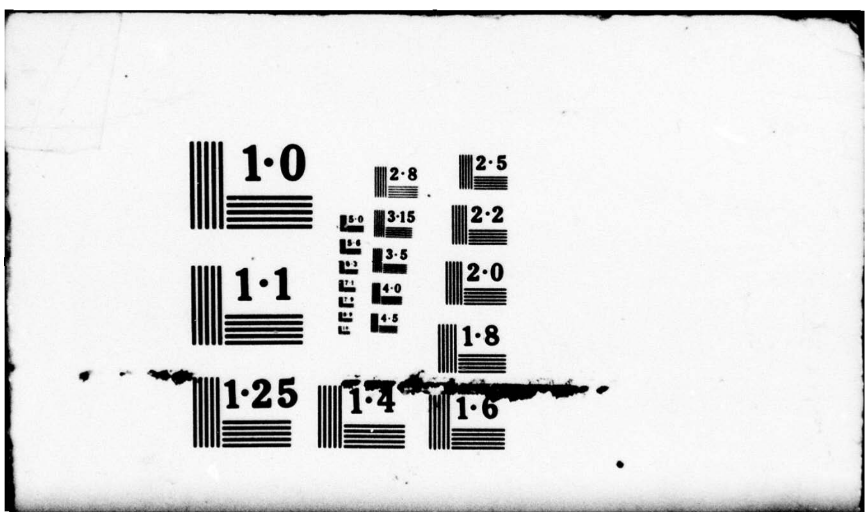
AD-A067 737 LOCKHEED-CALIFORNIA CO BURBANK F/G 1/3
ICING TESTS OF A UH-1H HELICOPTER WITH AN ELECTROTHERMAL ICE PR--ETC(U)
APR 79 R H COTTON DAAK51-78-C-0003
UNCLASSIFIED LR-28667 USARTL-TR-78-48 NL

1 OF 1
ADA
067737

END
DATE
FILMED
6-79
DDC


1·0
2·8
2·5
5·0
3·15
2·2
5·6
3·5
2·0
1·1
4·0
4·5
1·8
1·25
1·4
1·6

USARTL-TR-78-48

LEVEL II

ICING TESTS OF A UH-1H HELICOPTER WITH AN ELECTROTHERMAL ICE PROTECTION SYSTEM UNDER SIMULATED AND NATURAL ICING CONDITIONS

R. H. Cotton
LOCKHEED-CALIFORNIA CO.
P.O. Box 551
Burbank, Calif. 91520

April 1979

Final Report for Period 31 January 1978 - 31 March 1978

Approved for public release;
distribution unlimited.

Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

The primary purpose of this effort was to verify the helicopter icing design criteria presented in USAAMRDL-TR-75-34A through flight test of a prototype ice protection system designed to these criteria. A secondary purpose was to perform specific investigations preliminary to the UH-1 Partial Ice Protection System (KIT A) qualification program.

This Laboratory concurs in the findings stated herein, with the precaution that many of the design conclusions and recommendations are based primarily on simulated icing experience. Although natural icing test results to date qualitatively confirm the recommendations, the lack of rotor blade photographic system prevents quantitative confirmation. Additional flight tests and operational experience in natural icing are necessary to comprehensively verify the design criteria. It is planned to continue natural icing envelope expansion with the modified UH-1H as the KIT A test bed in 1979 and in future years to test ice phobic coatings and external stores.

The Project Engineer for this effort was Ms. Phyllis F. Kitchens of the Aeronautical Systems Division.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 USARTL-TR-78-48 / 2. GOVT ACCESSION NO.: 19 TR-78-48	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 ICING TESTS OF A UH-1H HELICOPTER WITH AN ELECTROTHERMAL ICE PROTECTION SYSTEM UNDER SIMULATED AND NATURAL ICING CONDITIONS.	5. TYPE OF REPORT & PERIOD COVERED: Final Report for Period 31 Jan 1978 to 31 March 1978
	6. PERFORMING ORG. REPORT NUMBER: Lockheed Report LR 28667
7. AUTHOR(s): 10 R.H. Cotton	8. CONTRACT OR GRANT NUMBER(s): 15 DAAK51-78-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Lockheed-California Co., P.O. Box 551, Burbank, California 91520 — 209 970	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 63209A 1L263209D103 00 002 EK — 17 00
11. CONTROLLING OFFICE NAME AND ADDRESS: Applied Technology Laboratory, U.S. Army Research & Technology Laboratories (AVRADCOM) Fort Eustis, Virginia 23604	12. REPORT DATE: 11 April 1979
	13. NUMBER OF PAGES: 79
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 14 LR-28667	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

12 84 p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

9 Final rept. 31 Jan - 31 Mar 78,

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ice	UH-1H	Natural Icing Testing
Snow	Electrothermal Deicing	Simulated Icing Testing
Deicing System	Ice Protection	Flight Tests
Advanced Rotary Wing Aircraft	Ice Prevention	

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

Natural and simulated icing tests were conducted during February and March 1978 with a UH-1H helicopter equipped with an advanced ice protection system. This was the fourth program of icing tests accomplished with this test aircraft and the second to include natural icing. The objective of this year's program was to expand the icing test envelope, to gather additional data on ice protection system design and performance characteristics, → over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

209 970

79 04 23 008

20. Abstract - Cont.

and to obtain specific data for use in a product improvement program for the UH-1 Partial Ice Protection System (Kit A). The testing was conducted at Ottawa, Ontario, Canada.

Seven tests in the spray rig and twelve natural icing flights were made totaling 25.8 hours of icing tests. Icing was encountered on seven of the natural icing flights. The icing conditions ranged from 0.03 g/m^3 of liquid water content at -5.5°C to 0.5 g/m^3 at -10°C. The number of blade deicing cycles required on any flight under these light icing conditions ranged from one to three, which did not exceed the previous icing severity level envelope experienced.

The ice protection system apparently performed satisfactorily and reliably on all of the natural icing flights as no problems were experienced. The lack of an in-flight rotor blade photographic system prevented quantitative assessment of system operation. Completely automatic operation of the blade deicing system was accomplished. It appears that further testing or operations in an icing environment can be performed without any changes to the configuration of the deicing system.

A photosystem needs to be developed that will permit photographing the blade's lower surface so that blade deicing results under natural icing conditions can be verified. Spray rig test observations show that complete blade deicing over the inboard portion of the blade is inconsistent and runback is experienced. It is not known whether this condition persists under natural icing conditions nor whether it is necessarily detrimental. Spray rig tests have attempted to evaluate the effects, but the results have been inconclusive because the weather conditions that prevailed at the time of the tests precluded valid test results.

Because of the relatively limited natural icing conditions under which the system has been operated, this report clearly defines these conditions so that future operators of the aircraft will be cognizant of the demonstrated envelope.

PREFACE

This report describes the results of the fourth winter of testing a UH-1H helicopter equipped with an advanced ice protection system. The design and testing of the ice protection system has been sponsored by the Applied Technology Laboratory (ATL), U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia.

The first two winters of testing were under simulated icing conditions. This testing was conducted for ATL by the U.S. Army Aviation Engineering Flight Activity (USAAEFA), Edwards AFB, California, with support by Lockheed-California Company. The subsequent testing has been conducted under the direct management of the Applied Technology Laboratory using flight and test personnel obtained from several government agencies and with Lockheed providing support in the form of maintenance of the ice protection system and instrumentation, test planning, test support, data reduction, data analysis, and test reporting.

The January-to-April 1978 test program was managed overall by Mr. Richard I. Adams of the Applied Technology Laboratory (AVRADCOM). The on-site project engineer and test manager was Ms. Phyllis F. Kitchens also of ATL.

The pilots were Mr. Charles E. Arnold, Engineering Test Pilot from the FAA Great Lakes Region and CPT. Michael F. McGaugh, Operational Test Pilot from the U.S. Army Aviation Board at Fort Rucker, Alabama.

The test aircraft maintenance was performed by SGT. G. Worrell. He was assisted by SFC. W.L. Kling in aircraft depreservation and pre-test periodic maintenance services. Both are from the Applied Technology Laboratory.

The Lockheed people involved and their responsibilities were:

Mr. R.H. Cotton - Test Director

Mr. L.C. Macy - Flight Test Engineer

Mr. D.R. Ekker and Mr. J. Van Wijk - Instrumentation Engineers

Mr. T.H. Oglesby - Data Reduction and Analysis Engineer

Mr. R.T. Omori - Ground Station Operator/Instrumentation Engineer

Mr. R.J. Lennert - Flight Test Electrician/Instrumentation Technician

Mr. R. Metcalf - Flight Test Mechanic

Mr. R.D. Songstad - Flight Test Electrician/Strain Gage Technician

A standard UH-1H helicopter from Fort Rucker, Alabama, was used to provide chase/rescue. This helicopter was crewed by the following Army personnel from Fort Rucker, Alabama:

MAJ J.E. Wilson - Command Pilot, US Army Aircraft Development Test Activity (USAADTA)

CW3 J.H. Dize - Copilot, US Army Aviation Board (AVNBD)

SSG H.R. Young - Crew Chief (USAADTA)

SP4 D.D. Chester - Medic, 427th Medic Co., 46th Engr. Battln, US Army Aviation Center (USAAVNC)

SGT J.M. Corralejo - Rescue/Fireman, 12th Company, 1st Battln. (USAAVNC)

SP4 C.H. Aery - Rescue/Fireman, 12th Company, 1st Battln. (USAAVNC)

Both the test and the chase aircraft were operated from Hangar 12 of the Canadian Forces Base Ottawa (South) at Ottawa International Airport, Ottawa, Ontario, Canada. The Canadian Forces provided the hangar and office space used by the test team as well as the miscellaneous logistical support required.

The test program included simulated icing tests in the Canadian National Research Council Spray Rig facility operated by Mr. Ron Price.

Both the ice detector and the icing rate systems used in the program were loaned and supported by their manufacturers. The infrared type was loaned by Leigh Instruments, Ltd., and the ultrasonic type was loaned by Rosemount, Inc. The latter also provided a dual element total air temperature sensor used for TEST OAT measurement.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

SECTION 1

INTRODUCTION

Simulated and natural icing tests were conducted on a UH-1H helicopter equipped with an advanced ice protection system incorporating electrothermal rotor blade deicing. This testing was part of an overall research and development program sponsored by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, to provide design and test criteria for helicopter ice protection systems and to develop the technology to meet these criteria. This report presents the results of the fourth winter of testing of the system.

The testing was conducted during February and March of 1978 at Ottawa, Ontario, Canada. The simulated testing was accomplished in the Canadian National Research Council's Spray Rig facility. The natural icing flights were made from and in the vicinity of the Ottawa International Airport. Both the simulated and the natural icing tests were the continuation of similar tests conducted to expand the envelope of icing conditions investigated.

Twenty-nine flights were made, accumulating 34.4 flight hours. Unfortunately the winter season at Ottawa had below normal precipitation and above normal surface temperatures; therefore, the program was not as productive as anticipated. Seven spray rig test periods yielded 4.5 hours in the icing cloud and although 12 natural icing flights were made, icing conditions were encountered on only seven, totaling approximately 4 hours in icing. On these flights the liquid water concentrations were relatively low and did not expand the exposure of the aircraft to icing.

Presented and discussed herein are the additional data and information obtained from the 1978 testing. This included finalizing the outside air temperature sensor and ice detector locations, checking the effect of increased FM antenna tilt on radio performance, and main rotor blade chordwise temperature distribution around the leading edge.

The results of the previous three winters' testing are reported in References 1 through 4.

1. Werner, J.B., THE DEVELOPMENT OF AN ADVANCED ANTI-ICING/DEICING CAPABILITY FOR U.S. ARMY HELICOPTERS, VOLUME II - ICE PROTECTION SYSTEM APPLICATION TO THE UH-1H HELICOPTER, Lockheed-California Company; USAAMRDL Technical Report 75-34B, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1975, AD A019049.

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

3. Cotton, R.H., OTTAWA SPRAY RIG TESTS OF AN ICE PROTECTION SYSTEM APPLIED TO THE UH-1H HELICOPTER, Lockheed-California Company; USAAMRDL Technical Report 76-32, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1976, AD A034458.

4. Cotton, R.H., NATURAL ICING FLIGHTS AND ADDITIONAL SIMULATED ICING TESTS OF A UH-1H HELICOPTER INCORPORATING AN ELECTROTHERMAL ICE PROTECTION SYSTEM, Lockheed-California Company; USAAMRDL Technical Report 77-36, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1978, AD A059704.

SECTION 2

DESCRIPTION OF THE ICE-PROTECTED UH-1H TEST CONFIGURATION

The test aircraft shown in Figure 1 is a UH-1H helicopter (Serial Number 70-16318) modified to incorporate an ice protection system for use as a flight test bed to evaluate an advanced anti-icing/deicing system concept. The system was designed by the Lockheed-California Company and installed under a previous contract. The modifications include electrothermal deicing of the main and tail rotor blades, heated glass windshields, and heated anti-ice blankets on the stabilizer bar and tip weights. Electrical power for these components is supplied by an ac generator installed as part of the modification. The ice protection system includes a deicing controller that uses inputs from an icing rate detector and an outside air temperature sensor to program blade deicing cycles and heater-on time.

The heated rotor blades are standard UH-1H blades modified by removing the original leading-edge erosion shield, rebuilding the blade back to contour with a fiberglass epoxy layer filler, and then bonding a new complete heated erosion shield assembly to the existing filler built-up blade. The resulting installation extends approximately 0.090 inch outside of the basic blade airfoil contour; therefore, a 1-inch-wide tapered fairing blends the aft edge of the erosion shield to the basic blade contour. The same procedure was used on the tail rotor blade except transition thickness is less.

The inboard portion of the main blade, where the blade thickness varies due to the structural doublers, was faired and a separate heated shield installed over the smoothed surface contour. The junction of the two sections of leading-edge erosion shield is at station 83. The material of the outboard section of the erosion shield is 0.030-inch steel and the inboard portion over the doublers is 0.016-inch aluminum.

The tail rotor blade erosion shield was replaced with one of electroformed nickel material that is 0.030-inch thick at the leading edge and tapers to 0.010-inch at the trailing edge. The inboard or doubler portion of the tail rotor blade is not heated.

The main rotor blade is divided spanwise into six separately heated zones, which are activated sequentially from tip to root to effect deicing. The tail rotor blades have a single heated zone. The heating-power density of

Figure 1. The Test Aircraft - UH-1H (S/N 70-16318).

the main blade varies with zone with 200 volts applied from 26 watts/in^2 at the root to 12 watts/in^2 at the tip to use the aerodynamic heating generated by blade rotational speed. The tail rotor blade heats at a uniform power density of 20 watts/in^2.

The ac electrical power leads are routed from the ac bus to the rotor through the inside of the main rotor shaft to slip rings installed on top of the hub. Slip rings are also provided on the tail rotor shaft to route the power to the tail rotor blades.

For research and development purposes, the deicing system can operate at three voltages - 160, 200, or 230 Vac, which are programmed as a function of liquid water concentration (LWC). This provides the capability to cycle through the heater zones at different rates to accommodate changes in icing severity. The system controller also includes provisions for adjusting the heater-on and heater-off times to aid in optimizing blade deicing.

The stabilizer bar and tip weights are continuously heated during icing conditions to provide an anti-icing capability at 5 watts per square inch with 200 volts, ac. The windshields are of laminated glass with a tin oxide (NESA) film in between the glass layers. At 200 volts, ac, they are heated at 3.3 watts per square inch (psi). The total power demand of the various ac-operated components is approximately 25.4 kVA at 200 Vac or 16.3 kVA and 33.6 kVA at 160 and 230 Vac, respectively. The distribution is approximately 13.2 kVA for main rotor blades, 4.0 kVA for tail rotor blades, 3.0 kVA for the stabilizer bar, and 5.2 kVA for the windshield.

Two different accretion-type ice detectors incorporating icing rate systems have been installed as part of the modification: an infrared-type and an ultrasonic-type. These are installed on 12-inch-high pylons or masts mounted on the cabin roof of the forward fuselage.

The outside air temperature input to the deicing controller is provided by a flush-type surface temperature sensor. This was located under the nose of the aircraft but relocated to the top of the cabin during this year's testing in order to provide an accurate signal.

The engine air inlet configuration is unmodified and does not incorporate any special ice protection features. In addition, the engine air inlet filter screens have been left installed during all testing conducted to date.

The lateral tilt angle of the FM radio antenna was increased 15 degrees with the standard MWO UH-1H mounting wedge prior to any icing testing. This was to provide additional clearance from the tail rotor plane, which had been found to be necessary during previous Army icing test experience, to preclude antenna strikes on the tail rotor. Subsequent test experience with this configuration showed more tilt was needed; therefore, an additional 15 degrees of tilt was added for a total of 42.5 degrees from the vertical plane.

The test aircraft also incorporates extensive test instrumentation and an on-board data acquisition system. The latter is a FM proportional-bandwidth magnetic tape recording system. For data retrieval at remote test sites and to provide for quick-look data assessment capability, a portable ground station was used.

A 16 mm motion picture camera is installed on top of the main rotor hub-mounted cannister that encloses the deicing system and instrumentation slip rings. The camera, which is heated and insulated, rotates with the rotor and is used to photograph the upper surface of one main rotor blade to permit assessment of blade icing and deicing.

A more complete description of the ice protection and instrumentation systems and the modifications since the initial installations can be found in References 1 through 4. In addition, the next section of this report describes in detail the configuration changes since the 1977 test program which were made in preparation for the 1978 flight tests.

SECTION 3

CONFIGURATION CHANGES FOR THE 1978 OTTAWA TEST PROGRAM

A minimum of problems were experienced during the 1977 Ottawa test program and only a few changes were considered to be necessary for any follow-on testing; therefore, the test aircraft was left at Ottawa in storage at the conclusion of the 1977 program. This section describes the minor changes and/or improvements that were made at Ottawa in preparation for the program.

3.1 MAIN ROTOR BLADES

The only change made to the main blade deicing configuration was to smooth the remaining surface discontinuity in the Station 83-85 area. This discontinuity was the five steps of 0.003 inch of thickness where the 0.030-inch steel erosion shield material thickness was tapered over a 5-inch span length to match the 0.016-inch-thick aluminum shield material at Station 83. This was done in an effort to eliminate the small amount of residual ice that was found in this area after some of the blade deicing cycles.

The rework was done only to the noninstrumented blade to allow a direct comparison with the other blade. The rework consisted of essentially sanding the paint thickness away from the high spots and then repainting the area. No filler material was needed.

3.2 BLADE DEICING CONTROLLER

No changes were made to the controller, as trouble-free operation of the controller was experienced on all flights of the 1977 program. The controller configuration had been modified for last year's testing from the original concept of scheduling heater-off time as a direct function of LWC to a configuration that permits the selection of an integrated icing rate signal (LWC x time) coming from an ice detector unit such as the integrating rate unit (IRU) that uses the infrared-type detector's LWC information. The purpose of this change was to insure blade deicing at a uniform ice thickness while operating in a nonuniform environment; i.e., LWC fluctuating with time. This change permits operation of blade deicing and other ice protection system features in the automatic mode only at the single voltage of 200 Vac. Consideration was given to modifying the controller to permit automatic operation at the other voltages, but it was not done in the interest of cost saving. It was felt that single-voltage operation at 200 Vac was adequate to demonstrate the concept. The IRU schedules tail rotor blade deicing at one-half the ice thickness of the main rotor per the rationale expressed in Reference 3.

3.3 TAIL ROTOR SLIP RING INSTALLATION

A failure of the tail rotor slip ring outboard bearing was experienced during the 1977 program, and excessive wear was noted again between the slip ring drive mating components. The slip rings were completely refurbished and the bearings changed to a caged type and a better class of bearing. The original bearings were uncaged Class I bearings. These were replaced with zero-time Class III caged bearings.

The wear problem was corrected by increasing the bearing area of the mating surfaces by 100 percent, changing the material of the CL1706-1-19 cone set from annealed stainless steel to 17-4PH steel and increasing the hardness of all mating surfaces to 190,000 - 225,000 psi heat treat.

3.4 HEATED STABILIZER BAR ASSEMBLY

A spare heated stabilizer bar and tip weight assembly was procured in case another inadvertent overheat was to occur, as the system does not have a temperature control or overheat protection system.

The ice protection system control logic was changed also to delete the presence of icing as a requirement for stabilizer bar heat. The circuit was modified to a simple on/off switch to assure continuous stabilizer heating during flight through intermittent icing conditions such as broken cloud conditions.

3.5 TEST INSTRUMENTATION

3.5.1 Blade Temperature Sensor Locations

The spanwise temperature sensors on the outboard portion of the main rotor blade, which were lost due to erosion damage, were replaced and relocated further aft from the leading edge.

The temperature sensor at Station 83.2 in zone 5, which was on the wraparound heater strip carrying ϕC electrical power from the upper to the lower blade surface, was relocated outboard slightly to Station 84.28. The purpose was to get away from the wraparound strip and measure the surface temperature of the steel-covered portion of zone 5.

A chordwise temperature survey consisting of six measurements was added to Station 110 in zone 4. The survey was limited to this number by the total number of available VCO's in the main rotor instrumentation system with allowances made for retaining some structural measurements or some spanwise sensors on adjacent zones for cross correlation with spanwise data. Station 110 was selected based on photo evidence from spray rig tests that showed this station to be the point where maximum chordwise ice coverage was experienced. It was anticipated that this would permit an evaluation of surface temperatures with and without ice coverage as well as chordwise temperature variations.

The temperature sensor in zone 6 previously located on the narrow heated area forward of the blade attachment fittings was moved outboard of the fitting to Station 55. This was done to check whether previous data at Station 46 was representative of zone 6. Figure 2 shows the revised configuration of the blade temperature sensors.

3.5.2 New Measurements

Engine torque was added to the measurement list to permit an evaluation of torque rise due to blade icing. It was recorded on the magnetic tape as well as on a sensitive indicator in the pilots panel with a digital readout to 0.1 percent accuracy.

Engine bleed air temperature and pressure measurements, located in the bleed air line as close to each of the ice detectors as practical, were added to the instrumentation. This was done to permit accounting for differences between installed values of these parameters and icing tunnel calibration values.

3.5.3 Hub-Mounted Camera

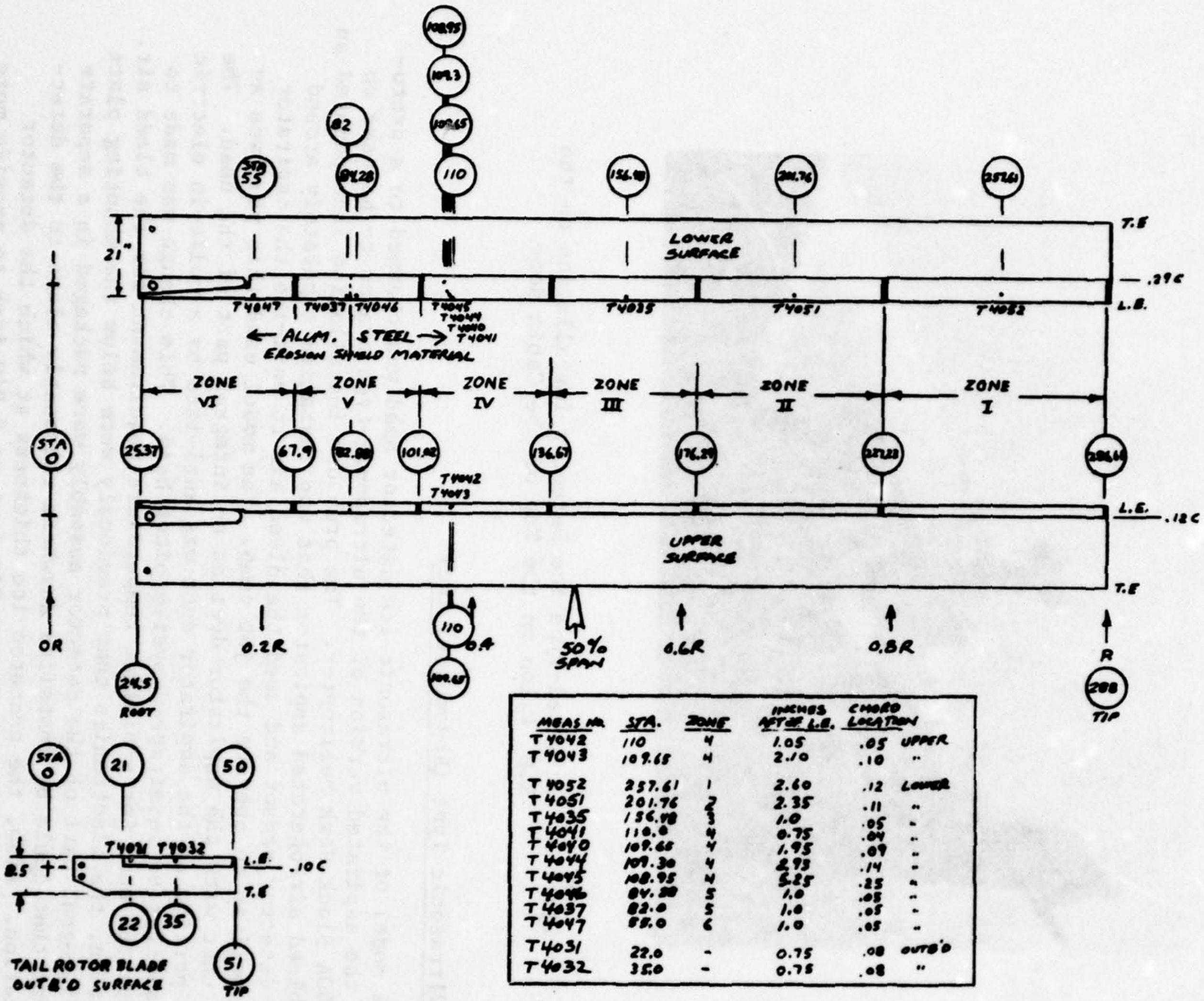
No satisfactory, or in fact usable, pictures of rotor blade icing were obtained with the hub-mounted 16 mm camera last year due to an undetected failure of the heated glass window covering the camera lens. The problem was corrected, and preflight checkout procedures were revised to verify proper operation of the heating system.

3.6 ICE DETECTION SYSTEMS

3.6.1 Infrared-Occlusion Type (Leigh Instruments, Ltd)

No changes were made to this system. Figure 3 shows the probe installation on the RH pylon located on the cabin roof. Excellent operation was obtained during the 1977 Ottawa program and verified further by the additional data on system capability and accuracy obtained during the confirmatory calibration runs made in the icing tunnel at the conclusion of the flight program. These results were included in Reference 4 as Appendix B.

A minor change was incorporated in the integrating rate unit (IRU) to output the tail rotor deice signal at one-half the ice accretion interval that was selected for the main rotor. This would allow the tail rotor to be deiced twice as often as the main rotor during automatic operation based on the recommendation of Reference 4.



MEAS NO.	STA.	ZONE	INCHES AFT OF L.E.	CHORD LOCATION	
T4042	110	4	1.05	.05	UPPER
T4043	109.65	4	2.10	.10	"
T4052	257.61	1	2.60	.12	LOWER
T4051	201.76	2	2.35	.11	"
T4035	156.98	3	1.0	.05	"
T4041	110.0	4	0.75	.04	"
T4040	109.65	4	1.95	.09	"
T4044	109.30	4	2.95	.14	"
T4045	108.95	4	5.25	.25	"
T4046	84.28	5	1.0	.05	"
T4037	82.0	5	1.0	.05	"
T4047	55.0	6	1.0	.05	"
T4031	22.0	-	0.75	.08	OUTB'D
T4032	35.0	-	0.75	.08	"

Figure 2. Locations of Main and Tail Rotor Blade Temperature Sensors.

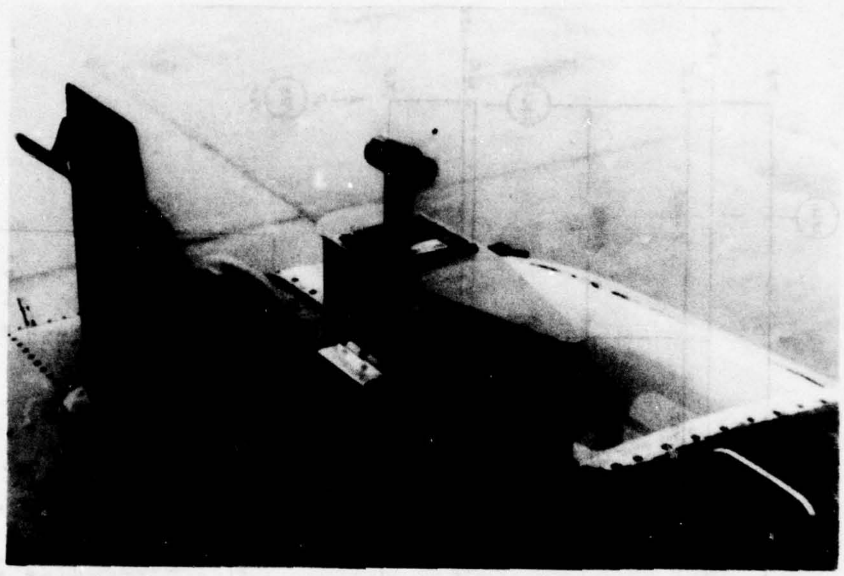


Figure 3. Infrared-Type Ice Detector Installation on the R.H. Pylon on the Top of the Cabin Roof.

3.6.2 Ultrasonic Type (Rosemount, Inc)

The model of the ultrasonic ice detector head was changed to a prototype of the aspirated version of the ultrasonic-type sensor to be used on the UH-60A Black Hawk helicopter. The previous installation incorporated an engine bleed air-operated aspirator that was installed separately around the ice detector sensor and used the bleed air to anti-ice the aspirator duct as well as to operate the jet pump. The model used this year was an all-new unit with the aspirator duct as an integral part of the head. The forward portion of the aspirator duct was anti-iced by a built-in electric heater similar to an airspeed system pitot head. This change was made to eliminate the need for a minimum temperature requirement for the bleed air. In addition, the electronics that previously were below the mounting plate and an integral part of the detector assembly were packaged in a separate component that could be installed anywhere reasonably close to the detector location. Also, the accreted ice thickness at which the detector probe is deiced was reduced from 0.080 inch to 0.040 inch to provide more probe deice cycles (counts) per blade deice cycle. Figure 4 shows the external configuration of the new ultrasonic-type detector.

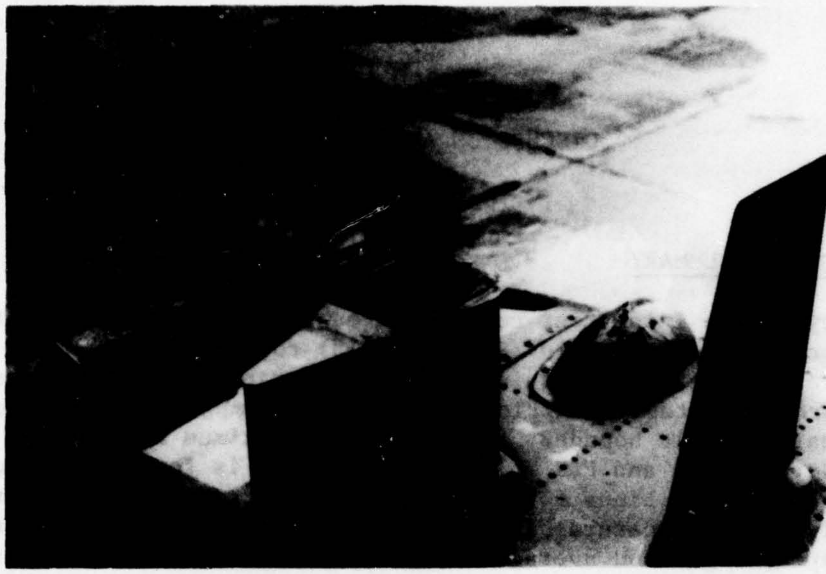


Figure 4. Ultrasonic-Type Ice Detector Installation on the L.H. Pylon on Top of the Cabin Roof.

SECTION 4

DISCUSSION AND RESULTS

4.1 ICING TESTING SUMMARY

A summary of the icing test conditions evaluated during all of the testing conducted with the UH-1H (S/N 70-16318) to date is shown in Figure 5. Presented are the liquid water concentrations (LWC) versus outside air temperature (OAT) test conditions. These are compared to the accepted LWC versus OAT test criteria boundary for continuous maximum atmospheric icing conditions (Reference 1 and FAR 25). This boundary is for a 15-micron volume mean droplet diameter. Lines for 20, 30, and 40 microns, which cover the range normally found in natural icing clouds, are shown also. The droplet size of the spray rig cloud averages approximately 30 microns and the HISS tanker approximately 150 microns, but all testing to demonstrate the ability to operate continuously in an icing environment is generally conducted to the 15-micron line.

The ice protection system is designed to operate under intermittent maximum conditions (15 minutes maximum) which, as shown also in Figure 5, can have liquid water concentrations approaching 2.0 grams per cubic meter (g/m^3) near 0°C and is approximately double the LWC for continuous maximum at all OATS. It was hoped to encounter intermittent maximum conditions under natural icing and thus demonstrate satisfactory ice protection system operation under all expected conditions. Unfortunately, LWC conditions in this range were not encountered although experience to date indicates that no problem should be expected.

A review of the testing experience accumulated to date with the ice protected UH-1H shows the following:

- A total of 321 blade deicing cycles have been accomplished. Of these, 264 were in the spray rig, 32 behind the HISS, and 25 under natural icing conditions.

- Main rotor blade deicing has been generally satisfactory with residual ice and runback of some degree experienced randomly on the inboard section of the blade (0.1 to 0.35R).

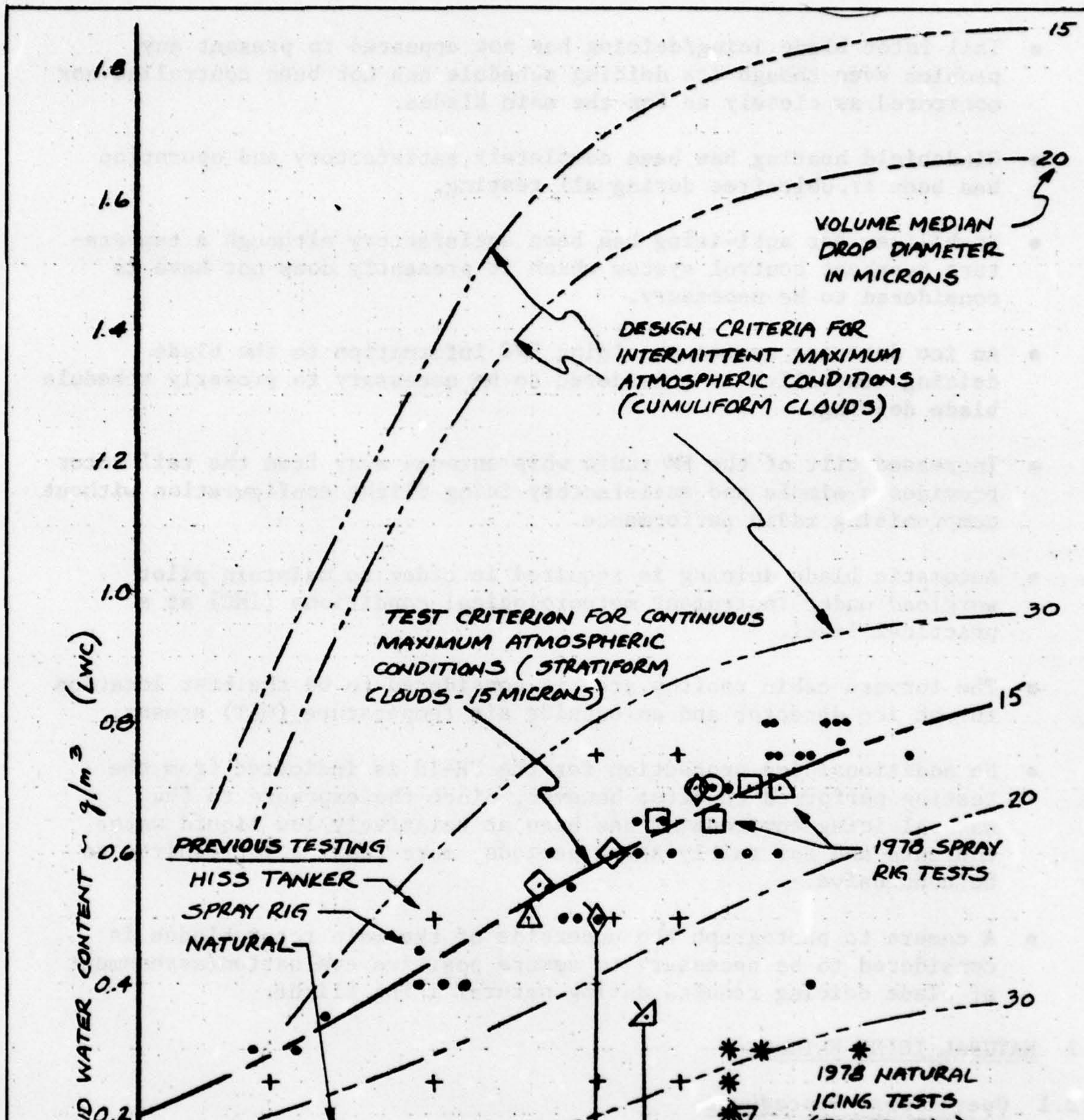


Figure 5. Summary of Icing Conditions Under Which the Ice Protected UH-1H Has Been Tested to Date.

- Tail rotor blade icing/deicing has not appeared to present any problem even though its deicing schedule has not been controlled nor monitored as closely as for the main blades.

- Windshield heating has been completely satisfactory and operation has been trouble-free during all testing.

- Stabilizer bar anti-icing has been satisfactory although a temperature overheat control system which it presently does not have is considered to be necessary.

- An ice detector system providing LWC information to the blade deicing controller is considered to be necessary to properly schedule blade deicing.

- Increased tilt of the FM radio whip antenna away from the tail rotor provides a simple and satisfactory icing flight configuration without compromising radio performance.

- Automatic blade deicing is required in order to maintain pilot workload under instrument meteorological conditions (IMC) at a practical level.

- The forward cabin rooftop area is considered to be the best location for an ice detector and an outside air temperature (OAT) sensor.

- No additional ice protection for the UH-1H is indicated from the testing performed to date; however, since the exposure to the natural icing environment has been at relatively low liquid water contents and for fairly short periods, more testing is required to be conclusive.

- A camera to photograph the underside of the main rotor blades is considered to be necessary to assure positive evaluation/assessment of blade deicing results during natural icing flight.

4.2 NATURAL ICING FLIGHTS

4.2.1 Operational Procedures

The operational procedures used during the test program were the same as those developed and used for the 1977 natural icing flights. The weather minimums under which testing was permitted were lowered with the Airworthiness Review Board's approval in an attempt to obtain natural icing test data under a broader and more severe range of liquid water concentrations. The procedures utilized and the weather restrictions permitted are described in detail in Reference 5. Briefly, the primary test area for the natural icing flights was in the area designated for icing testing by the Canadian Ministry of Transportation south of the Ottawa International Airport known as ICECAP. The weather minimums that governed the flights were:

Phase 1 (Experience buildup phase) - Forecast 500-foot (AGL) ceiling and 1 mile visibility at the Ottawa airport.

Phase 2 (Advanced phase) - Forecast 200-foot (AGL) ceiling and 1/2-mile visibility at the Ottawa airport.

If the forecast weather at Ottawa was less than 700 feet (AGL) ceiling and 2 miles visibility, an alternate airport was required. Alternate airport requirements were per AR 95-1, with fuel reserve requirements reduced to 20 minutes in Phase I and 30 minutes in Phase II.

Flights to or in alternate test areas were to be allowed as soon as experience permitted; however, this option was never utilized because of the unsuitable weather experienced during the test span. (Either the weather forecasts were such that a return to Ottawa the same day was impractical or the forecast weather probability did not justify the flight.)

When visual meteorological conditions (VMC) existed beneath the clouds, a U.S. Army chase/crash-rescue UH-1H helicopter was used in the program that accompanied the test aircraft to the edge of the ICECAP test area and rendezvoused for visual and photographic observation of the extent of test aircraft icing after it exited the icing test area. The chase aircraft remained on the ground on an alert status at the Ottawa airport when weather conditions did not permit VMC operation of that aircraft to and from the edge of the ICECAP test area.

An emergency locator transmitter (ELT) was installed on the test aircraft and a sensitive direction finder was installed in the crash-rescue helicopter to aid in the final location of the test aircraft in the event of an emergency under low visibility conditions. The crash-rescue crew included two firemen and a medic with their appropriate support equipment on board the aircraft.

The test aircraft crew consisted of the pilot, copilot and two flight test engineers, the same number as utilized during the 1977 program.

---

[5] Kitchens, P.F., TEST PLAN FOR SIMULATED AND NATURAL ICING TESTS OF A UH-1H WITH AN ADVANCED ICE PROTECTION SYSTEM, Applied Technology Laboratory, US Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604, January 1978.

4.2.2 Icing Envelope Expansion Procedure

The icing envelope expansion procedure used was to build up exposure to an icing environment by progressively increasing the number of blade deicing cycles accomplished on each flight or between visual observations of the aircraft's overall icing condition. Because of the light icing conditions found this year, however, the envelope did not even reach the previous limit of five cycles so the exposure envelope was not expanded.

The initial deicing test procedure that was used to determine when to deice was to monitor all of the available cues as to when the desired amount of blade ice had been accreted and then deice by manual operation of the system. Later, when an accurate OAT signal was obtained by relocating the OAT sensor to the cabin roof, the system was allowed to operate automatically with blade deicing scheduled by the value of the integrated icing rate accumulated sum that was set into the IRU. Reliance upon an icing rate integrating system like the IRU is necessary because experience has shown that there is no suitable visual or physically perceptible indication for the flight crew to determine the proper deicing interval.

The specific value for each of the heater-off time cues that was used for the blade ice accretion interval between deicings was based on previous spray rig and natural icing experience. Variations from these values were used in an effort to aid in the determination of the optimum condition as well as tolerances.

The cues that were monitored to determine the deicing interval were:

a. <u>The integrated icing rate sum on the IRU</u>. This was the best indicator of when to deice because it is an accurate total amount of ice accumulated that is obtained by integrating LWC from an ice detector with respect to time. Data collected from previous test experience were used to determine the proper or desired relationship of integrated rate units to blade ice thickness. Figure 6 presents the LWC indications from each of the two ice detectors during natural icing flight. The integrated rate totalized sum from the infrared type is shown. It is reset to zero after each blade deicing.

b. <u>The number of ice detector cycles or counts</u>. This also is an integration method from the ice detectors but it can have some inaccuracy due to the fact that the cycle time includes probe deice and recovery time that can vary under different LWC and OAT conditions. It appears, however, that this method will provide sufficient accuracy if the cycle time of the detector is approximately 10 percent of the cycle time of the blades. (This would provide 10 counts per blade deice cycle.)

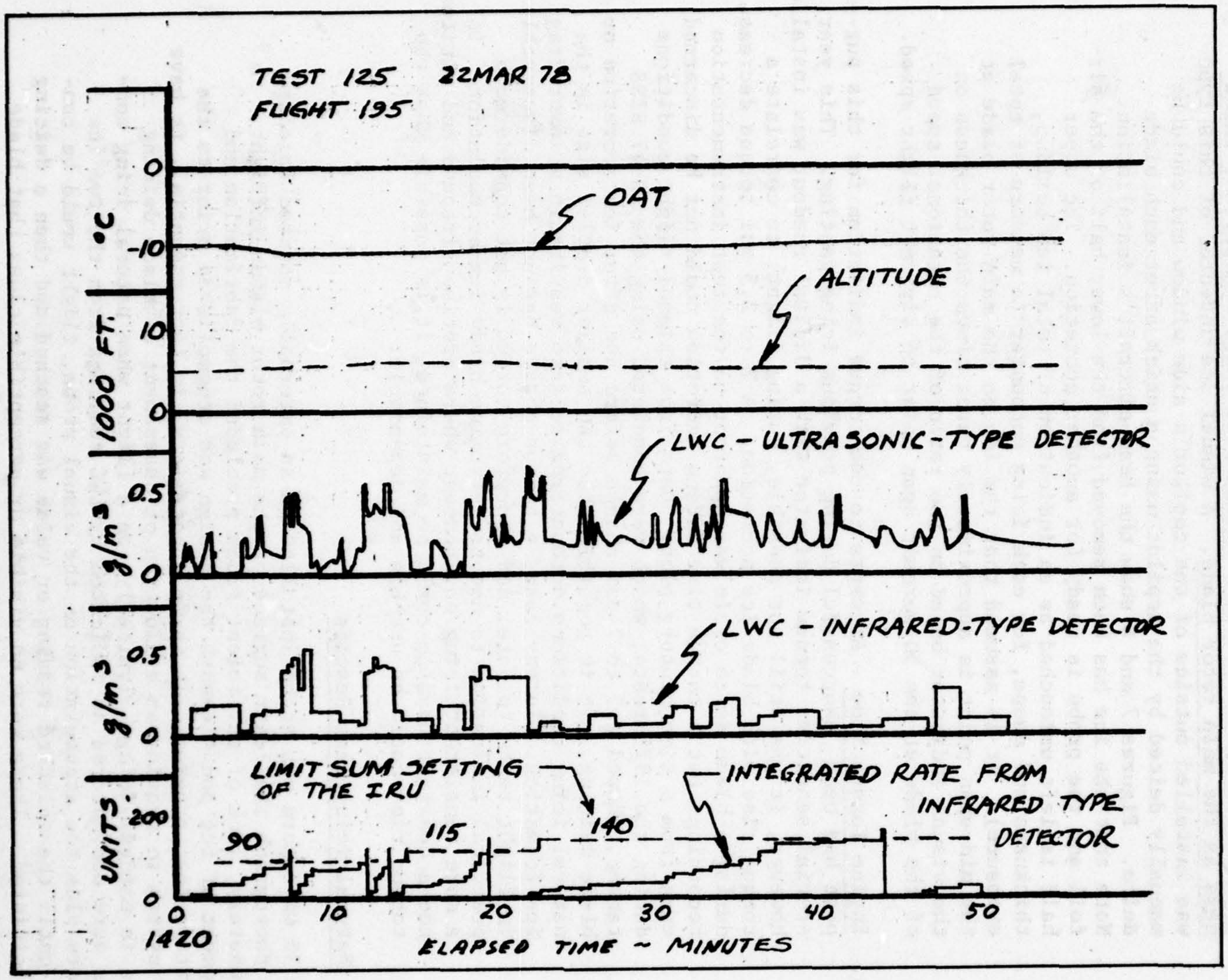


Figure 6. Ice Detector Indications During Flight in Natural Icing.

c. The thickness of ice buildup on the leading edge of a miniature airfoil section of the same aerodynamic shape and percent thickness as the main rotor blade. A visual ice detector of this type was installed outside of the copilot's side window and could be manually deiced by the copilot using a stick after each blade deice. Figures 7 and 8 show the test aircraft's installation. Note that the ice has been removed from the lower half of the airfoil and the probe is ready for another accretion. The upper half is left untouched as an indication of total ice buildup, thickness and shape, for each icing encounter (a measure of total exposure). It is assumed that the ice on the main rotor blade at the mid-span point is approximately three times the thickness on the visual indicator based on the ratio of the rotational speed of the blade at the 50-percent span point to aircraft flight speed.

d. Engine Torque Rise - Attempts to use torque indication for this purpose had been unsuccessful during previous icing testing. This year, a special sensitive torque indicator with a digital readout was installed; however, it was still not possible, during flight, to correlate a torque rise with blade ice accretion. A 2 to 2.5 psi torque decrease during a blade deice cycle was apparent on the test instrumentation recordings but a torque rise during accretion could not be discerned even from a time history plot. Data from trimmed flight conditions during the 1975 tests, which were conducted using the CH-47 HISS tanker, showed a 5 to 7 psi change before and after ice accretion or blade deicing. It is possible that the smaller droplet size in the natural icing conditions encountered to date results in a lower-drag ice formation. In any case, a torque change has not been discernable in flight tests to date, and therefore torque is not considered a practical indication to use to determine blade ice accumulation. In a more consistent icing environment where precise airspeed and altitude and a constant heading could be maintained, it is possible that the torque rise could be useable and dependable.

4.2.3 Natural Icing Test Results

A 35 mm camera was to be installed in an externally mounted fuselage pod to photograph the lower surface of the main rotor blades inflight. Unfortunately, lack of sufficient funds precluded the fabrication and development of the pod although the design was accomplished prior to the 1978 Ottawa test program. It is felt necessary, in fact essential, to have such a system to provide an evaluation or assessment of blade deicing results in natural icing. Typically, on a flight when natural icing conditions were encountered as indicated by LWC readings from the two ice detectors plus ice accumulation on the visual probe, flight would be continued until the selected reading or value was reached and then a deicing cycle initiated. There were no visible or perceptible clues that blade deicing did actually occur or whether it was complete or incomplete or whether the heater-on time resulted in runback. Since no adverse effects or characteristics were apparent, flight was continued until fuel limitations or lack of icing conditions dictated termination of the test.

Figure 7. Miniature Airfoil Section Mounted Outside of the Copilot's Window for Visual Indication of Ice Accretion.

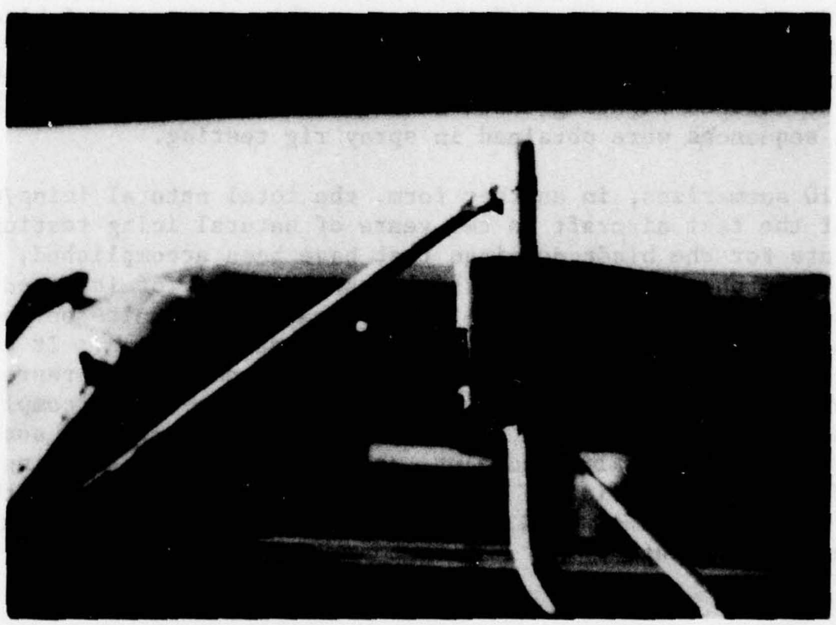


Figure 8. Close-up of Visual Icing Indication After a Natural Icing Flight With 0.2 Inch of Ice Accretion Above Thickness Measuring Probe and With Ice Removed From Leading Edge Below the Probe (Test OAT = -12.5°C).

It was hoped to encounter progressively higher LWC concentrations and thus increase the total length of exposure time in icing. Unfortunately, weather conditions this year were below normal and thus the exposure envelope was not increased over previous experience.

Figure 9 shows the test aircraft as photographed from the chase aircraft following 37 minutes in icing at -12.5°C at 7300 feet for two blade deicing cycles and 14 minutes after exiting the icing condition. Even though the OAT was still below 0°C, no significant icing on the test aircraft is apparent except on the engine air inlet side screen. Figure 26, another photo taken on the same flight, shows ice on the leading edges of the ice detector pylons and the UHF/VHF antenna. There was also some ice on the RH stabilizer leading edge. This illustrates the difficulty in a quantitative assessment of natural icing results especially with respect to blade deicing, the primary objective.

Table 1 lists the natural icing test experience of the 1978 Ottawa program and Table 2 summarizes the total natural icing experience of the test aircraft.

4.2.4 Main Blade Deicing

The hub-mounted 16mm camera was operated for all blade deicings but although the heated window functioned properly this year and pictures were obtained, there were no satisfactory or usable sequences of blade deicing. This is due primarily to the small amount of chordwise ice coverage on the upper leading edge to be visible against the white cloud background and the reduced lighting under instrument meteorological conditions. Some useable sequences were obtained in spray rig testing.

Figure 10 summarizes, in another form, the total natural icing/deicing experience of the test aircraft in two years of natural icing testing. This figure presents for the blade deicings that have been accomplished, the range of visual probe ice accretion thickness, the number of infrared ice detector cycle counts, and the sum of the integrated rate units on the IRU. Also shown is the OAT condition that existed for each deicing. It can be noted that the range of indications is relatively broad, which represents the variation in blade ice thickness that deicings have been accomplished. All deicings were uneventful, and the flights were assumed to be successful from a practical operational standpoint, as no uncontrolled shedding was detected. The best estimation of the range of blade ice thickness that corresponds to these values would be from 1/8 inch to 1/2 inch thick at the 50-percent span point.

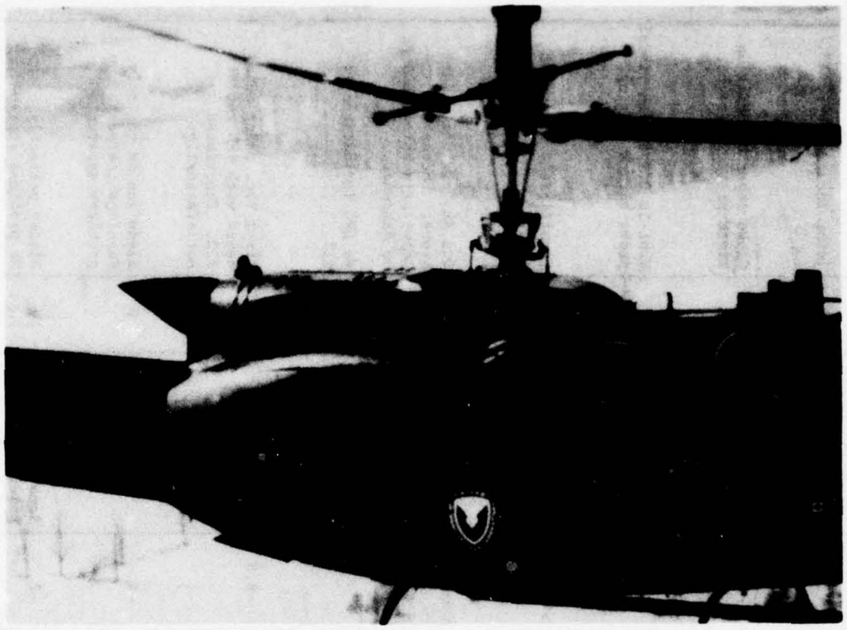


Figure 9. Test Aircraft Following Exit From Natural Icing Cloud on Flight 180, Showing Icing on Engine Air Inlet R.H. Screen.

Figure 10 indicates that most of the experience to date has been with blade deicings at the following values of the available cues:

IRU Sum	240 units
Infrared Detector Cycles	18 counts
Visual probe ice thickness	0.18 inches

Future testing should be based on these values with a caution on use of the visual probe ice thickness in as much as it is subject to more variables than the ice detector signals. It should also be noted, however, that whatever variables affect the visual probe ice thickness also affect blade ice thickness under the same conditions and therefore the probe is still a useful velocity-relative indication of blade ice.

The above listed values tend to permit more than 1/4-inch thickness of ice on the main blade (it is estimated to be approximately 3/8-inch). The recommended values are based, however, on spray rig testing which indicated that cleaner inboard blade deicing was accomplished with thicker ice. The 3/8-inch thickness is probably closer to optimum for this particular rotor since little or no power increase has been detectable and no asymmetric shedding was experienced on any of the natural icing flights. More operational experience in natural icing is needed to determine accurately the performance penalty associated with ice thickness before the optimum can be established conclusively.

TABLE 1. NATURAL ICING TEST SUMMARY (SHEET 1 OF 2)

Nat. Icing Flt. No.	1978 Date Test No. Flt. No.	Weather Conditions	Flight Profile	ICING TEST CONDITIONS Altitude - ft	OAT °C	LWC g/m 3	Minutes in Clouds	No. of Deice Cycles	Remarks
1	11 Mar T114 F180	Cloud layer at 6500 - 7500 ft.	Climbed to 7300 ft and flew in middle of cloud deck.	7300	-12.5	.02-.11	43	2	Icing intermittent.
2	11 Mar T115 F181	Cloud layer at 7000 - 8000 ft.	Climbed to 10,000 ft to look for best clouds in ICECAP, then descended into cloud layer.	7300	-10	.01-.12	34	1	Cloud layer breaking up since previous flight.
3	12 Mar T116 F182	Thin cloud layers at 3000 and 4000 ft.	Climbed to 6500 ft to survey ICECAP for best clouds.	4000	-5.5	.03-.20	34	1	Went to 0.2 in. on visual probe before deicing.
4	12 Mar T117 F183	Scattered clouds at 2400 to 4000 ft. Another layer at 5000 ft.	Climbed to 5000 ft but found no icing in cloud layers.	-	-4 to -7	0	30	0	Insufficient icing for test.
5	14 Mar T118 F185	Overcast with ceiling about 2000 ft. Light rain and wet snow falling.	Climbed to 10,000 ft in clouds but encountered little icing.	-	Constant -2 to 8000 ft.	-	88	0	0.1 in. max. on visual probe. Encountered heavy rain below 4000 ft. on descent.
6	15 Mar T119 F186	Thin cloud layers at 2000 and 8000 ft.	Climbed to 9000 ft but no icing in either cloud layer.	-	-	-	0	0	No LWC indications at all.
7	19 Mar T122 F190	Cloud layers between 4500 and 6800 ft.	Climbed to on-top then selected 5000 ft as thickest layer and found icing in one area only.	5000	-8.5	.05-.35	34	1	First flt. using auto deice with IRU set at 230. Functioned satisfactorily.
8	21 Mar T123 F192	Ceiling at 300 to 400 ft with freezing rain falling.	Hovered in moderate to light rain for 30 minutes.	10 AGL	-4	-	30	0	Blade ice on top only. Fuselage coated but no problems apparent.
	F193	Same as above.	Flew special VFR just below ceiling within vicinity of airport and hanger.	100 - 300 AGL	-2	Some Brief Leigh LWC's	30	14	Blades perfectly clean. No problems apparent.

TABLE 1. NATURAL ICING TEST SUMMARY (SHEET 2 OF 2)

Nat. Icing Flt. No.	1978 Date Test No. Flt. No.	Weather Conditions	Flight Profile	ICING TEST CONDITIONS Altitude - ft	OAT °C	LWC g/m³	Minutes in Clouds	No. of Deice Cycles	Remarks
9	22 Mar T124 F194	Scattered clouds at 2500 - 3000 ft	Climb to 2600 ft and fly through as many clouds as possible.	2700	-6	.02-.13	60	1	Visual probe had approx. 0.1 in. with auto deice set at IRU sum = 180.
10	22 Mar T125 F195	Cloud layer at 5000 - 6000 ft scattered to broken	Climbed to 5500 ft and found one cloud with ice. Kept reentering.	5500	-10	.03-.50	50	3	Auto deice with IRU sum set at 180, 230, and 280. Max. on visual was 0.42 in.
11	22 Mar T126 F196	Same as F125 except 30 minutes later.	Climbed to 5600 ft and flew icing search unsuccessfully.	-	-	-	30	0	Intermittent trace icing only.
12	26 Mar T127 F197	Low ceiling with light to moderate snow flurries - 1/2 to 1/4 mi. visibility.	Hover in falling snow.	10 Hover	-5	-	30	0	No inlet screen icing experienced.

TABLE 2. SUMMARY OF THE TOTAL NATURAL ICING TEST EXPERIENCE OF THE TEST AIRCRAFT

Item	1977 Program	1978 Program	Total to Date
1. Total number of icing search flights made.	10	12	22
2. Total number of flights on which icing was found.	5	7	12
3. Total number of blade deicing cycles on the flights.	16	9	25
4. Maximum number of blade deice cycles made on one flight.	5	3	5
5. Highest LWC concentration encountered (g/m^3).	0.3	0.5	0.5

4.2.5 Freezing Rain and Snow

It can be seen in Table 1 that natural icing test flights 8 and 12 were made in freezing rain and falling snow, respectively. These flights were made as secondary investigations. Most of the weather frontal passages experienced in the late winter period (March and April) were accompanied by freezing rain in and below the overcast; therefore, buildup flights were made to investigate icing characteristics.

The aircraft was first hovered for 30 minutes in moderate-to-light freezing rain conditions. An asymmetric shed of blade ice was noted as collective was lowered and again as RPM was reduced during shutdown. Post shutdown inspection showed the aircraft glazed with an overall layer of typical clear, pebbly-surface ice. The blade deicing system was not operated. There was evidence that the leading-edge ice on zones 5 and 6 had been fairly thick because at approximately .15R (the edge of the self-shed) it was 1/8 - 1/4 inch thick. Neither ice detector indicated any icing

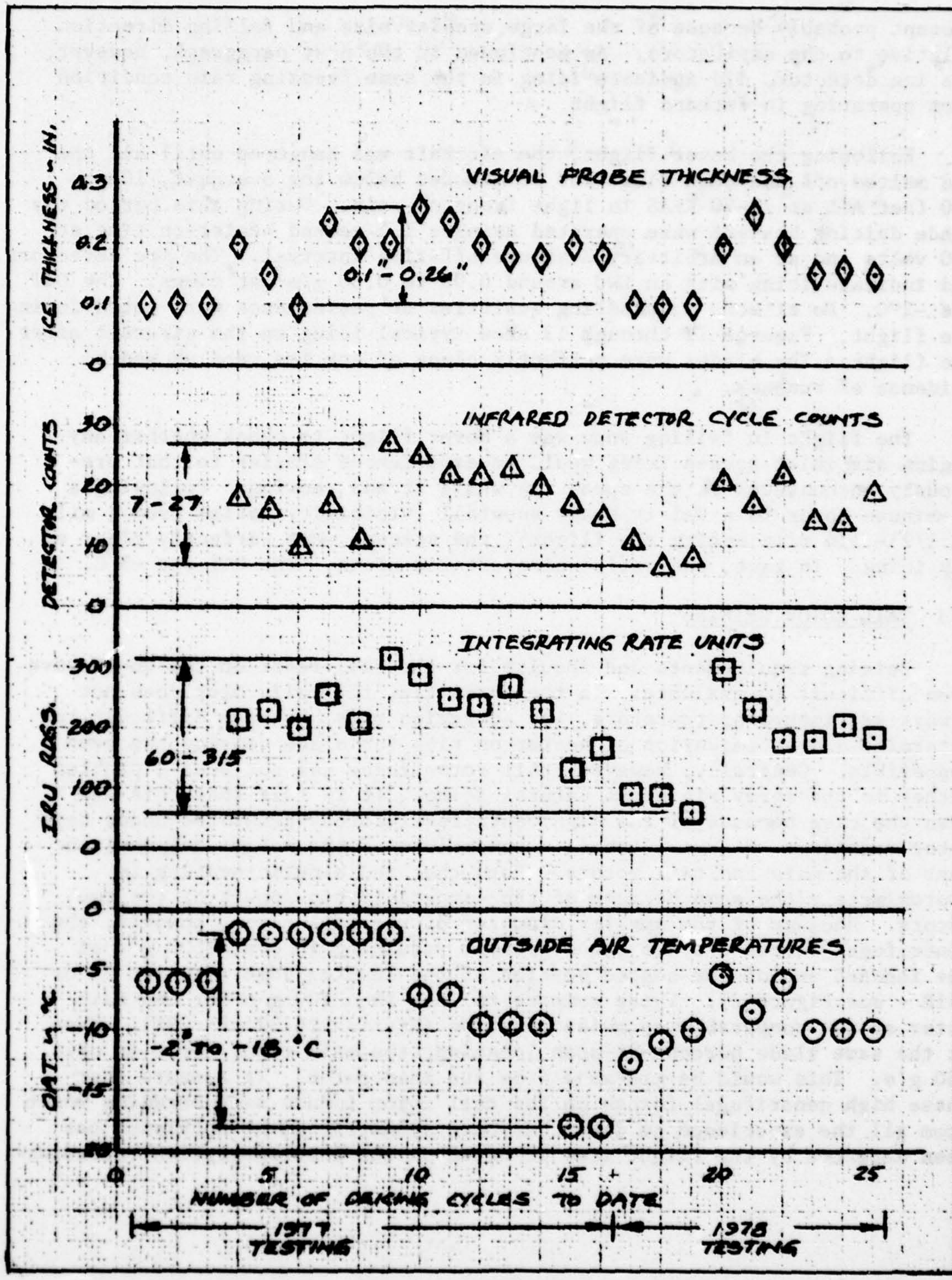


Figure 10. Summary of Indications of Main Rotor Blade Ice Accretion at which Deicings have been Accomplished Under Natural Icing Conditions to Date.

present probably because of the large droplet size and falling direction relative to the aspirators. As mentioned in the next paragraph, however, the ice detectors did indicate icing in the same freezing rain condition when operating in forward flight.

Following the hover flight, the aircraft was hangered until all the ice melted off and then flown for 30 minutes below the overcast, 100 to 300 feet AGL at 70-90 KIAS in light freezing rain. During this period the blade deicing heaters were operated using a 1.2-second heater-on time at 200 volts and at an arbitrary 2-minute off-time interval. The ice detectors did indicate icing with an LWC around 0.05 to 0.30 g/m^3 at times. The OAT was -2^{o}C. No effects on handling qualities or performance were noted during the flight. Figures 11 through 13 show typical icing on the aircraft after the flight. The blades were perfectly clear of any ice, and showed no evidence of runback.

The flight in falling snow was a hover flight to check whether any engine air inlet screen icing would be experienced similar to that previously encountered in the spray rig while it was snowing. Following a 30-minute hover in a fairly heavy snowfall (visibility varied from 1 mile to 1/2 - 1/4 mile during the flight), the screens were perfectly clear of any icing. In fact, the entire aircraft was clean. The OAT was -5^{o}C.

4.3 TAIL ROTOR DEICING

Deicing requirements and results for the tail rotor on the UH-1H have been difficult to evaluate. In the spray rig, the tail rotor does not always get immersed; therefore, ice accretion rate has been difficult to determine and optimization of heater-on time for blade deicing has been impossible. Generally, however, tail rotor icing has not been a problem either in the spray rig or in natural icing. It is felt that this has been the case because of the high centrifugal forces generated under tail rotor rotation. Figure 14 shows a comparison of the rotational environment of the main and tail rotors. Note that the kinetic heating is approximately the same because of the comparable tip speeds of the two rotors. Because of the smaller diameter of the tail rotor, however, the centrifugal forces are 4.5 times greater resulting in over 1500 g's at the inboard end of the heated portion of the leading edge (Station 21 or .41R - see Figure 2). These compare to less than 100 g's for the main rotor at the comparable spanwise location (Station 25.37 or .09R). Even at the same blade percent-of-span location, the main rotor force is only 350 g's. This would be mid-zone 4 on the main rotor. It appears that these high centrifugal forces on the tail rotor induce self-shedding which from all the experience to date, has been symmetric as no unbalance has been detected by the flight crew or noted on the instrumentation recordings.

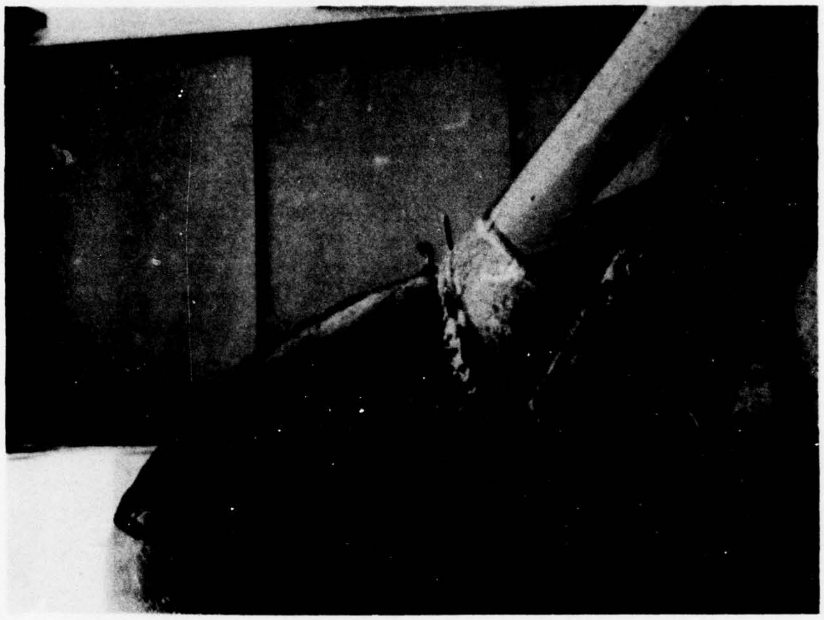


Figure 11. Aircraft Nose and Windshield After 30-Minute Flight in Light Freezing Rain (OAT -2°C).

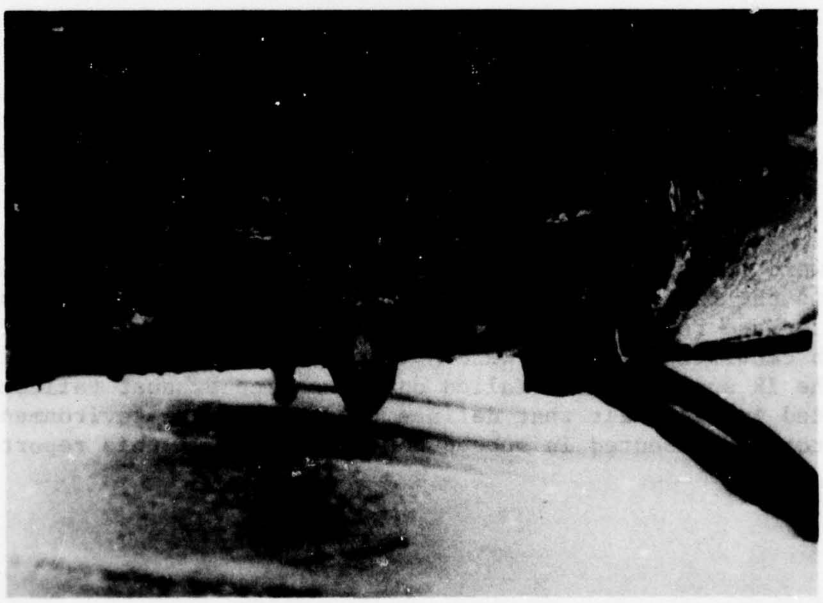


Figure 12. Lower Nose Area and Total Air Temperature Probe Installation After 30-Minute Flight in Light Freezing Rain.

Figure 13. Right Side of Forward Fuselage After 30-Minute Flight in Light Freezing Rain

During all of these tests, the off-time used for the tail rotor was the same as for the main rotor, whereas subsequent analysis has indicated that the tail rotor should be deiced twice as often as the main rotor. Thus the tail rotor blades were accreting a greater than desirable thickness of ice.

In forward flight, an additional factor, and perhaps equally as important, is the fact that the engine exhaust heats the air passing over the tail rotor and reduces and possibly eliminates any need for deicing even if high centrifugal forces were not present. This is especially true with the IR suppressor installed on the engine exhaust tailcone. Data collected in clear air that defines the temperature environment at the tail rotor is presented in subsequent paragraphs of this report.

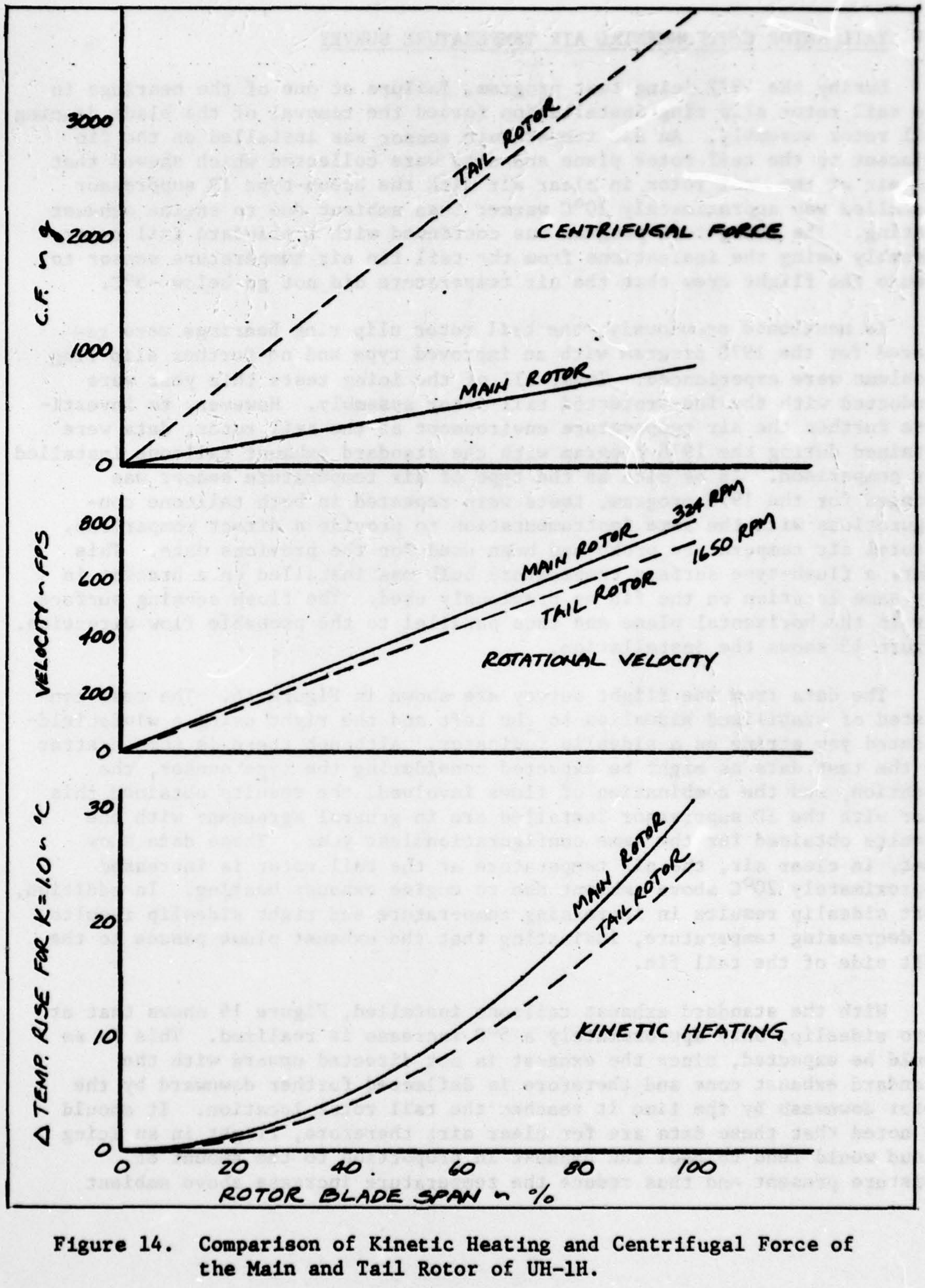


Figure 14. Comparison of Kinetic Heating and Centrifugal Force of the Main and Tail Rotor of UH-1H.

4.4 TAIL ROTOR ENVIRONMENTAL AIR TEMPERATURE SURVEY

During the 1977 icing test program, failure of one of the bearings in the tail rotor slip ring installation forced the removal of the blade deicing tail rotor assembly. An air temperature sensor was installed on the fin adjacent to the tail rotor plane and data were collected which showed that the air at the tail rotor in clear air with the scoop-type IR suppressor installed was approximately 20°C warmer than ambient due to engine exhaust heating. The icing test program was continued with a standard tail rotor assembly using the indications from the tail fin air temperature sensor to assure the flight crew that the air temperature did not go below -5°C.

As mentioned previously, the tail rotor slip ring bearings were replaced for the 1978 program with an improved type and no further slip ring problems were experienced. Thus, all of the icing tests this year were conducted with the ice-protected tail rotor assembly. However, to investigate further the air temperature environment at the tail rotor, data were obtained during the 1978 program with the standard exhaust tailcone installed for comparison. In as much as the type of air temperature sensor was changed for the 1978 program, tests were repeated in both tailcone configurations with the same instrumentation to provide a direct comparison. A total air temperature probe had been used for the previous data. This year, a flush-type surface temperature bulb was installed on a bracket in the same location on the fin as previously used. The flush sensing surface was in the horizontal plane and thus parallel to the probable flow direction. Figure 15 shows the installation.

The data from the flight survey are shown in Figure 16. The test consisted of stabilized sideslips to the left and the right using a windshield-located yaw string as a sideslip indicator. Although there is some scatter in the test data as might be expected considering the type sensor, the location, and the combination of flows involved, the results obtained this year with the IR suppressor installed are in general agreement with the results obtained for the same configuration last year. These data show that, in clear air, the air temperature at the tail rotor is increased approximately 20°C above ambient due to engine exhaust heating. In addition, left sideslip results in increasing temperature and right sideslip results in decreasing temperature, indicating that the exhaust plume passes to the left side of the tail fin.

With the standard exhaust tailcone installed, Figure 16 shows that at zero sideslip, only approximately a 5°C increase is realized. This is as would be expected, since the exhaust is not directed upward with the standard exhaust cone and therefore is deflected further downward by the rotor downwash by the time it reaches the tail rotor location. It should be noted that these data are for clear air; therefore, flight in an icing cloud would tend to cool the exhaust in proportion to the amount of moisture present and thus reduce the temperature increase above ambient

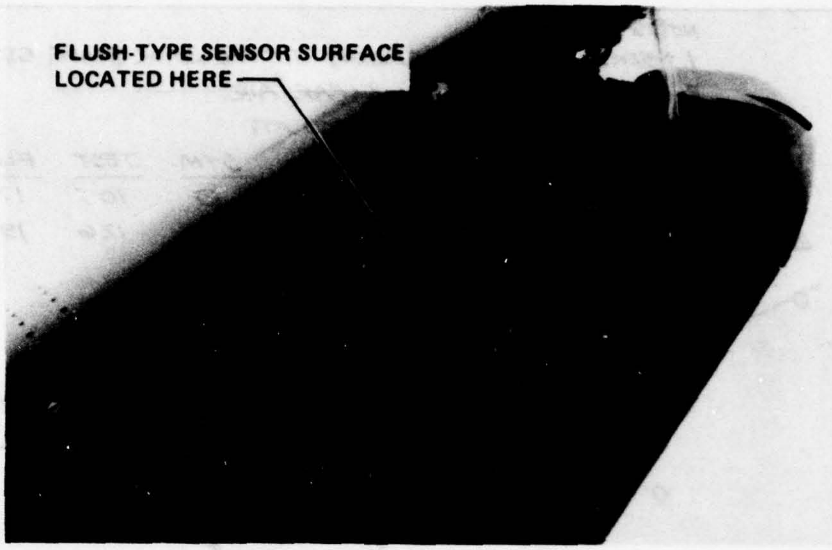


Figure 15. Installation of the Flush-Type Air Temperature Sensor on a Bracket Mounted on the Vertical Fin Adjacent to Blade Station 23 of the Tail Rotor.

from that measured in these tests. Data collected at different rates of climb and descent to 500 fpm indicated a negligible temperature change with variation in engine power.

4.5 STABILIZER BAR

A failure of the heater blanket on one of the stabilizer bar tip weights was experienced this year. This was the first and only failure that has occurred that was not the result of an inadvertent overheat. It occurred at the wiring connection to the heater element at the rubber boot seam, which is located on the trailing-edge side of the tip weight about 30 degrees down from the straight aft position. The failure occurred after 230 flight hours of use during the four years of this aircraft's icing test program; 116 hours of this time were heated flight operations. The unit that failed was one of the second set to be manufactured and is considered to be a production development problem that would not reoccur with more manufacturing experience.

4.6 HEATED WINDSHIELDS

The heated glass windshields have maintained clear vision for all of the testing to date and no problems have been experienced with the windshield temperature controllers.

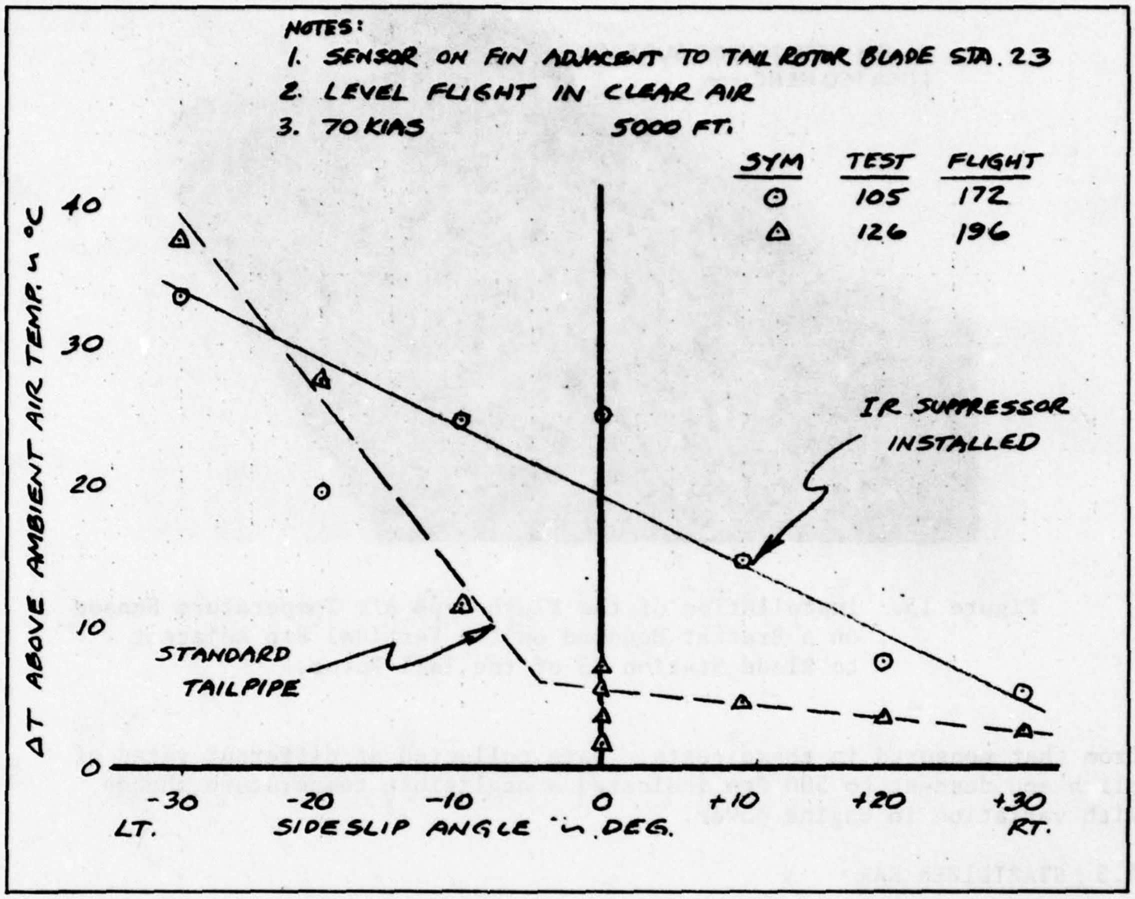


Figure 16. Air Temperature Increase Above Ambient at Tail Rotor With and Without the Infrared Suppressor Installed.

An objective of the test program since the onset has been to evaluate or determine minimum windshield heating requirements. The windshields are heated at 3.3 watts per square inch at 200 volts ac as described in Section 2. A variac has been installed in the power line to the left-hand (co-pilot's) windshield to permit decreasing the voltage to that windshield while flying in icing. This has been done during the limited icing test experience to date. Although voltages as low as 50-80 have been tried, no effect on windshield heating effectiveness was noted. It was noted that even the unheated 3-inch-wide band outside of the heated glass area remained clear or essentially clear most of the time; therefore, the validity of any conclusions was doubtful. This lead to operation without cabin heat (the standard defrosters were never operated either) in the event internal cabin heat was providing the anti-icing capability. No change was noted. In addition, prior to 1978 there had been problems experienced with the windshield temperature instrumentation which precluded defining any reliable trends.

To date, therefore, there has been no quantitative definition of minimum heating requirements.

4.7 FM RADIO ANTENNA

4.7.1 Tail Rotor Clearance

There was no additional data obtained this year on the magnitude of the lateral oscillations of the FM whip antenna under antenna icing conditions. The antenna was installed with the 42.5-degree tilt angle for all of the icing testing conducted and no evidence of tail rotor blade strikes was apparent. As reported in Reference 4, oscillations of ±18 inches were observed by the chase helicopter pilot on a post-natural icing in-flight rendezvous with 18 inches of clearance remaining. Evaluation of these estimated observations with the antenna/tail rotor plane geometry and with similar observations reported during HISS testing (Reference 1), which reported near tail rotor contact with 27.5 degrees of tilt, indicates a substantial discrepancy in the magnitude of the oscillation. The HISS testing observation is more pessimistic and implies an antenna tip deflection of approximately 3-1/2 feet. With the 42.5 degrees tilt a deflection of over 4-1/2 feet is available. It seems improbable that the antenna can structurally withstand a deflection of this magnitude; therefore, it has been concluded that the 42.5 degrees tilt is a satisfactory icing flight configuration. It is on this basis that the icing test flights have been conducted with the antenna installed without some means of monitoring tail rotor clearance.

4.7.2 Antenna Pattern Evaluation

Tests were conducted to evaluate the effect on radio performance of the increased tilt of the FM whip antenna found necessary for operation in icing. The tests consisted of measuring radio signal strength versus relative bearing and distance of the aircraft from a ground station. The aircraft was positioned in hover flight over specific ground check points 10 and 23 miles from the ground station. Voice transmissions were made on headings in 30° azimuth increments at a frequency of 36.9 MHz. Tests were initially attempted at 1000 feet AGL but increased to 2500 feet based on the performance experiments at the 10-mile point and estimating what altitude would be required at the 23-mile point.

The signal strength measuring equipment used at the ground station was a portable Stoddart receiver Model MBK 2000 with a NM-30 antenna.

The tests were conducted on two separate flights with the FM whip antenna mounted with the standard tilt (27.5°) on one flight and with the modified tilt (42.5°) on the other. The antenna patterns that were measured in each configuration are shown in Figure 17. These data show that the increased tilt used for icing tests provides equal or better performance at all azimuth positions. A plot of signal strength versus distance from the ground station for the 0°, 180°, 90° and 270° azimuth positions indicates linear variations for all directions that decrease to zero microvolts at a distance of 28-29 miles.

It appears that the increased antenna tilt angle is an acceptable solution to the antenna oscillation problem that is encountered in icing in that adequate tail rotor clearance is provided without compromising FM radio performance.

4.8 OUTSIDE AIR TEMPERATURE SENSOR AND LOCATION

Considerable effort was required during the course of the icing testing of this aircraft to identify a suitable outside air temperature sensor and location for use as an input to the ice protection system controller. The problems that were encountered were not anticipated. The initial objective was to use an inexpensive sensor of a flush type which did not add another protuberance to the aircraft nor require deicing in order to provide an accurate measurement in icing conditions.

A flush type MS 28038-2 bulb was selected and installed under the nose in a location shielded from direct sunlight and far enough aft not to be covered with ice during flight. Two sensors were located at FS 30 and LBL and RBL 20 for the initial tests. Considerable and confusing inconsistencies were experienced in testing prior to this year (See References 1 through 4), which were finally found to be due to the model of sensor being used. The model was sensitive to the temperature inside the aircraft compartment where the sensor was located. This problem was eliminated for this year's program by using a different model of the same flush type sensor.

Flight results during this year's testing showed that the underside of the nose was an unsatisfactory location because it measured 5° to 10°C warmer than the actual temperature and was not consistent. The basis for determination of the actual outside air temperature was a shielded-type resistance-element total air temperature probe normally accepted as a standard and used extensively in aircraft performance testing. This type is relatively expensive and incorporates a probe deicing feature. The LH sensor was relocated to the fuselage side just below the copilot's door. This resulted in considerable performance improvement in forward flight, but was now sensitive to sunlight and still gave inconsistent readings in hover. Figure 18 shows the two locations that were tried for the flush-type system OAT sensor and also the test OAT probe installation.

It was found that the standard UH-1H outside air sensor located in the upper left-hand corner of the pilots windshield always was in extremely close agreement with the "Test OAT" probe both in forward flight

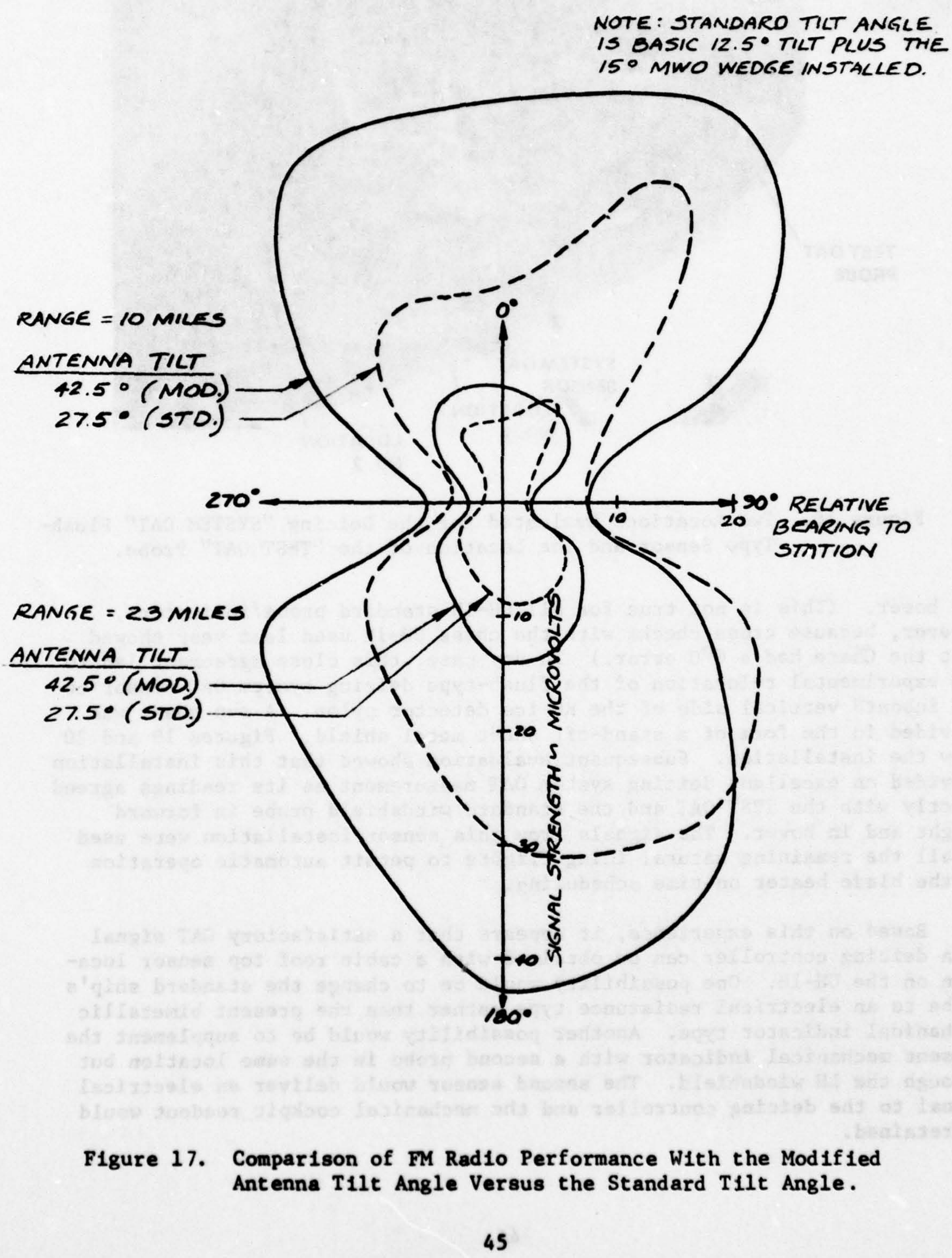


Figure 17. Comparison of FM Radio Performance With the Modified Antenna Tilt Angle Versus the Standard Tilt Angle.

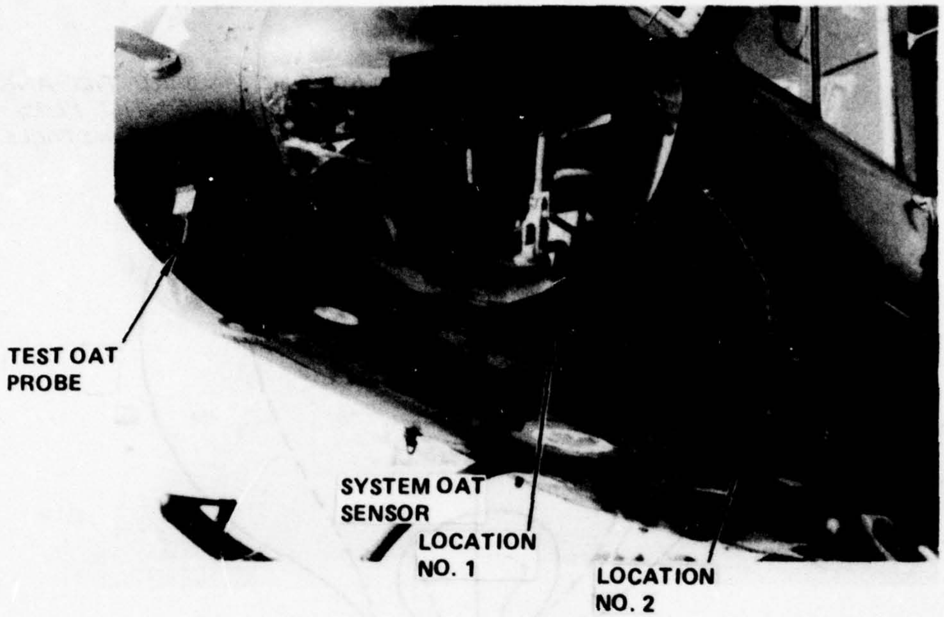


Figure 18. Two Locations Evaluated for the Deicing "SYSTEM OAT" Flush-Type Sensor and the Location of the "TEST OAT" Probe.

and hover. (This is not true for all UH-1H standard probe/indicators, however, because cross checks with the chase UH-1H used last year showed that the Chase had a 6°C error.) In any case, this close agreement led to the experimental relocation of the flush-type deicing system OAT sensor to the inboard vertical side of the RH ice detector pylon. A sun shade was provided in the form of a stand-off sheet metal shield. Figures 19 and 20 show the installation. Subsequent evaluation showed that this installation provided an excellent deicing system OAT measurement as its readings agreed exactly with the TEST OAT and the standard windshield probe in forward flight and in hover. The signals from this sensor installation were used on all the remaining natural icing flights to permit automatic operation of the blade heater on-time scheduling.

Based on this experience, it appears that a satisfactory OAT signal to a deicing controller can be obtained with a cabin roof top sensor location on the UH-1H. One possibility would be to change the standard ship's probe to an electrical resistance type rather than the present bimetallic mechanical indicator type. Another possibility would be to supplement the present mechanical indicator with a second probe in the same location but through the LH windshield. The second sensor would deliver an electrical signal to the deicing controller and the mechanical cockpit readout would be retained.

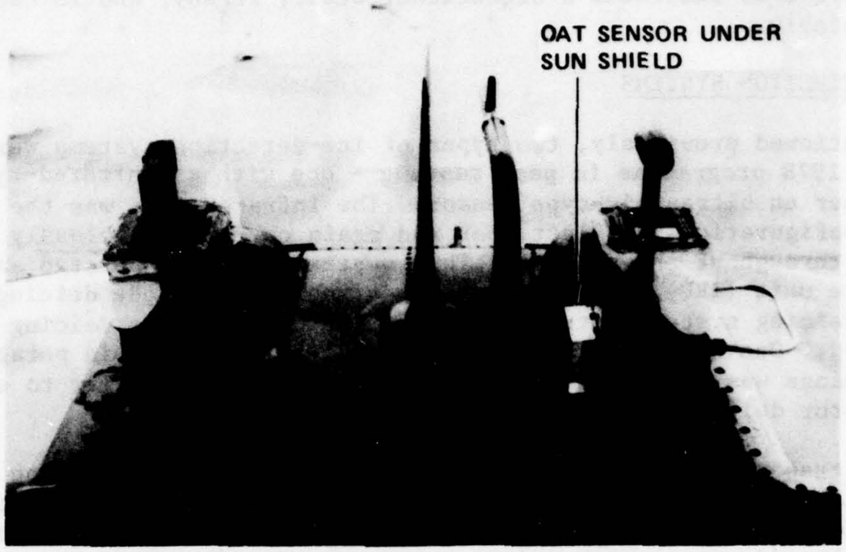


Figure 19. OAT Sensor for the Deicing System Controller Located on the Side of the RH Ice Detector Pylon.

Figure 20. Close-up of Deicing "SYSTEM OAT" Sensor Installation.

The windshield probe is a shielded unheated probe and therefore becomes coated with ice, but experience to date indicates that this condition does not appear to introduce a significant error, if any, and is considered to be acceptable.

4.9 ICE-DETECTION SYSTEMS

As mentioned previously, two types of ice-detection systems were used during the 1978 program as in past testing - one with an infrared-type sensor and the other an ultrasonic-type sensor. The infrared type was the identical unit and configuration used last year and again operated flawlessly and accurately throughout the program. This system also incorporated an integrating rate unit (IRU) which was used to signal rotor blade deicing through the blade deicing system controller. Thus, automatic blade deicing was accomplished. One change was made to the IRU, as described in paragraph 3.6.1, and that change was to provide a signal to the blade controller to operate the tail rotor deicer twice as often as the main rotor.

The ultrasonic-type ice detector was a different configuration from the previous year in that the aspirator was an integral part of the unit and incorporated electric heating of the forward portion of the aspirator duct for anti-icing (See paragraph 3.6.2). Some developmental-type problems were experienced with the test unit that were not fully resolved during the 1978 program. One problem was that the LWC indication was affected by the operation of the anti-icing heater when the engine was not running and therefore there was no cooling aspirator airflow over the sensor. Another problem was an unexplained zero shift in the sensing probe's analog-output voltage and the LWC reading. The first problem was solved by leaving the anti-icing heater off during preflight checkout. The zero shift was intermittently experienced but was apparent on both the cockpit indicator readout and the instrumentation recordings.

Typical indications of both systems are shown in Figures 21 and 22 during flight in intermittent natural icing. Generally good agreement is shown between the two systems. Operation of the IRU can be seen from the bottom parameter on each figure which is the IRU sum or the integrated rate units.

The zero shift, mentioned previously, did not appear on Flight 190 (Figure 21) but does show after time 38 minutes on Figure 22. Note that the ultrasonic-type LWC does not return to zero and the LWC indication is more than twice that of the infrared type after the zero shift. This can also be noted on Figure 6 after time 18 minutes. In addition, the spikes on the analog voltage trace at the ice detector probe deice point were not characteristic of last year's data (See Figures 17 through 21 of Reference 4). During the period of the zero shift, the ratio of the number of ice detector cycle counts for the ultrasonic to the infrared decreased also. Presumably these problems will be corrected in the production version of the new aspirated-probe configuration of this detector.

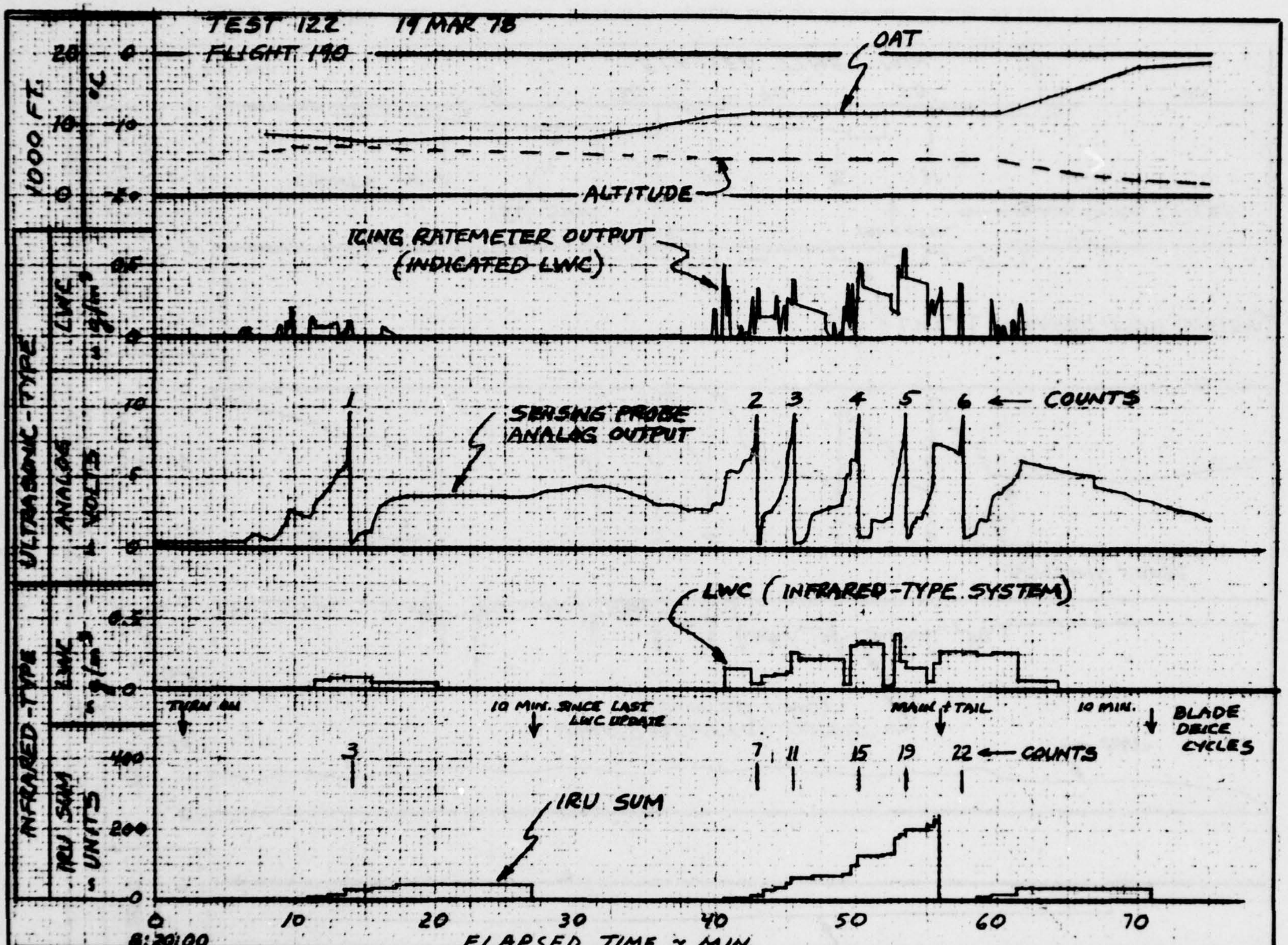


Figure 21. Time History of Ice Detector Operation on Natural Icing Flight 7.

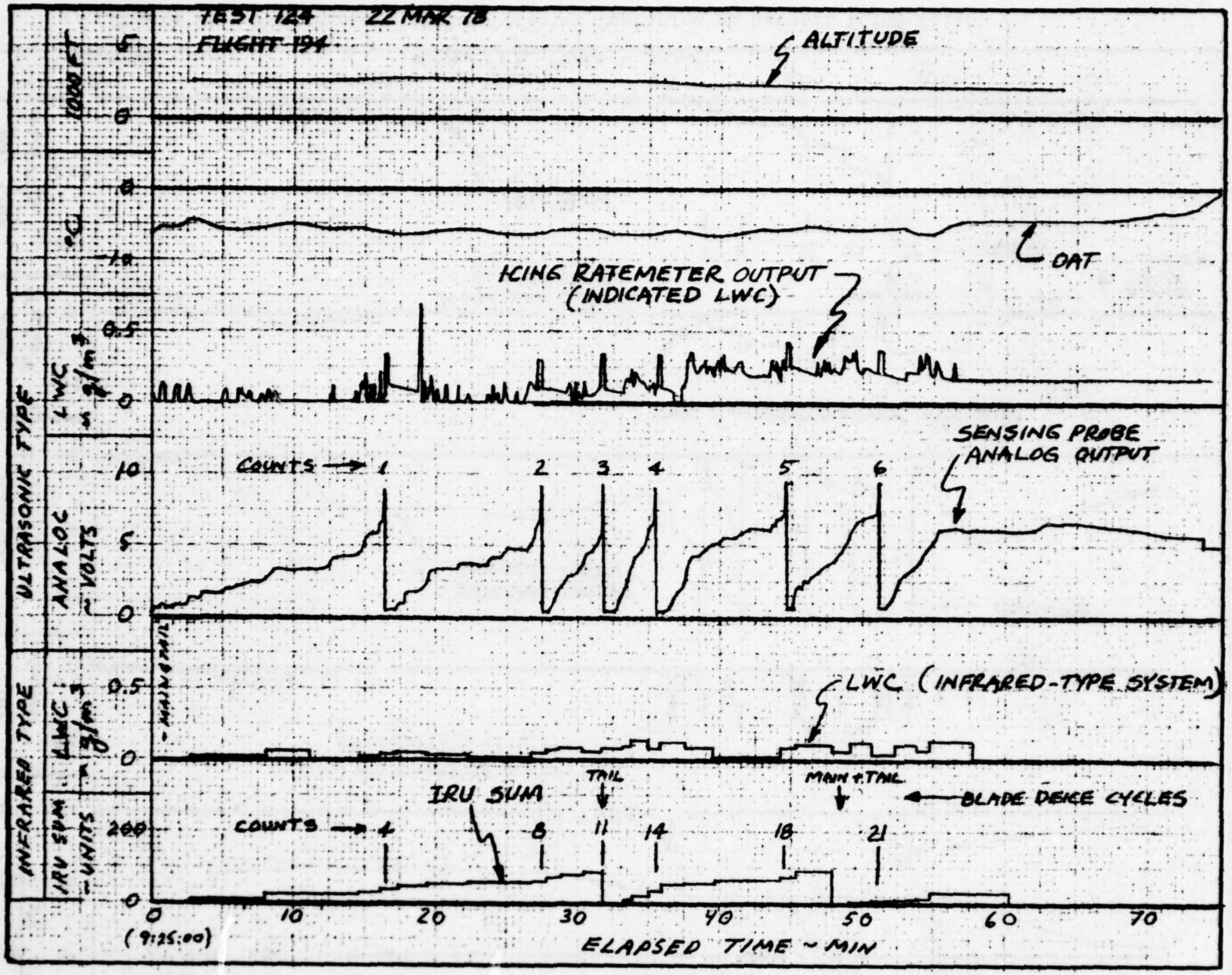


Figure 22. Time History of Ice Detector Operation on Natural Icing Flight 9.

During flight in freezing rain at near-zero temperature (-1 to -2^{o}C) both systems indicated icing as mentioned in paragraph 4.2.5; however, the infrared type indicated a positive LWC value more of the time than the ultrasonic type. This indicates better performance near the Ludlam limit for the infrared-type sensor.

The ice thickness on the ultrasonic-type detector probe at which probe deicing occurs was decreased from 0.080-inch to 0.040-inch for this year's testing in order to get more counts per blade deice cycle. The number of probe deice cycles or counts did increase but not as much as expected. The data indicate only a 55% increase rather than the expected 100% increase or double the last configuration's number. If the count system were used to schedule blade deicing, 5 counts of the ultrasonic would be equivalent to the 18 recommended in paragraph 4.2.4. for deicing using the infrared-type.

In summary, excellent operation of the infrared type detector was experienced this year similar to the 1977 program. Some problems were experienced with the ultrasonic type this year but are attributed to the developmental status of the new aspirated configuration.

4.9.1 Ice Detector Location Survey

In all of the icing test programs conducted to date with the test aircraft, UH-1H S/N 70-16318, the ice detectors have been located on top of 12-inch-high pylons on top of the cabin roof at fuselage Station 57. This location was selected initially to be forward of the permissible roof top step-on structure and then raised to assure that the catch zone was not affected by airflow deflection caused by the windshield. This general location still appears to be the most suitable location from the standpoint of ease of bleed air line routing, noninterference with maintenance work areas, not subject to damage during aircraft ground handling or maintenance operations, etc.

A survey was made during this year's testing to evaluate whether the 12-inch-high pylons were necessary as well as other candidate locations. The survey method was to install mast-like probes made from aluminum tubing 1/4 inch in diameter at several locations and to note the ice collection pattern and extent on the masts following natural icing encounters.

All locations were visible from the cockpit so as to permit in-flight viewing in case photographic documentation was not possible from the chase aircraft during in-flight rendezvous or on the ground following an icing flight. Four probes were installed: One on top of the LH fresh air scoop above the copilot's windshield. One forward of the scoop right at the top of the windshield. This location would not be practical in as much as the structure there does not lend itself to a simple detector installation but was used to check the water droplet path at the top of the windshield. One on the nose centered at the base of the windshield. This location is a feasible installation location but would require a battery compartment door-open support for maintenance operations in that compartment. The fourth was located on the nose near the LH lower outboard corner of the copilot's windshield. Figures 23 and 24 show the probe locations. In addition, it was planned to use ice accretion on the leading edge of the UHF/VHF antenna on the cabin roof as an additional check on the distance required above the cabin roof to be in the water droplet path. The survey results indicated that this mast-type probe technique was excellent for the purpose intended. The catch efficiency of the probes was uniform and roughly comparable to an ice detector. The ice accretion buildup on the leading edge of the probes was of constant thickness along the length of the probe with the boundary layer or stream line shadow effects apparent by the decrease in ice thickness as the fuselage surface was approached. This can be seen in Figures 24 and 25. Figure 24 shows the pattern on one probe following a spray rig flight (hover) where the flow is predominately downward. Figure 25 was following a natural icing flight. Yarn tufts were attached to the end of each mast and on the UHF antenna and ice detector pylons to aid in the in-flight observations. Figure 26 is an inflight photograph. Ice is visible on the UHF antenna and the LH ice detector pylon leading edges.

It was concluded from the observations that any of the test locations would be satisfactory and that on the top of the fuselage, even at their present fuselage station, the 12-inch-high pylons are unnecessary. Close inspection of Figures 25 and 26 shows ice on the leading edges of both the UHF antenna and the existing blunt-nosed pylons for the ice detectors down almost to their base. The normal 3 to 3.5-inch height of the sensing element from the mounting base of either type ice detector is judged to be adequate. The recommended location for a production ice detector would be on the cabin roof oriented in the same spot as the rooftop pitot-static airspeed probe mount but on the LH side of the UHF antenna. However, this location might present a problem accommodating the plumbing and electrical connections inside the cabin. The next recommendation would be at the outboard-forward edge of the test aircraft's LH ice detector pylon (approximately F.S. 49 and BL 12). This locates it in an ideal structural modification area, which presents an easy access for plumbing and requires no mast extension; it is also outboard of any shadow effect from the upstream fresh air scoop and is on the favorable side of the aircraft from the rotor downwash flow field standpoint.

Figure 23 also shows something of interest relative to the battery compartment vent tube icing problem that was indicated from HISS tanker icing tests in 1975 and reported in Reference 1. Inspection of the ice catch on the icing mast located at the base of the windshield center near the battery vent, showed very little, if any, ice accretion on the post near its base up to the height of the battery vent. This indicates that the smaller size droplets in a natural icing environment do not impinge on the battery vent tube but pass over it as opposed to the larger droplet size of the HISS cloud. Therefore, it appears that in natural icing it is unlikely that the vent will ice up and clog; additional experience in icing is necessary to confirm this.

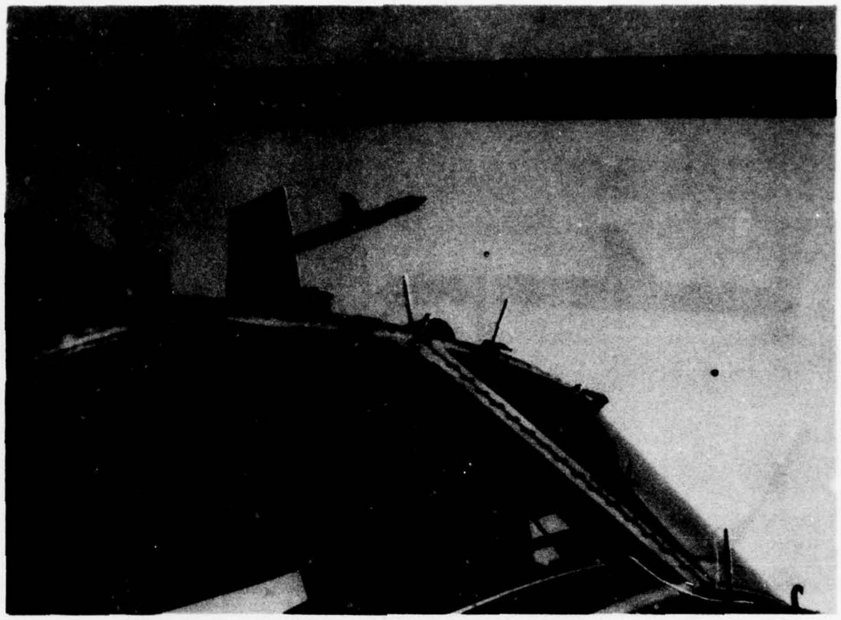


Figure 23. Three of the Stick-Like Masts Used in the Ice Detector Location Survey.

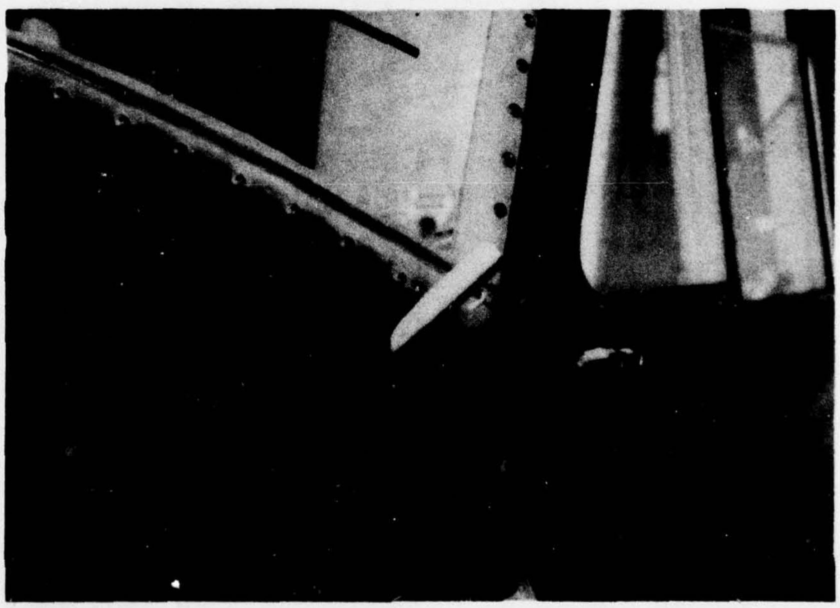


Figure 24. The Ice Detector Survey Probe Located Ahead of the Lower LH Corner of the Copilot's Windshield Following a Spray Rig Flight (OAT = $-6.5^{o}C$).

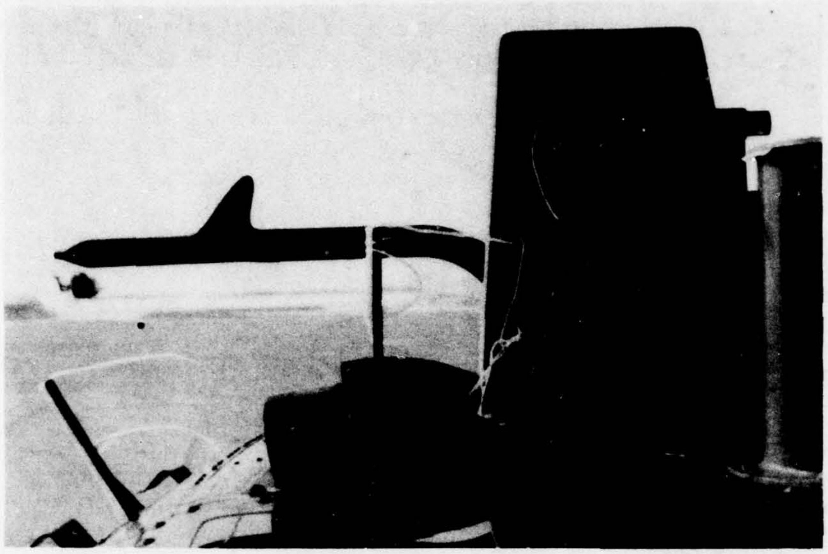


Figure 25. Close-Up of the Ice Detector Location Survey Probes Located on the Cabin Roof, Following a Natural Icing Flight.

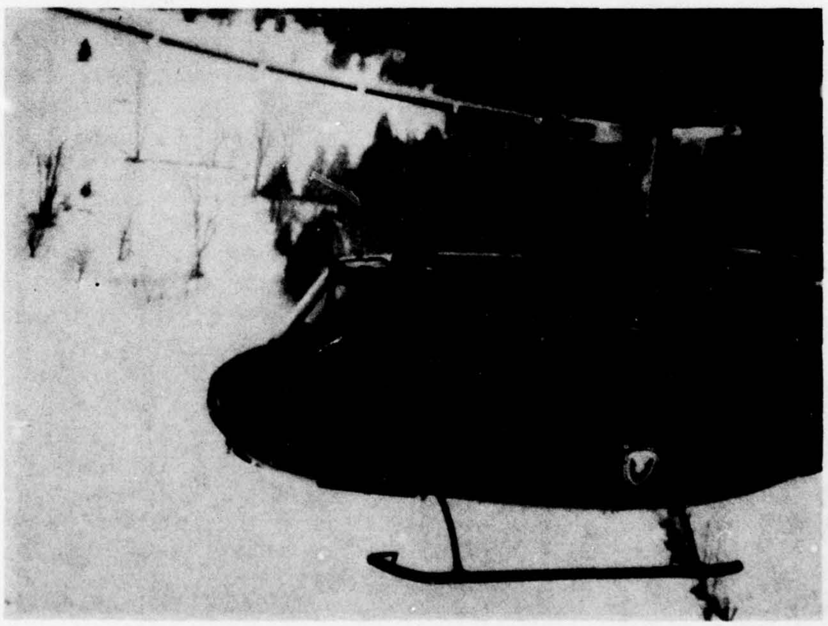


Figure 26. In-Flight Photo Following Natural Icing Cloud Exit (note ice on the UHF antenna and the ice detector pylon).

4.10 SPRAY RIG TESTING

Additional spray rig testing was accomplished this year to continue the detailed investigations that have been part of the overall objectives of the advanced ice-protection system test program. These detailed investigations have been aimed at exploring the effects of the blade deicing deficiencies identified in testing to date and defining the optimum design parameters such as power density and heater-on time.

Figures 27 through 30 show the test aircraft during operations in the Canadian NRC spray rig test facility.

4.10.1 Run Objectives

The testing in the spray rig attempted to investigate several areas of interest. These were:

a. Deicing results with thicker than 1/4-inch ice accretions particularly because spray rig results to date had shown residual ice and runback on the inboard portion of the blade.

b. The effect of power density on deicing. Most of the testing to date had been accomplished using 200 volts. 160 and 230 volts were available which would result in slower or faster heat rise characteristics.

c. Comparison of deicing the last cycle of a 30-minute run in-the-cloud versus out-of-the-cloud. Most of the time, blade deicing at the end of a 30-minute run was not as clean as for a single accretion/deicing. This test would show whether the last cycle out of the cloud was typical of the previous cycles and was of interest to determine which condition was probably occurring on the natural icing flights.

d. Further evaluation of heater-on time required for the inboard portion of the blade.

e. Extension of the temperature range of operation without deicing. Previous runs had been made at -3.5°C without any problems.

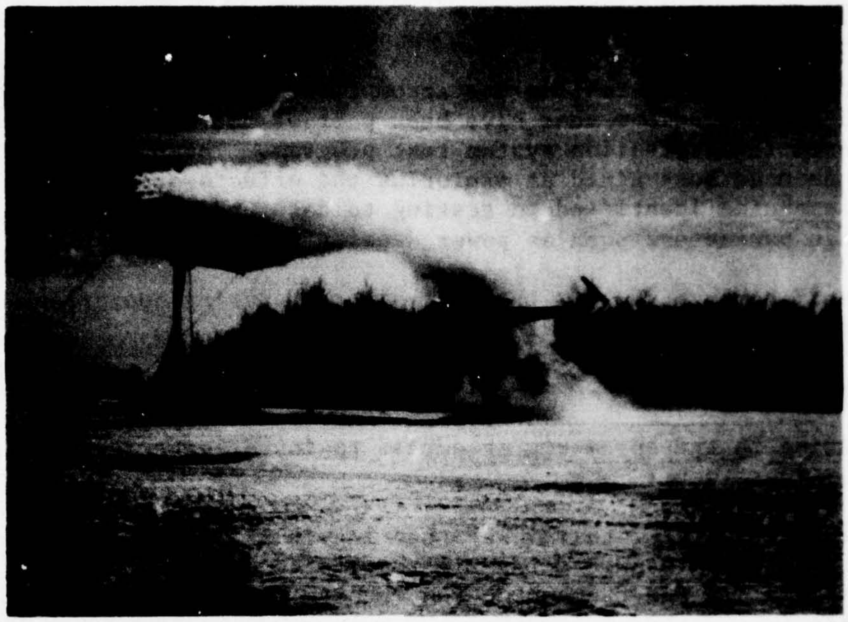


Figure 27. UH-1H Operating in the Spray Rig With 0.7 g/m^3 Cloud at $-7.0^{o}C$ with 9-10 mph East Wind (heavy inlet screen icing was experienced).

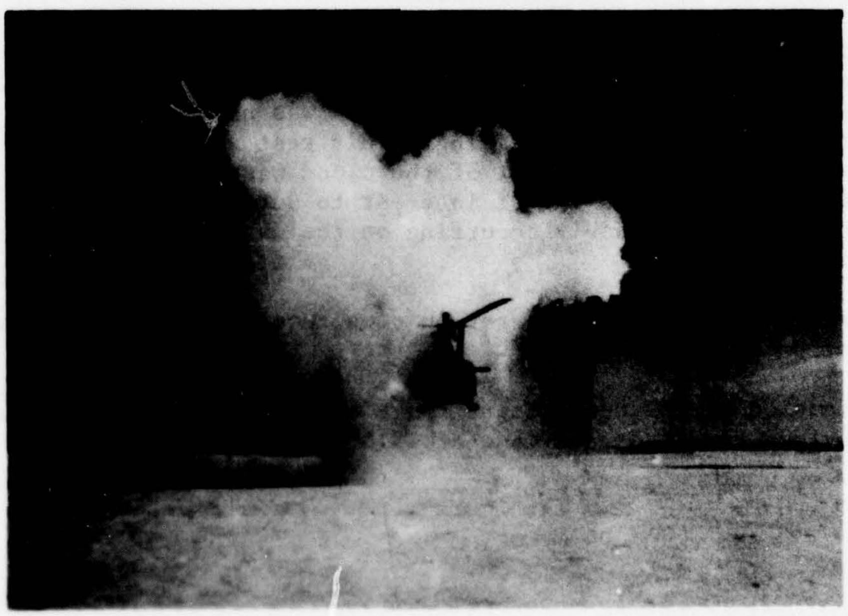


Figure 28. Rear View of Test Aircraft in the Spray Rig on Bright Clear Day With 0.7 g/m^3 LWC and $-7^{o}C$ OAT.

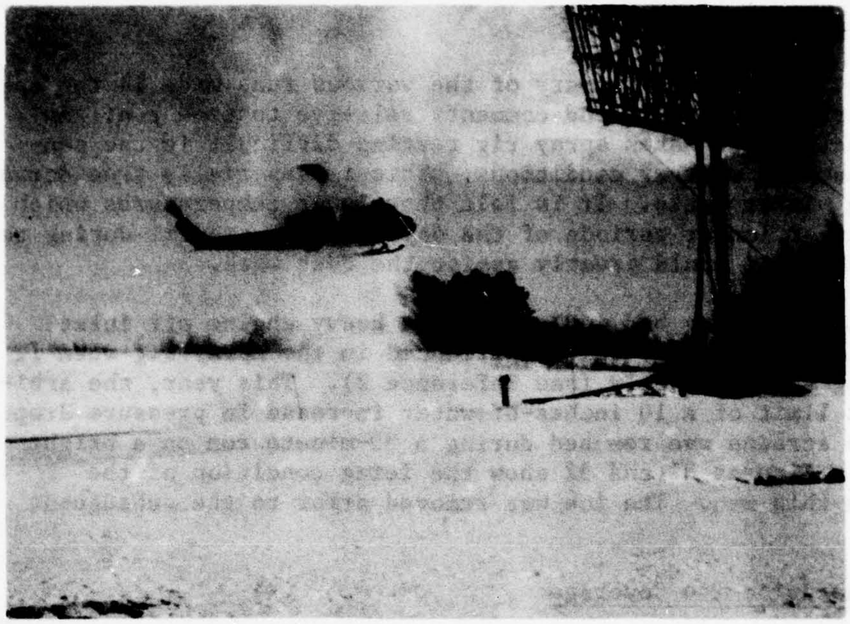


Figure 29. Spray Rig Operations With a 10-mph West Wind (cloud is 0.7 g/m^3 at -6.5^{o}C OAT).

Figure 30. View From the Cockpit During a Spray Rig Test Prior to Cloud Pulldown (20-mph wind and 0.55 g/m^3 at -11^{o}C).

4.10.2 Test Results

Table 3 presents a summary of the various runs made in the spray rig and pertinent results and comments relative to each run. An obvious factor that makes spray rig testing difficult is the constantly changing weather conditions. This is especially true during the waning winter weeks. It is felt that lower temperatures which would hold for longer periods of the day, such as prevail during the month of January, would greatly assist the test work.

Previous testing had indicated that heavy engine air inlet screen icing was usually only experienced in the spray rig when it was snowing simultaneously (see Reference 2). This year, the arbitrary test limit of a 10 inches-of-water increase in pressure drop across the screens was reached during a 30-minute run on a bright clear day. Figures 31 and 32 show the icing condition of the screens on this run. The ice was removed prior to the subsequent runs.

4.10.3 Chordwise Ice Coverage

Measurements were made of the extent and spanwise distribution of main rotor blade chordwise ice coverage. Figure 33 shows the quantitative results for the lower surface. The pattern shown is typical for the spray rig and shows a maximum chordwise coverage of 29 percent chord at the 35-percent span location. The rapid decrease with span is typical and undoubtedly related at least in part to blade twist. Figures 34 and 35 are photographs of a typical distribution and texture on the lower surface of the blade. The upper surface usually has a fairly uniform one-half to three-quarters of an inch coverage which would be approximately 3-1/2 percent chord. The leading-edge deicing heater coverage extends to 12 percent chord on the upper surface and a uniform 29 percent chord on the lower surface.

TABLE 3. SPRAY RIG TESTING SUMMARY (Sheet 1 of 2)

Spray Rig Test No.	1978 Date Test # Flt. #	Outside Air Temp- °C	Cloud LWC g/m^3	Run No.	Run Objective	Time in Cloud- Min.	Blade Ice Coverage Prior to Deicing	No. of Deice Cycles	Blade Deicing Results	Remarks
1	2 Mar T106 F173	-6.5	0.7	1	Single deice using 230 volts with on-time = 70% of last year's recomm.	2.5	Ice to 0.58 R where self shed. Ice thin in Zone 6 (inboard)	1	Blades perfectly clean after clear air deice	Shed some ice on lift-off
		-6.5 to -5.6	0.7	2	Multiple deicing results using 230 V with same on-time	30.0	Used same off-time as Run 1 so assume same blade icing each cycle.	12	Last deice cycle made in clear air but blades did not deice	Only slight run-back from Zone 6 indicated on-time was too short
2	3 Mar T107 F174	-12.1	0.5	1	Single deice using 200 volts with on-time = 90% of last year's recomm.	5.0	No Inbd ice! Only from .4 R to .75 R	0	Terminated test when found stab tip weight heater failure.	Low wind vel. & large crosswind gave inadequate rotor immersion.
3	6 Mar T108 F175	-8.2	0.65	1	Single deice using 200 volts with on-time = 90% of recomm'd.	2.0	Ice out to 0.6 R with 1/4-in. @ 0.5 R	1	Blades clean except thin layer on inb'd lower side of Zone 6.	Good deice
		-8 to -7	0.65	2	Multiple deicing results using 200 volts W/90% - 100% recomm'd.	32.0	Ice out to 0.62 R (assumed)	12	Residual ice to 0.38R with Sta 83 joint problem obvious.	Last deice made in clear air. Used 2.5 min off-time
		-6.5 to -5.4	0.7	3	Multiple deicing results using 200 volts W/125% recomm'd on-time plus thicker ice prior to deice.	30.0	Ice out to 0.62 R But 20% thicker	10	Blades clean but lots of Zone 5 & 6 alum skin runback	Longer on-time deices but results in runback.
4	7 Mar T109 F176	-11.8	0.55	1	Single deice using 200 volts W/96% recomm'd and 3/8-in. thick @ 0.5 R instead of 1/4-in.	4.5	Good ice coverage to 0.7 R with double horn shape.	1	Blades clean except inb'd 12". Some Sta 83 ice on instrumented blade	Clear air deice
		-11.4 to -10.6	0.55	2	Multiple deicing results using 200 volts and 50% thicker ice (3/8-in.) W/90% recomm'd on-time.	27.0	Assume same as above	6	No deicing inb'd of 0.35 - 0.40 R	Several layers apparent
				-	Repeat to Deice Zones 5 and 6	-	Residual from Run 2	1	Clean	
		-9.8 to -9.6	0.60	3	Multiple Deicing results using 230 volts and 3/8-in. thickness	18.0	Assume same as Run 1 and 2	4	Only 12-18 in. inboard ice and Zone 5 runback	230 V seems better
5	9 Mar T112 F178	-4.5	0.7	1	Operation at -4.5°C without deicing	30.0	Unknown	0	No problems apparent. Self-sheds symmetrical	Too warm to continue testing

TABLE 3. SPRAY RIG TESTING SUMMARY (Sheet 2 of 2)

Spray Rig Test No.	1978 Date Test 3 Flt. #	Outside Air Temp- $^{\circ}C$	Cloud LWC- g/m^3	Run No.	Run Objective	Time in Cloud- Min.	Blade Ice Coverage Prior to Deicing	No. of Deice Cycles	Blade Deicing Results	Remarks
6	16 Mar T120 F187	-7.0	0.7	1	Multiple deicing results 230 volts with last deice cycle while still in cloud (3/8 in. ice)	30.0	Spanwise ice to 0.6 R	8	Blades real clean except pronouncedly spanwise runback	230 volts increases spanwise runback (greater water flow) Bright clear day- heavy inlet screen icing experienced
		-6.5	0.7	2	Multiple deicing results using 160 volts with last deice in cloud (3/8-in. ice)	15.0	Same as Run 1 (Assumed - same off-time used.)	4	Blades real clean like after 230 V run	Last deice in the cloud better than outside the cloud
		-6.2	0.7	3	Operation at -6.2°C without deicing	10.0	Unknown. Off-time for 1/4-in. = 3.8 min ∴ approx. 0.7-in. thick @ R = 0.5 was maximum accretion	0	Self-shed with no problems - some sections of residual L.E. ice and hoar-frost type build-up aft of L.E.	Run duration limited by fuel
7	17 Mar T121 F189	-7.0	0.7	1	Deiced only Zones 1-4 to leave inb'd ice for auto rpm check	16.0	Unknown	2	Ice self shed during 3rd off-time (3/4-in. thick @ R = 0.5)	Light wind precludes good test. Cloud dense!
		-6.9	>.8	2	Check on chordwise coverage difference with 150 micron droplet size	14.0	Unknown (but suspect none because of light wind vel.)	0	Nothing on blades as suspected because none accreted!	4 mph wind insufficient to blow large droplet to airplane.

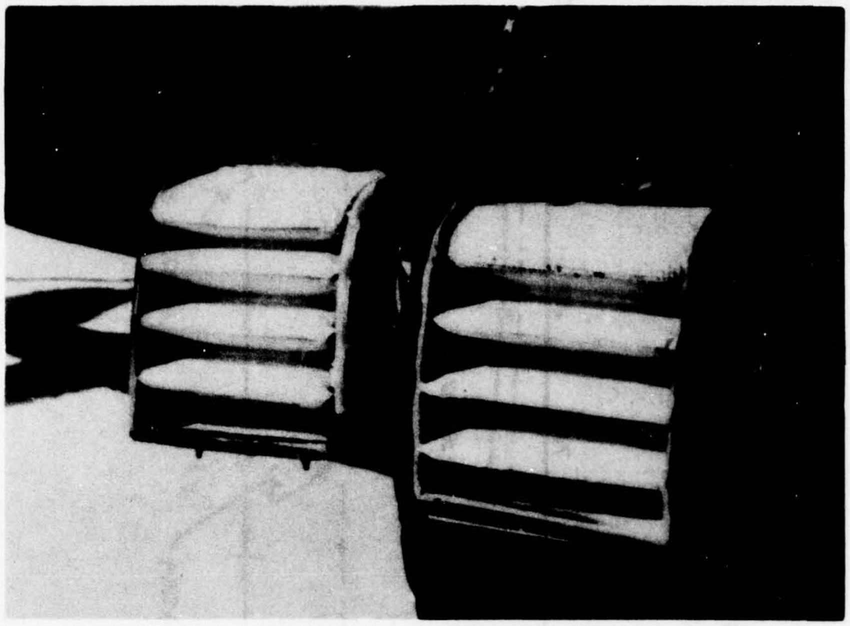


Figure 31. Right and Left Side Engine Air Inlet Screen Icing that Produced 10 inches $H_2O \Delta P$ - Spray Rig Cloud 0.7 g/m^3 at -7^oC.

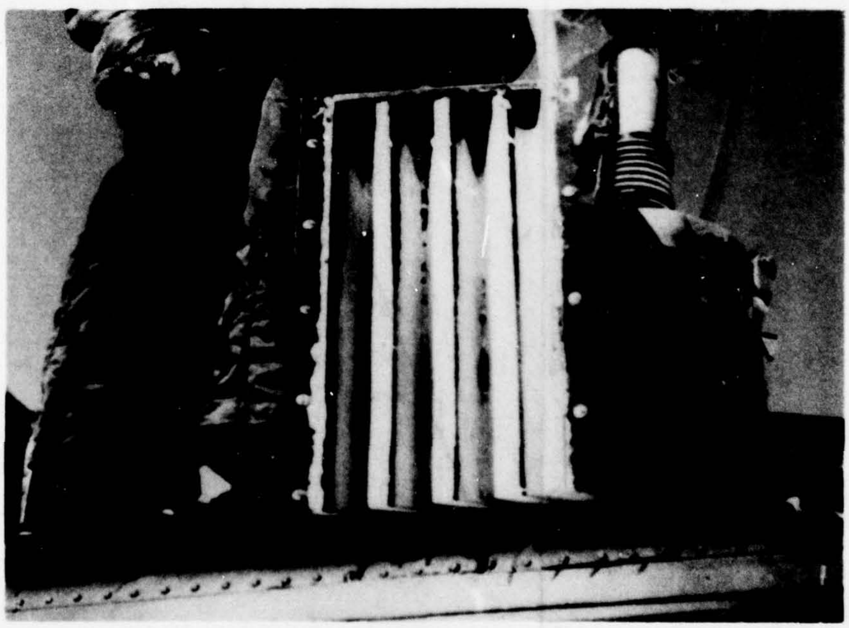


Figure 32. Top Engine Air Inlet Screen Icing from Same Spray Rig Run (30 minutes) as Above.

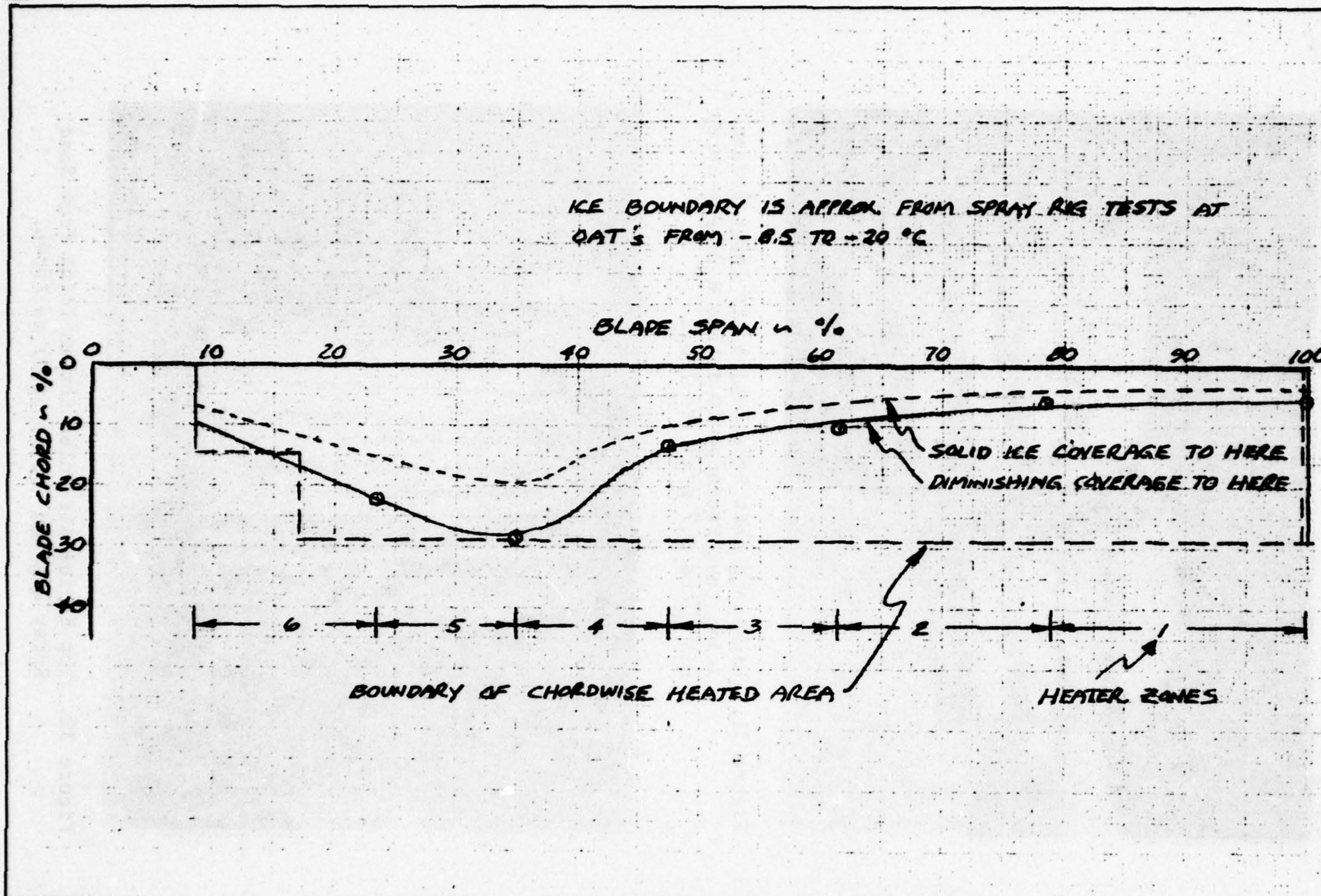


Figure 33. Chordwise Extent of Ice on Main Rotor Blade Lower Surface.

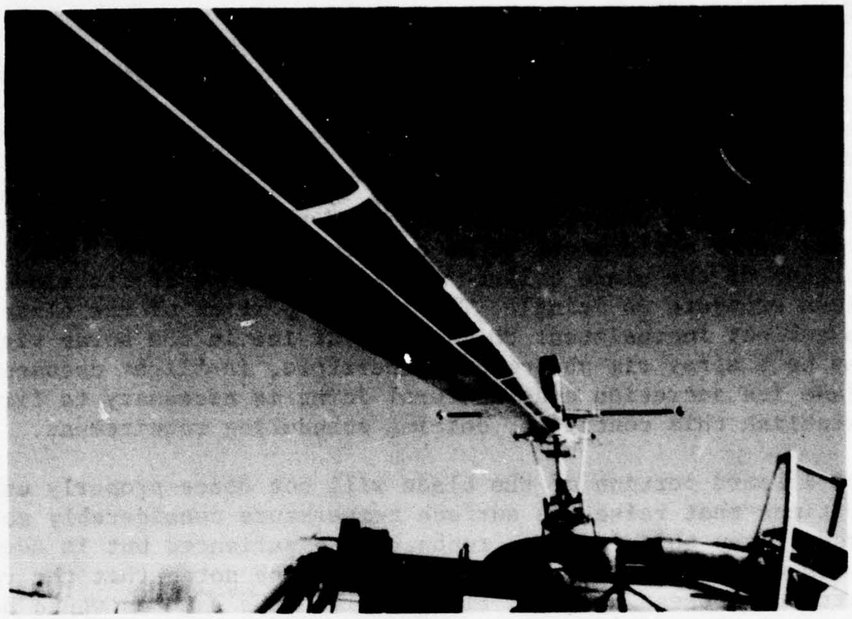


Figure 34. Typical Chordwise Ice Distribution From Spray Rig Operations (0.55 g/m^3 at -11.8^oC).

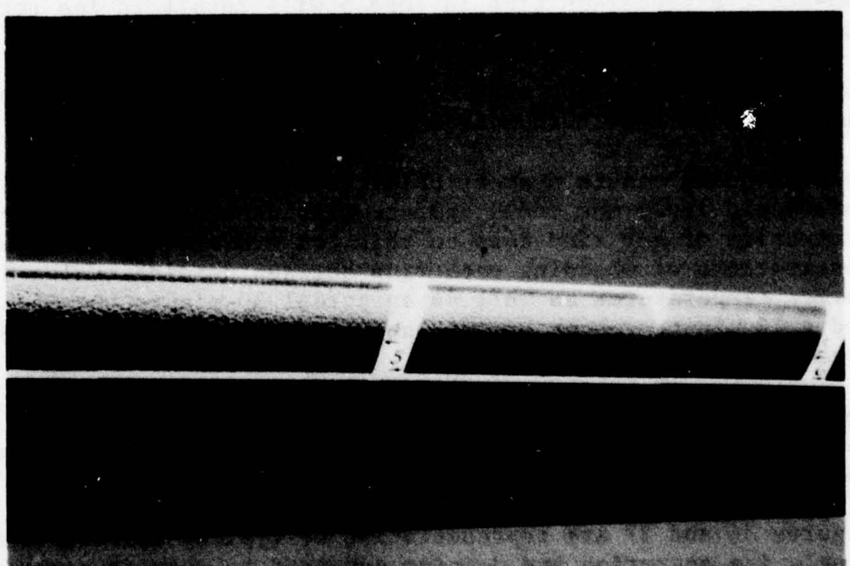


Figure 35. Close-Up of Blade Ice Density and Texture at 0.55 g/m^3 at -11.8^oC (note the double horn leading edge ice formation shape).

4.11 SPRAY RIG CONCLUSIONS

The results of the spray-rig testing indicated the following conclusions:

a. Cleaner inboard blade deicing does result from thicker than 1/4 inch at the mid-span point. This led to the use of thicker ice accretions on the natural icing flights prior to deicing. This also suggests that a deicing controller that deiced the inboard portion of the blade every other cycle might be an optimum configuration. The inboard portion of the blade collects less ice because of its slower velocity (less exposure to icing). The inboard portion of the blade also seems to collect inconsistent thicknesses of ice in the spray rig. This may be a spray rig phenomenon; therefore, in-flight documentation of blade ice accretion under natural icing is necessary to firmly establish this controller deicing scheduling requirement.

b. The inboard portion of the blade will not deice properly unless heater-on times that raise the surface temperature considerably above $0^{o}C$ are used. When this is done, runback is experienced but it does not appear to be detrimental to flight. It should be noted that the runback pattern on these modified blades is not the same as would be experienced if the heated erosion shield was flush with the basic blade contour. It appears that the 1-inch tapered transition from the .090-inch raised erosion shield results in more spanwise flow and possibly complete separation of some of the runback moisture.

c. Too-short a heater-on time in zone 5 will result in ice retention on zone 6 even though the zone 6 on-time may be adequate.

d. Power density does not seem to affect blade deicing. Use of 230 volts did appear to result in more spanwise flow of the runback.

e. Self-shedding occurs symmetrically down to approximately $-6.5^{o}C$. This would imply one could operate without blade deicing or blade ice protection of any kind down to this temperature. This is based on observations of shedding occurring between deicing cycles at this and warmer temperatures as well as an actual 30-minute run made at $-4.5^{o}C$ and a 10-minute run at $-6.2^{o}C$, and 16-minutes at $-7^{o}C$ where some asymmetry was noticed.

f. Deicing in the cloud definitely results in a cleaner blade probably because this condition results in a higher inboard blade temperature than out of the cloud. (See Figure 24 of Reference 4.)

g. Figures 36 and 37 are representative of typical deicing results of a single ice accretion and deicing compared to what is occasionally found following multiple deicings with the last deice cycle made in clear air. It is believed that the latter is the case on occasions when the spray rig cloud conditions result in only a thin coating of inboard blade ice.

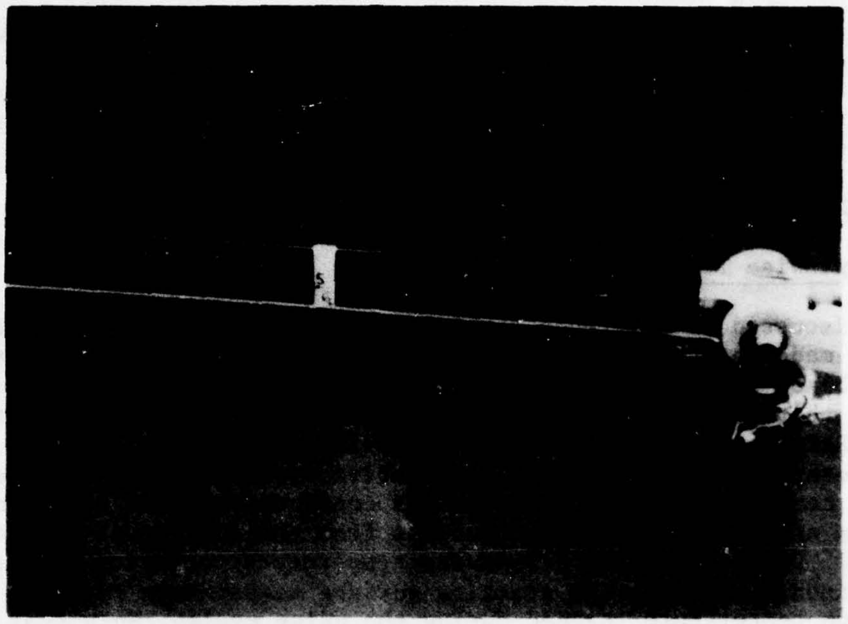


Figure 36. Inboard Blade Condition after Single Icing/Deicing at 0.55 g/m^3 and -11.8°C Using 200 Volts ac.

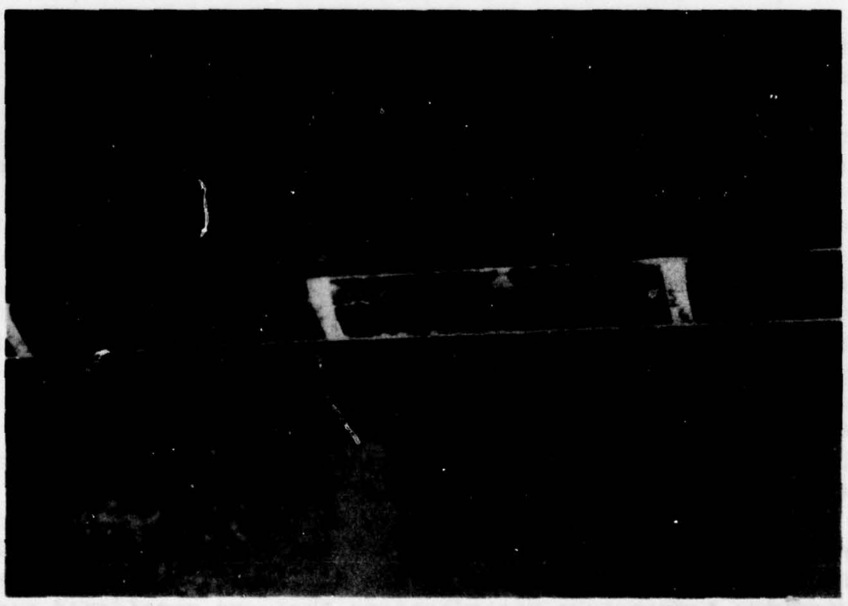


Figure 37. Inboard Blade Condition After 30-Minute Spray Rig Run at 0.55 g/m^3 and -11°C (Six Deice Cycles) Using 200 Volts ac and Same Heater-On Time as Above.

h. It appears that the chordwise heater coverage might be reduced and thus offer a weight saving if the distribution in natural icing is the same or at least similar to these data. Data are needed under intermittent maximum icing conditions where larger droplet sizes are encountered to insure adequate coverage.

4.12 BLADE TEMPERATURE MEASUREMENTS

4.12.1 Spanwise Temperature Variation

As discussed in Reference 4, blade surface temperature measurements have been made in each zone to aid in optimizing heater-on times, to determine the blade surface temperature before and during deicing in order to ascertain that deicing did occur, and to provide better design criteria information. Reference 4 also described the difficulty in establishing the spanwise temperature distribution representative of each of the different blade operating conditions. This analysis was continued without achieving any changes in assessment and/or conclusions from the additional data obtained this year. Figure 38 shows a spanwise temperature variation typical of the data obtained. Shown is the starting surface temperature for each zone and the maximum temperature reached during the deice cycle. Note that the surface temperature of the outboard zones is above 0° due to kinetic heating; thus no heater-on time is required as no ice would be present. Also note the high temperature that experience has indicated to be necessary to get zone 6 to deice and why this also results in considerable runback from zone 6. It appears that zone 5 should be set for a little longer heater-on time than used here to assure deicing because the peak surface temperature of the outboard half of this zone which has steel erosion shield material covering it, is marginal.

An interesting observation that can be made referring to Figure 38, is the fact that even though the heater-on time is constant for a given zone because the blade kinetic heating increases with blade radius, the blade surface temperature passes above 0°C in the tip-to-root sequence also within the zone as blade zone heating takes place. This characteristic further enhances the tip-to-root shedding in smaller increments than the full zone width geometry implies. This is apparent in hub camera pictures of blade deicing sequences, which show many cases of ice shedding in approximately one-half zone increments rather than a full zone at a time.

Figure 39 is a plot from data like that shown in Figure 38 of the spanwise station that the blade temperature variation crosses 0°C versus outside air temperature. This plot is an indication of the spanwise extent of blade icing for any air temperature. It also is an indication of the amount of kinetic heating or "net kinetic heating" of the blade. Considerable scatter is apparent in the data, indicative of the difficulty mentioned previously in defining spanwise temperature distributions that are considered representative of specific operating conditions. Because of the inconsistencies that have been noted in examining the available test data, the only differentiation

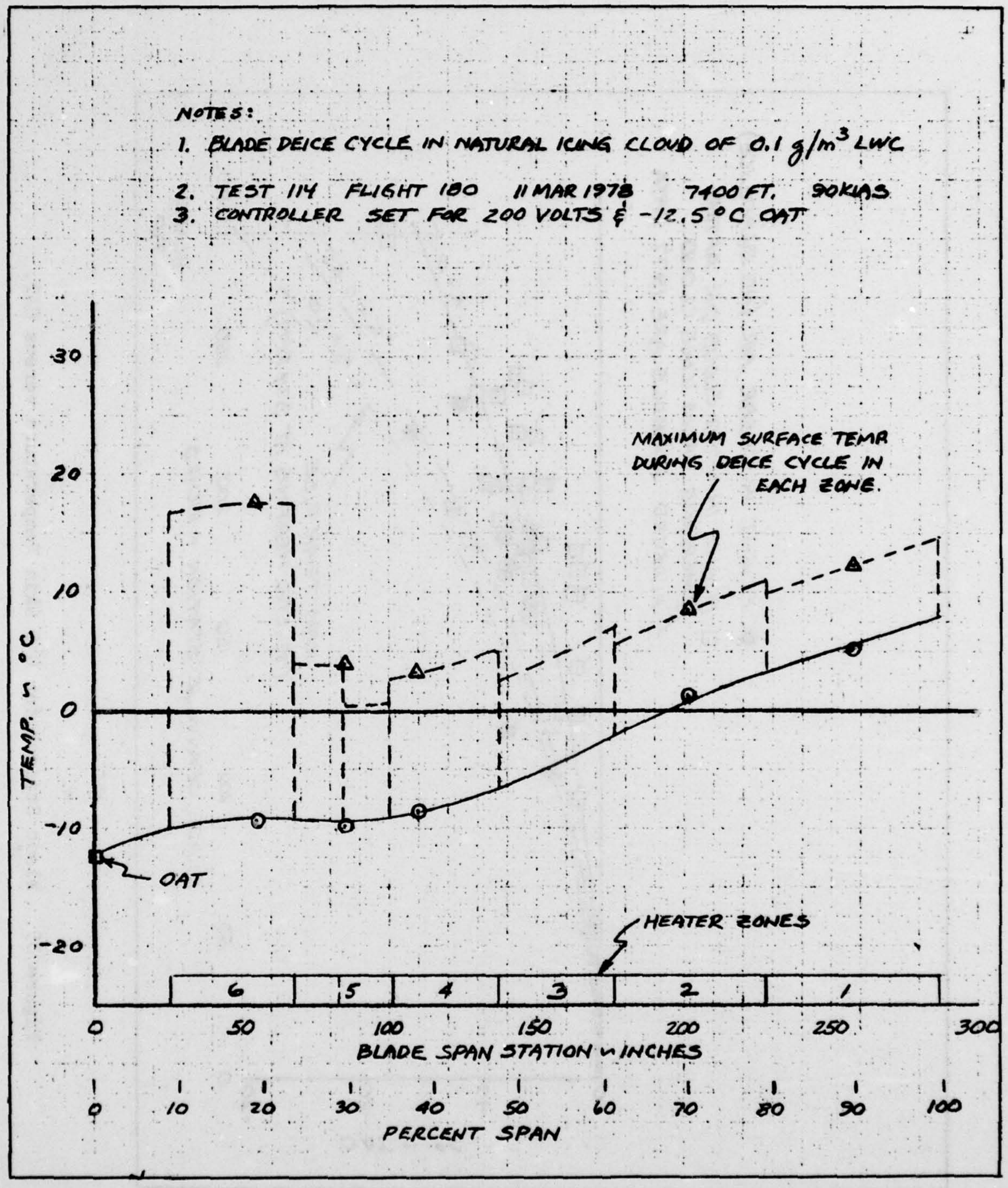


Figure 38. Main Blade Surface Temperature During Blade Deice Cycle on a Natural Icing Flight.

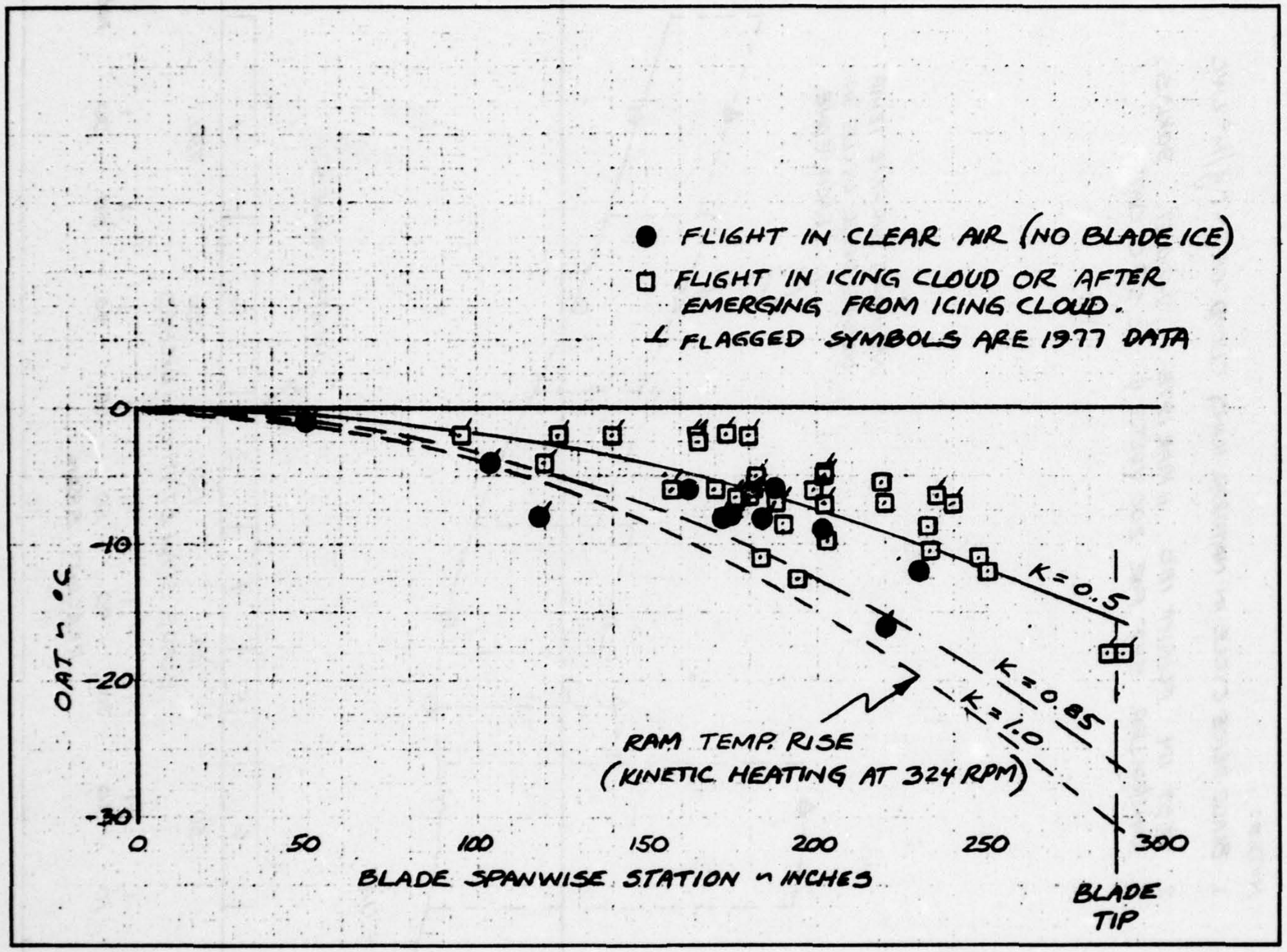


Figure 39. Blade Station for 0°C Skin Temperature versus OAT.

indicated on the test points is whether the data are for a blade with no ice in clear air or whether the blade was in or had been in an icing environment.

It appears from Figure 39 that to determine the heater-on time required to deice (raise the surface temperature to $0^{o}C$), the assumption that 50 percent net kinetic heating is realized is still a valid one.

4.12.2 Chordwise Temperature Distribution

Additional temperature sensors were installed on the main rotor blade for this year's testing to measure the chordwise temperature variations. The chordwise survey was made at span station 110 (0.38R) where observations during spray-rig testing noted the most chordwise ice coverage on the blades lower surface. Figure 40 presents data for several different operating conditions both in a natural icing environment and in the spray rig. All of the data shown are steady state for the environment conditions noted.

Typically, an essentially uniform chordwise temperature rise was measured following heater application. An example is shown for condition 1 of Figure 38. All of the other cases show only the heater-off condition.

The data show some irregularities in the chordwise temperature variation around the leading edge. It is felt that these are actual variations caused by surface ice variations because there is some consistency in their characteristics and they are within the instrumentation measurement accuracy.

For the conditions shown that are labelled "Ice on the Blade", the exact amount and distribution of ice is unknown but in all cases it was after operating in the icing environment long enough to accumulate 1/4 of an inch of ice on the leading edge at the midspan location. Case 8 was an exception in that the off-time was extended to accrete 3/8 of an inch on the blade.

Some of the irregularities or possible inconsistencies referred to above are:

1. The high surface temperature of condition 4 (approximately full kinetic heating) implies that there is no ice on the blade and yet occurred in natural icing after the IRU indicated 1/4 inch should have been accreted.

2. Case 5 shows greater than 100% kinetic heating (this implies an inaccuracy in either the OAT or the blade surface temperature measurement).

3. The lower temperature on the upper blade surface as compared to the lower is evident for most of the cases shown. This characteristic tends to agree with findings reported by the United Kingdom. They pointed out that at high blade angles of attack, a very low or even negative recovery factor occurs at the location of maximum local velocity on an airfoil (i.e., on the upper surface close to the leading edge) resulting in a high heat loss at this point.

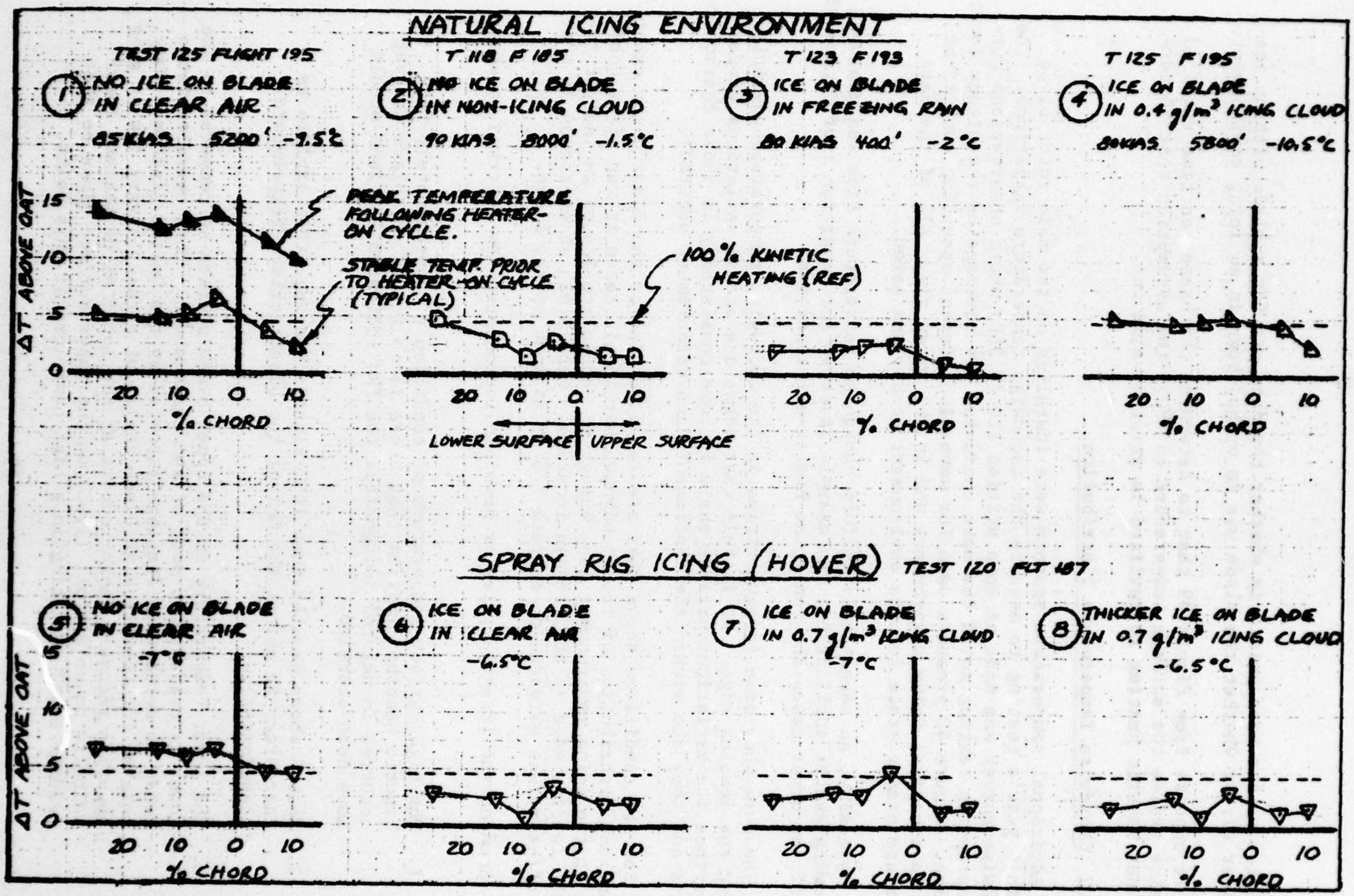


Figure 40. Blade Surface Chordwise Temperature Measurements at Span Station 110 (38% R).

In general, it appears that since the maximum chordwise temperature variation is only about 2°C, it is appropriate to use a uniform chordwise power density for deicing.

4.13 BLADE HEATER-ON TIME

The heater-on time setting of the blade deicing controller as operated during the program is shown in Figure 41 for the three generator voltage selections. The time differences shown for each zone are not based on actual requirements,which as discussed previously in Reference 4 are considerably different in slope for each zone, but are merely the present settings that approximate the single recommended schedule of Reference 4.

Figure 42 shows the actual heater-on times that were used this year for each of the natural icing flight deicings. These are for the 200-volt power density, which is the only setting available for automatic operation with the present configuration of the controller. Note that the heater-on time test points shown are longer than the present controller setting. These were obtained using manual or semi-automatic operation where longer on-times than the controller setting were used to assure blade deicing. Although all of the natural icing flight deicings were apparently satisfactory even when operating in the automatic mode with shorter on-times, it is recommended that for future testing the controller schedule be modified to agree more closely with the recommended schedule of Reference 4.

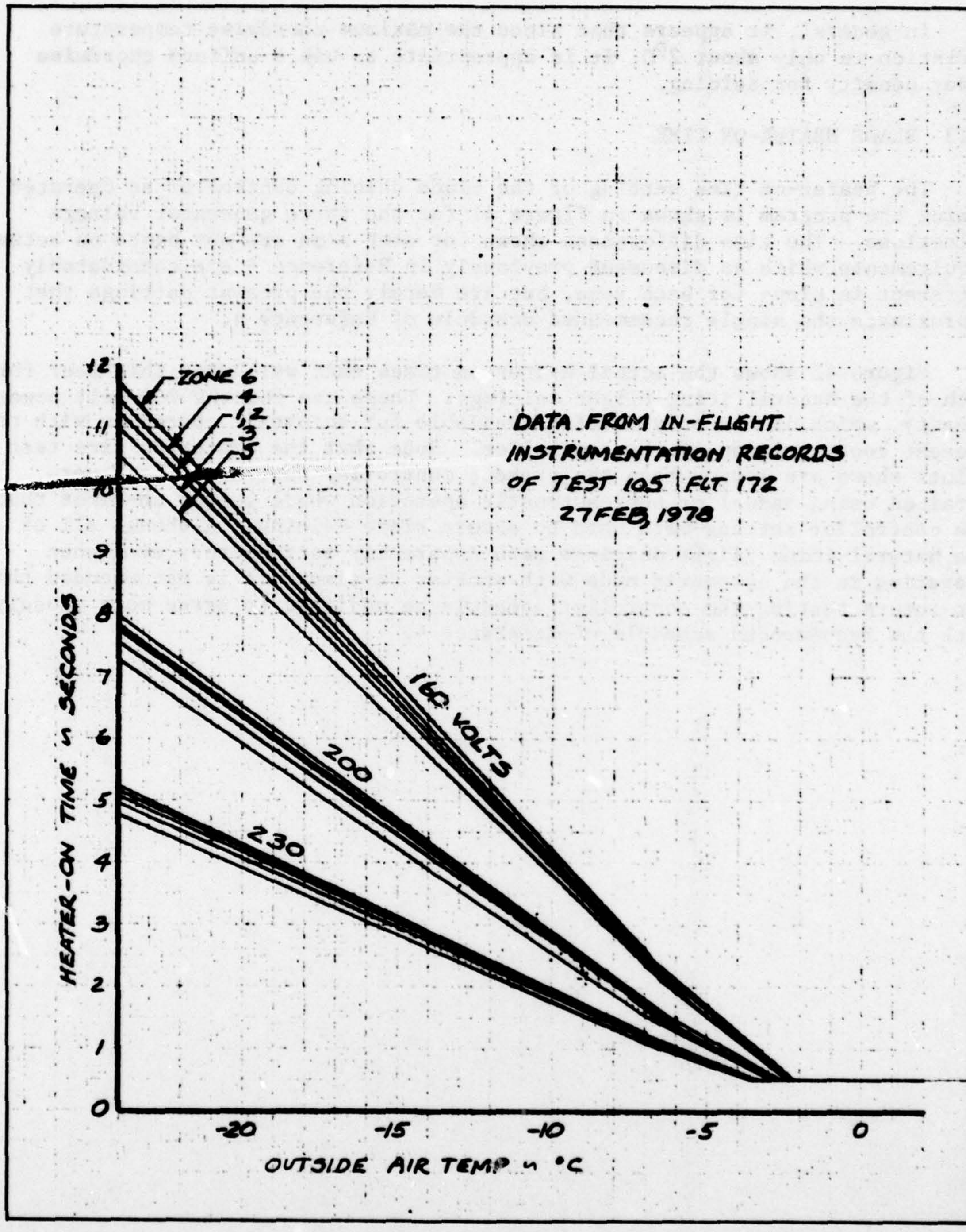


Figure 41. Present Scheduling by Controller of Main Blade Heater-On Time.

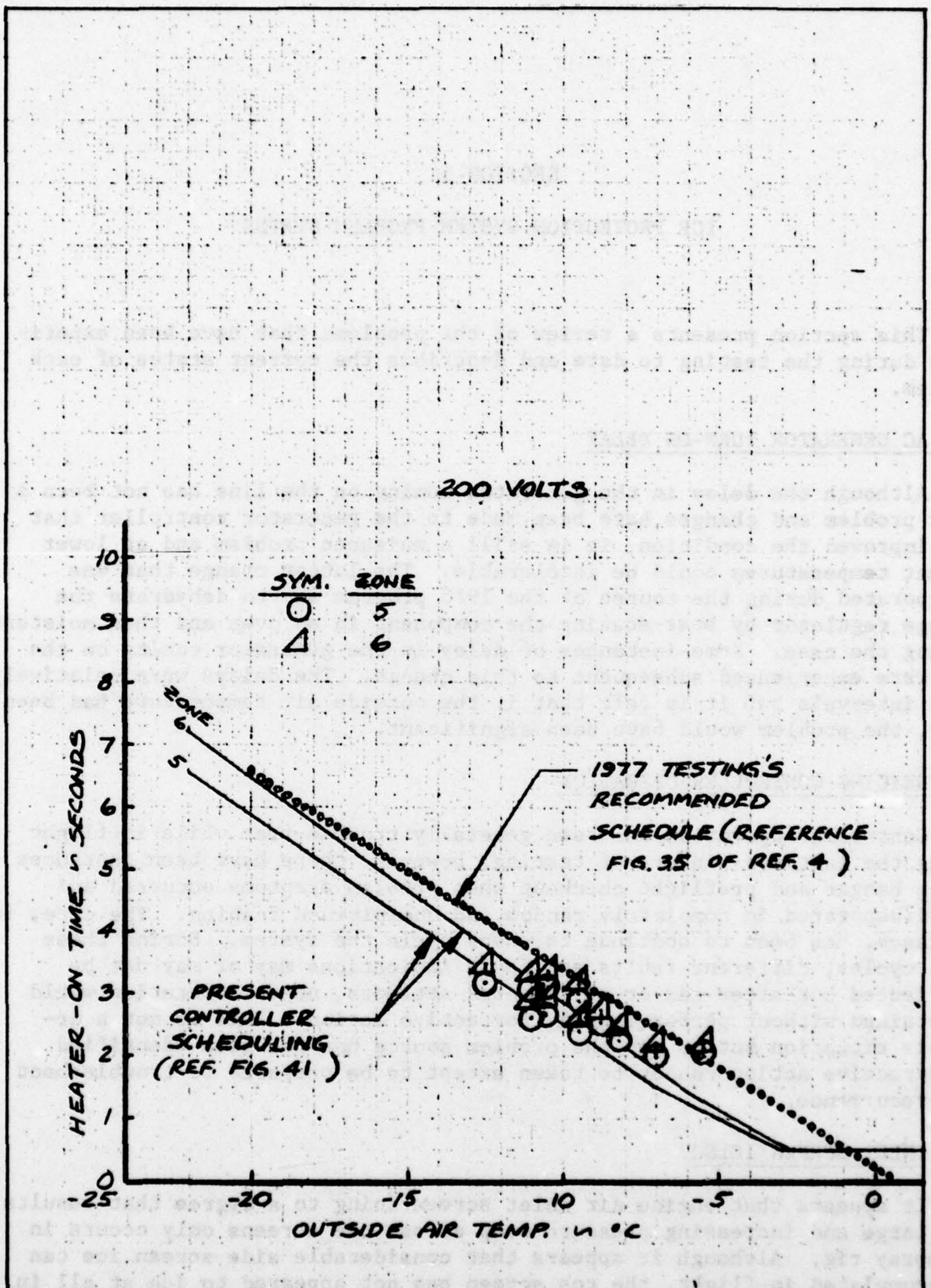


Figure 42. Main Rotor Heater-On Times Used on Natural Icing Flights During 1978 Testing.

SECTION 5

ICE PROTECTION SYSTEM PROBLEM STATUS

This section presents a review of the problems that have been experienced during the testing to date and describes the current status of each problem.

5.1 AC GENERATOR TURN-ON DELAY

Although the delay in the generator coming on the line has not been a major problem and changes have been made to the generator controller that have improved the condition, it is still a nuisance problem and at lower ambient temperatures could be intolerable. The latest change that was incorporated during the course of the 1978 program was to dehydrate the voltage regulator by heat-soaking the component in an oven and then moisture sealing the case. Some instances of delay in the generator coming on the line were experienced subsequent to this change. The delays were relatively short intervals but it is felt that if the outside air temperature had been lower, the problem would have been significant.

5.2 DEICING CONTROLLER OPERATION

Controller operation has been generally trouble-free while in-flight during the last two winters of testing; however, there have been instances during hangar and preflight checkout when problem symptoms occurred and then disappeared in completely random and unexplained fashion. The cure, in all cases, has been to continue to check cycle the system. During these check cycles, different faults and fault indications may or may not be experienced but after six or so repeated attempts, normal operation would be obtained without performing any corrective action. This is not a desirable situation but so far the problem source has not been identified so corrective action cannot be taken except to be prepared to troubleshoot each recurrence.

5.3 INLET SCREEN ICING

It appears that engine air inlet screen icing to a degree that results in a large and increasing pressure drop across the screens only occurs in the spray rig. Although it appears that considerable side-screen ice can be accumulated in-flight, the top screen has not appeared to ice at all in the relatively limited exposure to natural icing conditions encountered to date.

5.4 INCONSISTENT INBOARD BLADE DEICING

It has been impossible in three years of spray rig testing to consistently obtain clean shedding of the ice from the inboard portion of the blade (10-35% span). It is not known whether the same characteristics exist in flight. It is possible that the added aerodynamic drag forces in flight assist in the ice removal. The problem is associated with the surface discontinuity and erosion shield joint at Station 83 (mid Zone 5) and the different heating characteristics of the steel and aluminum erosion shield material that cover each half of zone 5. In zone 6, it appears that the blade bolt hole fittings close to the leading edge which are not heated hinder shedding. Hub camera pictures show that zones 5 and 6 often shed together and require a heated surface temperature considerably higher than $0^{o}C$ to deice at all. This higher temperature results in runback. Whether the inconsistent residual ice or the runback are significantly detrimental to flight has not been established.

5.5 STABILIZER HEATER BURNOUT

Two of the three failures of the stabilizer bar anti-icing heaters that have occurred were due to inadvertent overheat, which points to the need for a temperature control and overheat protection system. The third failure is attributed to initial product manufacturing problems, but combined with the other two, it emphasizes the necessity or advisability of having a spare available for future test operations.

5.6 HEATER-OFF TIME SCHEDULING

The varying magnitude and intermittant LWC encountered in natural icing showed that the off-time to accrete 1/4-inch of ice on the blades requires some means of integrating LWC with time and triggering a deice signal when the appropriate integrated sum is reached. The original controller design simply programmed off-time as a function of LWC. For flight test, two methods of integrating the ice detector rate signals have been evaluated. One uses the number of cycles or counts that the ice detector accomplishes and the other actually performs a rigorous integration using the LWC value from the infrared system rate meter and outputs the integrated sum. The integrated sum is then compared to a preselected value and a deice signal is generated when they are equal. This system works very satisfactorily. The count method is subject to some inaccuracy, as discussed in Reference 4, and is considered to be suited for test purposes only, rather than for operational use.

5.7 AUTOMATIC BLADE DEICING

To accomplish automatic blade deicing, the accuracy and magnitude of the required inputs to the controller had to be determined or the predicted values verified. The required inputs were the integrated LWC sum to schedule heater-off time (time to accrete 1/4 inch of ice on the blade) and outside air temperature (OAT) to schedule the heater-on time. The values of each time have been determined from spray rig testing to date. The integrated LWC sum is available from the IRU that operates on the information from the infrared ice detector. An outside air temperature sensor and location have been determined that provide an accurate OAT signal; therefore, automatic operation of the blade deicing system at one voltage (200 Vac) is now possible and was accomplished satisfactorily during the later natural icing flights this year.

Automatic blade deicing in the spray rig has not been demonstrated primarily because the LWC sensed by the detectors located on the top of the cabin is not representative of the cloud LWC nor are the detectors always exposed to the icing cloud. This is not a deficiency of an aspirated ice detector and could be eliminated if the detector were relocated to a place where it would be in the icing cloud at all times and not exposed to an erroneous LWC due to recirculation effects.

5.8 MAIN BLADE SHORTS AND DIELECTRIC STRENGTH DEGRADATION

The early developmental problems of main blade electrical shorts and reduced dielectric strength appear to have been resolved by the changes incorporated in the second set (actually a rework of the first set) of main rotor blades. No electrical short problems or degradation of the dielectric strength of the heater insulation has been experienced with the improved blades in a total of 77 flight hours and two winter test programs as opposed to failures which occurred at 25 to 44 flight hours on the original blade heater installation.

5.9 TAIL ROTOR BLADE EROSION SHIELD DELAMINATION

A minor delamination was experienced at the inboard trailing-edge corner of the heated erosion shield of one of the tail rotor blades with something less than 61 flight hours. This blade has been retained as the spare. The other two blades, which now have 68.5 and 89.2 hours, have not delaminated at this corner even though they are suspect because of a different tap test sound at the corner. There has been no growth of the suspect area in the 35 to 40 hours since the first blade problem was found. This corner area is where two of the heater conductor wires are directly under the erosion shield so there is a reason for the different sound.

5.10 BLADE INSTRUMENTATION PROBLEMS

A problem was experienced originally with erosion damage to the temperature sensors that were installed too close to the leading edge on the outer 50 percent of the blade. They were 1-inch back from the leading edge on the lower surface of the blade. These were relocated approximately 2 inches aft based on inspection of the eroded paint pattern; however, they were completely washed off during flight through heavy rain, which was normally encountered below a low-ceiling overcast. It appears that some better adhesive is required to hold and protect the temperature gages (resistance-element type) for flight in natural icing because it will inevitably involve some encounters with rain.

SECTION 6

CONCLUSIONS

The problems of electrical shorts and reduced dielectric strength that were experienced with the initial main blade heater installation definitely appear to have been eliminated with the improved design. Approximately 2 to 3 times more flight hours and two winter test programs have been accumulated without a failure with the improved blade configuration. The seventy seven flight hours is still a relatively low number of total hours to be conclusive, however.

The entire ice protection system has continued to operate and function satisfactorily for the second winter and appears suitable for further research flight testing.

More natural icing testing is necessary to expand the natural icing test envelope to cover the test criterion conditions for continuous maximum icing and for intermittent maximum conditions. Test experience to date indicates that no problems will be experienced but actual demonstration is necessary.

The icing test envelope expansion procedures followed to date appear safe and easy to do. Exposure build-up using the number of blade deicing cycles or number of ice detector cycles provides a positive method of integrating LWC x time, the exposure criterion.

Automatic scheduling of blade deicing is mandatory as there are no natural cues perceptible to the pilot. Engine torque rise was monitored this year using a sensitive torquemeter but it failed to provide a useable indication of icing or deicing.

The effects of the residual ice on the inboard section of the blade and runback found after deicing still need to be evaluated more thoroughly. The testing to date does not indicate a significant problem but the testing has been limited and therefore inconclusive.

More testing is necessary to investigate failure modes such as one heater zone inoperative to confirm the design philosophy of continuing operation in icing in this failed condition.

Tail rotor blade ice protection may not be necessary on the UH-1H due to the high centrifugal force field which, in all testing to date, has resulted in symmetrical self shedding of ice. This condition is further improved with the IR suppressor installed which results in a warmer air temperature operating environment at the tail rotor.

The top of the cabin roof is the best location on the UH-1H for both an OAT sensor and an aspirated ice detector.

Although no new data were obtained this year on FM antenna icing effects, it appears that the 42.5 degree lateral tilt is a satisfactory solution to the tail rotor strike problem. This mounting provides approximately 4½ feet of clearance, and avionics testing that was conducted this year showed that the increased tilt did not degrade the performance of the communications system.

Engine air inlet screen icing may not be dependent on mixed conditions as heavy screen icing was experienced in the spray rig on a bright clear day and no screen icing was experienced hovering in falling snow.

The problem of the delay in the generator coming on the line is not resolved but has not handicapped testing to a significant degree.

SECTION 7

REFERENCES

1. Werner, J. B., THE DEVELOPMENT OF AN ADVANCED ANTI-ICING/DEICING CAPABILITY FOR U.S. ARMY HELICOPTERS, VOLUME II - ICE PROTECTION SYSTEM APPLICATION TO THE UH-1H HELICOPTER, Lockheed-California Company; USAAMRDL Technical Report 75-34B, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1975, AD A019049.

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

3. Cotton, R. H., OTTAWA SPRAY RIG TESTS OF AN ICE PROTECTION SYSTEM APPLIED TO THE UH-1H HELICOPTER, Lockheed-California Company; USAAMRDL Technical Report 76-32, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1976, AD A034458.

4. Cotton, R. H., NATURAL ICING FLIGHTS AND ADDITIONAL SIMULATED ICING TESTS OF A UH-1H HELICOPTER INCORPORATING AN ELECTROTHERMAL ICE PROTECTION SYSTEM, Lockheed-California Company; USAAMRDL Technical Report 77-36 Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1978, AD A059704.

5. Kitchens, P. F., TEST PLAN FOR SIMULATED AND NATURAL ICING TESTS OF A UH-1H WITH AN ADVANCED ICE PROTECTION SYSTEM, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604 January 1978.