that the quality of runway traction management now enjoyed at USNASKEF is largely due to this dedication and the ability and desire of Fire Department personnel to learn from their experiences.

The airfield at USNASKEF is comprised of two main runways (03-21, 10,000 ft; and 12-30, 10,015 ft) and two short runways (07-25, 6,885 ft; and 34-16, 5,750 ft). The SCAN system installed at USNASKEF consists of four runway surface sensors located respectively at the approach ends of the two main runways, two readout stations (at the Fire Department Communications Center and at SIRC Operations Building) and two air temperature sensors located on the roofs of the respective readout-station buildings. Personnel at the Fire Department Communications Center constantly monitor the SCAN readouts (one monitor which cycles through the outputs from the four sensors) and alert the runway inspector when WET, ALERT or HAZARD conditions occur. In the event of these conditions, the inspector makes a visual and traction measurement inspection of all runway surfaces. In the case of obviously dry conditions (false alarms or early warning), they simply use braking ability of a pickup truck (qualitative) to measure runway traction. If ice/frost/snow is suspected, a MU-Meter is used (towed behind truck) to give "quantitative" runway condition readings (RCR) in terms of MU-Meter (MM) data. The relationship between MU-Meter traction coefficients and equivalent RCR values is shown below.

Traction Coefficient vs. RCR

MU-Meter Value	Tapley Value	Equivalent RCR	Braking Action
≥0.40	≥66	≥20	Good
0.39-0.36	54-63	16-19	Good-Fair
0.35-0.30	36-51	10-15	Fair
0.29-0.26	25-32	6-9	Fair-Poor
≤ 0.25	≤ 22	≤ 5	Poor

We had many opportunities to accompany the Runway Inspector (and made it a point to do so) to visually inspect the runways, to observe the measurement-acquisition and reporting procedures, and to inspect the MU-Meter strip chart records. In order to provide the most reliable data (relative to correlation with actual aircraft-experienced traction) the MM must be towed at 40 mph. The data are recorded on a strip chart (where ∿4 inches = ∿2 miles, giving a resolution of ∿50-100 ft), and the driver has an electronic interpreter (computer) which allows him to average readings over any desired distance. These averages are typically computed (and reported) for each third of the runway length. Obviously, a lot of information is lost in the averaging; but the data are recorded in much greater detail and could be reported as such. In the event of reduced traction (< 40; actually 0.4 MM reading) due to ice/snow/frost, the averages are obtained over shorter distances (4-6 times/runway, weaving down the centerline) and occasionally twice along the runway. F-4 Interceptor flights are cancelled in conditions of < 30 (0.3); bone-dry pavement usually registers ∿60 (0.6).

Urea is used sparingly (for financial reasons @ ∿$13/100 lb bag) at USNASKEF and only when necessary to melt hardened ice. As at Buffalo, it is not as effective in high winds (typical at USNASKEF) or temperatures lower than ∿20°F. (Here, the SCAN temperature data apparently provide considerable guidance.) As a general rule, they do not de-ice, either as a matter of strategy or as a result of a lack of weather situations which lend themselves to de-icing. However, we observed urea (applied to the Hi-Speed taxiway prior to our arrival) to provide continued melting action during the night (on snow melt which daily runs across that area and would freeze at night) at least through the initial six days of the visit.

It appears that SCAN data are used as back-up or additional input to visual inspection of runway surfaces at Keflavik. (After "a lot of initial trouble" with false alarms and erronous indications, they have apparently adjusted the electronics to compensate for most of these problems.) For stable (i.e., unchanging) weather conditions, whether blowing snow or clear skies with high frost potential, routine runway inspections suffice; however, a pilot braking report or a SCAN indication of reduced traction would initiate an immediate runway inspection. Once icing or snow conditions are recognized, SCAN surface indications are no longer monitored. If runway traction has deteriorated below acceptable limits, then SCAN surface temperature information is used to determine a course of action, i.e., the application of urea, brooming, etc.

Discussions of the cost effectiveness of SCAN with SIRC personnel resulted in the impression that savings are not as great as the initial correspondence from Keflavik suggested. USNASKEF has 3 sanders, 5 brooms, 7 plows, 3 blowers and one loader and an AIRC crew of ~13 plus supervisors. Annual maintenance and crew salaries were $142K and $146K, respectively, in FY76; $99K and $200K, respectively, in FY77. Urea usage was 68 tons ($17K) in FY76 and 140 tons ($36K) in FY77.

While an abundance of data and records have been secured, it appears that conclusive determinations of the influence of SCAN on SIRC costs will be difficult due to variation of a number of factors since SCAN installation (change in SIRC personnel and procedures, reliance on mu-meters, use of urea, and variations in weather). For example, the annual (calendar year) arresting gear usage by the F-4's of the Air Force 57th Tactical Interceptor Squadron (TIS) was as follows:

1975	125 arrests	Without SCAN
1976	178 arrests	Without SCAN
1977	138 arrests	With SCAN
1978 (to 27 Feb.)	94 arrests	With SCAN

"Weather was so bad in 1975 that frequently planes could not get off ground and may have contributed to a low number of arrests."

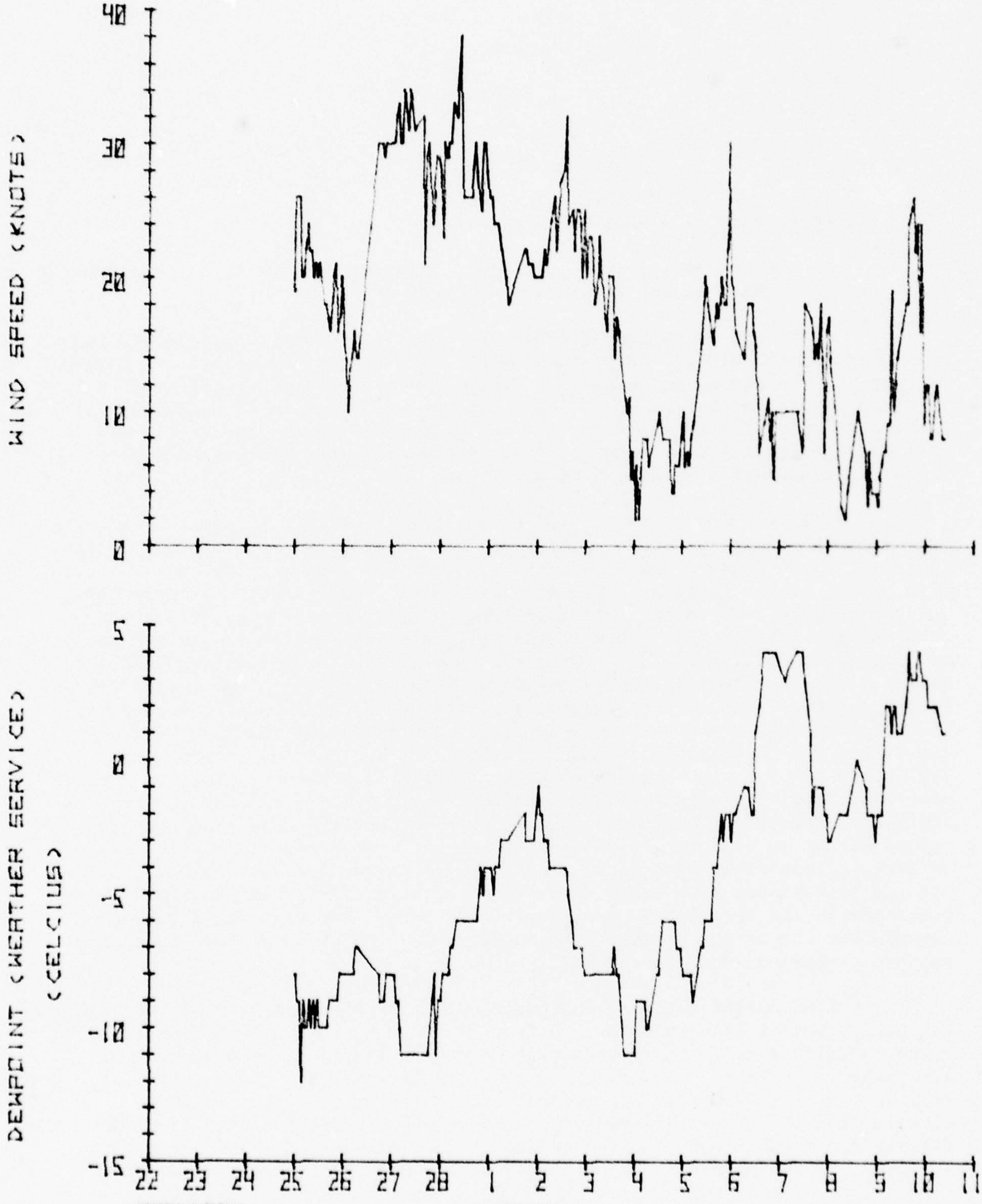
The SCAN system at USNASKEF was installed in September 1976 and originally contained the electronics for water depth sensing. Apparently, sensor configuration and adjustments in the electronics to enable water depth sensing compromised the ice detection capabilities of the sensors; therefore, the water depth measurement capability was removed from the system. The SCAN system was inoperative for the periods June-September 1977 and 5 December-10 January 1978, apparently due to radio telemetry problems.

Maintenance personnel were particularly critical of the present radio telemetry system. Early electronic problems with SCAN included: poor antennas which shorted out from weathering; frequent transmitter failure because of poor protection when antenna is disconnected; not well-defined frequency for each channel resulting in overlap and frequent incorrect indications by the system; and, insufficient output power of transmitters. A new telemetry system was recently furnished by SSI at no cost to the Navy and should alleviate the telemetry problems. The electronics maintenance group at Keflavik make monthly inspections and temperature calibrations of the SCAN system. The system apparently has sufficient electronic drift to require that such maintenance be routine.

In the view of Air Force personnel, "performance by the Fire Department was not nearly as good this year (Winter 1977-1978) as in previous years. Two years ago they (the Fire Department) had 16 people and worked until conditions were clear. Since they went to a 3-shift basis, there are not enough people at any given time." The F-4's won't take-off with RCR $<$ 9 (MM $<$ 30) but must land under any condition. If ice or hydroplaning is anticipated, they use arresting gear. (The gear have only failed once in three years.) TIS personnel would spread urea daily and not worry about cost. The TIS would like to see SCAN sensors all over the airport to help observe the spatial variability of ice. A 200 foot long swath of 10 foot diameter ice patches on the center third of the runway length would represent an unacceptable (critical) condition.

Fire department personnel stressed the safety aspects (as opposed to economic factors) in better traction control and said that the name of the game in ice/snow control is "preventative control". This was only the second winter's operation with the SCAN system, and they had a lot of trouble (of their own making) during Winter 1976-1977 because they tried to adjust out of system the occasional false alerts. According to the Chief, this "caused a lot of people to lose faith in the system," but not him. They had recent trouble (October-November-December 1977) with the transmitter/receiver components, but since ∼10 January 1978 the system has been "letter perfect". The Chief thinks "every airport should have one."

One final word about the hospitality and help extended to us by everyone with whom we came in contact at USNASKEF. In particular, the Fire Department and Naval Weather Service (NWS) must be credited in this regard. Our NWS contact cut corners and red tape in a number of areas that made our performance on this visit possible. The Runway Inspector was "assigned" to us, and he provided assistance and answers in every area we discussed. He is uncommonly knowledgeable and dedicated. The Fire Chief provided many insights into the problems of ice control and access to people and records which would have been otherwise difficult to obtain.



DEWPOINT AND WIND RECORDS--NAVAL WEATHER SERVICE
KEFLAVIK NAS--25 FEBRUARY-10 MARCH 1978

Scott Air Force Base, Illinois (7 April 1978)

At the request of base personnel, a representative of SSI was present for a large fraction of our interviews at Scott AFB.

Scott Air Force Base (SAFB) has one main (7040 ft) non-grooved runway (oriented 013-310), a large portion of which is covered with a new Porous Friction Course paving material (see Figure 20a). The primary air traffic consists of Air Force T-39's and C-9's, with a wide variety of transient aircraft also using the runways. Of the two primary aircraft, the T-39's are most critical of RCR since they have no reverse thrust capability and many do not have anti-skid braking systems.

SCAN was installed at SAFB in the Fall of 1976. The system transmits data from the sensors to the monitors via buried cables. Initial cost of the unit with three sensors was $32K with an additional $31K required for installation of the buried cable by a private contractor. Each sensor is currently located about 8 ft from the center of the runway; the sensor positions have been changed twice by SSI. Due to the accidental cutting of the buried cable by a civilian contractor, the system was inoperative for the entire 1976/1977 winter. The cable was spliced, and the unit was operational for the 1977/1978 winter; however, two of the three sensors frequently gave erroneous readings of both temperature and surface condition. The erroneous readings were apparently due to moisture in the buried cable. In addition, there was a systematic problem with surface condition indications which appears to have been minimized with adjustments to the SCAN logic by SSI personnel. The impression relayed by SAFB personnel is that the surface condition indications are still not of acceptable quality. The system being inoperative for the entirety of the first winter and frequently giving erroneous readings throughout the last winter have drastically reduced the confidence of most base personnel in the usefulness of the unit; although, they do have confidence in and make use of the surface temperature data. Maintenance for the system has been supplied, courtesy of SSI.

SIRC operations, and equipment, are the responsibility of the Civil Engineers group in the Pavement and Grounds Department at SAFB. General Air Force guidelines defining responsibilities and priorities for snow control are followed at SAFB. Snow control crews are divided into three shifts of ~11 men each for 24 hr/day operations; the 7:30 a.m.-4:00 p.m. shift is civilian and the others are military. "Best results are achieved from the military personnel" but that may be due to the lessening of aircraft traffic at night. Base Operations is concerned with runway surface condition and thus is responsible for operation of a James Brake device and dissemination of RCR data.

The mission requirements at SAFB are very limited and primarily involve training, medical and VIP transport support; hence they have little nighttime traffic and minimal alert status. As a result, their snow/ice control strategy is very casual, a prime deadline being ∿0630 when aircraft departures usually begin. During nighttime snowfalls, they simply plow and broom and then, depending on surface temperature (SCAN), apply urea. They only plow the middle 50 ft of the 150 ft wide runways because of the type of aircraft served there; plowing is accomplished in two 12 ft swaths on either side of the runway centerline. Surface temperature from SCAN is used to determine the best time for applying urea in time for the 0630 aircraft operations.

The following anecdote was offered as an example of their strategy and how SCAN would have helped had they more experience with it: "During late winter this year, with a cold runway surface, SAFB was experiencing sleet and rain until ∿2100 when the air cooled and snow began. They continued plowing and broom operations all night, but by morning RCR's were still bad. Had they anti-iced, the situation may have been better handled." Because of mission requirements and casual ice control strategy, SAFB personnel said the "SCAN system is not economically feasibile at SAFB."

Urea is the only chemical used at SAFB: sand is used only on roadways, but the same trucks are used for urea and sand and occasionally residual sand may get on the runways. A September 1976 SIRC Op. Plan suggests that 750 bags of urea are required annually, however, ∿2000 bags (100 lb/bag) of urea were used in the winter of 76-77 and ∿3000 bags (@ $6/bag) were used in the winter of 77-78; no data are available for previous years. Base personnel thought that no appreciable savings in urea had been realized as a result of SCAN. For 1 October 1977 to 28 February 1978, snow/ice control costs were quoted at $148K.

Probably because of their low-traffic and minimal SIRC requirements, SAFB has only a limited complement of ice/snow control equipment. They have 2 Airblast sweepers, 4 rollover plows, 2 graders, 2 blowers, 2 loaders and 1 urea-sand truck (with an additional truck on order).

Base Operations uses a James Brake Decelerometer to measure runway traction for field condition reports and to guide SIRC operations. RCR's are measured every 1000 ft within 25 ft of and on both sides of the RW centerline. During precipitation weather, they use SCAN surface temperature as a guide for use of the J.B. device (i.e., when surface temperature drops below 33°F). RCR's are also used to guide SIRC operations. They also use the alarm and hazard signals of the SCAN system because "it (the SCAN system) assists in assuring that they have up-to-the-minute runway condition reports."

The Air Force bought and installed the SCAN system at Scott to evaluate it for the Military Airlift Command. Due to the discontinuous operation of the unit (a point which will undoubtedly influence the conclusions of the evaluation), the unit will not receive as thorough evaluation as was planned. Apparently, their report will make the following conclusions: (1) SCAN provides unique measurements (if somewhat unreliable and frequently erroneous) of runway surface conditions and runway surface temperature; (2) data supplied by SCAN may be a useful aid in planning SIRC operations and the application of urea; (3) the mild winters and light air traffic (most of which are not urgent and can be delayed) at SAFB combine to minimize the economic feasibility and functional usefulness of SCAN at SAFB; and, (4) it is likely that some Air Force bases further north of SAFB would benefit sufficiently from SCAN to justify its acquisition.

* * *

Lambert Field (the major St. Louis airport) is now attempting to acquire federal funding to buy a SCAN unit. While agreeing that the system was not necessary at SAFB, the SSI representative was adamant in his contention that SCAN would be useful at Lambert Field (9th busiest U.S. airport following Pittsburgh). He suggested that heavy air traffic at Lambert Field differentiates it from SAFB and increases the potential usefulness of SCAN in optimizing SIRC operations and minimizing down time of Lambert Field runways. He also stressed the enhanced anti-icing capabilities resulting from SCAN data. (Pittsburgh and O'Hare are also in the process of obtaining SCAN systems.) Despite the rather casual approach to SIRC at SAFB, it was claimed that Lambert occasionally has to divert traffic to SAFB due to runway ice at Lambert.

Canadian Forces Base, Trenton, Ontario (29 March 1978)

The Canadian Forces Base-Trenton (CFBT) has one main 10,000 ft asphalt, nongrooved, crowned RW (06-24) and one 3,000 ft cross RW (13-31). CFBT has three SCAN sensors and two readout stations; one in the tower and one in the weather station. The air temp sensor is located ∿3 ft off the ground near the RW site of one of the sfc condition sensors, and the data are fed to the readout stations via underground cables. The present sensors are located 6 ft from the edge of the RW and hence are in an area not thoroughly cleaned during ice/snow control operations. The SCAN system was originally purchased in 1975 on a "trial basis," but sensor installation was delayed until November 1977. The system CFBT purchased in 1975 is the original version which has since been modified three times (and the water depth electronics removed) by the manufacturer as he upgraded the system.

At CFBT, RW condition is under the control of the Tower, and snow/ice control is handled by Base Transportation. A senior NCO supervises equipment operators and two Snow Clearing Foremen. The two foremen work 12 hour shifts, as necessary, throughout snow/ice control operations. When bad weather is forecast, the Tower and foreman are alerted; when precipitation begins, the Tower alerts the foreman who then inspects the RW and initiates appropriate action.

The Special Purpose Vehicles Division of Base Transportation employs 28 equipment operators (60% civilian) who are divided into two 14-man, 8-hour shifts; shifts are extended to 12 hours for continuous operations as needed. Continuous 12-hour shifts occurred the Winter 1977-1978 as follows: 6-16 December 1977, 20-23 December, 29 December-2 January 1978, 8 January, 14-15 January, 18-25 January, 27 and 28 January, (none in February), and 26-27 March 1978. Between 26 November 1977 and 29 March 1978, each operator accumulated an average 200 hours overtime. The winter of 1976-1977 was about the same as 1977-1978, and the operators were compensated (for their ∿200 overtime hours) with 60 days time off. The winter of 1975-1976 required only half the overtime accumulated in 1976-1977 or 1977-1978.

The Tower at CFBT controls and operates a mu-meter. Two civilians operate the device, and when the RW is dry and bare, it is only checked once a day. When weather is bad, the mu-meter is used as often as is necessary; it is sometimes used to guide ice/snow control operations. If a mu-meter run indicates reduced traction, the Tower alerts the Snow Foreman. After ice/snow control operations are completed, the runways are checked with the mu-meter.

Urea is the only chemical used at CFBT, although they are looking into heated sand (and warm storage). If there is any question of the need for urea, they apply it, at least down the RW center strip. One application includes the main RW and access taxiways and requires three tons of urea (@ $175/ton). Yearly urea usage has been as follows:

25 November 1977-29 March 1978	90 tons
Winter 1976-1977	45 tons
Winter 1975-1976	N.A.
Winter 1974-1975	40 tons
Winter 1973-1974	76 tons

CFBT has nine plows, seven blowers, four RW sweepers, one grader, one loader and seven dump trucks (four are used on RW's with sweepers; three are for roads and grounds--two sand spreaders and one utility). This equipment is stored indoors.

CFBT is conducting a limited "evaluation" of the SCAN system's performance for the Canadian Forces; at present CFBT does not hold a favorable view of the system. CFBT's disenchantment with the system apparently stems from their attempts to make maximum use of the readout signals. Problems with nonrepresentativeness, false alarms, nonindication of hazardous conditions, and differences in temperature signals read off the two separate readout stations have occurred. Their early attempts at complete reliance on the RW condition signals were met with failure, and they now use only the surface temperature information. No doubt the location of the SCAN sensors (6 ft from RW edge) in an area where control operations are marginal played a role in the poor performance of the system at CFBT.

Brunswick Naval Air Station, Maine (17 March 1978)

Naval Air Station Brunswick (NASB) does not have a SCAN system.

NASB is base for three permanent and two part-time squadrons of P-3's. There are 36 P-3's permanently based at NASB, with a potential for about 54; P-3's account for about 90% of their air traffic. During SCRAMBLEs, the P-3 crews have a maximum of four hours to get airborne. NASB has two parallel, nongrooved, 8000 foot RW's and an inactive shorter, perpendicular RW. The inboard RW (01R-19L) is the main instrumented RW and, consequently, the most active; RW 01L-19R is used primarily for "touch-and-go's."

SIRC operations at NASB are the responsibility of the Air Operations Officer. He is briefed on expected meteorological conditions by OinC NWSED and relays forecasts of icing/snow weather to the Public Works Officer who in turn alerts the Sea Bees. When precipitation begins or falling temperatures indicate potential freezing of wet RW's, the Weather Service contacts Public Works personnel who actually perform the SIRC operations. RCR's are measured by Tower personnel with a James Brake Decelerometer (mounted in a pickup truck) at irregular and sometimes infrequent intervals, depending upon availability of equipment and personnel. The measured RCR's are not available to SIRC personnel (Public Works) for gauging snow/ice control progress.

The lack of SIRC experience (compared to civil airfield operations) by personnel in general at NASB is probably due to frequent rotation of Navy personnel and appears to be a major drawback in the NASB approach to SIRC. It appears that NASB is gradually turning to civilian employees to perform SIRC operations. This trend was initiated in 1975-76 and has accounted for $70K to date during the 1977-78 winter. Presently, 20 civilians are used on a part-time basis (guaranteed 20 hours/week) and are called in on overtime for severe storms. At NAS Keflavik during periods with little required SIRC activity, civilian SIRC personnel were required to perform any of a number of tasks other than normal SIRC operations. It was suggested that U.S. labor unions are not likely to allow such ill-defined job descriptions at NASB. As a result, it might not be feasible to perform SIRC operations with a devoted civilian crew at stateside bases.

Urea is the only chemical used at NASB in SIRC operations, and it was introduced only last winter (1976-77) on a trial basis. Five tons of urea (∿$800) are required for a typical application to one of the 8000 foot RW's.

NASB has not been closed during the past eight years due to weather. However, during severe storms, the SIRC operations and aircraft landings are alternated at two hour intervals. P-3's can land on ice with nil-braking conditions (at pilot's discretion); alternate landing fields are 70, 100, and 150 miles away, respectively. They usually divert, under ice conditions, when cross winds are >15 kts.

NASB weather is said to be completely different from that occurring at Portland (∿30 miles to SW). Apparently "a cold pocket occurs along the coastal margin all the way south to Boston." NASB frequently gets 1-2 inches of snow followed by freezing rain, which can result in several inches of ice. They figure on plowing ice and snow ∿10 times/year; light snows require sweeping an additional six times/year. In the winter, the ground is usually cold, and, hence, snow on the RW is usually dry and nonmelting. The Weather Officer would like to have the SCAN readout in his office since SIRC preparedness relies totally on weather forecasts based on standard observation.

The following annual (Government FY) maintenance and material expenses were supplied:

	SIRC Vehicles* Maintenance and Materials		Snow Removal Civilian Labor and Materials	
	Labor	Material	Labor	Material (urea)
1978 up to 2/28/78	$50,711	$58,967	$75,805	$ 7,900
1977	74,250	71,204	60,971	12,407
1976 up to 3/15/76	51,719	47,792	35,742	5,419

*6 plows, 8 blowers, 3 brooms, 3 graders, 1 sander, 1 urea (dispenser)

These figures include all snow removal costs (roadways, RW, parking lots, etc.) at NASB, but do not include costs of military labor.

A number of NASB personnel, with the exception of the Public Works Officer, are anxious to acquire a SCAN system. They feel that anything that will help improve SIRC operations is worthwhile. Those in favor of the system voiced the following arguments: (1) SCAN would provide continuous information on RW conditions (i.e., dry, wet, or frozen) to be used in conjunction with RW inspections; (2) the unique measurement of RW surface temperature would be available to aid in predictions of RW freezing, the use of urea, and in the summer, better estimates of RW air temperatures for estimation of available engine thrust; and, (3) advanced warning of RW icing which would allow anti-icing rather than de-icing measures. The Weather Officer would like to have RCRs every hour, but manpower and equipment are not available to do this--"SCAN could provide this data for hourly reports" he said. The P.W. officer suggested that NWSED personnel mount a thermometer on the RW and periodically refer to it for determinations of RW surface temperature. Further, since the SIRC strategy is to maintain dry, clean RW's, he doubted the need for a means of measuring RW icing; "because snow removal is more of an art than a science."

Greater Buffalo International Airport, New York (13 February 1978)

Greater Buffalo International (GBIA) does not have a SCAN system.

GBIA has two runways (05-23 and 13-31) and experiences frequent and sometimes prolonged snow storms. GBIA handles about 400 flight operations (combined landings and takeoffs for commercial, passenger and private) each day, classifying it as a large-medium airport. As is explained below, GBIA personnel think that a SCAN ice detector system would be of minimal value to this particular airport.

The strategy of GBIA snow removal personnel is to prevent snow and ice from becoming a problem by constant attention to the runway surface. Their philosophy of operation is to keep the runways dry; snow, slush or ice are not allowed to accumulate on the main runway. Runway snow/ice control is a three-shift (8-10 men and supervisor), seven-day a week operation under the general direction of the General Manager at GBIA. Control operations begin immediately when snow starts or ice/slush appears on the runways. Constant updates on current weather and weather forecasts by the shift supervisors provide for constant preparedness during icing conditions. Snow (even lake effect) at GBIA usually begins at warmer temperatures ahead of or associated with fronts and is followed by much colder air behind the fronts.

The only chemical applied to runways at GBIA is dry, pelletized urea, and it is applied only at (air) temperatures >25°F. Urea does not work effectively under the dry, windy conditions usually encountered at Buffalo when temperatures drop below 25°F. Other chemicals such as Ucar and glycol are considered too slick (runway traction problems), especially when urea (combined with removal procedures) works so effectively at GBIA. Urea is purchased in 80 lb bags at a cost of about $165/s.ton. Bulk purchase would be cheaper, however, storage requirements (warm and dry) pose a problem. Anti-icing requires about 2 s.tons of urea to clear the main runway (8,200 x 75 ft) area. This represents an application rate of 6.5 lb/1000 ft^2. Deicing requires an application rate 2 to 3 times greater.

At temperatures >25°F, the procedure is as follows: (1) apply urea; (2) wait 20-30 minutes; (3) broom; (4) apply grit (heated sand); and (5) broom. The procedure requires about one hour, and the result is a dry runway which usually remains dry. Additional dry snow usually blows off or is readily removed by brushing. (Melted snow or slush is not allowed to remain on the runway, as it presents a potential hydroplaning hazard.)

At temperatures < 25°F, the runways are usually dry as a result of the above procedures. In this instance, dry urea is ineffective because of the relatively dry conditions, the low temperature and usually concurrent cross winds which blow it off the runway. Although techniques for applying prewetted urea exist, they are not considered necessary and, therefore, not used at GBIA (because runways are not permitted to become ice covered at low temperatures). For the infrequent occasion when this condition does occur, heated sand (followed by brooming) is effective. In the daytime, solar radiation raises runway temperatures to the point where urea may be effective.

Available equipment includes three plow/sanders: One dispenses warm sand; one dispenses the urea; and one disseminates salt on access roads and parking lots. In addition, brooms, blowers, shovel loaders and a mu-meter are available. Brooms must be replaced after about 1000 hours use @ ~$750/set), and approximately 8-10 broom refills are used per year (year-round usage); an equipment budget of about $200K for FY78 was mentioned. Storage barns are necessary for both equipment and materials; sand is kept warm (at 75°F) under radiant heaters.

A mu-meter and a type of inertial sensor are available for measuring runway traction. Measurements with these devices have been found to be inconsistent, especially under conditions of wet snow and grit, with the braking ability observed by pilots. Consequently, GBIA personnel rely upon pilot feed-back to judge runway surface traction; measurements, per se, are seldom if ever obtained.

The obvious professionalism and concern for safety at GBIA may be an important factor in the ability of personnel to handle the severe winter conditions. They said that "You have to use brooms and you have to use chemicals," and attributed the success of the award-winning GBIA snow removal system to "(1) enough equipment in good working order, (2) manpower always available, and (3) personnel who know their jobs." It is likely that the key to their ability to maintain good runway conditions is experience. The supervisory personnel know what actions to initiate for given runway conditions. Since they keep on top of the weather and are successful in SIRC operations, they feel that an ice detection system would be of minimal value at GBIA.

Adak Naval Air Station, Alaska (22 March 1978)

Naval Air Station Adak (NASA) does not have a SCAN system.

NASA has two crowned, ungrooved, 7000 ft, asphalt runways (05-23 and 08-26). As at NAS Brunswick, about 90% of the air traffic using NASA runways are P-3's, with the majority of the remainder being propeller-driven transports (C-130's). Because these aircraft can use reverse propeller pitch to provide deceleration during landings, there seems to be minimal concern about RCR's at NASA.

Within the last year or so the responsibility for SIRC operations at NASA have been transferred from Public Works to Air Operations. Few, if any, civilians are used in SIRC operations. (There are few civilians at Adak - period.) A 3/4" deep layer of ice or snow on the runways is the goal of SIRC operations at Adak. SIRC operations are performed with five snow-blowers and five roll-over plows; no chemicals or brooms are employed at NASA. The procedure is to plow ice or snow to within 3/4" of runway surface. When the banks of snow resulting from plowing get sufficiently large, they are blown from the runways. According to Weather Detachment personnel, the weather at NASA is such that the snow from major snowstorms is rarely ever on the ground for more than a day. A typical winter storm at NASA apparently begins with mixed snow and rain eventually turning to rain which melts all of the accumulated snow. Aircraft patrol activities at NASA apparently can be delayed until acceptable runway conditions are achieved, whether due to nature or SIRC operations.

Officers of Public Works, the VP's (P-3 patrol squadrons), and NWSED have recommended to the CO at Adak against the acquisition of a SCAN system. They feel that snow and ice are such temporary problems that there is no justification for the expenditure. Their casual approach to SIRC operations is undoubtedly due, in part, to relaxed mission objectives and the type of aircraft employed at Adak.

Niagara Falls Airport, New York (15 February 1978)

Niagara Falls Airport (NFA) does not have a SCAN System.

Three organizations have separate responsibility for different snow/ice control operations at NFA: the Air Force Reserves have the responsibility for maintaining the main instrument runway (28R/10L); Niagara Frontier Transit Authority for the short runways (24/06, 32/14 and 28L/10R); and the Air National Guard for clearing barriers at each end of 28R/10L. This report focuses only on the main runway and control operations of the Reserves.

The primary ice/snow control strategy used by the Reserves is plowing. They employ a fleet of 8 Oshkosh road graders with 12 foot plows and brooms with built-in air blasters. They begin sweeping operations (on request) when snow starts, and if the snowfall is too heavy, they turn to the plows. "At 40 mph, they can clear the runway in ∿1 hour;" after plowing, they broom with air blast (nonheated). In the event of severe ice, they just "plow over and over taking off ∿1/2" at a time."

They keep isopropyl alcohol and urea on hand but very seldom use these chemicals. "It is either too cold or too windy" for their general use at NFA. When they use chemicals, the procedure is as follows: (1) apply alcohol; (2) apply urea; (3) plow and brush. Grit is prohibited by Air Force regulations and is never used.

To determine when sufficient traction has been established, they use a James Brake Decelerometer which is attached to the bed of a pickup truck. The device displays a meter reading, RCR (runway condition reading), on a scale of 0 to 26. "An RCR of 12 or better implies good braking conditions." If the RCR is < 12, they continue plowing and brushing operations. If the RCR is 10 and 11, they feel it is "close enough and they cannot do any better."

APPENDIX C

Bi-Variate Distributions of Precipitation Type Versus Temperature for Adak, Anchorage, Brunswick, Indianapolis and Keflavik

These climatologies were prepared from the hourly observation series supplied by the National Climatic Center at Asheville on magnetic tape in a format called Tape Data Family-14. The bi-variate distributions were prepared for the temperature categories ≥ 37°F, 36°-35°, 34°-33°, 32°-31°, 30°-18°, and < 18°F and for the precipitation categories of none, rain, rain squall, snow, snow showers, freezing rain, freezing drizzle, and sleet. The table entries are in hours of a winter season, with 2904 total hours in a season. [(-) indicates less than one hour per season.]

Adak

	Winter Season Hours of Observation Per Category					
Temp (°F) Categories	≥37	36-35	34-33	32-31	30-18	< 18
Precipitation Categories						
None	498	356	313	246	412	14
Rain	286	116	35	2	-	-
Rain Squall	82	20	5	-	-	0
Snow	7	42	87	68	53	0
Snow Showers	8	36	63	62	89	-
Freezing Rain	-	-	-	-	-	-
Freezing Drizzle	-	-	-	-	-	-
Sleet	-	-	-	-	-	-

Anchorage

	Winter Season Hours of Observation Per Category					
Temp (°F) Categories	≥37	36-35	34-33	32-31	30-18	< 18
Precipitation Categories						
None	124	70	85	86	840	1211
Rain	22	12	9	1	1	-
Rain Squall	1	1	1	-	-	0
Snow	2	5	14	23	213	158
Snow Showers	1	-	1	-	6	4
Freezing Rain	-	-	-	2	3	-
Freezing Drizzle	-	-	-	-	5	-
Sleet	0	0	0	-	0	0

Brunswick

Temp (°F) Categories	Winter Season Hours of Observation Per Category					
	≥37	36-35	34-33	32-31	30-18	< 18
Precipitation Categories						
None	456	149	148	160	879	607
Rain	84	23	17	5	1	0
Rain Squall	20	9	7	2	-	0
Snow	1	7	23	28	144	56
Snow Showers	1	2	2	3	14	4
Freezing Rain	-	-	1	4	1	-
Freezing Drizzle	0	0	-	2	9	1
Sleet	-	-	1	1	3	-

Indianapolis

Temp (°F) Categories	Winter Season Hours of Observation Per Category					
	≥37	36-35	34-33	32-31	30-18	< 18
Precipitation Categories						
None	785	160	187	176	724	292
Rain	168	26	22	3	-	0
Rain Squall	44	12	14	4	-	0
Snow	1	3	16	25	97	22
Snow Showers	1	2	7	8	58	20
Freezing Rain	0	0	-	6	9	-
Freezing Drizzle	0	0	-	4	6	0
Sleet	-	-	1	-	1	-

Keflavik

Temp (°F) Categories	Winter Season Hours of Observation Per Category					
	≥37	36-35	34-33	32-31	30-18	< 18
Precipitation Categories						
None	630	254	232	203	804	66
Rain	276	57	22	3	-	0
Rain Squall	71	6	3	1	-	0
Snow	1	7	27	33	68	2
Snow Showers	2	10	24	28	66	3
Freezing Rain	0	-	-	-	-	0
Freezing Drizzle	0	0	-	-	-	0
Sleet	-	1	-	-	3	0