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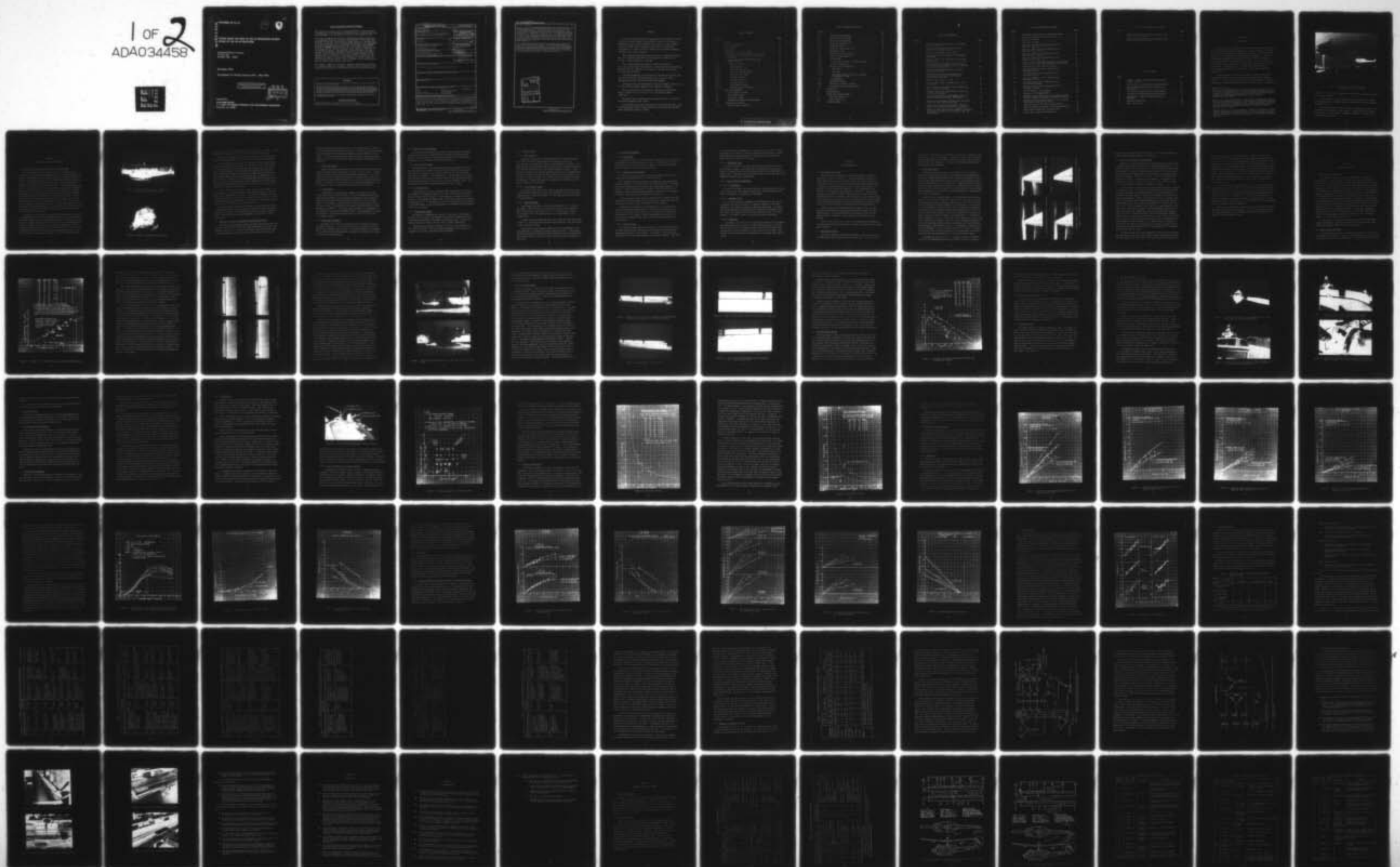

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OTTAWA SPRAY RIG TESTS OF AN ICE PROTECTION SYSTEM APPLIED TO THE UH-1H HELICOPTER

Lockheed-California Company
P.O. Box 551
Burbank, Calif. 91520

November 1976

Final Report for Period January 1976 - May 1976

Approved for public release;
distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This Directorate concurs in the findings presented in this report and recommends use of the information contained herein to enhance the design and development of ice protection systems for rotary-wing aircraft.

This report documents the results of simulated helicopter icing tests of the Lockheed UH-1H electrothermal deicing system. These tests were performed in the hover mode using the Ottawa Spray Rig. The Spray Rig tests are an extension of the forward flight simulated icing experiments performed during 1975 using the Helicopter Icing Spray System (HISS), recorded in USAAMRDL-TR-75-34A and -34B. The results of both sets of icing tests are not entirely conclusive due to inherent limitations in the simulation systems. The extension of these results to the performance of the deiced helicopter in natural icing conditions requires caution. While the Spray Rig tests have increased confidence in the dependability and efficiency of the Lockheed deicing system, and have indicated the range of certain design parameters, further testing in both the Spray Rig and natural icing is required to conclusively verify previous results and to optimize the system.

Mr. Richard I. Adams was the project engineer responsible for overall test program guidance; Ms. Phyllis F. Kitchens was his assistant. Both personnel are assigned to the Military Operations Technology Division.

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Simulated icing flight tests were conducted on an advanced ice protection system as applied to an Army UH-1H helicopter in the NRC spray rig at Ottawa, Canada. The system provides for electrothermal cyclic deicing of the main and tail rotor blades, electrically-heated windshield and stabilizer bar, and ice detectors. The aircraft had been tested previously in simulated icing conditions behind the CH-47 HISS.

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A total of 18.1 hours of testing were accomplished in 54 days at Ottawa. Test conditions ranged from 0 °C to -20 °C and liquid water contents equivalent to the recommended atmospheric icing criterion for continuous maximum. The deicing controller system demonstrated excellent functioning and reliability characteristics. In general, the deicing of the rotor blades was considered to be good. Test results were obtained to define recommended heater-on times for deicing as well as heater-off time between cycles. Limited tail rotor icing and deicing were evaluated. Natural icing flights were planned after system readiness was established but none were made due to the lack of proper weather conditions.

It is recommended that further testing be accomplished under natural icing conditions to complete the evaluation. Prior to this additional testing, another set of heated main rotor blades or modifications to existing blades, incorporating minor design and manufacturing changes, should be procured to preclude reoccurrence of the heater element-to-erosion shield short problem and other deficiencies noted from the experience to date.

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PREFACE

This test program,to perform simulated icing flight tests in the NRC Spray Rig at Ottawa, Canada, was conducted by the U.S. Army Aviation Engineering Flight Activity (USAAEFA) with support from the Lockheed-California Company under Contract DAAJ02-76-C-0012 to the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia.

The program was performed during the period 20 January 1976 through May 1976. Technical monitoring of the project for USAAMRDL was by Richard I. Adams and Phyllis F. Kitchens.

The Lockheed support was under the technical direction of R.H. Cotton, Flight Test Staff Engineer. Additional Lockheed Engineering personnel were F.L. Batchen, F.P. Lentine, J. Van Wijk, W.M. Crooks, H.D. Carr and C.C. Price.

The USAAEFA personnel who conducted the simulated icing flight tests were CW/4 John Tulloch, Engineering Test Pilot, and Capt. Louis Kronenberger, Project Officer and Flight Test Engineer.

The test aircraft was maintained by SP/6 Larry Sanders, 155th Avn. Co., Ft. Ord, California and R. Metcalf and R. Lennert of Lockheed.

The 2.75-inch rocket pod testing was directed and monitored by Major N. Batten and Mr. Don Davis of U.S. Army Missile Command (USAMICOM).

The spray rig was operated under the direction of Mr. Ron Price of the National Research Council (NRC).

The aircraft and test crew were hangered at the Canadian Armed Forces South Base Hanger Number 10 where support was provided by the 2nd Armed Forces Maintenance Squadron (2AFMS).

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SECTION 1

INTRODUCTION

An ice protection technology review and trade-off study was conducted, which concluded that the electrothermal cyclic deicing system is the concept that should be applied to helicopters requiring rotor blade ice protection. This review and study was reported in Reference 1. As part of that program, an advanced electrothermal deicing system was designed, built, and installed on an Army UH-1H aircraft. Initial simulated icing flight tests of this system were conducted during the winter of 1974/1975 and reported in References 2 and 3. These tests were conducted at Moses Lake, Washington, behind the Army CH-47 Helicopter Icing Spray System (HISS).

During the winter of 1975/1976, additional simulated icing flight tests were conducted in the NRC Spray Rig at Ottawa, Ontario, Canada (Figure 1). This report discusses the results of these tests. The test program was conducted during the period of 21 January 1976 to 16 March 1976.

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[1]Werner, J.B., THE DEVELOPMENT OF AN ADVANCED ANTI-ICING/DEICING CAPABILITY FOR US ARMY HELICOPTERS, Volume 1 - Design Criteria and Technology Considerations, USAAMRDL-TR-75-34A, Eustis Directorate, US Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1975, AD A019044

[2]Werner, J.B., THE DEVELOPMENT OF AN ADVANCED ANTI-ICING/DEICING CAPABILITY FOR US ARMY HELICOPTERS, Volume 11 - Ice Protection System Application to the UH-1H Helicopter, USAAMRDL-TR-75-34B, Eustis Directorate, US Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1975, AD A019049

[3]USAAEFA Project No. 74-13, Final Report, ARTIFICIAL ICING TESTS, LOCKHEED ADVANCED ICE PROTECTION SYSTEM INSTALLED ON A UH-1H HELICOPTER, US Army Aviation Engineering Flight Activity, Edwards Air Force Base, California, June 1975

Figure 1. Test UH-1H in the NRC Spray Rig (10 mph Wind, - 10 °C, 0.3 g/m^3)

A total of 18.1 hours of testing were accomplished in the spray rig during the 54 days at Ottawa.

It was planned to conduct natural icing flight tests also; however, satisfactory weather conditions were not available after system readiness was established.

The UH-1H aircraft was flown to Ottawa from Edwards AFB, Calif. and returned at the completion of the program. Standard UH-1H rotor blades were used on the ferry flights to minimize the amount of flight time on the modified test blades.

SECTION 2

DESCRIPTION OF THE TEST AIRCRAFT

2.1 ICE PROTECTION SYSTEM MODIFICATION TO UH-1H HELICOPTER

The test aircraft shown in Figures 2 and 3 is a standard UH-1H helicopter S/N 70-16318 that was modified under a previous contract to incorporate an advanced anti-icing/deicing system by Lockheed-California Company. The modifications provide for electrothermal deicing of the main and tail rotor blades, heated glass windshields and heated anti-ice blankets on the stabilizer bar and tip weights. These ice protection systems are operated with ac electrical power from an ac generator installed as part of the modification. The system has the capability to operate automatically, using icing condition inputs from an outside air temperature sensor and an ice detector with an icing severity output. Two ice detector and rate meter systems are installed for evaluation. One is an ultrasonic type; the other is an infrared occlusion type. Both sensors include aspirators using engine bleed air to induce increased airflow across the detector for hover operations. In addition, the aircraft incorporated the mounting wedge that increases the tilt angle of the FM antenna away from the plane of the tail rotor.

The heated rotor blades are standard UH-1H blades modified by removing the standard erosion shield and replacing it with a new one incorporating the heater elements and associated electrical wiring. The main blade leading edge is heated sequentially from tip to root in six separate spanwise zones. Each heater zone provides for chordwise coverage of 12 percent on the upper surface and 29 percent on the lower surface. Full span coverage of the main rotor blades is provided with a manufacturing joint at Station 83 (.29R). Stainless steel material is used for the erosion shield

Figure 2. Test Aircraft Following a 30-Minute Run at -10 °C, 0.5 g/m^3 Spray Cloud

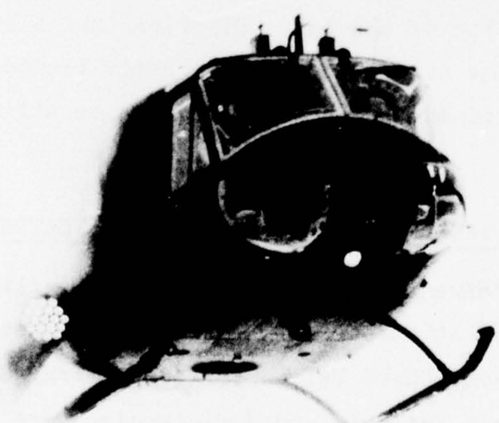


Figure 3. Rocket Pod Installation on the UH-1H

outboard of this station where the blade cross section is constant. Inboard of Station 83, aluminum is used to cover the faired doubler area.

The tail rotor heater covers the outer 60 percent of the blade span. The erosion shield material for the tail rotor is electroformed nickel.

The deicing system can operate as a function of liquid water content (LWC) at three different voltages: 160, 200 and 230 Vac. This provides for the capability to cycle through the blade heater zones at different heating rates depending on icing severity in the event the total time required to cycle through all the zones was longer than the desired off-time between heater cycles for an individual zone. It appears from the data obtained to date that for the two-bladed UH-1H with six heater zones per blade, these voltage variations are not necessary and even the lowest voltage would provide deicing for icing conditions up to a liquid water content of 2.0 grams per cubic meter.

The test deicing system has two control panels in the cockpit. The first panel is for normal operation of the protection system. The other panel is the blade deicing controller. This panel incorporates setscrews to permit adjustment of heater zone on-time either individually or collectively based on deicing test results. This panel includes heater zone-on lights, failure indicators, and off-time controls.

The ac electrical power leads are routed up through the rotor shaft to sliprings installed on top of the hub. Sliprings are also provided on the tail rotor shaft for the wiring to the tail rotor blades. The test aircraft and the modifications are described in more detail in References 1 and 2.

2.2 INSTALLATION CHANGES INCORPORATED SINCE PREVIOUS TESTING

The test aircraft underwent initial simulated icing flight tests the previous winter (1974/1975) at Moses Lake, Washington. These tests were conducted using the U.S. Army CH-47 Helicopter Icing Spray System (HISS). During that testing, certain failures and deficiencies were noted and design modifications accomplished prior to the Ottawa testing to correct the deficiencies and/or preclude recurrence. In addition, some minor changes were incorporated during the Ottawa program to improve operation of the system. The following describes the modifications that were incorporated either before or during the Ottawa program and whether they appeared to be effective.

2.2.1 Main Rotor Blades

Several problems were experienced during last year's Moses Lake testing with the deicing wiring installation at Station 83 on one blade. Although repairs had been made and the blade considered serviceable, it was designated the spare for Ottawa and the backup instrumented blade used on the hypothesis that the problems were peculiar to the first manufactured flight blade. This appears to be the case, as no problems were experienced with the Station 83 wiring on either of the two blades used this year.

2.2.2 Blade Sealing

A degradation of the dielectric strength of the main rotor blade heater insulation was noted last year. This was subsequently associated with moisture effects in a high humidity environment as high dielectric strength was regained during the blade storage period since the winter season. In an attempt to seal the blades from moisture ingress, the entire edge of the boot installation was coated with STABOND EP197, a waterproofing epoxy adhesive. This effort was unsuccessful, as degradation of the dielectric strength was experienced again. Blade inspection did reveal some peeling of the sealer, and epoxy materials can absorb on the order of 5 percent moisture.

2.2.3 Stabilizer Bar Heater

The heater boot on one of the stabilizer bar tip weights had become delaminated last year. It did not affect anti-icing operation; however, the boot was replaced prior to Ottawa. No further problem was encountered. This indicates that the delamination was probably a fabrication deficiency of the first item manufactured.

2.2.4 Main Rotor Slipring Wiring

The wiring inside the shaft to the main rotor sliprings was repaired and the wire guide tube (standpipe) that had failed was redesigned and replaced. The new design incorporated a universal joint at the slipring attachment, and no further problems were experienced.

2.2.5 Tail Rotor Nut Torque

The installation of the instrumentation mounting bracket on the tail rotor was modified to prevent the loss-of-torque condition found on the main tail rotor retention nut at the completion of last year's testing. The bracket is attached to the retention nut. Changes were made to reduce free play which had resulted in excessive wear, and fly weights were added which generate a positive torque on the nut under rotational forces. The modifications were effective in preventing any loss in torque.

2.2.6 FM Radio Antenna

A new mounting fitting for attaching the FM whip antenna to its base was designed to increase the antenna tilt away from the tail rotor plane. Two new fittings were fabricated. One provides for 15 degrees of tilt in addition to the standard 15-degree wedge. The other provides for 30 degrees of additional tilt. In the spray rig, no ice was accumulated on the antenna so the effectiveness of the increased angle of 15 degrees that was installed could not be evaluated.

2.2.7 AC Electrical System

The supplier investigated the problem of the delay in the generator coming on the line under cold temperatures and made a modification which demonstrated satisfactory performance in laboratory tests. However, the problem recurred at Ottawa and will require further investigation.

Occasionally, the generator dropped off the line when switching from 230 volts to 160 volts. The overvoltage instantaneous trip time was increased and no further malfunctions were experienced.

2.2.8 Deicing Control

2.2.8.1 OAT Indication

Laboratory investigation of possible sources for the approximately +5 °C error noted last year showed that the signal conditioning amplifier card in the deicing control box was sensitive to moisture. The meter limiting and calibrating resistors were moved to the meter terminals, and, based on laboratory tests, the problem appeared corrected. Flight results at Ottawa showed the same apparent error, so the 5 °C biasing resistor used last year to correct the error partially was reinstalled in the circuit. As shown in Section 4.14, however, this did not provide correct OAT readings. Further investigation is necessary to determine the cause and/or correction for this error.

2.2.8.2 Zone Indicator Lights

The light emitting diodes (LED) used in the deicing controller panel to indicate when the heater was on in any zone were too dim for good daylight detection. These were changed to 28 Vac lamps which were considered to be satisfactory.

2.2.8.3 Logic Controller

Three changes were made in the deicing controller box. A capacitor was added at the tail short over on-time input signal to the controller fault latch of logic controller card No. 8. This was done to minimize the susceptibility of the controller fault to electromagnetic interference (EMI).

A buffer was added between the main short output and the zone counter on card No. 3 to eliminate the zone skip after resetting a main short fault. It was a successful change.

The ground test and automatic update cycles were redesigned to coincide with zone 1 as originally intended rather than zone 6. This change eliminated the precise timing previously required to push the overload test button coincident with the zone 6 light illumination when conducting the short test.

2.2.9 Ice Detection Systems

2.2.9.1 Ice Detectors

The electrical power for the ice detectors was removed from the deicing system master power switch and routed directly to the detector switches. This change allows the ice detectors to remain on when the master power switch is turned off to reset fault indications.

2.2.9.2 Infrared Occlusion System

A ground test switch was added to permit maintenance check of the system without the engine running to supply bleed air.

Three indicator lights were added to display the L, M, and H (light, moderate, and heavy) icing signals from the infrared detector. The other ice detector signal was left on the deicing control panel indicator. Previously, a selector switch was used to control which ice detector was displayed. This change permitted simultaneous observation in the cockpit of both the infrared and the ultransonic ice detectors.

A light was added in the cockpit overhead panel to indicate when the infrared probe deicing heater was on; this aided in ascertaining that the ice detector probe was functioning properly during testing.

Shielded wire was added at the recommendation of the ice detector supplier between the photo-transistor circuits and the comparator circuits of the detector and the rate box as a precaution to minimize EMI susceptibility of the system. Proper system operation was noted with or without the shielded wiring, thus, it appears that shielded wire is not necessary.

2.2.9.3 Ultrasonic Type

The ultrasonic type detector was returned to the manufacturer after the Moses Lake testing to investigate an automatic deice problem experienced towards the end of that program. As a result of that failure investigation, the manufacturer replaced a faulty main amplifier. The value of the R317 resistor was changed also to assure deicing at the 0.040-inch ice thickness. In addition, several changes were incorporated to improve performance at the lower temperatures. These included increasing the heater power from 200 watts to 280 watts.

2.2.9.4 Inferential Type

A third ice detector and icing rate system was installed while the aircraft was at Ottawa. This system was the inferential type that consisted of a sensing head which was mounted adjacent to the right hand ice detector mast on the cabin roof and a rate box and LWC indicator which were temporarily mounted in the cockpit area.

2.2.10 UH-1H Aircraft Configuration

2.2.10.1 IR Suppressor

In order to evaluate the possible effect of the engine exhaust on tail rotor icing or main rotor heater-on times, tests were conducted with and without the exhaust IR suppression kit installed.

2.2.10.2 Generator Drive

It was noted when the ac generator was initially installed that the drive quill was worn from previous dc generator operation. This wear appeared to have increased during the testing at Moses Lake. In order to get a better baseline for evaluating the ac generator installation, the drive quill was replaced with a zero time component prior to the Ottawa program. No evidence of wear was noted at the 25-hour inspection.

2.2.10.3 Rocket Pod

A 19-round, 2.75-inch (M-200) rocket pod was installed on the right-hand rear-mounting point location to permit evaluating icing of the pod. Figure 3 shows the pod installation during a test with individual white polyurethane foam plugs inserted into the front end of the tubes. This was one of the ice protection configurations for the rocket tubes that was tested.

SECTION 3

TEST INSTRUMENTATION

3.1 DATA ACQUISITION SYSTEM

The flight test instrumentation and data acquisition system are described in detail in Reference 2. The instrumentation consisted of strain gages on the main and tail rotor blades and control system for monitoring structural loads, thermocouples on the blades and windshields to measure surface temperatures, and sensors monitoring pertinent ice detector and electrical system parameters. These measurements were recorded on an FM magnetic tape system in the aircraft. Onboard oscilloscopes were utilized to monitor structural loads in real time by an engineering observer crew member. The FM system was used to provide high level outputs from the sensors and thus minimize potential noise problems on the instrumentation signal lines that are necessarily routed from the rotors in close proximity with 3-phase, 400-cycle ac deicing wiring.

The photo panel that recorded engine and general flight condition parameters during previous testing at Moses Lake was deleted for the Ottawa program. The necessary sensitive instruments either replaced standard cockpit instruments or were added and the readings manually recorded.

Two main rotor blades and two tail rotor blades were instrumented for the program, although only one each was installed for testing and the others kept as spares.

3.2 DATA GROUND STATION

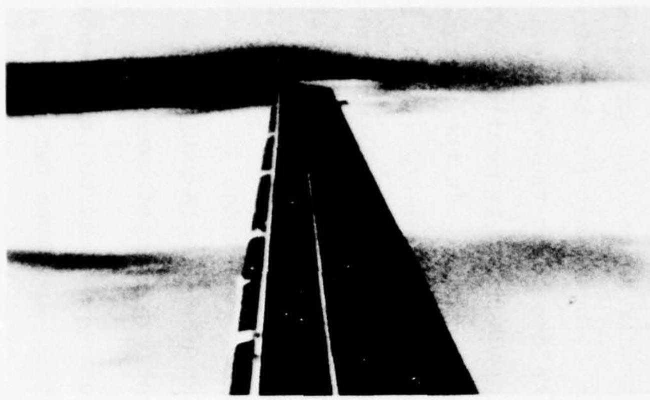
In order to extract data from the FM magnetic tape at the test site, a portable tape playback ground station was utilized. This was a small wheeled cart incorporating the necessary discriminators, a 6-channel brush recorder, and a time code translator. Between each test flight, pertinent data were extracted from the tape and reviewed for proper deicing systems operation and data collection. A similar ground station was used last year at Moses Lake, Washington.

3.3 ROTOR BLADE CAMERA

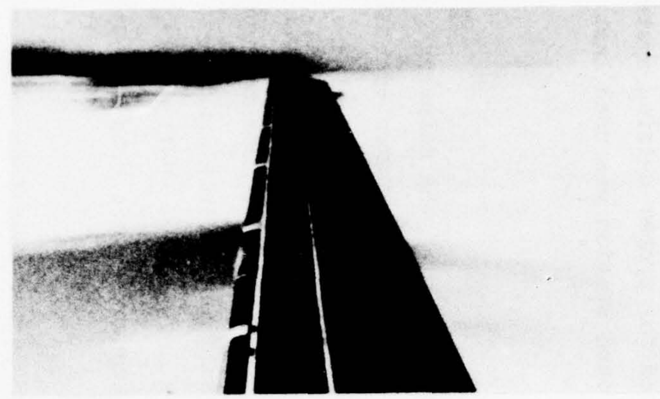
A 16mm motion picture camera was mounted on top of the slipring assembly on the main rotor hub, which photographed the instrumented blade in-flight. During the Moses Lake program last year, the heated window in front of the camera lens did not remain clear in icing conditions, and no pictures were obtained of ice on the blades. Changes were made to improve the window heater control, and a casing of insulating material was installed around the camera body to increase its heater efficiency. Following these changes, reasonably good pictures of deicing sequences were obtained at the end of the Ottawa program.

Figure 4 shows a sequence typical of the best frames from a deicing cycle accomplished while operating in the spray rig just below the cloud. For photographic purposes, the blades were painted flat black with white stripes outlining the heater boundaries of the six zones. An additional 0.5-inch-wide spanwise white stripe was added 6 inches aft of the heater boundary to provide a chordwise dimensional reference in the picture. It was found that unless there is a dark enough background to provide sufficient contrast, ice cannot be seen on the leading edge. In the pictures shown in Figure 4, the ice is visible only out to Station 102 (.35R), which is the zone 4/zone 5 boundary. Outboard of this, the white background of the snow at the spray rig and the small image size in the 16mm film make the assessment of ice accretion difficult to impossible. In addition, the chordwise coverage of ice on the upper surface of the blade is a minimum in the hover flight condition (relatively high blade angle), which adds to the difficulty in detecting blade ice with the top-mounted camera.

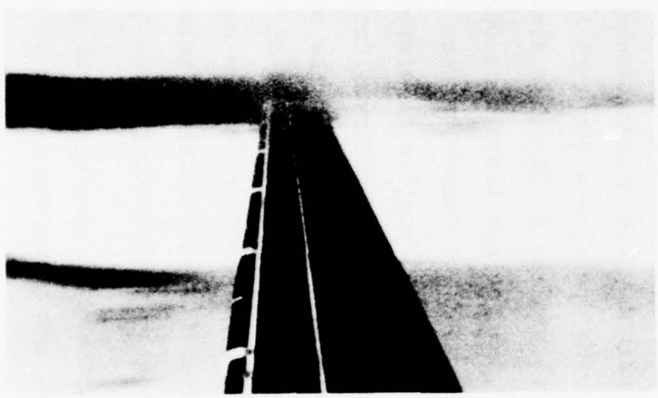
The camera was geared to run at 75 frames per second but, apparently due to the low temperatures, ran at approximately 40 frames per second,



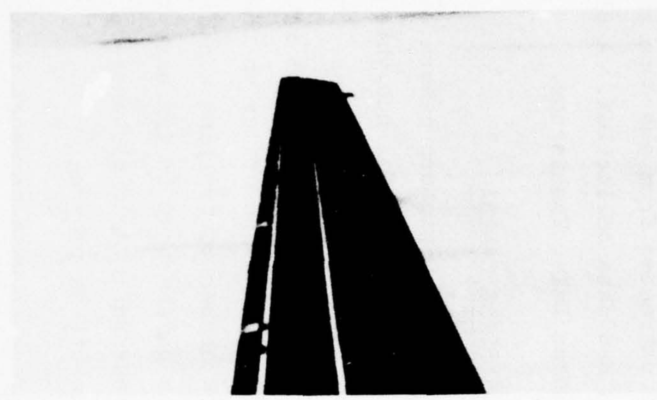
a. Deicing Complete to Station 83 (Mid Zone 5)



b. Inboard Half of Zone 5 Shedding



c. Deicing Complete to Zone 6



d. Full Span Deicing Cycle Complete

Figure 4. Blade Deicing as Photographed with Hub-Mounted 16mm Camera

resulting in 7-8 frames per rotor revolution. Additional improvement of camera heater efficiency appears to be necessary.

3.4 THERMOCOUPLE TEMPERATURE MEASUREMENTS

Evaluation of the thermocouple data obtained during the test program showed that there were two problems with the measurement accuracy. It was found that the data could not be used for absolute temperature determination because of a random and unexplainable zero shift. The thermocouple measurements are the temperatures of the windshield and the main and tail rotor blade surfaces. The zero shift that occurs in the transfer from external to internal dc electrical power appears to be constant for a given test but varies in magnitude from test to test. Therefore, there was no way to determine and apply a suitable correction.

All troubleshooting checks that were made showed there was no problem on external dc power. The previous calibrations were verified and using these, good agreement was obtained between stable surface temperatures recorded in the warm hangar or outside at low ambients and readings from a mercury thermometer. However, when operating on ship's dc power, there was no correlation between measured temperatures and calculated surface temperatures based on air temperature measurements. The error varied as much as 30 $^{\circ}$C and was generally colder than the actual temperature. However, it was found that the change in surface temperature with time on a given test agreed with independently measured air temperature changes. Also, the surface temperature rise (ΔT) during deicing heater operation agreed closely with theoretical calculations. Thus, it was concluded that the data could be used for temperature changes to aid in determining the proper heater-on time for deicing. This same problem was indicated in last year's test data but was attributed to the many electrical and EMI disturbances experienced during the 1975/1976 testing due to the chaffed wiring inside the rotor shaft.

The other problem which became apparent in evaluating the blade temperature rise data (ΔT) was that different changes were measured with the two instrumented main rotor blades. The thermocouples were installed on the first instrumented blade (used last year) directly on the surface. Calibration checks had indicated an accuracy problem associated with the common electrical ground of the erosion shield that was corrected by using a separate and independent power supply for each blade thermocouple. The second blade that was instrumented had a thin insulating material installed between the thermocouple and the blade surface to provide isolation from ground. The data from the two differently instrumented blades showed that the insulated thermocouples, as could be expected, measured a lower ΔT for rapid transient temperature changes, such as a heater cycle, than the uninsulated or grounded thermocouples. Data for both installations are shown in Section 4.13.

Most of the testing during the Ottawa program was done with the insulated thermocouple blade. However, the blade was replaced when heater-to-shield electrical shorts were experienced and the grounded thermocouple blade was installed. In determining the blade surface temperature rise required for deicing from these data, a correction was determined and used where necessary to convert insulated thermocouple data to grounded thermocouple data. The latter is obviously considered to be more representative of the proper surface temperature.

The tail rotor blades were instrumented with grounded thermocouples, therefore, no adjustment was necessary. Section 4.13 discusses the use of the blade temperature data in determining the required heater-on times based on surface temperature changes.

SECTION 4

DISCUSSION AND RESULTS

4.1 SPRAY RIG TEST CONDITIONS

The objective of the spray rig test program was to evaluate the effectiveness of the ice protection system, particularly rotor blade deicing, over as wide a range of air temperatures and moisture conditions as possible. The primary area of interest was between outside air temperatures (OAT) of 0 °C and -20 °C and at the liquid water content (LWC) for each temperature as recommended in Reference 1 for the continuous maximum condition (stratiform clouds) for 15 micron droplet size. This LWC versus OAT boundary agrees with FAR Part 25 requirements and is shown in Figure 5 compared with the data points of the UH-1H testing. The spray rig droplet size was reported to be 30 microns and therefore offers a somewhat more conservative basis than would be encountered in natural icing. Also shown in Figure 5 (for reference) are the test conditions covered during the previous UH-1H simulated icing testing at Moses Lake, Washington, during the winter of 1974/1975, using the U.S. Army CH-47 Spray Tanker (HISS). The spray tanker's droplets are reported to be considerably larger, i.e., approximately 150 microns.

It can be seen in Figure 5 that the boundary conditions were adequately investigated. Additional testing within the boundary at lower liquid water contents (LWC) would have been desirable.

4.2 SPRAY RIG TEST PROCEDURE

The test procedure used was to immerse the aircraft in the cloud for an estimated time interval to collect a 0.25-inch thickness of ice on the rotor blade at the 50-percent span point. An engine shutdown was made and

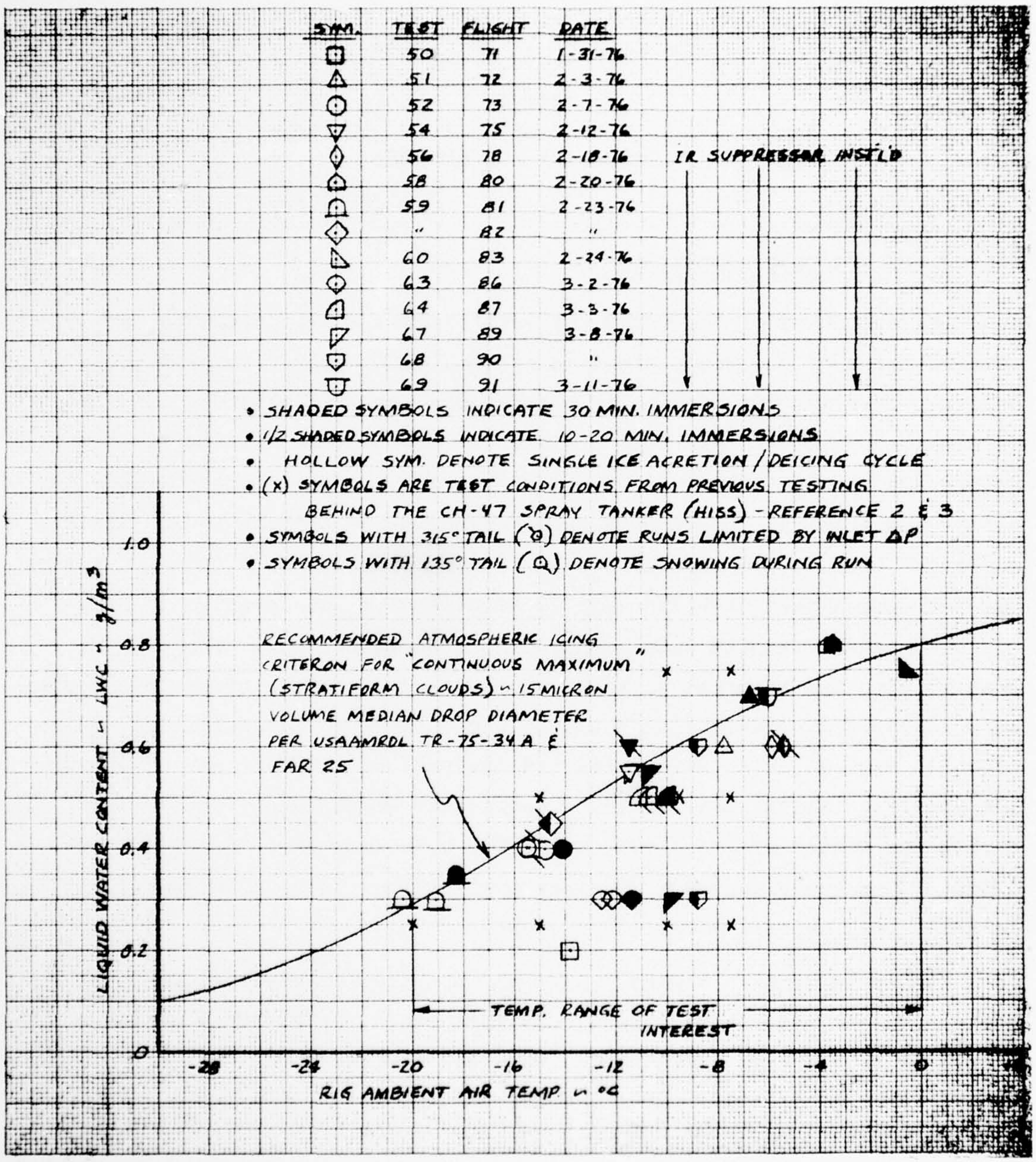
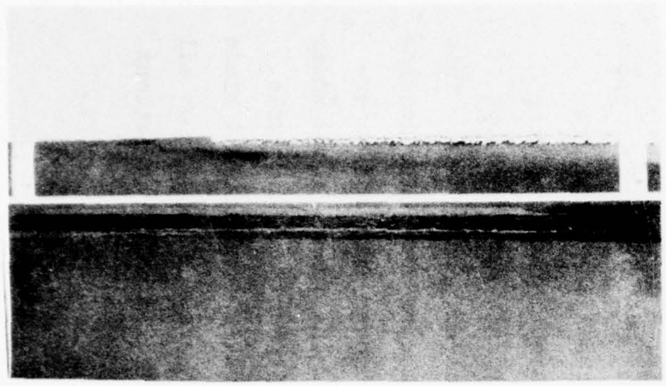


Figure 5. Summary of UH-1H Test Conditions in the Ottawa NRC Spray Rig

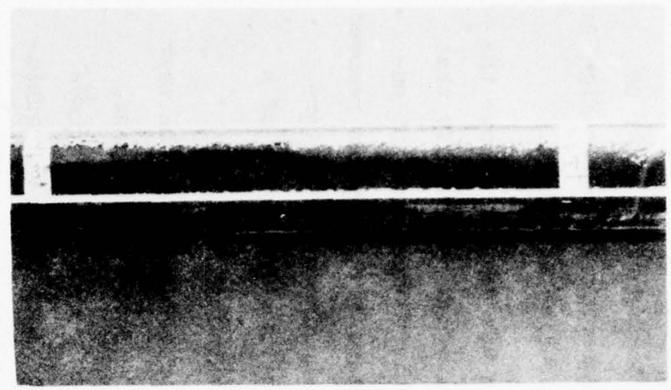
aircraft and rotor blade icing was visually inspected. If necessary, repeat runs were made and the ice accretion time was adjusted to establish the off-time for the 0.25 inch of ice. Allowances in run time had to be made for the wind velocity, gustiness, and rotor immersion factors. Figure 6 shows blade ice spanwise and chordwire distribution at -11 °C.

Between ice accretion runs, the deicing system was used to remove the ice for the next run. A shutdown inspection was made again to verify that the blades where clean prior to the next run. If the blades were not entirely clean, the deicing cycle was repeated or the residual ice was removed by hand, using a mallet and/or scraper. Thus, in the process of determining the proper off-time for 0.25 inch of ice, deicing evaluation of a range of ice thickness and spanwise coverage was obtained.

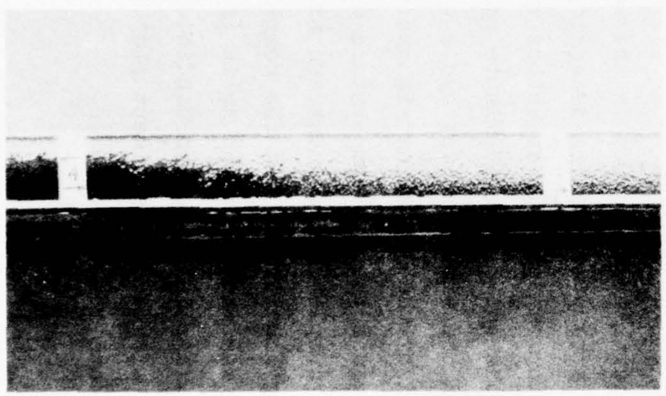
Once the time to accrete 0.25 inch of ice was determined for the test LWC and the single-cycle blade deicing appeared satisfactory, a nominal 30-minute run in the spray cloud was made, periodically cycling the blade deicers at the previously determined off-time interval to simulate continuous operation in an icing environment. This resulted in 5 to 12 deicing cycles, depending on test LWC in a 30-minute cloud immersion. All deicing cycles were initiated manually in the semiautomatic mode. Automatic operation was not attempted, pending determination that the icing condition inputs from the onboard ice detectors and other system parameters were proper. At the end of the 30-minute period, the aircraft was moved out of the cloud and the final deicing cycle was accomplished in clear air. This is considered by the NRC spray rig operator to be a more difficult deicing condition because the ice temperature drops when removed from the supercooled water droplet environment and simulates emerging from a cloud under natural icing conditions. At the completion of this last deicing cycle, the aircraft was shut down and again inspected visually for residual blade ice, runback, air inlet screen condition, and general ice collection on all parts of the aircraft. Pertinent photographs were taken and observations recorded on data sheets.



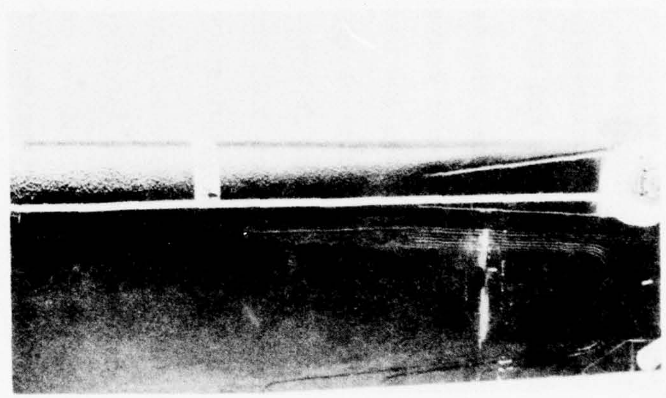
Zone 2



Zone 3



Zone 4



Zone 6

Figure 6. Rotor Blade Ice Distribution with 1/4-inch at 50% Span-Blade Lower Surface Following 3 Minutes at -11°C and 0.55 g/m^3 LWC

The deicing heater-on time schedule used initially was approximately the same as that used during the previous test program at Moses Lake. This schedule had appeared to give satisfactory results in that program although the evaluation of deicing effectiveness was based solely on in-flight observations from a chase helicopter. These nominal on-times were approximately the mid-point of the adjustment range for each control. The initial deicing results indicated runback, especially on the inboard blade area. On subsequent runs, the on-time was progressively reduced by selecting a warmer-than-ambient temperature setting with the cockpit outside air temperature (OAT) control. This "offset OAT" procedure provided a convenient test method for reducing the on-time versus OAT schedule. Alternatively it could have been accomplished with the setscrew adjustments available.

Because of the many variables which had to be evaluated, the deicing system was operated at 200 Vac for most of the testing to expedite optimizing the on-time. One run was made using the alternate voltages of 160 and 230 Vac in order to permit determining the on-times at these voltages which produce the same peak surface temperatures as for 200 Vac.

Operations in the NRC spray rig showed that the data gathered and the conclusions drawn are subject to careful analysis and evaluation of the test environment. It was found that for acceptable spray cloud operation with the UH-1H, the wind velocity should be a minimum of 10 mph. At lower wind velocities, satisfactory immersion of the rotor and the aircraft cannot be obtained within pilot visibility requirements. The difficulty in maintaining or obtaining satisfactory aircraft immersion in the spray cloud resulted in inconsistent spanwise blade icing distribution, permitted only a partial or momentary evaluation of the ice detector systems, and limited forward and aft fuselage (tail rotor) icing evaluations. Even at higher wind velocities, these factors were still present and repeat runs would be required to obtain sufficient data for an adequate quantitative evaluation. Figure 7 illustrates two typical variations in a spray cloud at low wind velocity. These pictures are during the same test run at -3.5 °C and LWC = 0.8 gram per cubic meter in a 7-mph wind. Neither condition is considered to be good. Figure 1 illustrates a more desirable

Figure 7. Spray Rig Cloud Variations with 7 mph Wind, -3.5°C, 0.8 g/m^3 LWC

cloud condition although the difficulty in obtaining full aircraft and rotors immersion is still apparent. However, spray rig testing does provide a good baseline for icing investigations and permits data collection in a minimum of time.

4.3 MAIN ROTOR BLADE DEICING

Overall, the deicing of the main rotor blades was satisfactory under all conditions tested. During the Ottawa program, 18 individual ice accretion conditions were inspected visually before and after a deicing cycle to evaluate deicing effectiveness. A total of 121 deicing cycles were accomplished under icing conditions.

Although they are considered not to be of enough magnitude to preclude testing in natural icing, there were two discrepancies in main blade deicing: mild runback in the inboard portion of the blade (20 - 40 percent span), and residual leading-edge ice of varying magnitude in the same area. The latter and possibly both appear to be caused by the manufacturing joint in the heater and erosion shield at Station 83 (29 percent span). At this station, two design features are concluded to be responsible for the imperfect deicing. The erosion shield material thickness changes from 0.016-inch aluminum over the inboard "doubler" area of the blade to 0.030-inch steel. This difference in skin thickness results in a step in the blade surface contour that opposes the spanwise shearing action of ice separation. In addition, there is apparently a 1-inch-wide cold band (lack of adequate heater coverage) caused by the wraparound conducter that carries the C phase ac current from the upper blade surface to the lower surface. This joint is approximately the midpoint of zone 5. Figures 8 and 9 are examples of the residual ice on the blade in this area after deicing. The white appearance of the ice at the joint shows the ice has separated (or been melted by the heater) and has an air space under it but was still retained on the blade. Many times the same area would be completely or almost clear of residual ice as shown in Figures 10 and 11. It was found also that the small bumps caused by the strain gage and thermocouple installations impaired deicing. The noninstrumented blade

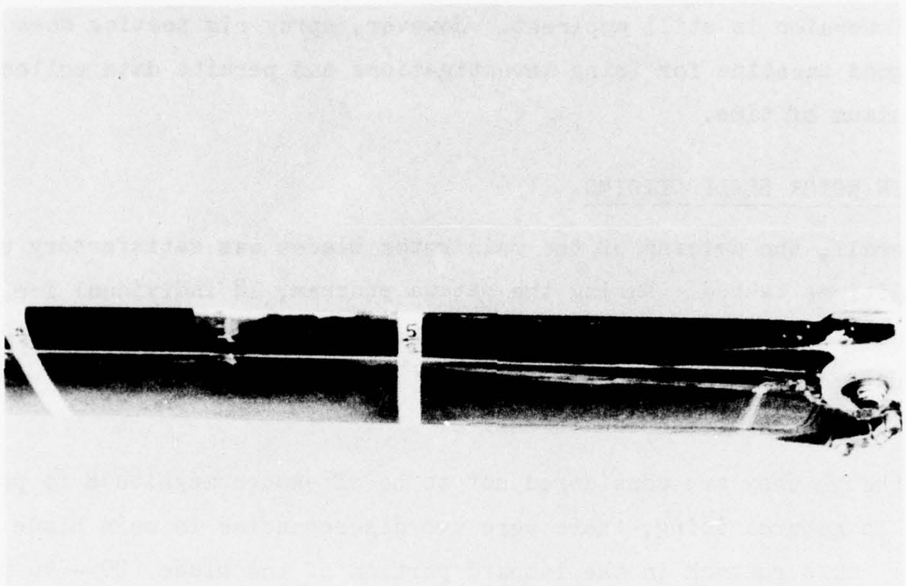


Figure 8. Residual Ice in Zone 5 After Attempting to Induce Runback With Three Deice Cycles at -14°C and 0.45 g/m³ LWC

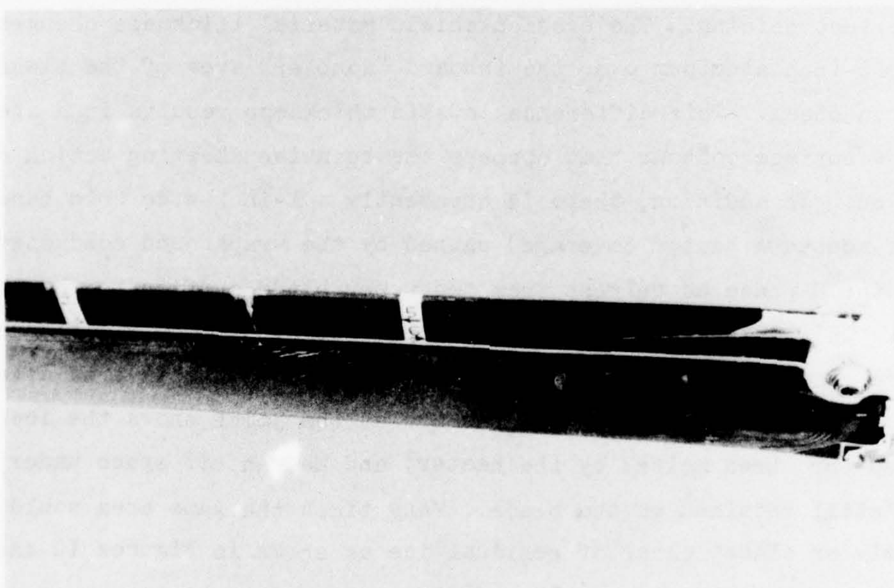


Figure 9. Residual Ice in Zone 5 at -10°C

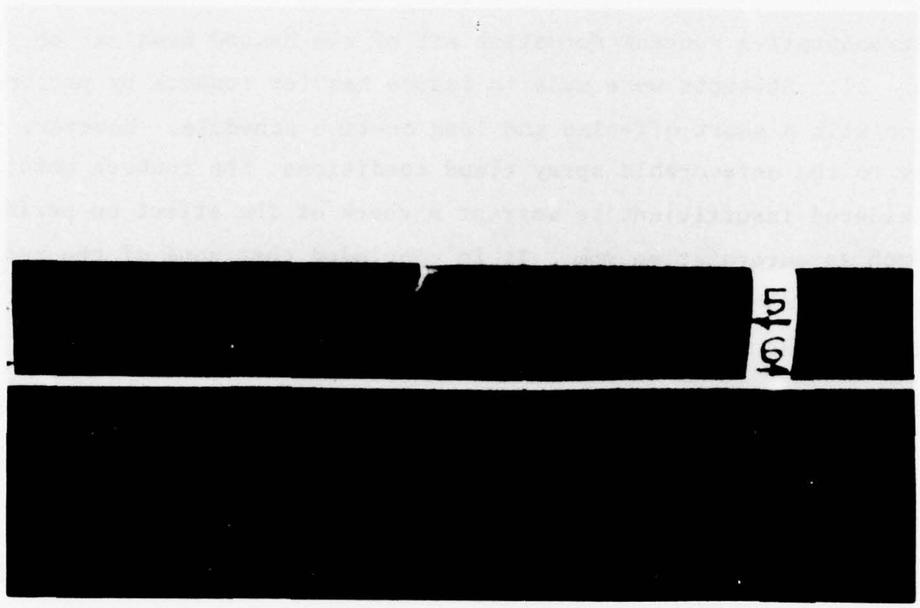


Figure 10. Zone 5 Condition after 30-Minute Run at -15°C, 0.4 g/m³ LWC

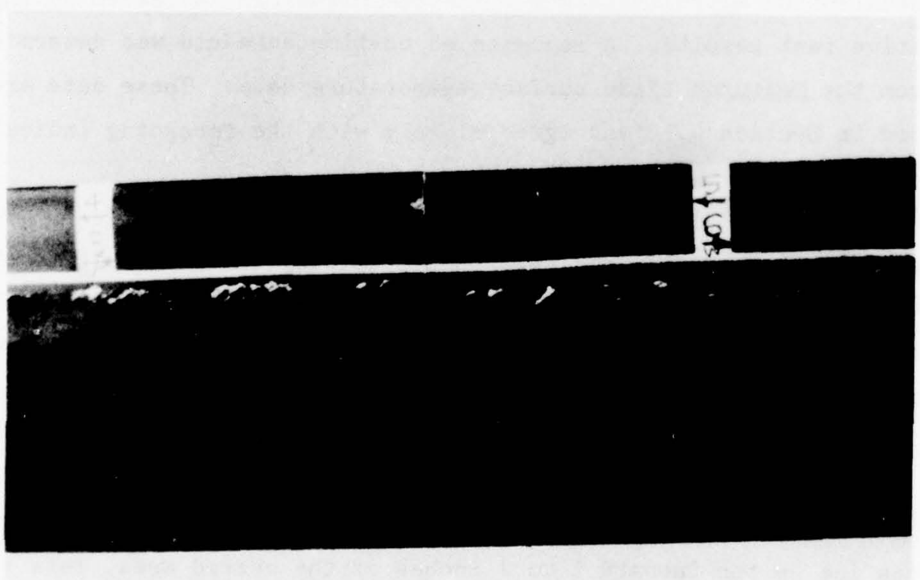


Figure 11. Zone 5 Condition and Runback After 30-Minute Run at -11°C and 0.55 g/m³ LWC

was always cleaner than the instrumented one which had residual ice wherever the surface was uneven.

Representative runback formation aft of the heated area can be seen in Figure 11. Attempts were made to induce heavier runback by prolonged operation with a short off-time and long on-time schedule. However, due possibly to the unfavorable spray cloud conditions, the runback obtained was considered insufficient to warrant a check of the effect on perform, ance, such as autorotation rpm. It is concluded that none of the runback experienced to date would be significantly detrimental to any flight condition such as cruise or autorotation.

Figure 12 shows the heater-on times that were evaluated during the program. As mentioned, the on-times were reduced by setting the OAT control to a warmer than actual temperature. This OAT offset method effectively shifted the on-time versus OAT schedule line downward and provided an expeditious way to make adjustments from run to run at the spray rig. Note on Figure 12 that only 2 points resulted in unsatisfactory deicing because of too short a heater-on time. An optimum on-time schedule versus OAT, equivalent to approximately a 10-degree offset, is indicated by these qualitative test results. A recommended on-time schedule was determined also from the measured blade surface temperature data. These data are presented in Section 4.13 and agree closely with the foregoing indications.

4.4 TAIL ROTOR BLADE DEICING

The effectiveness of tail rotor blade deicing was difficult to establish during the spray rig testing. The tail rotor would only accrete ice when the wind velocity provided a good cloud which reached the tail rotor. The available data, therefore, were extremely limited. There were ice accretions observed that varied in thickness from 0.03 inch to 0.20 inch at the midspan point. The outboard 12 inches had always self-shed. After deicing, the heated area of the blade was almost always clean. Sometimes there was ice on the inboard 1 to 2 inches of the heated area. This ice was an extension of the ice on the inboard unheated portion of the blade. Apparently this inboard ice would self-shed after a modest thickness had

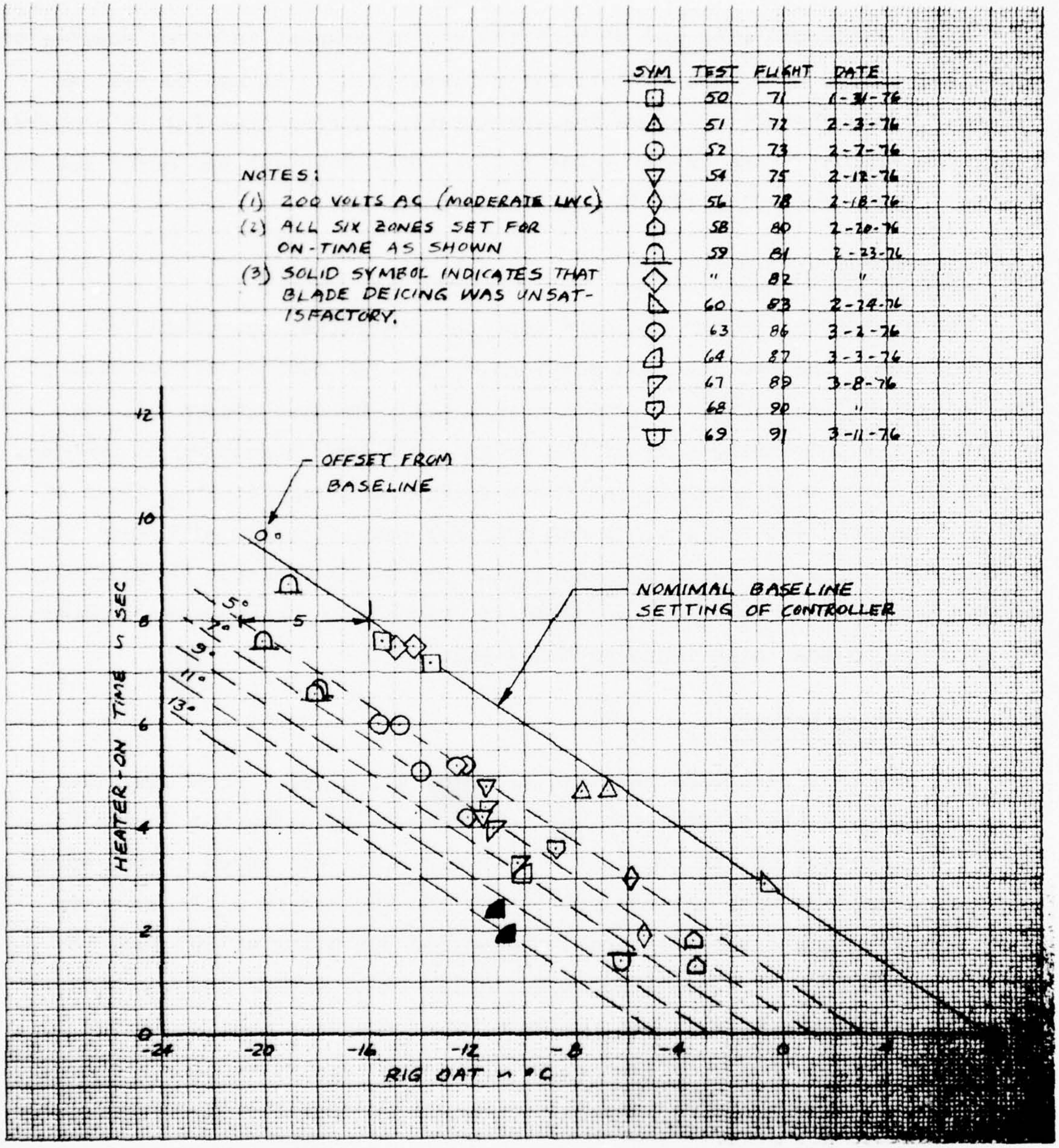


Figure 12. Summary of Main Rotor Blade Heater-On Times Used in Ottawa Test Program

accreted, since the entire blade was clean at least 50 percent of the time. None of the shedding was noticeable to the flight crew.

Tests conducted with and without the engine exhaust infrared suppressor installed showed no effect on tail rotor blade icing. As can be seen in Figure 2, from the aft fuselage ice accumulation during freezing rain operation, the exhaust plume is deflected by the rotor downwash and never reaches the tail rotor even with the IR suppressor installed.

4.5 STABILIZER BAR ANTI-ICING

The anti-icing heater blankets kept the stabilizer bar adequately clear of ice. The two unheated portions at the jam nuts on either side of the tip weights collected ice which occasionally bridged around the tip weight on the retreating side of the weight, but this presented no problem. Figure 13 shows this condition as found following 5 minutes in a cloud at -12.6 °C and LWC = 0.3 g/m^3. It did not look significantly different after a 30-minute exposure, which indicates that the ice self-sheds periodically without any detectable effect on aircraft operation. This agrees with the forward flight test experience at Moses Lake.

4.6 WINDSHIELD HEATING

The heated windshields remained clear at all times. An attempt was made to evaluate the minimum heating requirements by using the Variac to reduce the voltage on the copilot's windshield. All but three of the spray rig runs were made with the control set at 100 Vac and no difference was noted between it and the right-hand windshield operating at 200 Vac. However, there was never a significant accumulation of ice on the unheated edges of either panel which was typical during previous testing behind the HISS tanker. Thus, the test results are not conclusive due to the fact that the windshield did not get exposed to a significant icing environment in the spray rig.

4.7 ENGINE AIR INLET SCREEN ICING

The engine air inlet screens of the standard UH-1H do not incorporate any special provisions for ice protection. No changes were made to the air inlet configuration as part of the icing test modifications because previous icing test experience with the UH-1H has not indicated a requirement; however, the engine air inlet plenum was instrumented to monitor ΔP. Ice did collect on the screens in varying degrees during all of the spray cloud runs, but the pressure drop across the screens generally did not exceed a ΔP of 2 to 5 inches of water. If it appeared necessary, the screens were removed between runs and the ice melted off in a warm building prior to the next run.

On four of the 30 runs in the spray cloud, a rapid increase in ΔP was experienced and reached the test limit of 18 inches of water, which resulted in premature termination of the planned run. It was snowing during three of the four runs on which limit ΔP was reached. This may have been contributory.

Figure 14 shows an ice accumulation on the air inlet screens that looks significant but produced only a negligible change in ΔP. Figure 15 shows the heavy inlet screen icing that resulted in high ΔP. A rapid increase (15 seconds) in screen ΔP was noted after 5 minutes of operating at only 25 psi engine torque. The condition of the inner screen protecting the air particle separator for the same run is shown in Figure 16.

It was planned to check inlet icing in snowing conditions alone (not in the spray cloud) but the opportunity was not available. On one test, the aircraft was hovered around the airport ramp, stirring up 3 inches of freshly fallen snow with the rotor downwash. Although the aircraft was nearly obscured in the agitated snow, no change in inlet ΔP or ice accumulation on the inlet screens was experienced.

The operating conditions under which high ΔP was experienced are noted on Figure 5 by special symbol coding to show their relationship to each other and the other test conditions. This shows that no specific correlation with LWC, OAT or snow conditions is apparent. The one run with high ΔP with no snow present (Flight 82) was a low wind velocity condition where the cloud was very dense and enveloped the aircraft so

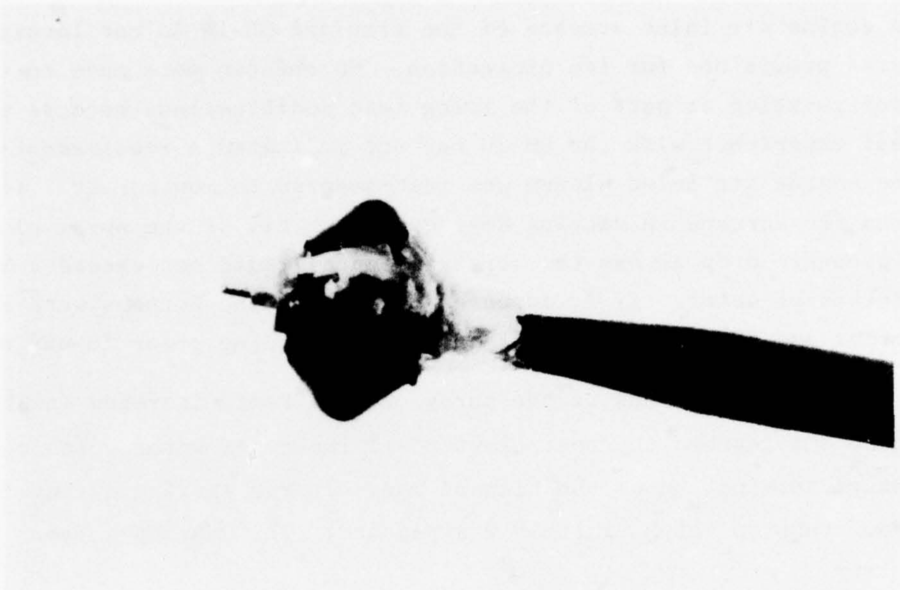


Figure 13. Typical Ice Accretion on the Unheated Portion of the Stabilizer Bar Tip Weight Installation

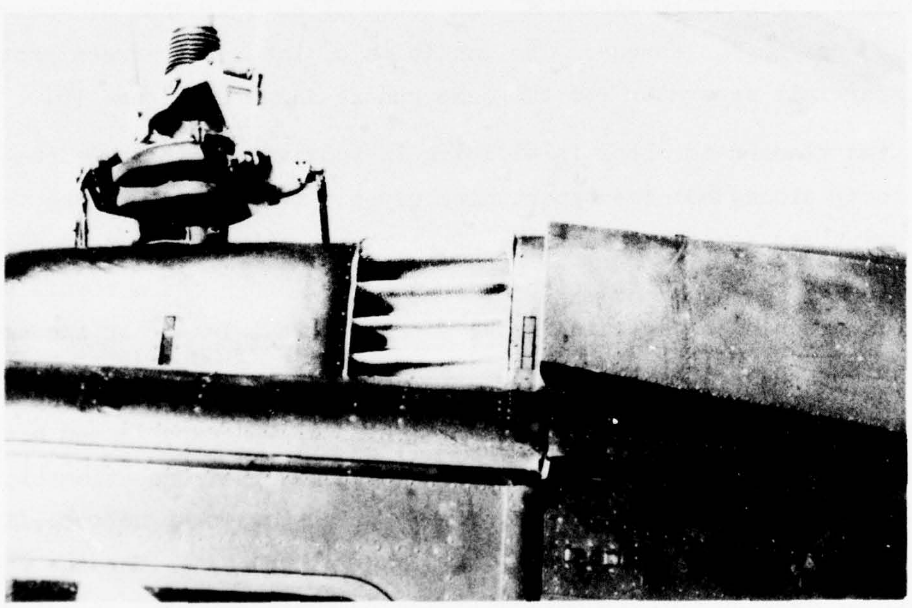


Figure 14. Engine Air Inlet Screen Condition After 30 Minutes in Cloud at -18°C and 0.35 g/m^3 LWC

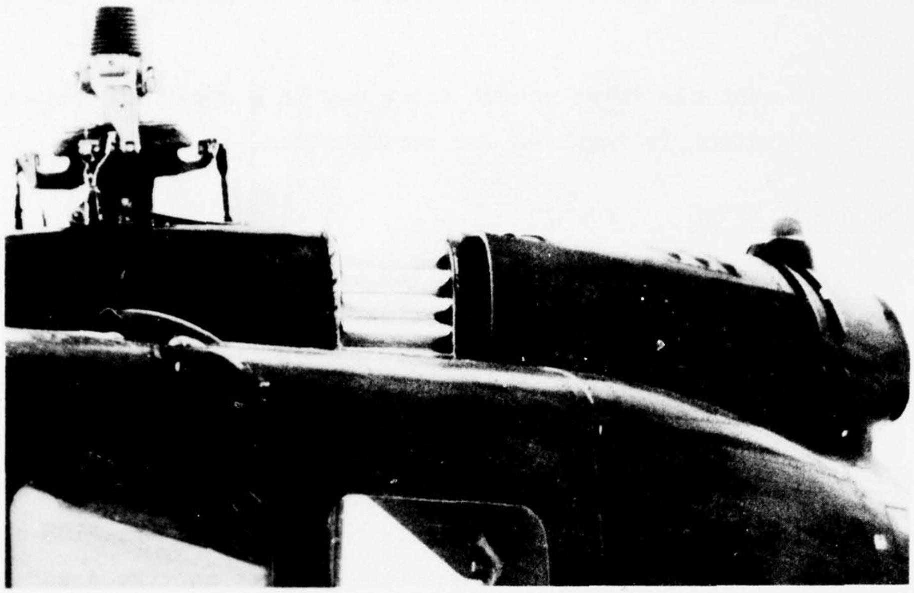


Figure 15. Engine Air Inlet Screen Condition After 5 Minutes in Cloud at -15.5°C and 0.4 g/m^3 LWC While Snowing

Figure 16. Engine Air Inlet Inner Particle Separator FOD Screen Icing after 5 Minutes at -15.5°C and 0.4 g/m^3 LWC While Snowing

completely that the run had to be conducted with the aircraft resting on the ground.

It is felt that the inlet screen icing may be a spray rig phenomenon, but further evaluation is required for verification.

4.8 UNPROTECTED AREAS

There were no unprotected areas on the aircraft that appeared from the Ottawa testing to require ice protection. The results of the rocket pod testing are not included in this report, as U.S. Army Missile Command personnel were on-site and monitored that activity.

4.9 STRUCTURAL LOADS AND VIBRATION

As was found in the initial testing last year behind the HISS spray tanker, neither the ice accretion on the rotor blades nor the shedding of the ice produced a detectable change in rotor structural loads. An on-board engineering observer monitored key parameters in real time during each run. In addition, main and tail rotor flapwise and chordwise bending moments and pitch link loads were recorded on the magnetic tape and the traces were reviewed between each test.

During some of the deicing sequences, the flight crew reported that specific zone ice shedding could be felt, but this was not detectable on the transmission lateral vibration trace. The flight crew also reported that ice shedding during deicing could occasionally be observed in the forward quadrant. Sometimes the ice would shed with relatively high velocity and other times it would seemingly float in larger light pieces down in front of and on the right side of the aircraft within the rotor circle.

4.10 DEICING SYSTEM OPERATION

Operation of the deicing system was considered to be excellent. Very few false fault lights were experienced in flight. The ones that occurred are discussed in Section 4.15. Two actual electrical grounds or shorts in the blade heaters were experienced in flight, and both were indicated on the control panel by the ac ground light.

The change in the heater zone lights to 28 Vdc lamps in place of the light-emitting diodes eliminated the difficulty in observing zone operation under daylight conditions that was reported from previous test experience.

All blade deicing was accomplished in the semiautomatic mode. The flight crew manually set the controller for the desired voltage and heater-on times and initiated the deicing sequence with the main and tail switches. Automatic operation with the system accepting air temperature and LWC inputs from the installed on-board sensors was not attempted. The system OAT gave random readings in hover, and the indicated LWC was always lower than the spray rig setting because the detectors were located on the forward end of the cabin roof where they were not immersed in the cloud and thus were not exposed to the proper cloud environment. It appears that testing in the automatic mode can only be accomplished under natural icing conditions or in a simulated icing cloud that fully and uniformly envelops at least the rotor and the ice detectors.

One change in design concept of the deicing controller that appears necessary is the method of scheduling the proper off-time between deicing cycles. The present configuration provides for off-time as a function of LWC with a 5-minute muting circuit controlling an update to reflect changes in LWC. This muting feature is intended to minimize ac generator voltage changes in response to short duration and frequent changes in LWC. In order to maintain a reasonable uniformity in the amount of ice accretion on the rotor blades between deicing cycles and yet accommodate the changes in LWC that actually are experienced under natural icing flight, the controller needs to integrate LWC with respect to elapsed time and provide a deice signal pulse when a predetermined value is reached. This will result in the off-time varying nonuniformly during flight through a nonuniform icing environment. An approach to this type of system was evaluated during the Ottawa testing and is described in Section 4.11.

4.11 ICE DETECTORS

As stated previously, two ice detector/icing severity meter designs were installed on the test aircraft for evaluation. These were an ultrasonic type and an infrared occlusion type. These were mounted on top of 12-inch-high masts on top of the aircraft cabin. Both detectors had aspirators to provide increased airflow over the sensor for operation in hover flight. The aspirator on the ultrasonic type detector is removable.

A third ice detector and rate meter utilizing the inferential technique was installed during the program. It did not incorporate an aspirator system, and therefore, it did not provide valid indications in hover. It was to be evaluated during the planned natural icing flights but these were not accomplished.

Figure 17 shows the installations of all three types after a series of cloud immersions at -12 °C in a 15-mph wind.

Cockpit indications and test tape recordings showed that both detector systems functioned properly, whereas during the Moses Lake testing last year the infrared type did not indicate in flight at all. Because the nose of the aircraft could not be fully immersed in the cloud in order to permit the pilot to maintain outside visual reference, both of the rate meters usually indicated lower than the LWC setting for the cloud. Thus, a quantitative accuracy evaluation could not be made. An overall evaluation based on flight crew reported observations is shown in Figure 18. This shows that the ultrasonic type generally read a lower LWC condition than the cloud. Based on these data, the infrared type appears, in general, to correlate with the cloud LWC. Both were supplied with the same bleed airflow at approximately 40 to 45 psi and 70°C. Further evaluation on a more quantitative nature is required.

One discrepancy was noted in operation of the ultrasonic type's rate meter. It appears that the hold period of 16 to 17 seconds on the rate indication while the detector probe deiced and cooled in preparation for the next accretion period was insufficient, as the rate indication would decrease to zero periodically. This was not noted during the previous winter's

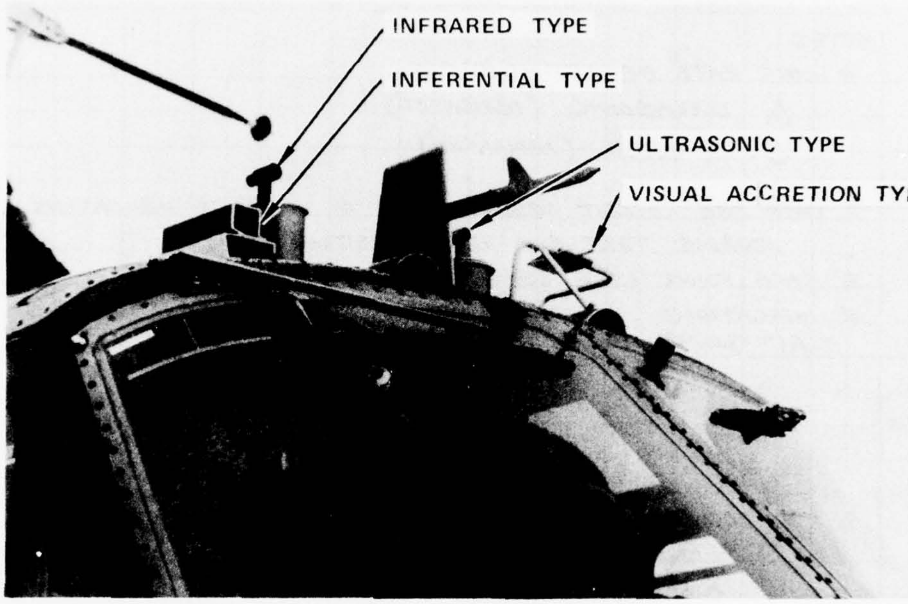


Figure 17. Ice Detector Installations on the Test Aircraft

testing and can be corrected. The amount of ice accretion between probe deice cycles was set for 0.040 inch thickness. The system can be adjusted to trip at as low as 0.020 inch thickness. This would permit deicing within the present hold time or the hold time can be increased. In order to use the ratemeter information to schedule blade heater off-time, a shorter updating time would provide greater accuracy and therefore be more desirable.

4.11.1 Use of Ice Detector to Program Off-Time

In preparation for natural icing flights and ultimately automatic operation of the ice protection system, a method of scheduling the proper off-time using an ice detector signal was evaluated. The present controller configuration programs off-time as a function of LWC with a 5-minute muting circuit between updates. This configuration would not control the amount of blade ice accretion between deice cycles uniformly in an icing environment that changed very much or very often. An accretion type of an

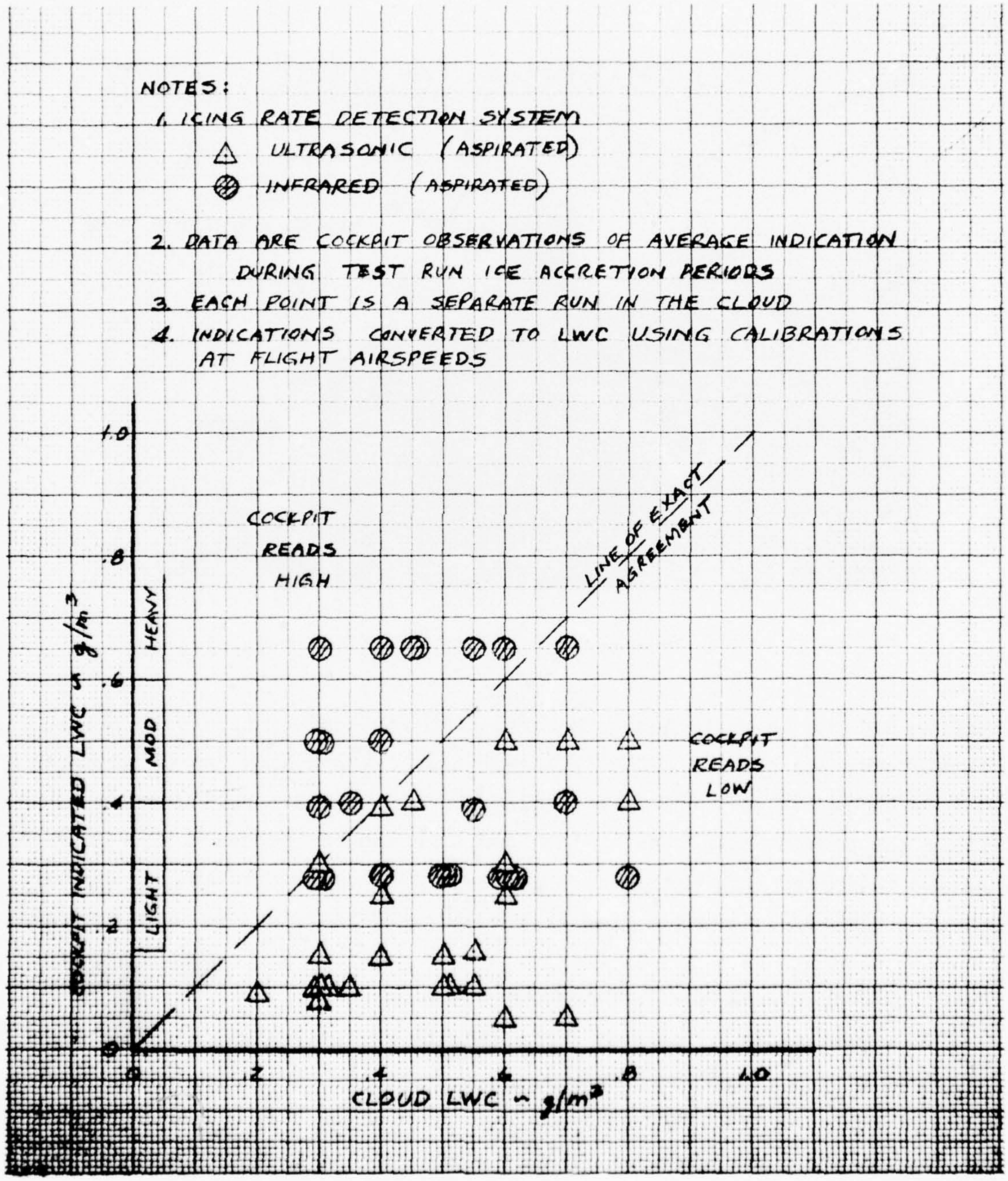


Figure 18. Cockpit Indicated LWC vs Spray Cloud LWC

ice detector deices each time a fixed amount of ice is collected and thus cycles at an interval that varies depending on the LWC or icing severity.

For the evaluation, a digital counter was added to the cockpit instrumentation that registered each deicing cycle of the ice detector sensor as a count. The number of counts that were registered during the time to accrete 0.25 inch of ice on the rotor blade was noted during the off-time interval for two 30-minute runs in the spray cloud at two different LWC values. The infrared detector signal was used for this purpose because it had the shorter cycle time of the two systems available and thus provided the greatest accuracy.

From the two runs it was determined that although the total counts for 0.25 inch of blade ice were not exactly the same for the two LWC's, they were reasonably close (9.0 for 0.55 g/m^3 and 9.6 for 0.3 g/m^3). A 30-minute run at an OAT of -11 $^{\circ}C$ was made with the spray rig operating at an unknown LWC. To further simulate a natural icing encounter, the LWC was changed during the run to a different LWC. The run was completed uneventfully with the blades deiced each 10 counts. Good correlation was found between the off-times that resulted and those determined from earlier tests. This procedure warrants further test evaluation and points out another use of the spray rig; namely, that of gaining confidence in onboard instrumentation and ice protection systems prior to natural icing testing.

4.12 OFF-TIME DETERMINATION

As described in Section 4.2, the initial testing at each cloud LWC consisted of runs to determine the time to accrete 0.25 inch of ice on the main rotor blades at the midspan point. The time thus determined was used as the off-time between deicing cycles when operating in the cloud for 30 minutes. Figure 19 shows the test data obtained from these ice accretion runs. All measured ice thicknesses were not the desired 0.25 inch and not always available at the midspan point because of self-shedding and nonuniform cloud immersion. Appropriate corrections were applied to the

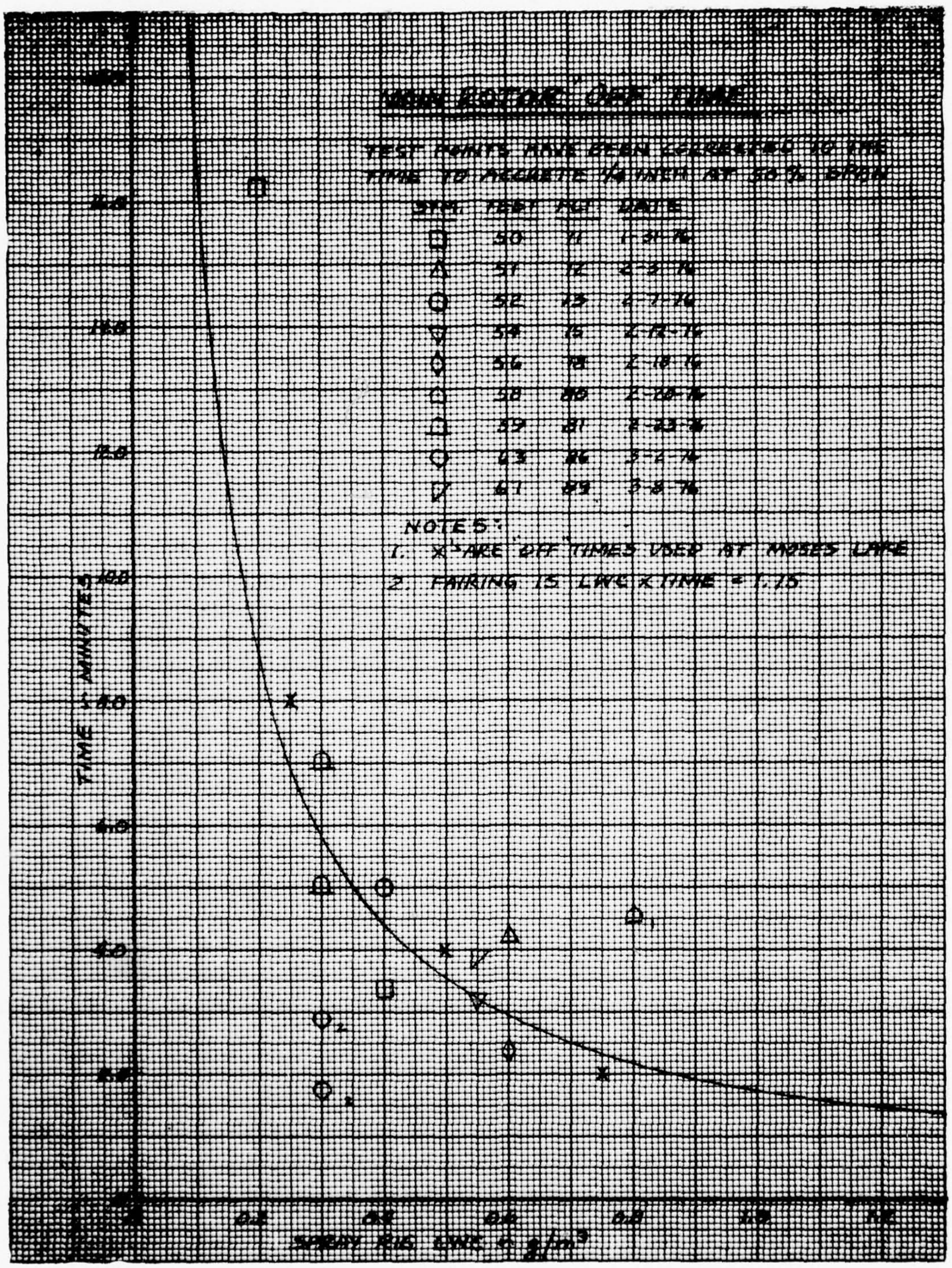


Figure 19. Main Rotor Off-Time

measured data using the local velocity ratio to correct thickness for span location and the desired-to-measured ice thickness ratio to correct the time. The fairing shown is for a product of LWC and time (in minutes) equal to a constant of 1.75. This obviously assumes that the catch efficiency is constant and independent of temperature. Figure 19 also shows the accretion times used during the HISS test program last year. As might be expected from the many variables in the spray rig tests, considerable data scatter is apparent. An attempt was made to associate the scatter with temperature and/or wind velocity but no positive relationship could be established. The points indicated by a subscript 1 and 2 were from runs with marginally light and relatively high wind speeds, respectively. Discounting these points, the curve is a reasonable basis for use in future testing of the UH-1H aircraft. It appears to be valid for in-flight or spray rig operation.

A similar evaluation of tail rotor ice accretion data was tried but there is little confidence in the indications from the results. An assumption was made that the criterion for thickness would be a scaling of the 0.25 inch on the main rotor on the basis of main to tail blade chord dimension ratio. This results in a desired thickness of one-tenth of an inch at the midspan point of the tail rotor blade. The available data for the tail rotor are shown in Figure 20. The data are extremely limited and show considerable scatter although the relative scatter is interestingly very similar to the same points for the main rotor. If the same fairing is used for the tail rotor, it indicates that the off-time for the tail rotor to accumulate 0.1 inch of ice is the same as the time for the main rotor to accumulate 0.25 inch of ice. However, on the basis that the velocity of the midspan point on the two blades is approximately the same, the tail rotor off-time should be on the order of one-half of that for the main rotor. The discrepancy is probably due to the fact that in the spray rig cloud, the tail rotor is not exposed to the same icing environment as the main rotor.

It is felt that the tail rotor data obtained in the spray rig is not representative of the hover condition because of the incomplete cloud

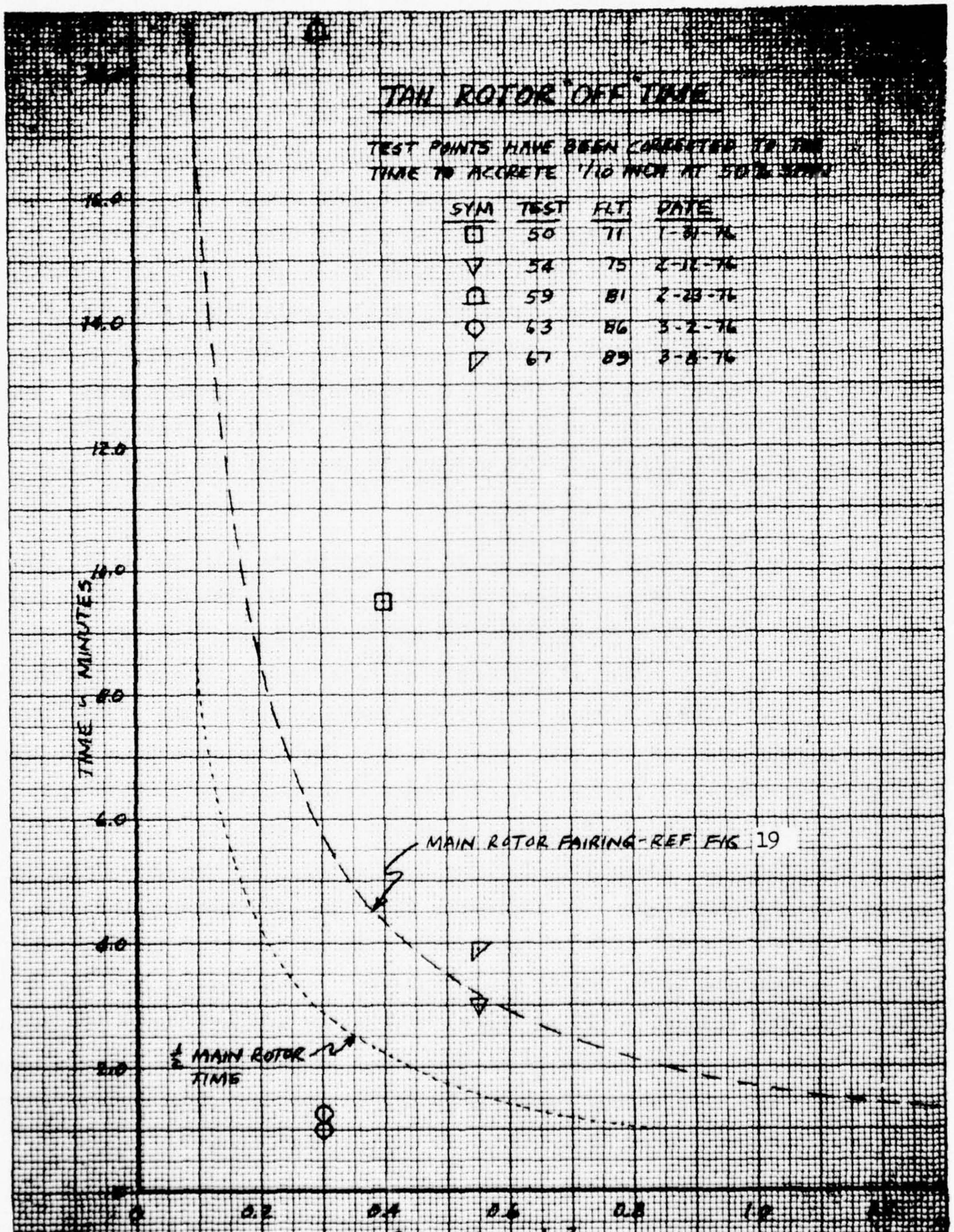


Figure 20. Tail Rotor Off-Time

coverage. Therefore, until more definitive data are obtained, the recommended tail rotor off-time to use is one-half of the main rotor off-time.

The present configuration of the deicing controller schedules the tail rotor off-time in multiples of the on-time, which in turn is a function of outside air temperature (OAT). It appears that this should be revised to schedule the tail rotor as a function of liquid water content the same as the main rotor.

4.13 HEATER-ON TIME DETERMINATION

As discussed in Section 4.3, the original heater-on times as scheduled by the controller were found to be too long and were progressively reduced in the process of testing for the optimum setting. These qualitative tests showed the on-time can be reduced considerably. To supplement these findings, the thermocouple measured surface temperature data were evaluated. Although the number of thermocouples were limited and the data were not accurate as absolute temperatures because of the instrumentation problem discussed in Section 3.4, they did provide satisfactory data when used on a delta change basis.

4.13.1 Main Rotor

Figures 21 through 24 present the basic data of blade surface temperature rise with heater-on time at 200 Vac for each of the four main blade stations measured. The curves present the temperature rise measured with and without ice on the blades.

During the testing, the instrumented blade was replaced with the back-up instrumented blade. As discussed in Section 3.4, the two blades have their thermocouples installed differently on the blade surface. One had the thermocouple attached with a layer of tape for electrical isolation between it and the blade which causes an insulating effect. Thus, during the short duration of the heater-on time, the data from this blade indicated a lower temperature rise than the other blade. Because the amount of data with the grounded thermocouples was extremely limited, the

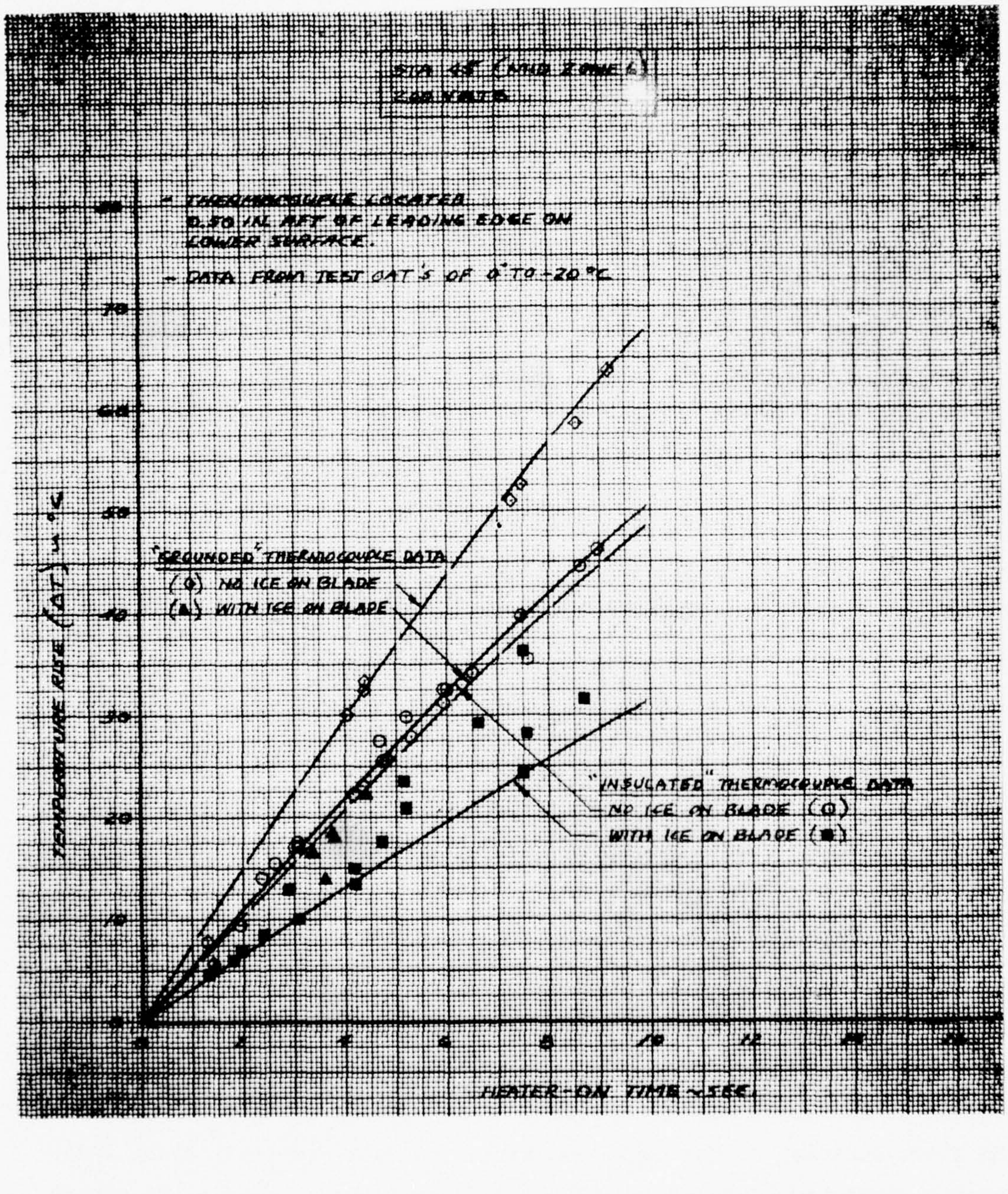


Figure 21. Main Rotor Blade Surface Temperature Rise vs Heater-On Time - Sta. 45

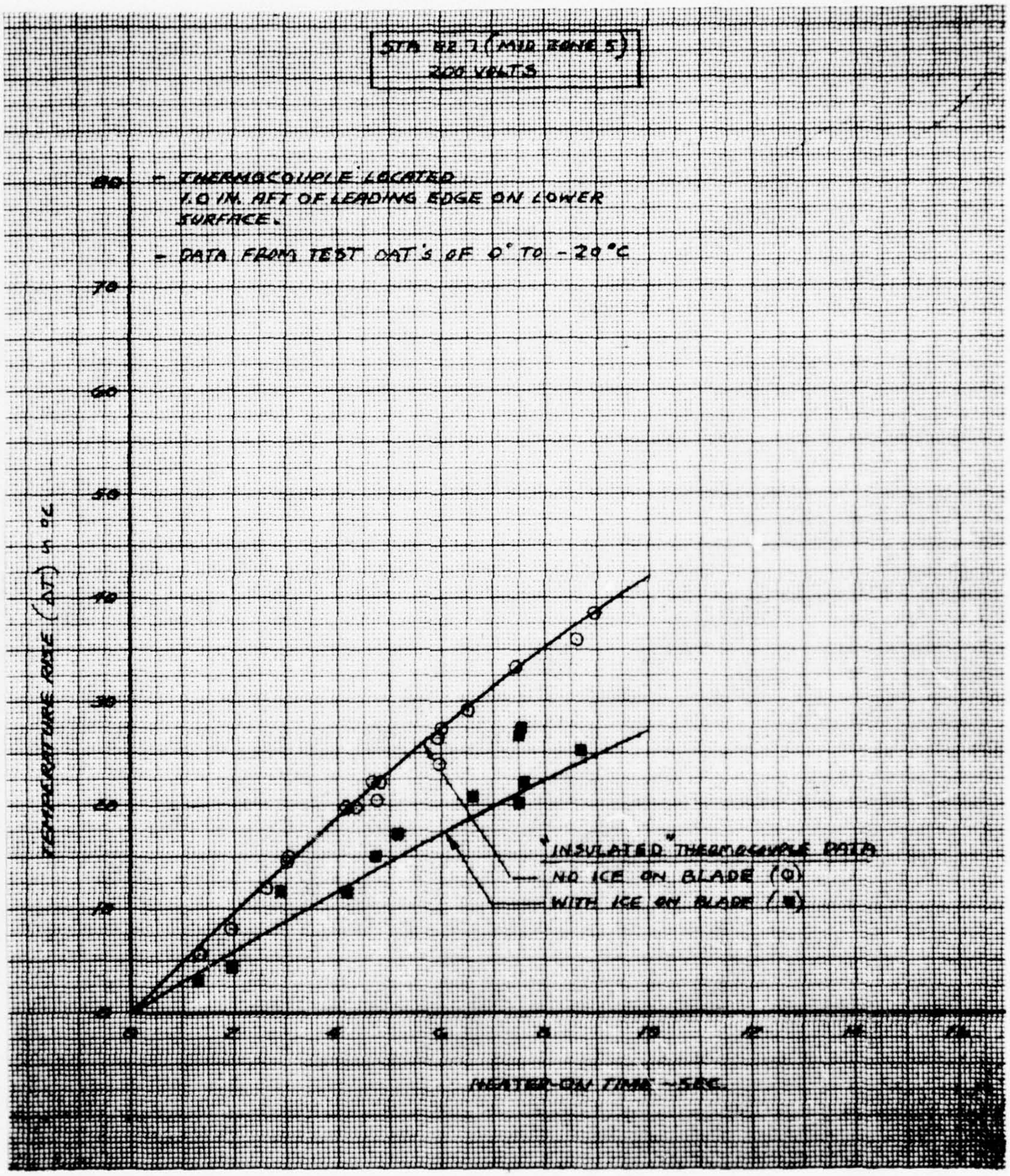


Figure 22. Main Rotor Blade Surface Temperature Rise vs Heater-On Time - Sta. 82.7

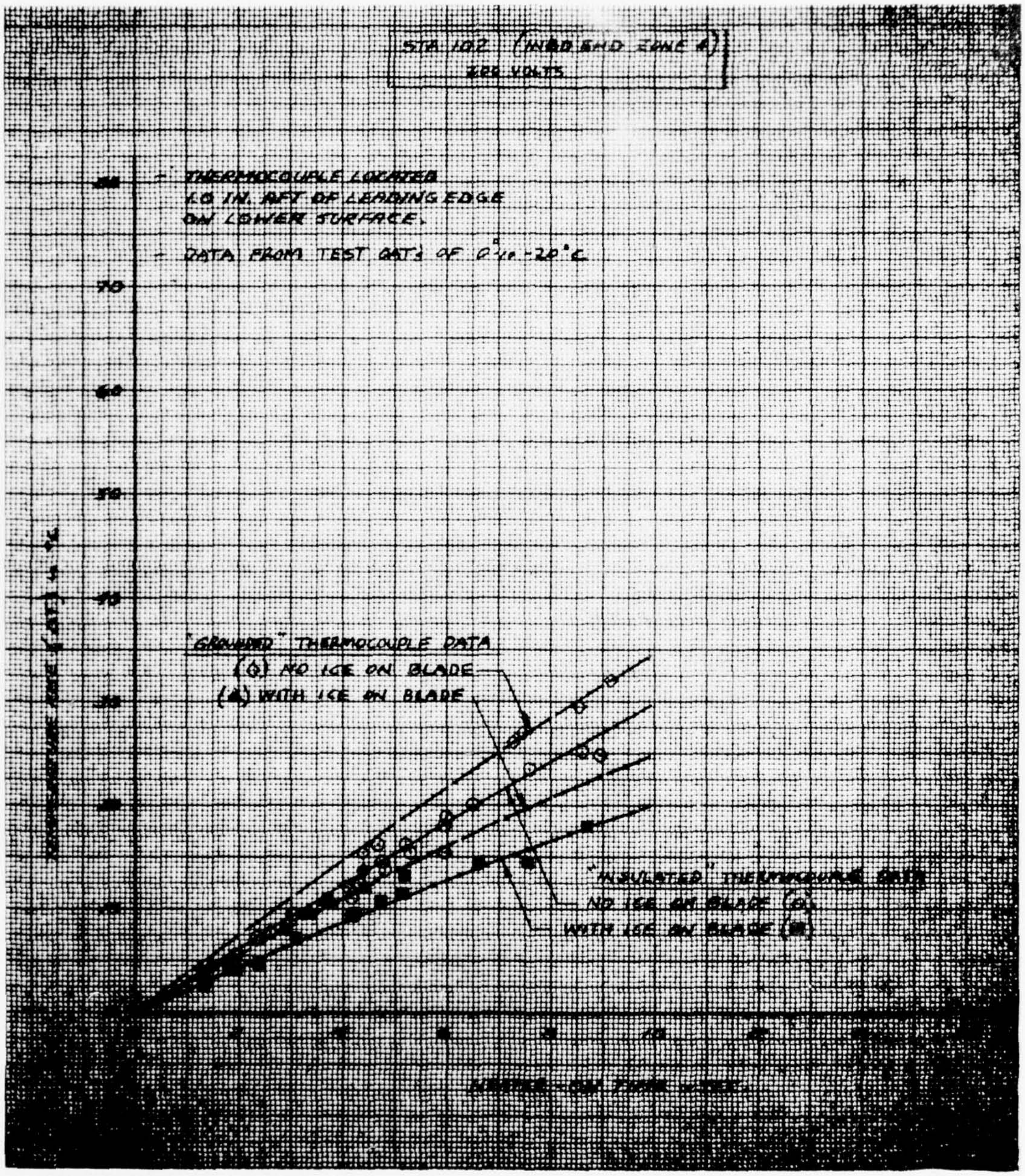


Figure 23. Main Rotor Blade Surface Temperature Rise vs Heater-On Time - Sta. 102

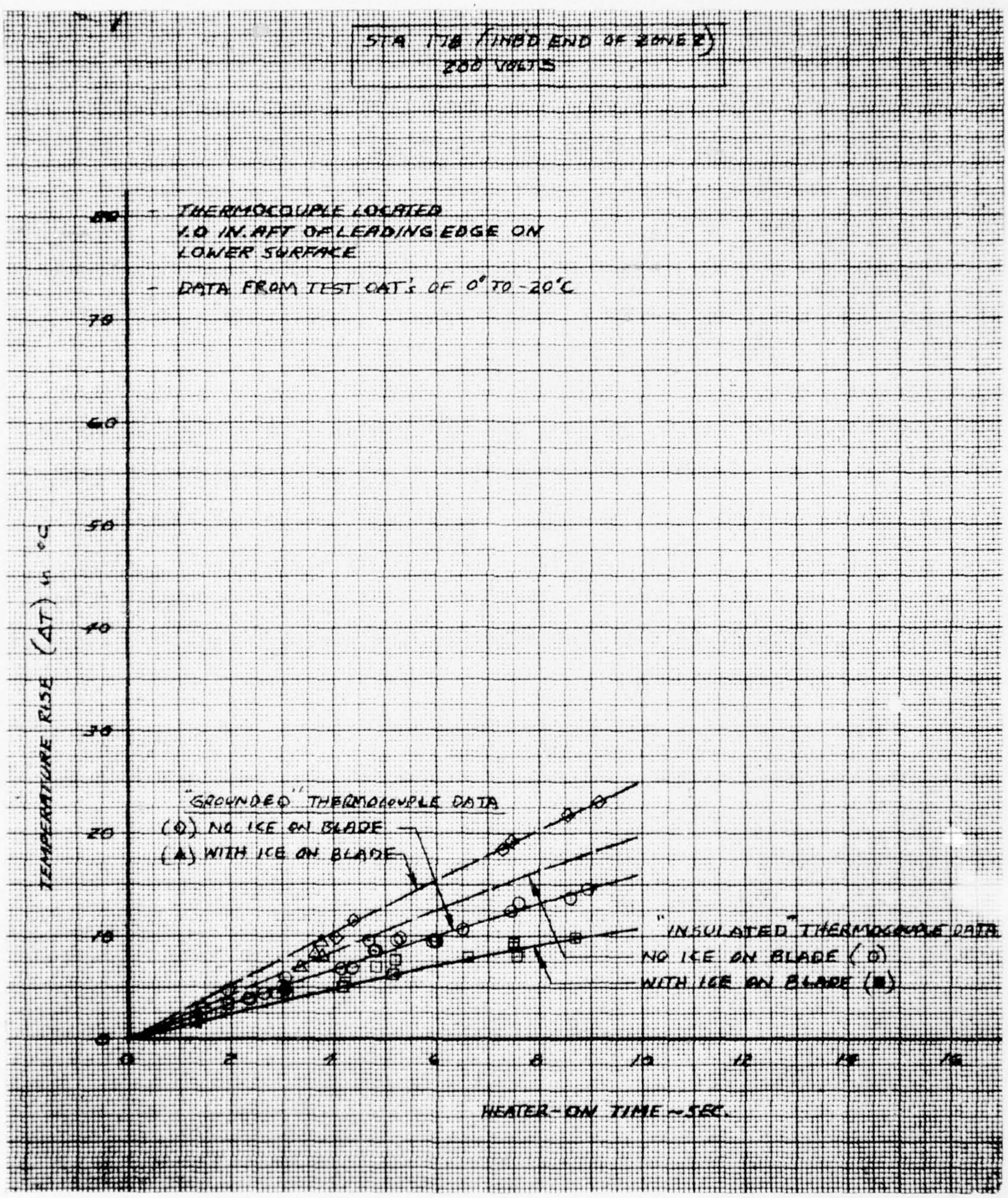


Figure 24. Main Rotor Blade Surface Temperature Rise vs Heater-On Time - Sta. 178

insulated thermocouple data were used to assist in establishing the curve fairings for the more representative "grounded" thermocouples.

The test points are from many conditions at various air temperatures. The data with no ice on the blades show very little test point scatter, indicating the temperature rise is, as expected, a function of heater-on time only and independent of air temperature. The test point scatter under deicing conditions is associated with the variation in amount of ice on the blade for the various runs. Comparison of the temperature-time histories of deicing cycles during a 30-minute cloud immersion with a clear air no-ice cycle showed that the temperature variation and peak value varied randomly from cycle to cycle from a minimum value up to the same as for no ice operation. Figure 25 is a typical example for blade Station 45 (mid-zone 6). This variation is associated with the inconsistencies of the spray cloud operation that results in inconsistencies in the amount and distribution of ice on the blade. The fairing shown for the condition of ice on the blade is, therefore, based on the minimum temperature rise test points in order to be representative of the most ice on the blade for heater-on time determination.

Figure 26 shows blade temperature variation versus blade span determined from test measurements that reflects the kinetic heating effect on the blade. Each test point shown actually represents many data points with approximately ±2 °C of scatter.

Using these data for surface temperature rise under heater operation and accounting for kinetic heating with ice, the heater-on time required to raise the surface temperature with ice on the blades to 0 °C for each thermocouple station was determined and shown in Figure 27. This temperature should be approximately the temperature required to deice. It can be noted that the schedule for any zone is considerably shorter than the nominal controller setting that was used during the Moses Lake testing and initially at Ottawa. It can be seen also that at Station 45, which is in the most inboard zone, an even shorter on-time is indicated. More testing is required to verify this and determine if runback can be eliminated.

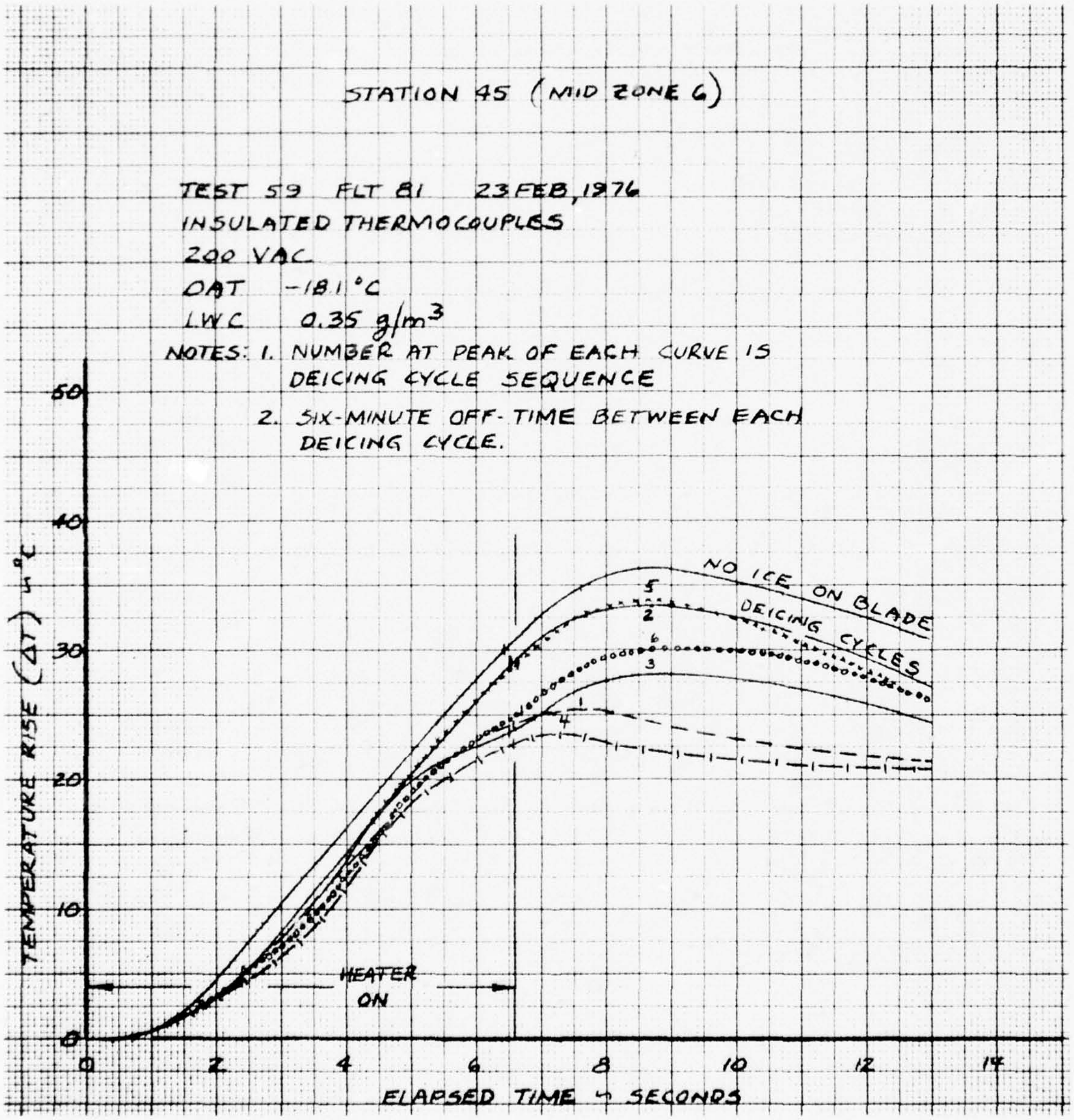


Figure 25. Time History of Blade Temperature Rise During Several Deicing Cycles in the Same 30-Minute Spray Cloud Run

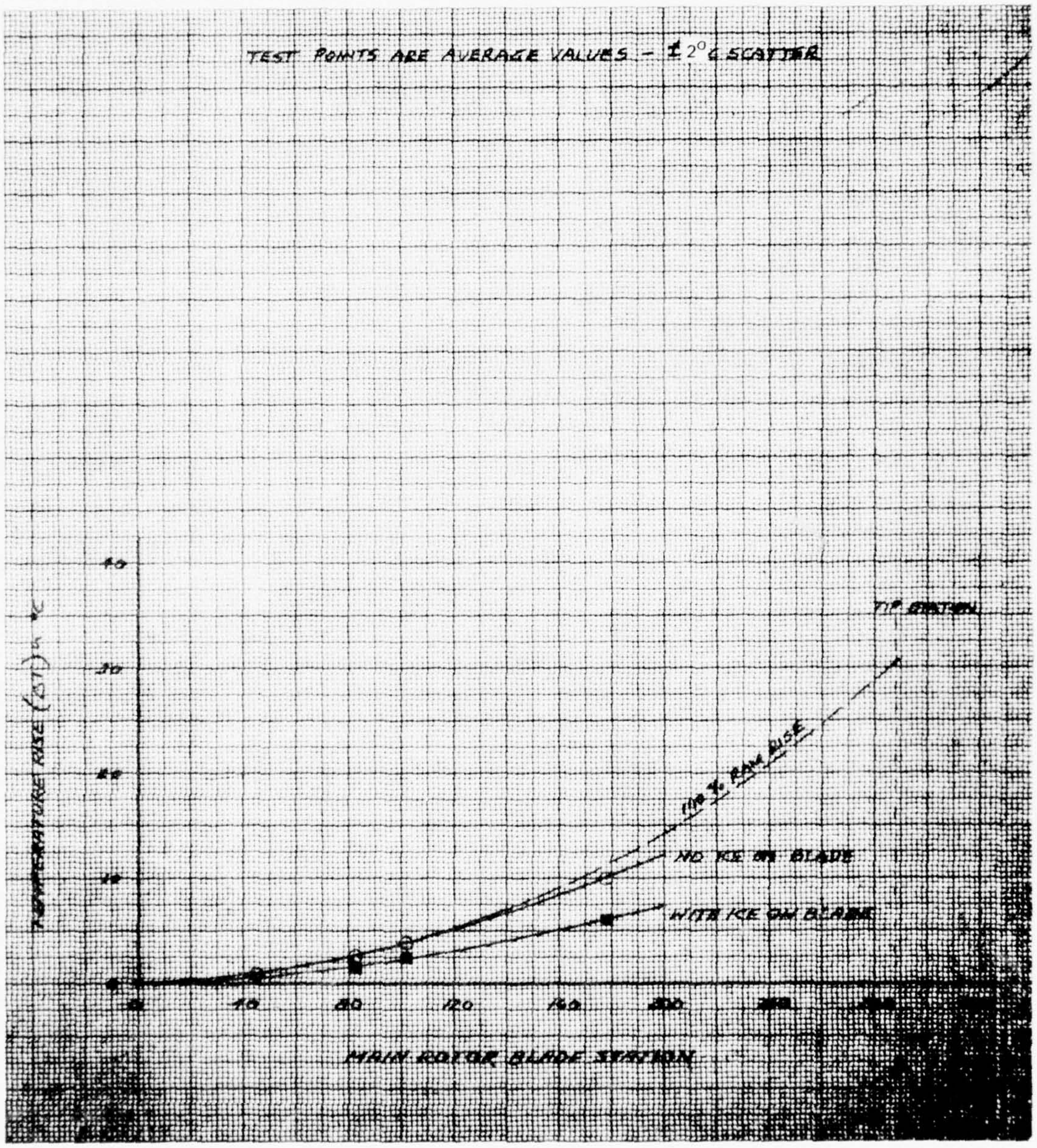


Figure 26. Temperature Rise Due to Kinetic Heating

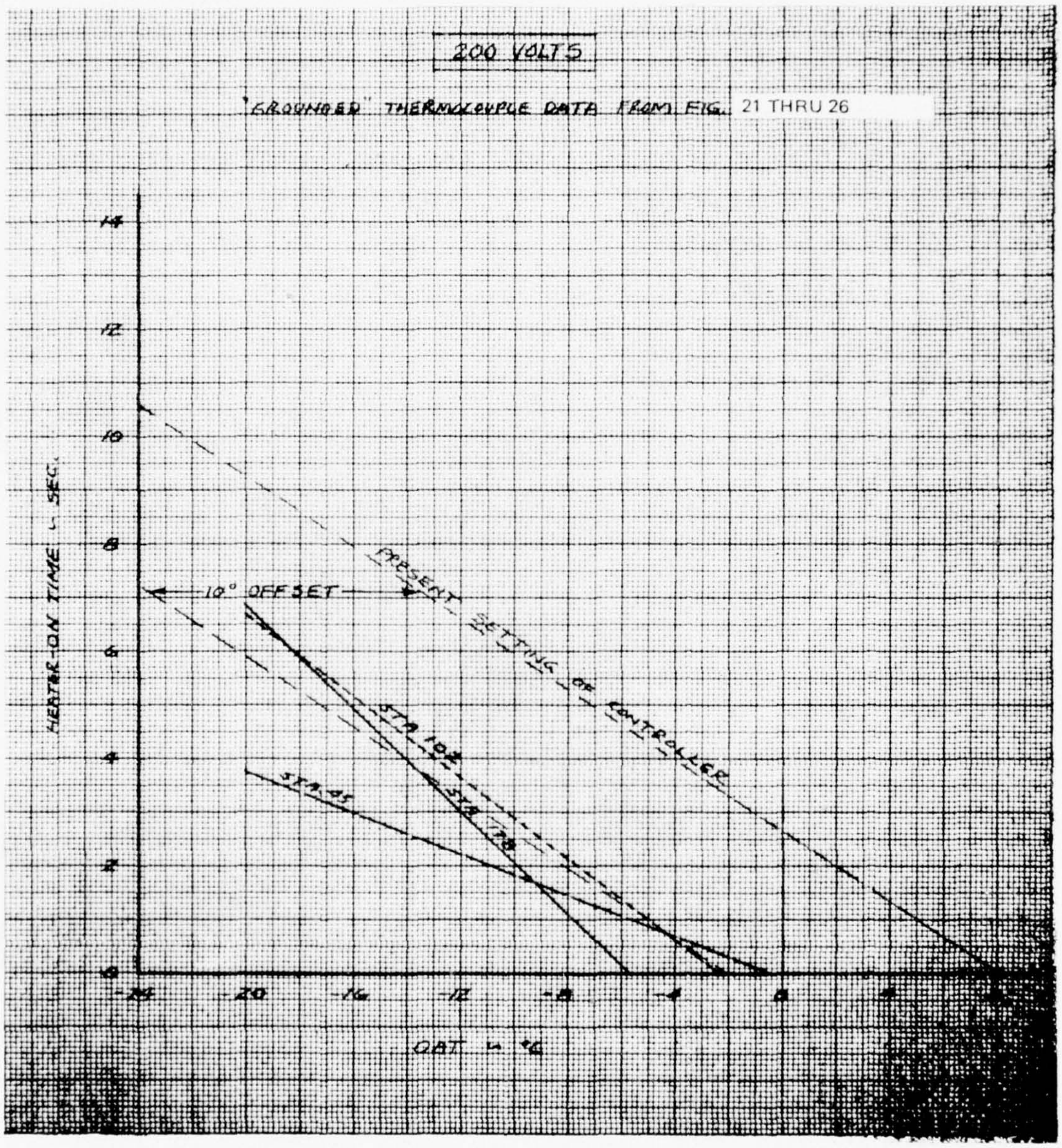


Figure 27. Main Rotor Heater-On Time to Raise Surface Temperature to 0°C

Comparison of these data with the qualitative deicing results of Figure 12 shows excellent agreement. It is concluded, therefore, that the optimum on-time, or at least the schedule that should be evaluated in future testing, is equivalent to an 8 to 10 degree offset from the present nominal setting of the controller. The difference between 8 and 10 degrees is only 0.7 second, therefore, in the interest of convenience, 10 degrees should be used. This would permit simply changing the OAT selector graduation labels from the present $+5^{\circ}$ to $-30^{\circ}C$ range to -5° to $-40^{\circ}C$ range. Zones 5 and 6 can be adjusted 1 to 2 seconds shorter at $-20^{\circ}C$, but this should be done after initially evaluating the longer time.

4.13.2 Tail Rotor

Surface temperature rise data for the tail rotor are shown in Figure 28. Using the temperature rise for grounded thermocouples and with ice on the blade and accounting for kinetic heating as derived for the main blade, the heater-on time to raise the surface to $0^{\circ}C$ is shown in Figure 29. Similar to the main rotor, the data indicate a shorter on-time can be used on the inboard area compared to the mid-span measurement. The 10-degree offset approximates the inboard results and since self-shedding seems to keep the tail rotor clear particularly outboard, the nominal 10-degree offset is recommended for future evaluation.

4.13.3 Recommended Heater-On Time as a Function of Generator Voltage

Figures 30 and 31 present the effect of generator voltage changes on main and tail blade surface temperature rise. Using these data as incremental effects and applying them to the data previously discussed, the recommended heater-on time to raise the surface temperature to $0^{\circ}C$ for the main and tail rotor blades for each voltage setting of 160, 200 or 230 Vac are shown in Figure 32. The slight difference in slope of the tail rotor schedule from the main rotor is merely the slight difference in characteristics of the individual controller electronic components.

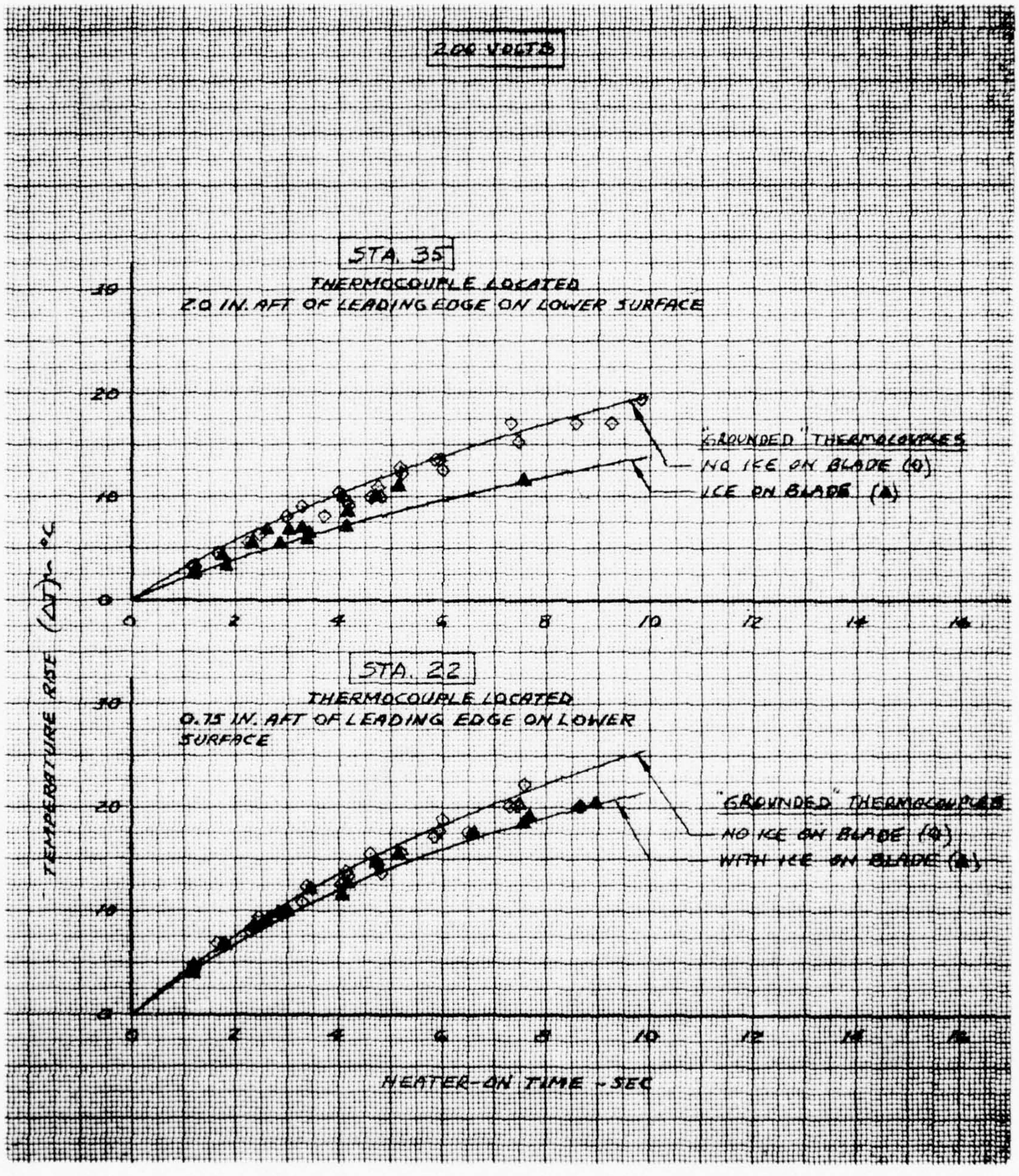


Figure 28. Tail Rotor Blade Surface Temperature Rise vs Heater-On Time

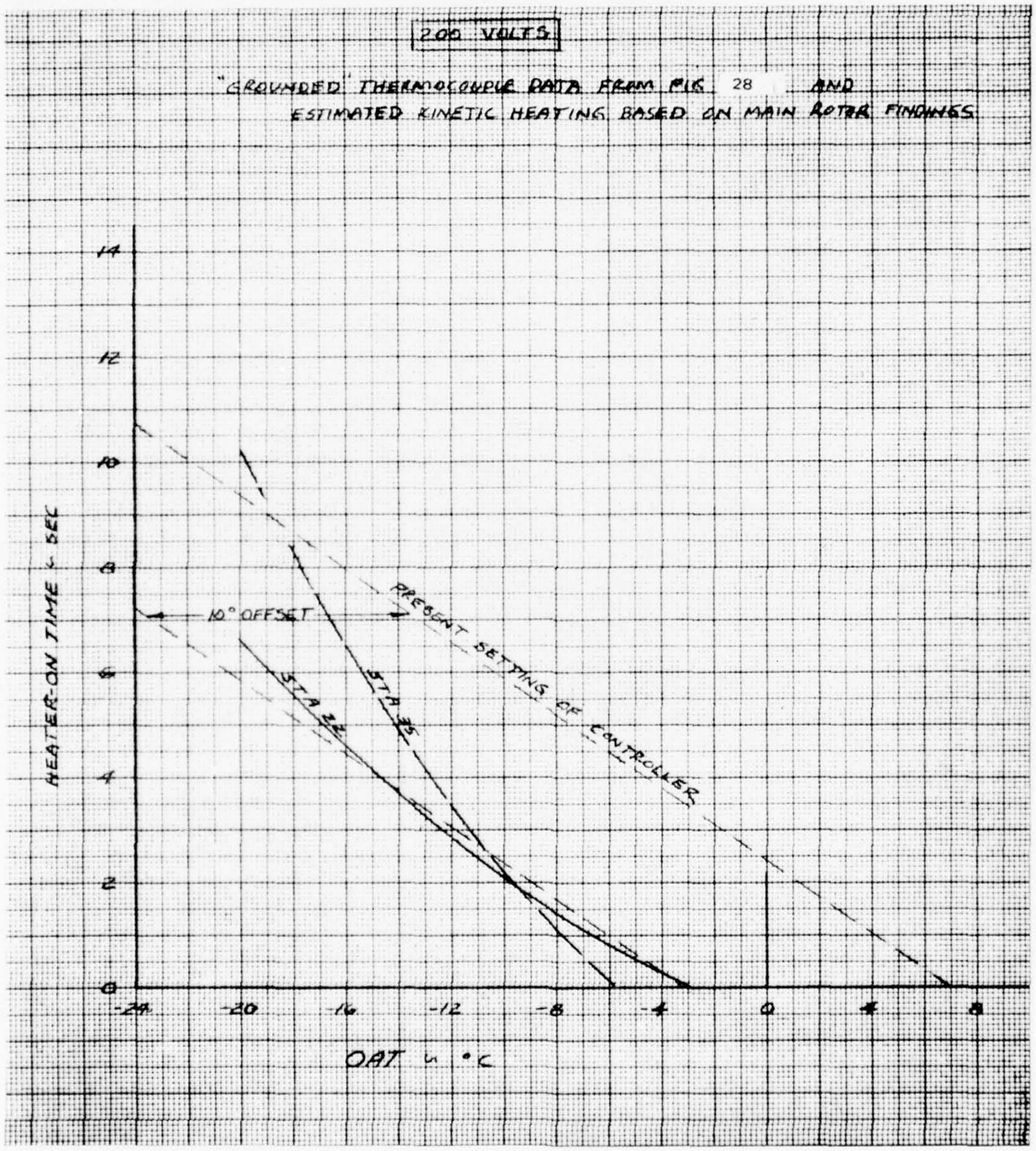


Figure 29. Tail Rotor Heater-On Time to Raise Surface Temperature to 0°C

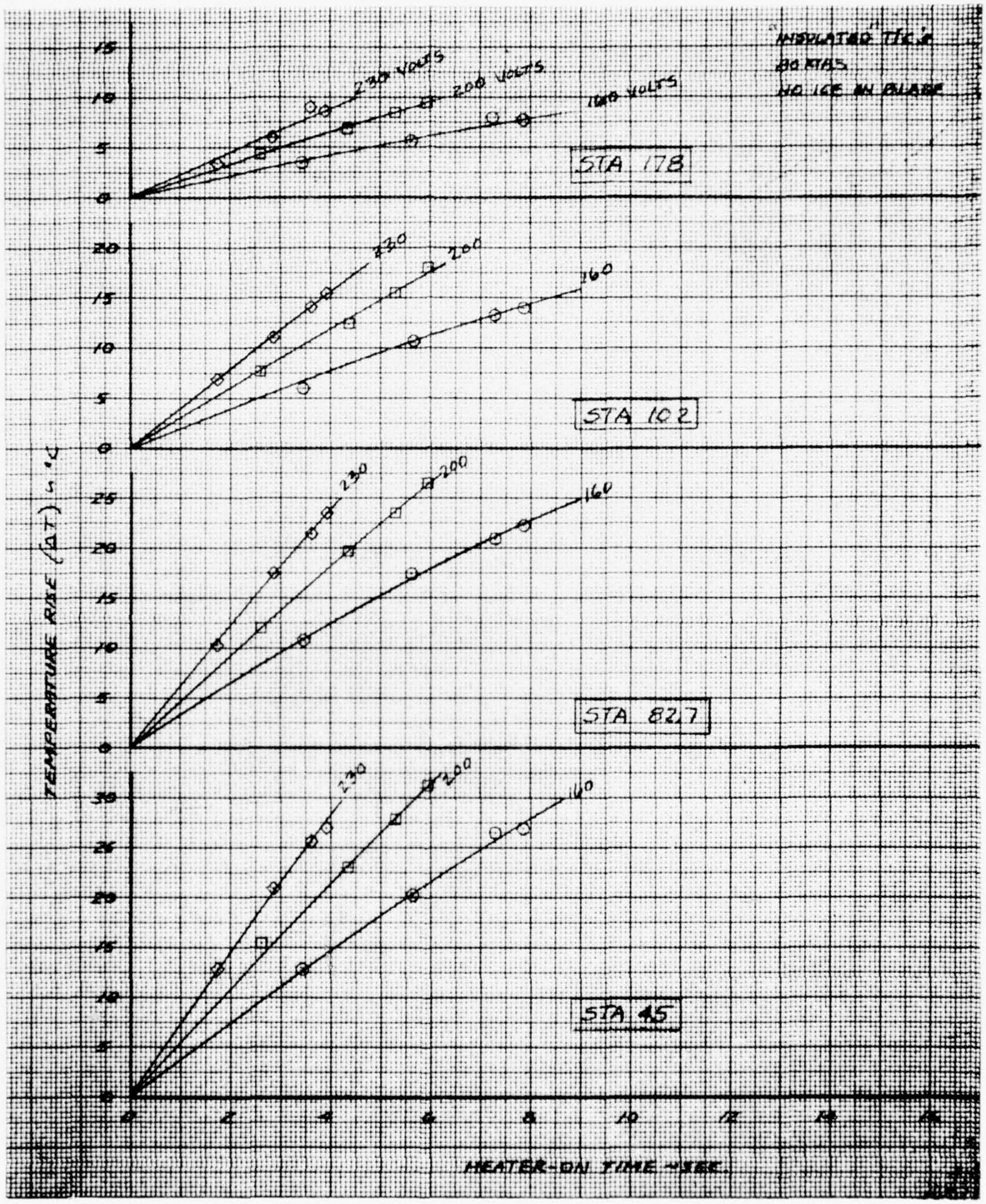


Figure 30. Main Rotor Blade Surface Temperature Rise for Different Voltages

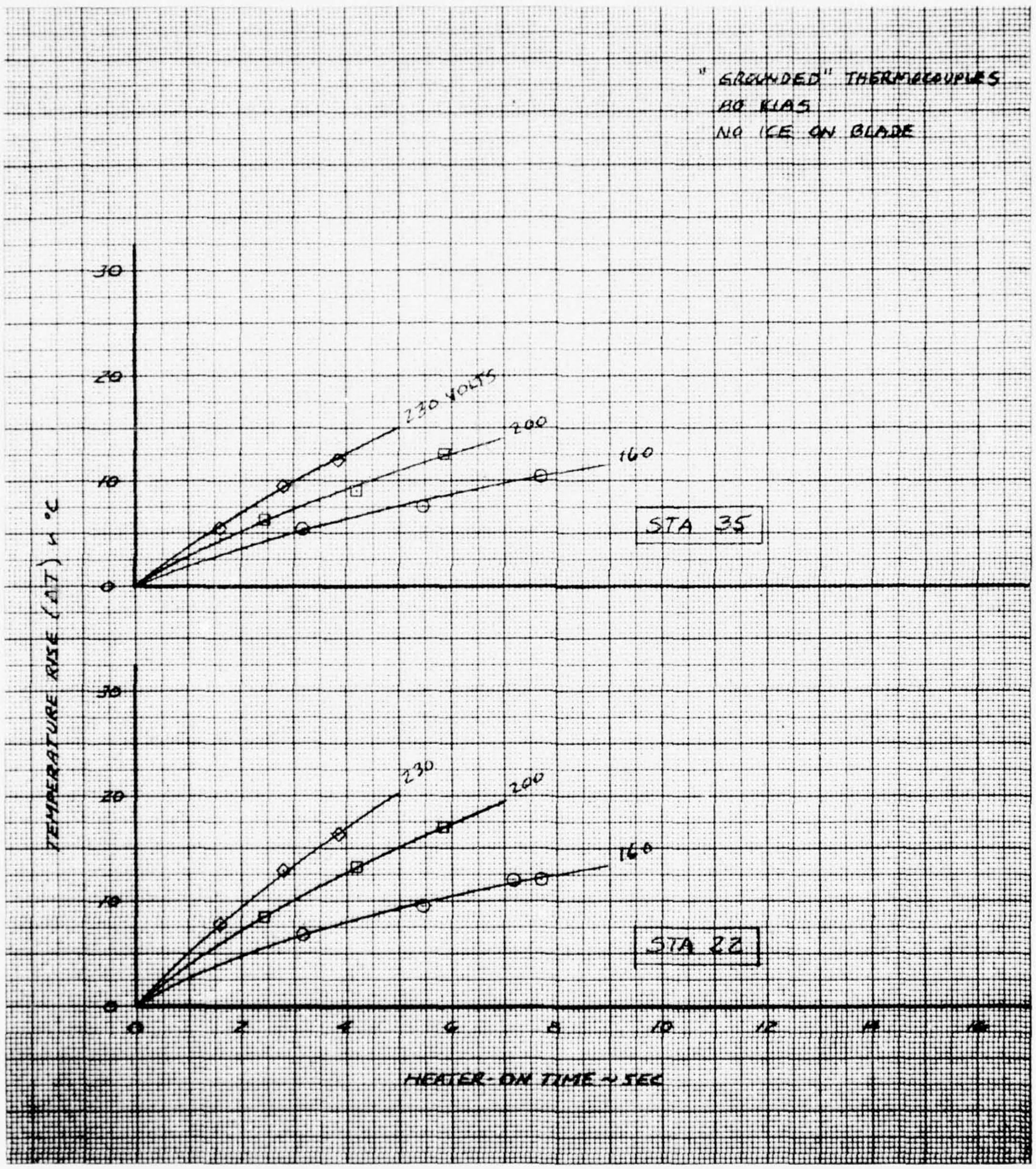


Figure 31. Tail Rotor Blade Surface Temperature Rise for Different Voltages

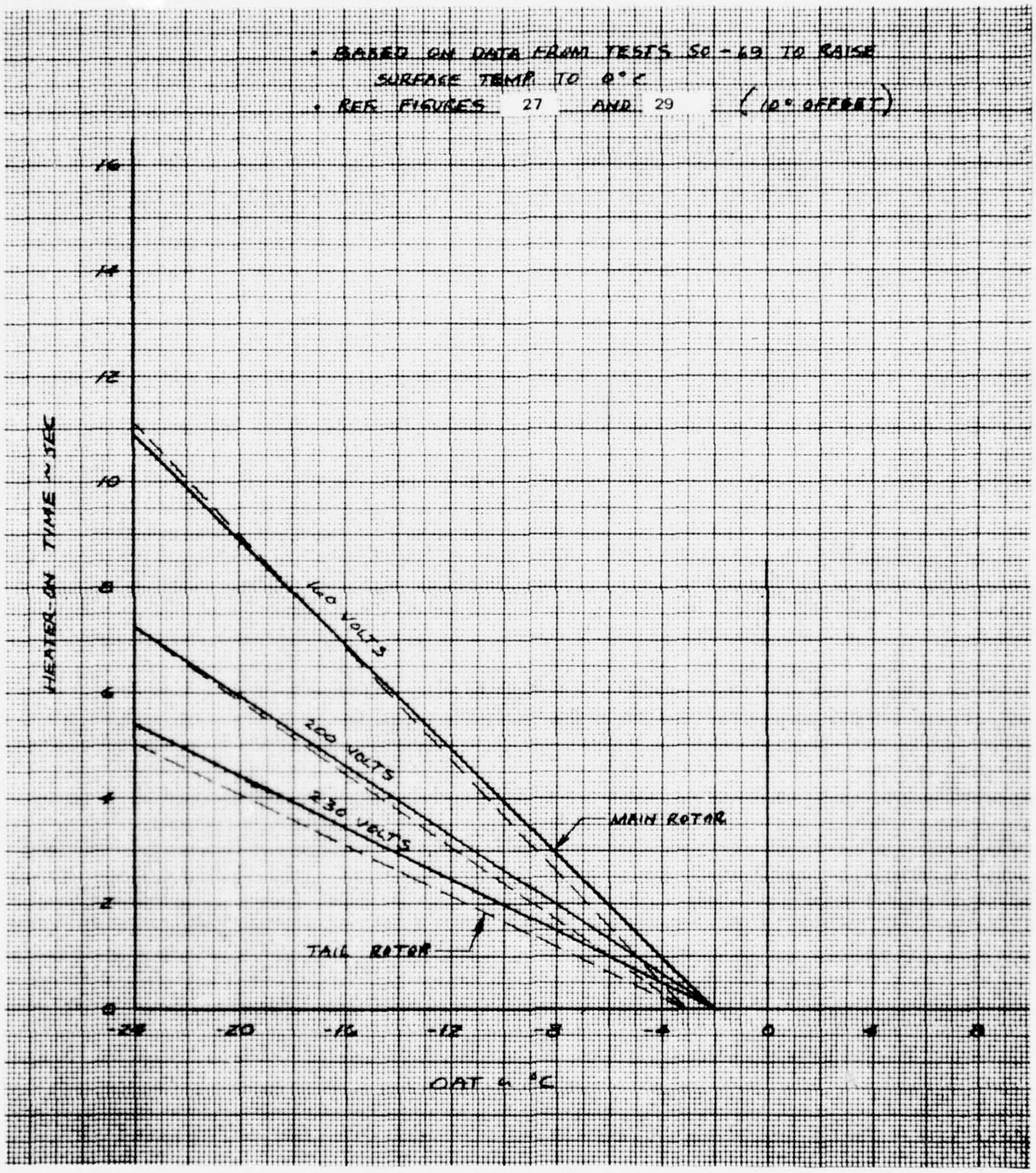


Figure 32. Deicing Heater-On Time Schedules

4.14 OAT MEASUREMENT

A limited evaluation of outside air temperature (OAT) measurement was made. Data from the three systems were compared with the spray rig facility measurement. The three systems consisted of a shielded and insulated probe installed on the nose of the aircraft reading out on a sensitive digital indicator (TEST OAT), the standard UH-1H probe/indicator installed through the windshield (SHIP OAT), and the flush type sensor installed on the underside of the forward fuselage and reading out on the deicing control panel (SYSTEM OAT).

Figure 33 shows the comparison of each system with the spray rig measurement. The flight data are shown for operation in clear air and while in the spray rig icing cloud. The data show that the TEST and the SHIP OAT read approximately 2 to 3 degrees warmer than the spray rig whether in clear air or in the icing cloud. This could be due to the exhaust recirculation effects in hover or it could be that the spray rig OAT is in error. Excessive test point scatter in the readings from the SYSTEM OAT indicates a problem of unknown nature at this time, but one which makes the present system and/or location unsatisfactory for a deicing system input. Conflicting trends and comparisons have been indicated by the data obtained so far. For example, lab tests indicated a humidity and/or moisture problem in the signal conditioning in the deicing control panel. A correction was made which eliminated the sensitivity in the lab; however, flight data still indicated approximately a 5-degree error. A biasing resistor was added to the circuit prior to the results shown in Figure 33 but a 5-degree average error is still indicated in hover. Limited comparison with a mercury thermometer showed good agreement under static conditions. Data in climb showed exact correlation with the TEST OAT but increasing error when compared to SHIP OAT. In level flight, the SYSTEM OAT showed decreasing temperature with increase in air speed whereas the TEST OAT showed the proper change. A more detailed investigation of the system calibration and possible signal conditioning errors should be accomplished prior to use as a SYSTEM OAT input. It is possible that the sensor location under the nose is unsatisfactory. Since there are two sensors presently installed, one could be relocated and evaluated in future testing.

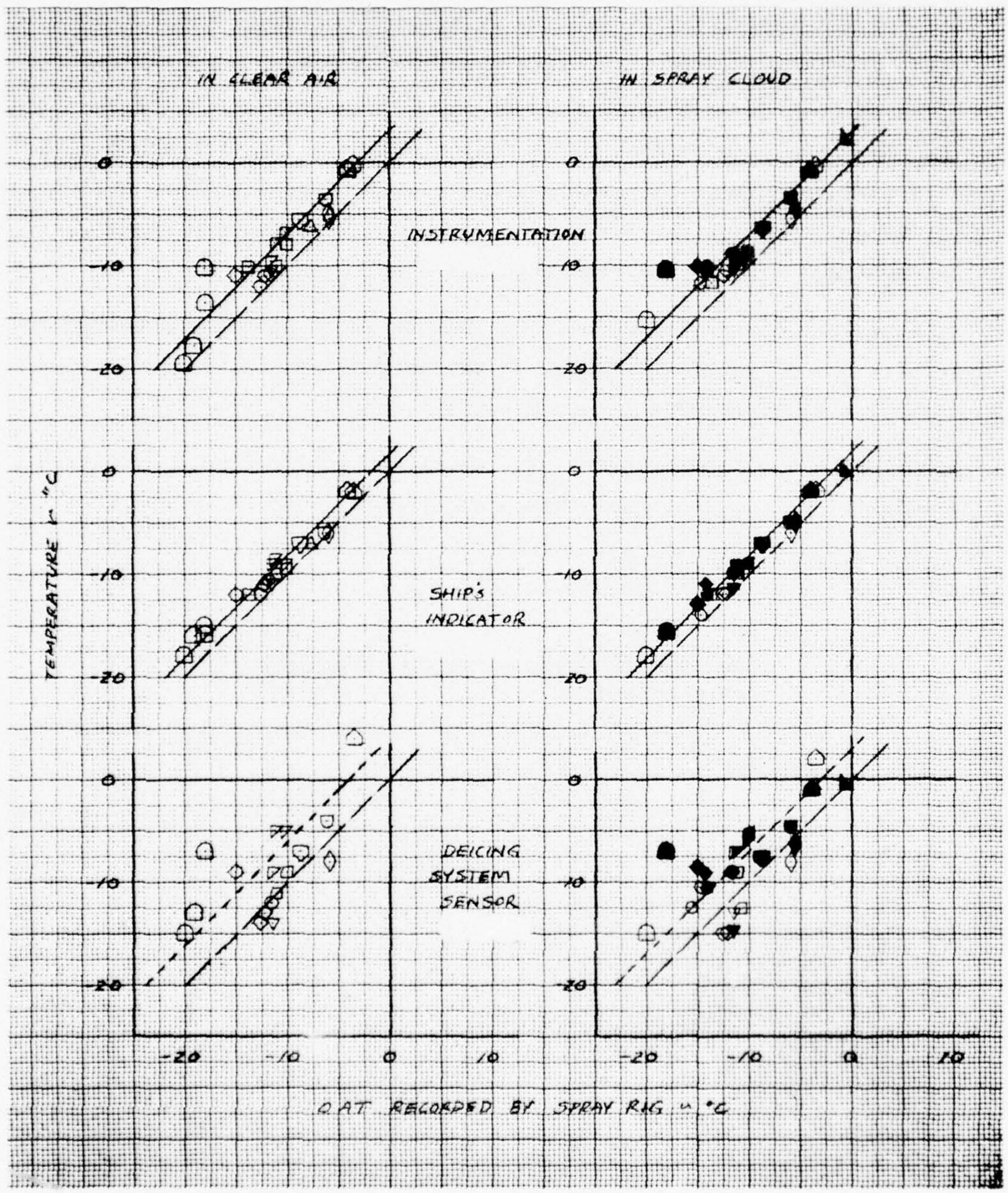


Figure 33. Comparison of OAT Measurements

4.15 DEVELOPMENT STATUS

Operation of the ice protection system during this year's testing was generally free of false indications or failures. The fault light indications and erratic operation which were experienced during the previous winter's test program were eliminated by the replacement of the broken wire guide and the resulting chaffed wires inside of the main rotor shaft going to the slip rings. Table 1 summarizes the number of problems and deficiencies experienced during this year's program. This summary shows 10 development items, 12 reliability items and 4 EMI items.

Although the number of malfunctions and failures is not considered to be excessive for a system as complex as the deicing system, investigation and correction would provide improved reliability.

Very few of the misoperations of the deicing control system occurred during flight. Most of them were discovered during routine maintenance checks on external ground electrical power. Several were in the spare or backup circuit cards not installed in the ship.

TABLE 1. SUMMARY OF NUMBER OF MALFUNCTIONS/DEFICIENCIES NOTED AT OTTAWA

SYSTEM \ CATEGORY		DEVELOPMENT	RELIABILITY	EMI
A	Deicing Control System	3	8	2
B	Ice Detection	4	-	2
C	Rotor Blades	1	4	-
D	AC Electrical System	2	-	-
TOTAL		10	12	4

The following types of problems have been found more than once and therefore are considered to be weak points in the prototype system:

- Deicing Control Boxes
    - o Broken wires on components mounted on the front panels of the control box and the controller unit.
    - o Opens in the integrated circuit (IC) sockets.
    - o Broken wires and pins in the ship's side connectors for the control box and the controller.
- Main Rotor Blades
    - o Breakdown of the insulation between the heating element and the erosion shield.
    - o Reduction in the dielectric strength of the insulation between heater and shield.
    - o Residual ice at the Station 83 erosion shield/heater joint after deicing.
- AC Generator Control
    - o Underfrequency/undervoltage sensitivity in the ac generator regulator and protection panel.

Tables 2, 3, 4, and 5 describe each malfunction or deficiency in more detail.

As shown in Table 2, only two EMI triggered fault indications were experienced. The main short light was triggered falsely only when the ultrasonic ice detector system switch was turned on and only on an average of one out of ten times. The actual point at which the false signal coupled into the circuitry was not determined. An attempt was made to suppress it with a capacitor installed at an arbitrary point but it was not successful. The controller fault light was triggered approximately three times during the program from undetermined sources. It occured during the overload test and was also suspected when the stabilizer bar was turned on. Both of these false fault indications occurred during checkout for flight and after the fault indication was cleared, no further problem was experienced.

A random skip of zone light indication on the deicing controller would occur after an hou of cycling in a warm hangar on dc ground power. One or

TABLE 2. DEICING CONTROL SYSTEM MALFUNCTIONS/DEFICIENCIES

ITEM	MALFUNCTION/DEFICIENCY	OPERATING CONDITION	SOURCE OF MALFUNCTION	ACTION TAKEN	RESULT
1	Main short light	Flight	EMI from ultrasonic detector turn on	EMI suppression capacitor added to main short latch	Unsuccessful. Need suppression somewhere else
2	Controller fault light	Ground	EMI from stab. bar turn on and overload test	None - only 3 occurrences with none in flight	Needs further investigation
3	Icing light flicker in clear air	Flight	Capacitor had been installed for precautionary EMI protection	Capacitor removed	Satisfactory
4	Controller fault light with external ac power on	Ground	Broken wire at pin of control panel	Repaired	Satisfactory
5	Zone skip (after prolonged cycling in warm hangar)	Maint. Check	Heat problem in logic controller card no. 3	None - not a flight problem but should be corrected	Open
6	Zone 6 BITE tripped anytime another zone BITE was tripped	Ground	Defective zone 6 BITE indicator	Replaced	Satisfactory
7	Excessive main rotor on-time in MOD LWC (resulted in controller fault from over on-time protection)	Maint. Check	Broken wire on MOD LWC on time adjust pot in logic controller	Repaired	Satisfactory

TABLE 2. DEICING CONTROL SYSTEM MALFUNCTIONS/DEFICIENCIES (Continued)

ITEM	MALFUNCTION/DEFICIENCY	OPERATING CONDITION	SOURCE OF MALFUNCTION	ACTION TAKEN	RESULT
8	MOD LWC signal of infrared detector did not indicate on system LWC meter	Maint. Check	Broken connector on card no. 10 of control panel	Repaired	Satisfactory
9	Zone 3 start on deicing cycle	Flight	Heat problem in card no. 3 of logic controller occurring on 1st cycle after master power turn on	Added an initialization circuit	Satisfactory
10	BITE indicators would not trip with spare card No. 7	Ground	Wire open at connector of spare card No. 7	Repaired	Satisfactory
11	Out of sync protection not functioning with spare card No. 7 installed	Maint. Check	Open integrated circuit (IC) socket on spare card No. 7	Repaired	Satisfactory
12	Main rotor zone 1, 3 and 5 lamps would not light with spare card No. 3 installed	Maint. Check	Open IC socket on spare card no. 3	Repaired	Satisfactory
13	Main rotor zone 3 lamp would not light with spare card no. 3 installed	Maint. Check	Open solder joint on spare card no. 3	Repaired	Satisfactory

TABLE 3. ROTOR BLADE HEATER INSTALLATION MALFUNCTIONS/DEFICIENCIES

ITEM	MALFUNCTION/DEFICIENCY	OPERATING CONDITION	SOURCE OF MALFUNCTION	ACTION TAKEN	RESULT
1	Electrical short burned a hole in main rotor blade erosion shield in hangar on ext. ac power	Maint. Check	Breakdown in insulation between heating element and erosion shield (Station 269.5)	Repaired temporarily in field by cutting an access hole in shield	Satisfactory - but repair area needed erosion protection
2	Electrical short between main blade heater and erosion shield (same blade as item 1)	Flight	Breakdown in insulation between heating element and shield (10" outboard of item 1)	Replaced blade (suspected moisture got in thru item 1 repair)	Satisfactory
3	Electrical short between main rotor blade heater and erosion shield (different blade than items 1 & 2)	Flight	Breakdown in insulation between heating element and shield (Sta. 88)	Terminated testing as all three failures (items 1, 2 & 3) indicated common problem along leading edge area	Subsequent blade teardown inspection confirmed fabrication deficiency
4	Decrease in dielectric strength of main rotor blade heater insulation. (Blade still functioning satisfactorily)	Maint. Check	Suspect moisture ingress in high humidity climate and test environment	Monitor status as part of failure analysis (teardown inspection for item 3 expanded to investigate item 4)	Blades operated OK at 50000 ohms. See separate discussion

TABLE 3. ROTOR BLADE HEATER INSTALLATION MALFUNCTIONS/DEFICIENCIES (Continued)

ITEM	MALFUNCTION/DEFICIENCY	OPERATING CONDITION	SOURCE OF MALFUNCTION	ACTION TAKEN	RESULT
5	Residual ice at Sta. 83 area of main rotor blades after deicing	Flight	Cold band in heater coverage at Sta. 83 and surface discontinuity	Minor smoothing of surface	Deicing improved but still needs design refinement
6	Delamination of inboard trailing-edge corner of tail rotor blade erosion shield on outboard side of blade	Maint. Check	Believed to be defective bond as opposite blade indicated suspect bond from initial fabrication tap test inspection	Corner lifted gently & Armstrong A-12 adhesive applied to reattach	Satisfactory as no change during subsequent use

TABLE 4. AC ELECTRICAL SYSTEM MALFUNCTIONS/DEFICIENCIES

ITEM	MALFUNCTION/DEFICIENCY	OPERATING CONDITION	SOURCE OF MALFUNCTION	ACTION TAKEN	RESULT
1	AC generator delay to come on line	Ground	Apparent moisture leakage in voltage regulator and protection panel	Pending	To be determined
2	Standby dc using ac generator and transformer/ rectifier would not stay on line	Ground	Underfrequency/ overvoltage sensitivity in the ac generator regulator and protection panel	Reset ac generator voltage regulator from 170, 210, 240 volts to 160, 200, 230	Satisfactory

TABLE 5. ICE DETECTION SYSTEM MALFUNCTIONS/DEFICIENCIES

ITEM	MALFUNCTION/DEFICIENCY	OPERATING CONDITION	SOURCE OF MALFUNCTION	ACTION TAKEN	RESULT
1	Icing light and HEAVY LWC indication in clear air (infrared detector)	Ground	EMI susceptibility of infrared probe and rate indicator	Suppression added to indicator	Satisfactory
2	LWC indication from ultrasonic ratemeter deflected as much as half scale on VHF transmission	Flight	EMI susceptibility of untrasonic ratemeter or probe or both	Probe and meter case ground pins and chassis were wired to structure near each component	Unsuccessful
3	System OAT (flush probe) reads approx. 5°C warmer than actual	Flight	Unknown. Lab investigation prior to 1976 testing indicated humidity & moisture effects on circuit card	OAT meter limiting resistors relocated to meter terminals. Corrected indications in lab tests	Unsuccessful in aircraft. Needs further investigation

more zones were skipped in the normal cycle sequence and would become more prevalent the longer the cycling continued and, consequently, the warmer the controller became. The source of the zone skip was isolated to Card 3 by heating it with a heat gun; however, the specific section or component causing the skip was not located. Operation during flight was not affected because of the lower ambient temperature and relatively infrequent cycling.

Table 3 shows that three main rotor blade heater failures occurred, all apparently due to some type of insulation breakdown between the heater elements and the erosion shield. All three shorts were indicated by the ac ground fault detection system. The first one, which was repaired temporarily at Ottawa, occurred during operation of the system on external power in the hangar and resulted in a hole being burned in the erosion shield at the point of failure. Under normal operation in flight, the same failure would have merely illuminated the ac ground fault light and continued deicing operation would have been possible (as was the case in the second and third occurrences). However, operation of the aircraft on external power voids the intended protection of the ungrounded neutral system. This is because most power carts used in a hangar have their neutrals tied to the hangar ground system. Aircraft ground points that are manually connected to the hangar ground system also create a path for the fault current to be conducted through a short in the blade. A more detailed description of the problem encountered when operating from an external power cart is contained in Section 4.16.

The three electrical shorts that were experienced in the main rotor blades were all located in the leading-edge area between the heating element and the erosion shield. As noted, two of the failures occurred in the same blade near the tip. The other occurred in another blade near the inboard end of the steel erosion shield. It appeared that there was a common problem in the leading-edge area. Since the third failure occurred only one day prior to the scheduled termination date of the program, it was not repaired and the testing at Ottawa was discontinued.

A degradation in the dielectric strength of the insulation between the heating element and the erosion shield was experienced also with the main rotor blades during the Ottawa program. This was noted in the previous year's testing at Moses Lake, Washington. Although this degradation has not been associated with any of the failures, it does imply a potential problem. The degradation is suspected to be due to moisture effects. This was indicated from measurements of the dielectric strength of the insulation in August after the blades had been stored at Edwards AFB in the low humidity environment of the Mojave desert area. It was found that a high resistance (50 megohms) was regained; therefore, prior to leaving for the Ottawa program, an attempt was made to seal the edges of the erosion shield installation by application of a waterproofing coat of epoxy cement. Soon after the blades had been exposed to the spray rig environment at Ottawa, however, the dielectric strength had dropped to the same 50,000 - 80,000 ohm range as measured at Moses Lake. Table 6 shows a chronological record of the dielectric strength measurements since initial fabrication. After return to Burbank, California, a teardown investigation of the erosion shield/heater element installation was made in an attempt to identify possible causes for this problem and the electrical short problem. The results of this investigation are described in Section 4.17.

Table 4 shows that the time delay in the ac generator coming on the line that occurred last year was experienced again. This problem was investigated by the supplier of the generator voltage regulator and protection panel, and a corrective modification was incorporated. However, although good operation was obtained during most of this year's program, the problem reoccurred towards the end. The spare regulator which had also been modified was installed, but the problem reoccurred after an initial period of satisfactory use. Further investigation of this phenomenon is necessary.

4.16 OPERATION ON EXTERNAL AC POWER

As described in Section 4.14, one main rotor blade was damaged during operation on external ac power in the hangar. An electrical short occurred between the heater element and the erosion shield which burned a hole

TABLE 6. MEASUREMENTS OF HEATER INSULATION DIELECTRIC STRENGTH

ROTOR BLADE SERIAL NO.	EDWARDS AFB, CA		MOSES LAKE, WA				EDWARDS AFB, CA			OTTAWA, ONT.				
	21 JAN 1975	27 JAN 1975	10 MAR 1975	22 MAR 1975	27 MAR 1975	28 MAR 1975	5 AUG 1975	10 OCT 1975	18 DEC 1975	29 JAN 1976	13 FEB 1976	24 FEB 1976	25 FEB 1976	27 FEB 1976
Main Blades - Insulation Resistance in Megohms														
A2-25934 (I_2)	-	-	5	.05	.05	.05	50	400	300	400	.05*	.02	.03	.03*
A2-25928	92	190	50	20	-	-	50	-	160	260	11	270	25	180*
A2-26092 (I_1)	94	165	.09	.30	.30	.40	50	250	-	-	-	-	-	-
Tail Blades														
A3-82998	-	-	-	-	-	-	-	-	1400	2000	200	200	15	15
A3-82939 (I)	-	-	-	-	-	-	-	-	1500	2600	700	20	1500	1200
A3-94515	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Notes: (1) All values are the resistance in ohms x 10^6 measured between ϕC (common to all zones) and ground after 1 minute with 500 volts applied.

(2) $I_{(1)}$ and $I_{(2)}$ denote instrumented blades (Ref only)

(3) *are vaues prior to short to ground failures

through the erosion shield at the point of the failure. Two other similar insulation breakdowns occurred in flight but merely resulted in an "AC GND" caution light and no blade damage. The ungrounded neutral of this ac system design, in contrast to a conventional grounded neutral system, is the reason for the differences in reaction. An ungrounded ac generator system was designed for the deicing system to permit continued deicing system operation following a heater insulation breakdown or short to aircraft structure, the most common type of heated rotor blade failure. However, this type of system is not directly compatible with most external ac power carts, especially electric motor-generator sets used in hangars because they are grounded.

Figure 34 illustrates schematically the conditions which existed when the hole was burned in the blade. External ac power was supplied by the external auxiliary power unit (APU), and the generator contactor (C1) connected it to the ac bus. Main rotor power relay (C2) is closed when the master power switch on the deicing controller is turned on. Shortly after the master power switch was turned on, an audible arcing occurred and the switch was immediately turned off, stopping the arcing.

Under normal conditions between deicing cycles when with heater power is not being applied to the blades (SCR's not conducting), three-phase half-wave rectified dc voltage is applied to the heater grid through diodes D1, D2 and D3 as part of the system's ac ground fault detection system. This voltage is approximately 165 Vdc between the heating elements and the erosion shield. When heater power is applied to deice, SCR's 1, 2, and 3 conduct, and ac voltage of each phase is applied to the appropriate heater element terminal, resulting in peak voltage of as much as 165 Vac between the heater element and the erosion shield. Either the dc or the ac voltage is sufficient to light the AC GND fault light if a short should occur between the element and the erosion shield. The resistance of the light circuit is sufficient to limit the current through the short to a nondestructive level. With the floating or ungrounded neutral at the generator, operation of the deicing cycle is still possible with

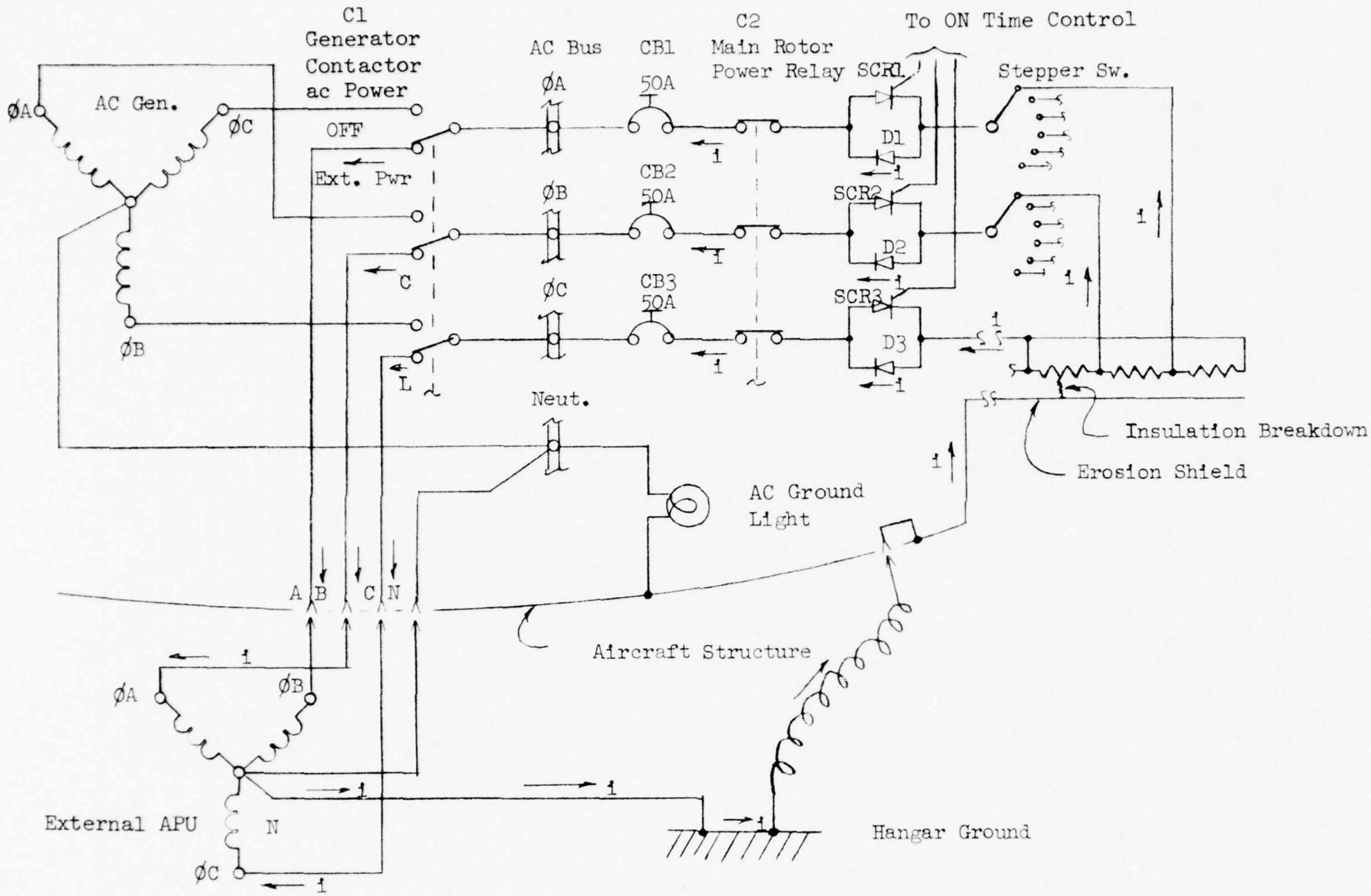


Figure 34. Schematic Showing External AC Power Connected to the Ship and Current Flow through an Insulation Breakdown

no deterioration in ability to deice the blades. Should a second insulation breakdown occur, an overcurrent condition would be sensed and the main short light would be illuminated and the deicing cycle halted.

In the case at Ottowa with an external APU supplying power, the current limiting AC GND light was shunted by the APU's neutral ground and the normal grounding cable attached to the aircraft in the hangar. In this configuration, when the insulation breakdown occurred, current through the fault was limited only by the impedances of the heating elements, phase power wires, diodes, and ground straps. As shown by the arrows in Figure 34, half-wave rectified fault current flowed from the cart neutral to hangar ground, through the aircraft ground strap to aircraft structure, through the aircraft structure to the erosion shield, through the breakdown to the heater elements, and back through the diodes D1, D2, and D3 and the system to the ground power cart phase terminals. Fault current was interrupted by opening of the main rotor power relay (C2) when the master power switch was turned off by the operator. Fault current flowed for approximately 2 seconds and was manually interrupted before the circuit breakers tripped.

There are ways to maintain the protection afforded by the ungrounded ac electrical system when operating on an external auxiliary power unit (APU). The neutral-to-hangar-ground connection of the power unit can be disconnected. This would require special placarding on the unit to warn other users of the nonstandard APU. In lieu of that, an isolation transformer could be inserted between the APU output and the external power receptacle of the aircraft, or a smaller isolation transformer could be interposed between the circuit breakers and the main rotor power relay in the aircraft as shown in Figure 35. The latter approach would add weight but this is considered acceptable for a test aircraft and provides the simplest compromise for the testing problem. There are other additional changes that could be implemented on a production design that would minimize the weight penalty.

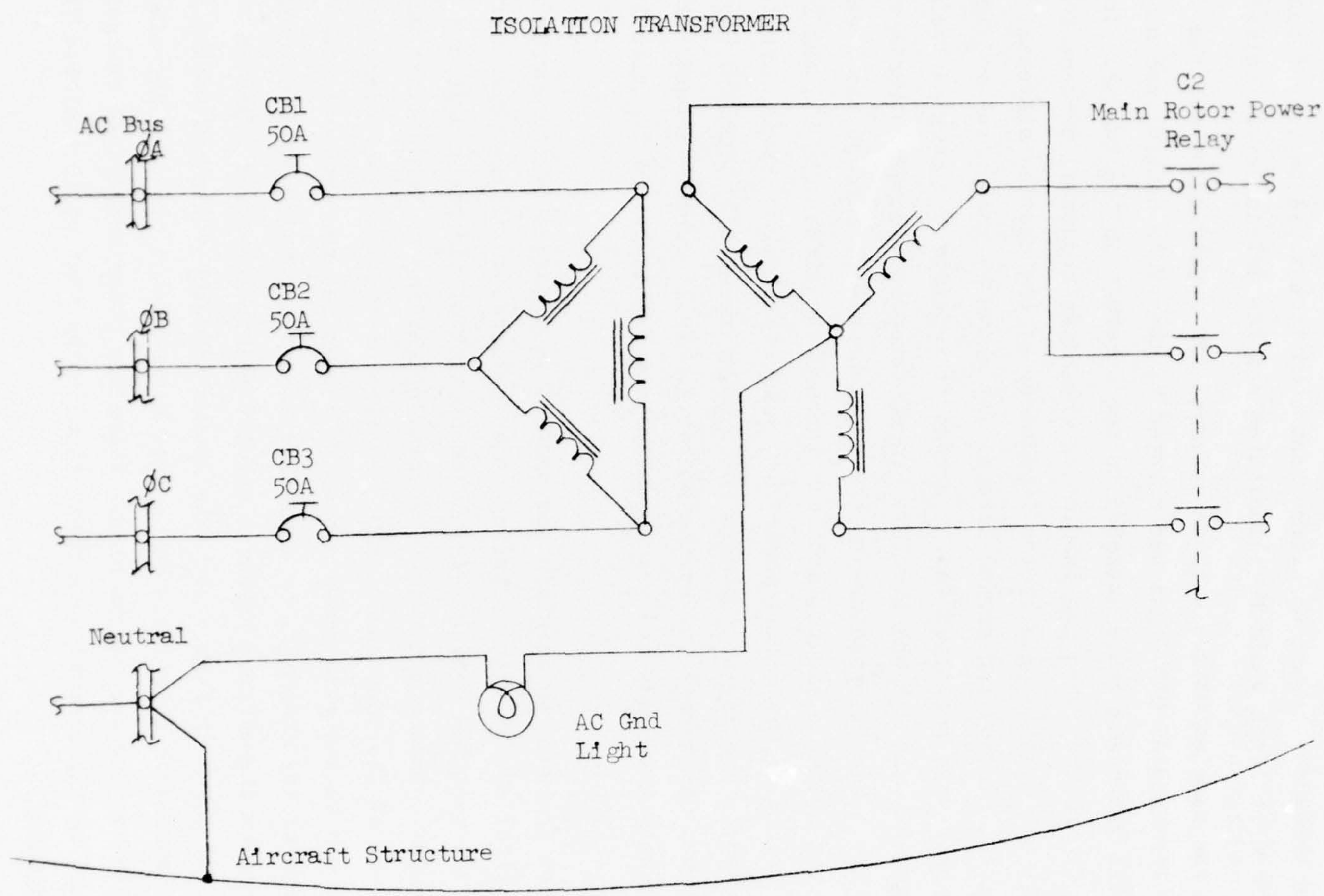


Figure 35. Schematic Showing Possible Insertion of an Isolation Transformer in the Aircraft Wiring

4.17 BLADE HEATER FAILURE INVESTIGATION

As a result of the three electrical shorts between the heating element and the erosion shield that were experienced during the Ottawa testing, a teardown investigation of one of the blades was made. This inspection was made in an attempt to determine the cause of the failures and thus define corrective changes for future design. A second objective was to determine a possible cause for the reduction in dielectric strength of the insulating material between the heating element and the erosion shield.

The blade selected for the investigation had two failures in the outer portion of the blade. The other failure was in another blade near the inboard end of the steel erosion shield but also along the leading edge. The erosion shield was removed by forcing a thin wedge between the erosion shield and the heater element. The shield peeled off rather easily under a progressive prying action and separated on the bond line between it and the heater outboard insulation material. Figures 36 through 39 show the blade with the shield removed and some of the overall condition underneath. Detailed inspection of the heater installation revealed the following:

- There was nothing obvious that would explain the exact failure mode.
- There were two or three places along the leading edge where the heater and its insulating material did not adhere to the erosion shield. This condition was present in the area where the two failures were experienced.
- The heater element did not adhere to its backing material of glass cloth laminates along almost the entire leading edge from 0 percent to 5 percent chord.
- There were void areas in the bonding adhesive between the erosion shield/heater element/backing material assembly and the basic blade contour. This condition was aft of the leading edge.
- There was an apparent difference in the insulating glass cloth used inboard of Station 176.6, the zone 2 and 3 boundary, from that used outboard. The cloth inboard appeared to be dry and and devoid of any impregnating resin. It is not known whether all the blades were like this, as only one blade was disassembled.

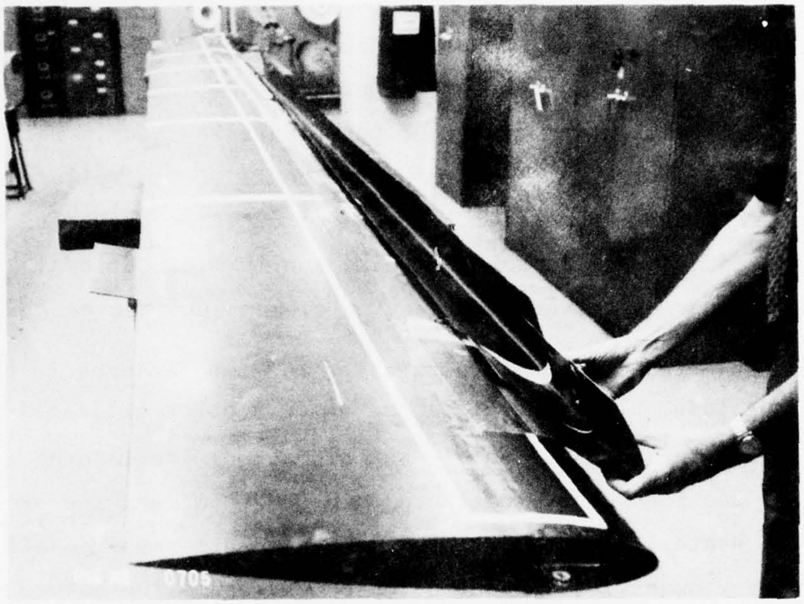


Figure 36. Blade S/N A2-25934 with Erosion Shield Removed

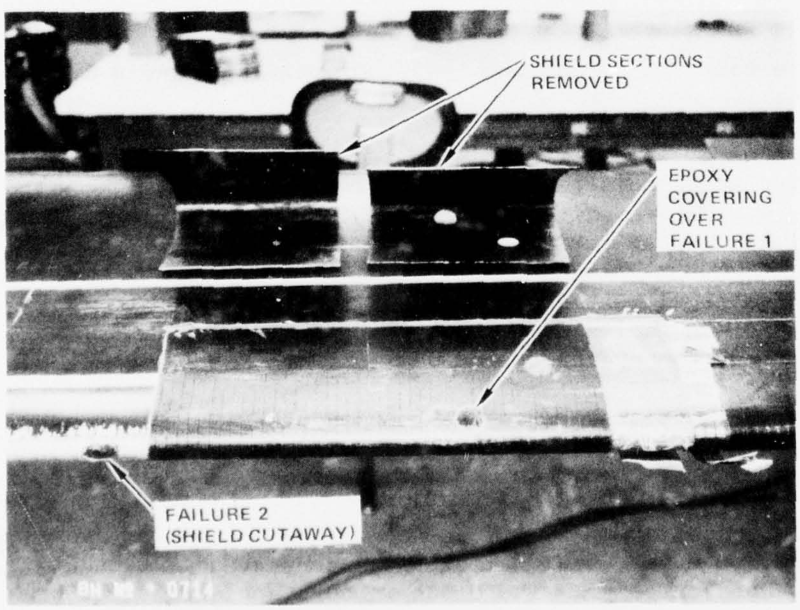


Figure 37. Under the Shield in the Area of the Outboard Failures

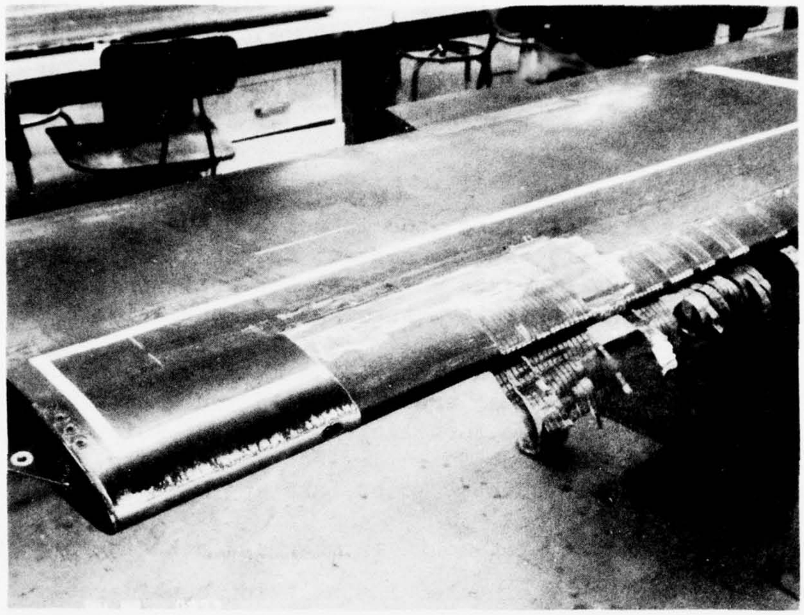


Figure 38. Heater Ribbon Peeled Back in Failure Area

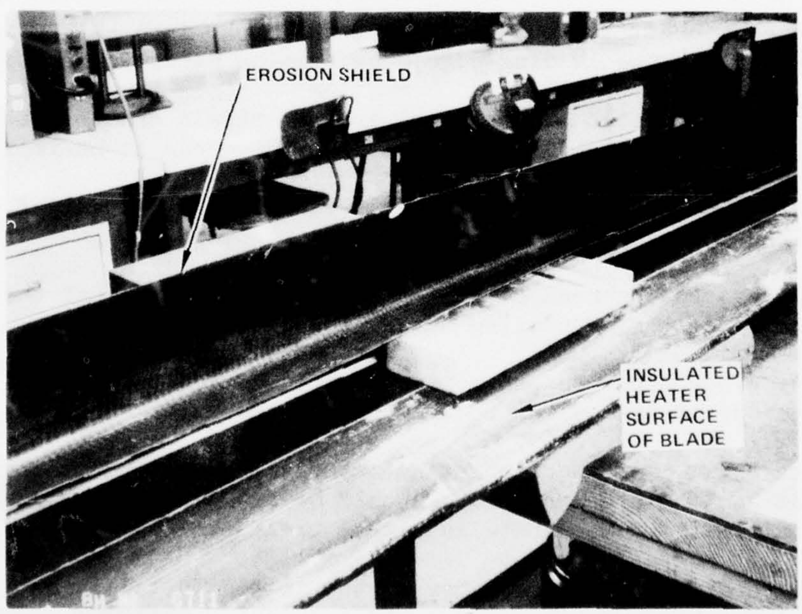


Figure 39. Zones 1 and 2 Inboard of Failure Area

- A few of the solder joints of the lead wire braids to the heater element tabs were not good solder connections and appeared to be similar to a cold joint.

From these indications, the following conclusions concerning the assembly were established:

- Although the exact failure mode is not obvious, the general condition of incomplete bonding contact and/or adhesion along the leading-edge area suggests potential hot spots that could eventually result in a breakdown through the insulation.

- The "dry" condition of the insulating material found under the inboard half of the steel erosion shield would easily absorb and conduct moisture if the installation were not moistureproof. This could explain the reduction in dielectric strength recorded in tests of this blade both at Moses Lake and Ottawa.

It is felt that minor refinements in the manufacturing process should be made that would improve the heater installation considerably. These are:

- The contour fit of the heater to the erosion shield in the leading-edge nose section needs to be improved.

- The contour fit of the heater and its 0.040-inch-thick backing material in the leading-edge nose section needs to be improved.

- The contour match of the steel erosion shield and the basic blade section in the leading-edge nose section needs to be improved.

- The built-up contour of the basic blade after removal of the original erosion shield needs to be improved.

- Q.A. procedures need to be implemented to insure that the type and quality of the insulating material are uniform.

- Q.A. procedures need to be implemented to insure good solder connections of lead wires to the heater element.

- The thickness of the insulating material between the heater element and the erosion shield should be increased to reduce the sensitivity of the installation to breakdown and/or penetration.

- The sealing around the edges of the shield installation from possible moisture ingress to the insulating material needs to be improved.

SECTION 5

CONCLUSIONS

- The deicing control system performed very well during this program. This indicates that almost all of the problems experienced during the Moses Lake testing must have been related to the chaffed wiring inside the main shaft because no other changes were made.

- Blade deicing, which has been evaluated now over a wide range of conditions in hover and forward flight, has no measurable effect on structural loads and no significant effect on vibration.

- Main and tail rotor blade deicing is effective except for some residual ice on the inboard portion of the main blade. This deficiency was noted last year and now is related to the 1.0-inch-wide cold spot and surface discontinuity at the Station 83 joint between the steel and aluminum erosion shields. Minor design refinements can be made on future blade installations that should eliminate or significantly improve the condition.

- The main rotor blade heater installation has a problem near the leading edge that resulted in electrical short failures after 40 to 50 flight hours. It appears from a blade teardown investigation that getting a better fit of the mating components (erosion shield-insulation-heater element-blade contour) during the manufacture and possibility increasing the thickness of the insulation will eliminate the problem.

- A deterioration in dielectric strength of the heater insulation was again experienced during the year's test program. Minor design refinement to assure sealing the edges from moisture ingress should eliminate this deficiency in future blade installations.

- The problem of a delay in the ac generator coming on the line at low ambient temperature was again experienced even though a change in the generator controller was made. This problem requires further investigation.

- The pictures obtained with the hub-mounted 16mm camera do not provide sufficient blade ice definition against a white background for ice accretion and/or deicing evaluation.

- Due to the frequency of unfavorable weather conditions (i.e., low wind, warm temperatures, freezing rain and snow), all of the desired test variables could not be investigated during the test period.

SECTION 6

RECOMMENDATIONS

- Changes in the main rotor blade heater installation to eliminate the deficiencies that have been identified should be incorporated in the blades prior to further testing.
- Natural icing tests should be conducted as a final evaluation of ice protection system effectiveness including the ice detectors and the need for icing severity indication.
- The heater-on time versus OAT developed from the Ottawa test results should be evaluated initially in future testing to confirm their accuracy.
- The heater-off time versus LWC established from testing to date should be evaluated further in future testing.
- The system controller should be modified to schedule heater-off time based on a fixed quantity of accreted ice. This could be the integration of LWC versus time or a number of ice detector deicing cycle counts using the currently available hardware.
- The tail rotor-off time should be scheduled as a function of LWC similar to the main rotor instead of heater-on time as the controller is presently configured.
- The ultrasonic type ice detector should be readjusted to cycle as often as possible in order to permit use of the count system to schedule main blade deicing.
- The thermocouple temperature measurement problem should be corrected prior to further testing.
- Blade instrumentation should include at least one surface temperature measurement per zone to aid in optimizing the heater-on times.
- A second camera should be installed to photograph the main blade lower surface for ice assessment. This could be a nonrotating camera strobed to illuminate and photograph the blade.
- The external ac APU ground problem should be reviewed to determine whether a system change is required for future design.

- Further Ottawa spray rig testing should be conducted to gain additional data on the following variables:

    1. Ice accretion rate and type as a function of cloud LWC, OAT, and mixed liquid water and crystal content.

    2. Rotor blade deicer heater blanket energy-on-time, power density and off-time as a function of LWC and OAT.

    3. Runback as a function of LWC, OAT, energy on- and off-times and power density.

    4. The effect of runback on autorotation.

    5. Substantiation of the adverse effects of ice buildup on the inboard section of the main rotor blade.

SECTION 7

OTTAWA TEST PROGRAM SUMMARY

7.1 SPRAY RIG TESTING LOG

A summary of the tests conducted in the NRC spray rig is presented in Table 7. Testing was accomplished under 15 different conditions. A total of 28.5 flight hours were accumulated at Ottawa. Of these hours, 18.1 were considered productive icing flight hours with 7.1 hours actually in the artificial icing environment. Figures 40 and 41 present typical test data sheets used for recording the ice condition found on the aircraft after a run in the icing cloud.

7.2 DAILY ACTIVITY LOG

Table 8 describes the daily activity for the 55-day calendar span at Ottawa, and is presented for use in future program planning. The program was conducted on a single-shift six-day-week basis. During the program most of the time required for unscheduled maintenance coincided favorably with unsuitable weather conditions. This resulted in good overall utilization of the test team. There were 35 work days during this span excluding rotor blade reconfiguration time. Testing was accomplished in 13 days, resulting in a program efficiency of 37 percent in terms of working days, or 24 percent in terms of calendar days. The aircraft down-time due to test instrumentation or other problems was only 3.5 days. The weather was unsuitable for testing on 19 of the 35 available test days.

TABLE 7. SPRAY RIG TESTING LOG

1976 DATE	TEST NO	FLT NO	OAT °C	WIND VEL/GUST MPH	WEATHER	LWC g/m^3	RUN NO	RUN OBJECTIVE	MINUTES OF IMMERSION	ICING INDICATIONS ULTRA-	ICING INDICATIONS INFRA-	INLET ΔP	DEICING RESULTS	REMARKS
31 Jan	50	71	-13.6	5ℓ	Overcast	0.20	1	1st Test	10	T	0	-	Blades clean	Cloud seemed thin
			-15.5	5ℓ	Snowing	0.40	2	Heavier Cloud	5	L-M	H-L-M	Reached limit	Inb'd zone 6 didn't shed	Cloud dense - Ran on ground
3 Feb	51	72	-7.8	10m	-	0.60	3	Single cycle	4	M	H	-	Some runback	Ready for 30-min. run
			-6.8	12m	-	0.70	4	1st 30-min run	35	M	H	-	Zone 5 runback	Good shed cycles
7 Feb	52	73	-15.6	7m	-	0.40	5	Shorter On-Time to stop runback	3	0.25	H	-	Sta 83 residual ice and minor zone 5 runback	Only left fw'd portion of of rotor disk in cloud.
			-14.8	7m	-	0.40	6	Longer off-time for 1/4-inch ice	5	0.15	L	-	Same as above.	Thin inb'd ice results in runback
			-14.0	7m	-	0.40	7	Multiple cycles	30	-	-	-	Layered residual ice at Sta 83	Sta 83 joint and instrumentation result in ice hang-up.
12 Feb	54	75	-11.5	8ℓ	Overcast	0.55	8	Zone 5 smoothed	3	-	-		Blades clean	Not getting much ice inb'd - smoothing seems to have helped.
			-11.6	8ℓ-10m	Snowing Heavily	0.60	9	Multiple cycles	23	.05	L	Reached limit	Zones 4,5,6 runback	Runback could be from snow
18 Feb	56	78	-5.9	10m	-	0.60	10	1st run with IR suppressor.	2	0.30	L	-	Blades very clean	Good cloud with good rotor immersion
			-5.4	10m	ℓto m fine snow falling	0.60	11	Multiple cycles	12	0.1-.4	L	Reached limit	Zones 4,5,6 runback	Snow confuses inb'd results
20 Feb	58	80	-3.5	7ℓ	clear	0.80	12	Warmer OAT	3	0.5	0	-	-	Ice out to 40% span
			-3.4	7ℓ	sunny	0.80	13	Multiple cycles	30	.3-.5	L	-	Zone 5 light runback	1/4-inch ice coating on inlet screens
23 Feb	59	81	-20.1	10m	-	0.30	14	Coldest OAT	6	0.1	L	-	Zone 5, 6 did not deice	on-time too short
			-19.1	10m	-	0.30	15	Longer on-time	6	0.1	M	-	Zone 5 runback	Wind marginal
			-18.1	7m	-	0.35	16	Multiple cycles	36	0.1	L-M	-	Blades clean except Sta 83 and slight runback	Cloud better last 10 minutes
23 Feb	59	82	-15.0	7m	-	0.45	17	Induce runback	12	-	H	-	No ice - not in cloud	Dense cloud - Used short off-time and long on-time
			-14.3	7m	-	0.45	18	Induce runback	6	0.4	H	Reached limit	-	A/C completely obscured - ΔP rise rapid
24 Feb	60	83	-0.7	7m	-	0.75	19	Induce runback	32	0	0	-	-	No ice near 0°C

TABLE 7. SPRAY RIG TESTING LOG (Continued)

1976 DATE	TEST NO	FLT NO	OAT °C	WIND VEL/GUST MPH	WEATHER	LWC g/m^3	RUN NO	RUN OBJECTIVE	MINUTES OF IMMERSION	ICING INDICATIONS ULTRA-	ICING INDICATIONS INTRA-	INLET ΔP	DEICING RESULTS	REMARKS
2 Mar	63	86	-12.6	20h	Cloudy	0.30	20	Single cycle	5	0.30	H	-	Crew can feel zone sheds	Ice too thick and self sheds
			-12.2	20h	Cloudy	0.30	21	Shorter off-time	4	0.10	M	-	Zones 5, 6 residual	Ice had double horn shape
			-12.2	20h	Cloudy	0.30	22	Multiple cycles	30	.1-.2	L-M	-	Zones 4, 5, 6 had some runback	Runback extended to blade t.e. from Zone 5
3 Mar	64	87	-11.1	15m	Freezing rain & light snow	0.50	23	Shorter On-Time to reduce runback	2	0.10	L	-	No evidence of deicing but ice is thin	Ice may be too thin to shed
			-10.7	15m		0.50	24	Increase off time	3	0.15	L	-	Residual ice inb'd 2 feet and aft portion of heater chord-zones 3,4,5	On-time too short
			-10.0	15m		0.50	25	Increased On-time	29	0.10	L	-		ac ground light came on
8 Mar	67	89	-11.5	10m	Perfect	0.55	26	Replaced blade	3	0.1	H	-	Clean except inb'd 6-12"	Exactly 1/4-inch at 50% span
			-11.2	10m	Perfect	0.55	27	Ice detector counts for 1/4-inch	30	T-.2	L-M	-	Minor runback	Shed ice floats down as if light weight (thin)
			-10.3	10m	Perfect	0.30	28	same as 27	30	T	L	-	Red blade didn't deice zones 4, 5, 6 but white blade perfectly clean	Results are confusing - why different blade deicing?
8 Mar	68	90	-8.9	10m	-	.6-.3	29	Simulated icing encounter	30	T	M-L	-	Blades clean even though saved last accretion to inspect.	More confusing results - Why didn't blades have ice?
11 Mar	69	91	-6.0	5-13	Clear	0.70	30	Simulated icing encounter	10	.05	L-M	-	Some natural shedding during run	ac ground light came on 3rd cycle

Notes: (1) Rocket pod on except for Flights 71, 72, 73 and 83

(2) IR Suppressor installed for Flight 78 and subsequent

(3) Separate cockpit readout provided for ultrasonic and infrared ice detectors after Flight 73 to permit simultaneous comparison

(4) Ultrasonic ice detector indication changed to read in g/m^3 after Flight 72 using available calibration data.

(5) Infrared system icing indications were "Light" (.16-.40 g/m^3) "Moderate" (.4-.6) and "Heavy" (>0.6)

(6) l, m, h correspond to light, moderate and heavy gusts

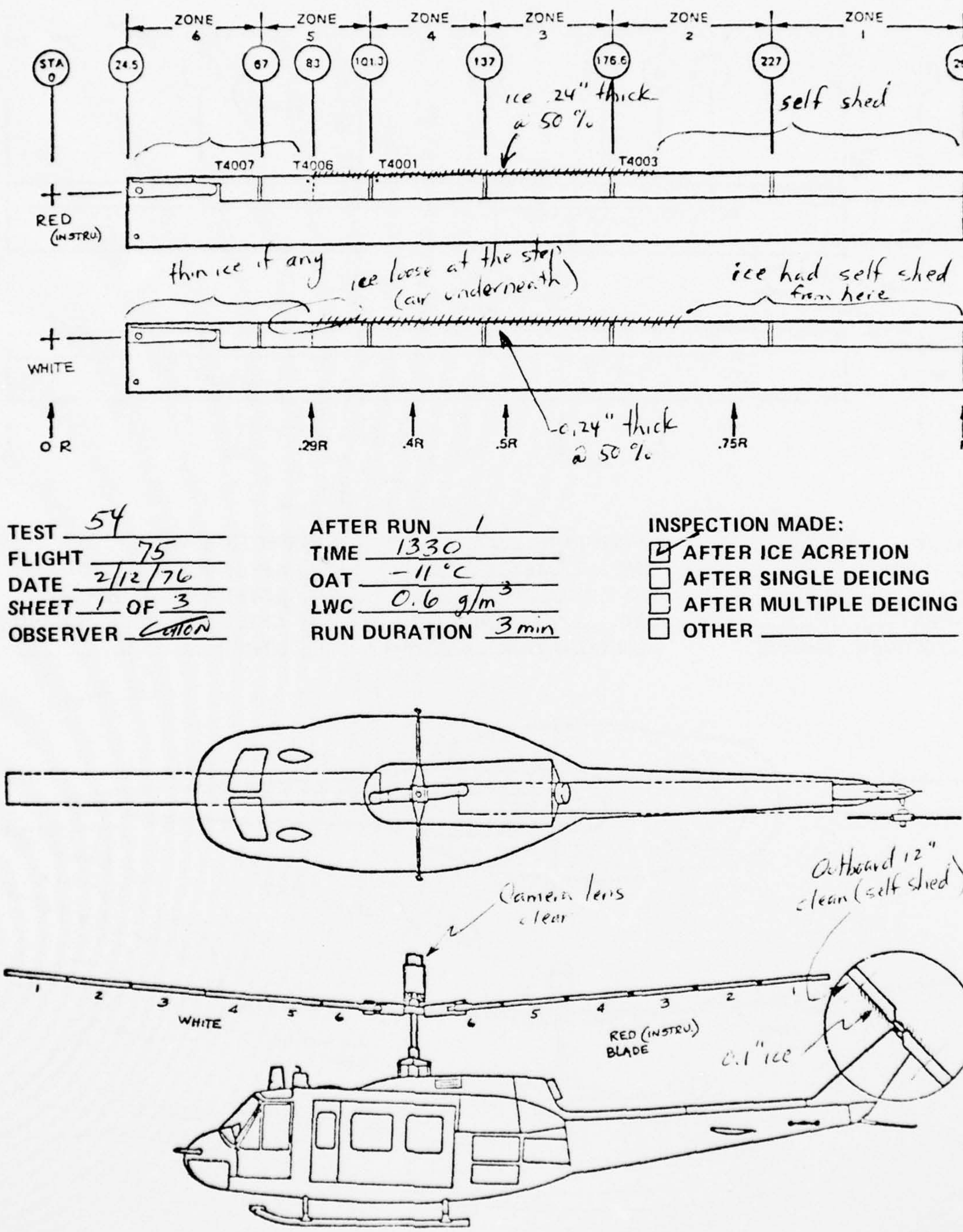


Figure 40. Typical Post-Icing Test Visual Observations Data Sheet - After Ice Acretion

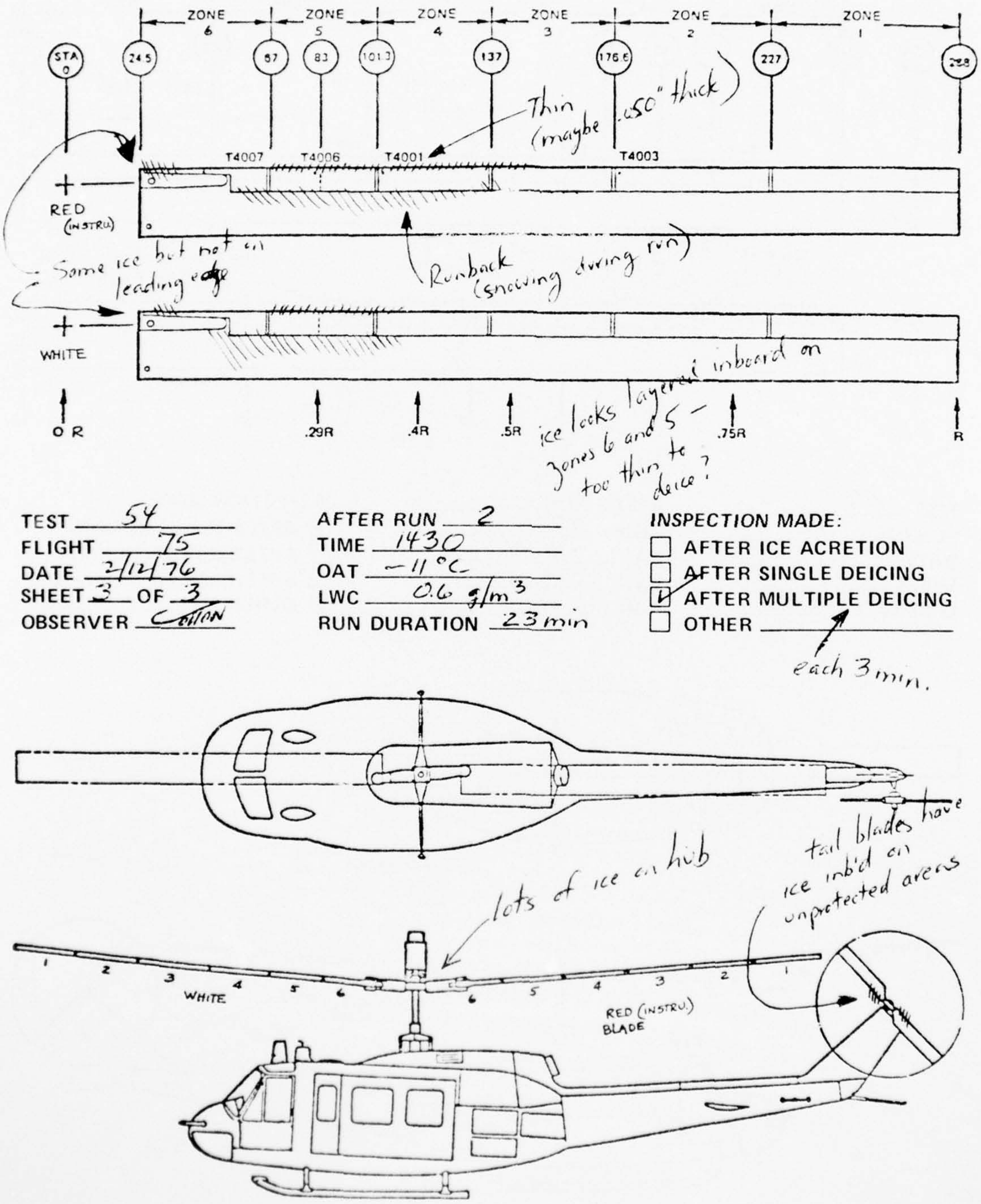


Figure 41. Typical Post-Icing Test Visual Observations Data Sheet - After Blade Deicing

TABLE 8. DAILY ACTIVITY LOG

OTTAWA DAY	1976 DATE	TEMP. °C	WEATHER	ACTIVITY
1	22 Jan	-	-	Test aircraft and support crew on-site and ready for reconfiguration.
5	26 Jan	-	-	Truck arrived with parts, tools and test equipment.
8	29 Jan	-4	Snowing	Reconfiguration completed. Ground run and weather-limited functional check flight (FCF) accomplished.
9	30 Jan	-	-	Completed FCF. Aircraft ready for icing test at 3 p.m.
10	31 Jan	-15	No wind, snowing later	Accomplished 1st spray rig test in afternoon, when wind suitable for test.
11	1 Feb	-	-	No scheduled work (Sunday).
12	2 Feb	-24	Snowing	Weather no good for testing.
13	3 Feb	-8	Overcast	Tested in Spray Rig.
14	4 Feb	-2	Snowing & no wind	Weather no good for testing.
15	5 Feb	-20	Clear but no wind	Weather no good for testing.
16	6 Feb	-23	Clear but no wind	Wind came up in p.m. but found broken deicing control wire.
17	7 Feb	-15	Marginal wind	Tested in Spray Rig.
18	8 Feb	-	-	No scheduled work (Sunday).
19	9 Feb	-10	Clear but no wind	Weather no good for testing.
20	10 Feb	-5	No wind	Weather no good for testing.
21	11 Feb	+2	No wind	Weather no good for testing.

TABLE 8. DAILY ACTIVITY LOG (Continued)

OTTAWA DAY	1976 DATE	TEMP. °C	WEATHER	ACTIVITY
22	12 Feb	-11.5	Overcast with snow	Tested in rig but snow clogged engine air inlet.
23	13 Feb	+3	-	Weather too warm for testing.
24	14 Feb	-10	Good for testing	Repaired blade heater damage.
25	15 Feb	-	-	No work scheduled (Sunday).
26	16 Feb	-1	Too warm for testing	FCF of blade repair and ice cap area checkflight
27	17 Feb	Warm	No wind	Weather no good for testing.
28	18 Feb	-6	Heavy snow terminated testing	Tested in spray rig.
29	19 Feb	-1	Too warm for testing	Flew oil-consumption check flight.
30	20 Feb	-3.5	Clear & sunny	Tested in spray rig.
31	21 Feb	-3	No wind	Weather no good for testing.
32	22 Feb	-	-	No work scheduled (Sunday).
33	23 Feb	-18.6	Marginal wind	Tested in spray rig.
34	24 Feb	-1	10 mph wind	Tested in spray rig.
35,36 37	25,26 27 Feb	Warm	No wind	Weather no good for testing.
38	28 Feb	-7	Snow	Hovered in snow.
39	29 Feb	-	-	No work scheduled (Sunday).
40	1 Mar	-	Clear	Dry run of natural icing flight using T-42, UH-1H crash/rescue aircraft and radar controller.

TABLE 8. DAILY ACTIVITY LOG (Concluded)

OTTAWA DAY	1976 DATE	TEMP. °C	WEATHER	ACTIVITY
41	2 Mar	-12	20-mph wind	Tested in spray rig (weather no good for natural icing).
42	3 Mar	-11.5	Light, freezing rain	Tested in spray rig (weather no good for natural icing).
43	3 Mar	-5	Low ceiling	Changed main blade. Chase flew Xmsn oil sample to Trenton.
44	5 Mar	-	Rain	Weather no good for testing.
45	6 Mar	-	Clear	Weather no good for testing. Flew clear air temp - alt. survey.
46	7 Mar	-	-	No work scheduled (Sunday).
47	8 Mar	-11	Clear with 10-15 mph wind	Tested in spray rig (3-30 min. runs).
48	9 Mar	-12	Clear with no wind	Weather no good for rig or natural icing testing.
49	10 Mar	-	Snowing, with low visibility	Weather no good for rig or natural icing testing.
50	11 Mar	-11	Clear with 10 mph wind	Tested in spray rig; no good for natural icing. "Short" in 2nd main blade terminated the program.
51	12 Mar	-	Good for rig or natural icing	Reconfiguration for ferry completed.
52	13 Mar	-	Snowing	Prevented check flight of standard blades.
53	14 Mar	-	-	No work scheduled (Sunday), but check flight accomplished.
54	15 Mar	-	-	Final packing/load truck.
55	16 Mar	-	-	Test crew returned to California.

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SECTION 8

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