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A PRELIMINARY EVALUATION OF THE POTENTIAL UTILITY OF THE SURFACE CONDITION ANALYZER (SCAN) SYSTEM FOR MONITORING RUNWAY WATER DEPTH AS RELATING TO RUNWAY TRACTION.

by

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14 Calspan [redacted] 6283-M-2

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

During 1978, Calspan Corporation conducted an independent research investigation of the basic principles and operational performance of the Surface Condition Analyzer system (SCAN)™ as an indicator of airport runway conditions with respect to icing and/or hydroplaning situations. This report documents a preliminary evaluation of the potential utility of the SCAN system in providing information relative to the hydroplaning potential of a wet runway.

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Section 1

INTRODUCTION AND SUMMARY

For the past two years 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 for 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, Chicago (O'Hare), Cincinnati, Detroit, Indianapolis, Kansas City and Pittsburgh. (Approximately 10 additional civil airports in the U. S. are planning procurement of ice detection systems.) The results of an operational research evaluation of its ice-detection capability and a complete description of the system are presented under separate cover as Part 1 to this report (Mack, et al, 1979). Preliminary evaluation of the water-depth measurement capability and its potential utility at Naval airfields is presented in this report.

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

The evaluation of the utility and Navy-wide applicability of the SCAN system to measurement of water depth and relating those measurements to runway traction encompassed three general areas of investigation: (1) limited review of the literature concerning aircraft hydroplaning; (2) study of the basic operating principles, conceptual design and electronic and mechanical engineering of the SCAN system; and (3) limited 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 Pensacola and Cecil Naval Air Stations, discussions and demonstrations at the manufacturer's plant, study of the manufacturer's drawings and schematics, review of the literature on hydroplaning, and climatological analyses.

Briefly summarizing, the principal findings of this investigation are as follows: (a) the basic 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 sensor pucks provide only a fair approximation of the runway surface; (c) there is no doubt that the sensor can detect the presence of water and provide a monotonic output signal as a function of water depth, at least from 0.01 to 0.15 inches of water, although the output appears to be dependent on the conductivity of the water being measured; (d) the system appears to have sufficient sensitivity and dynamic range to provide the necessary information on which decisions relative to hydroplaning must be made; (e) if fully functional, such a system could effect a significant reduction in arresting gear maintenance costs and an improvement in airfield safety. However, the device is as yet untested in the field, and the degree to which its accuracy and sensitivity may be effected by field deployment and by contamination on sensor surfaces is unknown.

Section 2
DISCUSSION

The objective of Task 3 under Contract N00014-78-C-0284 is to provide a preliminary evaluation of the potential applicability and utility of a water depth monitoring system for reducing hydroplaning-related problems at Naval airfields. Surface Systems, Inc. (SSI) now has a separate configuration for a water-depth sensing system, but the system has not been field-tested and, hence, could not be fully evaluated within the scope of our current contract. The overall evaluation, then, was based on information garnered from the following sources: review of the literature on aircraft hydroplaning, site visits and interviews at Pensacola and Cecil Naval Air Stations (both located in Florida), limited climatological analyses, our own experiences with the SCAN system during evaluation of its ice-detection capabilities, and discussions and demonstrations at the manufacturer's plant. Results of these efforts are summarized in this section.

2.1 Background

Hydroplaning of aircraft on wet surfaces has been studied by a number of investigators (e.g., Horne, 1974; Merritt, 1974; and Morrow, 1979) and has been found to be dependent on a variety of aircraft-landing parameters and surface conditions. These factors include: touchdown speed and pilot control; steerage and braking systems; tire-make-up, tread, inflation and footprint pressure; surface conditions such as microstructure, gradients and contamination; and weather including wind, temperature and water depth. Specifically, three critical water depths have been identified: < 0.05 inch (1.27 mm), advise pilots; 0.05 inch to 0.10 inch (2.54 mm), hydroplaning is possible; and > 0.10 inch, hydroplaning is probable. A limited bibliography of the literature on aircraft hydroplaning is provided in Appendix A.

Intuitively, water on a runway should be a transient condition (except for standing water in puddles) dependent on drainage and, with some lag, on rainfall intensity and duration. Since rainfall intensity can be quite variable during a given precipitation event and is directly related to water depth on a given runway, it would appear that a device capable of reliable, real-time measurement of runway water depth could be of significant value in improving airfield safety and reducing costs associated with current trapping (use of arresting gear) practice. Real-time measurements of water depth could provide the basis for objective decisions relative to aircraft landing, trapping, or remaining airborne until runway water subsides.

Both Pensacola and Cecil NAS's were visited by Calspan personnel in August 1978, and it appears that both airfields have significant hydroplaning problems due to high frequencies of intense rainfalls. It is our understanding that a number of other NAS's, particularly in southern states, also experience similar problems. Cecil, which has landings regulated by a "wet runway recovery bill", experiences ∿700 aircraft arrests per year (due to wet runways) and annual expenditures, for replacement parts alone, of ∿$150,000. Pensacola averages ∿120 arrests/year. However, as a result of several incidents just prior to our visit, Pensacola instituted a "wet recovery bill," and the number of arrests at Pensacola increased dramatically. Of the 98 wet-runway arrests at Pensacola in 1978, 81 occurred after implementation of the "wet recovery bill." Details of the wet recovery bills are not known, but it seems likely that the "bills" are not followed to the letter, because the designation of wet is currently a subjective determination made in a control tower located ∿0.5 mile from the runway.

In summary, it appears that Cecil, Pensacola, and probably a number of other NAS's would benefit significantly in terms of both increased safety and reduced arresting-gear maintenance costs if a device were available which could provide real-time knowledge of runway water depth and traction. Potentially, Cecil could recover the initial costs of a current SCAN system in one year with the savings realized in reduced wear on arresting gear.

2.2 Evaluation of the Potential Utility of the SCAN System for Monitoring Runway Water Depth

The original SCAN systems such as the one initially implemented at Keflavik NAS were installed with the advertised ability to measure water depth. However, the ice detection performance of the system was compromised by necessary modifications and "tuning" of the logic circuitry to provide the water depth information. In addition to the design problems, pilots were not satisfied with receiving values of water depth since they had no realization of the significance of such information and could not correlate the given values of water depth to traction coefficients or to the potential for hydroplaning. Consequently, the capability for determining water depth was removed from the commercially available system.

SSI has since proposed to develop a sensor system devoted specifically to determining the potential for aircraft hydroplaning. The unit would measure water depth and, through use of an appropriate algorithm, actually display runway traction coefficients. In the absence of definitive algorithms relating traction to aircraft speed, tire make-up and condition, footprint pressure, runway microstructure, water depth and winds, the system might simply display: DRY (no water); WET (< 0.05 inches); POSSIBLE HYDROPLANING (0.05-0.10 inches); or PROBABLE HYDROPLANING (> 0.10 inches of water on the runway).

The sensor arrangement with which SSI is experimenting closely resembles the SCAN ice-detection system* in external appearance, comprising a sensor puck (imbedded flush with the runway surface), a remote processing unit and a remote monitor display. The sensor puck for water depth measurement contains only the capacitance sensor and conductivity probe, the details of which are reserved as proprietary information. From our experience at Keflavik (see Mack et al, 1979), we know that the capacitance sensor (through a measurement of permittivity) is capable of detecting minute quantities of water. Further, it is our judgement that properly designed sensors based on measurement of a change in permittivity with a change in water depth are, in principle, capable of measuring runway water depth in real time.

During a visit to the manufacturer's plant, we witnessed a bench-top demonstration of a "bread board" model of the water depth sensing system. The

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*See Part I of this report (i.e., Mack et al, 1979) for a complete description of the SCAN System.

tests involved monitoring of the output voltages of both the capacitance and conductivity probes as the water depth on top of a SCAN sensor puck was gradually increased from 0.01 to 0.15 inches*. The output-voltage data from the capacitance sensor as a function of water depth for five such tests are presented in Figures 1 and 2.

Test No.s 1, 2 and 3 shown in Figure 1 were conducted by SSI prior to Calspan's visit. Test No.s 1 and 2 were conducted with the same sensor puck; Test No. 1 used distilled water, while Test No. 2 was conducted with a 3.5% solution of UCAR mixed with distilled water. Test No. 3 involved distilled water on a different sensor puck. The tests showed that the capacitance sensor provides a monotonic signal as a function of increasing water depth and that the absolute signal is somewhat dependent on the conductivity of the water.

In Figure 2, the data from Test No. 1 are compared with data from two tests (No.s 4 and 5) conducted in Calspan's presence. Again, the data indicate that the permittivity output is a monotonic function of water depth up to a depth of at least 0.15 inches, the absolute value being somewhat dependent on conductivity. The data from Tests 1, 3, 4 and 5 show, for a conductivity sensor output in the range 8.8 to 9.3 VDC, that the permittivity sensors can measure water depth at 0.01 inches to ±0.003 inches, at 0.05 inches to ±0.015 inches and at a depth of 0.10 inches to ∿±0.025 inches.

In summary, the SCAN permittivity sensors appear sufficiently sensitive, in a laboratory environment, to distinguish between the water depths (i.e., 0.01, 0.05 and 0.10 inches) found critical to the potential for hydroplaning. However, the permittivity output signal varies from sensor to sensor and is somewhat dependent on the conductivity of the water being sensed. How the sensor will perform at a remote location imbedded in a runway is unknown. Calibrations will probably be required on site for each individual sensor, and algorithms allowing compensation for variations in the conductivity of rainwater and surface runoff will be necessary. It is also likely that dirt and contaminant build-up on the sensor surface will affect both the capacitance output

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*Water was metered onto the top of a leveled puck from a graduated pipet. The known volume of water and surface area of the puck were then used to calculate water depth.

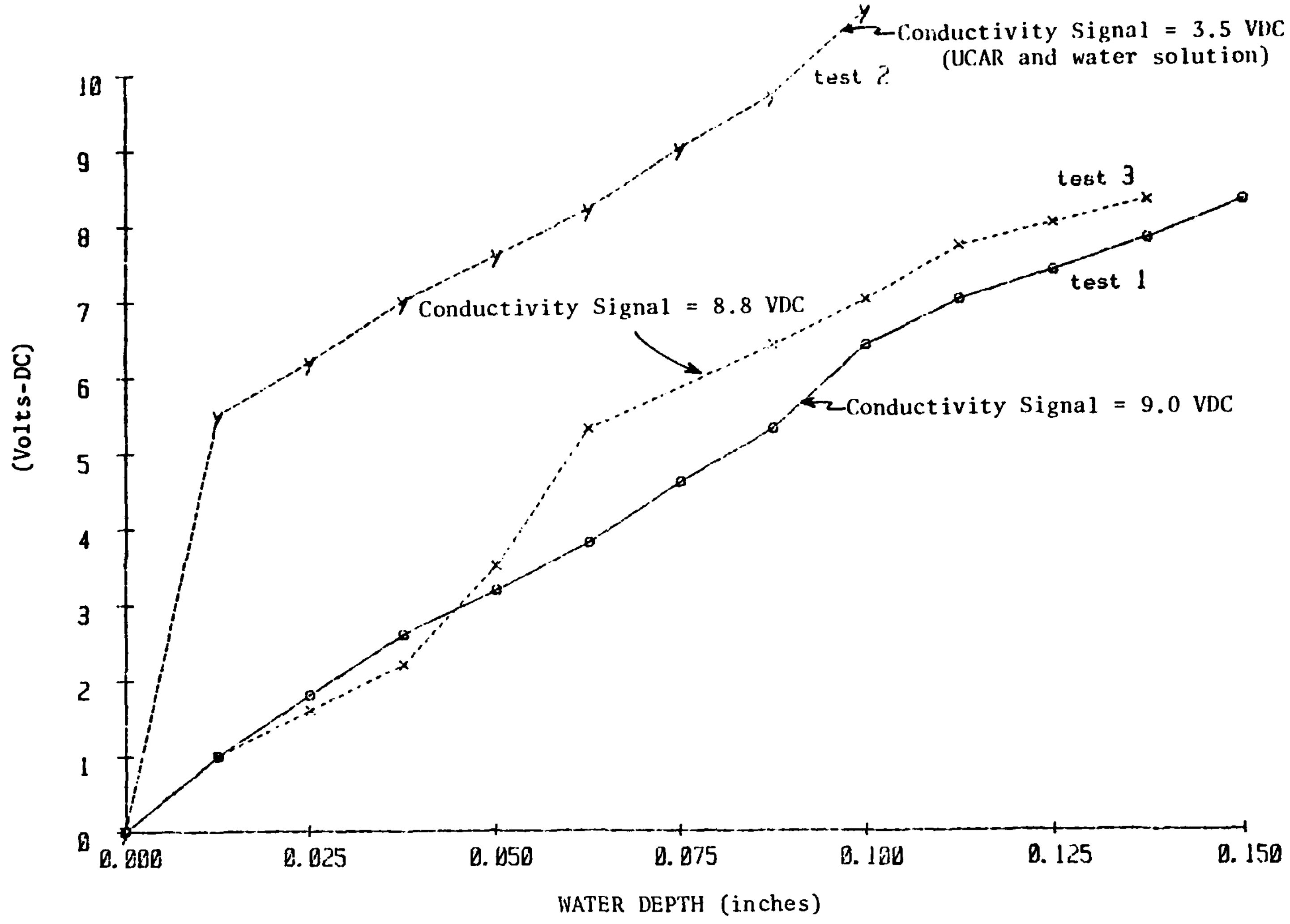

Figure 1: Output voltage of the SCAN permittivity sensor as a function of water depth on the sensor puck in three bench-top tests conducted by SSI. (Tests no.s 1 and 2 with the same sensor puck; test no. 3 was a different sensor.)

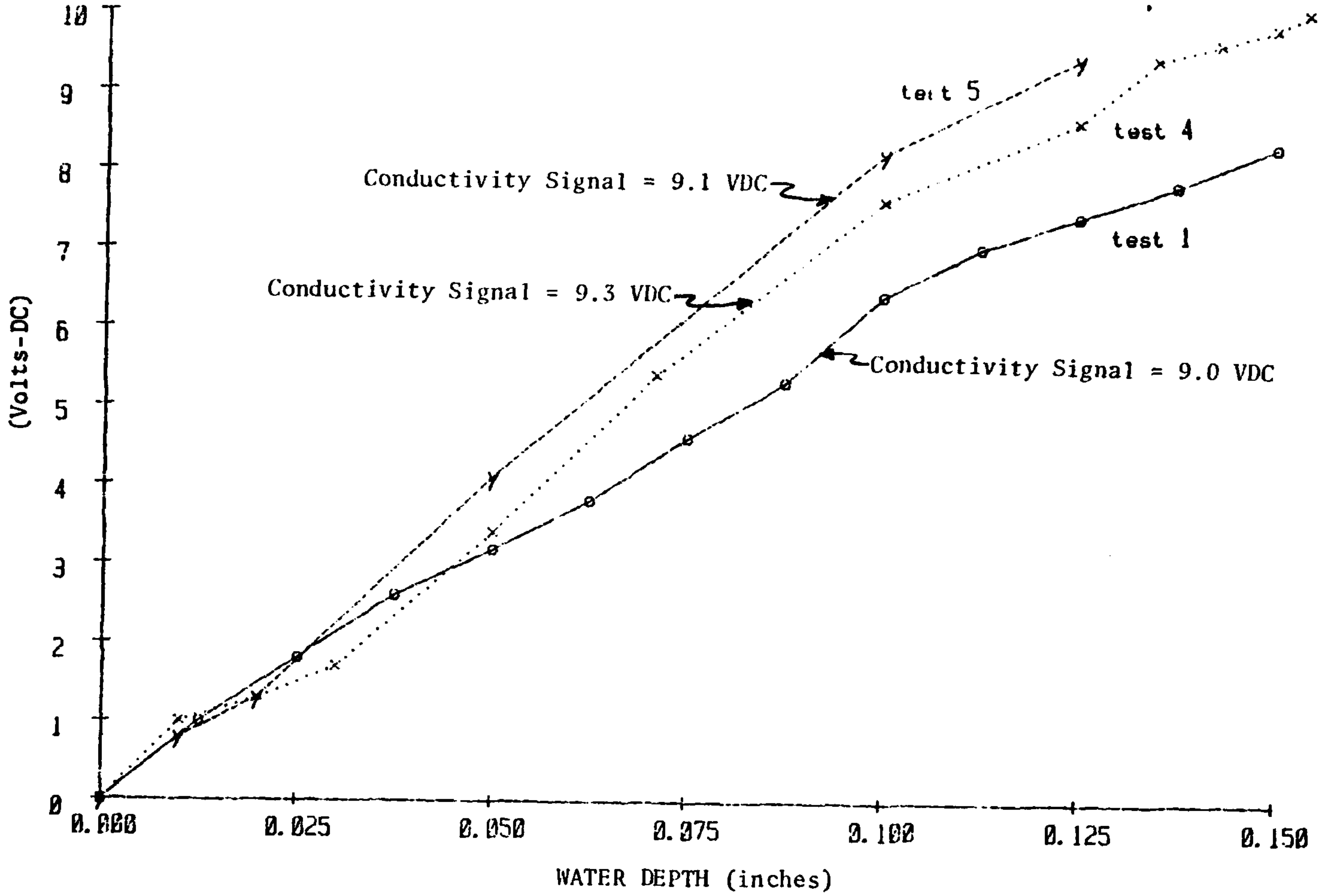

Figure 2: Output voltage of the SCAN permittivity sensor as a function of water depth on the sensor puck. (Tests no.s 4 and 5, both witnessed by Calspan, are compared with test no. 1 conducted previously by SSI.)

signal and the conductivity of any water which covers the probe. Routine recalibration, and possibly cleaning of the sensors, will likely be required for an operational system.

2.3 Thunderstorm Climatology of Naval Air Stations

The potential for aircraft hydroplaning problems, such as experienced at Pensacola and Cecil, arises because of heavy rainfalls, generally associated with thunderstorms, over short time periods. On the basis of weather alone, the requirement for hydroplaning-warning-equipment, therefore, depends on the frequency of occurrence of large rainfall rates. This information is not readily available for all naval stations. However, an estimate of the severity of a station's rainfall problem can be gained by looking at both the number of thunderstorm days and mean rainfall amounts which are contained in station climatic summaries. The data for this analysis was obtained from the U. S. Navy and Marine Corps Meteorological Station Climatic Summaries (1975).

All of the naval stations for which summaries are available and which experience more than 20 annual thunderstorm days are listed in order of decreasing annual thunderstorm days in Table 1. Also included in Table 1 are the mean number of thunderstorm days by month for the northern hemisphere thunderstorm season, April to October. In Table 2, the mean annual and monthly rainfalls are shown for the stations. The resulting set of stations represents slightly less than half of the total number of Naval Air Stations. The list is headed by New Orleans with 77 annual thunderstorm days and ends with Bermuda at 22 days. At the top, the list is dominated by low latitude stations; from 60 days/year down through 20 days/year, the stations are generally located at progressively higher latitudes. Cecil Field, which we know has significant hydroplaning problems, has more than 10 thunderstorm days/month for each of the summer months.

Obviously, knowledge of weather (specifically mean number of thunderstorm days) alone is not sufficient to make judgements concerning the seriousness of hydroplaning problems at particular stations. However, stations with similar mission requirements and primary aircraft as has Cecil and with more than ∿10 thunderstorm days/month for any given month should experience

Table 1

NUMBER OF THUNDERSTORM DAYS AT SELECTED NAVAL AIR STATIONS

Station	Annual Thunderstorm Days	Number of Thunderstorm Days						
		April	May	June	July	Aug	Sept	Oct
New Orleans, LA	77	4	7	11	19	15	8	2
Cecil Field, Jax, FL	67	4	7	11	16	14	6	2
Glynco, GA	66	4	8	11	15	14	6	1
Jacksonville, FL	65	4	7	10	15	13	7	2
Saufley Field, FL	63	4	5	11	14	14	4	2
Pensacola, FL	62	3	5	9	14	12	6	2
Whiting Field, FL	61	4	5	10	14	12	5	1
Cubi Point, Philippines	60	2	10	11	12	9	9	5
Mayport, FL	59	3	5	10	14	12	5	2
Charleston, SC	57	3	7	10	14	12	5	1
Key West, FL	56	2	4	8	10	12	10	5
Beaufort, SC	54	3	6	8	14	11	4	2
Memphis, TN	53	7	7	7	8	7	3	2
Meridian, MS	53	6	4	7	12	8	4	1
Albany, GA	48	3	6	8	11	8	3	1
New River, NC	47	4	5	7	13	10	3	1
Atlanta, GA	46	4	6	8	11	7	2	1
Cherry Point, NC	44	3	6	7	11	9	4	1
Dallas, TX	44	6	7	5	5	5	4	2
Guantanamo Bay, Cuba	40	1	4	5	5	7	8	7
Chase Field, TX	38	3	5	5	4	6	6	3
Glenview, IL	36	4	5	7	6	5	4	2
Oceana, VA	36	3	5	5	9	7	3	1
Roosevelt Roads, Puerto Rico	35	1	3	5	5	4	7	6
Norfolk, VA	34	3	5	6	8	6	2	1
Kingsville, TX	33	3	5	4	3	5	6	2
Naples, Italy	33	2	2	2	2	3	4	4
Patuxent River, MD	33	3	4	6	8	6	3	1
Sigonella, Sicily	33	3	4	3	3	3	4	5
Quantico, VA	32	2	5	6	8	6	3	1
Corpus Christi, TX	28	3	4	3	2	3	5	3
Lakehurst, NJ	27	2	4	5	6	6	2	1
Willow Grove, PA	24	2	3	4	5	5	2	1
Bermuda	22	1	1	2	3	4	3	2

Table 2

MEAN RAINFALL AT SELECTED NAVAL AIR STATIONS

Station	Mean Annual Rainfall in Inches	Mean Monthly Rainfall In Inches						
		April	May	June	July	Aug	Sept	Oct
New Orleans, LA	56.3	3.8	4.6	4.5	6.2	5.5	5.9	3.9
Cecil Field, Jax, FL	52.2	2.6	3.7	6.8	7.3	7.3	5.8	3.8
Glynco, GA	52.6	2.9	3.9	5.9	7.5	6.9	7.6	3.4
Jacksonville, FL	46.5	2.5	3.3	5.1	6.0	7.5	6.0	3.9
Saufley Field, FL	55.5	3.9	3.8	5.6	5.5	5.8	6.7	4.3
Pensacola, FL	53.4	3.6	3.0	5.0	5.9	5.9	7.0	4.2
Whiting Field, FL	59.7	4.3	3.9	6.8	6.9	6.0	6.5	2.8
Cubi Point, Philippines	134.7	0.6	8.6	23.2	31.8	33.5	25.7	7.2
Mayport, FL	42.9	1.9	2.9	5.5	5.5	5.7	4.6	3.1
Charleston, SC	52.5	2.9	4.3	5.9	8.0	6.6	5.2	3.2
Key West, FL	37.5	1.1	3.1	5.3	3.0	4.3	6.8	5.2
Beaufort, SC	51.6	2.6	4.4	5.4	7.8	8.5	3.3	3.3
Memphis, TN	47.3	5.0	4.2	3.3	3.6	3.1	3.5	2.4
Meridian, MS	47.9	4.6	3.4	3.5	4.8	4.0	2.2	2.5
Albany, GA	47.0	4.2	3.9	4.4	5.6	4.1	3.3	1.9
New River, NC	51.4	2.7	3.6	5.9	8.7	6.0	3.8	3.0
Atlanta, GA	48.7	4.3	3.4	3.7	4.7	3.0	3.6	2.8
Cherry Point, NC	53.5	2.5	4.1	5.1	8.4	6.5	6.1	3.6
Dallas, TX	31.9	4.4	4.4	2.7	1.8	2.4	2.9	3.0
Guantanamo Bay, Cuba	24.6	1.0	3.0	2.4	1.0	1.9	3.5	6.1
Chase Field, TX	29.5	1.8	4.0	2.8	2.0	2.7	5.5	2.3
Glenview, IL	34.1	3.5	3.4	4.2	3.8	2.7	3.3	2.4
Oceana, VA	45.5	2.5	3.5	3.2	5.1	6.0	4.4	4.1
Roosevelt Roads, Puerto Rico	58.8	3.7	7.3	4.8	4.8	5.5	6.3	6.9
Norfolk, VA	38.9	2.5	3.4	3.1	4.6	4.3	3.9	2.7
Kingsville, TX	24.6	1.3	2.8	2.7	1.6	2.7	4.5	2.5
Naples, Italy	34.9	2.9	2.0	1.5	0.7	0.9	2.9	5.3
Patuxent River, MD	40.7	3.0	3.8	3.5	4.5	4.5	2.9	2.8
Sigonella, Sicily	21.7	1.9	1.1	0.5	0.2	0.6	1.0	5.8
Quantico, VA	37.5	3.0	3.2	3.2	3.7	4.3	2.9	2.5
Corpus Christi, TX	28.5	1.8	3.0	2.9	1.2	3.1	5.6	3.2
Lakehurst, NJ	42.6	3.3	3.3	3.1	4.0	4.3	3.3	3.1
Willow Grove, PA	45.2	3.6	4.3	3.7	4.6	4.8	3.5	3.2
Bermuda	54.5	3.3	3.7	4.9	4.0	4.8	5.6	6.6

potential hydroplaning problems in that month nearly as frequently as does Cecil during the summer months.

Section 3

CONCLUSIONS AND RECOMMENDATIONS

Within the scope of this contract, we were to determine the potential utility of instrumentation for monitoring runway water depth and relating those measurements to runway traction. To date we have determined that such instrumentation is needed and, if implemented at Cecil NAS, for example, could effect a significant reduction in arresting gear maintenance costs and an improvement in airfield safety. Further, we have determined that, under laboratory conditions, the SCAN sensors are capable of monotonic output as a function of water depth in the range 0.01-0.15 inches. Real-time water-depth information coupled with the results of recent FAA studies (Morrow, 1979) of the relationship of the tire-footprint pressure to hydroplaning could provide the basis for objective decision-making during potential hydroplaning situations.

However, several questions remain unanswered:

1. How sensitive is the SCAN device to water depth under actual operational conditions? Can it reliably determine water depth and the difference between 0.01, 0.05 and 0.1 inches of water without loss of accuracy due to build-up of rubber and other contaminants on the sensor surface?
2. Can water depth be measured representatively on a runway with as few as 5 to 10 spot measurements?
3. Can water depth measurements be related to runway traction for various aircraft types?
4. How many Naval Air Stations experience significant hydroplaning problems?

In order to acquire quantitative answers to items (1) and (2), it is recommended that the Navy conduct field trials of a SCAN system designed specifically to measure water depth. Such trials should be conducted at a station which experiences > 10 thunderstorm days/month but has lower-priority aircraft activity to facilitate required on-runway measurements.

Analyses of mission requirements and aircraft usage, as well as weather factors, will be required for answers to item (4).

If the SCAN system or any other such device proves reliable in field trials, then a research and development effort would be warranted to provide definitive algorithms relating runway water depth to runway traction for various aircraft types and touchdown conditions.

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Appendix A

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