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# CATEGORY II ICING TEST OF THE HH-53C HELICOPTER

| DONALD J. DOWDEN<br>Icing Project Engineer | GREGORY A. M. ETZEL<br>Major, USAF<br>Systems Project Engineer | CLARK E. LOVRIEN, JR.<br>Major, USAF<br>Project Officer and<br>Project Pilot |
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TECHNICAL REPORT No.71-26
JUNE 1971

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17 APR 1972

Th[redacted]ny h[redacted] approval of ASD (SDQH), Wright-Patterson AFB, Ohio 45433.

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: ASD/SDQH 2-85 (Major Thompson/54440/R&D 9-2/H-53)

SUBJECT: ASD Addendum Report to FTC-TR-71-26

TO: Recipients of FTC-TR-71-26

This report is a part of and should remain attached to FTC-TR-71-26. Paragraph numbers below correspond to recommendations in FTC-TR-71-26.

1 through 9. Concur with intent. ASD has initiated action to incorporate the required information in the appropriate aircraft manuals. Those recommendations not already reflected in current manuals will appear in forthcoming supplements, changes, or revisions.

10. Concur with intent. The anticipated minimal exposure to icing conditions and the use of damage-avoidance procedures developed during these tests combine to reduce the possibility of significant increases in tail rotor replacement/repair costs. In the event service experience or future mission requirements indicate that rising costs merit consideration of alternate materials, the recommended engineering study should be undertaken. ASD plans no further action on this recommendation, pending future requirements, direction and funds. The recommendation should be considered for future helicopter procurements, if applicable.

11. Concur with intent, but not with recommended action. See comment in paragraph 10, above. In addition, clearance to operate in moderate icing conditions does not require the use of special ice inhibiting materials. Therefore, unless future missions require flight in more severe icing conditions or other requirements dictate additional effort to reduce potential tail rotor blade maintenance, further investigations are not justified. The recommendation should be considered for future procurements, if applicable, especially for other helicopters less capable of tolerating ice.

12 and 13. Concur with intent. ASD has initiated action to incorporate the required information in the appropriate aircraft manuals. Those recommendations not already reflected in current manuals will appear in forthcoming supplements, changes, or revisions.

14. Concur with intent. Investigative and corrective actions which began with the receipt of UMRs will be completed according to normal procedures.

15 through 17. Concur with intent. ASD has initiated action to incorporate the required information in the appropriate aircraft manuals. Those recommendations not already reflected in current manuals will appear in forthcoming supplements, changes, or revisions.

18. Concur. Since all aircraft have been delivered, the procurement of updating and modifications for H-53 helicopters has transitioned to AFLC System Support Managers. ASD recommends field corrective action by the TCTO process.

19. Concur. New windshields of improved design and different manufacture are now undergoing service evaluation. Retrofit of delaminated windshields should be accomplished on an attrition basis only.

20 through 26. Concur with intent. Since these recommendations apply only to the test camera installation, no action is planned for the H-53 aircraft or its systems. ASD will consider using the blade camera for future helicopter testing, as appropriate (to document rotor blade dynamics and/or icing phenomena). Incorporation of the recommended improvements to the blade camera should enhance its use during future tests.

27. Concur with intent, but not with recommended action. This recommendation should be considered for future tests involving the use of ice detector probes of this type. As explained in the test report introduction (under AIRCRAFT DESCRIPTION, Ice Detector System), this instrumentation was peculiar to the test helicopter. The recommendation does not apply to the standard configuration H-53 which does not use an ice detector probe.

GENERAL COMMENT: Procurement of the USAF HH/CH-53B/C was directed "off-the-shelf" with minimum modifications to the existing USMC CH-53A configuration. Directed lead times did not allow normal development procedures to be followed. For example, cockpit mockup inspection was precluded by the expedited procurement process. Initially no Category II tests were authorized. Deployment to combat prior to adequate testing allowed the operator to accumulate extensive experience in operating the system. Based on this experience, user requirements must be carefully considered in evaluating recommendations from testing. In some cases the costs associated with some desirable changes may not be commensurate with the system benefit or with the priority of user requirements. Numerous recommendations contained in this report should be considered in future procurements, if appropriate.

FOR THE COMMANDER

William D Eastman
WILLIAM D. EASTMAN, JR., LT COL, USAF
Chief, Helicopter Programs Division
Directorate of Combat Systems
Deputy for Systems

FTC-TR-71-26

# CATEGORY II ICING TEST OF THE HH-53C HELICOPTER

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W-P. AFB, Ohio 45433

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# FOREWORD

This report presents the results of the icing test phase of the Category II All-Weather Test Program of an HH-53C helicopter, USAF S/N 68-10354. The artificial icing tests were conducted at Eielson AFB, Alaska, during the period 19 March ~~to~~ 31 March 1971. The natural icing tests were conducted at Elmendorf AFB, Alaska, during the period 3 April to 10 April 1971. Data results from the reduction of photo and magnetic tape recordings will be published separately at a later date in appendix VIII, reference 1, of this report. The program originated with the assignment to the Air Force Flight Test Center (AFFTC) of the Category II All-Weather Test mission as outlined in an Air Force Systems Command (AFSC) Program Action Directive, dated 16 March 1970. This program action directive tasked the AFFTC to complete the Category II All-Weather testing of the HH-53C beginning with the termination of the Climatic Laboratory testing then being conducted at Eglin AFB, Florida, by the Aeronautical Systems Division (ASD). The icing tests were conducted under the authority of AFFTC Project Directive No. 71-24 with AFFTC priority 31 and Job Order Number 482AEO.

The cooperation and the support of the personnel of the 5010th Combat Support Group, Eielson AFB, Alaska, of the US Army Arctic Test Center at Fort Greely, Alaska, 11th Weather Squadron, and the 5040th Helicopter Squadron at Elmendorf AFB, Alaska, were greatly appreciated.

Foreign announcement and dissemination by the Defense Documentation Center are not authorized because of technology restrictions of the U.S. Export Control Acts as implemented by AFR 400-10.

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**Reviewed and approved by:**
**10 May 1971**

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**Commander, 6510th Test Wing**

**ROBERT M. WHITE**
**Brigadier General, USAF**
**Commander**

# ABSTRACT

Artificial icing tests were conducted during 19 through 31 March 1971 at Eielson AFB, Alaska. Natural icing flights were conducted during 3 through 10 April 1971 in the vicinity of Elmendorf AFB, Alaska. The helicopter and its anti-ice systems operated satisfactorily under all artificial and natural icing environments encountered. Rotor blade ice shedding was random and caused damage to rotor blades in the form of dents and punctures. Tail rotor blade dents occurred throughout all icing encounters (light and moderate conditions) when ice shedding took place. Tail blade punctures were noted during two flights in artificial icing conditions and once in natural icing, when the outside air temperatures (OAT) were approximately -15 and -18 degrees C. Colder temperatures (-18 degrees C) caused the ice to form farther out toward the main rotor blade tips, which resulted in a larger angle of incidence between shedding tip ice and the tail rotor blade plane of rotation. This increased the potential for puncture damage to the tail rotor blade pockets. Main rotor blade damage in the form of dents from ice strikes occurred occasionally during the icing program at the colder OAT's (below -15 degrees C). Rotor blade damage encountered was not judged to be a safety-of-flight hazard. The Engine Air Particle Separator (EAPS) system functioned satisfactorily with inlet doors closed in light and moderate icing conditions with no engine performance degradation noted. The EAPS was tested at airspeeds up to 160 KIAS, doors closed, with no structural or engine performance degradation noted. Airframe ice was of no consequence to the operation of the flight controls and the overall operation of the helicopter. The HH-53C should be cleared for flight in light and moderate icing and freezing rain conditions with or without EAPS installed, but such flights should be restricted to mission essential operation only, based on the probability of the occurrence of rotor blade pocket damage caused by ice strikes from shedding ice.

# TABLE OF CONTENTS

# LIST OF ILLUSTRATIONS

# LIST OF ABBREVIATIONS AND SYMBOLS

| Item | Definition | Units |
|---|---|---|
| ADP | Aerodynamic Discontinuity Principle | - - - |
| AFCS | Automatic Flight Control System | - - - |
| AGE | Aerospace Ground Equipment | - - - |
| APP | Auxiliary Power Plant | - - - |
| ARRS | Aerospace Rescue and Recovery Service | - - - |
| ASD | Aeronautical System Division | - - - |
| ATC | Air Traffic Control | - - - |
| EAPS | Engine Air Particle Separator | - - - |
| FOD | Foreign Object Damage | - - - |
| FPS | Frames Per Second | - - - |
| IFR | Instrument Flight Rules | - - - |
| KIAS | knots indicated airspeed | knots |
| LWC | liquid water content | grams/meter$^3$ |
| MRB | main rotor blade | - - - |
| $N_g$ | gas generator speed | percent |
| $N_r$ | rotor speed | percent |
| OAT | Outside Air Temperature | degrees C |
| Pa | Pressure Altitude | feet |
| RUMR | Routine Unsatisfactory Material Report | - - - |
| TCTO | Time Compliance Technical Order | - - - |
| $T_5$ | Turbine Inlet Temperature | degrees C |
| UMR | Unsatisfactory Material Report | - - - |
| WUC | Work Unit Code | - - - |

# INTRODUCTION

## GENERAL

The test helicopter, S/N 68-10354, was a rescue version of the H-53 and was similar to the CH-53C. The primary mission was search, location and recovery of combat crew members in all environments. The secondary mission was delivery of supplies to forward combat areas. The aircraft systems were instrumented to record environmental effects. The flight summary with the applicable parameters is presented in appendix I.

The icing test was the fourth in a series of environmental tests conducted on the HH-53C. The Adverse Weather test (reference 2), the Climatic Laboratory test (reference 3), and the Arctic test (reference 4) were accomplished previously. A U.S. Navy evaluation on the CH-53A under icing conditions was completed in 1966 (reference 5). Other HH-53C Category II test results will be presented in future AFFTC technical reports as tests are completed. A future test that is presently scheduled for the HH-53C is the desert environmental test.

## PROGRAM OBJECTIVES

The purpose of the icing test was to determine the operational suitability of the HH-53C systems and components in artificial and natural icing conditions up to and including moderate icing. Moderate icing is defined as the accumulation of one-half inch of ice on a small probe per 20 miles. Specific test objectives were:

1. To evaluate main rotor blade and tail rotor blade ice accretion/shedding characteristics in moderate artificial and natural icing conditions.

2. To evaluate any aircraft damage which might be caused by ice shed from the rotor blades.

3. To determine airframe and rotor blade ice accumulation/shedding characteristics in freezing rain conditions.

4. To evaluate the EAPS under icing and freezing rain conditions.

5. To evaluate rotor blade ice accretion characteristics in moderate icing conditions with rotor blade aerodynamic discontinuity principle (ADP) (anti-ice) tape installed (reference 6).

6. To determine icing operating procedures to be included in the Flight Manual (T.O. 1H-53(H)B-1) (reference 7).

7. To compile environmental data for future fixes, modifications, and design purposes.

8. To evaluate the performance of a motion picture camera installed on a main rotor blade sleeve and spindle housing.

## TEST HISTORY

The new test vehicle, HH-53C, S/N 68-10354, and test instrumentation were originally accepted by the Air Force at the Sikorsky Aircraft plant at Stratford, Connecticut, on 4 December 1969. Subsequently, adverse weather tests and Climatic Laboratory tests were conducted by the Aeronautical Systems Division (ASD). After the Climatic Laboratory test, the responsibility for conducting Category II tests for the HH-53C was transferred to AFFTC at Edwards AFB, California. The HH-53C was then flown to Eielson AFB, Alaska, where Arctic tests were completed during the period 6 January to 26 February 1971. Following the Arctic tests, the aircraft remained at Eielson AFB for the purpose of conducting the artificial phase of the icing program. The artificial icing tests were conducted from 19 through 31 March 1971. The aircraft departed for Elmendorf AFB, Alaska, on 3 April 1971 to seek natural icing conditions. The natural icing phase was completed on 10 April but systems evaluation continued until 13 April at which time the helicopter returned to Edwards AFB, California.

## AIRCRAFT DESCRIPTION

The HH-53C helicopter was manufactured by Sikorsky Aircraft Division of United Aircraft Corporation, Stratford, Connecticut. Power was provided by two T64-GE-7 engines which could be protected from foreign object damage (FOD) by installation of engine air particle separators (EAPS). All-weather capability was provided by an automatic flight control system (AFCS), engine and windshield anti-icing systems, and instrument landing and navigation systems. The helicopter was equipped with a hydraulic rescue hoist, strategically placed armor plating, armament consisting of three pintle-mounted 7.62mm miniguns, external auxiliary fuel tanks, and an aerial refueling system. The cargo compartment was equipped with two cargo winches, roller conveyors in the cargo compartment floor, cargo and litter tiedown facilities, and troop seat provisions. An auxiliary power plant (APP) provided a self-starting capability, power for cargo loading and unloading, and aircraft systems checkout while on the ground. The tricycle landing gear was retractable and a retractable tail skid provided tail rotor protection on landing.

The HH-53C helicopter used during the Arctic tests was in standard configuration except as noted in this section. The helicopter was instrumented with a low-speed digital airborne tape recording system. Each test parameter was sampled three times per minute. A photopanel was also installed to monitor selected system parameters. A motion picture camera was installed at the pitch horn attachment point on a main rotor blade sleeve and spindle housing with a counter weight on its corresponding opposite blade (figure 1). This camera was operated during the icing test to photograph the buildup and shedding of ice from a main rotor blade. The outputs from three cockpit mounted accelerometers were recorded by an oscillograph. EAPS internal static pressure was compared to aircraft static pressure from the pitot static system, and this information was presented in the photopanel. The following paragraphs described systems modified or added to this test helicopter.

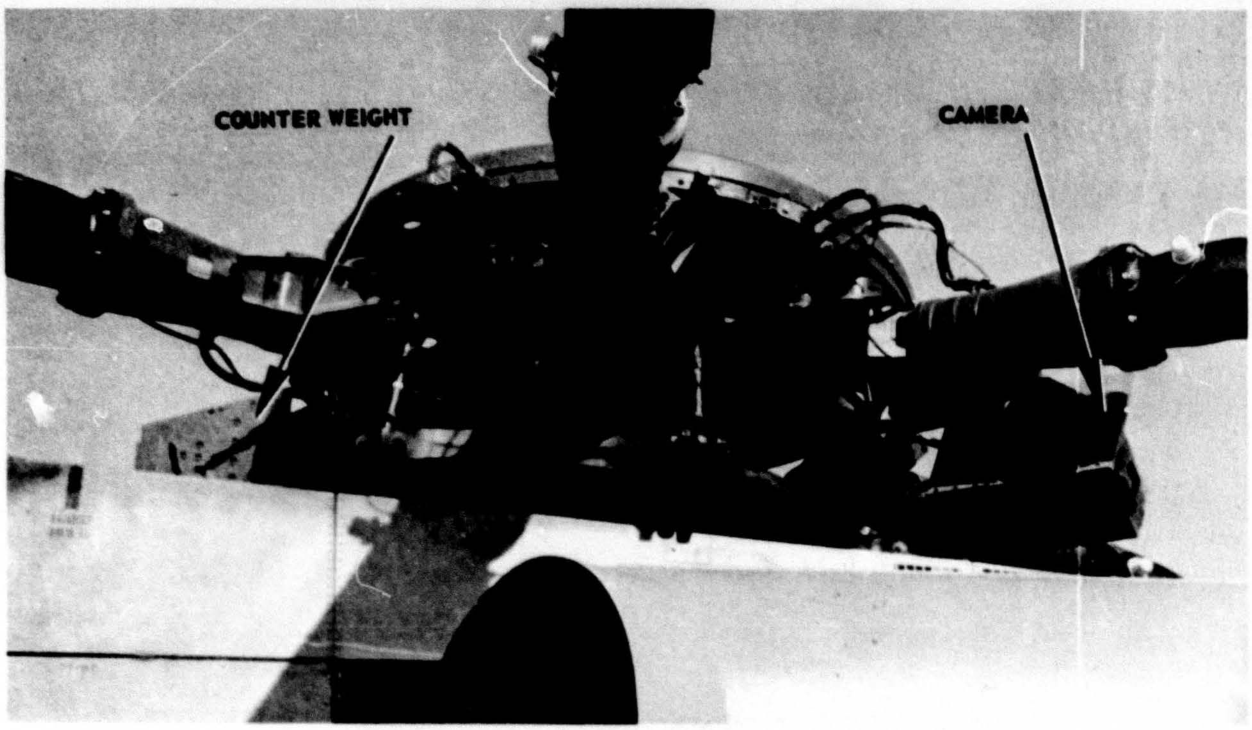

Figure 1 Rotor Blade Camera

### Ice Detector System

The test helicopter was equipped with an ice detector system which provided visual indication of icing conditions and consisted of an ice detector control panel, a sensing element, and necessary electrical circuits. The ice detector control, located on the overhead control panel, consisted of a switch with marked positions ON, OFF and TEST, and a light marked ICE DET (figure 2). When the switch was placed in the ON position, the system functioned automatically. When the switch was placed in the TEST position, the light illuminated to indicate system operation. The sensing element, located in the heater inlet duct, was an ultrasonic vibrating tube whose natural frequency of vibration decreased as ice accumulated. When the vibration frequency reached a preset value, a relay closed and the internal heater in the sensing element was activated for a period of five seconds. Five seconds of activation was adequate to shed the small amount of ice that accumulated on the sensing element. The light on the ice detector panel illuminated when ice was detected. An ice detector warning light was also installed in the photopanel. The system received power from the No. 1 ac and dc primary buses through circuit breakers marked ICE DET located on the copilot's circuit breaker panel.

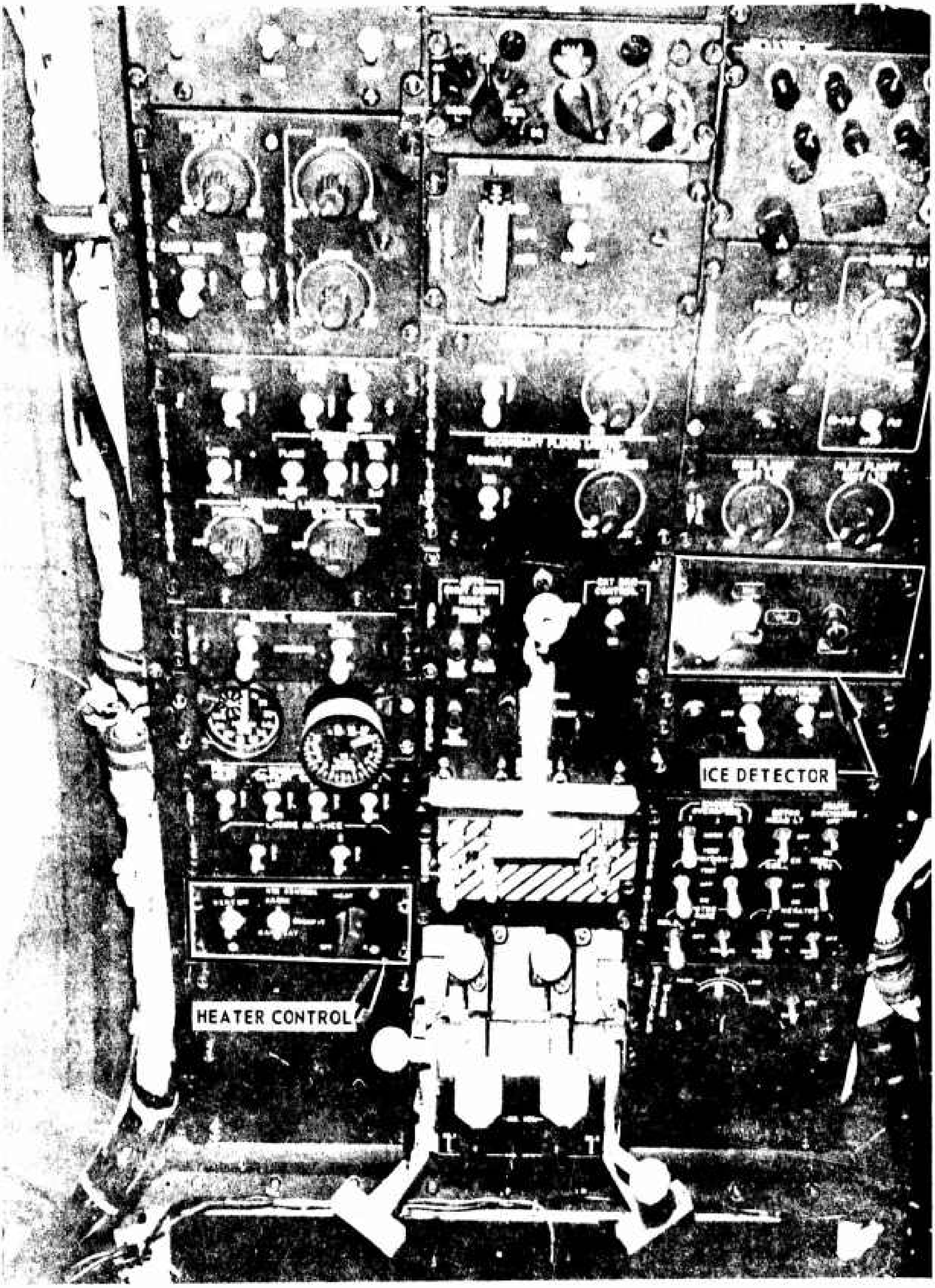

Figure 2 Overhead Cockpit Control Panel

### Machmeter

Prior to Arctic testing, the copilot's airspeed indicator was replaced with an advancing blade tip machmeter. The indicator was designed to continuously indicate the Mach number at the tip of the advancing rotor blade. It received signals continuously from the pitot-static system with adjustments for variations in rotor speed made manually to the dial face by the copilot. FTC-TR-71-11 (reference 8) presents the results of the machmeter tests.

### Heater Duct Modification

During arctic testing, a localized heat source was made available by mounting an adapter on the aircraft heater duct aft of the pilot's bulkhead. The adapter permitted attachment of a small diameter (5-3/4 inch) flexible heater duct ("Herman Nelson" heater type), which bled hot air from the aircraft's heater system, and directed that heat where it was required. When localized heating was not required, the flexible hose could be disconnected and a cover substituted on the adapter returning the heat distribution to normal. This was part of a prototype installation described in Sikorsky ECP 7381.

### Heating System

The modified heater system had sensing elements located in the cockpit and in the cabin. These sensors were designed to automatically maintain a temperature from 60 to 80 degrees F, in either the cabin or cockpit, by setting the heater control switch on CABIN or on COCKPIT position (figure 2). A third position MAX HEAT, bypassed both sensor elements and the heater operated until 285 degrees F was reached at the discharge duct. The heater then cycled the heater duct temperature around the 285 degrees F point until some change was made in the heater control switch. This was a portion of the prototype installation described in Sikorsky ECP 6614.

### Auxiliary Power Plant

Except for the following, the APP was the same as described in the Flight Manual (reference 7).

#### Dual Accumulator Modification.

An additional accumulator with a 150-cubic inch capacity was installed next to the existing 250-cubic inch accumulator. The additional accumulator provided an increased start capability for temperatures down to -65 degrees F (-54 degrees C). A manually operated valve located between the two accumulators was opened when the additional energy from the second accumulator was needed for starting.

#### APP Bootstrap Modification.

The hand pump used to charge the APP accumulators cavitated during cold weather operations. This was evidenced by either pump handle springback or complete lack of resistence during a pump pressure stroke. To prevent this, the utility hydraulic reservoir was statically pressurized by using a 3-cubic inch accumulator, which in turn created a positive 30-psi head pressure at the inlet side of the APP handpump.

#### APP Start Valve Modification.

APP start problems occurred at cold temperatures in the climatic laboratory due to restricted flow through the APP start valve. A modified valve (P/N OMP 2830-11), incorporating a change in the control orifice size, was installed at Eielson AFB on 11 January 1971.

#### APP Heavy Duty Clutch.

The APP clutch shaft sheared during the arctic tests. It was replaced by a heavy duty clutch used on the Marine versions of the H-53. The modification incorporated the larger diameter clutch, shorter APP-to-clutch drive shaft, slightly modified lubrication lines, and a different oil dam on the accessory gearbox at the clutch pad.

# TEST AND EVALUATION

## ICING ANALYSIS

### General

Artificial icing and freezing rain tests were conducted on the HH-53C to determine the capabilities of the overall aircraft in an icing/freezing rain environment. Natural icing tests were conducted to verify and substantiate artificial icing results. The artificial icing tests were conducted with the HH-53C in four specific configurations:

1. EAPS not installed.
2. EAPS installed on No. 2 engine, doors opened.
3. EAPS installed on No. 2 engine, doors closed.
4. Aerodynamic Discontinuity Principle (ADP) anti-icing tape installed on main and tail rotor blades, EAPS installed on No. 2 engine, doors closed.

### Test Procedures

#### Artificial Icing.

The artificial icing tests were flown at specified distances behind a C-130 equipped with a water spray nozzle (figure 3). The time in the icing cloud was then varied to obtain a desired total accumulation of ice. A test observer in the C-130 spray tanker used a hand-held range finder and the UHF radio to assist the helicopter pilot in maintaining the desired distance behind the tanker. Because of the relatively small diameter of the icing cloud in relation to the large rotor diameter of the HH-53C (72 feet 3 inches), an attempt was made to center the right engine in the middle of the icing cloud. This allowed maximum buildup on the center and right side of the fuselage and immersed the advancing blade in the icing cloud.

**Figure 3 C-130 Icing the HH-53 Helicopter**

Different rates of buildup and types of ice were obtained by varying the distance, water content and temperature. Ice thickness measurements were made immediately after landing during postflight inspections.

Artificial Freezing Rain.

This test was conducted under the same test procedures as in the icing test, using the icing water spray nozzle. The test helicopter was positioned closer to the spray nozzle than in the icing program, providing a simulated rain condition. Due to the small cross section diameter of the spray cloud at 300 feet behind the spray tanker, only the EAPS and its immediate area were heavily immersed, although the entire helicopter was exposed intermittently to the freezing rain.

Natural Icing.

Weather briefings were received in the morning and afternoon to determine the most probable area of moderate icing. The flight areas were limited because of the mandatory requirement to be under radar control at all times. When airborne, pilot inflight reports were monitored for actual reports of icing and if the occasion presented itself, the helicopter was vectored by ATC to the area of the reported icing. When icing conditions were encountered the following parameters were recorded. The duration of the icing encounter, the thickness of the buildup, the indicated airspeed, and the outside air temperature (OAT). From this data the determination of the type, as well as the intensity, of the icing was made.

## Airframe.

### Artificial Icing

Icing flights are summarized in appendix II. The terminology used in describing icing phenomena listed in appendix III were extracted from reference 9.

Ice accumulated on the vertical pylon, horizontal tail, rotor hub, flight controls, refueling boom, external sponsons, tanks and aircraft nose (figure 4). The rescue hoist accrued heavy ice throughout most of the test conditions. Maximum ice thickness of 1-1/4 to 1-1/2 inches was accrued on the previously mentioned airframe areas from artificial icing conditions of icing flights 9, 14 and 15. No structural damage was inflicted on the HH-53C airframe during all icing tests. Ice accumulation did not hinder flight control operation.

**Figure 4 Typical Ice Accumulation on HH-53**

The refueling probe was operated during icing flights 5, 9 and 14 with no mechanical problems evident.

The cabin heater inlet screen had an estimated 75 to 90 percent airflow blockage on icing flights 8 and 9 respectively, due to glime ice formation on the screen (figure 5). Subsequent tests conducted at colder outside air temperatures (OAT) had minor (10 percent) blockage of the heater screen area (icing flights 14 and 15). The cabin heater was inoperative throughout part of the artificial icing tests; however, it was believed that this condition did not significantly change the pattern of the ice buildup on the heater screen (appendix II). The heater inlet screen could be totally blocked off by ice formations should light or moderate icing conditions at OAT's from 0 degrees C through -13 degrees C be encountered for extended periods of time. The heater was inoperative during most of the flights when significant ice accretions on the heater inlet occurred. Possible heater system damage or erratic operation due to reduced airflow might result from heater operation after the heater inlet duct was iced over. If reduced airflow from the heater outlet ducts is realized while flying in icing conditions the heater should be turned off to preclude possible heater damage. A NOTE to this effect should be included in section IX of the Flight Manual. (R 1)[1]

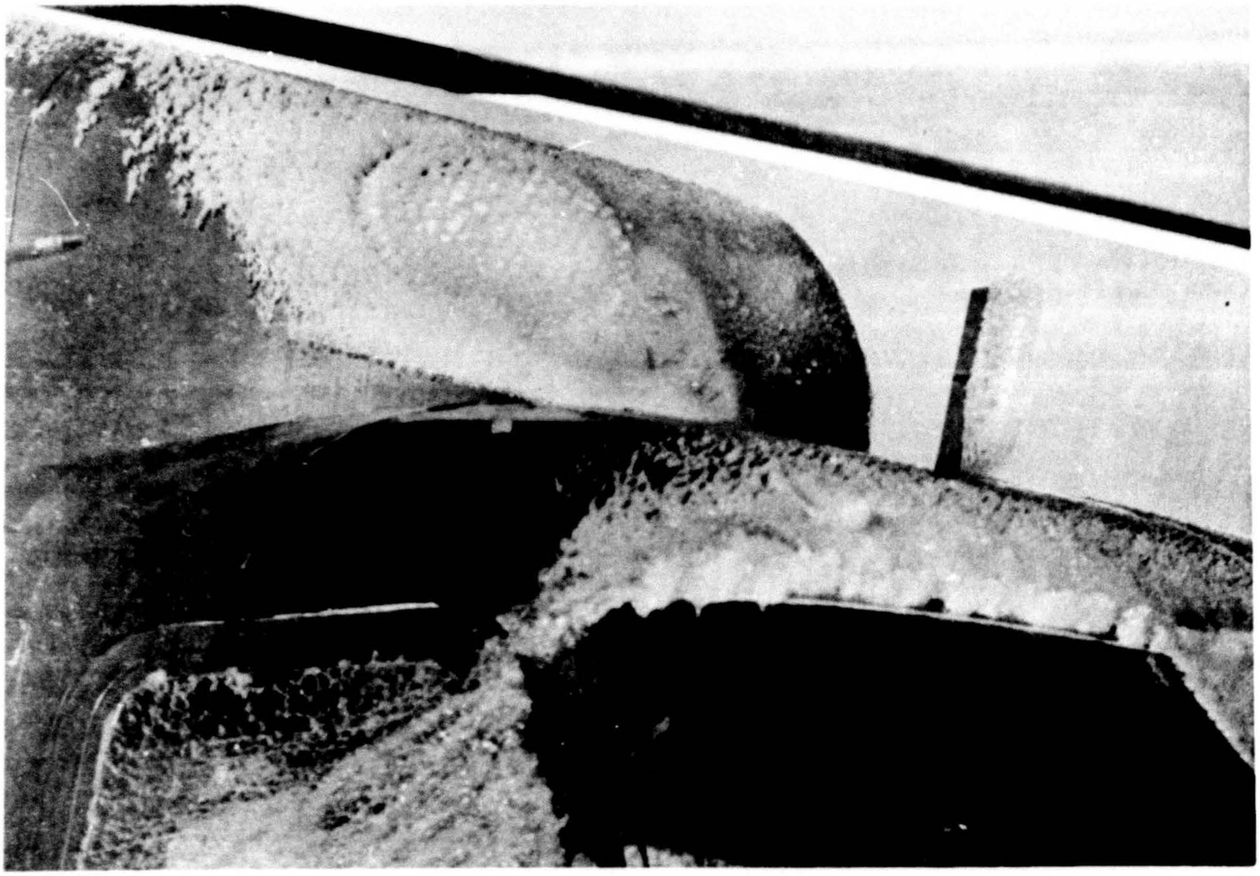

**Figure 5 Iced-Over Heater Inlet Duct Screen**

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[1] Numbers indicated as (R 1), etc., represent the corresponding recommendation numbers as tabulated in the Conclusions and Recommendations section of this report.

### Artificial Freezing Rain

No ice buildups affecting flight controls occurred during the artificial freezing rain test, (table I, appendix II, icing flight 13). Maximum airframe ice was 1-1/4 inch on the rotor hub and heater inlet screens. The heater inlet screen was 90 percent blocked due to ice formations. No structural damage was noted during the postflight inspection.

### Natural Icing

Ice accumulated in varying thicknesses (1/16 to 9/16 inch) on airframe components. The airframe components which received the most ice because of their collection efficiency were the windshield wipers, the forward HF antenna mast, rescue hoist and support members (figure 6). These components were visible from inside the aircraft. Because the surface temperature averaged above freezing (36 degrees F) during the tests it was impossible to evaluate ice buildup on such areas as the tail boom, rotor head and flight control servos, cabin heater inlet duct screen, and rotor blades before the ice melted or was shed. At no time during the flights did airframe icing present a problem or hazard.

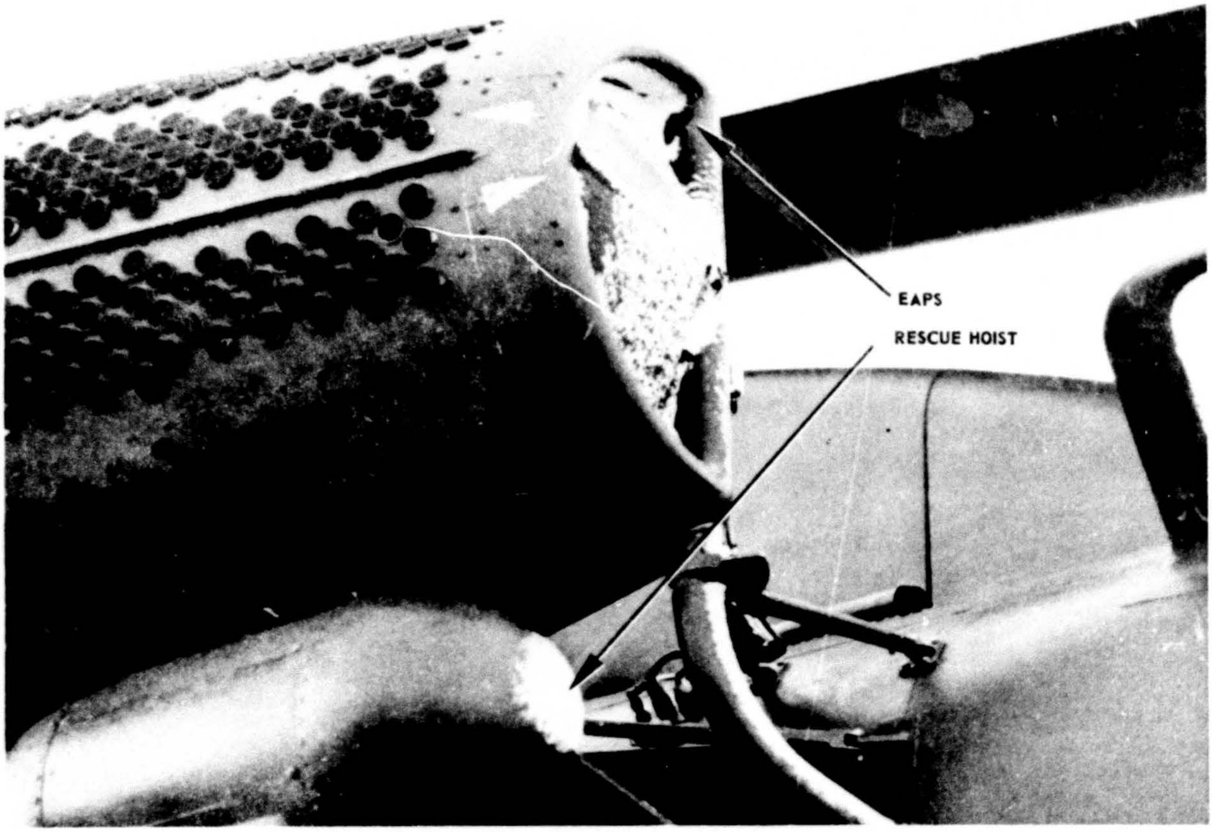


**Figure 6 Typical Ice Accumulation in Natural Icing**

Engine Air Particle Separator (EAPS).

Artificial Icing

A trace of ice buildup was noticed inside the EAPS ducting after icing flight 11 (EAPS doors opened). A maximum of 1/4 inch glime ice collected on the EAPS inlet lips and door edges. Ice fingers built up and out from the EAPS mini screens on the forward one-third of the EAPS (figure 7).

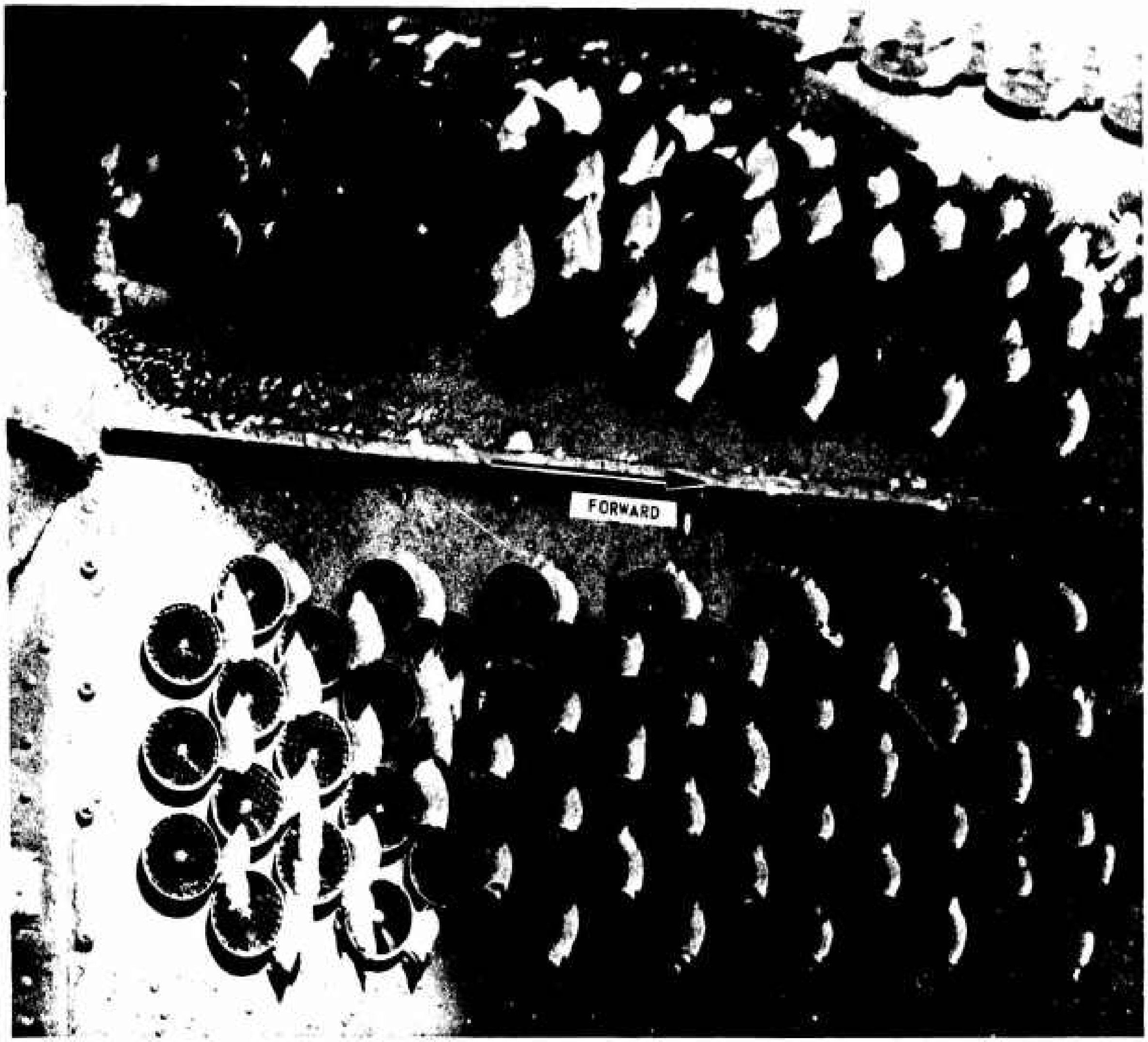


**Figure 7 Ice Fingers on EAPS Mini Screens**

Icing flights 12 through 15 were conducted with EAPS doors closed. Ice accumulated 15/16 inch and 1-1/2 inch thick on the EAPS inlet lips during icing flights 12 and 14 respectively (appendix II). A solid sheet of ice formed over the doors and lips during icing flights 12 and 14 (figure 8). The approximate maximum thickness of ice on the doors was 3/4 inch on icing flight 14. No ice was noticeable inside the EAPS during the artificial icing tests with the doors closed. Ice fingers formed on the leading edges of the mini screens on the bottom and the vertical inboard EAPS panel (figure 9). Maximum EAPS mini screen ice blockage was estimated at five percent on icing flight 14, appendix II.

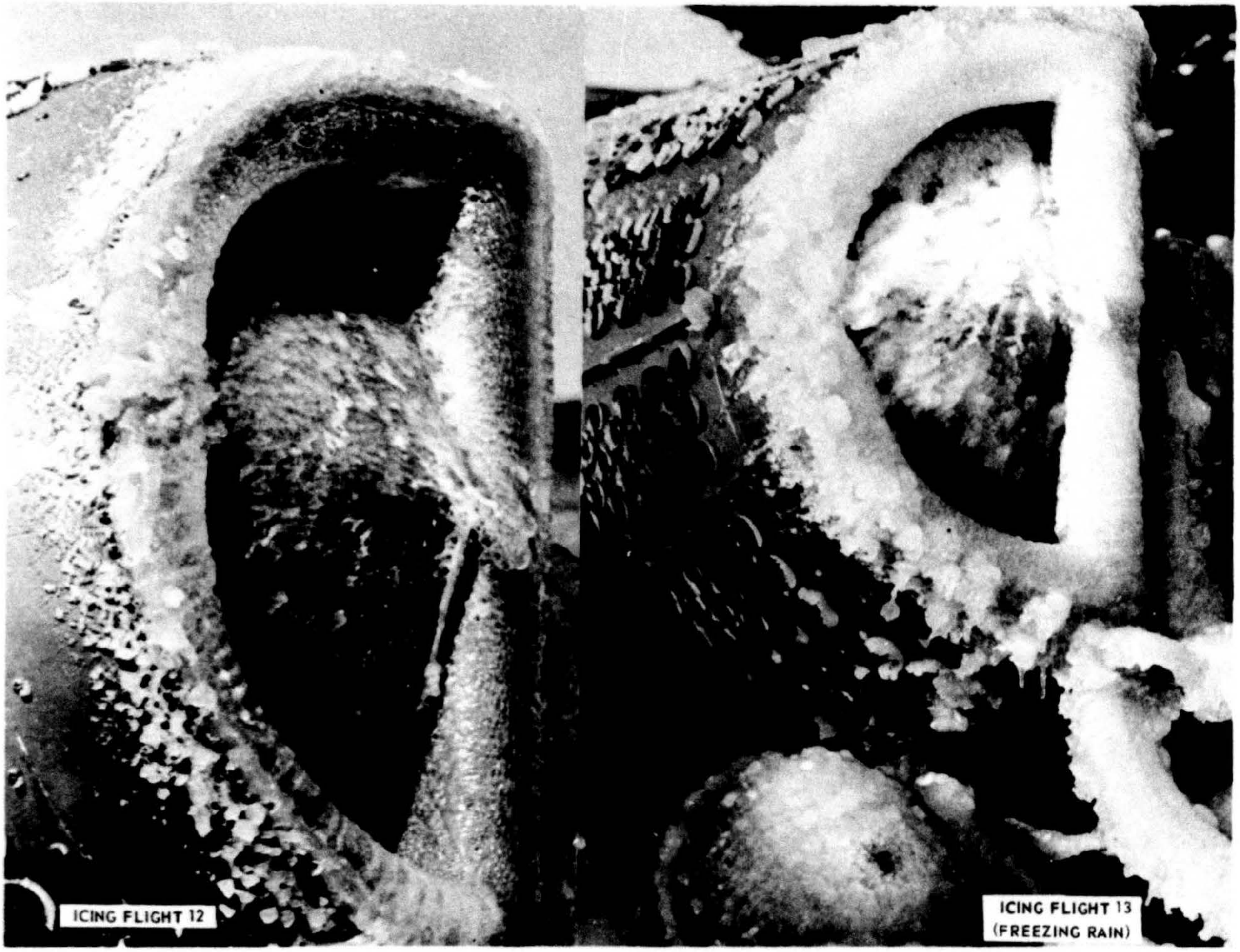


**Figure 8 Solid Sheet of Ice on EAPS Lips and Doors**

### Artificial Freezing Rain

Approximately 20 of the 759 EAPS mini screens were blocked with 1/8 inch ice on icing flight 13 (appendix II). The inboard EAPS panel was 30 percent blocked off with ice. Ice fingers were 1-15/32 inch long on the leading edge of the mini screens and on parts of the screens on the forward 1/3 of the EAPS. Ice was 5/16 inch thick inside of the closed EAPS on the forward lower surface, due to water runback.

Figure 9 Ice Fingers on EAPS

Natural Icing

The EAPS performed satisfactorily under all natural icing and snow conditions encountered. The EAPS doors were usually left in the open position during cruise until the first indications of icing were observed. At that time, the doors were closed and left closed until the inlet lips and doors were visually checked to be ice free. The maximum amount of natural ice was collected on the EAPS on icing flight 21. About 30 percent of the leading edges of the mini screens on the inboard (vertical) EAPS panel were observed to have rime ice formations.

### Engines and Engine Air Anti-Icing Systems.

#### Artificial Icing/Freezing Rain/Natural Icing

The engines functioned satisfactorily under all test conditions. The engine air inlet and air anti-icing systems functioned satisfactorily under all icing conditions encountered. Without EAPS installed, ice collected around the outer periphery of the engine inlets on the EAPS aft support rings (figure 10). None of this ice was observed to shed or enter the engine inlets. No engine damage was experienced during all icing test conditions. Engine operation with EAPS installed and doors closed in icing conditions up to moderate was unaffected by ice buildup on the EAPS. The EAPS, when operated with doors closed, precluded the possibility of engine FOD from ice ingestion.

Figure 10 Natural Ice on EAPS Aft Support Rings

The EAPS should be cleared for flight in icing conditions up to moderate with the doors closed. If icing conditions are encountered inflight with EAPS installed, the EAPS doors should be closed immediately to prevent the possibility of engine FOD from ice shed from the rotor system or off the EAPS inlet lip or doors. Once closed, the EAPS doors should not be opened again until the EAPS doors are visually checked clear of all ice in flight, or the helicopter is on the ground with the engines stopped. (R 2, R 3, R 4)

### Rotor Blades.

#### Artificial Icing

Both the ice accretion characteristics and the types of ice accumulated on the main and tail rotor blades varied in thickness and type during the artificial icing phase. The types of ice encountered were rime, glime, and clear (appendix III). Generally rime ice formed at OAT below -14 degrees C, glime ice formed between -7 through -14 degrees C, and clear ice formed between 0 and -7 degrees C. The spanwise blade ice accretion characteristics were directly related to OAT. Temperatures between 0 and -12 degrees C caused ice to adhere tenaciously on 75 percent of the blade span and temperatures below -12 degrees C generally caused ice to adhere tenaciously on 100 percent of the blade span. The artificial icing cloud was not large enough in diameter to encompass the entire rotor plane (both the advancing and retreating blades), but the cloud was large enough to provide an icing condition for the entire advancing blade (figure 11). Ice that formed on the blades was judged to be representative of typical ice formations found in natural icing conditions. Glime ice buildup on icing flight 9 ran underneath the spar, back to the pockets, and rime ice on icing flight 14 formed a 1-1/2 inch wide opaque band along the spar leading edge. Both conditions were representative of ice found in natural conditions (figures 12 and 13). The thickness of ice that accrued on the rotor blades throughout the artificial icing tests ranged from 1/16 inch (icing flight 1) to 1-1/8 inch (icing flight 15). All main rotor blade ice thicknesses presented were measured at the fourth pocket out from the rotor hub on the blade leading edge.

Aerodynamic Discontinuity Principle (ADP) tape (reference 6) was installed on the main and tail rotor blades after icing flight 14 to determine if the tape would discourage ice accumulation on the blade leading edge and induce earlier ice shedding due to reduced adhesion. The 12 mil thick ADP tape was designed for the H-3 helicopter blade, not the H-53 blade. Prior to the tape installation, all rotor blade spars were cleaned with isopropyl alcohol and then thoroughly wiped dry. Evaluation of the ADP tape was conducted on icing flight 15 which had the same test conditions as the previous icing flight. The ice accretion characteristics of the blade were changed. Ice formed farther back on the spars' upper and lower surfaces than experienced previously on icing flight 14 (figure 14). Also, the thickest and most defined accumulation of ice to date was noted (1-1/8 inch) on the main rotor blades. Possibly, the ice accrued further back on the top and bottom of the blade due to the spar being cleaner, i.e., oil free, from the alcohol cleaning. The ADP tape and cleaner blade leading edges apparently increased the water catch efficiency (ice accumulation rate) and the adhesion of the ice on the leading edges, when compared to the same test conditions encountered on the previous flight. Ice formed on the entire blade span, due to the cold temperature at the test point.

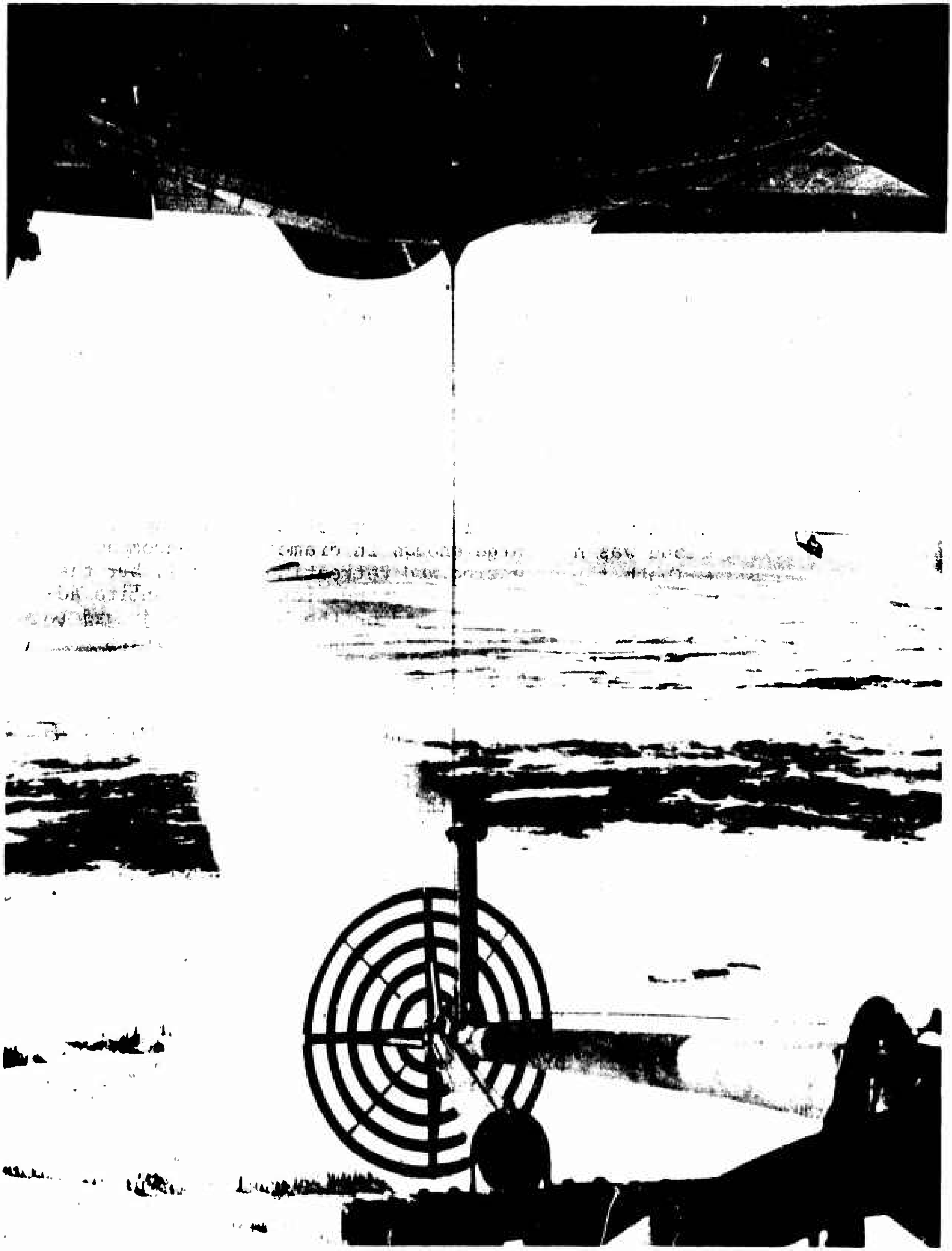


Figure 11 Advancing Rotor Blade in Icing Cloud

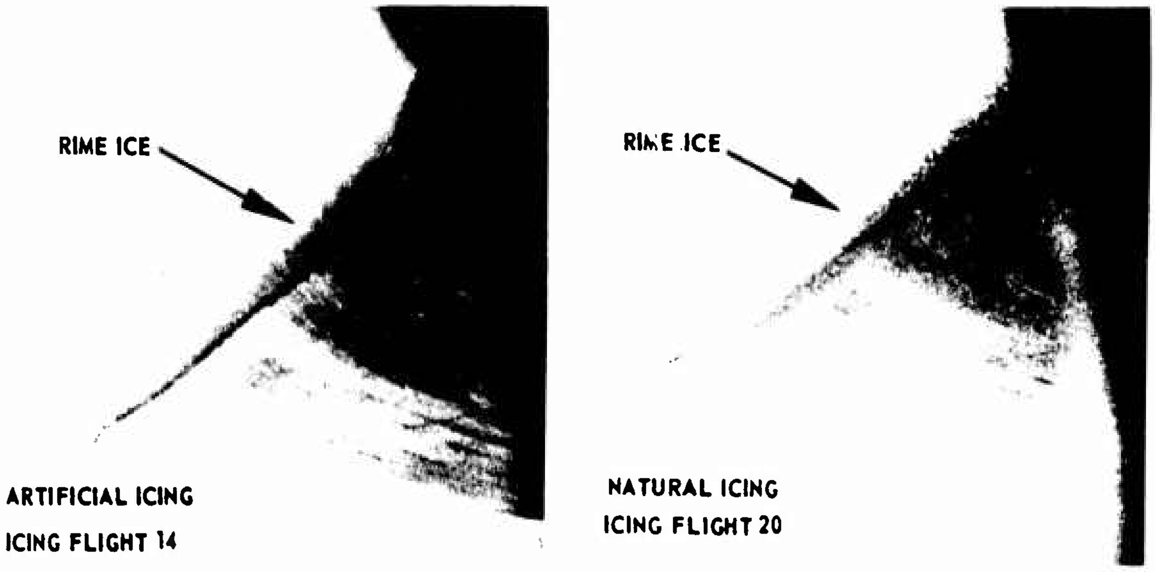


Figure 12 Artificial Blade Ice Compared to Natural Ice on Blade

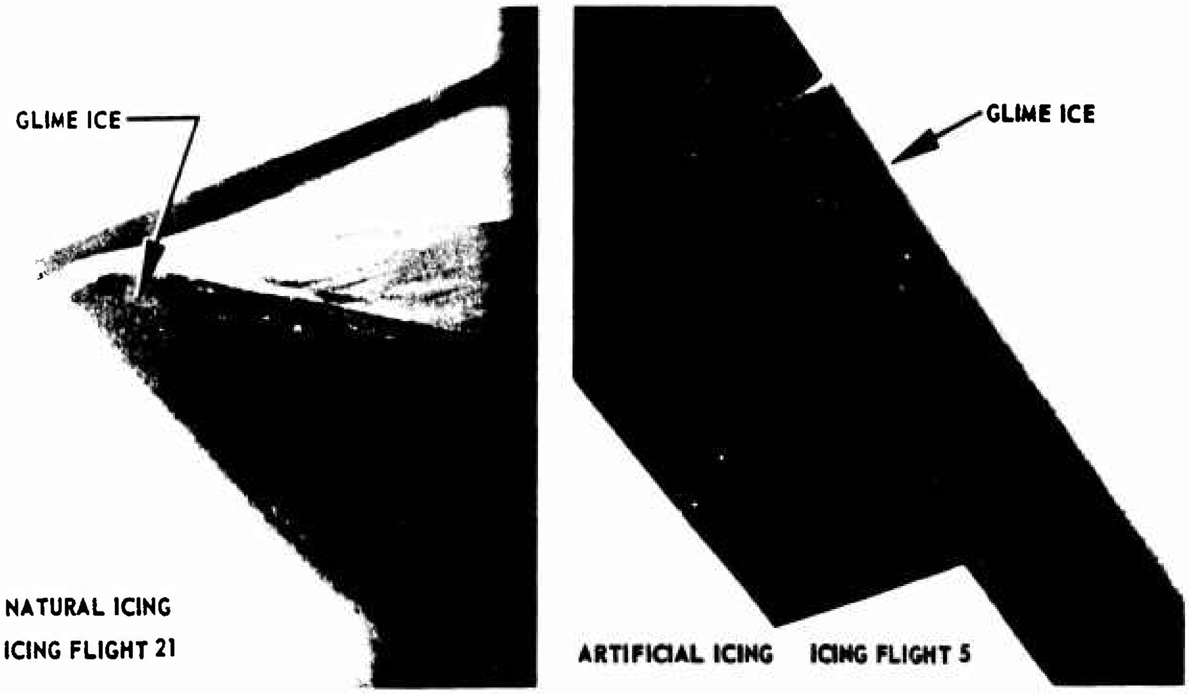


Figure 13 Artificial Blade Ice Compared to Natural Ice on Blade

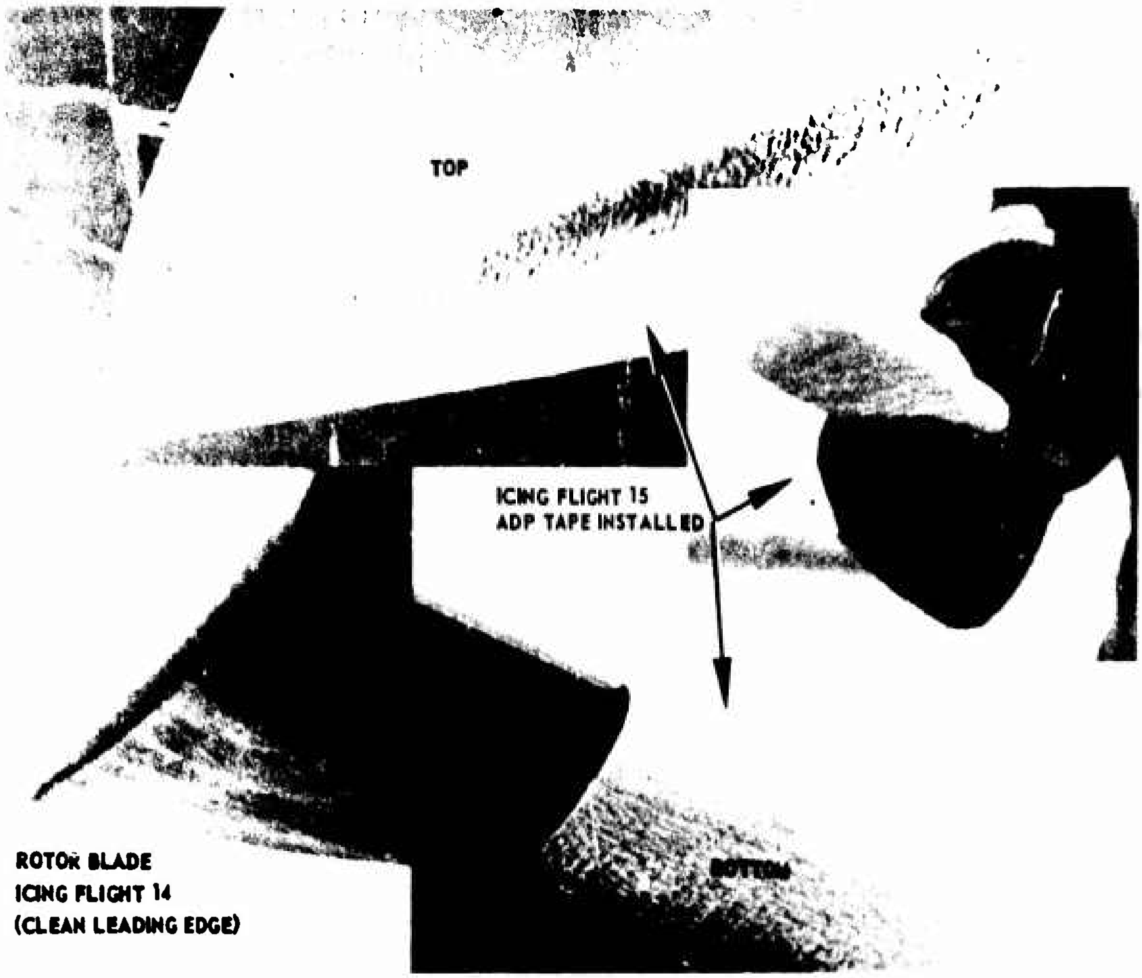


Figure 14 Ice on Top and Bottom of Blade Spar

Typical blade ice shedding occurred first from the tail rotor blades and then from the main rotor blades. Shedding usually occurred from the midspan and tip areas, and was generally asymmetric. Main rotor blade ice shedding was random throughout the circumference of rotation, but the ice thickness at which shedding occurred could be predicted, based on the measurement of ice remaining on the rotor blades at the termination of the flight and an assumed approximate average rate of ice accumulation, (appendix IV). Ice from the main and tail rotor blades typically shed when the accumulated ice thicknesses reached approximately 1/2 and 1/4 inch, respectively. Tail rotor ice shedding did not cause any airframe damage or aircraft control degradation. Main rotor blade shedding was significant and caused main and tail rotor blade damage and airframe vibrations. Ice shedding that occurred on icing flights 5 and 15 resulted in minor dents and holes on the tail rotor blade pocket skin. After icing flight 5 one tail rotor blade had two holes, 3-3/4 by 2 inch and 2 by 1 inch, and after icing flight 15 two tail rotor blades had a total of three holes of 7/8 by 1-1/4, 1/2 by 1/4, 2-1/2 by 1-1/4 inch (figure 15). The damage did not degrade the structural integrity of the blades and did

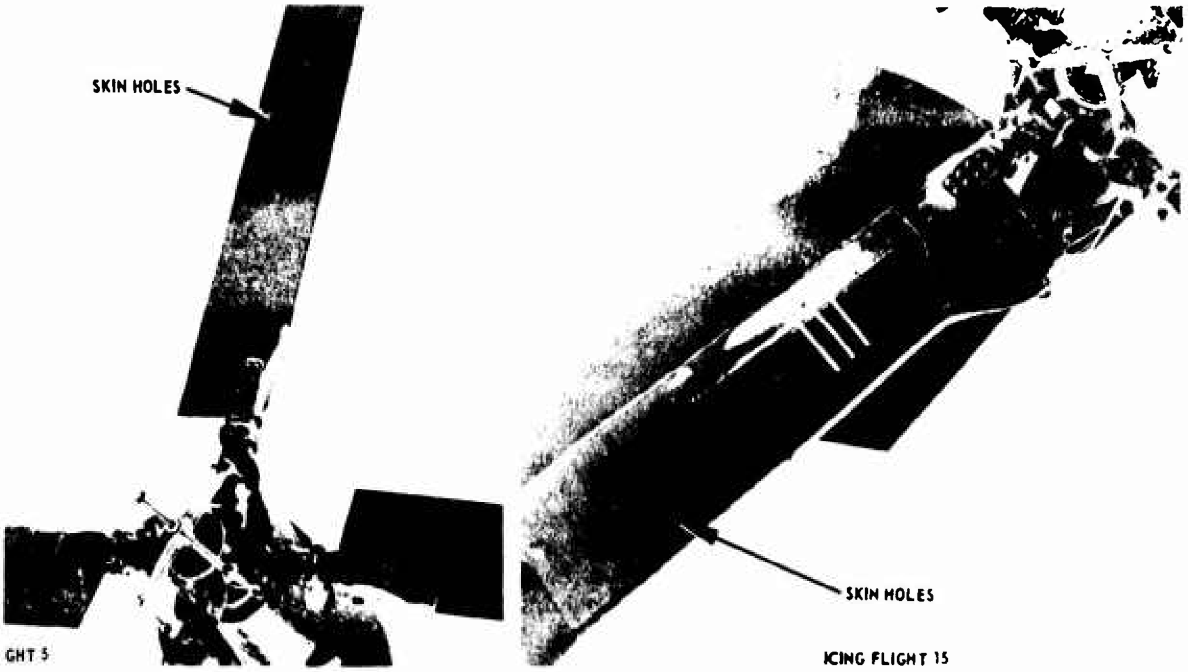


Figure 15 Damage to Tail Rotor Blades

not present any immediate safety of flight hazards. Generally tail rotor blade damage occurred at colder OAT's, when ice accumulated on 100 percent of the main rotor blade span. Colder temperatures (-18 degrees C) caused the ice to form farther out toward the main rotor blade tips, which resulted in a larger angle of incidence between shedding tip ice and the tail rotor blade plane of rotation. Damage, in the form of dents, was inflicted on the tail rotor blades consistently throughout the icing tests, however, the only damage requiring tail rotor blade replacement occurred during icing flights 5 and 15. Main rotor blade damage occurred occasionally in the form of small dents in the pockets due to ice strikes.

Main rotor blade ice shedding was random (occurring at anytime in flight) and tail or main rotor blade damage could occur at any time during flight in icing conditions (light and moderate icing). Shedding patterns on icing flight 15 were significantly different than previous flights (ADP tape installed). The ice that formed on the entire leading edge shed later than on previous icing flights. When the ice finally shed it had built up sufficient mass to cause tail rotor blade pocket damage (holes). The ADP tape as evaluated was unsatisfactory for H-53 helicopters.

### Freezing Rain

Icing flight 13 was a simulated freezing rain condition. The rotor blades accumulated clear ice, but due to the warmer OAT (-7 degrees C) ice formed only on 50 percent of the blade span. Main and tail blade ice shedding occurred with no damage and no aircraft control degradations.

### Natural Icing

The ice buildup on the rotor blades was recorded on film in flight, but by the time the aircraft landed all the ice had shed or melted. Shedding patterns were observed to be similar to those observed on artificial icing flights. A difference was the lack of accompanying significant lateral and vertical vibrations. No vibrations were noticed during natural icing flights possibly due to the small amounts of ice collected at each icing encounter, however, the shedding ice was visible from the cockpit and cabin. As in the artificial tests, ice that was shed from the main rotor blades hit the tail rotor blades. With one exception, only very small dents were observed on the tail rotor blades which in no way affected the aircraft's performance. The one exception was on icing flight 22, when a light icing condition at an OAT of -18 degrees C was encountered. Approximately 1/8-inch rime ice accumulated on the windshield wiper arms during this icing encounter. The rotor blades would accrete a significantly larger amount of ice than the windshield wipers under these conditions, due to their greater collection efficiency. Postflight inspection revealed a punctured tail rotor blade pocket. The damage consisted of a skin penetration about one square inch in size near the trailing edge of the blade, six inches from the tip cap. The hole was patched with ADP tape and the blade left in service for the ferry trip to Edwards.

## OPERATIONAL ANALYSIS

### General

During controlled artificial icing tests, conducted to gain increased knowledge about icing characteristics of the HH-53C helicopter, an attempt was made to relate the results to an operational situation. While the artificial tests did not duplicate natural icing conditions, the majority of these icing encounters produced ice very similar to that found under natural icing conditions, as shown in blade camera photographs (figure 16). The primary difficulties in simulating natural icing conditions were the water cloud turbulence and relatively small spray cloud cross section diameter in relation to the size of the helicopter. It was not felt, however, that this in any way reduced the validity of the operational knowledge and techniques developed during the tests. Appendix II summarizes the 15 artificial icing flights conducted.

### Test Results

#### Artificial Icing Flights.

The HH-53 helicopter, C-130 spray aircraft and safety chase/photo helicopter rendezvoused at predetermined coordinates south of Eielson AFB to conduct artificial icing tests. All artificial icing tests were conducted over unpopulated regions while inbound to Eielson AFB. The HH-53C rotors and EAPS were inserted into the icing cloud for various lengths of time to accumulate ice. After exiting the icing cloud, the helicopter was landed as soon as possible at Eielson AFB for evaluation of ice accumulation and inspections for airframe damage. All anti-ice systems were operated during the icing tests.

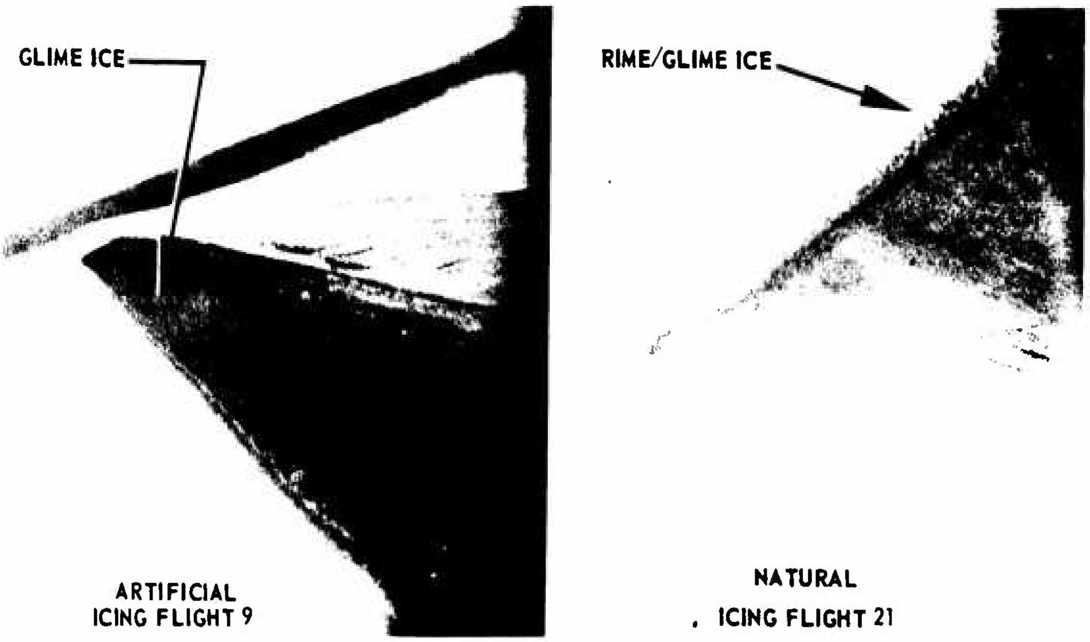


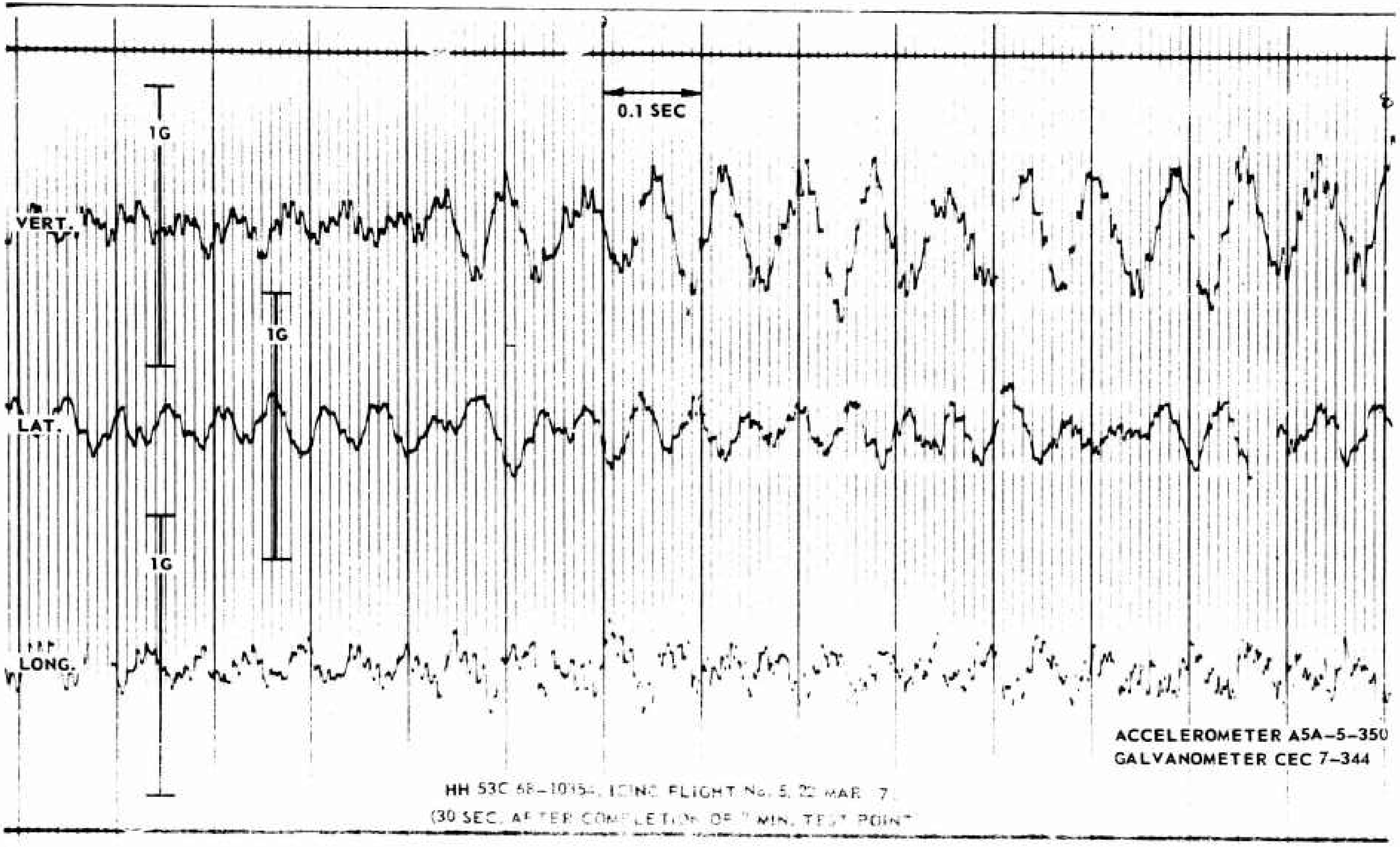
**Figure 16 Rotor Blade Ice – Artificial vs. Natural**

Light turbulence was experienced behind the C-130, so it was difficult to detect any vibrations due to ice buildup. However, it was relatively easy to detect the vibrations resulting from asymmetric shedding of ice from the main and tail rotor blades. In order to better evaluate the frequency and magnitudes of the vibrations reported qualitatively by the pilots, accelerometers were installed on the bulkhead directly behind the copilot's seat and the outputs were recorded on an oscillograph.

An analysis of the oscillograph traces yielded average values of inherent accelerations of ±.13 g vertical and ±.11 g lateral and longitudinal, measured as average peak to peak values on nine flights. The inherent acceleration values varied as a function of airspeed, gross weight, altitude and distance behind the tanker and included any effects of the blade icing camera installation.

Icing flights No. 1, 2 and 3 were flown in trace and light icing conditions. Ice buildups were 1/2 inch or less (measured on the forward HF antenna mount), and very little ice shedding was experienced. On these flights, no increased vibrations or operational problems were experienced.

Icing flights No. 4 and 5 were 7-minute test runs flown in moderate icing conditions. On both flights, a moderate medium frequency vertical vibration built up within 30 seconds after leaving the icing cloud. The vertical accelerometer indicated an increase of ±.17 g within one second and then a further increase of ±.08 g for a total acceleration level of ±.34 g after 16 seconds. These were defined by the pilots as moderate medium frequency vibrations (approximately 13 Hertz) (figure 17).



F[illegible] Vibration Data [illegible] Speed[illegible]

The maximum medium frequency vertical vibrations were experienced on icing flight No. 14. Qualitatively, they were classified by the pilots as moderate to heavy, and measured an average ±.51 g, peak to peak. On the same flight, the lateral and longitudinal vibrations reported were measured ±.10 g's peak to peak and ±.15 g's peak to peak respectively, at a higher frequency than that present in the inherent levels (figure 18). On icing flight No. 4, no attempt was made to reduce vibrations caused by asymmetric ice shedding through cycling of the flight controls. Ice shedding was observed in flight and the vibrations slowly disappeared after several minutes through self shedding of the blade ice. After engine shutdown, several small dents were found in the tail rotor blades and a 1-inch diameter dent was found in a tail rotor blade tip cap.

On icing flight No. 5, similar vibrations were experienced after exiting the icing cloud. After both a medium frequency vertical vibration and a lateral shuffle developed, the controls were exercised in an attempt to even the ice shedding on the blades and reduce the vibrations. Moving the cyclic had no effect on the vibration level. Next, the collective was moved full down then up to maximum power. This immediately started a gradual reduction in the vibration level, with the helicopter returning to a more normal vibration level within eight seconds after completion of the collective change. During the eight seconds, the vertical accelerations decreased from ±.22 g to ±.12 g above inherent levels. Vibrations experienced during subsequent flights in similar or heavier icing conditions due to asymmetric ice shedding were reduced or eliminated by varying the rotor rpm from 95 to 105 percent $N_r$ with the speed selectors while maintaining altitude with the collective. This proved to be a more satisfactory method of reducing vibrations than by climbing or descending with a collective change. In either case, the change in main rotor and tail rotor pitch was generally effective in reducing airframe vibrations earlier than would occur without pilot action. It was concluded that a change in rotor rpm by moving the speed selectors was the most effective method in reducing vibrations caused by asymmetric shedding of main and tail rotor blade ice. This would be an acceptable procedure under IFR conditions. A NOTE should be added to the Flight Manual, recommending that rotor rpm be varied when asymmetric ice shedding is encountered. (R 5)

Postflight inspection after flight No. 5 revealed tail rotor damage requiring the changing of one blade. Two holes approximately 1 x 1-1/2 inches were found in the blade pockets on the outer side of the blade. Up to this time, the standard procedure had been to land from a hover following each icing flight. Heavy ice shedding had been observed during the low speed portion of the approach and as the helicopter came to a hover for landing. It should be noted that the pitch of the tail rotor blades was greatest in a hover, exposing a larger area of the tail rotor blade pockets to the rotational axis of the main rotor blades. From these facts and the entry angle on the holes in the tail rotor blade pocket, it was concluded that the damage probably occurred in slow speed flight, in a hover or when changing the tail rotor pitch for ground taxi turns. Later icing flights demonstrated an additional factor could contribute to possible tail rotor pocket damage. As the OAT decreased, the main rotor blades accumulated ice further out the span towards the blade tips. Ice shed from the immediate tip area had a greater tangential velocity and a greater strike angle relative to the tail rotor blade plane of rotation, thus increasing the possibility of an ice strike on a tail rotor blade pocket at such an angle as to cause penetration. In order to reduce

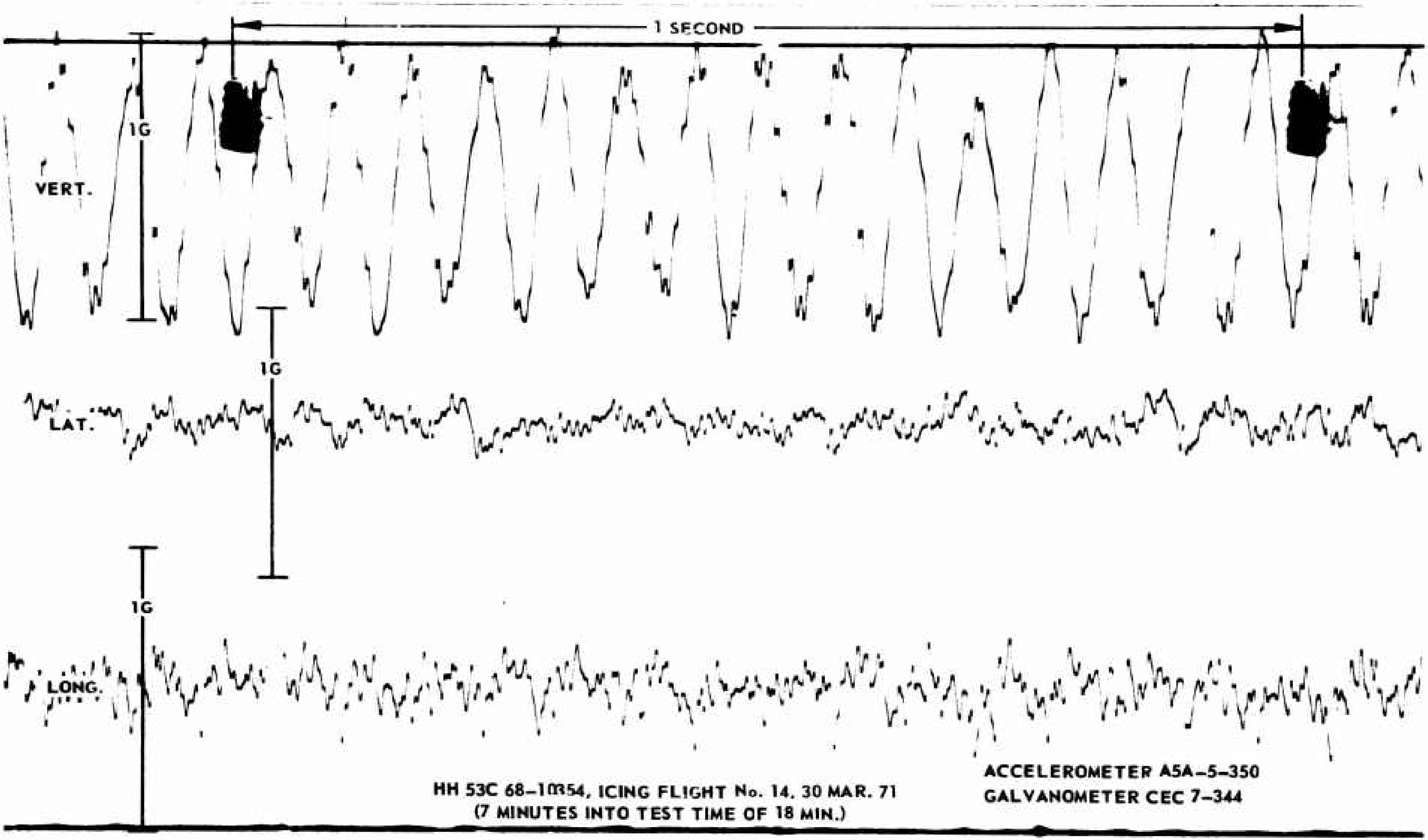


Figure 18 Vibration Change from Ice Shedding

the possibility of tail rotor damage, running landings followed by a straight ahead stop and shutdown were used on all subsequent artificial icing tests. On icing flights 6 through 14, minor pocket dents were found on the tail rotor and main rotor blades following each icing flight. These dents did not require any maintenance action and at no time jeopardized the structural integrity of the rotor blades. Review of high speed films taken from a chase helicopter verified random shedding from the main rotor blades in forward flight and occasional hits on the tail rotor blades.

On icing flight No. 15, ADP tape was installed on both the main and tail rotor blades in order to evaluate any possible improvement in reducing blade ice formation and shedding. A slight improvement was noted in reducing the level of tail rotor medium frequency vibrations. However, no improvement was noted in the icing characteristics of the main rotor blades. Instead of random shedding from the main rotor blades, during one shedding cycle observed when the blade passed through the one o'clock position, ice over 50 percent of the span of one blade shed all at once, showering the front of the helicopter with a large mass of ice particles. After flight termination, tail rotor damage was observed on two blades. One blade pocket had sustained a two-inch diameter puncture, and another blade pocket, two small 1/2-inch diameter punctures. Both tail rotor blades required changing. Again, it was extremely difficult to determine when the tail rotor damage occurred. Investigation showed the ice hit the damaged tail rotor blade pocket at almost a 90-degree angle rather than a glancing blow, indicating the damage may have occurred during rotor shutdown.

At no time during the icing tests was it felt that the magnitude of the tail rotor blade dents and punctures experienced in the blade pockets compromised safety of flight. It was concluded from the artificial icing tests that minor rotor blade damage in the form of dents may occur in flight in any icing condition as a result of random ice shedding. Tail rotor damage in the form of skin punctures may occur if ice is shed in slow speed flight, a hover or during taxi turns on the ground. A CAUTION should be added to the Flight Manual, recommending landing procedures when the aircraft has an ice accumulation. (R 6)

### Windshield Anti-Ice System

Operation of the windshield anti-ice system was satisfactory throughout the icing tests. The windshield anti-ice system was operated whenever flying in icing conditions and was highly effective in keeping the windshields ice free. One partial failure was experienced on the center windshield (reported in the systems analysis section). A total of 11 minutes were required to de-ice the windshield with high heat after ice was allowed to coat the windshield for one minute before turning on the de-ice system under light icing conditions.

A CAUTION should be placed in the Flight Manual advising that windshield anti-ice should be turned on at the first sign of icing conditions. Any delay in applying heat to the windshield could result in severely reduced visibility during a critical flight phase, e.g., approach and/or landing. (R 7)

## Power Changes

During each icing flight, observations were made to detect any increased power requirements caused by main rotor blade ice accretion and the increased weight of fuselage ice buildup. On icing flight No. 15 the most severe rotor blade and fuselage icing was encountered with anti-icing tape installed. On this flight a power check was made just prior to entering the icing cloud and immediately after the end of the icing run with the helicopter clear of the tanker aircraft turbulence. Indicated torque at the beginning of the run was 43 percent (each engine). At the end of the icing run the torque had increased to 57 percent (each engine). This increase in power required was the most severe encountered during the tests. The cold temperature encountered on this flight caused ice accretion over the greatest rotor blade span and further back over the blade chord than on previous flights at warmer outside air temperatures. This type and extent of ice accretion on the main rotor blades caused the greatest loss of blade aerodynamic efficiency and a subsequent increase in power equired. Power increases due to the added weight of fuselage ice accumulation could not be estimated. However, it was considered to be a small percentage of the total power increase. The most severe blade icing will occur in icing conditions at the coldest outside air temperatures. This will result in ice accretion further towards the blade tip, resulting in a greater loss of aerodynamic efficiency. Test results indicate the HH-53C had sufficient power available to maintain a normal cruise under moderate icing conditions at any allowable gross weight.

## Refueling Probe

The head of the refueling probe acquired ice in sufficient quantities to defeat first contact refueling connections, based on ground observations (figure 19). Should aerial refueling be attempted after flight in an icing condition, the pilot may have to make several passes at the drogue basket attempting off center contacts to knock off the accumulated ice. The success of this procedure could be visually verified by the scanner on the tanker. After the probe head has been visually scanned and determined to be clear of ice, wet refueling can commence using normal procedures. A NOTE should be placed in the Refueling Manual describing procedures to follow in the event aerial refueling is attempted after flight in icing conditions. (R 8)

## Anti-Flapping Restrainers

During artificial icing flights when significant depth of ice was accumulated (1/4 to 1/2 inch, light icing for five minutes and all moderate icing flights) one or more of the main rotor blade anti-flap restrainers hung out in the flight position during rotor shutdown (figure 20). This represented no operational or safety problems during the icing tests since there was no significant wind blowing during shutdowns. The anti-flap restrainers returned to the non-flight position as soon as the ice melted. Pilots and ground crewmen should be alerted for main rotor blade flapping during rotor shutdown in windy conditions after ice has accumulated on the main rotor head. Under these circumstances it will be necessary to park into the wind to minimize chances of blade/fuselage or rotor head damage during shutdown. A CAUTION should be placed in the Flight Manual describing procedures to follow on rotor shutdown after icing conditions have been experienced. (R 9)

Figure 19 Glime Ice on Refueling Probe

Figure 20 Ice on Flight Servos and Anti-Flapping Restrainers

### Natural Icing Tests

Flights in natural icing conditions were flown after the build up program conducted under artificial icing conditions proved it was safe to do so. The natural icing flights were flown to validate the results of the artificial icing tests and to discover if there were any significantly different test results due to total helicopter immersion in uniform natural icing conditions compared to the partial and non-uniform immersion experienced under artificial conditions. The artificial icing tests indicated the severest vibrations and power increases occurred under moderate icing conditions, or after long flights in light icing conditions where ice accretion was sufficient to allow ice shedding from the tail and main rotor blades. Attempts to find the desired moderate icing conditions were unsuccessful, however, five flights were flown in trace to light natural icing conditions.

Icing flight No. 16 produced a total of 1/8-inch accumulation of rime ice (measured on the windshield wiper arms) in trace to light icing conditions at 6,000 feet Pa and a temperature of -10 degrees C. Some asymmetrical ice shedding was observed producing light medium frequency and light lateral low frequency vibrations during the shedding sequence. Rotor rpm changes were successful in eliminating these vibrations when encountered. No operational problems were experienced and postflight inspection revealed no aircraft damage. All the ice melted prior to landing, preventing a detailed analysis of the ice patterns and thicknesses. All operating anti-ice systems functioned properly during the flight. A second flight on the same day produced similar results. At 6,000 feet Pa, -9 degrees C temperature, a total of 9/16 inch or rime ice was accumulated. Some ice shedding was noted after leaving icing clouds, but was observed to be relatively light. No operational problems were encountered and no damage to the helicopter was experienced on this flight. Icing flight No. 20 was flown in trace to light icing conditions. Moderate icing conditions were encountered for one minute during climbout, but produced only a 1/16-inch accumulation of ice. The flight was flown at altitudes from 2,000 to 5,000 feet Pa, with temperatures from -5 degrees C to -8 degrees C. These relatively high temperatures produced a one-inch total accumulation of clear ice on the HF antenna mast. However, little main rotor blade ice shedding was noted indicating a much smaller span-wise ice buildup due to the warmer OAT.

Icing flight No. 21 was flown in building cumulus clouds in an attempt to find moderate icing conditions. The flight produced only a 1/2-inch buildup of rime ice mixed with snow. Altitudes ranged from 4,000 to 8,000 feet PA in temperatures from -5 degrees C to -13 degrees C. Some shedding from the main rotor blades was noted whenever the helicopter exited an icing cloud. Again, no aircraft damage was noted. Further planned natural icing tests were terminated due to a lack of suitable icing conditions in the Elmendorf AFB area.

On the first leg of the return ferry flight to Edwards AFB, icing conditions were encountered inadvertently (icing flight No. 22). While cruising at 10,000 feet Pa, OAT of -18 degrees C, a building cumulus cloud was encountered for 3.5 minutes (nine nautical miles), producing a total ice buildup of 1/8 inch (measured on the windshield wiper arms) in light icing conditions. Immediately after exiting the icing cloud, a relatively large amount of ice was observed shedding from the main rotor blades followed by some normally expected fuselage ice strikes.

After a long descent and flight at low altitude, little or no additional ice was noted behing shed from the main rotor blades during the hover landing. However, postflight inspection revealed a one-inch diameter puncture in the outer trailing edge of one of the tail rotor blade pockets. The tail rotor damage was very similar to that experienced on artificial icing flight No. 15. It should be noted that the flight conditions were almost the same. Both flights were in relatively cold OAT's for ice formation (-18 degrees C). A careful analysis of the flight conditions and review of blade camera film on previous flights indicated the tail rotor damaged may have occurred in flight. The decreased OAT allowed formation of ice further out on the span of the main rotor blade towards the tip. Thus the ice shed under these conditions was closer to the tail rotor plane and had a higher velocity when shed, increasing the probability of striking a tail rotor blade pocket at a great enough angle to puncture the thin aluminum skin.

Damage in the form of dents in the pockets due to ice strikes was apparent on all six of the main rotor blades. There was no apparent change of aircraft vibrations or rotor tip path plane from these minor dents. As additional flying time was acquired, two further effects of ice strike damage to the blades came to light. One strike on the edge of a pocket caused eventual separation of four inches of pocket-to-rib bonding between two adjacent pockets. This separation was covered with ADP tape and no further problems occurred. Another similar strike caused the same type of eventual pocket-to-rib separation, however, this lead to a one-inch spanwise crack in the pocket. The crack started at the edge of the pocket in the dent about mid-chord on the blade. The pocket-to-rib bonding prevented the edges of the pocket on either side of the crack from bending up. This crack was stop drilled and covered with ADP tape and no further problems occurred.

The tests conducted in natural icing conditions verified those results obtained under artificial icing conditions, but also indicated that outside air temperature is a more important factor than the degree of icing conditions or rate of accumulation. A temperature decrease below approximately -12 degrees C increases the possibility of minor tail rotor damage due to ice shed from the main rotor blades.

## Operational Summary

Ice shedding caused tail rotor blade pocket damage in the form of dents and punctures from ice strikes. This damage occasionally required maintenance downtime and/or a tail rotor blade change. ADP anti-icing tape was installed on the rotor blades' leading edges to reduce ice accumulation and to induce earlier ice shedding. It was felt that earlier ice shedding would tend to reduce both the frequency and severity of tail rotor blade damage. On the flight that the tape was evaluated, tail rotor blade ice shedding occurred sooner, but main rotor blade ice shedding was significantly delayed, and shed all at once from larger areas of the span than previously observed. It should be noted that the 12 mil thick H-3 blade tape used formed a significantly larger percentage of the tail rotor blade cross sectional area than it did for the main rotor blade cross sectional area. On the ADP tape evaluation flight, not only was the tape installed but the blade spars were vigorously cleaned with isopropyl alcohol. These two items were the only significant changes between the test conditions of the ADP tape evaluation flight and the preceeding flight. It appears then that there was some correlation between ice shedding characteristics and ADP tape thickness versus blade cross sectional area; catch efficiency and adhesion of ice on the ADP tape; and surface condition of the blade spars.

As a natural consequence of clearing this helicopter for flights in light and moderate icing conditions, some blade damage will result, occasionally requiring rotor blade repairs or replacement. If this situation is unacceptable for the anticipated H-53 fleet exposure to icing conditions for reasons of cost or operational readiness, the following recommendations should be considered. Since the helicopter was judged capable of safe flight in moderate icing conditions, an engineering study should be made to consider the feasibility of using stronger, more dent and puncture resistant materials for the tail rotor blade pockets. Further investigations should be made of available materials/fluids for use as ice inhibitors on the H-53 and other helicopters. (R 10, R 11)

Artificial and natural icing flights identified one major problem area: main and tail rotor blade damage (pocket dents and tail rotor blade pocket punctures) from ice strikes due to shedding main rotor blade ice in light and moderate icing conditions. Damage to the rotor blades that occurred during all the icing flights was not structurally significant and presented no safety of flight hazards. Asymmetric main rotor blade ice sheddings during all icing flights were not severe enough to cause helicopter vibrations greater than moderate and presented no safety of flight hazards. The anti-icing systems operated satisfactorily under all icing conditions encountered. The EAPS (door closed) operated satisfactorily under moderate freezing rain conditions for 13 minutes with no apparent problems or noticeable engine performance degradation. The HH-53C helicopter operated satisfactorily under all icing conditions encountered during the artificial and natural icing flights, however, main and tail rotor blade pocket damage occurred intermittently, resulting in aircraft downtime for maintenance. Based on the preceeding conclusions and discussion, recommend the HH-53C helicopter be cleared for flight in light and moderate icing and freezing rain conditions with or without EAPS installed, but such flight should be restricted to mission essential operations.

A NOTE should be placed in the Flight Manual advising that the helicopter is cleared for mission essential operations in icing conditions up to moderate. (R 12, R 13)

## SYSTEMS EVALUATION

### General

Each section of this systems evaluation contains a brief systems analysis, specific test objectives, procedures, results, conclusions, and recommendations as applicable. Order of presentation is by work unit code (WUC) (reference 10). Significant deficiencies and those major items that were not documented in unsatisfactory materiel reports (UMR's) are discussed in the following sections. A summary of routine UMR's (RUMR's) by work unit code appears in appendix V. RUMR's were submitted per T.O. 00-35D-54; there were no emergency unsatisfactory reports submitted during the icing tests. Status of action on these RUMR's may be obtained from the Helicopter System Program Office, ASD (SDQH), Wright-

Patterson AFB, Ohio 45433. Conclusions and recommendations made in each RUMR are not contained in the Conclusions and Recommendations section unless specifically noted. Those deficiencies documented in RUMR's that are still open for action should be corrected. (R 14)

The HH-53C, when hangared overnight and/or exposed to overnight cold soaks averaging 25 degrees F or above, demonstrated excellent overall operational availability and reliability. This was in spite of the fact that the majority of the components that gave significant problems during the arctic tests were still installed. Under the test temperatures encountered these components now functioned properly or nearly so. This corroborates the fact that almost all the previous difficulties experienced and documented on the artic test were due to the extremely low ambient temperatures.

## Test Objectives

All HH-53C systems and subsystems were evaluated for functional suitability, compatibility, and reliability, when operating under mild cold (above 0 degrees F) and under inflight icing conditions. The systems evaluation was conducted as a follow-on to those tests performed by the same test team on the same test aircraft under arctic conditions (reference 4). One specific purpose was to perform a reevaluation of those components or subsystems that had proven to be problem areas under arctic conditions. The helicopter systems and subsystems were tested to determine the capabilities, limitations, and hazardous characteristics under artificial and natural icing conditions.

## Test Procedure

The test procedure followed with regards to protecting the helicopter from cold effects is outlined below. The procedure followed resulted in part from the experience of the test team with this helicopter in arctic conditions and from the typical procedures used by operational Air Force helicopter units in cold climates. The helicopter was hangared during the entire artificial icing test phase except for the short times before flight or during rapid turnarounds. The helicopter was parked on the ramp during the natural icing test phase. Ambient temperature data were gathered throughout the test program, recorded continuously during each test, and are included in appendix I.

## Test Results

### Nose Gear Strut (WUC 13000).

The nose gear strut leakage and bottoming problem reported in reference 4 did not recur. The same strut that was deficient under arctic conditions was still installed on the test helicopter throughout the icing tests and it proved to be trouble free when operated under the test temperatures encountered. The only exception to this was the infrequent recurrence of a problem that existed with this particular strut from the time that the helicopter was at the Climatic Laboratory, namely occasional leakage from the strut when the helicopter was parked with the nose gear cocked.

### Main Servos (WUC 14000).

New steel light weight primary tandem flight control servos had been installed during the arctic tests because of excessive leakage from the aluminum type (reference 4). These steel servos accumulated approximately 12 hours of operation during the arctic tests, and an additional 44 hours under the milder temperatures encountered during the icing tests and ferry flight to Edwards AFB. One servo developed a slight leak around the piston seal from unknown causes after approximately 37 hours of operation. This deficiency is under investigation and will be reported by UMR if required.

### Main Rotorhead (WUC 15000).

The excessive main rotor head sleeve and spindle leakage reported during the arctic tests did not occur during the icing tests. The sleeve and spindle reservoirs were serviced at the start of the icing tests and then did not require any servicing until 35 hours of flight had been accrued. The rotor head experienced temperatures in flight as low as 0 degrees F and altitudes as high as 11,000 feet PA. Total time on this rotor head at the termination of the icing tests and ferry flight to Edwards AFB was 44 hours.

### Engine Air Particle Separator (EAPS)(WUC 22271).

After it was discovered that EAPS icing was at a minimum with the EAPS doors closed, research was conducted to determine the feasibility of expanding the EAPS doors closed airspeed limit beyond 100 KIAS. This would allow closing of the EAPS doors at normal cruise speeds when icing conditions are encountered. This was requested and authorized by the SPO after the test results in icing conditions at normal airspeed limits were so successful. Prior to subjecting the EAPS to icing at airspeeds above 100 KIAS (normal Flight Manual limit) two tests were performed.

The first involved a test of the mechanical integrity of the EAPS doors both on the ground with the aircraft parked and in flight at airspeeds up to 160 KIAS. The static ground test involved attempts to force the EAPS doors to open, to close or to dislodge inward by hand, using all reasonable force. The doors remained in the selected positions with no tendency to buckle or to move the actuating jackscrew. It was assumed from this test that airloads could not move the doors.

The second test was both an inflight check of EAPS door function and mechanical integrity at airspeeds above 100 KIAS, and a baseline calibration of the instrumentation measuring EAPS static differential pressure. The EAPS doors were cycled open and closed at 10-knot increments starting at 80 KIAS up to 160 KIAS. At each airspeed the doors were checked for any visible deformation, vibration, and proper function, prior to proceeding to the next test airspeed. Postflight inspection revealed no loss of mechanical integrity, deformation or abnormalities whatsoever.

During this inflight test, the static pressure inside the EAPS was compared to the ambient static pressure sensed by the helicopter's pitot static system. The static pressure inside the EAPS was obtained from the standard production EAPS static pressure line where it entered the aircraft cabin. The EAPS test data are presented in appendix VI. The data indicated that engine operation was stable when EAPS doors were operated above normal Flight Manual limits. Under all icing conditions encountered, ice accumulations on the EAPS caused maximum differential pressure changes of two inches of water, doors closed.

Iced over EAPS doors were electrically opened without difficulty on the ground during postflight inspections. The engine was not running. The solid sheet of ice (up to 3/4 inch thick) over the inlet doors broke away easily, once into numerous large fragments, another time into two equal halves (figure 21).

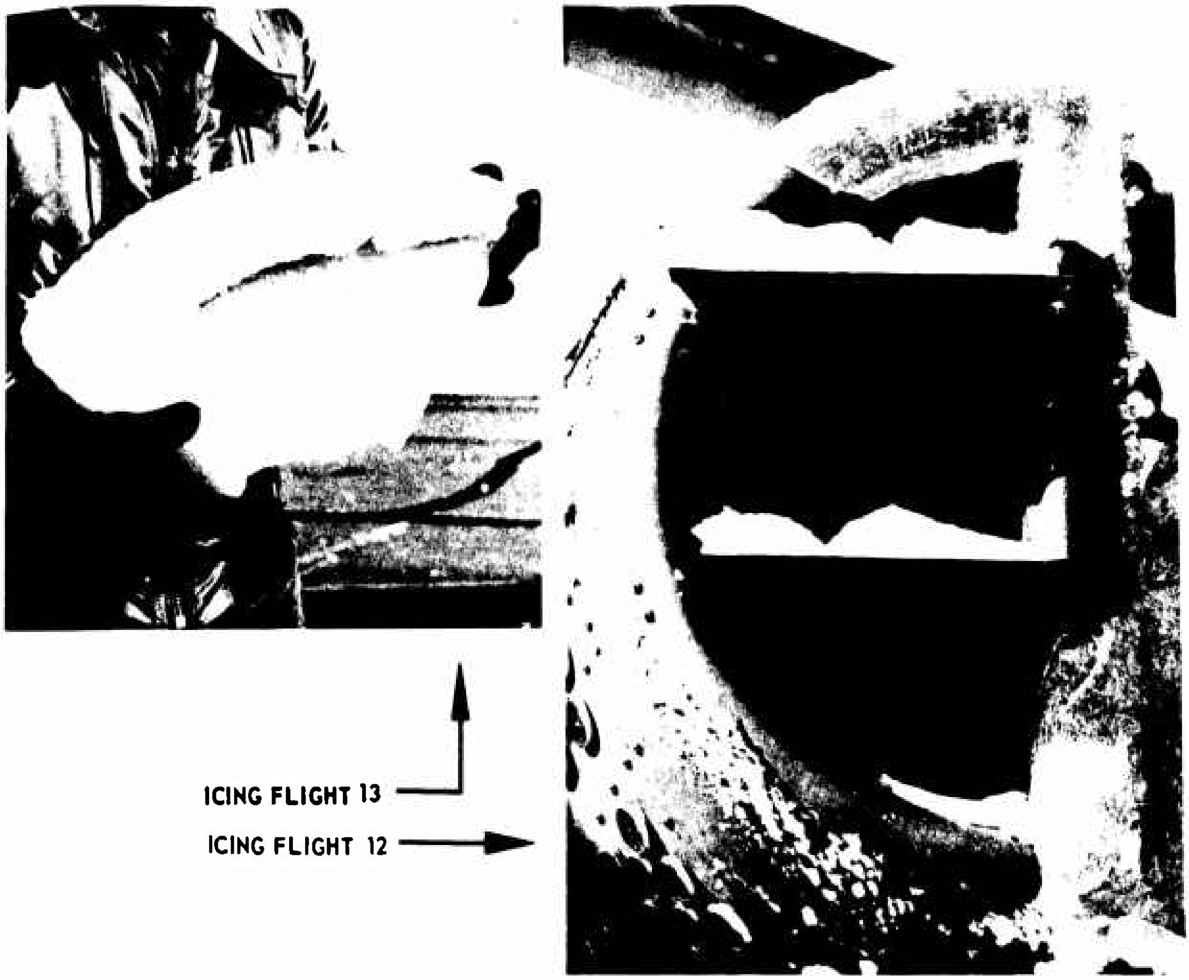


**Figure 21 Ice Slab from EAPS Door (Flight 13)**

Due to possible engine ingestion of ice fragments, iced over EAPS doors should not be opened until the engine has been shutdown after landing. (R 15)

An additional test was performed at a later date, that of shutting the EAPS scavange blower off when the EAPS doors were closed during 130 KIAS cruise. No change in static differential pressure or engine operation was noted.

Throughout the EAPS evaluation, when the doors were opened and closed, particular attention was paid to engine operation. The engine operated in a stable manner throughout the tests, even when subjected to rapid changes in inlet pressure at the 160 KIAS test point, as well as when maximum ice accretion occurred on the EAPS. The ice that formed on the EAPS was self-shedding in flight. This was confirmed by simultaneous observations from both the chase helicopter and the photopanel observer who saw noticeable decreases in the static differential pressure reading as the ice was shed.

There were no adverse mechanical or aerodynamic effects noted with either the EAPS or engine when the EAPS doors were operated above the present Flight Manual limits up to 160 KIAS. There were no adverse engine effects noted when the EAPS scavange blower was shut down, with the EAPS doors closed, during cruise flight. The present EAPS Flight Manual limit airspeed should be deleted to allow unrestricted use of the EAPS doors under icing conditions. The Flight Manual should indicate that continued cruise flight is possible in icing conditions if the EAPS scavange blowers fail or are turned off. (R 16, R 17)

After the ice that had been collected by the EAPS melted, water was found pooled inside the EAPS, immediately in front of the engine intake. This water, if refrozen, would represent a serious FOD source to the engine. The water had to be wiped out after each flight, since there was no drainhole in the inner EAPS skin. Water also pooled in between the inner and outer EAPS skins, which represented a source for corrosion. The EAPS lacked proper water drain capability. Small water drain holes should be drilled in the lowest portion of the EAPS inner and outer skins. (R 18)

### Windshields (WUC 41210).

The arctic tests commenced with one known discrepancy in the windshield systems, a delamination of approximately 10 percent of the area of the copilot's windshield located in the aft most part of the window (figure 22). The windshield anti-ice system was rarely used during the arctic tests. During the icing tests, the windshield heating system was used extensively, both on low and high heat. The system was completely effective in maintaining ice free vision under all conditions tested (except in the vicinity of the delaminated areas) when turned on one minute prior to entering icing conditions. The delamination area in the copilot's window increased approximately five percent. This increase was attributed to use of windshield heat. A random sprinkling of small (approximately 1/16 inch diameter) bubbles appeared in two of the three heated areas in the pilot's window between icing flights on the same day.

Two areas of delamination appeared in the center windshield overnight after having been used during the previous days (figure 23).

One third of the center windshield lost all anti-ice capability after icing flight 9. This portion of the windshield had a delamination

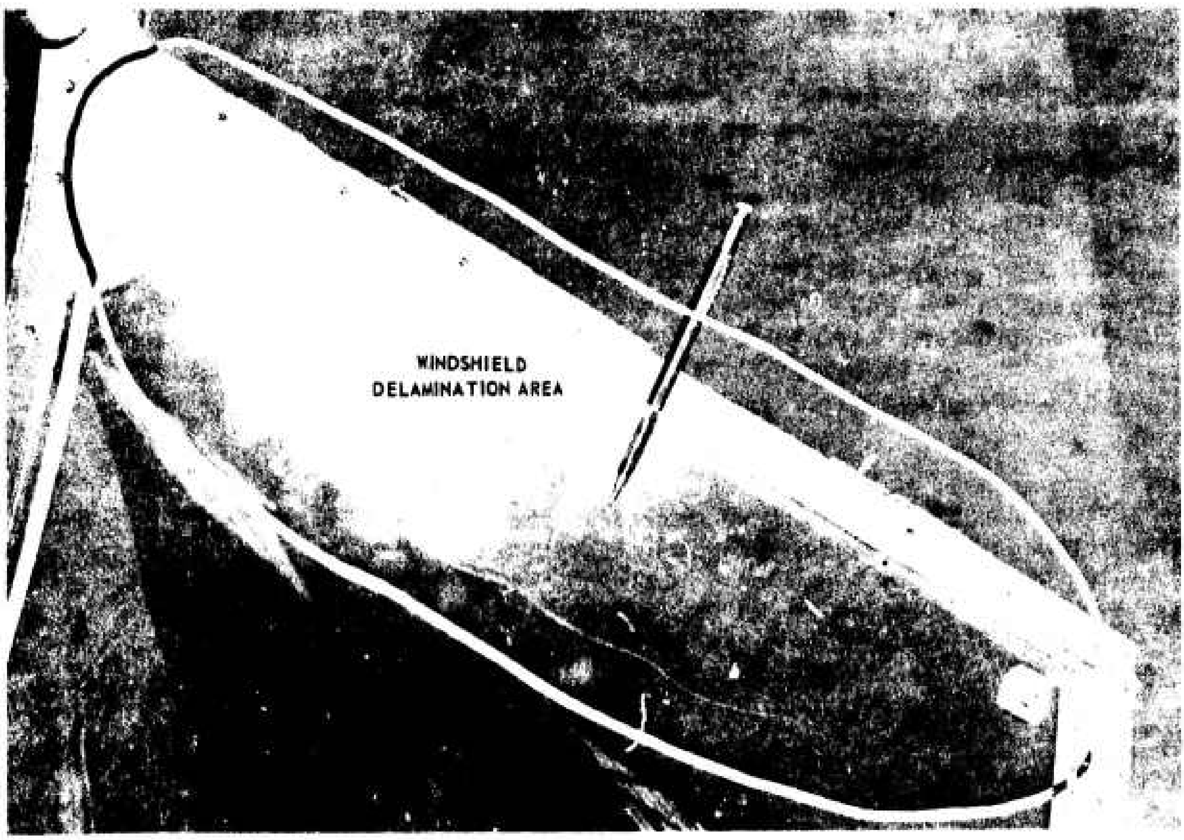


Figure 22 Windshield Delaminations

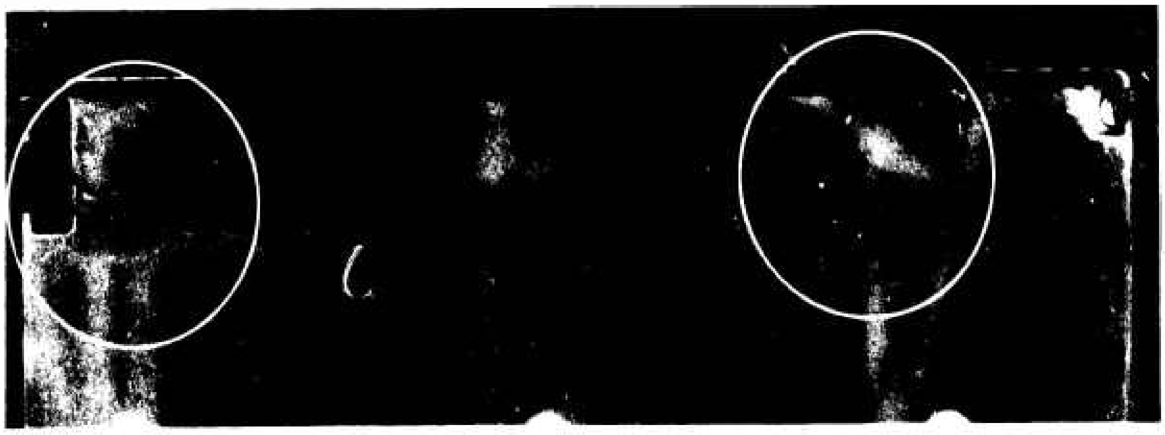


Figure 23 Windshield Delaminations

in which a burned or smoky area, immediately adjacent to the imbedded bus bar, was visible. The windshield anti-icing systems were in use for approximately 7 hours during the artificial icing tests and approximately 10 hours during the natural icing tests. As evaluated, the windshield anti-icing system was highly effective in maintaining ice free vision up to and including moderate icing conditions when turned on one minute prior to encountering icing conditions. The windshield was unsatisfactory in terms of its extremely short service life when using the anti-ice heating capability, due to frequent delaminations. The quality control inspection procedures employed during manufacturing and acceptance should be improved and/or the windshield design improved to eliminate the delamination problem. (R 19)

Miscellaneous.

The engine dual start valve (WUC 22000) reported in reference 4 continued to malfunction and caused both engines to motor three times on start, however, this only occurred on the coldest days. The Doppler Navigation Set (WUC 72000) was still erratic in operation with the same position and destination problems present as reported in reference 4. Additionally, navigation accuracy on the ferry trip varied randomly from 2 to 12 percent of the total distance traveled. The majority of the problems with the helicopter were basically electrical in nature. For example, there were problems with the UHF and FM radios, with the Doppler, tacan, and intercom. There were failures of the rotor tachometer generator and the copilot's course indicator. The main landing gear wiring harness repeatedly caused erroneous unsafe main landing gear indications; and the vent blower relay burned out. See appendix V for RUMR Summary.

Rotor Blade Motion Picture Camera (WUC 77000).

An evaluation of the feasibility and performance of a rotor blade mounted movie camera and the film it produced were objectives of the icing tests. Analysis of the unit is provided in the event that further utilization of this, or a similar installation, is anticipated. The camera was mounted on the inboard end of a main rotor blade sleeve and spindle housing, with a counterweight mounted on the opposite blade (figure 1). The advantages and deficiencies of this camera installation are discussed below.

Advantages

The camera provided a good tool with which to study blade dynamics in a single axis (blade bending) as well as ice accretion and shedding characteristics in flight, subject to some limitations.

The camera housing incorporated a heated window which was completely effective in protecting the camera lens and providing clear view under moderate icing conditions at OATs of -18 degrees C.

The pilot's reported no unacceptable vibrations or changes in handling and control characteristics while the camera was installed. Main rotor blade tracking to ±1/8 inch tolerance was critical to maintaining smooth flight after the camera had been installed.

## Deficiencies

Perspective problems caused by the short distance between the camera axis relative to the blade axis combined with the long length of blade, made precise interpretation of location of ice shedding impossible. The rotor blade should be marked as an aid to spanwise position location.

Film breakage occurred and was suspected to be caused by operation of the camera in a high vibration and high g environment. A camera that incorporates a "no loading zone" type of film transport mechanism should be used to minimize film breakage.

The blade icing camera was installed at the end of the arctic tests, and when tested after cold soak, the swivel fittings on the camera hydraulic lines at the rotor head beanie leaked. The camera incorporated a hydraulically operated sliding metal shutter for camera lens protection. The hydraulic lines were capped off at the rotor head to prevent loss of utility hydraulic system fluid. The hydraulic shutter was deemed to be an unnecessary and complicating feature in view of the protection afforded to the camera lens by the heated window. The hydraulic shutter mechanism and associated hydraulic lines should be eliminated.

The DBM-4C camera used was loaded from the side of the camera. In this installation, the camera was mounted approximately 90 degrees from the normal orientation, thus the camera had to be loaded and unloaded from below, and the film reels had an annoying tendency to fall down out of the camera. This loading-side-down orientation of the camera also caused excessive time for loading between flights. The orientation of the camera should be changed to permit easier loading.

Alignment of the camera required eight man-hours due to the poor design of the camera cover box and camera mounts. The camera could not be removed from the camera housing because the access hole in the housing was too small to allow the camera to pass through. The housing and camera both had to be removed in order to gain access to the camera mount for camera alignment. The camera cover and access panel should be redesigned for easier camera accessibility and alignment.

An analysis of the films taken by the camera revealed that the maximum frame rate available, 48 FPS as limited by camera motor speed, was too low to stop the motions of blade bending and actual ice fragment shedding. Additional camera motors with higher speed ranges should be made available.

The magazine capacity of the camera was too small. Only 160 seconds of film (200 feet at 48 FPS) were available, yet icing flights lasted up to 18 minutes. Additional film footage and increased frame rate would reduce the chances of missing significant events. Additional film capacity should be provided in future camera installations. It is recommended that the camera installation be improved in the above areas, as it should be a valuable tool in further research of helicopter rotor blade icing and the dynamics of newly designed rotor blades. (R 20, 21, 22, 23, 24, 25, 26)

The blade camera was a useful tool in determining ice accretion characteristics and blade dynamics, but it had many deficient operational qualities that degraded the camera's overall usefulness.

Ice Detector System.

The ice detector probe, located in the cabin heater inlet duct, was unreliable during the test program (appendix VII). During test point 12, an artificial icing condition, the ice detector system did not activate until it had been in a light icing condition for 8 minutes and on other flights it activated frequently, prior to entering the icing cloud. Also, during a flight in search of natural icing, the ice detector system activated in clear air, with no icing evident. The cabin heater was inoperative during part of the artificial icing/freezing rain tests, but was operational during the natural icing test phase.

The intermittent operation of the ice detector probe was possibly caused by its location within the cabin heater duct, and/or air flow blockage due to ice accumulation on the heater screen (figure 24). The ice detector system was unreliable. The operation of the ice detector probe should be checked and the sensor relocated to an area that would be more conducive to ice accretion in unrestricted airflow. (R 27)

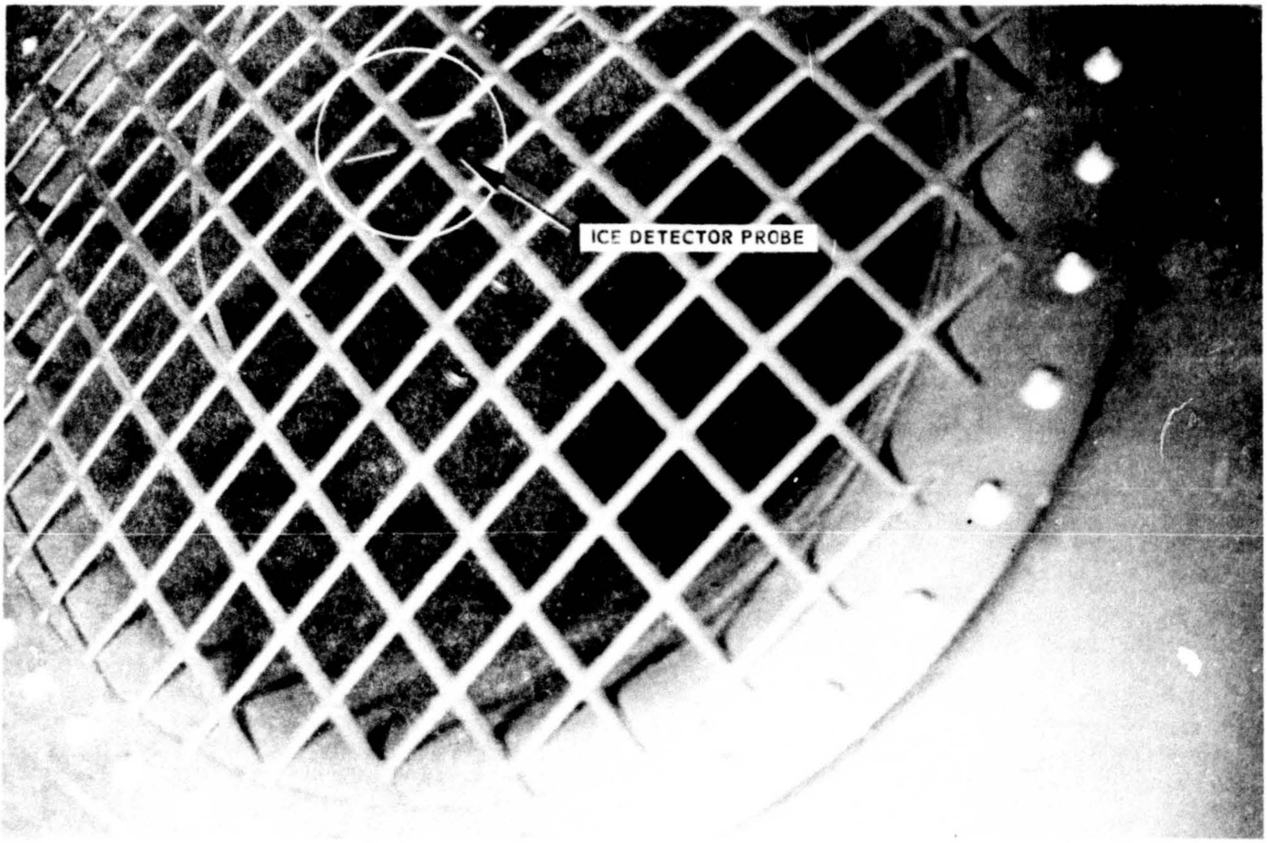


**Figure 24 Heater Inlet Screen with Ice Detector Probe Inside**

# CONCLUSIONS AND RECOMMENDATIONS

## GENERAL

The HH-53 helicopter and its anti-ice systems operated satisfactorily under all artificial and natural icing conditions encountered. Rotor blade ice shedding was random and caused damage to the rotor blades in the form of dents and punctures. These occurrences during the test did not compromise the structural integrity of the rotor blades. The ail rotor blade dents occurred throughout all tests (light and moderate icing conditions) when ice shedding occurred. Tail blade pocket punctures were noted during icing tests at colder OAT's (-18 degrees C) and were probably caused by ice shedding from the main rotor blade tips. Colder temperatures caused more ice to form further out toward the blade tips. Main rotor blade damage in the form of dents from ice strikes occurred occasionally at the colder OAT's (below -15 degrees C). The EAPS system functioned satisfactorily with inlet doors closed in light and moderate icing conditions with no engine performance degradation . Also, the EAPS was flown up to 160 KIAS doors closed, with no structural or engine performance degradation noted. Airframe ice, whether resulting from icing or freezing rain, was of no consequence to the operation of the flight controls and the overall operation of the helicopter. Based on the preceding conclusions, the HH-53C helicopter should be cleared for flight in light and moderate icing and freezing rain conditions with or without EAPS installed, but such flights should be restricted to mission essential operations.

## ICING EVALUATION

No damage was inflicted on the HH-53C airframe during any icing tests. No hazards or problems due to airframe icing were created on any icing flight.

The heater inlet screen could be totally blocked off by ice formations should light or moderate icing conditions at OAT's from 0 degrees C through -13 degrees C be encountered for extended periods of time. Possible heater system damage or erratic operation due to reduced airflow might result from heater operation after the heater inlet duct was iced over.

1. The information given below concerning heater operation in icing conditions should be included in the Flight Manual (page 9 ).

NOTE

HEATER OPERATION - ICING CONDITIONS

The heater inlet duct screen will become iced over if icing conditions at OAT's between 0 degrees C and -13 degrees C are encountered for extended periods of time.

> If this occurs, erratic heater operation may result due to reduced airflow. If reduced airflow from the heater outlet ducts is noticed while flying in icing conditions, the heater should be turned off to preclude possible heater damage.

The engines, engine air inlet and engine air anti-icing systems functioned satisfactorily under all icing conditions encountered.

Engine operation with EAPS installed and doors closed in icing conditions up to moderate was unaffected by ice buildup on the EAPS. The EAPS, when operated with doors closed precluded the possibility of engine FOD from ice ingestion.

2. The EAPS should be cleared for flight in icing conditions up through moderate with the doors closed (page 15 ).

3. If icing conditions are encountered in flight with EAPS installed, the EAPS doors should be closed immediately to prevent engine FOD from ice shed from the rotor system or off the EAPS inlet lip or doors (page 15 ).

4. Once closed, the EAPS doors should not be opened again until the EAPS doors are visually checked clear of all ice in flight, or the helicopter is on the ground with the engines stopped (page 15 ).

Ice strike damage did not affect the structural integrity of the rotor blades and did not present any immediate safety of flight hazards. Main rotor blade ice shedding was random and asymmetric. Tail or main rotor blade minor damage could occur at any time during flight in an icing condition.

The ADP tape as evaluated was unsatisfactory for H-53 helicopters.

## OPERATIONAL ANALYSIS

A change in rotor RPM, by moving the speed selectors, was the most effective method in reducing vibrations caused by asymmetric shedding of main and tail rotor blade ice.

5. The information given below concerning vibrations caused by asymmetric rotor blade ice shedding should be included in the Flight Manual (page 23 ).

NOTE

VIBRATIONS-ASYMMETRIC ROTOR BLADE ICE SHEDDING

> If uncomfortable vibrations are encountered due to asymmetric ice shedding from the tail rotor or main rotor blades, change the rotor RPM ($N_r$). A vertical medium frequency and a low frequency shuffle may be experienced. This may require cycling the rotor RPM through the full governed

range several times in order to reduce or eliminate vibrations caused by uneven distribution of ice on the blade leading edges.

Minor rotor blade damage may occur in flight as a result of random ice shedding. Tail rotor damage in the form of skin punctures may occur if ice is shed in slow speed flight, a hover, or during taxi turns on the ground. At no time during the icing tests was it felt that the magnitude of the tail rotor dents and punctures experienced in the blade pockets compromised safety of flight. Minor tail rotor blade damage in the form of dents occurred during all flights on which significant main rotor blade ice shedding took place.

6. The information given below concerning landing procedures when aircraft ice is evident should be included in the Flight Manual (page 25).

CAUTION

ICE-LANDING PROCEDURES

> If a landing must be made with ice remaining on the helicopter after flight through icing conditions, a running landing should be made, followed by a minimum of taxi turns in order to reduce the possibility of tail rotor blade damage from ice shedding from the main rotor blades. If a hover landing must be made with ice remaining on the helicopter, there is a possibility that tail rotor blade damage may occur. Ground personnel must remain well clear of the helicopter until the main rotor is stopped to prevent injury from ice slung by the rotor blades during shutdown.

The windshield anti-icing system was operated whenever flying in icing conditions and was highly effective in keeping the windshields ice free (except in the vicinity of the delaminated areas) when turned on one minute prior to encountering icing conditions.

7. A CAUTION should be placed in the Flight Manual advising that windshield anti-ice should be turned on at the first sign of icing conditions. Any delay in applying heat to the windshield could result in severely reduced visibility during a critical flight phase, e.g., approach and/or landing (page 25).

Test results indicate the HH-53C had sufficient power available to maintain a normal cruise under moderate icing conditions at any allowable gross weight.

The head of the refueling probe acquired ice in sufficient quantities to defeat first contact refueling connections.

8. The following information should be included in appropriate section of the Refueling Manual: (page 26).

NOTE

AIR REFUELING AFTER ICING CONDITIONS ARE ENCOUNTERED

> Should aerial refueling be attempted after flight in an icing condition, the pilot may have to make several passes at the drogue basket attempting off center contacts to knock off the accumulated ice. The success of this procedure could be visually verified by the scanner on the refueling tanker. After the probe head has been visually scanned and determined to be clear of ice, wet refueling can commence using normal procedures.

During artificial icing flights one or more of the main rotor blade anti-flap restrainers hung out in the flight position during rotor shutdown. While no problems occurred as a result of this on the icing tests, this could allow blade flapping which could result in possible materiel damage and personnel injury. The anti-flap restrainers returned to the nonflight position as soon as the ice melted.

9. The following information should be included in the Flight Manual under ICING (Section IX) (page 26 ):

CAUTION

> Pilots and ground crewmen should be alerted for main rotor blade flapping during rotor shutdown in windy conditions after ice has accumulated on the main rotor head. Under these circumstances, it is necessary to park into the wind to minimize possible blade/fuselage rotor head damage, or personnel injury during shutdown due to anti-flapping restrainers.

Maintenance and repair costs will increase as a result of flights in icing conditions. If anticipated HH-53C fleet exposure to icing conditions is judged sufficient to make rotor blade replacement/repair costs significant, the following recommendations should be acted upon.

10. Since the helicopter was structurally capable of safe flight in moderate icing conditions, an engineering study should be made to consider the feasibility of using stronger, more dent resistant materials for the construction of the tail rotor blade pockets and tip caps (page 30 ).

11. Further investigation should be made of available materials/fluids for use as ice inhibitors on the H-53 rotor blades (page 30 ).

The HH-53C was safe to fly in moderate icing conditions.

12. The HH-53C helicopter should be cleared for flight in light and moderate icing and freezing rain conditions with or without EAPS

installed, but such flight should be restricted to mission essential operations (page 30).

13. A NOTE should be placed in the Flight Manual advising that the helicopter is cleared for mission essential operations in icing conditions up to moderate (page 30).

NOTE

ICING

> The HH-53C helicopter is cleared for flight in light and moderate icing and freezing rain conditions with or without EAPS installed, but such flights should be restricted to mission essential operations. This restriction was based on the probability of the occurrence of rotor blade damage caused by ice strikes from shedding ice in light and moderate icing conditions.

## SYSTEMS EVALUATION

The HH-53C, when hangared overnight and/or exposed to overnight cold soaks averaging 25 degrees F or above, demonstrated excellent overall operational availability and reliability in spite of the fact that the majority of the components that gave significant problems during the arctic tests were still installed.

14. Those deficiencies documented in RUMR's that are still open for action should be corrected (page 31).

The ice that formed on the EAPS in flight was self-shedding.

There were no adverse mechanical or aerodynamic effects noted with either the EAPS or engine when the EAPS doors were cycled above the present Flight Manual limits, up to 160 KIAS. There was no adverse effect noted on the engine or change in differential pressure noted when the EAPS scavange blower was shut down with the EAPS doors closed, during cruise flight. Iced over EAPS doors were electrically opened without problems when covered with ice as much as 3/4 inch thick.

15. Iced over EAPS doors should not be opened until the engines have been shut down after landing (page 33).

16. The present EAPS Flight Manual limit airspeed should be deleted to allow unrestricted use of the EAPS doors under icing conditions (page 34).

17. The Flight Manual should indicate that continued cruise flight is possible in icing conditions if the EAPS scavange blowers fail or are turned off (page 34).

The EAPS lacked proper water drain capability.

18. Small water drain holes should be drilled in the lowest portion of

the EAPS inner and outer skins (page 34).

The windshield anti-ice system was highly effective in maintaining ice free vision in icing conditions up to and including moderate, when turned on immediately prior to encountering icing conditions.

The heated windshields were unsatisfactory in terms of extremely short service life when using the anti-ice heating capability due to frequent delaminations.

19. The windshield quality control inspection procedures employed during manufacturing and acceptance should be improved and/or the windshield design improved to eliminate the delamination problem (page 36).

The blade camera installation was a useful tool in determining ice accretion characteristics and blade dynamics, but it had many deficient operational qualities that degraded the camera's overall usefulness. The camera installation should be improved in the following areas, as it should be a valuable tool in further research of rotor blade icing and dynamics.

20. The rotor blade should be marked in some manner to provide relative distances in a defined field of view (page 37).

21. A camera that incorporates a "no loading zone" type of film transport mechanism should be used to minimize film breakage (page 37).

22. Eliminate the hydraulic shutter mechanism and associated hydraulic lines (page 37).

23. Orient the camera to permit loading from the side or top vice the present loading-side-down orientation (page 37).

24. Redesign the camera cover box/access panel to permit removal of the camera for alignment or maintenance without first having to remove the entire camera cover (page 37).

25. Additional camera motors with higher speed ranges should be made available (page 37).

26. Increase available film magazine capacity (page 37).

The ice detector system was unreliable.

27. The operation of the ice detector probe should be checked and the sensor relocated to an area that would be more conducive to ice accretion in unrestricted airflow (page 38).

# APPENDIX I
# TEST SUMMARY (SYSTEMS)

| Systems Test | Test Accomplished | Date (1971) | Soak Time (hr) | Average Soak Temp (deg F) | Flt Hrs | Comment |
|---|---|---|---|---|---|---|
| 1 | Icing Flt No. 1 | 21 Mar | 0.5 | 6 | 0.7 | Copilot's windshield delaminated - Trace icing. |
| 2 | Icing Flt No. 2 | 21 Mar | 0.5 | 16 | 0.6 | Light icing. |
| 3 | Icing Flt No. 3 | 22 Mar | 0.3 | 13 | 0.7 | Light icing. |
| 4 | Icing Flt No. 4 | 22 Mar | 0.3 | 26 | 0.6 | Moderate icing. |
| 5 | Icing Flt No. 5 | 22 Mar | 0.4 | 27 | 0.6 | Tail rotor blade holed. Moderate icing. |
| 6 | Operation Check | 26 Mar | 0.2 | 16 | 0.5 | Tail rotor blade change - Heater inoperative. |
| 7 | Icing Flt No. 6 | 27 Mar | 0.5 | 10 | 0.6 | Light icing. |
| 8 | Icing Flt No. 7 | 27 Mar | 0.1 | 17 | 0.7 | Light icing. |
| 9 | Icing Flt No. 8 | 27 Mar | 0.2 | 21 | 0.7 | Moderate icing. |
| 10 | Icing Flt No. 9 | 28 Mar | 0.2 | 22 | 0.7 | Moderate icing. |
| 11 | Icing Flt No. 10 | 29 Mar | 0.3 | 13 | 0.6 | No. 2 EAPS installed - Trace icing. |
| 12 | Icing Flt No. 11 | 29 Mar | 1.0 | 18 | 0.5 | Light icing. |
| 13 | Icing Flt No. 12 | 29 Mar | 1.0 | 24 | 0.8 | Light icing - Center windshield delaminated. |
| 14 | Icing Flt No. 13 | 29 Mar | 1.2 | 25 | 0.7 | Moderate icing. |
| 15 | Icing Flt No. 14 | 30 Mar | 0.5 | 4 | 1.2 | Moderate icing. |
| 16 | Icing Flt No. 15 | 31 Mar | 0.1 | 2 | 1.2 | Heater repaired. ADP tape on. Moderate icing. Tail rotor blades pocket punctured. |
| 17 | Operation Check | 3 Apr | 1.2 | 23 | 0.5 | Tail rotor blades change. |
| 18 | Ferry to Elmendorf | 3 Apr | 1.2 | 24 | 2.0 | Unsafe main landing gear indications. |
| 19 | Icing Flt No. 16 | 4 Apr | 18.0 | 34 | 2.2 | Light natural icing. |
| 20 | Icing Flt No. 17 | 4 Apr | 1.7 | 40 | 2.1 | Pilots windshield delaminated. Light natural icing. |
| 21 | Icing Flt No. 18 | 5 Apr | 18.0 | 31 | 2.7 | No ice. |
| 22 | FCF | 5 Apr | 3.0 | 39 | 0.5 | Main rotor tracked. |
| 23 | Icing Flt No. 19 | 5 Apr | 0.0 | 00 | 0.5 | No ice. |
| 24 | Icing Flt No. 20 | 6 Apr | 14.0 | 32 | 2.2 | Light icing. |
| 25 | Abort | 7 Apr | 25.0 | 31 | 0.0 | Rotor tachometer inoperative. Main rotor blade pocket crack. |
| 26 | Icing Flt No. 21 | 7 Apr | 0.5 | 38 | 1.7 | Light icing. |
| 27 | FCF | 9 Apr | 3.0 | 34 | 0.3 | Blade camera removed. Track main rotor blades. Unsafe main landing gear indications. |
| 28 | Icing Flt No. 22 Ferry to Yakutat | 10 Apr | 15.0 | 25 | 2.6 | Light icing, tail rotor blade pocket punctured. Main landing gear unsafe indications. |
| 29 | Ferry to Juneau | 10 Apr | 1.0 | 36 | 1.7 | Unsafe main landing gear indications. |
| 30 | Ferry to Annette | 11 Apr | 18.0 | 35 | 2.7 | |
| 31 | Ferry to Vancouver | 11 Apr | 1.0 | 40 | 4.0 | Main rotor blade pocket crack. |
| 32 | Ferry to McChord | 12 Apr | 17.0 | 42 | 1.0 | Unsafe main landing gear indications. |
| 33 | Ferry to Medford | 12 Apr | 3.0 | 50 | 2.3 | |
| 34 | Ferry to Sacramento | 13 Apr | 16.0 | 45 | 2.0 | Unsafe main landing gear indications. |
| 35 | Ferry to Edwards | 13 Apr | 1.0 | 50 | 2.5 | |

# APPENDIX II
# HH-53C ARTIFICIAL AND NATURAL ICING CONDITIONS

Table I

HH-53 ARTIFICIAL ICING CONDITIONS

| Icing Flight | Airspeed (KIAS) | Liquid Water Content (gram/meter$^3$) | Outside Air Temperature (deg C) | Pressure Altitude (ft) | Distance Behind Tanker (ft) | Approximate Gross Weight (lb) | Time In Cloud (min) | Remarks |
|---|---|---|---|---|---|---|---|---|
| ROTOR BLADE ICING | | | | | | | | |
| 1 | 120 | 0.10 | -12 | 6,500 | 600 | 35,700 | 5 | Trace icing-1/16 inch ice on main rotor blade (4th pocket) near hub. 1/8 inch ice on HF antenna. No ice shedding. |
| 2 | 120 | 0.30 | -13 | 7,000 | 600 | 33,500 | 5 | Light glime icing-1/8-3/16 inch ice buildup on main rotor blade. 1/4 inch ice on HF antenna. No ice shedding. |
| 3 | 100 | 0.30 | -14 | 8,000 | 600 | 32,200 | 7 | Light rime icing-1/4 inch ice on main rotor blade. 3/8 inch ice on HF antenna. No rotor blade ice shedding. |
| 4 | 100 | 0.50 | -17 | 9,000 | 600 | 30,700 | 7 | Moderate rime icing-7/16 inch ice on main rotor blade near hub (4th pocket) 9/16 inch ice shedding occurred when HH-53C changed altitude/airspeed during ice cloud exit. Minor vibrations experienced. |
| 5 | 115 | 0.50 | -15 | 8,300 | 500 | 31,600 | 7 | Moderate rime icing-1/2 inch ice on main rotor blade 3/4 inch ice on HF antenna. Ice shedding occurred 30 seconds after exiting spray cloud. Moderate vibrations. Tail rotor blade pocket punctures. |
| 6 | 120 | 0.40 | -11 | 2,500 | 600 | 31,400 | 7 | Light rime icing-5/16 inch ice on HF antenna. 1/8 inch ice on main rotor at 7/8 span. No shedding. |
| 7 | 120 | 0.40 | -11 | 4,000 | 600 | 29,900 | 14 | Light rime icing-1/2 inch ice on main rotor blade. 1/4 inch ice on main rotor blade at 75 percent span. 15/16 inch on HF antenna. Ice shedding occurred at 9.5 minutes and 13 minutes. |
| 8 | 120 | 0.50 | -13 | 5,000 | 500 | 31,300 | 10 | Moderate glime icing-11/16 inch ice on main rotor blade at 4th pocket near hub. 7/8 inch ice on HF antenna. Ice shedding at 6.8 minutes and 7.8 minutes. |
| 9 | 95 | 0.65 | -11 | 8,500 | 500 | 28,800 | 15 | Moderate glime icing 7/8 inch ice on main rotor blade. 1 inch ice on HF antenna. 1-1/4 ice fingers on heater inlet screens, 90 percent blockage. |

Table I (Concluded)

| Icing Flight | Airspeed (KIAS) | Liquid Water Content (gram/meter$^3$) | Outside Air Temperature (deg C) | Pressure Altitude (ft) | Distance Behind Tanker (ft) | Approximate Gross Weight (lb) | Time In Cloud (min) | Remarks |
|---|---|---|---|---|---|---|---|---|
| EAPS ICING - DOORS OPEN | | | | | | | | |
| 10 | 120 | 0.10 | -10 | 3,500 | 600 | 36,600 | 5 | Trace icing 5/8 inch ice on HF antenna, 1/4 inch ice on EAPS lips, 7/ 2 inch on EAPS door. No ice blockage on EAPS. |
| 11 | 120 | 0.30 | -10 | 3,500 | 600 | 35,100 | 5 | Light glime icing 2/3 inch ice on HF antenna 1/4 inch on EAPS lips. Trace ice buildup inside EAPS. |
| EAPS ICING - DOORS CLOSED | | | | | | | | |
| 12 | 85 | 0.37 | -10 | 3,500 | 600 | 34,200 | 20 | Light rime icing 1-5/16 inch ice on HF antenna. 15/16 inch ice on EAPS lip. 13/32 inch ice on EAPS door, 25 percent heater duct blockage. |
| ARTIFICIAL FREEZING RAIN | | | | | | | | |
| 13 | 100 | 0.80 | -7 | 1,900 | 300 | 33,300 | 13 | Moderate clear icing conditions. HF antenna 2 inch thick. Heater duct screen 90 percent ice blockage. 1-15/32 ice fingers on EAPS screens. Approximately 20 EAPS ducts had 1/8 inch ice on them. Trace ice inside EAPS. |
| ROTOR BLADE ICING | | | | | | | | |
| 14 | 100 | 0.60 | -18 | 6,000 | 600 | 36,600 | 18 | Moderate rime icing condition. No EAPS blockage due to ice. Ice on main rotor blade out to within 4 pockets of tip after landing and shutdown, main rotor blade 5/8 inch ice. Ice near tip 1/4 inch thick. 1-1/2 inch ice on HF antenna. 1-1/2 inch EAPS lips. 3/4 inch on EAPS doors. No ice inside of EAPS. |
| 15 | 100 | 0.60 | -19 | 8,500 | 600 | 34,400 | 18 | Moderate rime icing conditions. 1-1/8 inch ice at 23rd pocket on main rotor blade 5/8 inch ice at No. 10 pocket. Heater not blocked. HF antenna 1-3/4 inch ice. Ice did not shed symmetrically and ice did not shed as early as in all previous tests. Ice on blade tips to within 3 pockets 1/4 to 3/8 inch thick. No handling problems. Tail rotor blade pocket punctures. |

## Table II

## NATURAL ICING CONDITIONS

| Icing Flight | Airspeed (KIAS) | Temperature OAT (deg C) | Duration (min) | Average Thickness Ice (in.) | Remarks |
|---|---|---|---|---|---|
| 16 | 120 | -10 | 3.5 | 3/16 | Light clear-rime mixture. |
| 17 | 120 | -9 | 19[a] | 9/16[a] | Light clear-rime mixture. |
| 18 | No natural icing encountered. | | | | |
| 19 | No natural icing encountered. | | | | |
| 20 | 120 | -6 | 1 | 1/16 | Moderate clear-rime mixture. |
| | 132 | -6 | 3 | 1/8 | Light clear-rime mixture. |
| | 126 | -9 | 3 | 1/16 | Trace clear-rime. |
| 21 | 125 | -6 | 1 | 1/32 | Trace rime mixed with snow. |
| | 90 | -13 | 4 | 1/8 | Light rime mixed with snow. |
| | 120 | -10 | 3 | 1/8 | Light rime mixed with snow. |
| | 110 | -13 | 3 | 1/16 | Light rime mixed with snow. |
| | 105 | -13 | 1 | 1/32 | Light rime mixed with snow. |
| 22[b] | 120 | -18 | 4 | 1/8 | Light rime. One tail rotor blade pocket punctured. |

[a] This was not continuous operation in icing conditions, but total accumulated.

[b] This flight was enroute to Yakutat, Alaska, on the return trip to Edwards.

# APPENDIX III
# ICING DEFINITIONS[a]

| Icing Condition | Liquid Water Content[b] (grams/cubic meter) |
|---|---|
| Trace | $0 < 0.1$ |
| Light | $0.1 < 0.5$ |
| Moderate | $0.5 < 1.0$ |
| Heavy | 1.0 |

Rime Ice - An opaque ice formed by the instantaneous freezing of small supercooled droplets.

Clear Ice - A semi-transparent ice formed the slower freezing of larger supercooled droplets.

Glime Ice - A mixture of clear ice and rime ice which is very common.

Trace Icing - Accumulation of one-half inch of ice on a small probe per 80 miles. The presence of ice on the airframe is perceptible but the rate of accretion is nearly balanced by the rate of sublimation. Therefore, this is not a hazard unless encountered for an extended period of time. The use of deicing equipment is unnecessary.

Light Icing - Accumulation of one-half inch of ice on a small probe per 40 miles. The rate of accretion is sufficient to create a hazard if flight is prolonged in these conditions but insufficient to make diversionary action necessary. Occasional use of deicing equipment may be necessary.

Moderate Icing - Accumulation of one-half inch of ice on a small probe per 20 miles. On the airframe, the rate of accretion is excessive, making even short encounters under these conditions hazardous. Immediate diversion is necessary or use of deicing equipment is mandatory.

Heavy Icing - Accumulation of one-half inch of ice on a small probe per 10 miles. Under these conditions, deicing equipment fails to reduce or control the hazard and immediate exit from the icing condition is mandatory.

Collection Efficiency - The ratio of the mass of water contained in the oncoming flow to the mass of water trapped by a surface in a given time interval.

[a] (reference 9)

[b] Based on a mean drop size of 25 microns.

# APPENDIX IV
# ROTOR BLADE ICE SHEDDING
# ARTIFICIAL ICING

| Icing Flight | OAT (deg C) | Airspeed (KIAS) | Approximate Helicopter Gross Weight (lb) | Approximate[a] Main Rotor Blade Ice Thickness when Shed (in.) | Approximate[a] Tail Rotor Blade Ice Thickness when Shed (in.) |
|---|---|---|---|---|---|
| 7 | -11.0 | 120 | 29,900 | 0.43 | 0.28 |
| 8 | -12.5 | 120 | 31,300 | 0.54 | 0.32 |
| 9 | -10.5 | 95 | 28,800 | 0.52 | 0.25 |
| 14 | -18.0 | 100 | 26,600 | 0.41 | 0.31 |
| 15 | -19.0 | 100 | 34,400 | 0.59 | 0.26 |

[a] Thicknesses were calculated based on an assumed constant rate of ice accumulation in artificial icing conditions.

# APPENDIX V
# ROUTINE UNSATISFACTORY MATERIEL REPORT SUMMARY

| AFFTC RUMR No. | Date (1971) | Deficiency | Action Status |
|---|---|---|---|
| | | LANDING GEAR (WUC 13000) | |
| R71-135 | Pending | Landing gear wiring harness (13226) | Open |
| | | AIR CONDITIONING, PRESSURIZATION AND SURFACE ICE (WUC 41000) | |
| R71-130 | 29 Mar | Burned cabin heater relay (41110) | Open |
| R71-131 | Pending | Copilot windshield delaminating (41210) | Open |
| R71-132 | Pending | Center windshield delaminating (41210) | Open |
| R71-133 | Pending | Pilots windshield delaminating (41210) | Open |
| | | HYDRAULIC AND PNEUMATIC POWER SUPPLY (WUC 45000) | |
| R71-128 | 25 Mar | Crimped Hydraulic Line (45143) | Open |
| R71-129 | 31 Mar | Filter Wrenching Surface Design Deficiency (45145) | Open |
| | | UHF COMMUNICATIONS (WUC 63000) | |
| R71-127 | 23 Mar | Bad DC Motor in UHF Radio (63111) | Open |

# APPENDIX VI
# HH-53C EAPS STATIC DIFFERENTIAL PRESSURE CALIBRATION

31 Mar 71 $N_r$ = 101 -102 pct

| OAT (deg C) | Pressure Altitude (ft) | Airspeed (KIAS) | No.1 Engine $T_5$ deg C | No.2 Engine $T_5$ deg C | No.1 Engine Torque (pct) | No.2 Engine Torque (pct) | No. 1 Engine $N_g$ (pct) | No. 2 Engine $N_g$ (pct) | Static Diff Pressure (in. $H_2O$) | EAPS Door Position |
|---|---|---|---|---|---|---|---|---|---|---|
| -11 | 1,000 | 82 | 427 | 435 | 38 | 43 | 81.2 | 83.5 | +0.2 | Open |
| -11 | 1,000 | 82 | 429 | 433 | 38 | 43 | 81.7 | 83.3 | -5.1 | Closed |
| -11 | 1,050 | 95 | 437 | 441 | 39 | 44 | 82.0 | 83.7 | -5.4 | Closed |
| -11 | 1,070 | 95 | 435 | 435 | 39 | 44 | 81.8 | 83.7 | +1.1 | Open |
| -12 | 1,020 | 104 | 437 | 437 | 41 | 47 | 82.0 | 83.8 | +2.2 | Open |
| -12 | 1,020 | 104 | 437 | 440 | 41 | 47 | 82.1 | 84.1 | -5.9 | Closed |
| -13 | 980 | 114 | 443 | 448 | 44 | 49 | 82.3 | 84.3 | -6.3 | Closed |
| -13 | 970 | 114 | 441 | 445 | 44 | 49 | 82.2 | 84.2 | +3.5 | Open |
| -13 | 970 | 124 | 457 | 449 | 49 | 54 | 82.8 | 84.5 | +1.6 | Open |
| -13 | 1,000 | 124 | 459 | 458 | 49 | 54 | 83.0 | 84.9 | -6.6 | Closed |
| -13 | 970 | 132 | 469 | 478 | 54 | 59 | 83.4 | 85.7 | -7.2 | Closed |
| -12 | 970 | 133 | 470 | 476 | 54 | 59 | 83.1 | 85.5 | +6.2 | Open |
| -12 | 940 | 143 | 488 | 490 | 62 | 67 | 84.0 | 86.3 | +7.1 | Open |
| -13 | 920 | 143 | 493 | 498 | 62 | 67 | 84.1 | 86.6 | -8.2 | Closed |
| -13 | 900 | 153 | 525 | 525 | 73 | 78 | 85.3 | 87.8 | -9.0 | Closed |
| -12 | 890 | 153 | 525 | 521 | 73 | 78 | 85.6 | 87.9 | +8.5 | Open |
| -11 | 960 | 165 | 569 | 558 | 91 | 96 | 87.2 | 90.1 | +9.8 | Open |
| -11 | 1,000 | 166 | 575 | 568 | 91 | 96 | 87.6 | 90.6 | -9.6 | Closed |

# APPENDIX VII
# ICE DETECTOR RELIABILITY[a]

| Icing Flight | Total Icing Light Indications (Number) | Icing Light Indications In an Icing Condition (Number) | Aircraft Heater | Approximate Liquid Water Content (gram/meter$^3$) | Airspeed (KIAS) | OAT (deg C) | Approximate Time in Condition (min) | Icing Condition |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 (Off) | On | 0.1 | 120 | -12 | 5 | Trace |
| 2 | 0 | 0 (Off) | On | 0.3 | 120 | -13 | 5 | Light |
| 3 | 8 | 1 | On | 0.3 | 100 | -14 | 7 | Light |
| 4 | 5 | 0 | On | 0.5 | 100 | -17 | 7 | Moderate |
| 5 | 16 | 2 | Not Used | 0.5 | 115 | -15 | 7 | Moderate |
| 6 | 4 | 0 | Inoperative | 0.4 | 120 | -11 | 7 | Light |
| 7 | 5 | 3 | Inoperative | 0.4 | 120 | -11 | 14 | Light |
| 8 | 11 | 2 | Inoperative | 0.5 | 120 | -13 | 10 | Moderate |
| 9 | 18 | 6 | Inoperative | 0.7 | 95 | -11 | 15 | Moderate |
| 10 | 22 | 4 | Inoperative | 0.1 | 120 | -10 | 5 | Trace |
| 11 | 8 | 4 | Inoperative | 0.3 | 120 | -10 | 5 | Light |
| 12[b] | 21 | 17 | Inoperative | 0.4 | 85 | -10 | 20 | Light |
| 13[c] | --- | --- | Inoperative | 0.8 | 100 | -7 | 18 | Moderate |
| 14[b] | 12 | 11 | Inoperative | 0.6 | 100 | -18 | 18 | Moderate |
| 15 | 4 | 2 | Inoperative | 0.6 | 100 | -19 | 18 | Moderate |
| 16 | 2 | 1 | On | --- | 120 | -10 | 4 | Light |
| 17 | 2 | 0 | On | --- | --- | --- | --- | None |
| 18 | 0 | 0 | On | --- | --- | --- | --- | None |
| 19 | 8 | 1 | On | --- | --- | -7 | 8 | Light |
| 20 | 4 | 2 | On | --- | --- | -10 | 11 | Trace |

[a] The photopanel camera was operated during all icing conditions, but due to use of variable frame rates, some of the icing light indications may have not been recorded. However, the data presented above was representative of the ice detector reliability.

[b] Photopanel not on during appreciable portions of flight, i.e., climbout and descent.

[c] Photopanel camera malfunction.

# REFERENCES

1. Dowden, Donald J.; Etzel, Gregory A.M., Major USAF; Lovrien, Clark E., Jr., Major USAF, Category II Icing Tests of the HH-53C Helicopter, FTC-TR-71-26, Appendix VIII, Air Force Flight Test Center, Edwards AFB, California, to be published.

2. Reilly, Donald A., Captain USAF, et al., Adverse Weather Tests of the HH-53C Helicopter, ASD-TR-70-51, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, December 1970.

3. Barbagallo, John L., Climatic Laboratory Evaluation of the HH-53C Helicopter, ASTDE-FTR-70-29, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, 7 December 1970.

4. Etzel, Gregory A.M., Major USAF, Barbagallo, John L., Lovrien, Clark E., Jr., Major USAF, Category II Arctic Tests of the HH-53C Helicopter, FTC-TR-71-12, Air Force Flight Test Center, Edwards AFB, California.

5. Wilcox, Kenneth H., Major USMC, et al., ST22R-66, Environmental Testing of the CH-53A Helicopter During Cold Weather Operations, Naval Air Test Center, Patuxent River, Maryland, 15 March 1966.

6. Jusyk S., Preliminary Test Report of Aerodynamic Discontinuity Principle Tape Deicing System for Main and Tail Rotor Blades, SER-61828, Sikorsky Aircraft, Stratford, Connecticut, 24 March 1963.

7. Flight Manual, USAF Service HH-53C, and CH-53C Helicopters, T.O. 1H-53(H)B-1, 20 June 1970, changed 31 December 1970.

8. Ritter, Rodney L., Captain USAF, et al., Advancing Blade Tip Machometer Evaluation, FTC-TR-71-11, Air Force Flight Test Center, Edwards AFB, California.

9. Forecasters Guide on Aircraft Icing, AWSM-105-39, Hq Air Weather Service (MAC), Scott AFB, Illinois, 7 January 1969.

10. Work Unit Code Manual, HH-53B, T.O. 1H-53(H)B-06, 15 September 1970.

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13. ABSTRACT

Artificial icing tests and natural icing flights were conducted in Alaska. Helicopter and anti-ice systems operated satisfactorily under all artificial and natural icing environments encountered. Rotor blade ice shedding was random and caused damage to rotor blades (dents and punctures). Tail rotor blade dents occurred throughout all icing encounters (light and moderate conditions) when ice shedding took place. Tail blade punctures were noted during two flights in artificial icing conditions and once in natural icing, when outside air temperatures (OAT) were approximately -15 and -18 degrees C. Colder temperatures (-18 degrees C) caused ice to form farther out toward main rotor blade tips, which resulted in larger angle of incidence between shedding tip ice and tail rotor blade plane of rotation. This increased potential for puncture damage to the tail rotor blade pockets. Main rotor blade damage (dents) from ice strikes occurred occasionally at colder OAT's (below -15 degrees C). Rotor blade damage encountered was not judged to be safety-of-flight hazard. The engine air particle separator (EAPS) system functioned satisfactorily with inlet doors closed in light and moderate icing conditions with no engine performance degradation noted. The EAPS was tested at airspeeds up to 160 KIAS, doors closed, with no structural or engine performance degradation noted. The HH-53C should be cleared for flight in light and moderate icing and freezing rain conditions with or without EAPS installed, but such flights should be restricted to mission essential operation only, based on probability of occurrence of rotor blade pocket damage caused by ice strikes from shedding ice.

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| KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
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