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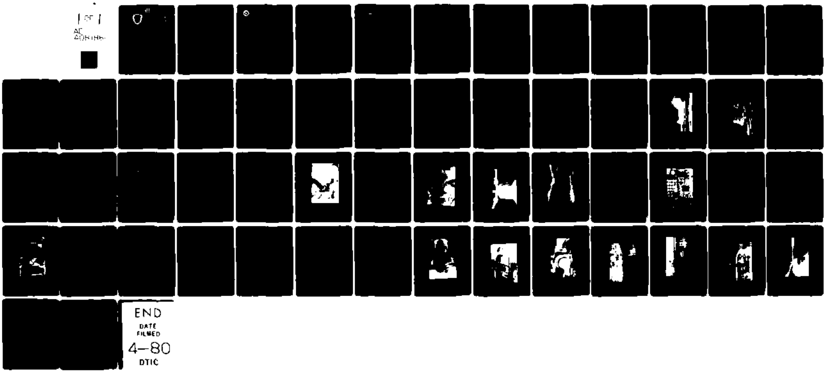

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ARTIFICIAL ICING TEST CH-47C HELICOPTER WITH FIBERGLASS ROTOR BLADES

FINAL REPORT

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UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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DEPARTMENT OF THE ARMY
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DRDAV-DI

2 . JAN 1980

SUBJECT: Directorate for Development and Qualification Position on Final Report Artificial Icing Test CH-47C Helicopter with Fiberglass Rotor Blades, USAAEFA Project Number 78-18

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1. The purpose of this letter is to establish the Directorate for Development and Qualification position on the subject report. The CH-47C with fiberglass blades (FRBs) demonstrated the capability to operate within a limited light intensity icing environment with and without rotor blade deicing. Testing under artificial icing conditions behind the JCH-47C Helicopter Icing Spray System (HISS) were conducted at most liquid water contents (LWC) and temperatures within the light intensity icing envelope. Validation of the light intensity icing envelope was conducted under natural icing conditions, however less than 50% of the light intensity icing envelope was achieved. Because of the difference in the HISS artificial cloud and natural icing conditions and the limited natural icing tests, the capability of the CH-47C with the FRBs to operate safely in the full light intensity icing envelope has not been established, and cannot now be established; however, the effective operation of the FRB deicing system is as expected.

2. This Directorate concurs with the conclusions in the report except for sub-paragraph 24b, which indicates that an icing envelope is feasible for the CH-47C with FRBs that do not incorporate deicing system following only the correction of two deficiencies. While an undefined, but safe, capability may exist, these tests did not provide sufficient information to project a safe light intensity icing envelope without heated rotor blades.

3. This Directorate concurs with the recommendations. Action has been taken to correct the deficiencies and shortcomings reported. Corrective action includes modifications to incorporate covers for the droop stops, screens for the fuel vents, and redesigned cabin heater drain. These modifications will be evaluated during the 1979/1980 icing season on the YCH-47D. Since the CH-47C configuration is similar to the YCH-47D for these modified items, test results from the YCH-47D icing tests will be applicable to the CH-47C.

DRDAV-DI
SUBJECT: *Directorate for Development* and Qualification Position on Final Report Artificial Icing Test CH-47C Helicopter with Fiberglass Rotor Blades, USAAEFA Project Number 78-18

4. Data derived on the icing characteristics of the YCH-47D FRB will be used as a basis for defining an icing envelope for the CH-47C with FRB, if sufficient testing can be accomplished, rather than retesting the CH-47C/FRB itself.

Chas C Crawford Jr

CHARLES C. CRAWFORD, JR.
Director of Development
and Qualification

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CH-47C	Fuel Tank Vent Icing
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Prototype Deice System	

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The United States Army Aviation Engineering Flight Activity in conjunction with the Boeing Vertol Company conducted an evaluation of the CH-47C helicopter with fiberglass rotor blades and a prototype blade de-ice system. The rotor blades were tested under natural and artificial icing conditions at St. Paul, Minnesota from 24 January to 2 March 1979, and required 30.1 flight hours of which 17.7 hours were in an icing environment. Testing was conducted in two phases: (1) protected, where the blade de-ice system was allowed to operate automatically and (2) unprotected, where the blade de-ice system was held in standby status. The fiberglass rotor blade system was evaluated at conditions varying from 0.1 gm/m^3

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liquid water content (LWC) to 0.8 gm/m^3 LWC and temperatures varying from -4°C to -16°C. Time in the icing environment varied from a minimum of 28 minutes to a maximum of 2 hours and 25 minutes. The protected rotor blade de-ice system operated satisfactorily. The unprotected rotor blades operated satisfactorily under the limited conditions tested. Minimal ice accretion and minimal asymmetric shed characteristics were observed. Two deficiencies for flight under icing conditions unrelated to the fiberglass rotor blades were noted. The deficiencies are: (1) failure of the droopstops to engage after flight in icing conditions; and (2) ice accretion and subsequent blockage of the fuel vents. Two shortcomings were also noted relating to the battery vent and cabin heater fuel drain becoming blocked by ice. Following correction of the two deficiencies, a limited envelope could be utilized for flight in icing conditions. Further testing is required to define an unprotected rotor blade icing envelope and should include an expanded range of temperature, LWC, and aircraft gross weight.

PREFACE

The artificial icing test of the CH-47C with fiberglass rotor blades was conducted jointly by the United States Army Aviation Engineering Flight Activity (USAAEFA) and the Boeing Vertol Company at St. Paul, Minnesota. The test aircraft was maintained and instrumented by Boeing Vertol Company.

USAAEFA thanks the Minnesota Army National Guard and the Army Reserve Aviation Support Facility for the tremendous support they provided. The Guard provided the test team with office and hanger space, and some of the small touches of home; while the Reserve ably provided support aircraft throughout the test. Special thanks are due to PFC Christie Iverson for her unflagging assistance and support.

Figures 2 and 3 of appendix B are used with the permission of Boeing Vertol Company.

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TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

1. The United States Army Aviation Research and Development Command (AVRADCOM) awarded a contract to the Boeing Vertol Company to design and fabricate a fiberglass rotor blade (FRB) with an integral de-icing capability for use on the CH-47. On 5 October 1978 AVRADCOM tasked the United States Army Aviation Engineering Flight Activity (USAAEFA) to plan, test, and report on artificial icing tests of the CH-47C with fiberglass rotor blades using the Helicopter Icing Spray System (HISS) to create the artificial icing environment (ref 1, app A). A test plan (ref 2, app A) was prepared in response to the AVRADCOM test request.

TEST OBJECTIVES

2. The objectives of this evaluation were:

a. Determine the effectiveness of the FRB de-icing system and provide the contractor with data for system optimization.

b. Determine within the limitation of the HISS the potential of a CH-47C with unprotected FRB to operate in a light intensity icing environment.

DESCRIPTION

3. The CH-47C is a twin-engine, turbine-powered, tandem rotor cargo helicopter manufactured by Boeing Vertol Company. A detailed description of the CH-47C helicopter is contained in the operator's manual (ref 3, app A). A description of the test helicopter and fiberglass rotor blades is also contained in appendix B. The test helicopter, S/N 74-22287 (Boeing production number B-706), was a standard production CH-47C with the following changes:

a. Fiberglass rotor blades.

b. T55-L-712 engines.

c. Modified cockpit self-tuning vibration absorber.

d. Aft pylon fixed, tuned absorber removed.

e. Modified forward transmission cover actuator mount lugs.

f. Modified swiveling actuator lower mount bearing and attachment hardware.

g. Rotor hub assembly lightning protection.

h. Emergency power system and revised engine start switch.

i. Modified longitudinal cyclic speed trim (LCT).

j. Rotor blade de-ice system.

k. Instrumentation package.

TEST SCOPE

4. The CH-47C FRB icing tests were conducted in the vicinity of St. Paul, Minnesota, from 24 January through 2 March 1979 by USAAEFA and Boeing Vertol Company. Twenty-one flights for a total of 30.1 hours were flown with 21 productive hours of which 17.7 hours were in the icing environment. Boeing Vertol Company installed the instrumentation in the test aircraft, provided instrumentation and maintenance support, and a copilot. Flight limitations contained in the operator's manual and the airworthiness release (ref 4, app A) were observed throughout the test. The tests were accomplished at average gross weights of 30,000 and 37,000 pounds, a mid center-of-gravity (cg) location, pressure altitudes from 2400 to 12,000 feet, true airspeeds of 80 to 130 knots, and a rotor speed of 225 rpm. Icing was accomplished at ambient temperatures of -4 to -16 degrees centigrade, with liquid water content (LWC) varying from 0.1 to 0.8 grams/meter^3 (gm/m^3).

TEST METHODOLOGY

5. The test was conducted in two phases:

a. In the first phase, all elements of the FRB de-ice system were tested. The standard windscreen, engine, pitot tube, stability augmentation system (SAS) port anti-ice, as well as the blade de-ice systems were activated prior to entering the spray cloud.

b. In the second phase, only the standard equipment was activated prior to immersion. The FRB de-ice system was available as a backup.

6. For flights behind the HISS the test aircraft was stabilized beside the cloud at the test airspeed, and baseline data were taken. The aircraft was then positioned in the spray cloud so that both rotors were immersed. After the desired immersion time, the aircraft was again stabilized outside the cloud and data recorded. The test aircraft was phototgraphed to determine the ice accretion characteristics during and following immersion, as well as on the ground following aircraft shut-down. Immersion times were based on pilot judgement, system operation, visual observation, duration of HISS water supply, and prior test results.

7. For flight in the natural environment the test aircraft would file for flight under instrument flight rules (IFR) with St. Paul approach control (APC). The entire flight would be flown in icing conditions under positive control with St. Paul APC. The chase aircraft was either airborne, in visual flight rules (VFR) conditions below the clouds or on standby at St. Paul Airport.

8. Three Rosemount ice detection and accretion rate systems were installed on the aircraft. One system was monitored in the cockpit and provided rate and detection information to the pilot and was also recorded by the instrumentation. The other two systems could be selected by the pilot to control the rotor blade de-ice system. Data during the tests were recorded manually and on magnetic tape. A description of the instrumentation and a list of parameters is contained in appendix C.

9. Test techniques and data analysis methods are presented in appendix D. The methods used to determine cloud parameters and definitions of icing types and intensities are also presented in appendix D.

RESULTS AND DISCUSSION

GENERAL

10. The CH-47C with fiberglass rotor blades and integral blade de-ice protection was evaluated in six flights. Conditions varied from 0.25 LWC to 0.75 LWC and temperatures varied from -5°C to -16°C in an artificial icing environment behind the Helicopter Icing Spray System (HISS). Time in the icing environment varied from 28 minutes to 1 hour. Blade heat cycle time was adjusted following flights 1 and 3 after which the prototype de-ice system operated satisfactorily. The unprotected fiberglass rotor blades were evaluated in 12 flights under a combination of natural and artificial icing conditions which varied from trace to moderate ice with temperatures ranging from -4°C to -15°C. Time in the icing environment varied from a minimum of 29 minutes to a maximum of 2 hours and 25 minutes. The unprotected rotor blades operated satisfactorily under the limited conditions tested. Minimal ice accretion and minimal asymmetric shed characteristics were observed. There was no idnication of a torque rise during either the protected or unprotected test phase. Two deficiencies for flight under icing conditions were noted, but were not related to the fiberglass rotor blades. The deficiencies are: (1) failure of the droop stops to engage after flight in icing conditions; (2) ice accretion and subsequent blockage of the fuel vents. Two shortcomings were the battery vent and cabin heater fuel drain becoming blocked by ice. Following correction of the two deficiencies, a limited envelop could be utilized for flight in icing conditions. Further testing should be accomplished to define the unprotected rotor blade icing envelope and should include a wider range of temperatures and LWC.

PROTECTED FIBERGLASS ROTOR BLADES

11. The CH-47C with fiberglass rotor blades and integral blade de-ice protection was evaluated during 6 flights at the conditions listed in table 1. The test techniques utilized for this testing are described in appendix D. Due to the limited scope of the test the protected rotor system was evaulated only in artificial icing conditions behind the HISS which is described in appendix B.

12. The prototype rotor blade de-ice system operated satisfactorily, but required adjustment of the heat cycle on-time following flights 1 and 3. During the initial flights it was observed that the system on-time did not correlate with the on-time predicted from previous experience with the CH-46 and YUH-61A blade de-ice systems. The problem was traced to cabin heat leaking into the temperature sensor that controlled the cycle time. Correction was accomplished by adjusting the resistance of the circuit until the desired on-time was achieved. After system on-time adjustments were completed, the system operated satisfactorily and provided excellent rotor blade ice protection.

13. During the protected phase of testing, no cockpit indications of rotor blade ice accumulation were observed. Engine power (torque) steadily decreased throughout all flights as a result of fuel burn off. Vibration levels remained essentially constant while in the icing cloud, and except for one 45 second period of mild one per revolution (1 per rev) lateral oscillations indicating a mild asymmetric

Table 1. Heated Blade Phase Test Conditions[1]

Flight	Date 1979	Average Pressure Altitude (ft)	Average OAT (°C)	LWC (gm/m3)	Relative Humidity (%)	Deice Cycles	Time in Cloud (min)	Time[2] to First Detect (min)	Max Ice[4] Buildup (in)	Average Ice[3] Accretion (15 min) (in)	Remarks
1	2/1	2500	-16	0.25	65-85	12	60	25	1/4	Not Available	V_H +15; blade deice ON time increased (+1.5 sec) after flight
2	2/10	4700	-13	0.25	75	6	60	36	1/4	Not Available	
3	2/12	4000	-10	0.50	10	14	36	4	1/2	0.76	Blade deice ON time increased (+1.5 sec) after flight; aircraft cold soaked for 30 min prior to flight
4	2/13	4600	-11	0.25	80-95	5	33	0	1/4	0.54	
6	2/19	8400	-5	0.50	60	14	40	2	3/8	Not Available	Small indentation found on forward head prior to Flt 7
7	2/19	9500	-5	0.75	40	14	28	2	3/8	0.5	#1 engine anti-ice OFF

[1] Clean configuration with rotor speed 225 rpm; mid cg. All flights were behind the HISS. Engine start gross weight, 32300 lbs; True airspeed, 90 knots.
[2] Time until the first deice cycle of one of the three detectors.
[3] Determined using data recorded from the three detectors.
[4] The maximum thickness of ice usually measured on the OAT probe on the aircraft after flight.

ice shed, no cockpit indication of asymmetric blade shed was observed. Indication of a vibration was not found in the strip out data. This vibration occurred on flight 3 (-10°C and 0.5 LWC) prior to the final blade heat cycle on-time adjustment (para 12). Analysis of high speed film showed that the rotor blades did accrete ice from approximately two-thirds to full span along the leading edge. With the de-ice system operating properly (subsequent to flight 3) in the automatic mode (see system description, appendix B) the accreted ice was shed symmetrically. Within the scope of this test, the prototype rotor blade de-ice system provided excellent rotor blade protection.

UNPROTECTED FIBERGLASS ROTOR BLADES

14. The CH-47C with unprotected fiberglass rotor blades was evaluated in 12 flights during a combination of natural and artificial icing conditions listed in table 2. Test techniques are described in appendix D. The rotor de-ice system was maintained in a standby mode in the event it was required, but was not used at any time during the unprotected phase of testing.

15. Table 2 shows that the unprotected system was evaluated at conditions that varied from -4°C to -15°C, with the LWC values of 0.1 to 0.8 gm/m^3 and in cloud times from 29 minutes to 2 hours and 25 minutes. Test altitude varied up to 12,000 feet pressure altitude, and on flights 11 through 19 the engine start gross weight (ESGW) was increased from 32,300 to 38950 pounds. The higher gross weight was evaluated to further load the rotor system and to increase the test scope for potential envelope expansion. At the higher gross weight the only change in flight characteristics was slightly higher power required. Ice accumulations in excess of four inches were recorded on portions of the fuselage. With the exception of one minute of mild one per rev lateral oscillations occurring during flight 12, there were no observable cockpit indications of acreted rotor blade ice or asymmetric shed characteristics. This vibration could not be verified in the data. Throughout all test flights, there was a decrease in engine power required (torque) for steady state conditions due to fuel burnoff. Vibration levels remained constant at a given airspeed regardless of time in icing conditions.

16. In natural ice conditions after approximately 30 minutes the aircraft was maneuvered with bank angles up to 30 degrees in both directions and airspeed sweeps were accomplished to evaluate any change in handling qualities that might have occurred due to ice accretion. No changes in handling qualities were noted. Some cruise guide indicator (CGI) activity was observed during flight 12 at 12,000 feet pressure altitude and -7.5°C, particularly when maneuvering the aircraft. The aircraft was being maneuvered at the level flight limit airspeed (V_H) and the CGI indications noted were normal for the conditions being tested.

17. Analysis of in-flight high speed photographs taken during artificial ice conditions showed low ice accretion characteristics and slight asymmetrical shed tendencies for the unprotected rotor blades. Ice would accrete from 2/3 to full span, then shed symmetrically at either station 88 (see blade description, app B) or approximately 50 percent span. As stated in paragraph 15, for all flights, only minimal cockpit indication of asymmetric shed was observed. Within the limited scope of this test, the unprotected fiberglass rotor blades show low ice accretion and minimal asymmetric shed characteristics. Operation of the CH-47C in icing conditions with unheated fiberglass rotor blades appears feasible following

Table 2. Unheated Blade Phase Test Conditions[1]

Flight	Date 1979	ESGW (lb)	Average Pressure Altitude (ft)	KTAS	Average OAT (°C)	LWC[2] (gm/m^3)	Relative Humidity (%)	Icing[3] Environment	Time in Cloud (min)	Time[4] to First Detect (min)	Max Ice[6] Buildup (in)	Average Ice[5] Accretion (15 Min) (in)	Remarks
8	2/19	32,300	2400	90	-6	0.25	55/65	H	60	37	1/2	Not Available	#2 engine anti-ice OFF.
9	2/20	32,300	3200	90/120	-4	0.55	95	N	65	1	2 1/2	0.44	Droop stops out on shutdown; fuel vents blocked.
10	2/21	32,300	3200	90/120	-7.5	0.25	95	N	65	1	3/4	0.17	One droop stop out; fuel vents blocked.
11	2/21	38,950	4400	90	-5	0.75	60/65	H	29	2	1 1/2	0.67	#2 engine anti-ice OFF.
12	2/22	38,950	12,000	90	-7.5	0.25/0.8	95	N	80	2	1 1/2	0.4	Copilot's windshield OFF. *fuel vents blocked*; cruise guide indicator active. Rain on descent washed off ice.
13	2/23	38,950	3200	90/130	-7.5	0.25	95	N	60	2	1 1/4	0.35	Droop stops out; fuel vents blocked; engine screens covered.
14	2/24	38,950	11,000	90	-15	0.25	15	H	60	28	3/8	0.18	#2 engine anti-ice OFF.
15	2/24	38,950	11,300	90	-15	0.50	15	H	34	10	3/8	0.39	Fuel vent half blocked.
16	2/28	38,950	10,900	90/120	-12	0.15	95	N	50	7	3/8	0.21	Light steady ice accumulation.
17	2/28	38,950	9000/11,000	90/120	-8.5	0.10	95	N	60	38	1/4	Not Available	Icing rate slightly greater than sublimation.
18	3/1	38,950	2500	80/110	-5	0.25	95	N	145	1	4	0.4	Droop stops out.
19	3/1	38,950	2500	80/110	-6	0.10/0.25	95	N	98	2	1	0.2	Droop stops out.

[1] Clean configuration with rotor speed 225 rpm; mid cg.
[2] LWC for natural icing flights estimated from instrumentation probe.
[3] N = natural icing conditions, H = HISS icing conditions.
[4] Time until the first deice cycle of one of the three detectors.
[5] Determined using data recorded from the three detectors.
[6] *Same as #4 on Table 1.*

correction of the two deficiencies. Further testing is required to define an unprotected fiberglass rotor blade icing envelope and should include an expanded range of temperatures, liquid water content, and gross weight.

ICE ENVIRONMENT IDENTIFICATION

18. Figure 1 presents the average ice accretion in 15 minutes as a function of outside air temperature (OAT), for values of constant liquid water content. The ice accretion rate was determined from data recorded from the three ice detectors (See appendix D). Data for this plot were taken from tables 1 and 2 which, in turn, were derived from in-flight data. There are five natural icing test conditions and three unheated and three heated test conditions in an artificial icing environment. Although figure 1 does not take into account all parameters which may affect ice accumulation such as relative humidity, cloud cover, water droplet size, varying airspeeds, or artificial and natural environment (photos 1 and 2, appendix E, show a comparison of artificial and natural icing on the CH-47C), the data does indicate specific trends. The data show that ice accretion was greatest at approximately -10°C with colder or warmer temperatures yielding less ice accumulation. Additionally, other factors being equal, a higher liquid water content resulted in higher ice accumulation. Correlation of actual ice accretion on the cockpit OAT probe (photo 1, appendix E) with predicted ice accretion from the Rosemount ice detector showed good agreement. Correlation was attempted only in natural icing conditions on flights 12, 13, 18, and 19. On these flights, the OAT gage, which is readily visible from the pilot's seat (right side) indicated ice buildup which correlated closely with the Rosemount ice detector rate indication and elapsed time. Correlation of total ice accretion with time integrals of recorded Rosemount rate were also obtained with measured post flight accumulations on the landing gear, HF antenna supports, etc. An ice buildup of 1/4 inch in 15 minutes on the OAT probe is a conservative gage of light ice.

DROOP STOP FAILURE TO ENGAGE

19. After all flights in natural ice conditions, except flight 12 which terminated with approximately 20 minutes of heavy rain, one or all droop stops on the aft rotor head failed to engage on engine shutdown. Photograph 3 appendix E shows an aft rotor droop stop with ice accumulation. The droop stops accrete ice readily, and as little as 1/8th of an inch accumulation can change the centrifugal force characteristics sufficiently to prevent the springs from engaging the droop stops on shutdown. The fiberglass rotor blades have less droop statically than metal rotor blades and hence, are less likely to contact the fuselage or tunnel covers during shutdown than the metal rotor blades. However, engine shutdown under gusty wind conditions or while another helicopter is landing or taxiing nearby may cause strike damage to the tunnel cover, drive shafting, or fuselage. Failure of the droop stops to engage after flight in icing conditions is a deficiency. Droop stop engagement failures did not occur during artificial icing.

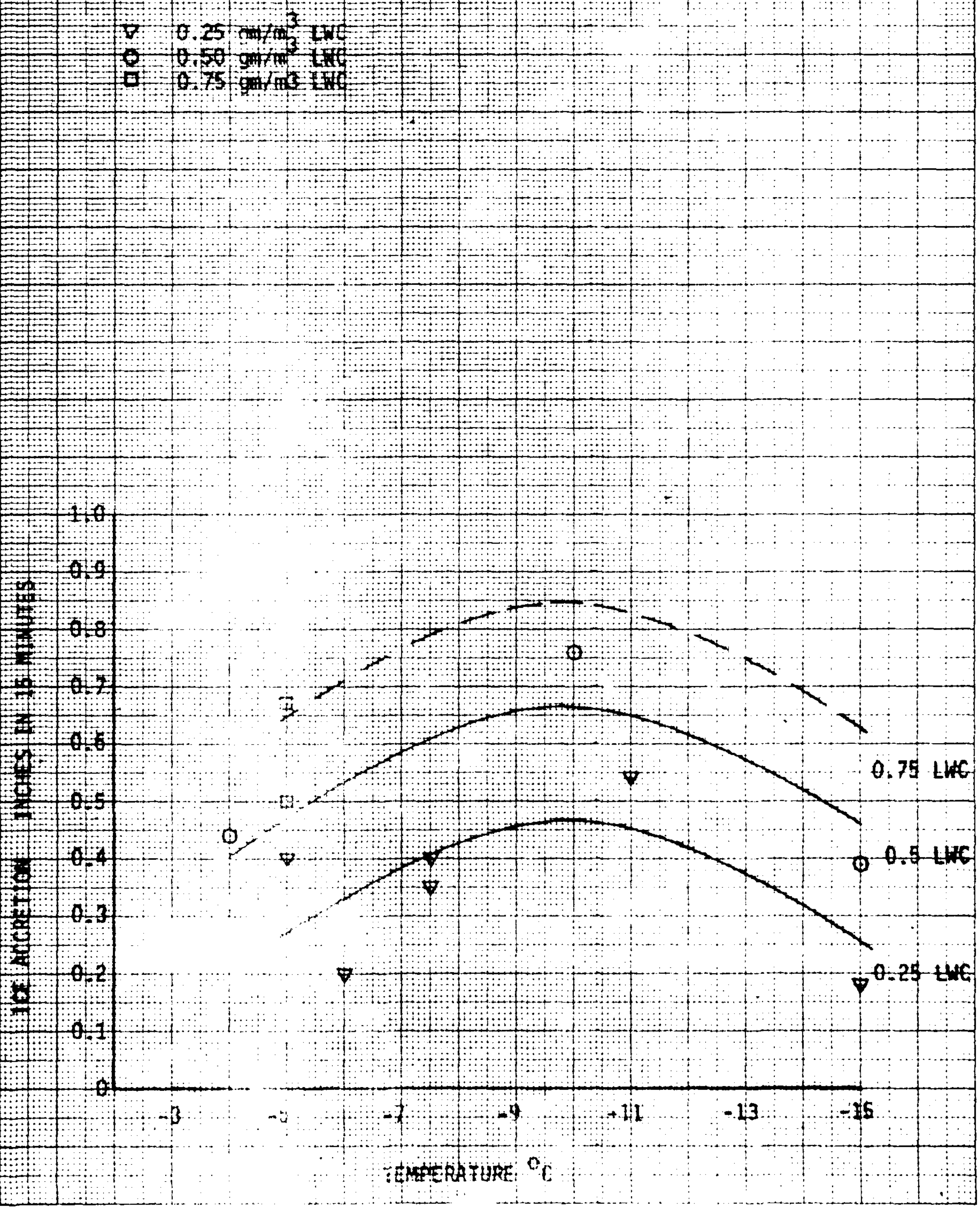
FUEL VENT BLOCKAGE

20. During flight in natural icing conditions, crew members in the aft cabin observed ice accretion on some of the auxiliary fuel tank air vents. The first natural

FIGURE 1

AVERAGE ICE ACCRETION RATE

1. DATA WERE TAKEN FROM TABLES 1 AND 2 AND REFLECT ICING RATE VS TIME.
2. TEST CONDITIONS INCLUDE NATURAL AND ARTIFICIAL ICING ENVIRONMENT WITH BOTH PROTECTED AND UNPROTECTED SYSTEM OPERATION.



ice flight was terminated after approximately one hour in icing conditions due to blockage of visible auxiliary fuel tank vents. Post flight inspection revealed ice blockage of all fuel vents, the battery vent, and the cabin heater fuel drain. Photographs 4 through 6 app E show the ice blocked fuel and battery vents. Partial or total vent blockage was observed on all flights in natural icing conditions. Information from the contractor on the blocked fuel vents was that blockage of the main tank fuel vent was more critical than that of the auxiliary tank, but that any fuel vent blockage could create a vacuum and may cause fuel cell collapse. This could result in internal structural damage to mounting points and support structure. Ice accretion and subsequent blockage of the fuel vents is a deficiency for flight in icing conditions. Blockage of the battery vent which could cause a back up of battery overflow and chemical burn damage to the battery compartment, is a shortcoming. Ice blockage of the cabin heater fuel drain could cause fuel pooling in the combustion chamber following heater failure or shutdown and create a fire hazard if a restart were attempted. The cabin heater fuel drain accreteing ice and becoming blocked is a shortcoming for flight in icing conditions. The following caution should be added to the operator's manual:

CAUTION

> If cabin heater fails or is shut down after flight in icing conditions, do not attempt a restart until it has been determined that the cabin heater fuel drain is not blocked.

ENGINE ANTI-ICE

21. The test aircraft was equipped with flow bypass engine screens. Theory and ice tunnel tests indicated that the engine screens would ice over rapidly (photo 7, appendix E) causing air flow entering the engines to make two approximately 90° turns, thereby separating water droplets from the air negating a need for engine anti-ice. A deletion of the requirement for engine anti-ice bleed air would result in an increase in power available with associated increase in payload, range, endurance, or power margin for single engine capability. On four subsequent flights all behind the HISS, one or the other engine anti-ice system (not both together) was deactivated to determine if ice would form on the engine inlet. Instrumentation was not available for in flight evaluation with the deactivated anti-ice system. The post flight evaluation was limited by the elapsed time from icing conditions until engine shut down, during which engine heat melted or sublimated accreted ice. Sufficient ice was observed on the engine inlet to indicate that further investigation and testing will be necessary before engine anti-ice can be deleted from the CH-47 helicopters.

WINDSHIELD DEFOG SYSTEM

22. During flight 12, the cockpit defog system's ability to de-ice the windshield was evaluated. In light icing conditions, the copilot's electrical windshield anti-ice system was deactivated and windshield ice allowed to accumulate. After approximately five minutes with the anti-ice system off, the windshield became opaque with a thin layer of ice. After an additional five minutes, the windshield defog system was activated. The defog system cleared the iced windshield in approximately one minute and the

windshield remained clear as long as the defog system was in operation. Windshield wipers were not used. The windshield defog system is an excellent backup for the electrical windshield anti-ice system. The electrical windshield anti-ice system and all other installed de-ice and anti-ice systems (standard equipment) operated satisfactorily.

THRUST CONTROL ROD ADJUSTMENT

23. During ground operations, it was necessary to maintain the thrust control rod above the 3 degree detent to prevent droop-stop pounding. This pounding is caused by a neutrally damped vertical blade oscillation at approximately 1 per rev frequency imposed by the rotor system through the flight controls. On a properly rigged CH-47C with metal rotor blades, placing the thrust control rod below the 3 degree detent or cross controlling the flight controls while on the ground will produce droop stop pounding. The addition of the wider cord fiberglass rotor blades required a one degree adjustment in the pitch change links for proper autorotational rotor speed. The pitch change link adjustment caused a change in the proper detent position for CH-47 helicopters equipped with fiberglass rotor blades. The manufacturer should adjust the thrust control rod detent to preclude droop stop pounding.

CONCLUSIONS

GENERAL

24. Within the scope of this test, the following general conclusions were reached:

a. The prototype rotor blade de-ice system provided excellent rotor blade protection (para 13).

b. Operation of the CH-47C in icing conditions with unheated fiberglass rotor blades appears feasible following correction of the two deficiencies (para 17).

c. Windshield defog is an excellent backup for the electrical windshield anti-ice system (para 22).

d. Two deficiencies and two shortcomings were identified for flight under icing conditions and apply to all CH-47 helicopters regardless of rotor system.

DEFICIENCIES

25. The following deficiencies for flight in icing conditions were identified and are listed in order of decreasing importance:

a. Failure of the droop stops to engage after flight in icing conditions.

b. Ice accretion and subsequent blockage of the fuel vents.

SHORTCOMINGS

26. The following shortcomings for flight in icing conditions were identified and are listed in order of decreasing importance:

a. The cabin heater fuel drain accreteing ice and becoming blocked (para 20).

b. Ice blockage of the battery vent (para 20).

RECOMMENDATIONS

GENERAL

27. Correct the deficiencies prior to releasing the aircraft for flight in icing conditions.

28. Correct the shortcomings as soon as practical.

SPECIFIC

29. Further testing at an expanded range of temperature, liquid water content, and gross weight is required to define an unprotected fiberglass rotor blade icing envelop (para 17).

30. The following caution should be placed in the Operator's Manual (para 20):

> If heater fails or is shut down after flight in icing conditions, do not attemp a restart until it has been determined that the heater fuel drain is not blocked.

31. When fiberglass rotor blades are installed the thrust control rod detent should be adjusted to alleviate droop stop pounding (para 23).

APPENDIX A. REFERENCES

1. Letter, AVRADCOM, DRDAV-EQ, 5 October 1978, Subject: Artificial Icing Tests of the JCH-47C Helicopter with Fiberglass Rotor Blades, AVRADCOM Test Request, Project No. 78-18.

2. Test Plan, USAAEFA, Project No. 78-18, *Artificial Icing Test CH-47C Helicopter with Fiberglass Rotor Blades*, January 1979.

3. Technical Manual, TM-55-1520-227-10-2, *Operator's Manual, Army CH-47C Helicopter*, 23 August 1978.

4. Letter, AVRADCOM, DRDAV-EQ, 19 January 1979, Subject: Airworthiness Release for CH-47C Helicopter, S/N 74-22287 with Fiberglass Rotor Blades, USAAVRADCOM/USAAEFA Project No. 78-18.

5. Final Report, USAAEFA, Project No. 75-04, *Modified Helicopter Icing Spray System Evaluation*, March 1977.

6. Final Report, USAAEFA, Project No. 73-04-1, *Artificial Icing Tests, CH-47C Helicopter*, August 1974.

7. Field Manual, FM 1-30, *Meteorology for Army Aviators*, 31 May 1976.

8. Army Regulation, AR310-25, *Dictionary of United States Army Terms (Short Title: AD)*, 1 March 1969.

APPENDIX B. DESCRIPTION

TEST AIRCRAFT

General

1. The test helicopter was a standard CH-47C with the following modifications:

a. Fiberglass Rotor Blades conforming to Part Number 114R1702, in lieu of standard metal blades.

b. Calibrated/instrumented T55-L-712 engines.

c. Cockpit self-tuning vibration absorbers tuned at 220 to 240 rpm with mass increased to 95 pounds.

d. Aft pylon fixed tune vibration absorbers removed.

e. Forward transmission cover actuator mount lugs bored and shot peened.

f. Modified swiveling actuator lower mount bearing and attachment hardware.

g. Rotor hub assembly lighting protection provisions.

h. Emergency power system and revised engine start switch.

i. The Longitudinal Cyclic Speed Trim System (LCT) was modified to provide altitude bias to the aft LCT actuator similar to that already provided to the forward LCT actuator.

j. Rotor blade de-ice system installed.

k. Instrumentation package installed.

2. Photographs 1 and 2 show the CH-47C with fiberglass rotor blades and the intake and exhaust ports for the prototype de-ice system generator. The following general aircraft information is presented:

General Aircraft Information

Dimensions:

Length (Fuselage)	51 ft
Length (rotor blades turning)	99 ft
Height (over rotor blades at rest)	18 ft, 8 in.
Width of cabin	9 ft
Tread (forward gear)	10 ft, 6 in.
Tread (aft gear)	11 ft, 2 in.
Width (rotor blades turning)	60 ft

Photo 1. CH-47C with View of De-ice System Generator Inlet and Exhaust Ports.

Photo2. CH-47C with View of De-ice System Generator Inlet and Exhaust Ports.

Weight Data:

Empty weight (specification)	21,722 lb
Design gross weight	33,000 lb
Alternate design gross weight	46,000 lb

Center-of-Gravity:

3. Center-of-gravity limits for this test were expanded from the standard CH-47 C limits and are shown in figure 1.

Center-of-gravity reference	FS 331.0 (centerline between rotors)
Forward limit (from cg reference)	21.0 in. forward (28,550 lb and below)
Aft limit (from cg reference)	18.0 in. aft (28,550 lb and below)

T55-L-712 Engine:

Emergency power	4500 shp
Maximum power	3750 shp
Military rated power	3400 shp
Normal rated power	3000 shp

Areas:

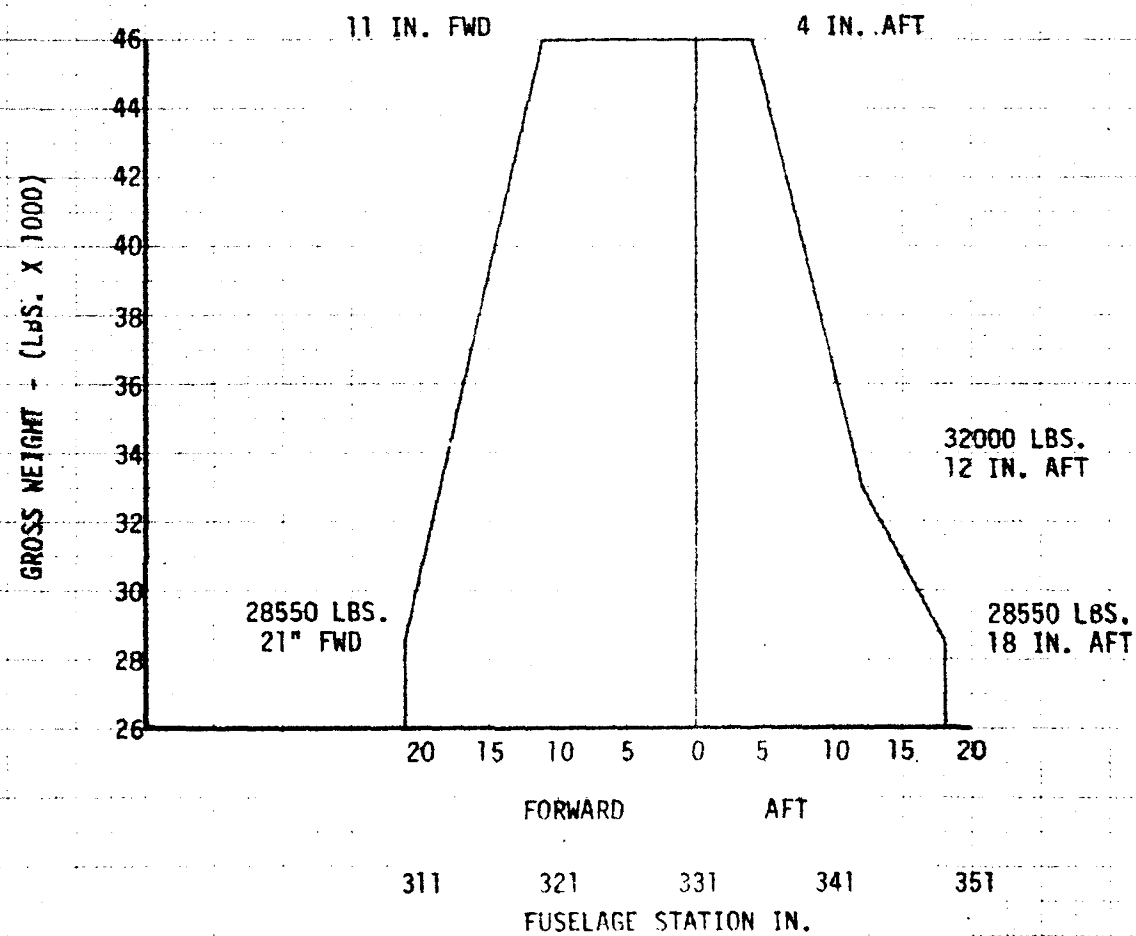
Rotor blade area (6 at 80 sq ft)	480 sq ft
Projected disc area	5000 sq ft
Swept disc area (2 rotors at 2827 sq ft used in performance calculations)	5654 sq ft
Geometric solidity ratio	0.085
Sail area (cross-section area of aircraft at butt line zero)	487 sq ft

Dimensions and General Data:

Rotor spacing (distance between center line of rotors)	39 ft, 2 in.
Sail area centroid	FS 367.5 water line 28.6
Rotor blade clearance:	
Ground to tip (forward rotor static)	7 ft, 10.6 in.
Leading edge of aft pylon to forward rotor blade tip (rotor blade static)	16.7 in.
Leading edge of aft pylon to forward rotor blade tip (rotor turning)	40 in.
Rotor Data:	
Power loading at alternate design gross weight (46,000/6,000)	7.67 lb/hp
Blade droop stop angle:	
Aft rotor	1.5 deg

FIGURE 1

CH-47C FRB
GROSS WEIGHT/CENTER OF GRAVITY DIAGRAM



Forward rotor	4.75 deg
Blade coning (stop angle)	30 deg
Blade twist (centerline of rotor to tip)	-12 deg (fig. 1)
Rotor diameter	60.0 ft
Rotor speed normal operation	225 rpm
Power ON maximum	240 rpm
Power OFF maximum	245 rpm
Power ON or OFF minumum	212 rpm
Number of blades (each rotor)	3
Airfoil section designation and thickness	VR-7 to 85% radius tapered to VR-8 at tip (fig. 2)
Aerodynamic chord (root and tip)	32.00 in.

General Flight Control Description

4. The flight control system is irreversible and is powered by two independent hydraulic boost systems, each operating at a 3000-psi pressure. Operation of the helicopter is not possible unless one of the boost systems is in operation.

Control Surfaces:

5. The movable control surfaces consist of six main rotor blades, three mounted on each rotor head. The forward and aft rotor heads are in tandem along the longitudinal axis of the helicopter. The forward rotor blades are individually interchangeable and the aft rotor blades are individually interchangeable. The rotor heads are fully articulated, which permits blade movement about the pitch, flap, and lead/lag axes.

6. The fiberglass rotor blade radius is 30 feet, with a blade chord of 32 inches. The planform is constant-chord between blade station 97 and 360; from blade station 97 inboard it transitions to a circular root end section. The airfoil is changed from the metal blades (23010 airfoil) of the B and C models; the fiberglass blades have a 12% thick VR-7 airfoil out to the 85% radius, tapering uniformly to an 8% thick VR-8 airfoil at the tip. The twist is -12 degrees. The blade is designed to operate at a constant 225 rpm. Structurally, the blade has a composite D-spar with a precured heel covered by a titanium cap and, on the outer 30% of radius, a replaceable nickel erosion cap. The aft section of the blade is Nomex honeycomb covered with a glass fiber skin cross-plied at 45 degrees to the longitudinal axis of the blade. The root of the blade is formed of unidirectional glass fiber straps wrapped around the root fitting. The blade nose block has a balance weight; at the tip there is a set of removable tungsten tracking weights accessed through a bolted-on coverplate. A diagram of the blade is presented in figure 2.

FIBERGLASS ROTOR BLADE DE-ICE SYSTEM

General

7. The test CH-47C SN 74-22287 was equipped by Boeing-Vertol with fiberglass rotor blades with integral de-ice blankets. The electrical power and control system for de-icing the blades was a prototype configuration not representative of a production system, completely seperate from the aircraft electrical system. Photos 3 through 7 show the components of the fiberglass rotor blade de-ice system. The

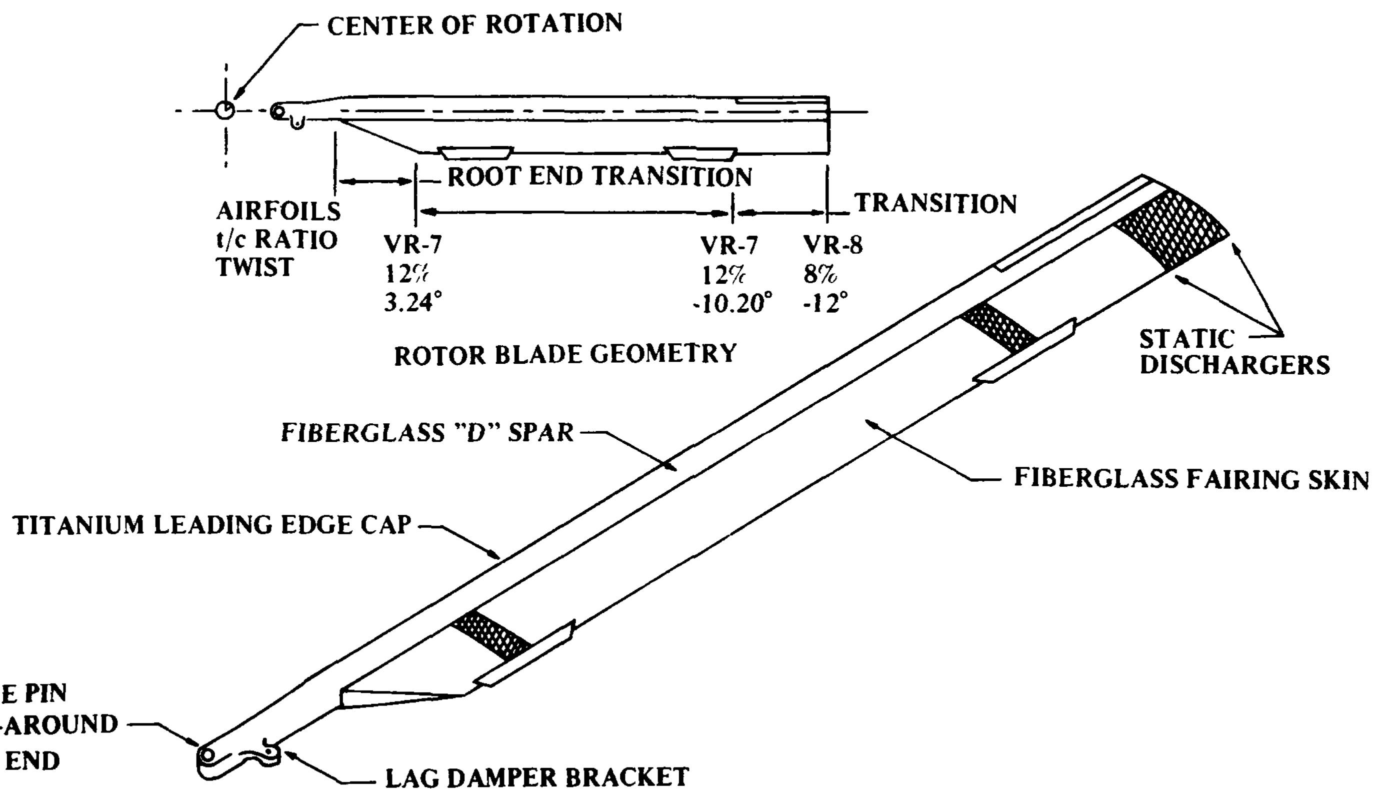


Figure 2. CH-47C Fiberglass Rotor Blade.

system consisted of the following elements:

a. Fiberglass rotor blades with integral electrical de-icing blankets.

b. Cabin mounted gas turbine driven generator.

c. Cabin installed, pallet mounted system control and power distribution elements.

d. Hub mounted power distribution elements.

e. Forward and aft pylon mounted ice detectors.

f. Fuselage mounted heated OAT sensor.

g. Cockpit display and controls.

Detailed Description

Fiberglass Rotor Blade:

8. The FRB incorporates an integral 6 element electrical de-icing blanket (see fig. 3). Blanket coverage extends for the full length of the titanium leading edge cap and provides for de-icing capability over 3.53 inches (11% of chord) from the leading edge of the upper surface and 7.37 inches (23% of chord) from the leading edge on the lower surface. The Goodrich Company manufactured etched metal foil electrothermal heating elements start at blade Sta. 88.0 and extend to blade Sta. 356.0 for a total length of 268.0 $\pm$ 0.25 inches. The de-icing blanket consists of 6 spanwise oriented heating elements and 2 return leads. Heating elements and return leads are braided copper and are positioned by means of attachment to a light carrier material impregnated with resin to ensure sound bonding when cured into the leading edge assembly. Blanket braids are butt spliced to the blade cable assembly at the root end, laid into the root end slot and covered over with epoxy filler. The blade cable assembly connector is attached to the lag damper bracket. The blanket provides 27 watts/in^2 with 195 Vrms, 400 Hz power supplied by the generator system. 13,869 watts per element on all three blades on one head are applied simultaneously.

Gas Turbine Driven Generator Set:

9. The cabin mounted, gas turbine driven generator set (FSN6115-075-1639 Air Research Model GTGE70-6-1) provided the source for blade de-ice electrical power (photo 3). The unit was intended for landing station ground support and was skid mounted. It was rated at 45KW at 120/208V, 3 phase, 4 wire to the system control and power distribution panel. The generator was installed between Sta. 360 and Sta. 440 and restrained in all axis by means of standard cargo tiedowns. The gas turbine air inlet was provided through two flexible inlet ducts mounted between a plenum added over the generator set inlet and two right hand side cabin windows. Gas turbine exhaust routing was through a stainless steel duct connected between the generator set exhausts and an aft right hand cabin window. Inlet leading edge fences were provided to minimize water and debris ingestion. The generator set fuel supply was provided from the left aux fuel tanks from a dip tube added at an existing fuel cell access hole. A breakaway filter was provided at the tank exit. A fuel shut off valve was provided in the tubing run to the generator set fuel inlet.

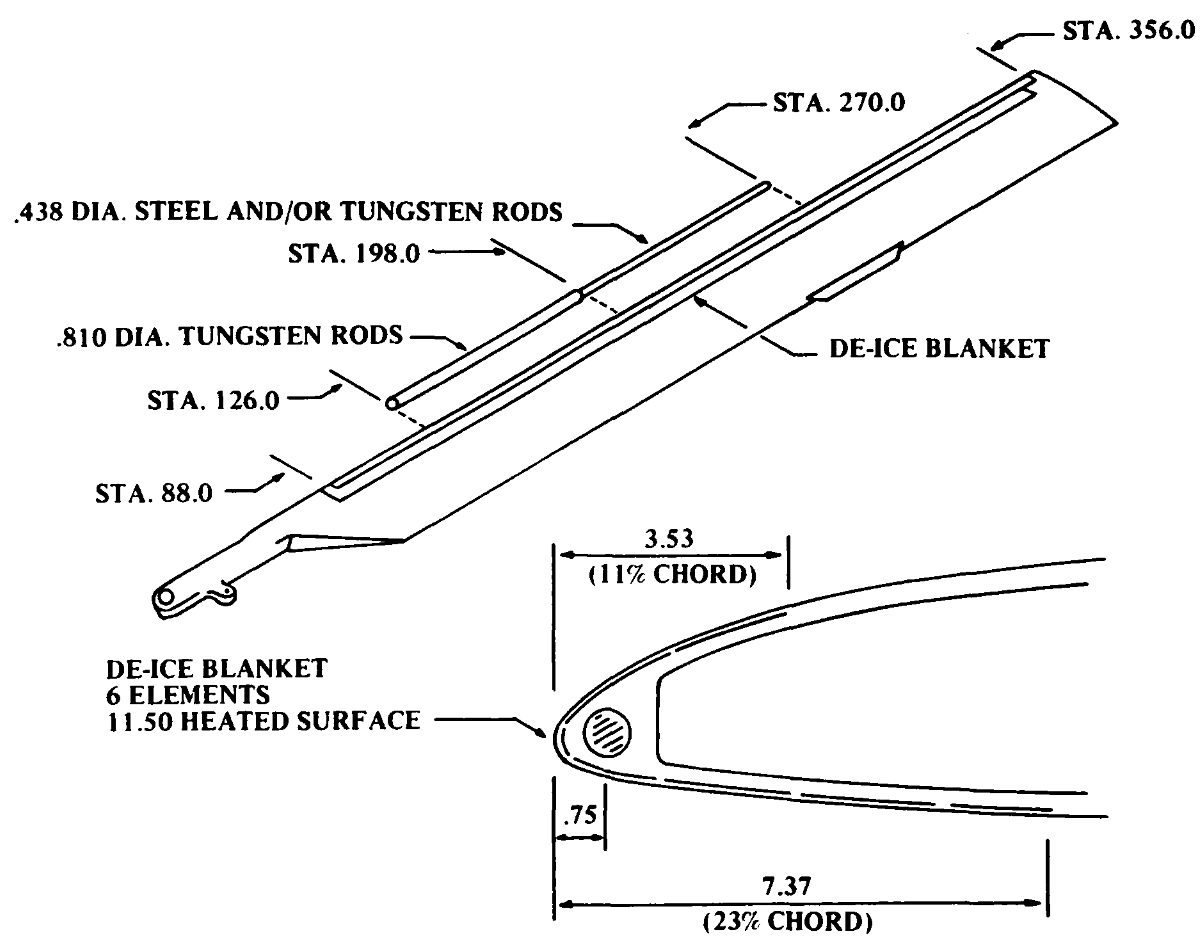


Figure 3. CH-47 C Fiberglass Rotor Blade De-Ice Blanket.

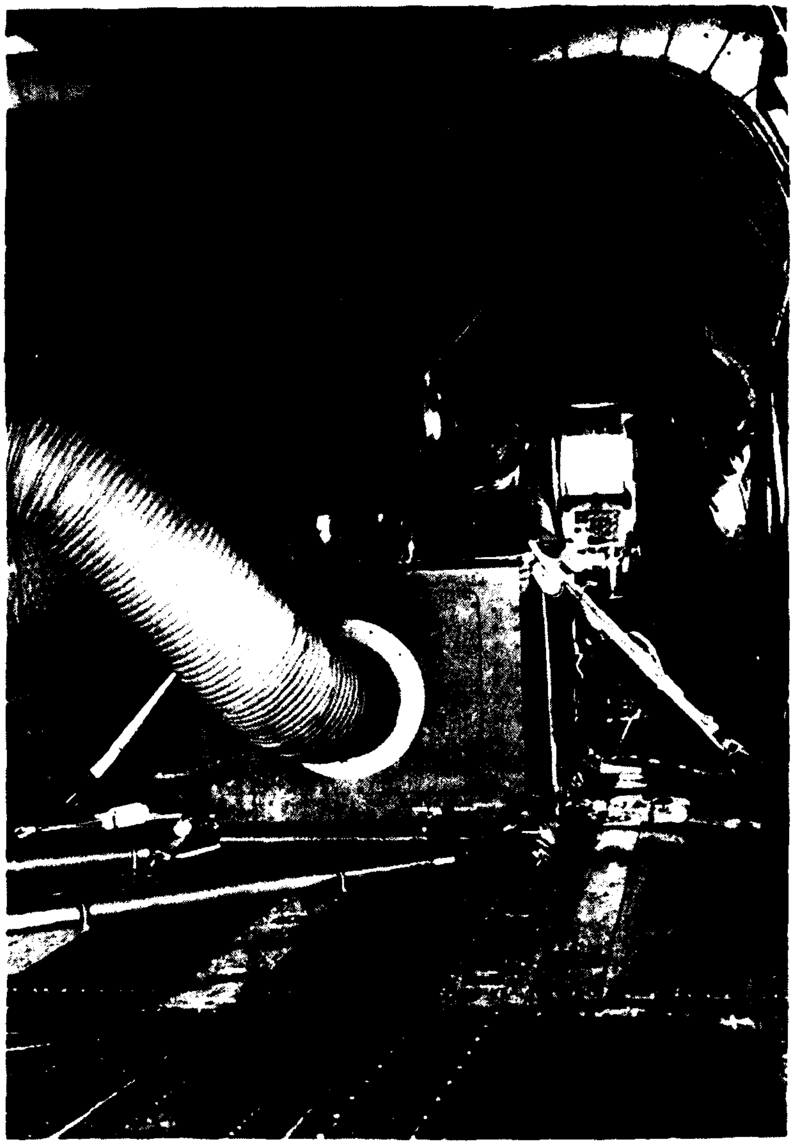


Photo 3. De-ice System Generator Installation.

System Control and Power Distribution Elements:

10. The de-ice system control and power distribution system was contained on a 3' x 5' pallet. The pallet was floor mounted between station 260 and 320 (photo 4). The basic system components mounted on the pallet included the controller, pulse counter and test box as well as auxiliary control switches and relays. The controller (B/V, P/N A02ES125-14) was supplied with both 115/200 volt AC and 28 VDC power. When a 28 VDC positive ice signal was received from the pulse counter, 200V, 400 hertz, 3 Ø power was pulsed to the rotor blade heating elements. The 1st through 6th, 200 VAC pulses were fed to the fwd rotor power transfer unit. The 7th through 12th 200 VAC pulses were fed to the aft rotor power transfer unit. The controller always returned to the No. 1 position unless the system shut down during operation. The system OAT temperature sensor resistance unbalanced an internal bridge and determined the length of time each heater element would be energized. This time could be adjusted by means of the pulse on-time adjustment resistor. A dummy temperature sensor resistance was connected for ground test purposes and gave a simulated signal approximately equal to temperature of 30°F when the test switch was placed in the test position. The pulse counter (B/V, P/N A02ES172-1) received and counted the ice detector probe signals from the selected probe only. The third signal received was transferred to the controller to provide it with a 28 VDC positive ice signal. The test box (BV, P/N SK27789-1) was installed to provide a method for using the de-ice controller and to provide indicating lights for observation of system operation. The controller output pulses were connected to the test box for balanced loading while also being connnected to relays for control of the 200 VAC power to the blade de-ice distributors.

Hub Mounted Power Distribution Elements:

11. Power conducted from the cabin mounted elements through the fwd and aft transmission shaft standpipes was transferred to the rotating system by means of a standpipe mounted 4 brush slip ring. The slip ring provided power to a power distributor, A02ES125 which supplies power to each individual blade blanket through appropriate cabling. The slip ring and distributors were mounted within a closed aluminum cover to provide environmental protection (photo 5).

Ice Detection:

12. Ice detection was provided for the system through either the fwd pylon or aft pylon mounted Rosemount ice detectors (photos 5 and 6). Selection of the desired detector was by means of pallet-mounted selector switch. Ice detectors were located in pylon areas chosen (based on air flow and review of previous test data) to provide required icing correlation. The forward ice detector was located on the right side of the forward pylon at W.L.58, approximately 4 inches from the leading edge of the fairing (photo 5).

OAT Sensor:

13. OAT sensing was provided from an OAT sensor located on the right lower fuselage approximately Sta. 95 forward of the fwd left gear. It provided the signal to the system control which determined the length of time each individual heater element was energized.

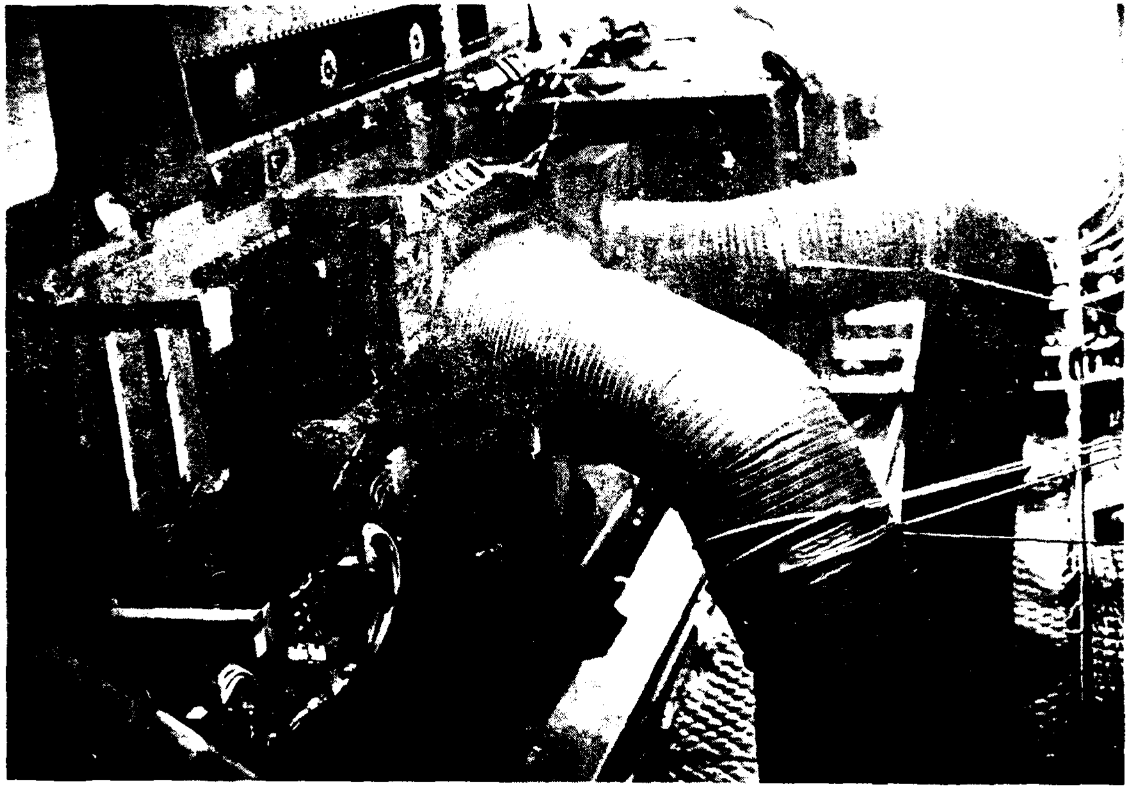


Photo 4. De-ice System Monitor and Control Pallet.

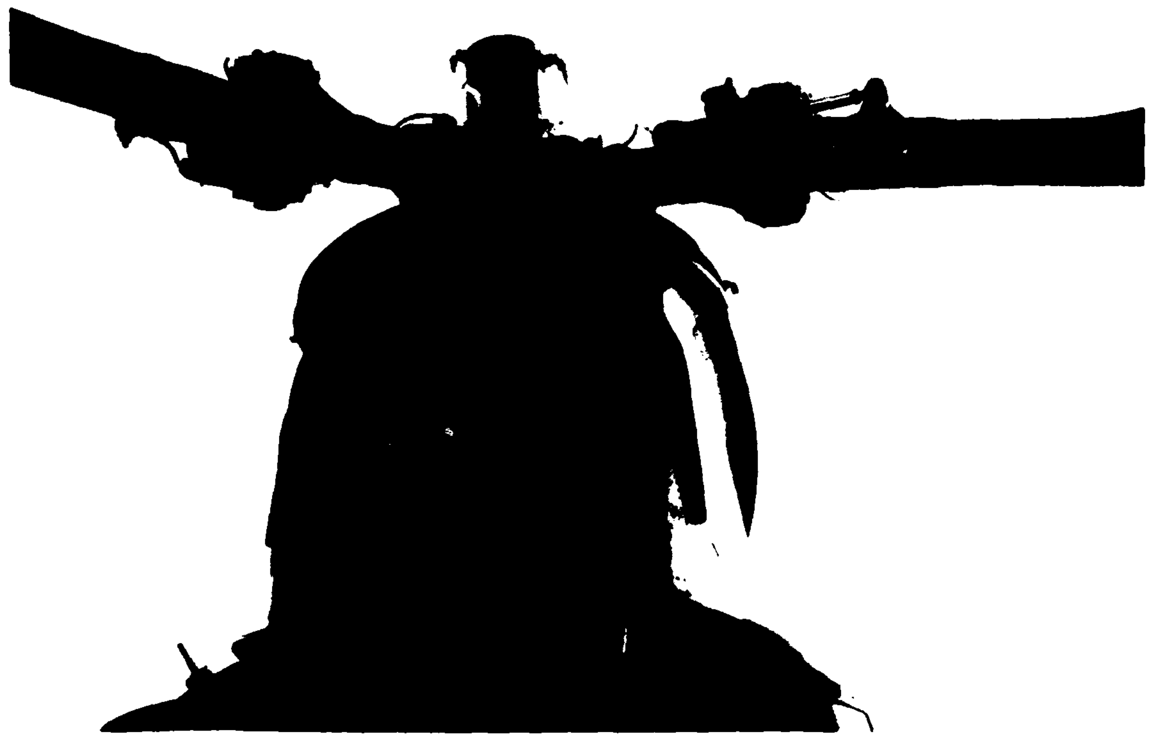


Photo 5. Forward Pylon Ice Detector.

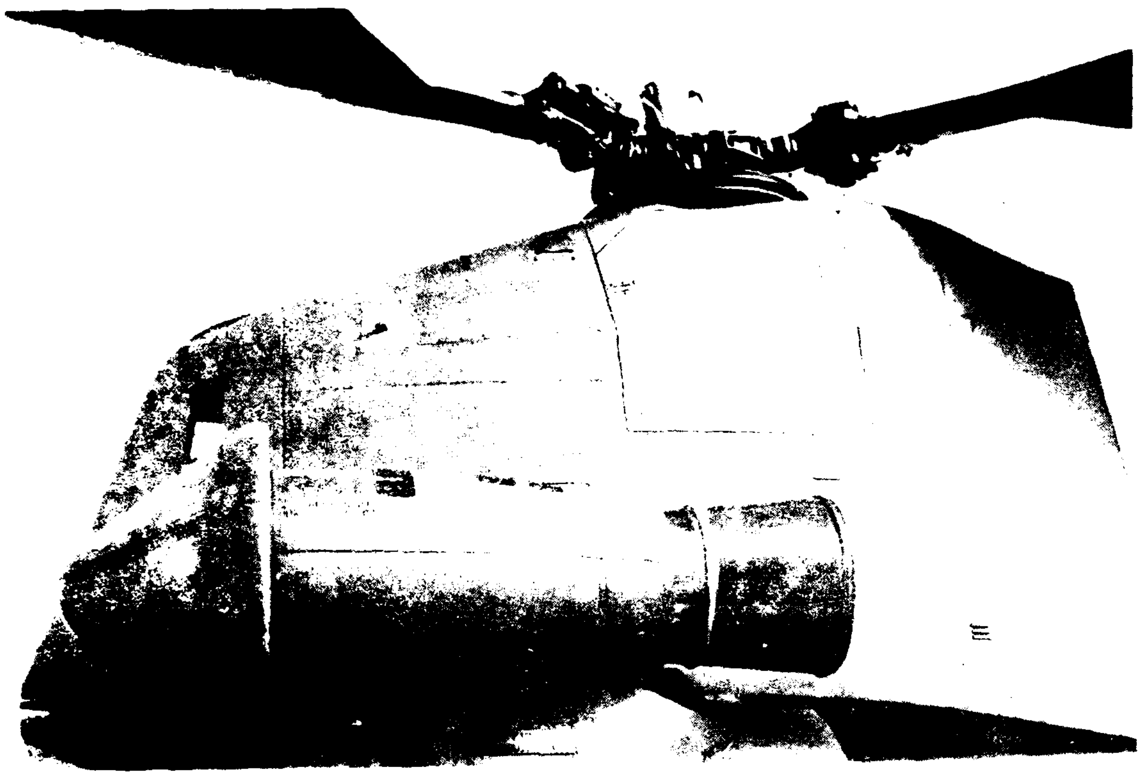


Photo 6. Aft Pylon Ice Detector.

Cockpit Displays and Controls:

14. Cockpit displays and controls included de-ice auto/manual select switch, auxilary power unit (APU), fuel shut off, APU fire bottle discharge switch, Rosemount ice accretion indicator and advisory lights to indicate: power on, ice detect (selected head), de-ice cycle start, de-ice cycle complete, and individual rotor system de-ice cycle pulses. System circuit breakers were also mounted in the cockpit (photo 7).

HELICOPTER ICING SPRAY SYSTEM (HISS) DESCRIPTION

15. The HISS is installed in a CH-47C aircraft. The icing spray system equipment consists of a spray boom, boom supports, boom hydraulic actuators, an 1800-gallon unpressurized water tank, and operator control equipment (fig. 4). The spray boom consists of two 27-foot center sections and two 16.5-foot outer sections. The total weight of the system is approximately 4700 pounds empty. With the boom fully extended, the upper center section is located in a horizontal plane 17 feet below the aircraft and the lower center section 20 feet below. The booms are jettisonable and the water supply (1800 gallons) can be dumped in approximately 10 seconds with the boom in any position. A total of 172 nozzle locations are provided on the spray boom. A bleed air supply from the aircraft engines is used to atomize the water at the nozzles. For a detailed description of the icing spray system, see reference 5, appendix A.

16. The LWC and water droplet size distribution of the spray cloud are controlled by varying the water flow rate and the distance of the test aircraft behind the spray aircraft. Controls and indicators for the water flow rate and bleed air pressure are located on the water supply tank. A radar altimeter is mounted in the rear cargo door opening of the CH-47C and is directed aft. The distance between the test and spray aircraft is measured by the radar altimeter and the information is presented in the spray aircraft cockpit. The methods used to establish the desired LWC are contained in reference 5, appendix A.

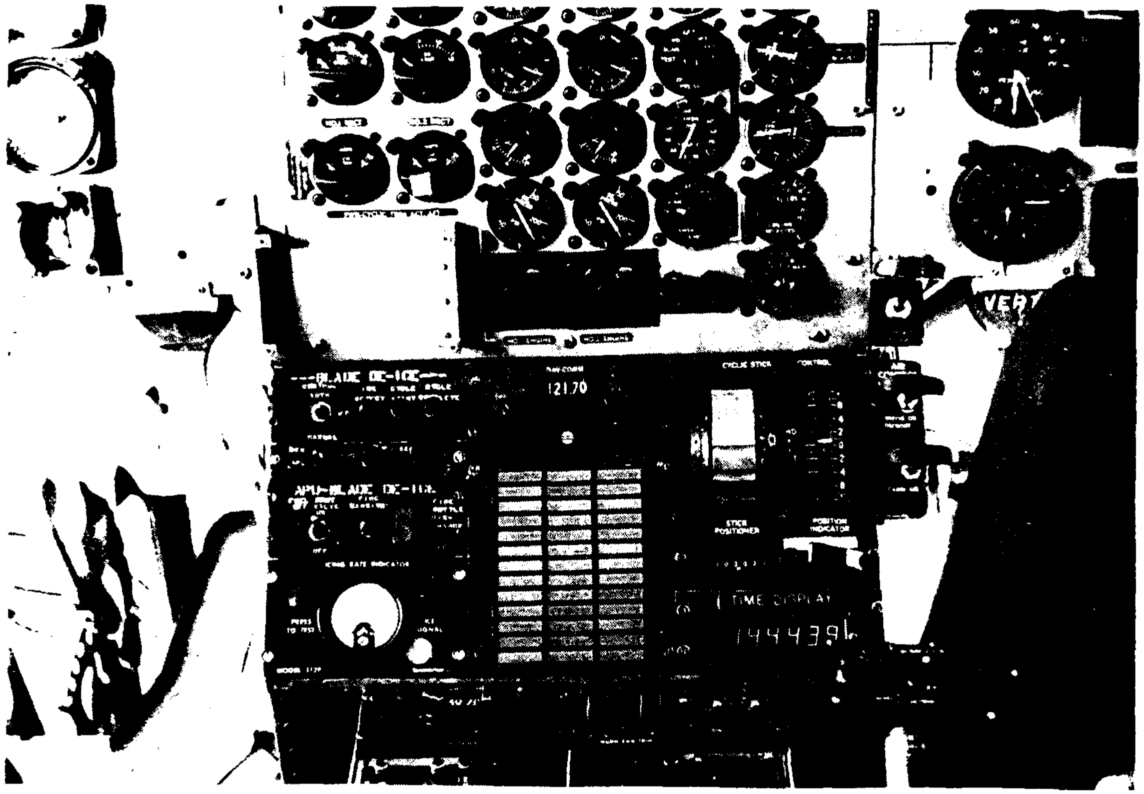


Photo 7. Cockpit De-ice System Display and Control Panel.

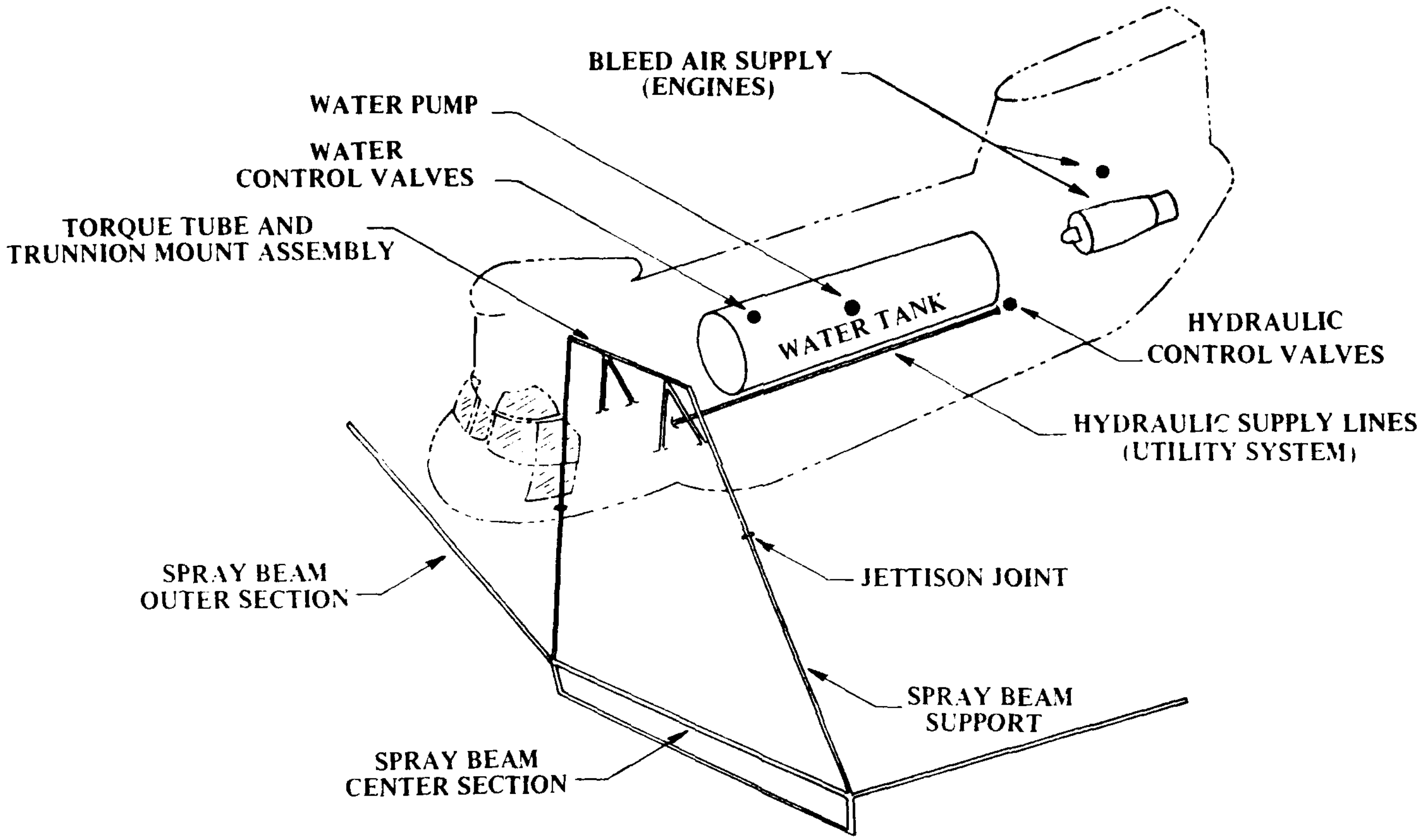


Figure 4. Helicopter Icing Spray System Schematic.

APPENDIX C. INSTRUMENTATION AND SPECIAL EQUIPMENT

INSTRUMENTATION

1. In addition to, or instead of standard aircraft instruments, calibrated test instrumentation was installed aboard the test aircraft. This instrumentation was installed and maintained by the contractor. Data were recorded by hand from cockpit instruments and on magnetic tape. Photograph 1 shows the instrumentation package on board the test aircraft.

2. The calibrated test instrumentation used during this program are contained in the following:

Pilot Station

Airspeed (prod)
Altitude (prod)
Free air temperature (prod)
Rate of climb (prod)
Rotor rpm (test)
Engine torque (both engines) (prod)
Engine turbine inlet temperature (both engines) (prod)
Engine N_1 (both engines) (prod)
Collective control position
Event switch
Instrumentation controls
Time of day
Run number
Icing rate
De-ice system operation indicator lights

De-icing Engineer Station

Ice detector select switch
De-ice system operation indicator lights
Run number

Tape Recorded Parameters

Airspeed
Altitude
Free air temperature
Rotor speed (test)
Rate of climb
Engine torque (both engines)
Engine N_1 (both engines)
Collective control position
Time
Run number
Pitch attitude

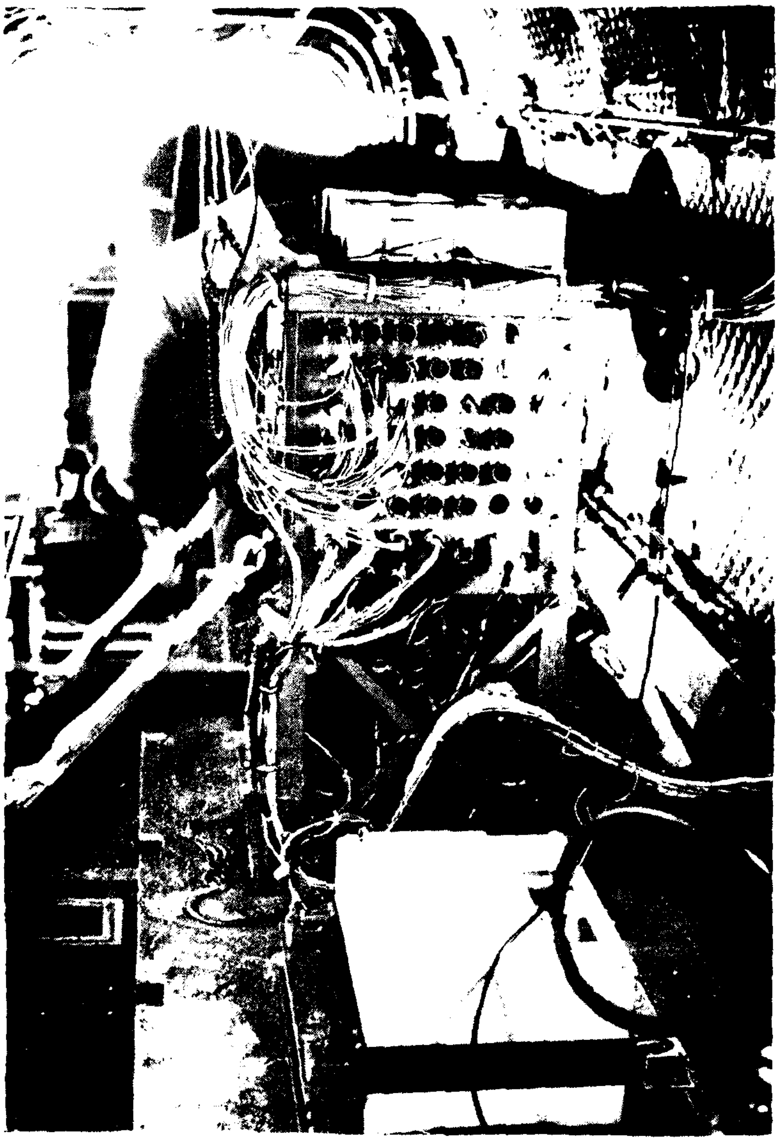


Photo 1. Instrumentation Package with Tape Recorder.

Vibration
  Station 95 vertical accelerometer
    Lateral accelerometer
    Longitudinal accelerometer
  Station 360 vertical accelerometer
    Lateral accelerometer
    Longitudinal accelerometer
Rotor de-ice voltage phase A
Rotor de-ice voltage phase B
Rotor de-ice voltage phase C
Rotor de-ice current phase A
Rotor de-ice current phase B
Rotor de-ice current phase C
Forward fixed link load
Aft fixed link load
Icing rate (front left probe)
Probe de-ice cycle on time (all probes)

SPECIAL EQUIPMENT

Ice Detector System

3. Three Rosemount 871FA121 ice detectors were installed on the test aircraft as described in appendix B. The detector on the left side of the forward pylon was utilized as the icing rate indicator in the cockpit, providing a continuous readout of icing rate in terms of T, L, M and H. It was also recorded by the data system as a record of actual icing rate and accumulation. This detector's (SN 021) calibration indicated that it de-iced (cycled) after an accumulation of 0.037 inches of ice. The other forward pylon detector and the aft pylon detector were utilized by the rotor blade de-ice system. The forward detector de-iced after an accumulation of 0.039 inches and the aft detector after an accumulation of 0.020 inches of ice. Either of these detectors could be selected by the engineer to activate the blade de-ice system. A light in the cockpit indicated each de-ice cycle of the detector selected to run the system. The de-ice cycle from both forward and aft detectors were recorded. Either location, forward or aft, was acceptable to initiate operation of the de-ice system. While operating in a natural icing environment the frequency of operation of the detectors was compatible with their respective calibrations.

Blade De-ice System

4. The blade de-ice system is described in appendix B. The operation of the rotor blade de-ice system and power requirements were recorded by the data system and displayed on indicator at the de-ice system engineer station.

Cockpit Display

5. The cockpit display consisted of indicator lights, icing rate meter, and controls as listed in appendix B. The indicator lights illuminated for vaious functions including: selected detector de-ice cycle, rate detector de-ice cycle, blade de-ice cycle START, blade de-ice cycle COMPLETE, pulse to the forward, and aft rotor head. Switches in the cockpit allowed the selection of automatic or manual cycling

of the de-ice system and actuation of the APU fire extinguisher.

Reading	LWC (Gm/m^3)
T	.22
L	.53
M	1.05
H	2.10

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. The CH-47C fiberglass rotor blade de-ice system was a prototype installation. It was designed to demonstrate the feasibility of a fiberglass rotor blade with de-ice capability on the CH-47 aircraft. A CH-47C with metal rotor blades was tested in an artificial icing environment (ref. 6, app A). The CH-47C FRB icing test program was divided into two phases. The first phase (protected rotor blades), was conducted in the artificial icing environment with the de-ice system operational and functioning. The second phase was conducted with the de-ice system operational as a back-up and was flown in both the artificial and natural icing environment.

2. All test flights in phase 1, protected rotor blades, were flown behind the Helicopter Icing Spray System (HISS). All anti-ice and de-ice systems to be tested were turned on while enroute to the test area. Level flight characteristics were recorded to provide baseline data. When the HISS was established at the target free air temperature, airspeed, and LWC, the test aircraft moved into the spray cloud from below and approximately 200 feet behind the spray aircraft. Distance from the HISS was determined by the HISS's aft-facing radar altimeter and relayed to the crew of the test aircraft. The test pilot used this data to maintain a distance of 180 to 200 feet seperation. Additional records were made when the aircraft was stabilized in the cloud. The aircraft remained in the cloud until the HISS water supply was exhausted. When the test aircraft exited the cloud, another record was taken of level flight characteristics. On landing, photographs and a physical record of all ice buildup were made.

3. Phase 2, unprotected rotor blade testing, was flown in both the aritificial and natural icing environment. The procedures behind the HISS (artificial ice) were the same as those followed for phase 1 testing. The tests flown in the natural icing environment were conducted into known or predicted icing conditions. The test aircraft would file for instrument flight and remain under positive control of the St. Paul approach control (APC). Chase would monitor the flight in visual flight conditions below the overcast or remain on standby at the St. Paul Airport. The test aircraft remained in icing conditions for one hour or until the fuel tank vents appeared to be nearly blocked. Documentation photographs were taken upon landing at St.Paul Airport.

Ice Accretion

4. Ice accretion was monitored in flight using the Rosemount ice detector mounted in the left side (copilot's side) of the forward pylon. In addition high speed motion pictures were taken of the test aircraft from the chase aircraft during each artificial (HISS) icing test.

5. Ice accretion was documented with postflight photographs and physical measurements of the ice remaining on individual components of the airframe and rotor.

6. Average ice accretion in a 15 minute period was determined using data recorded from the three ice detectors. Using the known ice buildup required to initiate the detector's de-ice cycle, and measuring the time between detector de-ice cycles, the average accumulation per 15 minutes was determined.

Base Line Data

7. Base line data were obtained during trim level flight at the test airspeed, altitude and free air temperature, established by the HISS. Data were recorded before icing the test aircraft and again after icing was completed. A true airspeed of 90 KTAS was used throughout artificial icing and airspeed was varied 80-130 KCAS in natural icing conditions.

Weight and Balance

8. The weight and balance of the test aircraft were determined by weighing the aircraft at the Boeing Vertol plant after all airframe modifications and instrumentation changes were completed. Modifications in loading were subsequently calculated as they occurred.

HISS Flow Rate Calculation Method

9. Water flow rate of the HISS, to establish the desired icing severity level for each test flight, was determined by using the technique described in reference 5, appendix A, "Modified Helicopter Icing Spray System Evaulation" USAAEFA Project 75-04.

ICING DEFINITIONS AND INTENSITIES

10. Icing characteristics were described using the following definitions of icing types and intensity (ref 7, app A). The icing intensity definitions are those used in global weather forecasting.

a. Icing type definitions:

RIME ICE	Opaque ice formed by the instantaneous freezing of small super cooled water droplets.
CLEAR ICE	Clear or translucent ice formed by the relatively slow freezing of large super cooled water droplets.

b. Icing intensity

TRACE	The presence of ice is perceptible on the airframe and the rate of accretion is low (LWC 0.0 to 0.1 gm/m^3).
LIGHT	Ice accumulation is evident on the aircraft with a rate of accumulation somewhat greater than trace icing (LWC 0.1 to 0.5 gm/m^3).
MODERATE	The rate of accretion of ice on the airframe is noticeable and easily exceeds the rate of sublimation (LWC 0.5 to 1.0 gm/m^3).

11. Results were categorized as deficiencies or shorcomings in accordance with the following definitions (ref 8, app A).

Deficiency: A defect or malfunction discovered during the life cycle of equipment that consitutes a safety hazard to personnel; will result in serious damage to the equipment if operation is continued; indicated improper design or other cause of an item or part, which seriously impairs the equipment's operational capability. A deficiency normally disables or immoblilizes the equipment; and if occurring during test phases, will serve as a bar to type classification action.

Shortcoming: An imperfection or malfunction occurring during the life cycle of equipment, which should be reported and which must be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation, or materially reduce the usability of the material or end product. If occurring during test phases, the shortcoming should be corrected if it can be done without unduly complicating the item or inducing another undesirable characteristic such as increased cost, weight, etc.

APPENDIX E. PHOTOGRAPHS

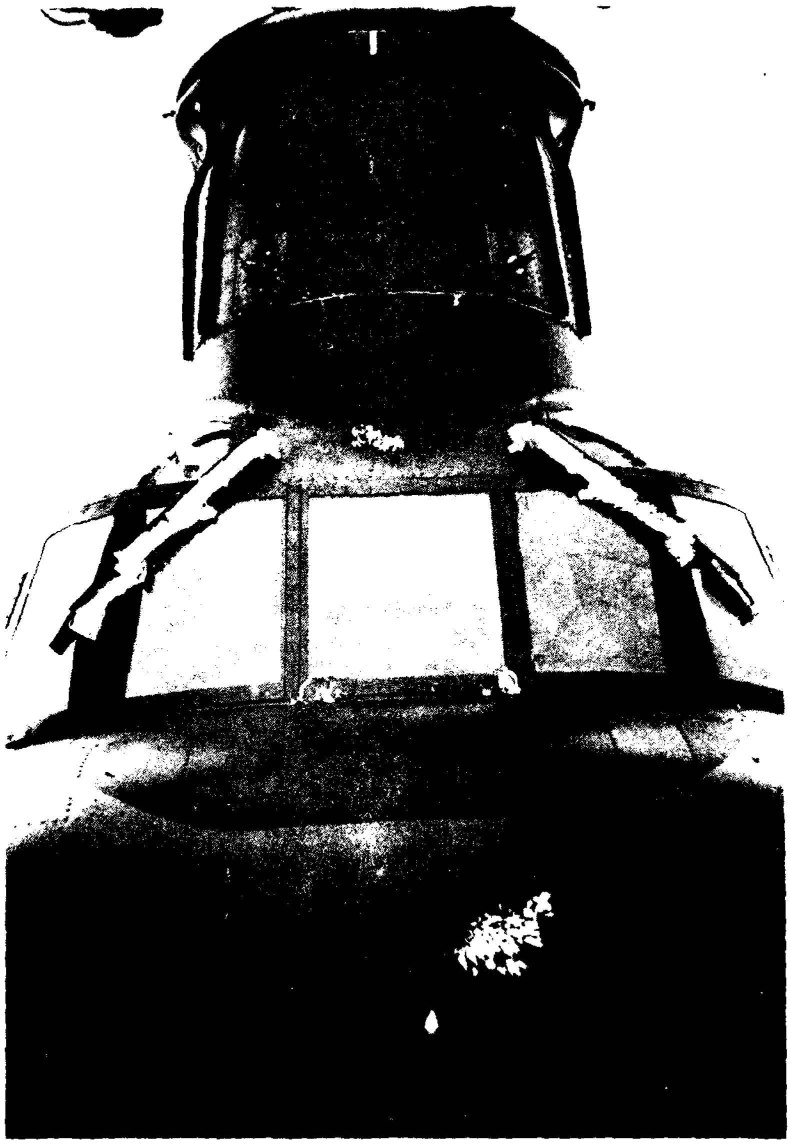


Photo 1. CH-47C Ice Accumulation from Natural Icing Environment.

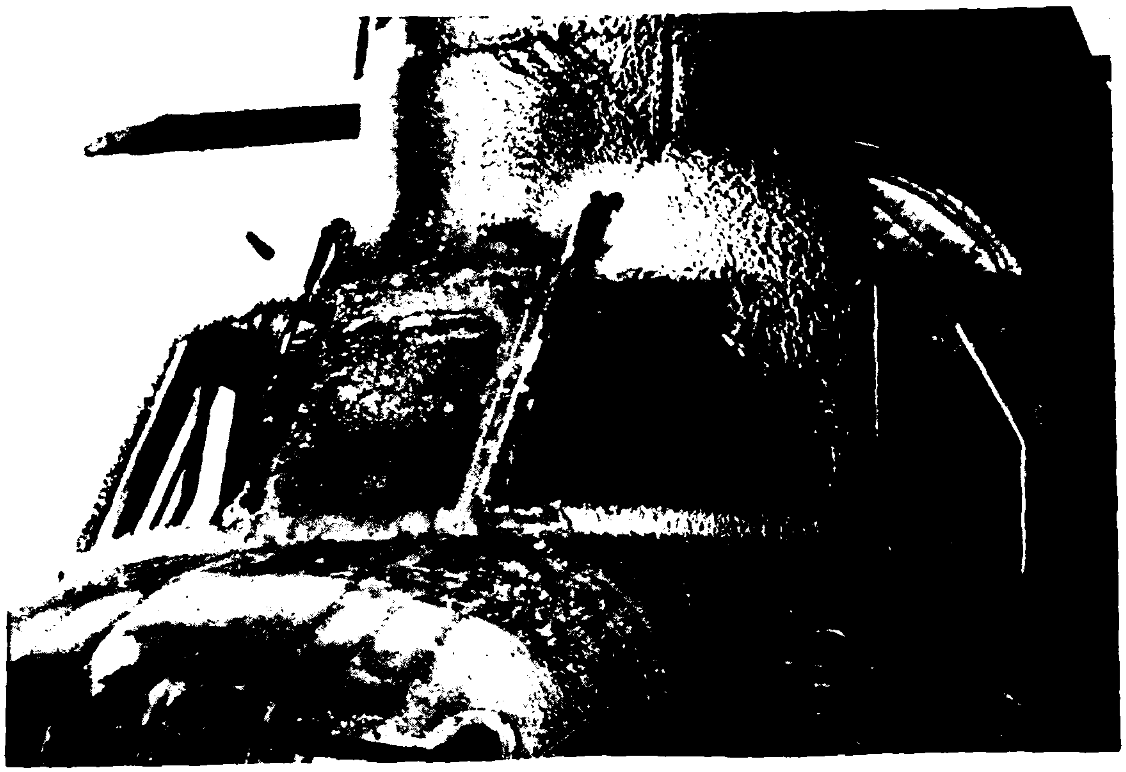


Photo 2. CH-47C Ice Accumulation from Artificial Icing Environment.

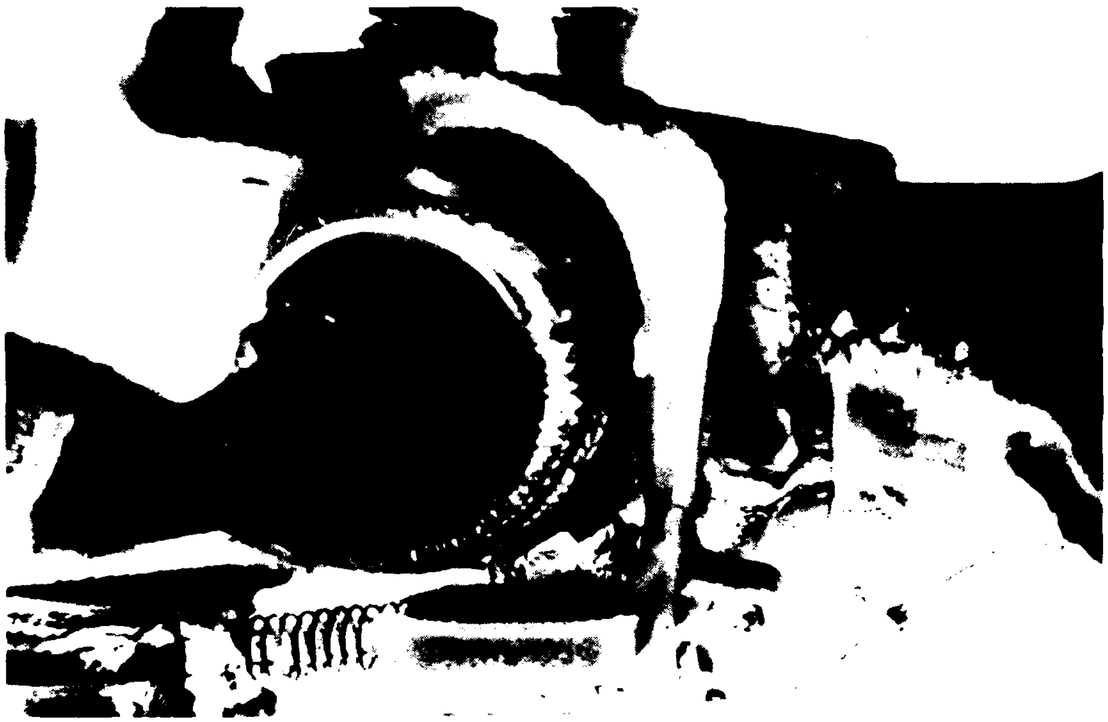


Photo 3. Aft Rotor Droop Stop Ice Accumulation Natural Icing Environment.

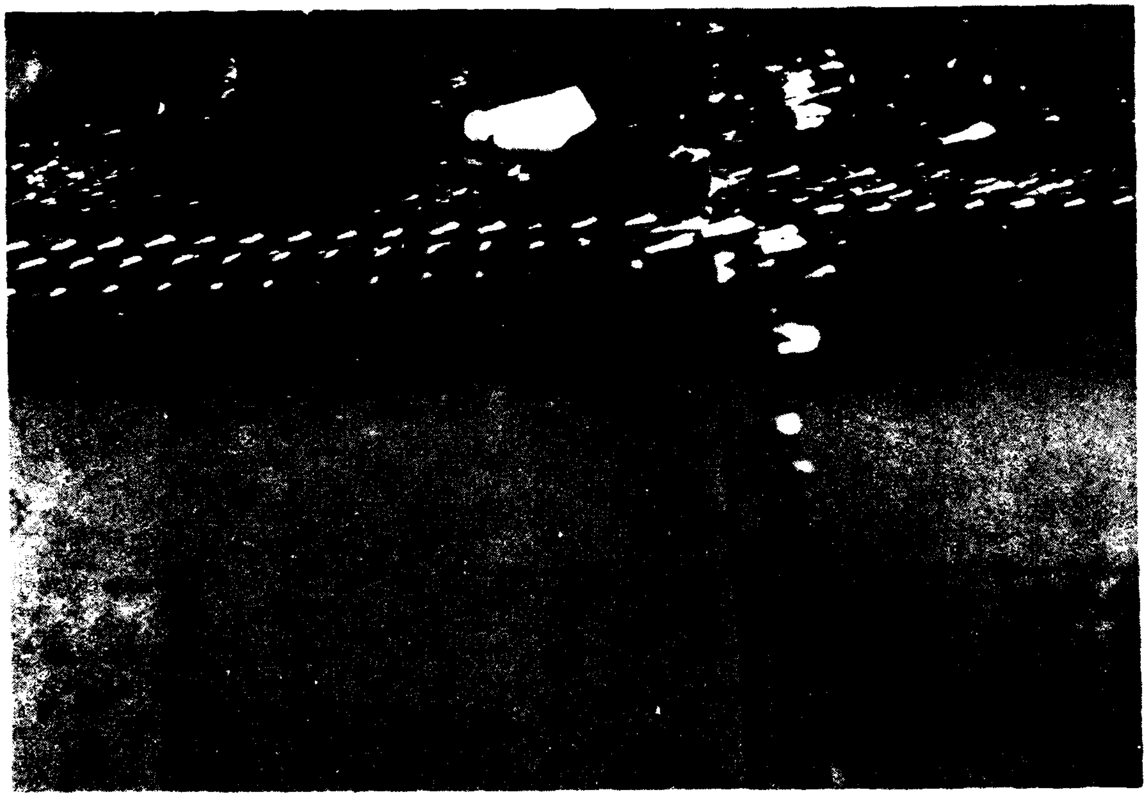


Photo 4. Fuel Vent Icing.

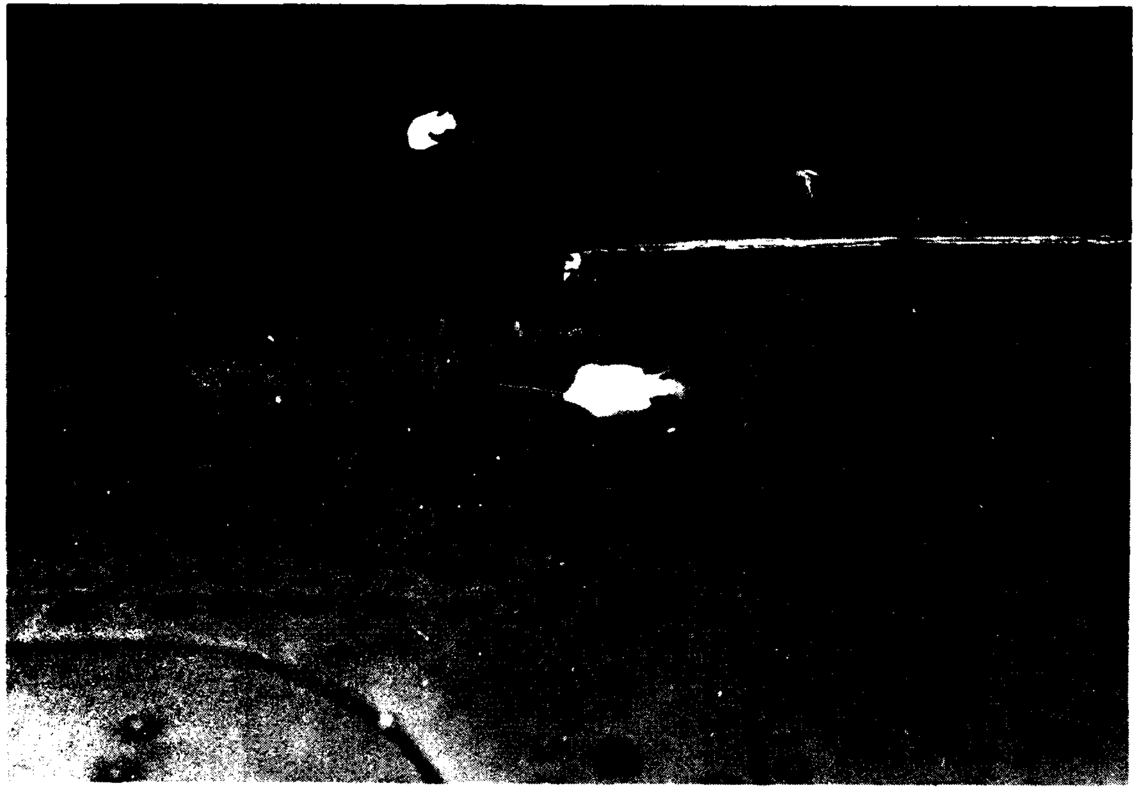


Photo 5. Fuel and Battery Vent Icing.

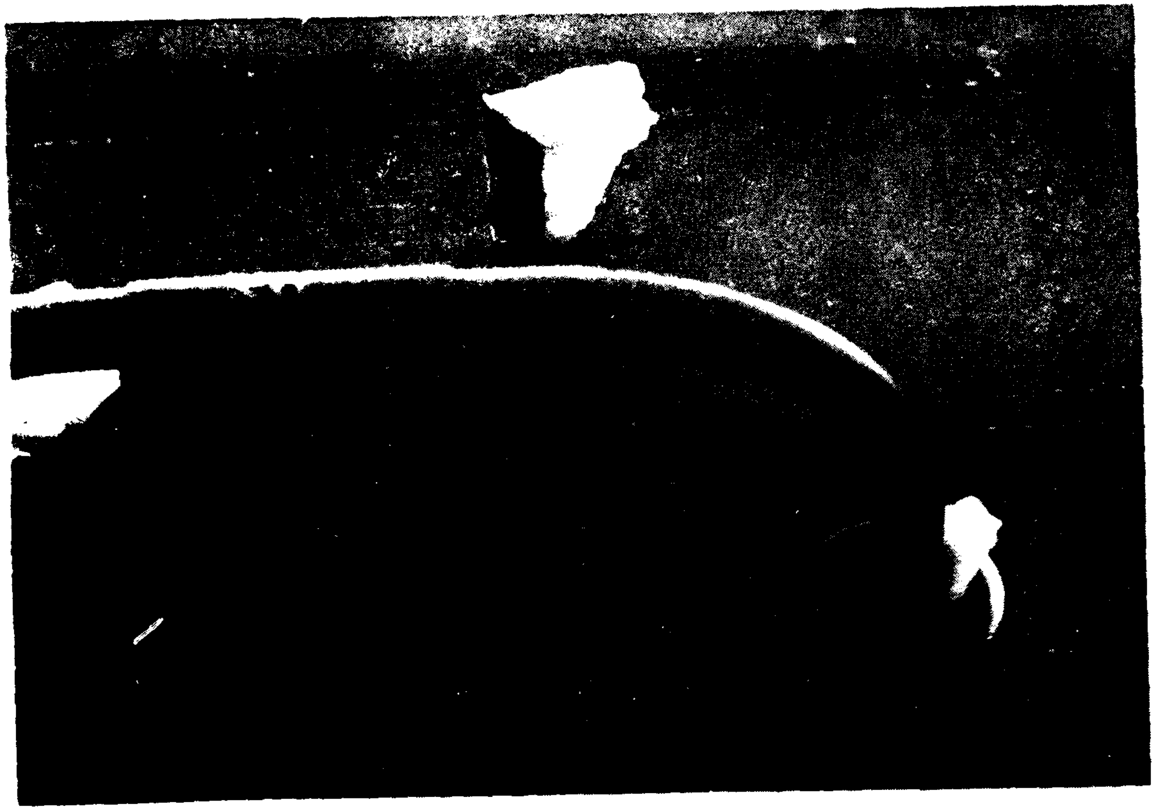


Photo 6. Fuel Vent Icing.

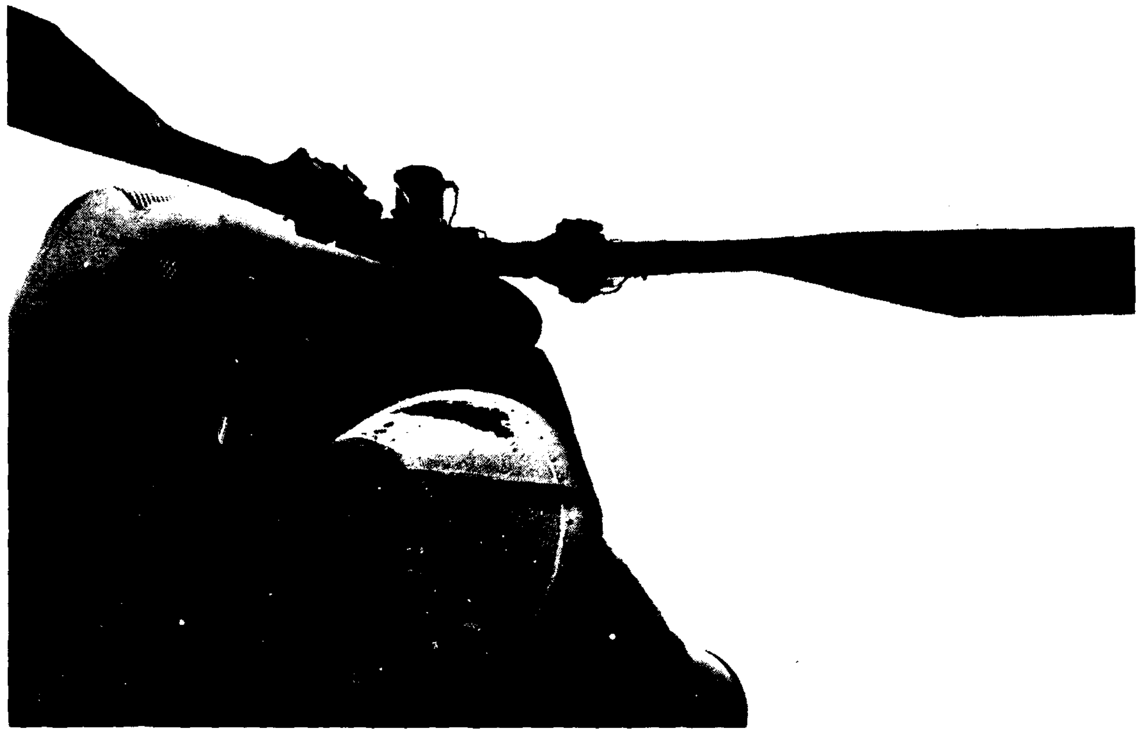


Photo 7. Engine Screen Icing.

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