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# ROTARY WING ICING SYMPOSIUM

## SUMMARY REPORT
## VOLUME I

4 - 6 JUNE 1974



DEAN E. WRIGHT
COLONEL, TC
COMMANDER

USAAEFA-74-77-VOL-1

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

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Icing test facilities
Helicopter icing simulation system

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

The Rotary Wing Icing Symposium hosted by the US Army Aviation Engineering Flight Activity brought together leading experts in the field of helicopter icing from several countries. In attendance were over 130 military, government and civilian manufacturing personnel representing organizations from the United States, Canada, England, France and Germany. Presentations were given in the fields of flight testing, icing protection systems, flight operations in icing, and icing test → over

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20. Abstract

facilities. In his keynote address Paul Yaggy, Director of the Unites States Army Air Mobility Research and Development Laboratory, cited the growing emphasis for all weather operational availability. Colonel Dean E. Wright, Commander of the United States Army Aviation Engineering Flight Activity introduced the Army's Helicopter Icing Simulation System and five experimental test pilots of the Activity presented results of icing tests on the AH-1G, AH-1Q, UH-1H and CH-47C helicopters. Military requirements for helicopters capable of operating in icing conditions were discussed in a session chaired by Colonel William E. Crouch, of The Department of the Army. Colonel Horace B. Beasley of the Army Materiel Command was the moderator of discussions concerning new ice protection systems. An international flair was provided during two sessions chaired by Royal Navy Captain J. T. Checketts, British Ministry of Defence and Mr. Alan Wilson, OBE, of the Aeroplane and Armament Experimental Establishment, Boscombe Down. Icing problem areas were found to be similar among the varied types of helicopters from the different countries. Problem areas found to be common were icing of engine inlets, rotors, and windshields. Many varied approaches to solution of these problem areas were exchanged among the attendees which made the symposium a success. This summary report is prepared in three volumes. Volume I includes the symposium opening remarks, papers presented, and discussion in Session I. Sessions II and III papers and discussion are included in Volume II. The closing remarks, presentations, and discussion during Sessions IV and V are contained in Volume III.


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## PREFACE

The US Army Aviation Engineering Flight Activity acknowledges the outstanding participation of all who attended the Rotary Wing Icing Symposium. The papers presented by the participants were highly informative and of excellent quality. Their contributions played a significant part in the success of the symposium and achieved the aim of the conference to provide an exchange of information concerning operational and test results, testing methods and facilities, and protective measures.

# PROLOGUE

Questions to authors and discussions were recorded on magnetic tape. Recording system and procedural inadequacies rendered certain portions inaudible. Mr. Hayden edited the tapes and attempted to paraphrase the comments to convey the sense of the conversation. Should any transcriptions inadequately describe the intended comment or response, please direct your wrath to Mr. Hayden and your written corrected texts to the US Army Aviation Engineering Flight Activity for literal post publication.

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## ROTARY WING ICING SYMPOSIUM OPENING REMARKS

MR. PAUL F. YAGGY, DIRECTOR — US ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY

GOOD MORNING, GENTLEMEN. WELCOME TO THE US ARMY ROTARY WING ICING SYMPOSIUM SPONSORED BY THE US ARMY AVIATION SYSTEMS COMMAND. OUR HOSTS, COL WRIGHT AND THE STAFF OF THE US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY, JOIN ME IN AN EXPRESSION OF APPRECIATION FOR YOUR INTEREST AS EVIDENCED BY YOUR ATTENDANCE HERE TODAY. OUR PROGRAM ORGANIZERS, COL WRIGHT, RICHARD LONG, AND CHARLES CRAWFORD, HAVE PREPARED AN EXCELLENT FORUM AND ARE TO BE COMMENDED FOR THEIR EFFORTS IN ORGANIZING THIS SYMPOSIUM. WE HAVE A WIDE REPRESENTATION OF ORGANIZATIONS PRESENT, FROM BOTH THE UNITED STATES AND ITS ALLIES. AT THE RISK OF NEGLECTING SOMEONE, I SHALL ACKNOWLEDGE A FEW OF OUR DISTINGUISHED GUESTS.

THE CHAIRMEN OF THE VARIOUS SESSIONS IN THE SYMPOSIUM ARE:

- COL DEAN WRIGHT, COMMANDER, USAAEFA
- COL WILLIAM CROUCH, CHIEF, AVIATION SYSTEMS DIVISION, ODCSRDA
- CPT J. T. CHECKETTS, ROYAL NAVY, MINISTRY OF DEFENCE, U.K.
- COL HORACE BEASLEY, CHIEF, AIR SYSTEMS DIVISION, USAMC
- MR. ALAN WILSON, ENGINEERING DIVISION, A&AEE, BOSCOMBE DOWNS, U.K.

NEXT, I WOULD LIKE TO ACKNOWLEDGE THE PRESENCE OF MR. VINCENT HANEMAN, JR., DEAN OF ENGINEERING AT AUBURN UNIVERSITY AND MEMBER OF THE ARMY SCIENTIFIC ADVISORY PANEL, AND MR. T. R. RINGER AND HIS STAFF FROM THE NATIONAL RESEARCH COUNCIL, CANADA.

IN ADDITION, WE HAVE REPRESENTATIVES FROM FRANCE AND GERMANY AS WELL AS REPRESENTATIVES FROM THE US DEFENSE INDUSTRY AND THE US NAVY, AIR FORCE, AND COAST GUARD.

THE PRIMARY PURPOSE OF THIS SYMPOSIUM ON THE PHENOMENA OF ROTARY WING ICING IS ACTUALLY THREEFOLD: FIRST, IT IS TO PROVIDE AN UP-TO-DATE BRIEFING ON THE STATUS OF THE ARMY HELICOPTER ICING SPRAY SYSTEM AND PROCEDURES FOR QUALIFICATION OF ARMY HELICOPTERS IN ARTIFICIAL AND NATURAL ICING CONDITIONS; SECOND, IT IS TO PROVIDE INFORMATION ON PROBLEMS OF HELICOPTER OPERATIONS IN AN ICING ENVIRONMENT OBTAINED BY OTHER AGENCIES; AND THIRD, IT IS TO REPORT ON ACTIVE PROGRAMS FOR THE DEVELOPMENT OF PROTECTIVE EQUIPMENT FOR AIRCRAFT, BOTH ANTI-ICE AND DEICE.

THE ARMY INTEREST WHICH GENERATED THIS SYMPOSIUM STEMS FROM THE OPERATIONAL EXPERIENCE OF US ARMY AVIATION UNITS, PARTICULARLY

IN EUROPE, WHICH HAS REPEATEDLY DEMONSTRATED AN URGENT REQUIREMENT FOR THE CAPABILITY TO OPERATE ARMY HELICOPTERS IN KNOWN OR FORECASTED ICING CONDITIONS. IN RECOGNITION OF THIS FACT, ALL ARMY AIRCRAFT SYSTEMS UNDER DEVELOPMENT, AS WELL AS FUTURE SYSTEMS, WILL SPECIFY ALL-WEATHER FLIGHT CAPABILITY. CONSISTENT WITH THIS DETERMINATION TO ACQUIRE ALL-WEATHER, MID-INTENSITY WARFARE MISSION CAPABILITY, THE DEPARTMENT OF THE ARMY HAS DIRECTED THE AVIATION SYSTEMS COMMAND, VIA THE ARMY MATERIEL COMMAND, TO EXPLORE THE ADEQUACY OF ARMY HELICOPTERS TO FLY IN ICING CONDITIONS.

THE INVOLVEMENT OF AVSCOM IN DEFINITION OF SAFE FLIGHT UNDER INSTRUMENT METEOROLOGICAL CONDITIONS DATES FROM 1958. HOWEVER, INTENSIVE INVOLVEMENT BEGAN WITH STUDIES IN 1970 TO ESTABLISH QUALIFICATION REQUIREMENTS FOR INSTRUMENT FLIGHT OPERATION. IN EARLY 1971, A STUDY WAS CONDUCTED BY THE AVSCOM DIRECTORATE OF RESEARCH, DEVELOPMENT AND ENGINEERING TO DEFINE A SPECIFIC PROGRAM FOR QUALIFICATION OF CURRENT ARMY HELICOPTERS FOR FLIGHT IN ICING CONDITIONS. IN ADDITION TO ESTABLISHING POSSIBLE EQUIPMENT REQUIREMENTS FOR FLIGHT UNDER ICING CONDITIONS, THE REPORT OF THIS PROGRAM NOTED THAT ADEQUATE TEST FACILITIES WERE NOT AVAILABLE.

IN 1971 THERE WERE THREE FACILITIES AVAILABLE TO CONDUCT CONTROLLED ARTIFICIAL ICING TESTS. ONE OF THESE IS THE CLIMATIC HANGAR AT EGLIN AIR FORCE BASE WHICH PERMITS TIE-DOWN OPERATIONS ONLY. THIS FACILITY IS PRIMARILY USEFUL IN IDENTIFYING ENGINE/FUSELAGE INTERFACE PROBLEMS AND CHARACTERISTICS FOR LOW-TEMPERATURE FLIGHT OPERATION, A LOGICAL FIRST STEP IN ANY NEW AIRCRAFT ICING QUALIFICATION PROGRAM.

A SECOND FACILITY IS MAINTAINED BY THE CANADIAN NATIONAL RESEARCH COUNCIL. IT IS A GROUND-BASED FACILITY TO GENERATE AN ICING SPRAY CLOUD, WHICH PERMITS TESTING DURING IN-GROUND-EFFECT AND OUT-OF-GROUND-EFFECT HOVER AND LOW-SPEED FLIGHT. THIS SYSTEM HAS BEEN EXTENSIVELY USED DURING ICING QUALIFICATION TESTS BY THE CANADIAN AND BRITISH GOVERNMENT TEST AGENCIES AND BY US CIVILIAN CONTRACTORS.

THE THIRD FACILITY IS THE US AIR FORCE FIXED WING C-130 ICING SPRAY SYSTEM WHICH HAS A SINGLE-NOZZLE SPRAY GUN AND GENERATES CLOUD DIAMETERS UP TO 20-25 FEET. THIS SYSTEM OPERATES AT AIR SPEEDS GREATER THAN NORMAL HELICOPTER IMC CRUISE SPEEDS, AND IS NOT APPLICABLE TO ROTARY WING INVESTIGATIONS.

TO MEET THIS DEFICIENCY, A PROGRAM WAS INITIATED BY THE US ARMY TO DEVELOP AN ARTIFICIAL ICING SPRAY SYSTEM THAT WOULD HAVE THE

CAPABILITY OF PROVIDING A CLOSELY CONTROLLED IN-FLIGHT ICING ENVIRONMENT COMPATIBLE WITH ARMY HELICOPTER SIZES AND SPEEDS. THIS LED TO THE DEVELOPMENT IN 1972 AND 1973 OF AN ARMY HELICOPTER ICING SPRAY SYSTEM (HISS). THIS PROGRAM WILL BE COVERED IN DETAIL BY AEFA IN SESSION I OF THIS SYMPOSIUM.

IN PARALLEL WITH THIS EFFORT, THE EUSTIS DIRECTORATE OF THE ARMY AIR MOBILITY R&D LABORATORY EMBARKED UPON A RESEARCH AND DEVELOPMENT PROGRAM TO ESTABLISH THE REQUIREMENTS FOR PROTECTION SYSTEMS FOR FUTURE GENERATION ARMY HELICOPTERS AND TO ASSURE THAT TECHNOLOGY WILL BE AVAILABLE TO SATISFY THOSE REQUIREMENTS. SESSION IV OF THIS SYMPOSIUM IS DEVOTED TO THIS EFFORT. SESSION II IS DEVOTED TO BRIEFINGS ON OTHER ICE PROTECTION SYSTEMS. SESSION III WILL COVER SPECIFIC PROBLEMS OF OPERATIONS IN AN ICING ENVIRONMENT.

I FEEL CERTAIN THAT WE HAVE IN THIS SYMPOSIUM THE NECESSARY INFORMATION TO WELL DEFINE NOT ONLY THE REQUIREMENTS FOR PROVIDING ICING PROTECTION FOR PRESENT DAY HELICOPTERS, BUT ALSO THE RUDIMENTS OF A PROGRAM FOR ACCOMPLISHMENT. WE SOON SHALL BE ABLE TO DEFINE THE HELICOPTER SYSTEMS THAT REQUIRE PROTECTION AND THE PROBABILITY OF OCCURRENCE OF ICING CONDITIONS, AND TO ESTABLISH THE PROBABILITY OF HELICOPTERS ENCOUNTERING VARIOUS ICING SEVERITY LEVELS.

HOWEVER, THE SYSTEMS WE ARE LOOKING AT TODAY REPRESENT STATE-OF-THE-ART TECHNOLOGY AND IMPOSE SEVERE PENALTIES UPON THE HELICOPTER --WEIGHT, COMPLEXITY, MAINTAINABILITY, LIFE CYCLE COSTS. THE CHALLENGE, THEN, IS TO CONTINUE OUR RESEARCH AND DEVELOPMENT EFFORTS TO PROVIDE FOR TRULY ADVANCED ICE PROTECTION SYSTEMS. IT IS OUR DESIRE THAT THIS SYMPOSIUM WILL SPUR YOUR ENTHUSIASM TO ACCEPT THE CHALLENGE AND TO CONQUER.

# PRODUCT IMPROVEMENT PROGRAM FOR HELICOPTER ICING SPRAY SYSTEM (HISS)

Charles C. Crawford
Chief, Flight Standards
and Qualifications Division
US Army Aviation Systems Command
St Louis, Missouri 63166

As you know, we at AVSCOM have added a helicopter icing spray system, known as the HISS to the Army's inventory to evaluate the performance of Army helicopters under controlled icing conditions (slide 1). During the qualification tests and actual icing tests performed in Alaska, it was apparent that we didn't meet all our design objectives. For instance, the width of the spray cloud was greatly reduced by the CH-47C helicopter's rotor tip vortices which swirled the edges of the spray cloud up and over the desired test window. The depth of the cloud was not deep enough to encapsulate both the rotor system and fuselage of the tested helicopter concurrently. Due to the HISS rotor downwash and rotor tip vortices the tested helicopter had great difficulty in station keeping; and at lower airspeeds a hole was blown out of the spraycloud by the rotor downwash. The rest of the deficiencies are included in slide 2. As you can see from this slide the liquid water content was not uniform throughout the cloud. There was difficulty in disassembling the spray rig for inspection and repair; there was corrosion in the boom water lines; and the structures and mechanisms located along the centerline of the CH-47 fuselage presented operational difficulty for the aircrew.

We are now in the process of modifying the HISS by adding a lower boom and lowering the entire assembly as seen by slides 3 and 4. This addition of a second boom plus the lowering of the entire system will give us a greater cloud depth, greater separation of the cloud from rotor system which will decrease cloud roll up. As seen from these slides, the outer boom is shorter and the outer tips are canted downward. The shortening of the rig was dictated by the limited air supply and the canting of the outer boom tips also decreases the roll-up at the outer edges of the spray cloud. Slides 5 and 6 list the other changes to the system such as improving the inspection and servicing by modularization of the water line plus the use of corrosion resistant materials where corrosion had occurred. The dual line sources and staggered array of atomizers will provide a better liquid content distribution. The interior of the CH-47 fuselage centerline was cleaned up by elimination of some of the structural and mechanical obstructions which gave greater operational ease and safety for the aircrew. We will be using the icing spray system to test the S-58, and Model 214A in the spring of 1975 followed by the support of Eustis in their tests on the Lockheed Advanced Ice Protection System. As shown in slide 7, the OH-6 and OH-58 will be tested followed by the UTTAS and AAH at some later date.

## SUMMARY

The modification to the HISS will enable the Army to test the UH-1, AH-1, OH-6 and OH-58 aircraft under complete encapsulated icing conditions. The modification will also enlarge the test envelope by decreasing the lower airspeed limit and increasing the upper airspeed of the test aircraft. The spray cloud will be widened and the spray distribution and water droplet size control will be improved (slide 8).

HELICOPTER
IN-FLIGHT
ICING TEST
FACILITY

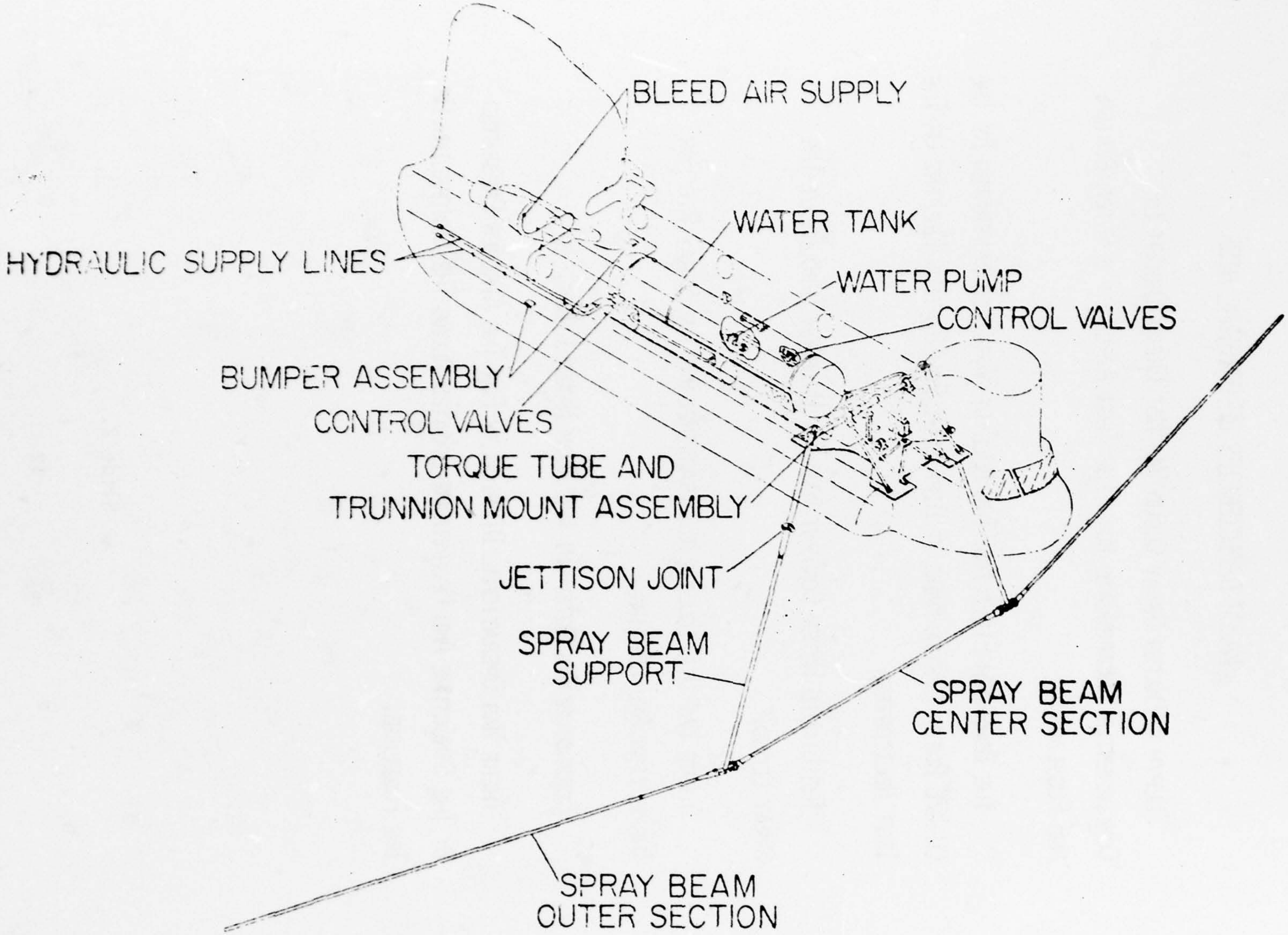



Figure 1-1. Icing Condition Simulation Equipment in CH-47C Aircraft

Slide 1.

## MAJOR DEFICIENCIES OF ORIGINAL HISS

DEPTH OF WATER SPRAY CLOUD WAS NOT GREAT ENOUGH TO CONCURRENTLY ENCAPSULATE BOTH THE TEST AIRCRAFT'S ROTOR SYSTEM AND FUSELAGE.

THE DOWNWASH FIELD AND THE ROLL-UP VORTICES GENERATED BY THE CH-47C ROTOR SYSTEM MADE IT DIFFICULT FOR STATION KEEPING OF THE TEST HELICOPTER.

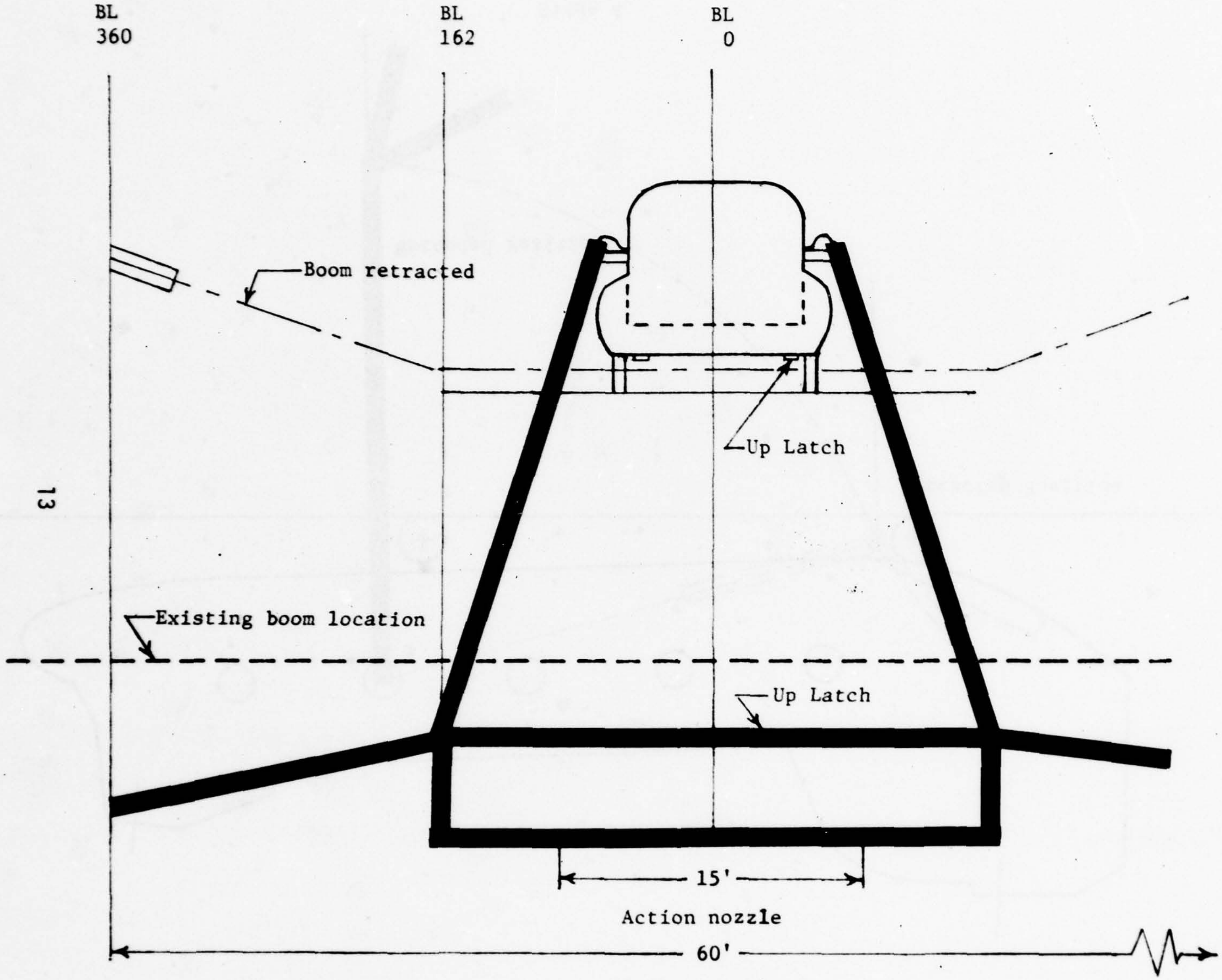
THE LIQUID WATER CONTENT WAS NOT UNIFORM THROUGHOUT THE SPRAY CLOUD.

THERE WAS DIFFICULTY IN DISASSEMBLING THE SPRAY RIG FOR INSPECTION AND REPAIR.

CORROSION WAS NOTED IN THE BOOM WATER LINES.

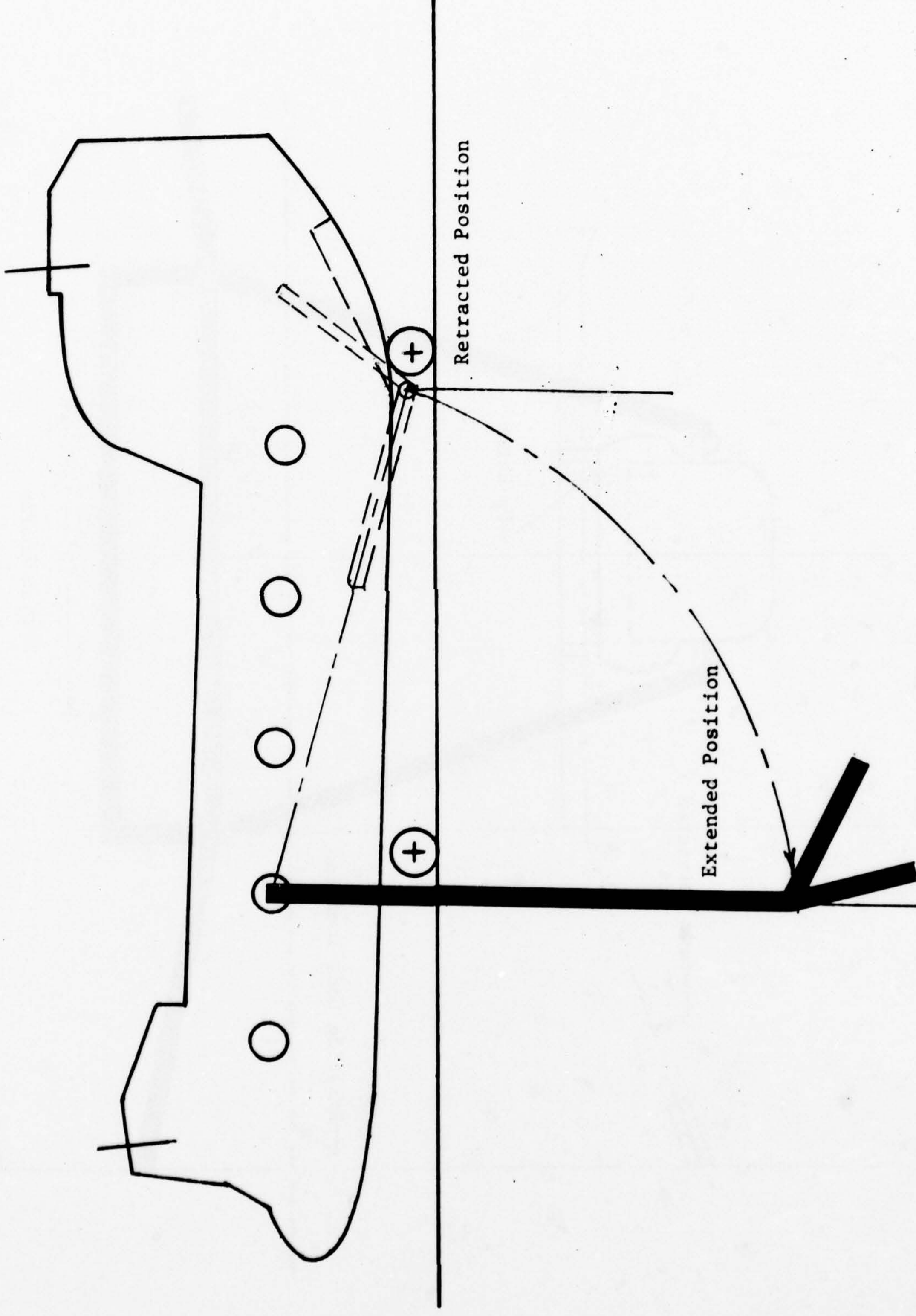
THERE WAS OPERATIONAL DIFFICULTY FOR THE AIRCREW PRESENTED BY THE STRUCTURE AND MECHANISMS LOCATED ALONG THE CENTERLINE OF THE FUSELAGE.

Slide 2.




Action nozzle

Slide 3.




Slide 4.

## ADVANTAGES OF DUAL BOOM MODIFICATION

IMPROVED INSPECTION AND SERVICING. MODULAR CONTRSTUCTION OF WATER LINE SYSTEM WILL PERMIT EARLY DISASSEMBLY FOR INSPECTION AND REPAIR. UTILIZATION OF CORROSION-RESISTANT MATERIALS WILL MINIMIZE NEED FOR MAINTENANCE, AND WILL INCREASE RELIABILITY.

MORE UNIFORM LIQUID WATER CONTENT (LWC) DISTRIBUTION. DUAL LINE SOURCES, AND STAGGERED ARRAY OF ATOMIZERS WILL PROVIDE GREATER UNIFORMITY OF LWC WITHIN THE CONFINES OF THE CLOUD.

GREATER OPERATIONAL EASE AND SAFETY FOR AIRCREW. THE ELIMINATION OF STRUCTURES AND MECHANISM PRESENTLY LOCATED ALONG CENTERLINE OF FUSELAGE WILL PARTIALLY CLEAR THIS AREA AND IMPROVE PASSAGE FORE AND AFT IN THE CH-47C AIRCRAFT.

GREATER CLOUD DEPTH. SEMI-DEPTH WILL INCREASE FROM APPROXIMATELY 5.7 FEET TO APPROXIMATELY 9.3 FEET. FULL DEPTH INCREASE WILL BE FROM 12.7 FEET TO 14 FEET.

GREATER SEPARATION OF CLOUD FROM DOWNWASH FIELD OF ROTOR SYSTEM. TOP OF CLOUD IS MOVED APPROXIMATELY 5 FEET FROM EXISTING LOCATION.

CLOUD ROLL-UP IS DECREASED. OUTER SECTIONS OF UPPER BEAM ARE CANTED DOWNWARD 10° TO COUNTERACT THE EFFECT OF ROLL-UP AT OUTSIDE OF CLOUD.

Slides 5 and 6.

TENTATIVE ICING TESTS

S-58T (SIK): SPRING 1975

MODEL 214A: SPRING 1975

LOCKHEED'S ADVANCED ICE PROTECTION SYSTEM

OH-6 AND OH-58

UTTAS: TO BE DETERMINED

AAH: TO BE DETERMINED

Slide 7.

## SUMMARY

THE MODIFICATION TO THE HISS WILL ENABLE THE ARMY TO TEST THE UH-1, AH-1, OH-58 AIRCRAFT UNDER COMPLETE ENCAPSULATED ICING CONDITIONS. THE MODIFICATION WILL ALSO ENLARGE THE TEST ENVELOPE BY DECREASING THE LOWER AIRSPEED LIMIT AND INCREASING THE UPPER AIRSPEED OF THE TEST AIRCRAFT. THE SPRAY CLOUD WILL BE WIDENED AND THE SPRAY DISTRIBUTION AND WATER DROPLET SIZE CONTROL WILL BE APPROVED.

Slide 8.

OPENING REMARKS
SESSION I

DEAN E. WRIGHT
COLONEL, TC
COMMANDER

US Army Aviation Engineering
Flight Activity
Edwards Air Force Base, CA
93523

I would like to make a few general announcements before beginning this session.

First, I would like to welcome you to Edwards Air Force Base. The United States Army Aviation Engineering Flight Activity is a tenant on the base. If you do have some free time, I would like to invite you to visit the Activity. We are in Building 1820 on Wolfe Avenue.

The papers which will be presented during the symposium will be printed and distributed in the near future. Also, if you desire minutes of last year's IFR conference, they are available.

The purpose of this symposium is to enhance the exchange of information between the various countries, services, and organizations assembled here. It is very simple for us to include another parameter into our test program or to look at another area, if we know that you would be interested.

For the past year, the icing program has had Number 1 priority at the Activity. Our first task was to qualify the helicopter icing simulation system and then to move into testing of the Army's first line helicopters.

This morning we will cover out test procedures and the results of our tests. To conclude the morning, Mr. Crawford of the Army Aviation Systems Command, Flight Standards Division, will discuss product improvements being planned for the helicopter icing spray system.

LTC Warren Griffith, my Director of the Icing Program, will describe the spray system, and the test procedures. Colonel Griffith received a Bachelor of Science in Mechanical Engineering from the University of Wyoming, completed Test Pilot School in October 1970, and joined the Engineering Flight Activity in January 1972.

Major Larry Brewer will discuss the results of testing with the UH-1 aircraft. Major Brewer received his Bachelor of Science from the United States Military Academy and a Master of Science in Systems Management from the University of Southern California. He completed U.S. Naval Test Pilot School training in June 1971, and joined the Engineering Flight Activity in September 1972.

Major Carl Mittag will then discuss our natural icing tests and the correlation with the results obtained from operations behind the spray system. Major Mittag received a Bachelor of Science in Aeronautical Engineering from the California Polytechnical Institute, completed Test Pilot School in October 1972 and joined the Activity in November 1972.

CW4 James Reid will outline the results of our icing investigation with the AH-1G Cobra. He has a Bachelor of Science Degree in Aeronautical Engineering from Embry Riddle, completed Test Pilot School in June 1972 and joined the Activity upon graduation.

Captain James O'Connor will conclude with the results of our testing of the CH-47 helicopter. Captain O'Connor received a Bachelor of Science in Aerospace Engineering from Iowa State, completed Test Pilot School in June 1973 and joined the Activity upon graduation.

Because of the sequence, I ask that questions be held until all presentations have been made.

# US ARMY HELICOPTER ICING TESTS

LTC Warren E. Griffith, II
Chief Integrated Systems Test Division

US Army Aviation Engineering Flight Activity
Edwards AFB, CA 93523

This morning we would like to present the results of the icing tests conducted by AEFA this winter.

These tests include artificial icing on the UH-1H, AH-1G and CH-47C helicopters and a limited natural icing test on the UH-1H.

(Slide 1) Our program this morning will follow this format. I will give a brief look at the HISS then discuss a few items of our qualification program which were common to all the tests. The project pilots will then discuss their respective tests and present their results.

Before getting into the tests themselves, I would like to briefly describe the HISS.

A CH-47C helicopter is used (Slide 2) to transport 1800 gallon water tank, supply hydraulic power and bleed air and serve as mounting point for the spray boom assembly.

75 foot-wide spray pipe 15 feet below helicopter.

There are separate supply lines for air and water, which are mixed at specially designed atomizers to create the desired cloud of water droplets. For better photographs the water is colored with a florizine sea marker dye. Giving a very yellow color.

During flight (Slide 3) the spray boom is positioned as shown.

For nonspraying operations such as takeoffs and landings (Slide 4) the boom is retracted.

A radar altimeter, located in the rear of the HISS, positioned to look aft at the test aircraft, was used to maintain horizontal distances between the two aircraft.

Flight qualification was conducted at AEFA during the summer of 1973 prior to initiating icing tests. Comprehensive calibration efforts were made using various methods. A unique flight was conducted using the AF's B-52 (Slide 5) which they used for their spray cloud calibrations behind a C-130 and KC-135 tanker. (Slide 6) Our major calibration effort was conducted in Alaska using a Piper Aztec provided by the Calspan Corporation of Buffalo, N.Y. Their aircraft was instrumented to provide LWC, droplet size in microns, relative humidity and free air temperature. All of our calibrations showed that the system could produce the desired spray cloud liquid water contents over the entire range of from trace to heavy icing. Also it creates drops with mean sizes on the order of 50 microns which approximates cumulonimus cloud characteristics.

(Slide 7) Just as a review these are the definitions of the various types of ice.

D.A. has requested expeditied testing of all first-line Army helicopters and in compliance we have devised this program (Slide 8). Ft. Wainwright, Alaska was selected due to the early occurrence of weather cold enough to allow icing tests at low altitudes. We have just completed the testing at Moses Lake, Washington.

(Slide 9) These are the objectives we have set for our icing tests.

First, establish the maximum ice severity levels in which aircraft can operate without any special modifications.

Any deficiencies noted will be categorized with respect to the icing severity level at which they require correction.

Flight envelope restrictions appropriate for flight in icing conditions will be established and incorporated in the operator's manuals.

Each aircraft is tested in a configuration which includes all equipment deemed necessary for safe operation of the helicopter during testing.

This equipment includes (Slide 10) windshield anti-ice/deice (Slide 11) on the UH-1H (alcohol spray) (Slide 12) (heated glass). We also acquired from the Sierracin Corp. heated panels for the windshields on the OH-6 and OH-58. Due to time constraints however, we were unable to test these windshields this last winter.

(Slide 13) To provide icing severity information to the pilot we installed an ice detector (Rosemont detector and rate meter).

(Slide 14) The rate meter is graduated to read from trace to heavy icing severity levels.

(Slide 15) In a further attempt to provide the pilot with exact information about the amount of ice on the fuselage an ice accumulation probe which was locally manufactured was installed. This probe consisted of an airfoil section with the leading edge oriented normal to the free air stream. The thin rod is parallel to the free stream and is graduated in 1/4 inch increments to provide an easy reference for determining the thickness of the accreted ice.

(Slide 16) A complete list of instrumentation is shown on this slide.

(Slide 17) The same general procedure is employed in all icing tests.

Our approach involves incremental buildup of ice on aircraft. The buildup is both in terms of quantity and rate or icing severity.

A chase aircraft is used on every flight for photo and rescue.

I will now briefly describe our artificial icing procedures.

First the test aircraft is positioned in the spray cloud to accumulate a preselected quantity of ice on the visual ice probe.

The aircraft is then positioned clear of the cloud where photographs are taken of it and engineering tests are conducted. These tests were longitudinal stability, maneuvering stability, vibration tests, performance, and autorotations. When unsatisfactory conditions are experienced a limit is established - These unsatisfactory conditions might be a change in performance, vibration levels, engine operation, external visibility, or excessive engine torque.

Due to the physical thickness of cloud, which is approximately 5' to 8', the aircraft was iced in parts; first the rotor then the fuselage. This was usually done on separate flights rather than during the same flight.

Postflight examination of ice was accomplished when possible. Temperatures during the natural icing tests were above freezing on the surface and precluded this post flight examination.

For our natural icing tests we changed our procedures slightly.

The first aircraft launched was a light twin engine fixed wing. This aircraft was equipped with our visual probe, a Rosemount ice detector and a Rosemount sensitive OAT. If the desired conditions of temperature and icing severity existed in the area then the test helicopter and its chase was launched. On the way to the test area the fixed wing aircraft briefed the test aircraft as to the existing weather conditions and the test altitude to fly. The fixed wing would then climb to at least 1000 feet above the test altitude and when the test aircraft reached the test area and was established in the pattern it would climb to the test altitude. The chase aircraft would remain below the clouds, VFR, and by flying headings and airspeeds provided by the radar controller, stay within a mile of and directly behind the test helicopter. The test helicopter would then fly in the cloud as long as necessary to accrete the amount of ice desired. The same engineering tests were then conducted.

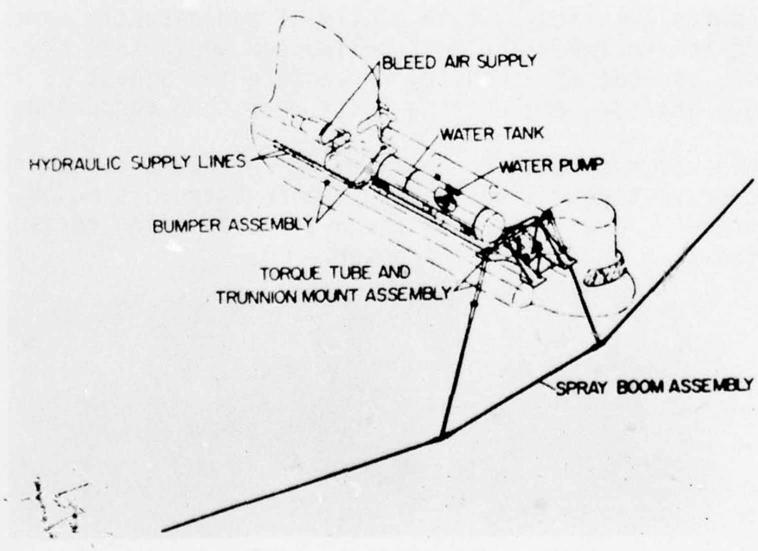
This has been a brief overview of the items common to all of our testing. I would now like to introduce Major Larry Brewer who will discuss the artificial icing tests conducted with the UH-1H helicopter.

## HELICOPTER ICING QUALIFICATION PROGRAM

- INTRODUCTION
- HELICOPTER ICING SIMULATION SYSTEM
- ICING TEST PROGRAM, OBJECTIVES, APPROACH
- RESULTS TO DATE
- CONCLUSIONS

Slide 1.

## HELICOPTER ICING SIMULATION SYSTEM




Slide 2.

Slide 3.

Slide 4.

Slide 5.


Slide 6.

## ICING TYPE DEFINITIONS

- **RIME ICE:** AN OPAQUE ICE FORMED BY THE INSTANTANEOUS FREEZING OF SMALL SUPERCOOLED DROPLETS.
- **CLEAR ICE:** A SEMITRANSPARENT ICE FORMED BY THE SLOWER FREEZING OF LARGER SUPERCOOLED DROPLETS.
- **GLIME ICE:** A MIXTURE OF CLEAR ICE AND RIME ICE WHICH IS VERY COMMON.

Slide 7.

## HELICOPTER ICING TEST PROGRAM

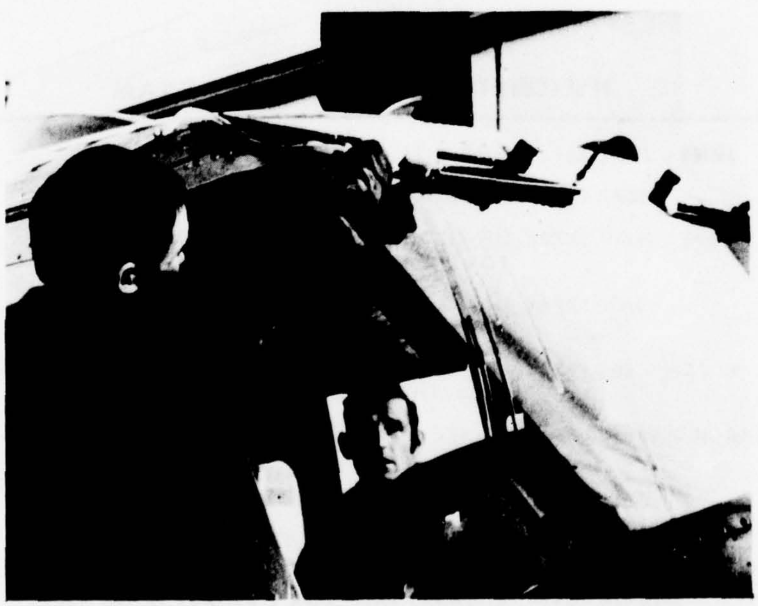
| | |
|---|---|
| JUNE - JULY 1973: | HISS QUALIFICATION PROGRAM |
| SEPT 1973: | CALIBRATION OF HISS CLOUD |
| SEPT - NOV 1973: | UH-1H & AH-1G HISS TESTS AT FORT WAINWRIGHT, ALASKA |
| JAN 1974: | UH-1H HEATED WINDSHIELD & AH-1Q HISS TESTS AT EDWARDS, AFB, CA. |
| JAN - FEB 1974: | UH-1H NATURAL ICING TESTS AT FORT LEWIS, WASHINGTON |
| MARCH - APRIL 1974: | CH-47C & AH-1G HISS TESTS AT MOSES LAKE, WASHINGTON |
| FALL 1974: | HISS PIP QUALIFICATION PROGRAM |
| WINTER 1974: | AMRDL ICE PROTECTED UH-1H TESTS AT NCR, OTTAWA AND WITH HISS |
| WINTER 1974: | FURTHER HISS AND NATURAL ICING TESTS |
| WINTER 1975: | UTTAS HISS TESTS |

Slide 8.

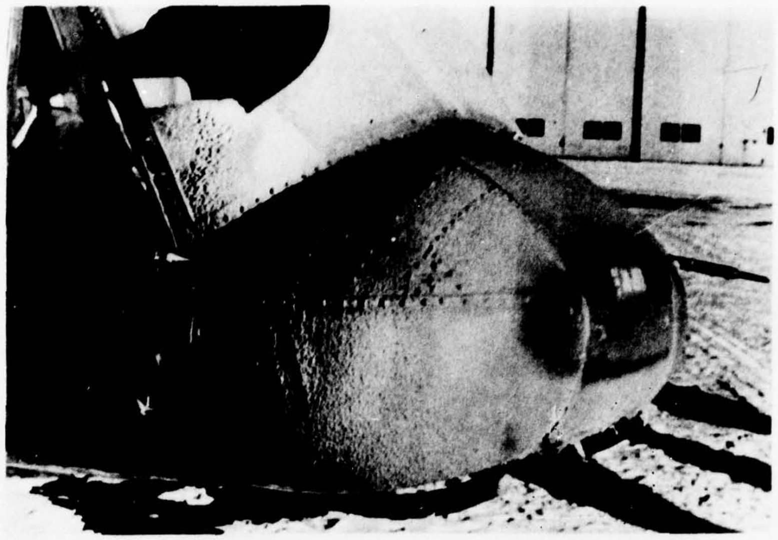
# ICING TEST OBJECTIVES

- DETERMINE CAPABILITY OF ARMY HELICOPTERS TO SAFELY OPERATE IN AN ICING ENVIRONMENT
- DETERMINE PROBLEMS REQUIRING RESOLUTION PRIOR TO RELEASE FOR FLIGHT IN ICING
- PROVIDE DATA FOR DETERMINATION OF FLIGHT ENVELOPE RESTRICTIONS

Slide 9.

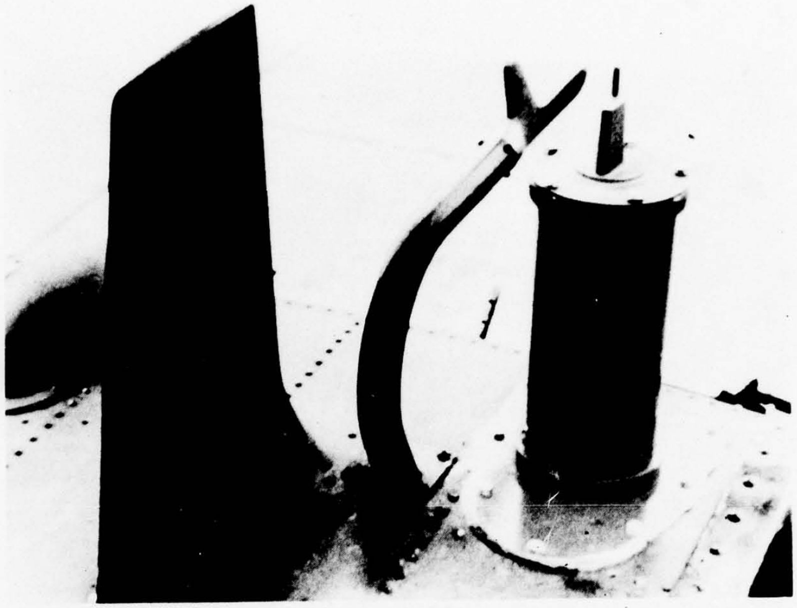


Slide 10.



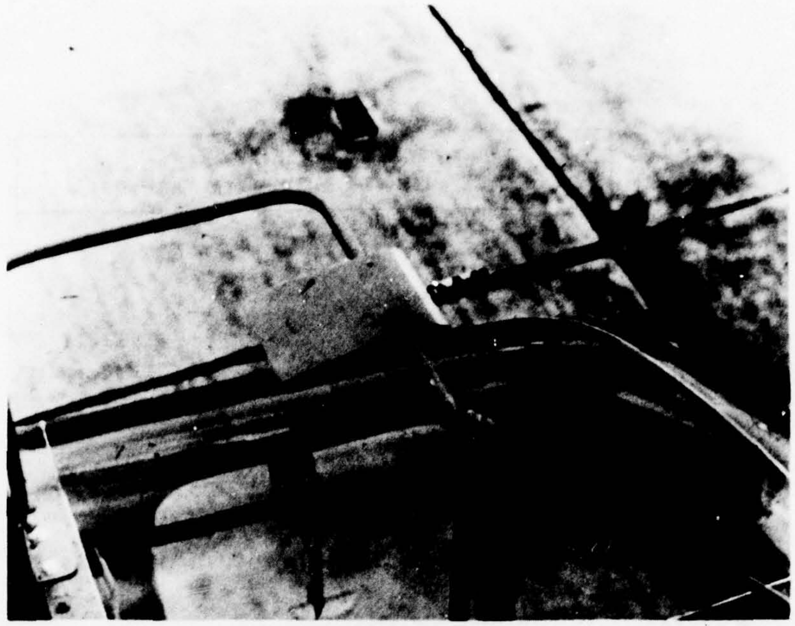
Slide 11.

Slide 12.



Slide 13.


Slide 14.

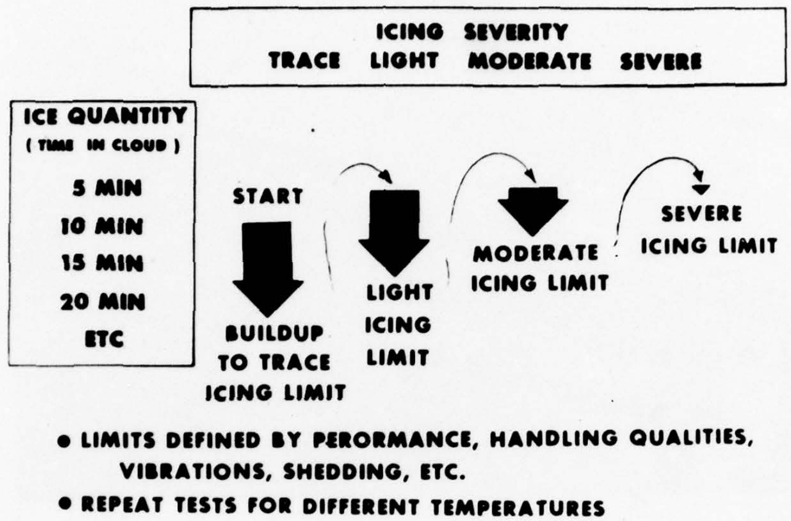


Slide 15.

## ICING TEST INSTRUMENTATION

- SENITIVE OUTSIDE AIR TOTAL TEMPERATURE
- ROSEMOUNT ICE DETECTOR SYSTEM WITH ICING RATE INDICATOR
- CAMBRIDGE INSTRUMENTS RELATIVE HUMIDITY SYSTEM
- VISUAL ICE ACCRETION PROBE
- TV MONITOR OF ENGINE INLET
- ENGINE PLENUM DIFFERENTIAL PRESSURE
- PHOTOPANEL RECORDING FLIGHT CONDITIONS, ENGINE PARAMETERS, AND CONTROL POSITIONS
- AIRBORNE TAPE OR OSCILLOGRAPH RECORDING VIBRATION LEVELS AND ICE DTECTOR SIGNALS
- HIGH SPEED PHOTO COVERAGE FROM CHASE AIRCRAFT

Slide 16.


ICING SEVERITY
TRACE LIGHT MODERATE SEVERE
ICE QUANTITY
( TIME IN CLOUD )
5 MIN
10 MIN
15 MIN
20 MIN
ETC
START
BUILDUP TO TRACE ICING LIMIT
LIGHT ICING LIMIT
MODERATE ICING LIMIT
SEVERE ICING LIMIT
• LIMITS DEFINED BY PERORMANCE, HANDLING QUALITIES, VIBRATIONS, SHEDDING, ETC.
• REPEAT TESTS FOR DIFFERENT TEMPERATURES

Slide 17.

# UH-1H HELICOPTER ARTIFICIAL ICING TESTS

Major Larry K. Brewer
Experimental Test Pilot

US Army Aviation Engineering Flight Activity
Edwards Air Force Base, California 93523

## INTRODUCTION

The operational experience of US Army Aviation Units in Europe has repeatedly pointed out an urgent requirement for the capability to operate Army helicopters in known or forecast icing conditions. A review of climatological data for Central Western Germany indicates over 50 percent occurrence of low stratiform cloud cover and simultaneous freezing temperatures at moderate altitudes during the winter months.

In early 1971, a study was conducted by the US Army Aviation Systems Command (AVSCOM) Directorate of Research, Development and Engineering to define a program for qualification of current Army helicopters for flight in icing conditions. This study concluded that none of the first-line Army helicopters had adequate deicing/anti-icing provisions for sustained flight in moderate icing conditions. Accordingly, AVSCOM initiated a program for the development of a helicopter artificial icing spray system which would have the capability of providing a closely controlled in-flight artificial icing environment.

The helicopter icing spray system configuration selected for procurement was a CH-47C helicopter. This aircraft transports an 1800-gallon water tank, supplies hydraulic power and bleed air, and serves as a mounting point for the 75-foot-wide spray boom assembly.

The US Army Aviation Engineering Flight Activity (USAAEFA) was subsequently directed by AVSCOM to conduct the initial artificial icing tests.[1] Fort Wainwright, Alaska, was selected as the test site to avoid delaying the tests until the CONUS winter months and because of the availability of the required test temperatures and prevailing

[1] Letter, AVSCOM, AMSAV-EFT, 14 February 1973, subject: Army Helicopter Simulated Icing Tests, AVSCOM Test Request, Project No. 73-04.

weather conditions, as reflected by the National Weather Service Manuals.[2,3] The UH-1H helicopter was scheduled first in the test sequence because it had already been exposed to limited icing tests and was not prohibited from flight in forecast light icing conditions.

## TEST OBJECTIVES

The objectives of this evaluation were as follows:

To determine the capability of the UH-1H helicopter to safely operate in an icing environment.

To determine what, if any, problems must be resolved before release of the UH-1H helicopter for flight into known icing conditions.

To provide data which can be used to determine the flight envelope restrictions that should be imposed on the UH-1H helicopter when released for operational usage in icing environments.

## TEST AIRCRAFT DESCRIPTION

The test aircraft, a UH-1H utility helicopter, serial number 64-13679, was manufactured by Bell Helicopter Company. A detailed description of the standard UH-1H helicopter may be found in the operator's manual.[4] The standard auxiliary exhaust heater system and the standard engine air inlet filters for the Artic environment were installed. The engine air particle separator had been removed from the aircraft in accordance with normal winter procedures and the engine air inlet filters (3) installed. Nonstandard equipment installed on the airframe to assist in the conduct of this evaluation included a windshield alcohol anti-ice system mounted on the pilot's windshield wiper, a visual ice accretion measuring device (visual probe) located externally on the cabin roof above the copilot's overhead plexiglass panel, and a Rosemount ice detection system mounted on the cabin roof aft of the

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[2] Manual, National Weather Service, Uniform Summary of Rawinsonde Observations, Fairbanks, Alaska, IAP N6449 W 14752, January 1948 to June 1970, Book 2 of 2, 27 January 1972.

[3] Manual, National Weather Service, Revised Uniform Summary of Surface Weather Observations; Fairbanks, Alaska, LADD AFB N 64 51 W 14735 ELEV 460 FT, August 1971.

[4] Operator's Manual, TM 55-1520-210-10, Army Model UH-1D/H Helicopters, 25 August 1971.

copilot's overhead plexiglass panel used to quantify icing rate and accretion. Other special equipment and instrumentation used during these tests included a television camera mounted in the engine inlet area, a television monitor, a 35mm Automax camera, a plenum chamber differential pressure sensor. A video tape recorder, a six-channel direct-writing analog recorder, and a voice recorder.

## TEST SCOPE AND METHODOLOGY

The icing tests of the UH-1H helicopter were conducted in the vicinity of Fort Wainwright, Alaska, from 17 September through 29 October 1973. A total of 16 icing test flights were conducted consisting of 13.7 productive hours, of which 4.4 hours were in the artificial icing environment. These tests were accomplished at a gross weight of approximately 7100 pounds, a mid center-of-gravity location of 142 fuselage station, pressure altitudes from 2000 to 10,000 feet, airspeeds of 60 to 90 knots indicated airspeed (KIAS), and a rotor speed of 324 rpm. Icing was accomplished at static temperatures of -5, -10, and -14°C, which were anticipated to be representative of temperatures necessary for clear, mixed, and rime ice, respectively.

The procedure used to accumulate ice on the airframe and rotor systems of the test aircraft was the same throughout the tests. All normal and special anti-ice/deice systems were activated prior to entering the spray cloud. The test aircraft was next positioned in the spray cloud to accumulate a predetermined amount of ice and then moved to a position clear of the spray cloud to conduct specific engineering tests. Because of the limited spray cloud dimensions, the test procedure was to ice either the rotor system or the fuselage during any given flight.

## SPRAY SYSTEM CHARACTERISTICS

A wake turbulence evaluation was conducted with the UH-1H helicopter behind the CH-47C helicopter prior to beginning the icing tests. Rotor system downwash, vortex effects, and associated turbulence prevented accurate positioning in the spray cloud at distances greater than 300 feet. The lowest turbulence levels were encountered at 100 to 300 feet behind the CH-47C. However, even at this distance, the light-to-moderate turbulence made station keeping difficult and stabilization in the spray cloud impossible. The rotor downwash effect of the CH-47C also required the UH-1H to be in a forward flight climb condition in order to maintain its station-keeping position in the spray cloud.

This resulted in approximately a 15 percent torque increase above normal cruise power settings. Due to maintenance problems, the usable cloud dimensions were approximately 5 feet thick, 25 feet wide, and 200 feet long.

## ICING TEST RESULTS

### ICING SEVERITY

Flying in the various icing severity conditions resulted in ice accumulation on the fuselage which conformed to the FAA icing severity definitions (figure 1). However, the ice accumulation on the main rotor system did not conform to those definitions. For example, during a flight under programmed light icing conditions, 1/4 inch of ice was accumulated on the visual probe after 20 minutes in the spray cloud, conforming to the FAA light icing definitions. After landing, 7/8 inch of ice was measured on the leading edge of both main rotor blades approximately 9 feet from the hub, indicating that rotor rotation amplifies ice accumulation. The ice on the leading edge of the main rotor blades was measured after landing, and was therefore affected by warmer temperatures on the surface, sublimation, and unpredictable shedding characteristics. A typical pattern of ice distribution on the leading edge of the main rotor blades after a brief exposure to programmed light icing conditions was approximately 1/2 inch thick measured to approximately 75 percent of the blade span. The ice accretion on the fuselage does not provide the pilot with a direct indication of ice accretion on the rotor system, which is the critical component of the aircraft with respect to icing conditions.

| | |
|---|---|
| Trace icing | Accumulation of 1/2 inch of ice on a small probe each 80 miles |
| Light icing | Accumulation of 1/2 inch of ice on a small probe each 40 miles |
| Moderate icing | Accumulation of 1/2 inch of ice on a small probe each 20 miles |
| Heavy icing | Accumulation of 1/2 inch of ice on a small probe each 10 miles |

Figure 1. Icing Severity Definition.

## ICE SHEDDING

For all test conditions, ice shedding from the main rotor did not result in ice striking the fuselage or tail rotor. This will be shown in a summary film at the conclusion of these presentations. Due to the moderate turbulence in the artificial icing cloud, it was not possible to consistently accumulate measurable quantities of ice on the outboard rotor sections. Buildup and shedding of ice on the FM whip antenna caused large amplitude oscillations and contact with the tail rotor on several occasions. Over 2 inches of the antenna were severed during these tests. Antenna oscillations are also shown in the motion picture film.

Several instances of inadvertent asymmetrical ice shedding occurred during the tests. The worst condition was at -9°C following accumulation of an estimated 3/4 inch of ice on the main rotor blades. One blade suddenly shed from 90 percent radius to 42 percent radius while the other blade retained all its ice. Severe vertical vibrations followed making cockpit instruments unreadable. The asymmetric condition persisted for a total of 7 minutes and not until the aircraft had reached lower altitudes and -5°C temperatures did the rotor shed ice again and attain a symmetrical ice loading. Vibration levels increased by 0.5g at 1-per-rotor-revolution (1/rev) and significant pylon and mast motion were reported by the chase aircraft. A very thorough post-flight inspection revealed no major aircraft damage; however, considerable control system looseness was evident.

On one flight, following accumulation of approximately 1 inch of ice at a moderate accretion rate, attempts were made by the pilot to induce symmetrical shedding from the main rotor by rapidly varying main rotor speed, then by pumping collective, and finally by rapid cyclic control pulse inputs. One of the cyclic inputs resulted in an asymmetric shedding of ice followed by a considerable increase in aircraft vibration. Because of the possibility that deliberate control inputs may cause asymmetric rotor blade ice shedding, it is cautioned that this procedure not be employed.

## VISIBILITY

Early in the testing, it was found that the windshield and chin bubbles rapidly ice over, restricting all forward visibility. The installed UH-1H windshield defog system was activated but was unable to clear the windshield. Even when the defogger was used to preheat the windshield prior to entering the icing cloud, it was unable to keep the windshield clear of ice. A test deicing system operated in conjunction with the windshield wipers was effective in removing the ice. Attempts to clear the ice using the windshield wipers and alcohol system resulted in considerable scratching and gouging of the windshield. The side windows remain clear of ice even in moderate icing conditions.

INLET ICING

During the artificial icing tests, it was not possible to accumulate significant quantities of ice on the engine inlet screens, despite over 1 inch of buildup on all forward facing portions of the fuselage.

TORQUE INCREASE

Increased indicated torque accompanies ice accumulation on the main rotor and is a useful indication of ice accretion. With an ice accumulation in excess of approximately 5/8 inch on the inboard portions of the main rotor (which is indicated to the pilot by a approximately 20 percent torque pressure increase), it was not possible to maintain autorotational rotor speed above the lower limit (294 rpm) at 60 KIAS. The resulting low rotor speeds would provide insufficient rotor kinetic energy to ensure safe autorotational landings. Flights should not be continued when it is determined that greater than 1/2 inch of ice will accumulate on the main rotor, due to the associated degradation of autorotational capability. It was not possible to cause symmetrical shedding of the ice which accumulated on the inboard rotor sections, even with repeated sharp control inputs and aircraft maneuvering.

## CONCLUSIONS

From the testing completed last fall, it was concluded that intentional flight into light icing conditions would require (1) an adequate windshield anti-ice system (probably including a glass windshield) for both the pilot and copilot, (2) an improved sensitive outside air temperature gage, and (3) that ice accumulation should not exceed that value (approximately 1/2 inch) which results in loss of autorotational capability.[5] In no event should flight be attempted at temperatures of $-10^{o}C$ and below when visible moisture is present, nor should flight be conducted

[5]Final Report, USAASTA, Project No. 73-04-4, Artificial Icing Tests, UH-1H Helicopter, Part I, January 1974.

in freezing rain pending further testing. A solution to the asymmetric ice shedding problem is urgently needed if moderate icing flight capability is to be attained.

Based upon these test results, the icing tests continued with artificial icing tests of the AH-1G Cobra, and natural icing of the UH-1 were initiated. Major Carl Mittag will now discuss his UH-1 tests.

# UH-1H HELICOPTER NATURAL ICING TESTS

Major Carl F. Mittag
Project Officer

US Army Aviation Engineering
Flight Activity
Edwards Air Force Base
California 93523

## INTRODUCTION

As was discussed by Major Brewer, there were many problems identified during the artificial icing tests of the UH-1H in Alaska. However, of primary concern was whether the icing characteristics observed in the artificial environment were representative of those in a natural environment. This became the primary objective of the natural icing tests in addition to the artificial icing test objectives (slide 1).

## UH-1H WINDSHIELD

However, prior to actually starting the natural icing tests, it was obvious that a more efficient means of providing windshield anti-ice/deice was needed than was provided with the alcohol system on the Alaska aircraft. As a result, Bell Helicopter Company was kind enough to provide to us a heated glass windshield developed by Pittsburgh Plate Glass. This windshield was installed in the UH-1H on the copilot side only and tested in the artificial icing environment behind the HISS. In addition, a limited evaluation was conducted to determine if there were any undesirable optical characteristics in a non-icing environment.

The anti-ice/deice capability of the heated glass windshield is graphically illustrated in this slide (slide 2).

The heated section of the glass windshield was completely effective in preventing ice buildup when it was activated prior to entry into the HISS spray cloud. Turning the system on after entry into the spray cloud required 45 seconds to deice approximately 1/8 inch of ice from the heated section. The optical characteristics of the windshield were satisfactory when evaluated under daylight, twilight, and night conditions in a non-icing environment.

Once the heated windshield proved to be satisfactory in an icing environment, the test aircraft was configured for the natural icing tests.

## TEST AIRCRAFT

The test aircraft was a standard UH-1H helicopter except for the installation of pilot and copilot heated glass windshields, a visual ice probe located above the copilot's overhead plexiglass panel, a Rosemount ice detector system mounted over the pilot's overhead fresh air vent, and a heated total temperature probe mounted on the lower portion of the aircraft's nose shown here (slides 3 and 4).

Data recording was accomplished by means of magnetic tape which recorded vertical, lateral, and longitudinal vibrations from accelerometers located at the pilot's station, main rotor transmission area and tail rotor $90^{\circ}$ gearbox area. A typical accelerometer mounting is shown here on the $90^{\circ}$ gearbox (slides 5 and 6).

In addition to the magnetic tape, we used a photopanel to record control positions and performance date (slides 7 and 8).

## TEST CONDITIONS

The natural icing tests of the UH-1H were conducted at $-2.0^{\circ}C$ to $-5.5^{\circ}C$ static temperature and pressure altitudes from 3400 feet to 5600 feet. The total exposure time was 1.7 hours accomplished in four test flights. Observed accumulations varied from 1/8 inch to 3/4 inch. The testing was accomplished in the vicinity of Fort Lewis Washington during the month of February (slide 9).

The test methodology that was used was different from the artificial icing tests. Because the icing environment could not be controlled, we elected to use an aircraft with anti-ice/deice capability to survey the natural environment. The survey aircraft was a T-42A Beech Baron equipped with a total temperature sensor, an ice detection and rate system, and a visual probe.

A typical flight began by launching the T-42 to the test area under radar control. If the desired conditions of temperatures and icing severity existed, then through air traffic control channels the test helicopter and its chase were told to launch. On the way to the test area the survey crew briefed the test crew as to existing weather conditions and the altitude to fly. At this time the T-42 would climb to 1000 feet above the test altitude. Once the test helicopter reached the test area, positive radar contact would be established with the radar controller. The test helicopter would then climb to the test altitude. The chase aircraft would remain below the clouds, VFR, and by flying headings and airspeeds provided by the radar controller, stay within a mile of and directly behind the test helicopter. The test helicopter would fly a race track pattern using radio navigation aids and remain in the cloud as long as necessary to accrete the amount of ice desired.

Photographic documentation was accomplished by having the test helicopter fly to VFR conditions at the test altitude and then having the chase climb to the test altitude. Measurement and photo documentation of ice accumulations on the surface was nearly impossible because above freezing temperatures were always present.

Although the resulting scope of this evaluation was limited basic correlation of certain natural icing test results with artificial test results were achieved. I would now like to discuss the test results as observed during the natural icing tests. My discussion will be categorized into these subjects (slide 10).

## ICING SEVERITY

Flight of the icing survey aircraft in the natural icing environment quickly determined that we could not fly the UH-1H helicopter at a constant icing severity level. Icing severity varied with the aircraft's position in the clouds because of the natural differences of the cloud environment. However, temperature remained essentially constant for level flight. The changing rate in icing severity can be seen here by data obtained with the UH-1H helicopter (slide 11).

Shown is the percent of time that the icing rate system was indicated in each particular range. Fuselage ice accumulation and increased engine torque pressure, required to maintain constant airspeed and altitude, became the limiting test parameters. The type of ice encountered during our testing was limited to rime ice by the prevailing weather conditions. A typical natural ice accumulation is shown here accreted on the visual icing probe and for comparison, a typical artificial ice accumulation on the same type probe (slides 12 and 13).

The next two slides show ice accumulation of the bearing yoke of the non-rotating swash plate. First natural ice, then artificial ice (slides 14 and 15).

During the four test flights the maximum ice accumulation varied from 1/8 inch to 3/4 inch, measured on the visual probe.

Correspondingly, on these flights the Rosemount ice detection and rate system displayed icing severities from trace to moderate and occasionally heavy. Correlation was able to be obtained by timed ice accretion on the visual probe and icing severity indicated by the Rosemount system. Thus, the pilot was provided with immediate and accurate information about ice accretion on the helicopter's fuselage.

For each flight as the visual probe ice accumulated, increased engine torque requirements to maintain constant airspeed and altitude were observed. These results correlated with the results obtained during the artificial icing tests. The similarity of both data indicates that the ice accumulated on the main rotor system at a faster rate than on the fuselage. Hence, the Federal Aviation Administration icing severity definitions are not directly applicable for the UH-1H rotor systems.

## ICE SHEDDING

I would now like to discuss ice shedding characteristics as we observed them. Because of Major Brewer's experience in the UH-1H in Alaska, ice shedding was not intentionally induced during any of the testing. It was evaluated only as it occurred. The ice shedding that we saw during natural icing correlated very closely with the artificial icing shedding. For example, at -4.5°C total temperature, we observed symmetrical shedding into a point of approximately 42 percent radius (or 10 feet). Whereas, during artificial icing at -4°C total temperature, symmetrical shedding was observed to a point of 38 percent radius. Periodic or cyclic shedding from the main rotor at -5.5°C static temperature was observed on our last flight. During this flight, the engine torque to maintain constant airspeed and altitude had to be increased by the pilot as main rotor ice accumulated. When engine torque was approximately 23 percent above the level flight no ice torque requirements, a mild lateral vibration was felt. This vibration was caused by ice shedding from one main rotor blade followed almost immediately by a corresponding shed from the opposite blade. A 8-12 percent decrease in torque required to maintain the same airspeed was immediately noticed. The characteristic of increasing torque and decreasing torque was observed at periodic intervals during this flight and corresponds to the natural periodic shedding characteristics observed by other agencies.

After the level flight ice accumulation of 45 minutes and with 3/4 inch of ice on the visual probe, an auotorotation was initiated from 5000 feet pressure altitude. Ice shedding occurred almost immediately from the main rotor mast because of changes in torsional load. As warmer temperatures were encountered during the descent, symmetrical ice shedding occured from the main rotor. As far as could be determined, there was no impact of shedding ice with the helicopter. Right after this autorotation, the helicopter was immediately landed in above freezing temperatures. During shutdown, ice was being shed in all directions from the main rotor and presented a hazard to ground personnel. Extreme caution must be observed by ground personnel when approaching an iced helicopter because of the danger of being struck by shedding ice.

## VIBRATION LEVELS

Vibration levels were measured using the onboard instrumentation previously described. Vibrations measured during level flight, autorotation and any during ice shedding were apparently normal or any transients were masked by the normal helicopter vibrations.

## LEVEL FLIGHT PERFORMANCE

The level flight performance of the UH-1H helicopter was evaluated to determine any changes resulting from exposure to a natural icing environment. Increasing engine torque requirements to maintain constant airspeed and altitude during exposure to the icing environment was the best indicator of degraded level flight performance. For example, during the last flight and after exposure to moderate icing for 45 minutes, the engine torque pressure required to maintain a constant 96 KTAS and 3400 feet pressure altitude had increased 23 percent above the torque pressure required for the no-ice condition. Total accumulated ice on the main rotor could not be determined because of above freezing temperatures on the ground. However, the maximum fuselage ice accumulated was 3/4 inch measured on the visual probe. The helicopter was not power limited at these conditions.

## AUTOROTATION

The autorotational characteristics of the UH-1H helicopter were evaluated to determine autorotational capability after exposure to natural icing. The results are shown in this slide (slide 16). During the last flight and after exiting the cloud it was suspected that a substantial amount of ice sublimation or shed from the main rotor during 15 minutes required for photo documentation prior to the autorotation. During this time engine torque pressure decreased from 23 percent to 12 percent above the no ice conditions to maintain constant airspeed and altitude. However, the remaining ice accumulation on the main rotor blades caused a marked degradation of the maximum autorotational rotor speed attainable. During the autorotation, the autorotational rotor speed stabilized at 285 rpm. The minimum permissible sustained rotor speed for the UH-1H helicopter is 294 rpm. Trends in the engine torque increases required to maintain constant airspeed and altitude associated with decreased autorotational rotor speed were essentially the same for my tests and Major Brewer's tests.

## HANDLING QUALITIES

The handling qualities of the helicopter were evaluated for each flight. Recorded data and crew comments showed no apparent changes in the handling qualities with ice accumulation. These results agree with those of Major Brewer's testing.

## ICE PROTECTION SYSTEMS

All of the standard anti-ice/deice systems of the helicopter operated effectively. The only exception was that the defrost system was incapable of preventing ice formation. However, when the defrost was operated with cabin heat and with the heated windshields prior to entering icing, the windshields would stay clear of ice for approximately 20 minutes in average moderate icing conditions. Better heat conduction and a smoother external surface probably resulted in this improved anti-ice/deice capability. As mentioned before, electrically heated glass windshields were installed on the test helicopter. The heated parts of the glass windshields were completely effective in preventing ice accumulation during all of the test flights. The unheated parts of the windshield remained free of ice during the first 20 minutes of exposure to the icing environment only when the cabin heated and windshield defrost systems had been operated prior to entry into the icing conditions. When ice accumulated on the unheated sections, it formed in the shape of spiked crystals and accumulated randomly without causing the windshield to become totally obscured. During Flight 4, the helicopter was exposed to moderate icing severity conditions for approximately 30 minutes without prior activation of the heated glass windshield, windshield defrost, or cabin heat systems. Ice did not begin to form on the windshield until approximately 10 minutes after entering the clouds. The ice formed and accumulated on other parts of the fuselage in the same manner as on the previous flights with the windshield never becoming totally obscured. During this time, approximately 1 inch of ice formed on the windshield wiper blades. Activation of the heated windshields removed all accumulated ice from the heated section within 30 seconds. As the accumulated ice melted, the heated moisture flowed upward and refroze on the unheated sections.

## MISCELLANEOUS

### Engine Inlet Icing

Various miscellaneous results were obtained during these tests and I would now like to cover these. It was found that post-icing in-flight photographs of the inlet area showed that signi-ficiant amount of ice had accumulated on the left engine filter screen.

This characteristic was contrary to the results of Major Brewer's testing. In the slide you can see that approximately 50 percent of the screen is covered; however, there was no increase in engine exhaust gas temperature, nor was there any change in the measured engine inlet plenum differential static pressure when compared with the no-ice condition. These results would indi-cate that engine air inlet filter icing is less of a limiting factor than main rotor icing for the UH-1H helicopter (slide 17).

### FM Antenna

After the first icing flight, post flight inspection revealed that the FM antenna had been damaged. Ice buildups on the antenna pro-bably caused unstable motion, causing the antenna to strike the tail rotor. This characteristic can be corrected by addition of a wedge block underneath the antenna mount. This block is available in Army supply channels.

## TEST RESULTS

I would now like to conclude by presenting the significant test results of the natural icing tests (slide 18).

The artificial icing characteristics are representative of natural icing characteristics for the UH-1H helicopter.

The autorotational rotor speed decreases with ice accumulation and can decrease below operational limits.

FM antenna ice accretion causes oscillations which result in the antenna striking the tail rotor.

And in closing, just remember that for the icing tests, happiness is year 'round ice (slide 19).

I would now like to introduce Chief Warrant Officer Jim Reid who will discuss the AH-1G testing.

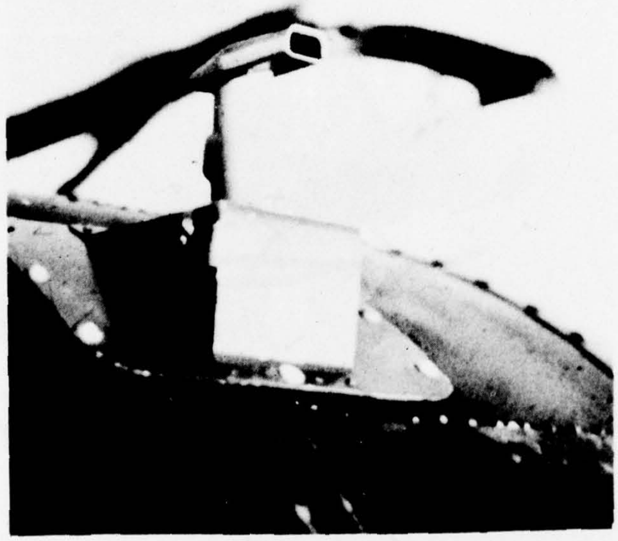
## NATURAL ICING TEST OBJECTIVE

- VERIFY THAT ARTIFICIAL ICING CHARACTERISTICS ARE REPRESENTATIVE OF NATURAL ICING CHARACTERISTICS

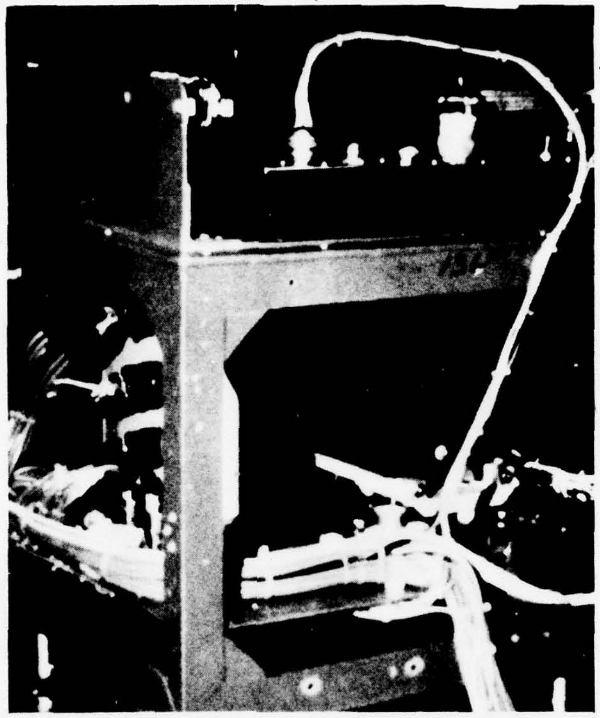
Slide 1. Natural Icing Test Objective.

Slide 2. Heated Glass Windshield Capability.

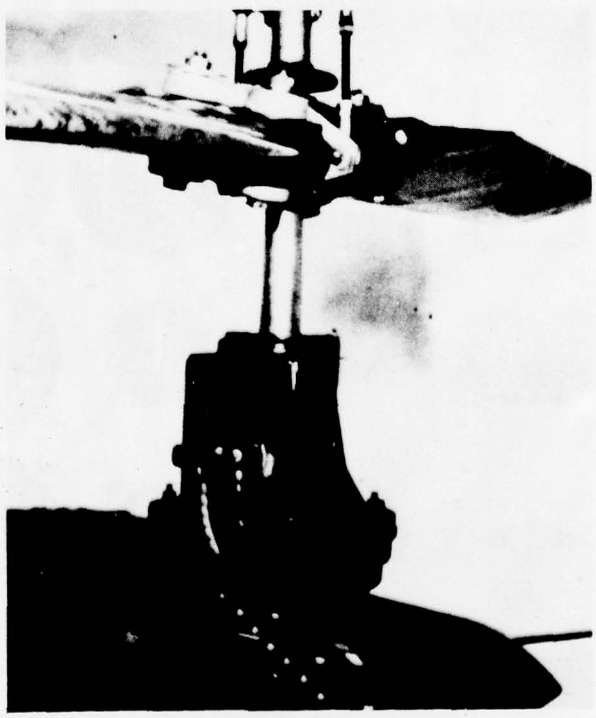
Slide 3. UH-1H Test Helicopter.



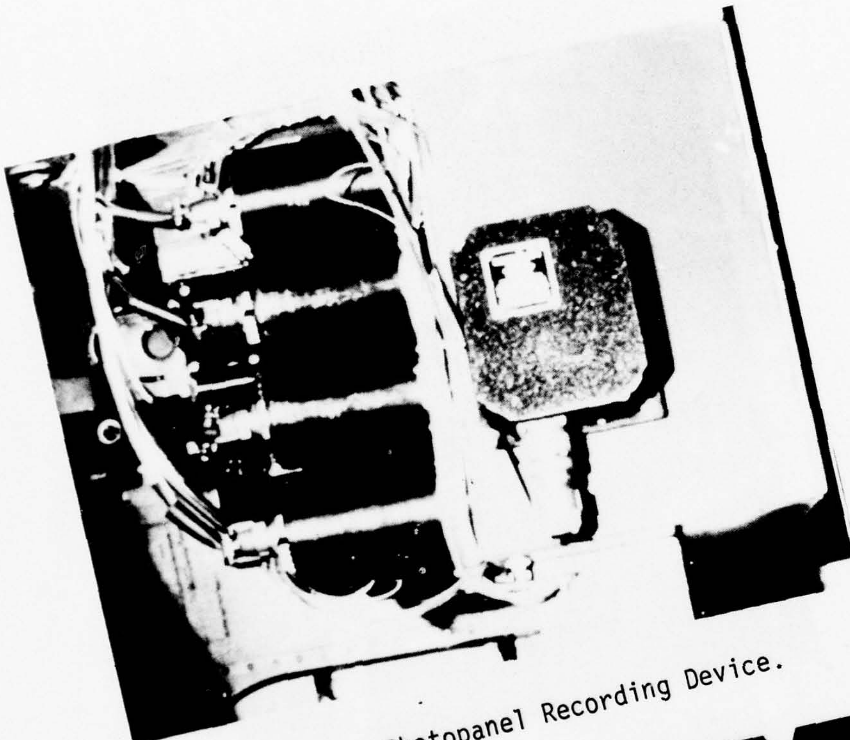
Slide 4. Total Temperature Probe.



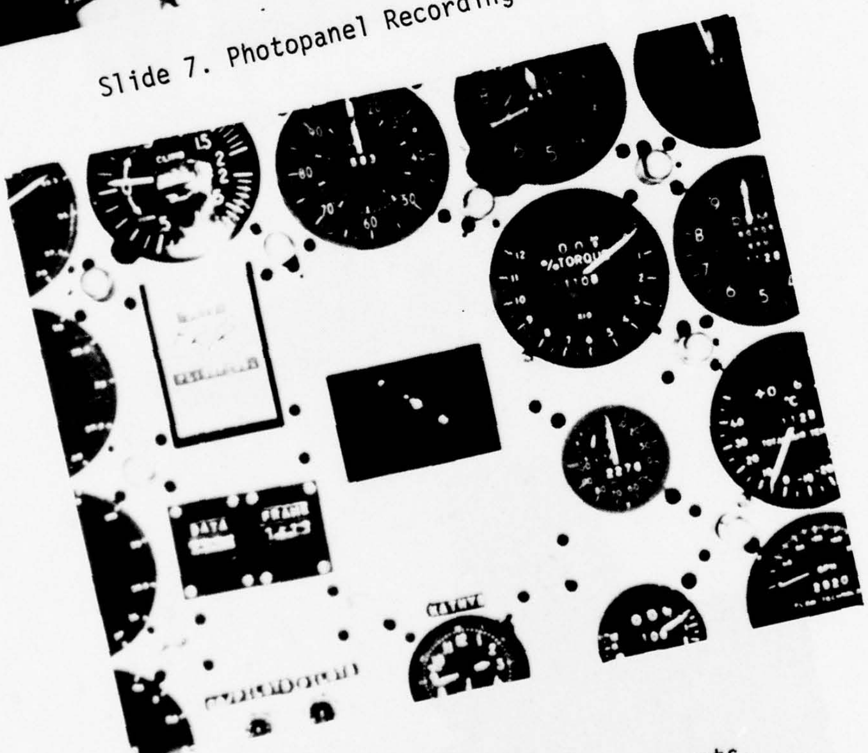
Slide 5. Magnetic Tape System.



Slide 6. Accelerometer Mounting On The Gearbox.



Slide 7. Photopanel Recording Device.



Slide 8. Photopanel Instruments.

## TEST CONDITIONS

| FLIGHT NUMBER | ICING THICKNESS INCHES | TIME IN ICING MINUTE | AVERAGE STATIC TEMPERATURE °C | MEAN SEVERITY |
|---|---|---|---|---|
| 1 | 3/16 | 17 | -5.5 | LIGHT |
| 2 | 1/8 | 17 | -2.0 | TRACE |
| 3 | 1/4 | 21 | -4.5 | TRACE |
| 4 | 3/4 | 45 | -5.5 | MODERATE |

NOTE: MEAN SEVERITY MEASURED BY ICING RATE METER

Slide 9. UH-1H Natural Icing Test Conditions.

## DISCUSSION SUBJECTS

- ICING SEVERITY
- ICE SHEDDING CHARACTERISTICS
- VIBRATION LEVELS
- PERFORMANCE
- HANDLING QUALITIES
- ICE PROTECTION SYSTEMS
- MISCELLANEOUS

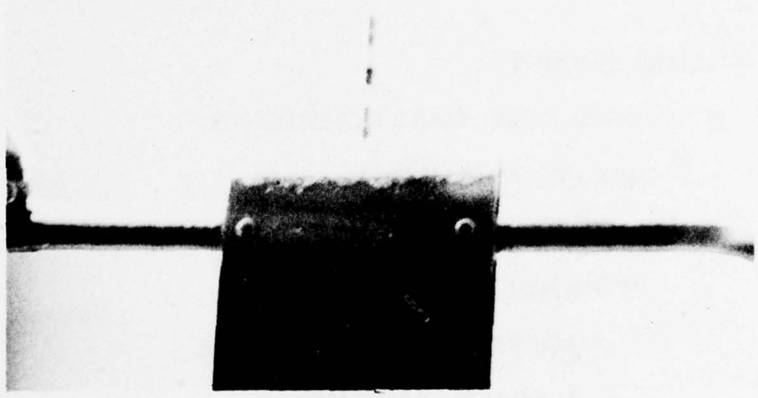
Slide 10. Test Results Discussion Subjects.

## ICING RATES

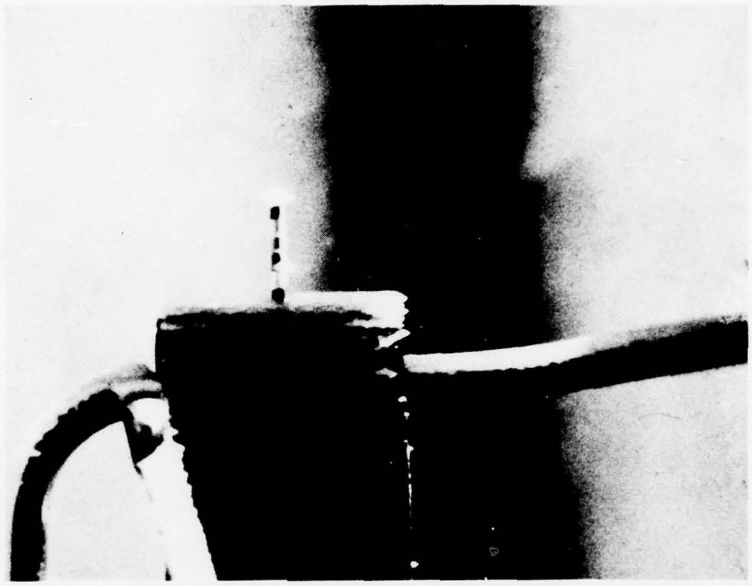
PERCENT OF TIME AT INDICATED ICING RATE

| FLIGHT NUMBER | NO ICE-TRACE | TRACE-LIGHT | LIGHT-MODERATE | MODERATE-HEAVY | FULLSCALE |
|---|---|---|---|---|---|
| 1 | 24 | 13 | 61 | 2 | 0 |
| 2 | 84 | 9 | 3 | 4 | 0 |
| 3 | 54 | 10 | 19 | 13 | 4 |
| 4 | 14 | 8 | 26 | 44 | 8 |

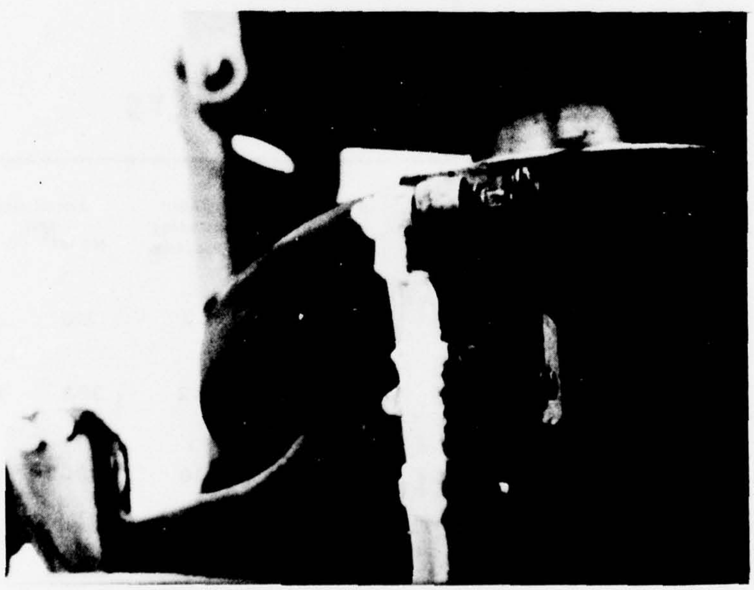
Slide 11. Icing Severity Rates.



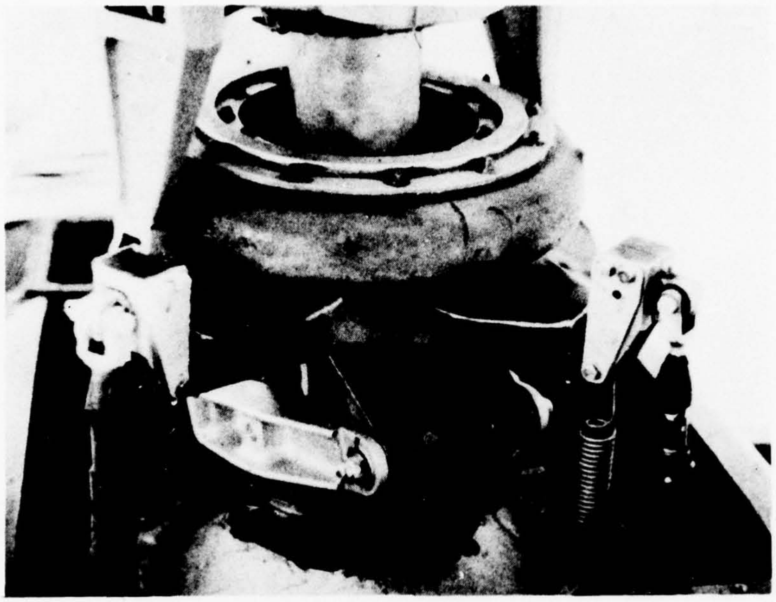
Slide 12. Probe Natural Ice Accumulation.



Slide 13. Probe Artificial Ice Accumulation.



Slide 14. Bearing Yoke Natural Ice Accumulation.



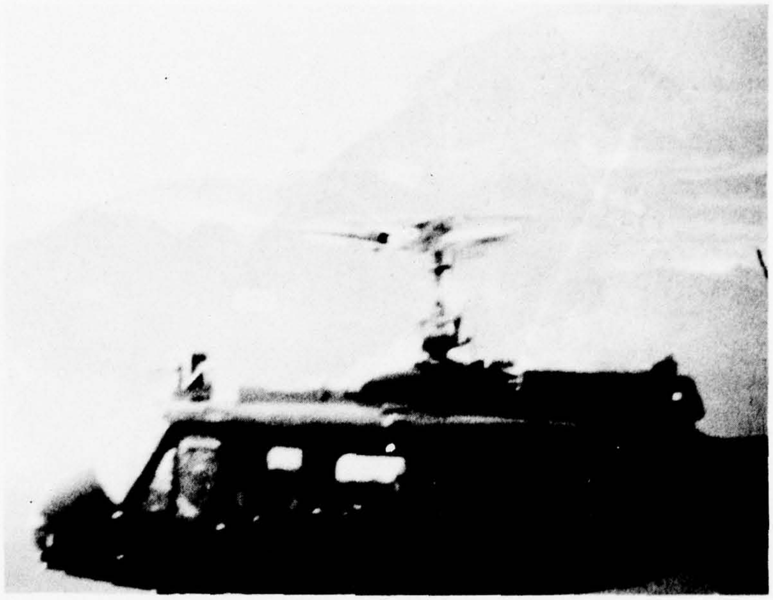
Slide 15. Bearing Yoke Artificial Ice Accumulation.

## AUTOROTATION RESULTS

| FLIGHT NUMBER | ICING EXPOSURE MINUTES | STATIC TEMPERATURE | VISUAL PROBE ICE THICKNESS INCHES | TORQUE INCREASE PERCENT | ROTOR SPEED RPM NO ICE | ICE |
|---|---|---|---|---|---|---|
| 1 | 17 | -5.5 | 3/16 | 3 | 310 | 304 |
| 3 | 21 | -4.5 | 1/4 | 12 | 303 | 293 |
| 4 | 45 | -5.5 | 3/4 | 10 | 300 | 285 |

NOTE: NO ICE AND ICE ROTOR SPEED COMPARED AT IDENTICAL DENSITY ALTITUDES

Slide 16. UH-1H Autorotational Characteristics.

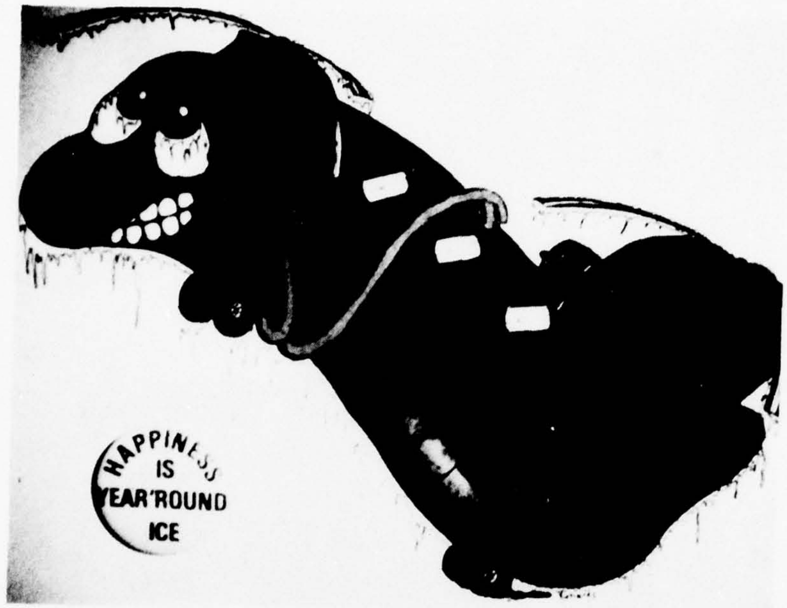


Slide 17. Engine Inlet Icing.

## NATURAL ICING TEST RESULTS

- ARTIFICIAL ICING CHARACTERISTICS ARE REPRESENTATIVE OF NATURAL ICE CHARACTERISTICS
- AUTOROTATIONAL ROTOR SPEED DECREASES WITH MAIN ROTOR ICE ACCUMULATION
- TAIL ROTOR STRIKES BY OSCILLATING ICED FM ANTENNA

Slide 18. UH-1H Helicopter Significant Test Results.




Slide 19. Year 'Round Ice.

# ARTIFICIAL ICING TESTS

## AH-1G HELICOPTER

CW4 James W. Reid
Project Pilot

US Army Aviation Engineering
Flight Activity
Edwards Air Force Base, CA
93523

## INTRODUCTION

The AH-1G Cobra artificial icing tests were conducted this past October and November near Fort Wainwright, Alaska, and in March and April of this year near Moses Lake in Washington state. A total of 16 icing test flights were conducted with over 4 hours in the artificial icing environment. The test helicopters were equipped with only the standard engine anti-icing and the canopy rain removal systems for ice protection. The test helicopter in Alaska was modified with the Automax camera for recording performance parameters and a direct-writing oscillograph for vibration information. The test helicopter used at the Moses Lake Test Site was equipped with a photopanel and magnetic tape recorder instrumentation package. Both aircraft were equipped with a visual probe and Rosemount icing rate system. A differential pressure system was installed to monitor engine inlet icing (slides 1, 2, and 3).

The test conditions encompassed -4, -9, and -13$^{o}$C static air temperatures at light and moderate icing severities. The Alaska Cobra had four rocket pods with inert rockets mounted on its wing stations, the Moses Lake Cobra was tested in the clean configuration (slides 4 and 5).

## TEST RESULTS

### ICE-SHEDDING CHARACTERISTICS

The ice-shedding characteristics of the main rotor blades on the AH-1G were similar to those identified for the UH-1H helicopter. Shedding appeared to be symmetrical at -4$^{o}$C and could be induced by varying the rotor speed with the engine governor trim switch. Shedding could not be induced with deliberate flight control inputs at any of the test temperatures. At the colder temperatures (-10 and -13$^{o}$C) shedding could not be induced by varying the rotor speed. Random asymmetric ice shedding was experienced at the relatively warm temperature of -6$^{o}$C, but produced only a slight increase above the normal vibration level and was not a hazard to flight. As testing progressed to colder temperatures, the vibration level increased after experiencing asymmetrical shedding. Severe vertical and lateral vibration levels were encountered after exposure to programmed light icing for 15 minutes at -13°C. The asymmetric condition continued during a rapid descent to warmer temperatures. The rotor shed ice at approximately -6°C and the vibration level was normal, indicating the rotor ice was now symmetrical on both blades.

AUTOROTATION CHARACTERISTICS

Prior to accumulating ice on the rotor system, for the autorotation tests an autorotation was made through the test altitude for base-line rotor speed and rate-of-descent information. The engine power required to maintain altitude and airspeed was also established. Testing at -4°C identified the degradation in rotor speed after an ice accumulation on the main rotor. After accumulating ice on the rotor system for 10 minutes at -9°C in light icing, engine power required to maintain airspeed and altitude had increased approximately 36 percent over that acquired for level flight to 31 PSI. An autorotation was attempted at the best descent airspeed by first lowering the collective pitch control full down and then closing the throttle to the flight-idle position. In that period of time the rotor speed decayed from 324 RPM to 290 RPM. The handbook operational limit is 294 RPM. An immediate power recovery was made and no attempt was made to determine if the rotor speed would have stabilized. The rate of descent reached 3600 ft/min, almost double the base-line rate of descent. At -11°C and programmed moderate icing severity, this same limit in autorotation capability was reached with only 4 minutes in the cloud. During this attempted autorotation, the rate of descent exceeded 4800 ft/min and a power recovery was immediately initiated.

CANOPY ICING

The rain removal system was turned on prior to entering the icing environment and did keep a large portion of the front canopy clear of ice at -4°C, at -9 and -13°C. The rain removal system was not effective and only the lower 8 to 10 inches remained clear of ice. The pilot's normal forward field of view through the canopy would be in the area of the sight reticle. In temperatures of -9°C, vision through thisarea was completely restricted. The runback and freezing along the sides also restricted forward vision thru the side of the canopy (slides 6 and 7).

TAIL ROTOR SYSTEM

The vertical fin, tail rotor hub, pitch change links, and the leading edge of the tail rotor blades near the hub accumulated ice at all test temperatures. Although no change in tail rotor performance was attributed to the ice accumulation, a potential hazard exists with the standard AH-1G when large buildups of ice accrete on the tail rotor. The helicopter tested at Moses Lake was modified with an IR suppressor tail pipe. This device deflected the hot exhaust gas into the rotor downwash. This caused a much larger exhaust plume which did encompass the tail rotor system with sufficient heat to deice the tail rotor and most of the vertical fin (slides 8 and 9).

ENGINE INLET

The AH-1G was flown in the icing environment with the engine air induction screens in both the open and closed position. The slide shows the engine air induction screen on the right side of the fuselage in the open position with an accumulation of ice. When flown with the screens in the closed position, only a trace of ice appeared on the screen and no change in differential pressure across the inlet plenum' was noted (slide 10).

Small particles of ice did adhere to the engine air particle separator screen. A thorough postflight inspection of engine inlet guide vanes and the first-stage compressor blades was made after each flight. The lack of any perceptible dents or stains on the compressor blades indicates the ice particles were separated and vented overboard by the air particle separator (slide 11).

COMMERCIAL ANTI-ICING SPRAYS

A commercial anti-icing aerosol spray advertised to retard ice accretion by inducing early shedding was applied on the helicopter rotor blades, canopy, and other parts of the fuselage with a high affinity for ice accumulation. The spray had no visible effect on the ice shedding characteristics of the AH-1G and its use was immediately discontinued.

WEAPONS SYSTEM

The rocket pods with inert rockets accreted large formations of ice. A protective cover appears to be necessary, and this is the subject of a presentation this afternoon by the Missile Command (slides 12 and 13).

Turret weapons after 1 inch of ice accumulation on the visual probe are shown in slide 14.

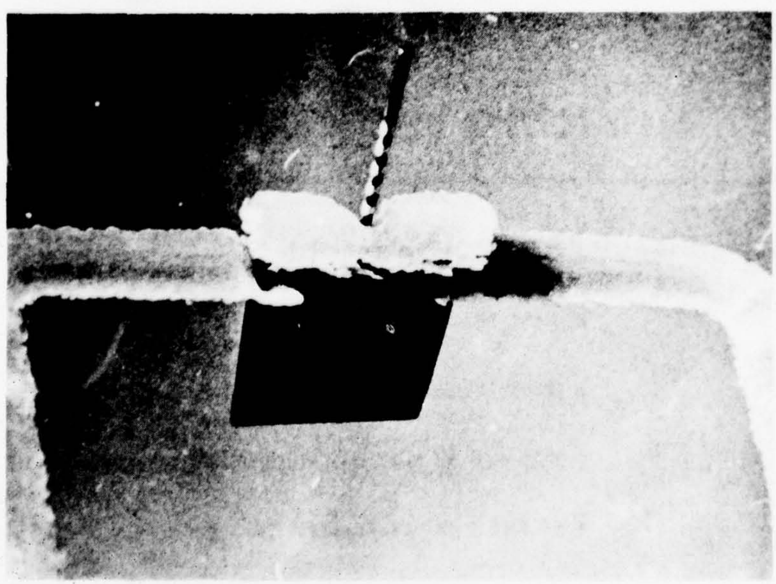
Slides 15 and 16 show the effects of dry-firing the turret weapons system.

The AH-1G Icing Test results are summarized below.

AH-1 ICING TESTS RESULTS

- Severe vibrations were encountered after asymmetric ice shedding from the main rotor blades.
- Rotor speed in autorotation severely degraded with ice accumulation on the rotor blades.
- Varying rotor speed, with the engine governor switch, was effective means in shedding ice at temperatures warmer than -6$^{o}$C.
- Anti-icing sprays were not effective in preventing ice accumulation on the rotor system.
- Forward view obscured by ice accumulation on the canopy.
- Ice protection required for wing stores and turret weapons.

SLIDE 1. AH-1G ARTIFICIAL ICING TESTS



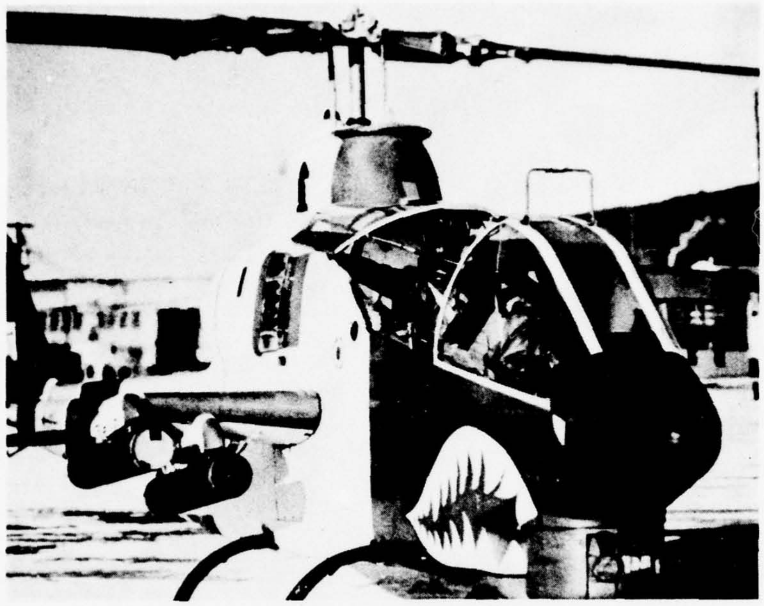
SLIDE 2. VISUAL ICING PROBE.


SLIDE 3. ROSEMOUNT ICING RATE METER.

## AH-1 ICING TEST CONDITIONS

- 16 ICING FLIGHTS COMPLETED
- −4°C TO −13°C TEMPERATURES
- LIGHT TO MODERATE ICING RATE
- 0.25 AND 0.5 GM/M³ LIQUID WATER CONTENT
- 90 KNOTS INDICATED AIRSPEED

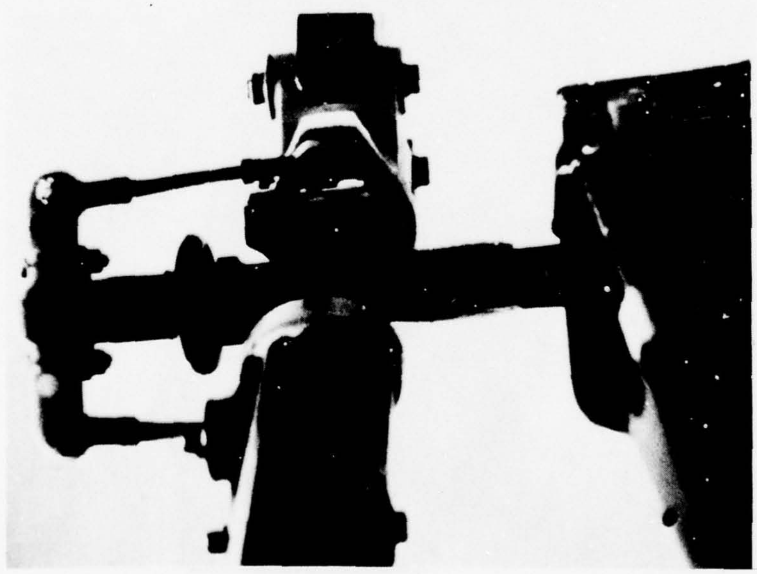
SLIDE 4. AH-1G ICING TEST CONDITIONS.



SLIDE 5. AH-1G WITH ROCKET PODS INSTALLED.

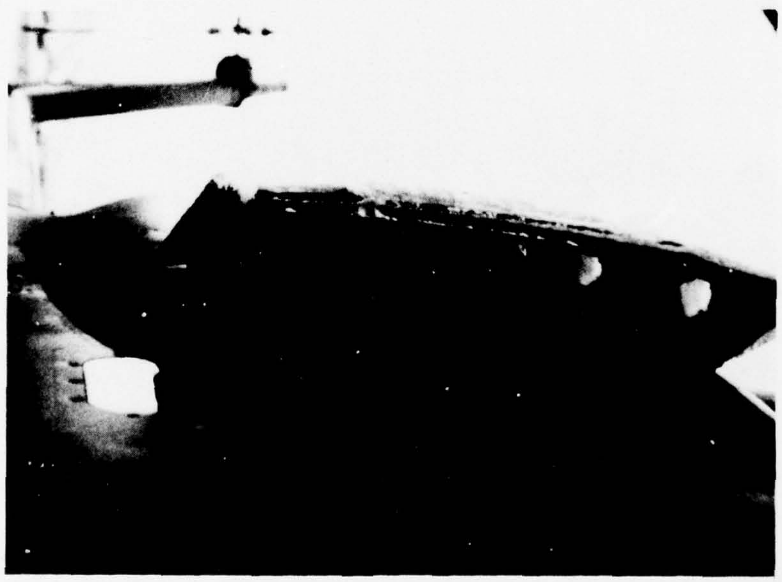
SLIDE 6. AH-1G FRONT CANOPY WITH ICE ACCUMULATION.

SLIDE 7. RUNBACK AND REFREEZING CAUSED RESTRICTED FIELD OF VIEW.

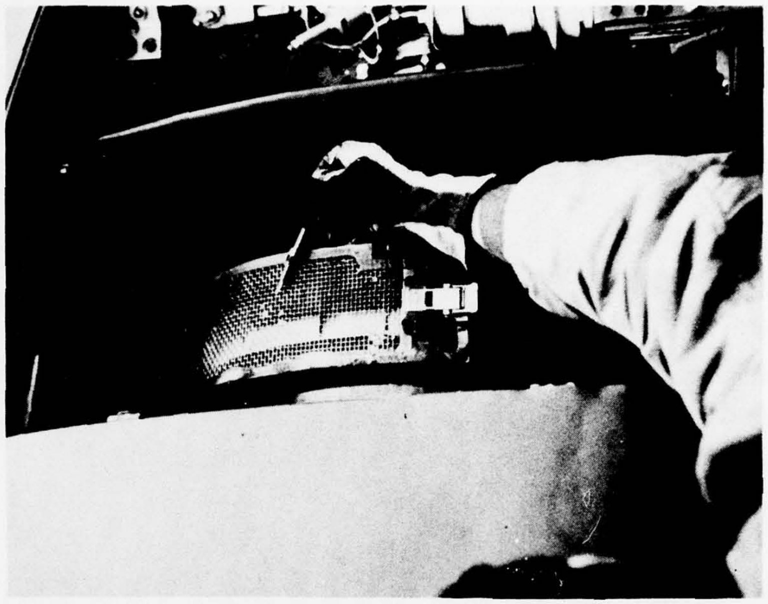


SLIDE 8. ICE ACCUMULATION ON THE TAIL ROTOR COMPONENTS.

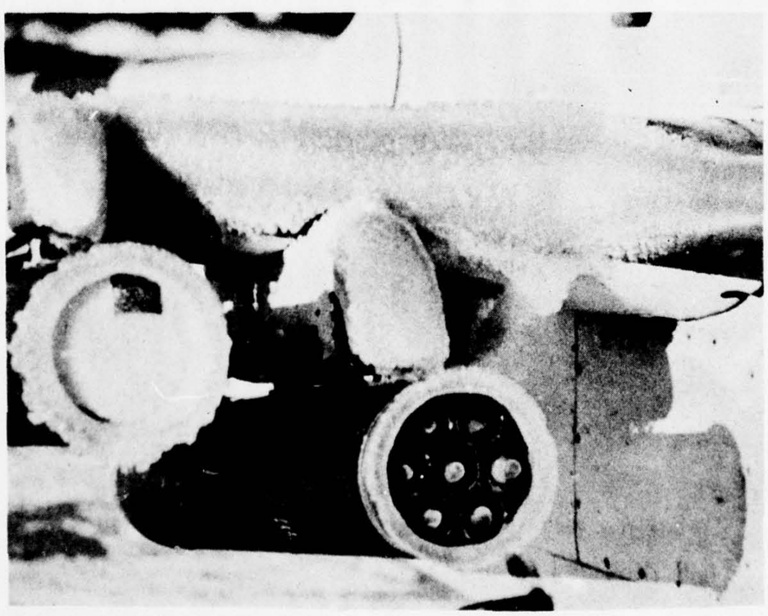
SLIDE 9. AH-1G WITH IR SUPPRESSOR TAILPIPE INSTALLATION



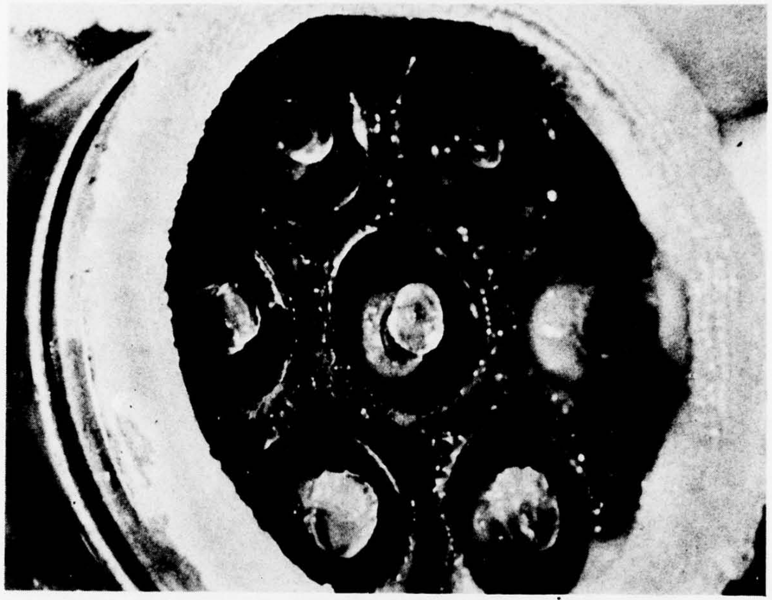
SLIDE 10. ICED ENGINE AIR INDUCTION SCREEN IN THE OPEN POSITION.



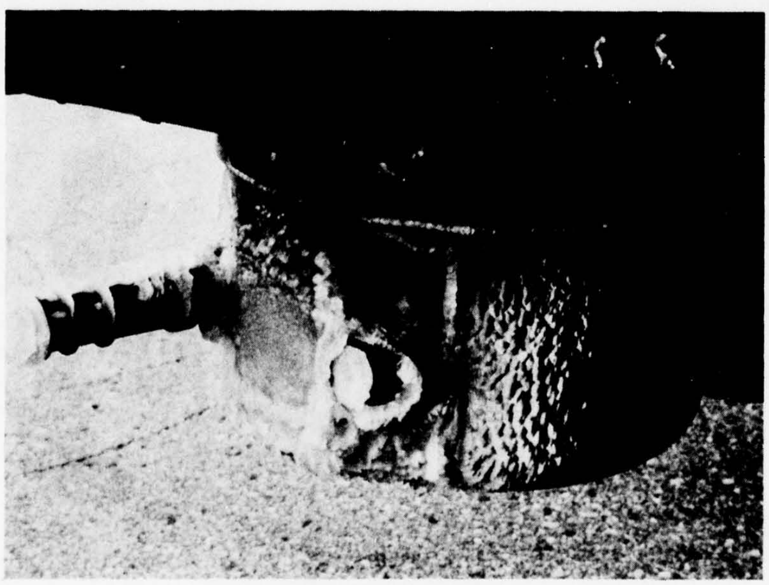
SLIDE 11. SMALL ICE PARTICLES
ON THE ENGINE AIR PARTICLE SEPERATOR SCREEN



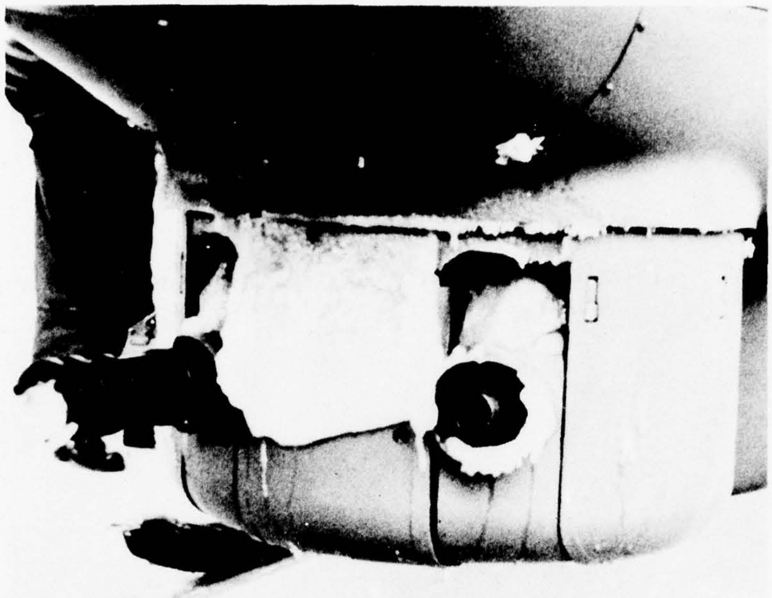
SLIDE 12. ICE ACCUMULATION ON THE WING STORES.



SLIDE 13. ICE ACCUMULATION IN THE ROCKET PODS.



SLIDE 14. ICE ACCUMULATION ON THE TURRET WEAPONS.



SLIDE 15. ICE REMOVED BY DRY FIRING THE TURRET WEAPONS.

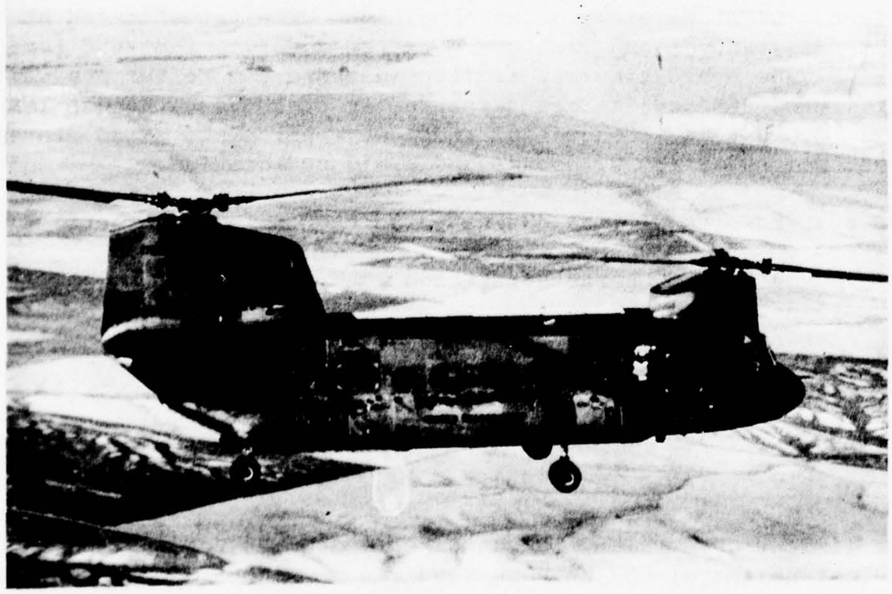
SLIDE 16. ICE REMOVED ON THE MINIGUN AFTER DRY FIRING.

ARTIFICIAL ICING TESTS

CH-47C HELICOPTER

Cpt. James C. O'Connor
Project Pilot

US Army Aviation Engineering
Flight Activity
Edwards Air Force Base,
California 93523



CH-47C - "CHINOOK"

Following the completion of the AH-1G artificial icing tests, the CH-47C, Chinook, was evaluated during April of this year in Moses Lake, Washington. The test aircraft was a tandem rotor, helicopter manufactured by the Vertol Division of the Boeing Company. The helicopter was powered by two Lycoming T55-L-11A turboshaft engines. All tests were conducted with the engine inlet screens removed, cargo hook stowed and cabin heat and anti-ice systems "ON". Test instrumentation included a Rosemount ice detector and visual ice accretion indicator located on the forward pylon, heated sensitive total temperature probe located on the nose, photopnael and magnetic tape recorder mounted in the cargo compartment.

A total of five test flights were conducted, of which 2 hours and 51 minutes were in the artificial icing environment. The time in icing, the far right column, Table 1, was split equally between the forward and aft rotor systems, except on the last flight. Light to heavy icing conditions were investigated at the -6°C temperatures and light to moderate icing at the -8°C temperatures. The evaluation was limited in scope due to the nonavailability of desired test temperatures at pressure altitudes less than 10,000 feet. Generally, tests were performed at an average gross weight of 28,500 pounds and a mid cg location.

The test results will be discussed in the following order:

- Spray system characteristics
- Icing severity
- Ice shedding characteristics
- Ice protection systems
- Performance
- Handling qualities

## SPRAY SYSTEM CHARACTERISTICS

The limited spray cloud thickness of 5 feet as compared to the 17-foot height of the Chinook required individual icing of the forward rotor, aft rotor, the windshields or the lower portion of the fuselage. Total emersion of the Chinook, or even simultaneous icing of both rotor systems could not be accomplished. This will be seen in the movie at the completion of the presentation. Ice sublimation and shedding while the other rotor is being iced biases the quantitative accuracy of the autorotational, level flight and vibration data. Within the limited scope of the tests conducted, the spray system was found to be adequate for the preliminary investigations conducted.

## ICING SEVERITY

Icing severities ranged from light to heavy with a maximum of 1 inch accumulated on the visual probe at -8.7 and -8.6°C in light and moderate conditions, respectively. The total amount of ice accumulated on each flight was limited by the quantity of water in the spray helicopter. Because of the location of the visual ice accretion probe and the limited cloud thickness, the probe could not be continuously emersed to get a total accumulated for the flight. The type of ice accumulated was glime ice. Note in figures 1, and 2, ice on nearly 100 percent of the blade and the ice on the head assembly.

Figure 3 shows the aft pylon and rotor area. Limited quantities of ice were accumulated on the aft rotor. This is believed to be caused by the induced flow effects of the forward head on the limited spray thickness. The top engine oil cooler inlets would periodically ice completely over and then the ice would separate inward clearing the screens. No damage was done to the coolers. As can be seen the engine inlet and heated portion of the drive shaft tunnel are clear of ice. Ice thicknesses and type on the blades could not be post flight documented due to the above freezing temperatures on the ground.

## ICE SHEDDING CHARACTERISTICS

Symmetrical ice shedding occurred in light to heavy icing at -6°C to -6.6°C and in light icing conditions at -8.7°C. Asymmetrical shedding was observed on the last flight after 10 minutes in the spray at -8.6°C in moderate icing conditions. This condition remained for three minutes. During this time the lateral vibration level at the pilot's station increased from zero to 2/10g at 1/rev. Spanwise shedding on all flights was random and not repeatable among the blades. Random self shedding of blade ice was observed at approximately 4 minute intervals.

Thrust control rod inputs of ± 1 inch, rotor speed changes of 10 rpm and circular cyclic inputs of 3/4-inch radius were used to induce shedding. The rotor speed changes were found to be the most effective method of inducing shedding. These methods did not always induce shedding and cannot be relied upon to induce shedding.

The compressor blade damage seen in figure 4 was caused by shedding ice on flight five. Post flight inspection revealed both engines had been damaged, with the right engine receiving the most severe damage. It appears ice entered the inlet and lodged between the first compressor stage and the variable inlet guide vanes twisting the blades. Damage to the next set of stator vanes also occured. Similiar engine foreign object damage has occurred in operational units. Although an inflight failure did not occur, the possibility exists for a single or dual engine failure caused by ice injection. Engine inlet protection for the Lycoming T55-L-11A engines designed to operate in an icing environment is required for flight in icing conditions.

On the same flight four rotor blades, two on each head, received, damage (figure 5). The blade surface deformations ranged in size from 1/4 inch to 1 1/2 inches spanwise, 3/4 to 6 inches chordwise and 3/100 to 1/10 inch deep. The aft rotor blades incurred approximately 80 percent more dents than the forward blades. The aft green blade received the most severe damage with 18 dents. Testing was suspended following this flight. Both engines and four blades were replaced prior to the ferry flight to Edwards.

## ICE PROTECTION SYSTEMS

The installed anti-ice systems performed satisfactory on all flights. No ice accumulated on the engine inlets and the heated portion of the drive shaft tunnels. The pilot/copilot's and center windshields remained clear of ice. The copilot's windshield anti-ice was deliberately left off on some flights. Activation of the anti-ice after ice accumulation would not clear the windshield. As recommended in the operator's manual, the five minute warm up period for the anti-ice systems prior to entering icing conditions was adequate.

## PERFORMANCE

Level flight engine power increases after ice accumulation ranged from 5 to 31 percent above a no-ice condition. The largest power increase occurred after 15 minutes exposure to heavy icing conditions at $-6.6^{\circ}C$. At the colder temperature of $-8.7^{\circ}C$ a 5 percent increase in light icing was observed after 50 minutes exposure. In moderate icing at the same temperature a 16 percent increase was observed after 26 minutes. For the reasons mentioned previously in the spray system characteristics, no correlation can be drawn between torque increase, temperature and severity from this data. Generally, as documented on other test flights, a degradation in level flight performance will occur after accumulating ice.

A 70 KIAS autorotation was conducted at the end of each test flight. A stabilized rotor speed of 245 rpm could be obtained on all flights.

HANDLING QUALITIES

Handling qualities were qualitatively evaluated by the pilot while performing engineering tests outside of the spray cloud. There were no apparent changes in handling qualities with ice accumulation, except for asymmetrical shedding. Quantitative data shows no significant change in control positions.

SUMMARY

The significant test results from the CH-47C artificial icing evaluation are:

Symmetrical Shedding
- Light to Heavy $-6^{o}C$
- Light $-9^{o}C$

Asymmetrical Shedding
- Moderate $-9^{o}C$

Self-shedding
Engine Damage - Ice FOD
Blade Damage
Anti-ice Systems Satisfactory

## CH-47C TEST CONDITIONS

| FLIGHT NUMBER | AVERAGE STATIC OUTSIDE AIR TEMPERATURE °C | MEAN SEVERITY | TIME IN ICING (MIN) |
|---|---|---|---|
| 1 | −6.0 | LIGHT | 30 |
| 2 | −6.6 | HEAVY | 15 |
| 3 | −6.4 | LIGHT | 51 |
| 4 | −8.7 | LIGHT | 50 |
| 5 | −8.6 | MODERATE | 26 |

AVERAGE GROSS WEIGHT 28500 LB MID CENTER OF GRAVITY ROTOR SPEED-235 RPM
AVERAGE TRUE AIRSPEED-97 KNOTS DENSITY ALTITUDE RANGE-4900 TO 10800 FEET

TABLE I. TEST CONDITIONS

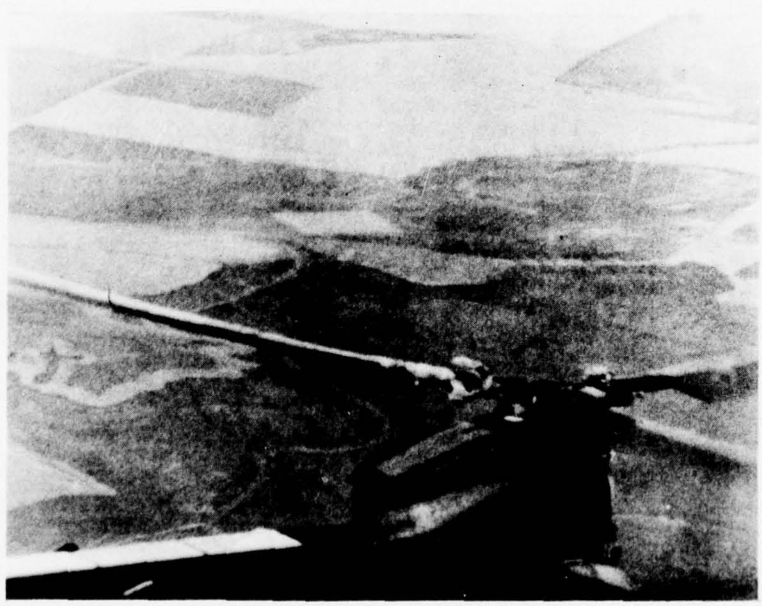


FIGURE 1. FORWARD PYLON

FIGURE 2. FORWARD PYLON

FIGURE 3. AFT PYLON

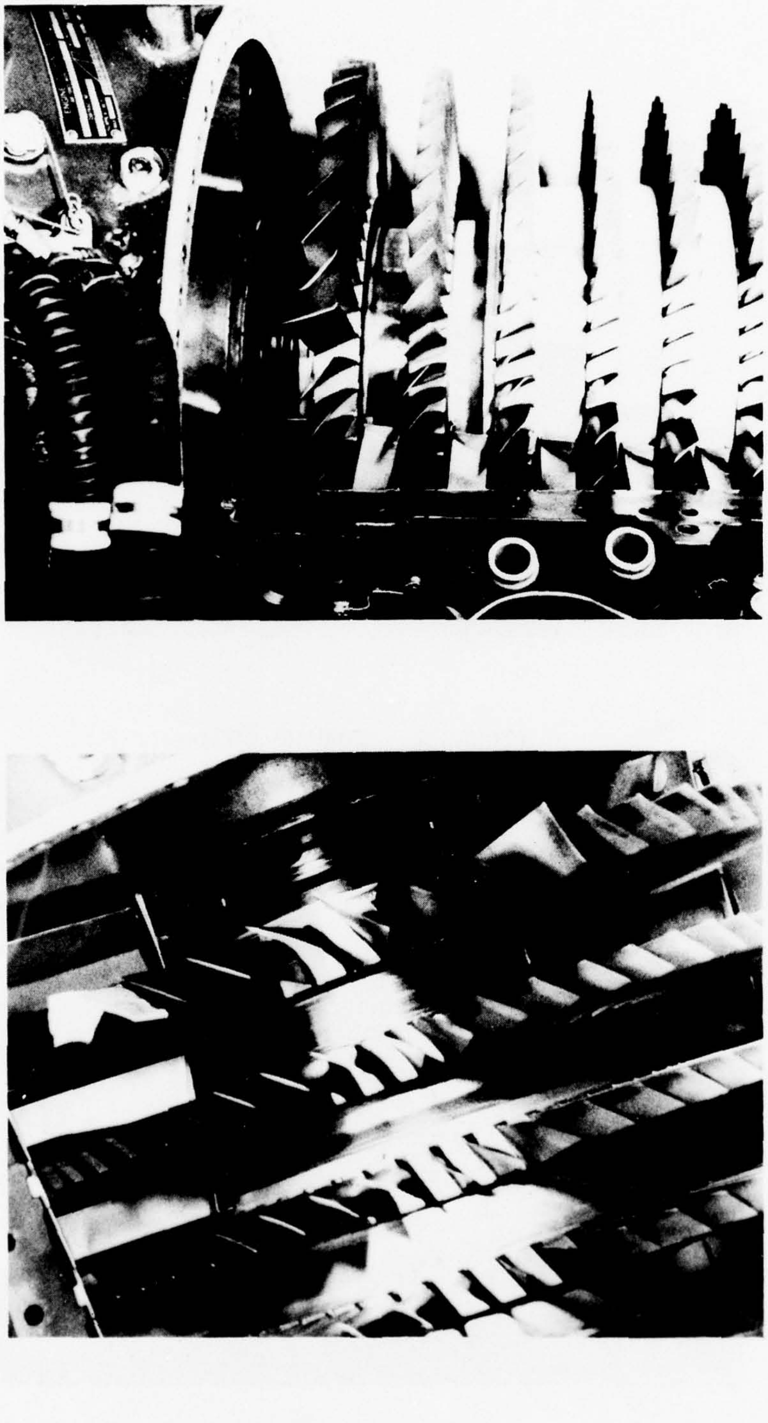


FIGURE 4. ENGINE DAMAGE

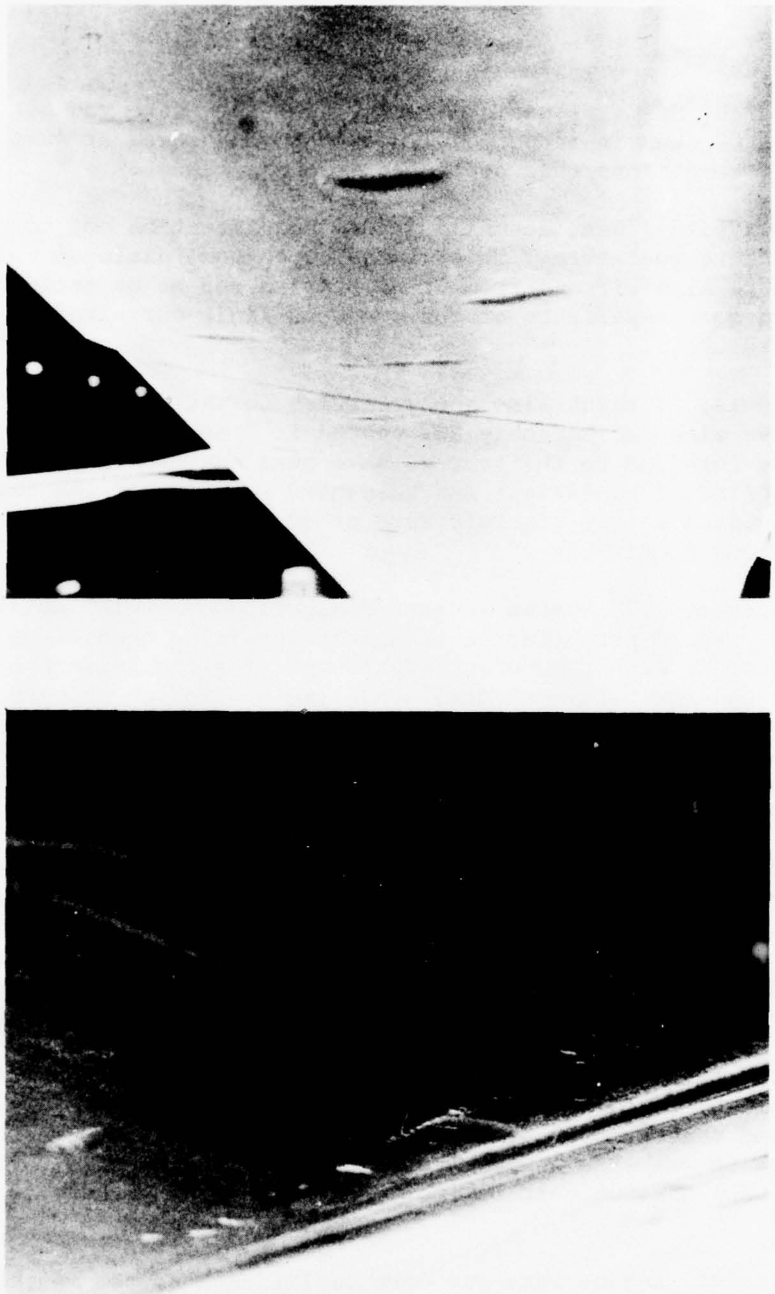


FIGURE 5. AFT BLADE DAMAGE

## SESSION I DISCUSSION

Lt. Welch, NATC: I noticed in your testing there you got down to -13°C. Was it intentional not to go any lower or just atmospheric conditions that prevented it?

LTC Griffith: Dan, actually it was our intention not to go below that temperature. This was based on some dialogue we had with Mr. Alan Wilson from Great Britian and so we decided until we had more experience of our own we'd limit ourselves to that temperature.

Mr. Lewis: I think also a correlation to that is the fact that we have also deliberately NOT tested in freezing rain conditions or ice fogs due to the fact we have been advised that these are more critical conditions and we wanted to see what the basic limitations to the aircraft were prior to entering into the more hazardous conditions.

LTC Graham, 2.75 System Project Manager: Commercial aviation uses a ground prophylactic treatment for icing conditions. You see them in Alaska between flights spraying the surface of the wings and the tail surfaces. Have you or are you going to try any of that, because we have large accumulations on non-aerodynamic surfaces on the pylon and launchers as you observed from the slides and perhaps those would be reduced, at least for short periods of time.

LTC Griffith: We tried a commercial spray as Mr. Reid mentioned on areas where ice is accreted, specifically the nose of the Cobra, the leading edge of the rotor blades, and part of the wind screen and found very little or no effect on any of the shedding characteristics. The ice stuck on there just the way it had all along. Our basic charter is to see how the performance and handling qualities are degraded with icing and what limited things must be accomplished to make our current aircraft capable of flying in icing conditions and we haven't really addressed that problem of operating a mission on ice. We're just trying to see what we have to do to the airplane to fly it in ice. The mission part of it I'm sure is going to have to come later.

Mr. Lewis: Let me make one more amplification; you may have noticed in the in-flight photos of the alcohol deicing windshield wiper system that we had quite a bit of runback and we did notice during some of the testing that the excess alcohol did keep the ice clear on the portion of the rotor controls and pylon area where it did impinge. You may be aware that there have been rotor systems devised which do spray alcohol but they are mechanically very cumbersome and haven't seen wide use.

Major Brown, OCDRA: I'd like to ask either Larry or Carl a couple questions. First of all the correlation between fuselage ice and rotor blade ice in natural icing conditions, did it correlate the same way it did under the aritfical spray and how do you account for the difference in the engine inlet icing between natural and artificaly icing tests?

Major Mittag: We based our correlation between the natural and artificial on the fact that appearance-wise they looked similar and increased power requirements with ice accumulated on the rotor blades was similar. Although we couldn't measure the accumulation on the main rotor blade, we did see increased power requirements and degraded autorotation rpm capability. As far as engine inlet icing we feel that possibly the water droplet size produced by the artifical rig is much larger than what we saw up at Fort Lewis, and that actually the water droplet is making that turn into the filter in the natural condition whereas in the artifical environment it's just going right on by.

Mr. Lewis: There's another area that we hope will be corrected by our improved icing spray system and that is that it is possible that the narrow thickness of the spray cloud is sufficiently defused by the rotor wake as to prevent large accumulations of ice in the inlets or the aft fuselage. We hope with the thicker cloud that this situation may be remedied and Mr. Crawford will discuss that later.

Dr. Rosen, Sikorsky: I'd like to ask a couple of questions concerning the CH-47. During the asymmetric shed that you did note, can you give us an idea of what vibration you encountered and whether or not it was as severe as you had on the UH-1?

CPT O'Connor: It was not as severe, it was a lateral, there were no vertical vibrations. The UH-1 I believe was mainly a vertical vibration. Ours was strictly lateral and it went from negligible g level up to 2/10 of a g and as far as the pilot could see in the cockpit you could still read the instruments but you had to concentrate on reading them, and it was at a 1 per rev frequency.

Dr. Rosen: There is one other question Warren, and I was wondering if you could help me here? In terms of the engine compressor damage that was done. Did the ice originate on the forward pylon in your opinion or off the forward rotor or don't you know?

CPT O'Connor: We're not exactly sure where it came from but from observing the ice on the forward pylon on previous flights any ice coming from that area (and very little did come from the forward pylon) fell down and away from the aircraft. We feel, or we think it might have come from the head assembly; the vertical pins, or from the forward blades themselves.

I'm Jim Plackis, Head of FAA Flight Testing, New York region and I'd like to ask the question, has any consideration been given to the possible inducement of ground resonance or air resonance in a hover condition when you have a asymmetrical icing condition on the blades?

Mr. Lewis: Let me try to answer that one. With the natural icing tests, we very rarely had sufficient accumulations of ice on the helicopter when we approached a hovering condition to cause any abnormal vibrational situation that you might categorize as either air resonance or on the ground, ground resonance. We did make numerous landings with the UH-1H helicopter and also the Cobra in Alaska with fairly substantial amounts of ice but these were always in a symmetrical disposition and as a consequence there was nothing that we would have seen that was abnormal in the way the helicopter hovered or made ground contact.

Now, after the helicopter contacts the ground, a great deal of ice was shed and more than likely some of it was asymmetrical. This never gave rise to any ground resonance conditions on the UH-1H but you have to keep in mind that the UH-1H does not demonstrate ground resonance under any other kind of conditions that I'm aware of so it may not be a factor.

Mr. Maurice, French A.F.: To answer to this question, we had some ground resonance on the Gazelle with icing trials.

Mr. Lewis: Is the Gazelle susceptible to ground resonance under any other kind of degraded maintenance conditions, such as, I think you have oleo struts or do you have rigid gear on the Gazelle? Do you have a fixed gear or do you have a hydraulic gear? Fixed gear. And you have had resonance, ground resonance problems? How about air resonance problems?

Mr. Maurice: No, just ground resonance.

Mr. Lewis: Let me ask then if Alan Wilson would comment whether or not the British have seen ground resonance on the wide range of helicopters they have tested.

Mr. Wilson: The straight answer to your question is no, we've seen no ground resonance. As a result of our early work in the rig we established certain limiting conditions and we went out of our way to avoid asymmetric shedding as far as possible. We did on one of the early flights with the Wessex 3, which I think you all agree is fairly prone to ground resonance, we had a very severe asymmetric shed, but landed without any problems.

Mr. Lewis: Thank you, let me ask if we have NRC comments on the same phenomenon. How about Dan Welch?

LT Welch: In testing the UH-2 this year up in Ottawa we had one occasion where we had one bad engine cover and one good one and we were single engine testing in about a 2 foot hover in the rig and had a rather severe asymmetric shed which caused about a 1 foot split in the blade cone. I set it down onto the deck and I think if I had remained light on the struts it would have developed into severe ground resonance, but it started to get into it before we had full weight on the gear.

Mr. Lewis: Thank you. Does anybody else have any comments as with respects to ground resonance? If we can procede we have a question here in the 2nd row.

Mike Kawa from Bell Helicopter: In your testing of the Hueys, you mentioned only one area of the tail rotor icing. Was this a problem in any of your testing?

LTC Griffith: Actually, we had no problems with tail rotor icing on the Hueys, either the Cobra or the H model.

Mr. Kawa: Was it because of the rotor being clear of the spray? It looked like it might have been in clean air, part of the rotor in clean air.

LTC Griffith: I don't believe that was the case. I think we put the tail rotor in the cloud on enough occasions that it should have iced if it had been prone to ice. We did get ice on the Cobra tail rotor, in the hub and drive shaft area and I suspect if we could have seen it in flight we probably would have seen more along the leading edges on the blade, but we had no problems with it, with the Cobra. On the Huey it appears as if the exhaust heat goes over the tail rotor and warms it sufficiently to keep it from icing. We had no problems either behind the spray rig or in natural icing.

Mr. Kawa: In regard to fuselage icing, based on what you've seen would you expect this to be a problem within the condition range that you did test? I notice you only went up to liquid water content of .5 grams per cubic meter.

LTC Griffith: I believe we actually did .7 or .75 on our artificial icing in Alaska on the Huey. We got a fairly substantial amount on the fuselage and again the only problem that we saw was in the engine inlet area with natural icing and that appears that the spray rig doesn't create the very fine high number of small drops that occur in nature.

Mr. Kawa: That's my next question. How did you measure liquid water content in droplet size and did you measure it right at the rotor head?

LTC Griffith: The calibration of the plume was conducted by the Calspan Corporation of Buffalo New York. They flew an Aztec fixed wing aircraft in the cloud at the distances which we did our testing and they actually captured drops on a slide and counted populations and droplet sizes. Then they provided us with the data to include a correction factor chart for taking into account relative humidity and we set up the flow rates and air pressure based on this data they provided us and also provided by All American Engineering who built the system. Using those two sources we set up what we were told would be the conditions desired and we just flew in it and accepted it. The Rosemount system on the aircraft did provide an icing rate that corresponded to what we had established and also the visual probe correlated with what we had established. So we felt fairly confident what we were setting up actually existed.

Thank you.

Mr. Wilson: We've now done something in excess of 100 hours actual flight in natural icing, where we've actually experienced icing conditions over quite a wide range of severities, temperatures and so on and that the aircraft included the Scout, Wasp, Wessex, Sea King and at no time have we had any trouble on the tail rotor.

Mr. Lewis: There's another data point on that too, Dick Cotton from Lockheed I think might comment that they did temperature survey tests over the empennage and tail rotor of the AH-56 in conjunction with some testing that was conducted at Ottawa of that aircraft and very substantial temperature rises were evident.

One of the reasons why we were concerned about the IR suppressor was that we knew that this or future generations thereof would be probably standard inventory items and we were concerned there might be sufficient diffusion of the exhaust plume to allow increased tail rotor icing so that was the reason for our initial test. We were gratified to see actually, if anything, there's plenty of heat there and the diffusion of the cloud assists in the deicing of the tail rotor.

I think there's a question in the third row from the rear.

Frank Duke, Boeing Vertol: I had two questions (1) will there by any attempt to understand the impact on the tactical use of the aircraft resulting from flight in ice, such as altering formation flying tactics and also multiple aircraft in a small zone with ice shedding and that sort of thing? Will there be any attempt to try to define that?

Mr. Lewis: I'm not going to try to answer that because we're not tacticians. However, I think Colonel Crouch might like to make a comment or two.

Col. Crouch: Taking into consideration the information we gleaned from these tests and appling it across the board to tactics we're going to have to revise perhaps our tactical operations, our modus operandi, if you will, but we'll apply the lessons learned accordingly. I've got a question right now while I'm on the floor. What does a pilot need right now in the helicopter in order to operate in icing conditions?

Mr. Reid: Sir, he needs a little switch to turn on the rotor deicing system. If he loses his autorotation capability with a single engine helicopter and he has asymmetric shedding problems while on instruments, I don't think the survivability would warrant subjecting the helicopters to this problem.

LTC Griffith: We have identified the fact that the man has to be able to see out of the windscreen to land. You don't have to see to go through a cloud but you have to perform the outside mission that the aircraft's designed to do, whatever that mission may be. So you have to have something to take the ice off those parts of the aircraft that the pilot wants to look through. You also have to have some way of keeping down asymmetric sheds. Now Mr. Reid mentioned rotor blade deicing for autorotations but you've got to be able to fly the aircraft in a vibration environment that you can survive, that the airframe will survive that the pilot can function in. So not withstanding autorotational requirements which some folks I'm sure will attempt to argue down with two engine aircraft but you've still got to be able to read instruments inside the airplane. You've got to, the equipment has to survive, the pilot has to be able to survive and the vibration levels can't go out of sight, so you have some capability of keeping the same amount of ice on all the blades, if you're going to be able to operate with ice on them at all. Those are some things, you have to keep the engine running, you can't fly without the engine running, so the aircraft can't have an engine problem. We documented the obvious - the Chinook sucked in air from an inlet looking forward and when there's ice in that air it's going to suck the piece of ice in too. Everybody's proved that and we just proved it again but it's an expensive lesson. The Huey with the flush-mounted inlets, the inlets parallel to the air stream appear not to have quite the problem. We did ice up the two side screens, we iced up one for sure, we assumed the other one was iced. We couldn't see it because it wasn't photographed. The top one though did not ice so it appears as though that top screen might not be the problem the side screens are. I think that maybe touches on some of the points that you ask.

The question was "Is anything being done to correct the problems of the screens and are there ECPs for the windshield? I think those are questions that need to be; that's why we're here to get that to industry and to the other segments of the Army and other aviation fields. We have submitted Equipment Performance Reports on windscreens. The Bell folks have published quite awhile ago when you fly in ice take the screens off the Huey and we haven't tested in natural icing with the screens off. We wanted to be sure that was a procedure that we couldn't fly with them on and maybe that would answer that problem.

Gentlemen in the 2nd row.

CPT Checketts: I was just going to amplify the answer to Colonel Crouch. In our studies in UK, we determined four priorities for protection of helicopters. The first of which is engine protection above and beyond everything. Secondly, clear view thru forward wind screens, thirdly, ice detection and severity indication, and fourthly protection of rotors. I think since our last winter's trials we've put rotors a bit higher up the scale.

We've a gentlemen in the 3rd row, far side.

Wayne Fisher, PPG Industries: As far as your program is concerned, are you people actively looking for solutions to the problems that you ran into, as your running this testing or isn't that part of your effort?

We'll solicit an answer from Mr. Crawford.

We are looking for ways to solve these particular problems. That does not mean Monday morning we're going to accept a large number of unsolicited proposals.

Mr. Fisher: Are there intentions if you do come up with solutions, alright for instance that windshield on UH-1 heated to pursue that and possibly redo the fleet with that type of window?

Mr. Crawford: I think some of the aircraft are going to operate in the Alaska environment and European environment would certainly have to be retrofitted with windscreens; but if we talk about the entire Huey fleet your talking about a lot of helicopters.

Yes you are.

Mr. Lewis:

It has to be a balanced pursuit too, you can't just put a windshield on when you have an aircraft with perhaps rotor or inlet problems and this is the basis of the comprehensive study that's being performed by the Eustis Directorate.

Ted Hoffman, Bell: Concerning your autorotation rpm degradation, did you investigate the effects of changing rigging on the rpm? Or was that at a given blade angle?

LTC Griffith: We investigated it to such a limited extent that I guess the answer really is no. When we first started our testing, we did a few autorotations to determine the rotor speed before we started icing and we found it was low, so we set it up to the maximum we could and then iced from there. But we did not try any rigging changes to see if we could obtain higher steady state autorotational rotor speeds after we had iced the aircraft.

SQDN. LDR Lake: We, as a standard procedure, always depitch our aircraft as much as the manufacturer will allow us to. We always go to the sub-artic setting and if possible another 2 degrees below that. As a matter of interest on the Puma aircraft we did last year, despite having these extra 2 degrees we still ran out of rpm. I would like to ask a question if I could.

We are becoming more and more concerned about the handling of the aircraft in natural icing and are reaching a stage where we are doing standard and flight envelope checks as you would on Category 1 Program. I call it Category 1 because the manufacturer hasn't done it, so we have to. And we are concerned at the amount and speed at which the flight envelope is coming back and when on your reports say you have done handling checks and there are no problems I'd like to know the extent to which you've investigated the flight envelope? The weights you operate, whether you've been to $V_{NE}$ and what g's you've pulled with ice on the blades and natural icing and in synthetic icing.

Mr. Lewis: To be perfectly honest with you, the checks that we've done are very limited. We viewed the icing operation as a sub category of IFR operations or instrument flight rule operations and consequently the majority of our tests have been done either at the IFR cruise speeds which in most aircraft is about 90 knots or in the case of autorotation we have varied about the airspeed for best decent to find where we bombed out in our rotor speed. We've done nothing in terms of going out to $V_{NE}$ or pulling large load factors at airspeeds other than at the ones we tested at. Now at each test, in the early Huey test, we did quite a few of your standard engineering tests, your control inputs looking at the dynamic response of the aircraft. Looking at controllability, static stability, and so on, we saw so few effects of these at the IFR cruise speeds that we've reduced the numbers of those tests as we've gone on.

Do you have anything to amplify, Col. Griffith?

LTC Griffith: No, I'd be interested to know what you found. Could you give us a word or two or is that later?

I think to amplify slightly this is our first year at it. We are fledglings at this business. We ask for and got a tremendous amount of assistance from Mr. Wilson and we're trying not to reinvent the wheel in alot of these areas but some of the preliminary work that we did, I'm sure is the same thing you did. You have to go thru that part of it just to see if the machines going to stay in the air. And we found that it, I think our confidence has built considerably in how the aircraft will handle ice. We have an awfully long way to go and that's what we want to do starting next year is concentrate in some areas. I think there's a lot of dialogue here, some specific areas we need to look at that you can point us to.

Third row from the rear.

Lt. Terry Eargle, Naval Air Test Center: I have a couple of questions. You mentioned earlier that you used the Calspan gelatin slide technique for determining size of your droplets and your liquid water content. I wonder if you would, No. 1 qualify both of those for us as to what you were getting out of your artifical spray rig and No. 2, how this compared with your natural icing test?

LTC Griffith: No. 1, the data that we saw indicates that the mean droplet size is 50 microns but the median droplet size or that drop that represents the middle drop in liquid water content is 150 microns. Thats why I stated that it approximates a cumulus cloud and not a stratoform cloud. It's bigger drops then you'll find in the fog or nice stable clouds, and its a much bigger drop, the median drop is much bigger that what we think we saw naturally. But we do not take this system out and measure a cloud. We do not have the capability ourselves. We have to hire it, contract for it. So we don't have our own internal capability. This was a calibration that was conducted on the spray rig in Alaska on site. So it was a one time shot. That's what we've seen and that's what we think still exists with our system.

Mr. Lewis: Also Terry, for the liquid water content they also employ a Johnson Williams meter. We have access to that and we will use that in future tests.

Dr. Rosen: I think that you have demonstrated with a great deal of success that the rig is capable of putting out a very, very representative liquid water content and I think that is no longer a question. I think you have done that both using the small probe, the visual probe, you have gotten good correlation and you would expect using the small probe that the collection efficiency would be relatively invarient with droplet size, would be extremely high, whether you had a 50 micron droplet or 20 micron droplet and the point that I made to you Dick many times is that I am concerned with the 20 micron droplet which is perhaps more representative of the real world as opposed to the 50 micron. Just to think about it from a math standpoint, that's 2 1/2 cubed. That makes a big difference on the subsequent droplet trajectory in motion and I think this is what you did observe when you did see the inlet ice up in the real conditions. O.K. what does this all lead to? Is the Army considering and I think perhaps you are but I want to make sure you are at least in my mind, considering during your product improvement program remedying the situation. Getting to the point where you've got a tool now that's mabe 99-95 percent there, how about that extra 5 percent?

Mr. Lewis: That leads us into our next paper. I don't think you could have done any better. Actually, let me answer your question so before and the answer is not in the first stage of the product improvement. The first stage is a geometrical improvement but we have not closed the door to future efforts which would involve the droplet size. We are running short on time, however, I want to emphasize that we don't want to shut off the dialogue that we've just begun this morning. All of our icing people will be here throughout the conference. We would entertain questions at any time. We hope to talk with you at lunch and at the bar and so on because there's a lot more that you have that we would benefit from and I think there's a lot more that we have that will help you. So let me close the current question and answer session by thanking all of our folks for their presentations and I'd like to now introduce Mr. Crawford who's going to discuss The product improvement for the helicopter icing spray system.

PAUL F. YAGGY

Director, US Army Air Mobility Laboratory
(Acting Director of RD&E, AVSCOM)

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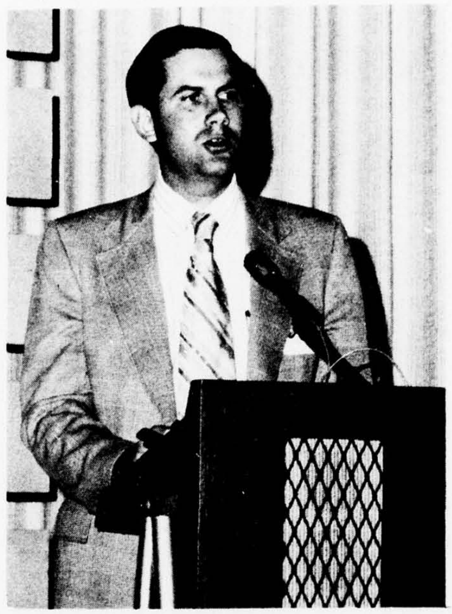

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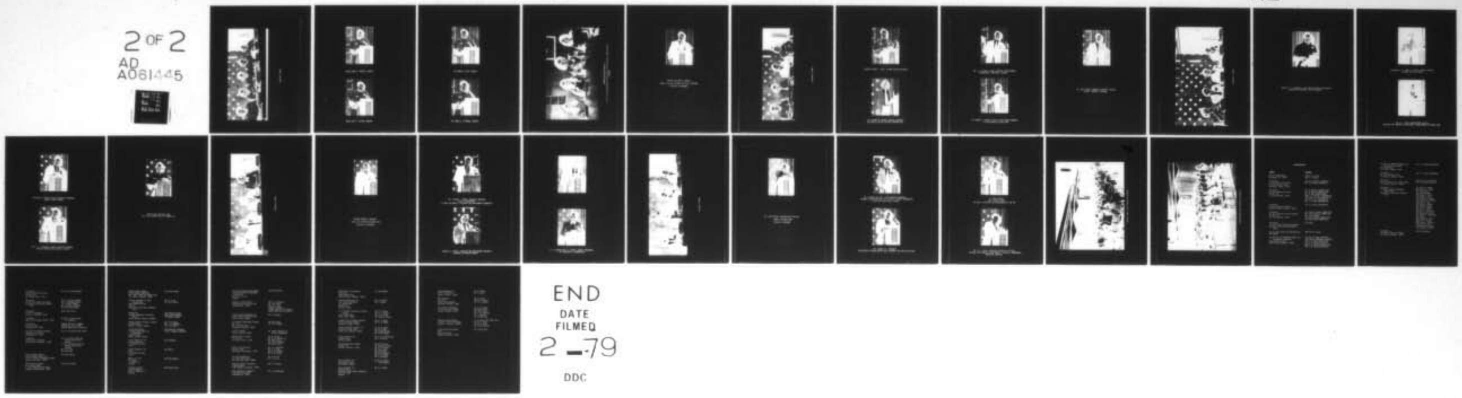

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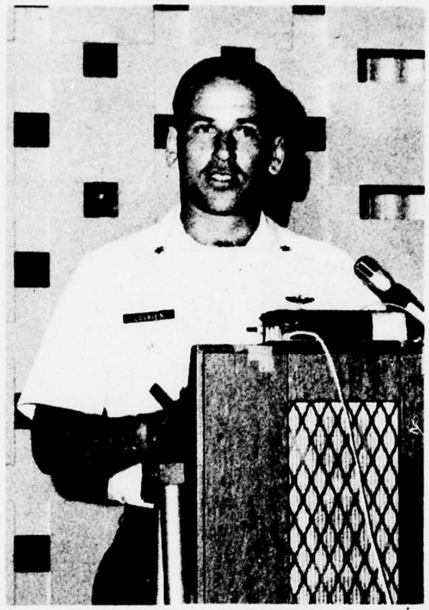

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| Embassy of Great Britain<br>3100 Massachusetts Avenue NW<br>Washington DC 20008 | CPT J. T. Checketts<br>Mr. Alan Wilson<br>Mr. G. C. Abel<br>CDR M. Southgate<br>LTCDR Anderson (Air Officer)<br>SQDN LDR Lake (Air Officer) |
| British Airways Helicopters Ltd<br>London (Gatwick) Airport South<br>Horley, Surrey, England | Mr. F. Atkinson |
| All American Engineering Company<br>Box 1247<br>801 S. Madison Street<br>Wilmington, Delaware 19899 | Mr. Bob Veazey<br>Mr. F. M. Highley |
| Auburn University<br>Auburn, Alabama 36830 | Dr. Vincent Haneman Jr,<br>Dean of Engineering |
| Bell Helicopter Company<br>PO Box 482<br>Fort Worth, Texas 76101 | Mr. T. Hoffman<br>Mr. G. W. Johnston Jr<br>Mr. Myron Kawa<br>Mr. John E. Kidwell<br>Mr. H. W. Upton |
| Boeing Vertol Company<br>PO Box 16858<br>Philadelphia, Pennsylvania 19142 | Mr. J. C. Deardorff<br>Mr. F. H. Duke<br>Mr. A. A. Peterson<br>Mr. R. N. Stevens |
| Cox and Company, Inc<br>215 Park Avenue South<br>New York, New York 10003 | Mr. D. B. Cox<br>Mr. J. L. Cox |
| Dynamics Controls Corporation<br>8 Nutmeg Road<br>South Windsor, Connecticut 06074 | Mr. T. P. Farkas |
| Forge Aerospace Corporation<br>1705 DeSales Street NW<br>Washington DC 20036 | Mr. C. W. Messenger |

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| Flight Systems Incorporated<br>Box 2400<br>4000 Westerly Place<br>Newport Beach, California 92663 | Mr. Earl Binkley |
| Garrett Manufacturing Ltd<br>The Garrett Corporation<br>255 Attwell Drive<br>Rexdale 605<br>Ontario, Canada | Mr. C. Fauquier<br>Mr. G. Paclik |
| B. F. Goodrich Aerospace & Defense Products<br>500 S. Main Street<br>Akron, Ohio 44318 | Mr. T. W. Blaser<br>Mr. R. J. Gardner<br>Mr. A. M. Larue<br>Mr. Frank D. Snyder |
| Goodyear Tire & Rubber Company<br>Aviation Products Operation<br>Rockmart, Georgia 30153 | Mr. F. J. Naiser<br>Mr. G. P. Siddall |
| Hughes Helicopter Company Inc<br>Centinela & Teale Street<br>Culver City, California 90230 | Mr. W. H. Barlow<br>Mr. B. Q. Hall<br>Mr. Ronald Holasek<br>Mr. A. M. Petach |
| Leigh Instruments Ltd<br>Charleton Place<br>Ontario, Canada | Mr. P. H. B. MacLennan<br>Mr. J. W. Wells |
| Lockheed-California Company<br>PO Box 551<br>Burbank, California 91503 | Mr. R. H. Cotton<br>Mr. Richard B. Estey<br>Mr. F. P. Lentine<br>Mr. Steve Myers<br>Mr. Jerry Ryan<br>Mr. K. K. Schmidt<br>Mr. H. Van Wijk<br>Mr. J. B. Werner |
| Lucas Aerospace Ltd<br>The Airport, Luton<br>Bedfordshire, England | Mr. B. D. Lazelle, Chief Engineer |
| Lucas Aerospace Ltd<br>Electrical Group<br>Maryland Avenue, Hemel Hempstead<br>Herts. HP 24SP<br>England | Mr. P. A. Walsh |

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| Normalair-Garrett Ltd<br>402 S. 36th Street<br>Phoenix, Arizona 85034 | Mr. P. Browne<br>Mr. D. Grant |
| PPG Industries<br>Suite 777<br>Central Bank Building<br>Huntsville, Alabama 35801 | Mr. N. Dendy<br>Mr. W. A. Fischer<br>Mr. S. G. Nienow |
| The Sierracin Corporation<br>12780 San Fernando Road<br>Sylmar, California 91342 | Mr. J. A. Haynes<br>Mr. David Judson<br>Mr. Jan B. Olson<br>Mr. T. R. Stefancin<br>Mr. G. Watkins<br>Mr. George Wiser |
| Sikorsky Aircraft Division<br>of United Aircraft Corporation<br>Stratford, Connecticut 06602 | F. K. Everest, BG, USAF (Ret)<br>Mr. H. T. Jensen<br>Dr. K. M. Rosen<br>Mr. Loran Schnaidt |
| Teledyne-McCormick Selph<br>Box 6<br>3601 Union Road<br>Hollister, California 95023 | Mr. George Klotz |