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HISS CALIBRATION, ICE PHOBICS AND FAA R&D EVALUATIONS

FINAL REPORT

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AUGUST 1981

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

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

Artificial and natural icing tests of a JUH-1H helicopter were flown in the vicinity of St. Paul, Minnesota, during the three month period of January through March 1981. Productive flight time totaled 15.4 hours in the artificial icing environment behind the Helicopter Icing Spray System (HISS) and 3.1 hours in natural icing. Test conditions ranged from -5°C to -20°C and 0.25 to 1.0 gram per cubic meter (gm/m^3) liquid water content (LWC) for the artificial testing and -6°C to -9°C and 0.1 to 0.5 gm/m^3 LWC for the natural testing. Tests in the artificial icing environment behind the HISS were flown to define the nature of the HISS cloud in terms of LWC, cloud particle size and distribution; and to quantitatively determine the effects of an ice phobic coating on the capability of the UH-1H to

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fly in icing conditions. The ice phobic coating did not significantly affect the capability of the UH-1H to fly in icing conditions. The capability of the UH-1H to operate in icing conditions was assessed during the artificial icing flights behind the HISS and during the natural icing flights. Flight into moderate or higher intensity icing should be prohibited because of the severe vibrations experienced as a result of asymmetric ice shed. Prolonged flight (over 10-15 minutes) into light icing is not recommended and should only be attempted with caution and with an option to vacate the icing condition due to consequences of encountering icing of higher intensity. Data to support Federal Aviation Administration research and development requirements were obtained at every opportunity during the test program.

DEPARTMENT OF THE ARMY
HQ, US ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120

DRDV-D

SUBJECT: Directorate for Development and Qualification Position on the Final Report of USAAEFA Project No. 80-13, HISS Calibration, Ice Phobics and FAA R&D Evaluations

SEE DISTRIBUTION

1. The purpose of this letter is to establish the Directorate for Development and Qualification's position on the subject report. The objectives of the project were to recalibrate the JCH-47C Helicopter Icing Spray System (HISS) as well as support ice phobics coating icing tests for the Applied Technology Laboratory (ATL) and obtain test data for the Federal Aviation Administration (FAA) requirements.

2. This Directorate agrees with the conclusions and recommendations. However, the following comments are made relative to the report and are directed to the report paragraphs as indicated.

a. Paragraph 19. Calibration of the HISS cloud was necessary following incorporation of an improved HISS boom nozzle configuration. The calibration data in the report shows a significant improvement in the cloud median volumetric droplet diameter as compared to those obtained during prior years' testing. The droplet size now approximates that exhibited under natural icing conditions, however this was done at the expense of reducing the cloud size from a 60 foot width to a 38 foot width and the depth from 12 feet to 8 feet. This Directorate is managing a long term effort to significantly improve the HISS or to develop a new one with an improved capability. This is necessary to increase the cloud size, improve performance (endurance and airspeed), better control droplet size and water flow rate and improve the current design to simplify operations. The FAA Technical Center has supported the effort with funding. Such funding has been used to obtain HISS data, data on tested helicopters and to improve the HISS configuration. The FAA intent is consistent with the US Army intent to eventually develop a HISS which will provide an artificial icing environment suitable for allowing complete US Army qualification or FAA certification of helicopters for flight under natural icing conditions.

b. Paragraphs 20 through 32. The results of the ice phobics evaluation are essentially consistent with prior years testing in that they are inconclusive. The use of the tested GE G661 ice phobic coating did not improve the main rotor blade ice shedding characteristics and was unpredictable. In some cases the ice phobic coated main rotor blades resulted in degrading the shedding characteristics when compared to clean blades as evidenced by the increase in unacceptable vibrations when ice shedding occurred. These comparisons were made under similar conditions of liquid water content (LWC), temperature, altitude range, humidity, airspeeds, and cloud exposure. Unless significant improvements are made to ice phobic coatings such that their use on helicopter rotor blades allows early and predictable shedding characteristics, further testing would be unproductive.

c. Paragraph 33. Attempts were made to obtain data for the FAA R&D evaluation. Such data was to include cloud droplet size, cloud LWC, relative humidity, solar radiation, and ice crystal content. Data was obtained for most of the preceding and is reported separately in the MRI report. However, the acquiring of solar radiation and ice crystal content data was not successful due to the instrumentation and lack of adequate test time and controlled conditions. Any future testing for the collection of solar radiation and ice crystal content data should be dedicated and not piggybacked on other testing such as was done during the ice phobics evaluation.

d. Paragraphs 34 and 36. No further testing of ice phobic coatings by the US Army Aviation Engineering Flight Activity (USAAEFA) is planned at this time.

e. Paragraphs 35, 36, and 38. Currently the recommendations and restrictions relative to the procedures to be followed for flight into icing conditions are contained in the appropriate UH-1 Operator's Manuals. These procedures are consistent with the conclusions and recommendations contained in this report.

3. The overall results of the report evaluations substantiate that further improvements are required for the HISS and that the ice phobics coating compounds offer no improvements to the UH-1 rotor blade ice shedding characteristics and in some cases degrades the shedding characteristics.

FOR THE COMMANDER:

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

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INTRODUCTION

BACKGROUND

1. The Army's need for an all-weather operational capability has led to extensive icing tests in both natural and artificial conditions. Initial testing was conducted in 1973 and follow-on tests have been conducted each winter since. The United States Army Aviation Research and Development Command (AVRADCOM) tasked the United States Army Aviation Engineering Flight Activity (USAAEFA) to conduct further icing tests during the 1980/1981 icing season (ref 1, app A).

2. The USAAEFA utilized a CH-47C helicopter modified with a Helicopter Icing Spray System (HISS) (ref 2) to produce the artificial icing conditions used during testing. Prior to the 1979/1980 icing season, USAAEFA modified the HISS boom nozzle configuration. While the modifications significantly improved the spray cloud characteristics, they resulted in increased airframe vibrations and boom oscillations, as well as reducing the spray cloud size. To correct these problems AVRADCOM tasked USAAEFA (ref 3) to conduct a HISS evaluation and identify and incorporate improvements. As a result of modifications to the HISS, a spray cloud recalibration was required.

3. The Applied Technology Laboratory (ATL), US Army Research and Technology Laboratories (AVRADCOM), has sponsored both natural and artifical icing tests, which were conducted by USAAEFA. The ATL required additional artificial testing to quantify the effects of ice phobic coating of main and tail rotor blades. Additional natural icing tests were required to further explore the capability of the UH-1H to operate in icing conditions. The UH-1H is presently restricted from flight into known moderate icing.

4. The Federal Aviation Administration (FAA) has a requirement to establish icing certification and operational requirements for commercial helicopters operating with minimum ice protection systems capability. AVRADCOM agreed to support FAA requirements via the provisions of an interagency agreement (ref 4). Consequently, the icing tests included FAA as well as AVRADCOM requirements.

TEST OBJECTIVES

5. The objectives of this test program were to:

a. Conduct recalibration of the HISS spray cloud for the 1980/1981 icing tests.

b. Quantitatively determine the effects of a General Electric (GE) G661 ice phobic coating on the main and tail rotor blades of a UH-1H helicopter.

c. Further explore the capability of the UH-1H helicopter for flight in icing conditions.

d Support the FAA research and development (R&D) requirements to the maximum extent possible.

DESCRIPTION

6. The test JUH-1H helicopter (SN 70-16318) was manufactured by Bell Helicopter Textron (BHT), and incorporates a Lockheed-California advanced ice protection system (ref 5) and BHT partial ice protection system (kit A) (ref 6). The combination of these two systems is addressed in this report as the ice protection system (IPS). A more complete description of the IPS is contained in appendix B. A detailed description of the test helicopter is contained in the operator's manual (ref 7) and supplement thereto (ref 8). A detailed description of the test instrumentation is contained in appendix C. The G661 ice phobic coating is a silicone based compound intended to promote early ice shedding from the main and tail rotor blades.

TEST SCOPE

7. Artificial and natural icing tests were conducted in the vicinity of St. Paul, Minnesota, during the three-month period commencing in January 1981. Productive flight time totaled 15.4 hours in the artificial environment behind the HISS and 3.2 hours in natural icing. The natural icing testing was limited by an extremely dry winter at the test site.

8. The USAAEFA had overall responsibility for conduct of the test. Cloud physics data were acquired using instrumentation supplied and maintained by Meteorology Research Incorporated (MRI) under an ATL contract. The MRI instrumentation is further described in appendix C. Maintenance support for the IPS was provided by an ATL contract. Representatives from ATL monitored the testing and assisted in applying the ice phobics coating to the helicopter rotor blades.

9. The test aircraft was operated within the limitations of the operator's manual (ref 7) as augmented by the airworthiness release (ref 9) and the test plan (ref 10). The tail rotor portion of the IPS was inoperative during the test. The general test conditions are shown in table 1 for the artificial icing tests and in table 2 for the natural icing tests. Target airspeed was 90 knots true airspeed (KTAS) for the artificial tests and 87 knots calibrated airspeed (KCAS) for the natural tests. Exceptions are discussed in the Results and Discussion section of this report. Tests were conducted at a target rotor speed of 324 rpm. Pressure altitude ranged between 1500 and 10,000 feet for the tests. Take off gross weight was approximately 8500 pounds at a mid center-of-gravity (cg) location (fuselage station 139).

TEST METHODOLOGY

10. A short test to verify operation of the IPS was conducted at the beginning of the first test flight. The operation of the IPS was verified by flying with the rotor immersed in the HISS cloud for 15 minutes, exiting the cloud, activating the IPS, and observing the ice sheds from the rotor system.

Table I. Artificial Icing Summary

Flt No.	Date	Outside Air Temperature (°C)	Programmed LWC (gm/m^3)	Relative Humidity (%)	Immersion Time (minutes)	Time to First[1] Moderate Vibration Shed (minutes)	Time to First Severe Vibration Shed (minutes)	Blade Condition	Torque Rise (psi)	Autorotation[2] Rotor Speed (rpm)	Autorotation[3] Degradation (rpm)	Pressure Altitude (feet)
2	27 Jan	-9	0.50	82	21.5	N/A	21.5	Clean	6.9	296	16	1900-2380
					19	15	N/A					
3	28 Jan	-14.5	0.50	71	6.6	N/A	6.6	Coated	None	304	—	2500-2480
					6.3	N/A	6.3					
4	29 Jan	-15	0.50	75	13.7	13.4	13.7	Clean	5.5	307	—	2240-2440
					13.3	13.2	13.3					
5	29 Jan	-15	0.50	85	4.9	4.9	N/A	Coated	4	307	19	2140-2700
					4.3	4.3	N/A					
			0.25		60	18	N/A					
6	29 Jan	-15	0.25	85	60	25	N/A	Clean	None	322	17	3300-3640
7	30 Jan	-10	0.75	48	13.4	10	13.4	Clean	9	322	28	2000-2670
					15.7	7	15.7					
			1.0		7.8	7	4				30	
					13	3.4	3.5			—	—	
8	30 Jan	-10	0.75	48	35.7	6.5	34.5	Coated	2.4	308	14	1540-2900
					33	6	32					
9[4]	31 Jan	-5.5	0.75	20	60	7	23	Coated	5.6	320	14	3460-4940
10	31 Jan	-5	1.0	21	60	8.5	27	Coated	3.8	310	10	3370-4320
11	3 Feb	-20.5	0.50	62	23	N/A	23	Clean	5.7	321	14	3430-4130
					21.3	20.2	21.3					
12	6 Feb	-11.5	1.0	56	28.5	5	8	Coated	5.6	318	15	3900-4720
					9.6	N/A	8			—	—	
13[5]	9 Feb	-16.5	0.75	29	10.2	N/A	4	Coated	None	315	10	6580-6720
					6.2	N/A	4					
14	12 Feb	-15.5	0.75	83	13	9	13	Clean	5.2	—	—	1950-2380
					4.5	N/A	4.5[4]					
15[4]	13 Feb	-4.5	0.75	49	58.4	5	N/A	Clean	9.8	334	—	6770-7950
16[4]	2 Mar	-11	0.50	75	60	17	43	Coated	None	317	3	3150-3450
19	4 Mar	-5	1.0	90	57.6	12	42.2	Clean	2.5	328	23	1980-2450
20	6 Mar	-18.5	0.25	36	60	55	N/A	Clean	1.4	—	—	9190-9610

NOTES:

[1] Moderate vibration levels would normally be unacceptable for operational pilots after a short period of time.
[2] Autorotation rpm at 90 KTAS prior to immersion in the HISS cloud.
[3] Autorotation rpm degradation at 90 KTAS after HISS cloud immersion.
[4] Main rotor and/or tail rotor blade ice strike damage occurred during flight.
[5] Tail rotor shed

Table 2. Natural Icing Summary

Flight No	Date	Outside Air Temperature (°C)	Rosemount LWC (gm/m^3)	Leigh MK 10 LWC (gm/m^3)	ASP[1] LWC (gm/m^3)	Immersion[2] Time (minutes)	Maximum IRU[3] Counts	Blade Condition	Torque Rise (psi)	Visual Ice Accretion (inches)	Pressure Altitude (feet)
17	3 Mar	-6.5	0.59	0.33	0.26	63	2976	Clean	N/A	2.1	8000-9320
18	3 Mar	-5.5	0.17	0.12	0.11	22.2	496	Clean	None	0.5	8870-9700
21	9 Mar	-9	0.20	0.14	0.09	72	1473	Coated	1.2	1.4	5350-5800

NOTES

[1] Axially scattering probe particle measuring spectrometer
[2] Moderate vibration levels were only experienced on flight 17 after an immersion time of 32 and 45 minutes. The IPS was not activated.
[3] Integrating rate unit ice accretion measurement device.

11. The HISS cloud was calibrated at a distance of 150 feet behind the HISS at target airspeeds of 90 and 120 KTAS using the calculated water flow rates corresponding to cloud LWCs of 0.25, 0.50, 0.75, and 1.00 grams per cubic meter (gm/m^3). The 90 KTAS calibration was done by the test helicopter described in this report, and the 120 KTAS by a UH-60A helicopter also being tested (USAAEFA Project No. 80-14). The same MRI cloud parameter instrumentation was used for both aircraft. The calibrations were conducted in conjunction with other evaluation flights by laterally centered slow vertical sweeps up and then down through the cloud and then immersing the MRI cloud parameter sensors in the center of the cloud for approximately one minute. Observers aboard the HISS and a chase aircraft provided advice regarding the position of the sensors in the cloud. Two red and two amber lights mounted on the rear of the HISS, visible to the test helicopter crew, provided longitudinal position guidance. The red lights were illuminated when the test helicopter was too close to the HISS (less than 150 feet) and the amber lights for too great a distance (more than 165 feet). When the distance was correct, neither set of lights was illuminated.

12. The ice phobics evaluation was conducted behind the HISS by flying with the test helicopter rotor system immersed in the spray cloud. The target distance between the test helicopter and the HISS was maintained at 150 feet, using the procedures described in the previous paragraph. Observers aboard the HISS and a chase helicopter provided lateral and vertical position guidance. Tests were flown both with and without the ice phobics coating applied to the rotor blades, duplicating temperatures and LWCs as closely as possible; however, other test variables such as pressure altitude, relative humidity, solar radiation, etc. were uncontrolled.

13. The test helicopter remained in the HISS cloud for approximately one hour at each test condition unless safety considerations dictated a shorter immersion period. In those cases, the IPS was activated and a second immersion was completed. Reasons for terminating an immersion early were excessive vibrations (qualitative determination by any crew member) as a result of assymetric ice sheds or a 5 psi torque increase due to ice accretion on the rotor system. The increase in power required due to flying in the downwash from the HISS and the power changes necessary for station keeping made it difficult to determine when a 5 psi torque increase due to ice accretion had occurred.

14. A trimmed level flight data point was taken in formation with the HISS and autorotative rotor rpm was checked at 87 KCAS prior to immersion in the HISS cloud and repeated for comparison after immersion; unless precluded by excessive vibrations, in which case the IPS was activated to clear the ice from the rotor blades. Autorotative rotor RPM was initially adjusted at Edwards AFB, California in accordance with reference 13, and 16 appendix A. Autorotative rotor RPM was later increased to 315 to 320 rotor RPM (90 KTAS) at St. Paul, Minnesota to provide safe autorotative RPM (294-339 rotor rpm) with ice accretion on the main and tail rotor blades. A discussion of test techniques and data analysis methods is presented as appendix D.

15. Data were recorded by hand and on magnetic tape while flying in the HISS cloud and during the trim level flight and autorotative rpm points. Qualitative ratings, in accordance with the vibration rating scale in appendix D, were assigned to the vibrations experienced. Intermittent photographic documentation of the amount and location of the ice on the rotor system was obtained from high speed (400 frames per second) movie and still cameras aboard both the HISS and chase helicopters. The HISS cloud contained a yellow dye to make the ice more visible in the photographs. The movie coverage was the more useful of the two photographic techniques because of the ready comparison of the extent of the ice formations on the two rotor blades and the ability to view the film in slow motion. There was no correlation of the photographic coverage with a specific time or event aboard the test helicopter; however, large numerals applied to the test helicopter with tape allowed correlation by flight number.

16. Evaluation flights were flown in natural icing conditions when they existed in the vicinity of the test site. Flight near the top of the cloud layer proved to be the most productive in terms of icing severity. Minneapolis approach control or Minneapolis center provided air traffic control clearances for the natural icing flights. The test helicopter remained in the cloud until fuel remaining dictated a return to base. The same criteria for IPS activation were used as for flights behind the HISS; however, none of these limit conditions were encountered during the natural icing flights. Because of ice accretion during climb to test altitude, trim level flight data points prior to ice accretion were not accomplished, nor was autorotative rpm checked.

17. The G661 silicone compound was applied with a paint roller in approximately 1/3 to 1/2 man-hours to the leading edges of the blade forward of approximately 35 percent chord prior to each flight with ice phobics. The coating was removed prior to flights with clean blades by repeatedly wiping the blades with cleaning cloths soaked with tolulene or denatured alcohol until the compound could neither be seen nor felt and 3M hot melt adhesive box sealing tape adhered firmly to the blade surface.

RESULTS AND DISCUSSION

GENERAL

18. Test flights in the artificial icing environment behind the HISS were flown to: define the nature of the HISS cloud in terms LWC cloud particle size, and distribution, and to quantitatively determine the effects of the ice phobic coating on the capability of the UH-1H to fly in icing conditions. The ice phobic coating did not significantly affect the capability of the UH-1H to fly in icing conditions. The capability of the UH-1H to operate in icing conditions was assessed during both the artificial and natural icing flights. Prolonged flight (over 10-15 minutes) into light icing (0.15 to 0.50 grams per cubic meter) is not recommended and flight into moderate (0.50 to 1.00 grams per cubic meter) or higher intensity icing should be prohibited because of the moderate to severe vibrations experienced as a result of asymmetric ice sheds. Data to support the FAA R&D requirements were obtained at every opportunity during the test program.

HISS CLOUD CALIBRATION

19. The HISS cloud was calibrated at a target distance of 150 feet behind the HISS at water flow rates calculated to give cloud LWCs of 0.25, 0.50, 0.75, and 1.00 gm/m^3. The calibration was done using instrumentation supplied and maintained by MRI under contract. The data were analyzed and reported on by MRI (ref 11). The MRI data are summarized in table 1 and figures 1 and 2, appendix E.

ICE PHOBICS EVALUATION

20. The quantitative evaluation of the effects of the ice phobic coating of the rotor blades on the capability of the UH-1H to operate in icing conditions was conducted in the artificial icing environment behind the HISS. The evaluation consisted of comparing the results of flights with the coating applied to the results of flights at the same target conditions with clean blades. The comparison was made for flights at the same target temperature and LWC. However, other variables such as pressure altitude, relative humidity, and solar radiation could not be duplicated. Comparisons were made for elapsed time in the cloud until the first moderate or first severe vibration, the worst vibration experienced, the increase in power required, and degradation in autorotative rotor rpm for each test condition. The vibration ratings were qualitative judgements by the crew members based upon the vibration rating scale of figure 1, appendix D. No comparison was possible at -20°C because no flights were conducted with coated blades at that temperature. Target airspeed for all flights was 90 KTAS except for the two flights at -5°C with clean blades. These were flown at a target airspeed of 80 KTAS because the test helicopter did not have enough power to maintain position behind the HISS at 90 KTAS.

21. Immersion times in the HISS cloud until the first moderate vibration and the first severe vibration are presented in figures 3 through 8, appendix E. Comparisons of these times shows that the coated blades were slightly inferior to the clean blades. Comparing times until the first moderate vibration: the coated blades were inferior for five of the test conditions, superior for two of the test conditions, while there was essentailly no difference between coated and clean at one test condition. In the comparison of times until the first severe vibration, the coated blades were inferior for four test conditions and superior for three test conditions, while a moderate vibration was the worst experienced with either at one test condition.

22. The level of the worst vibration experienced and the length of immersion for each test condition are presented in figures 9 through 11, appendix E. Comparison of the worst vibration severity shows that coated blades were inferior to clean blades for five test conditions equal for two test conditions, and superior for one test condition; however, a more meaningful comparison considers immersion time at each test condition. Coated blades were inferior once and equal twice for the three test conditions where the test helicopter remained in the cloud for 60 minutes. The coated blades resulted in a more severe vibration after a shorter immersion period than did the clean blades for one test condition. The comparison is inconclusive for the remaining four test conditions because the more severe vibration occurred after a longer immersion than the less severe vibration.

23. The increases in power required during each immersion and the degradation in autorotative rpm are shown in table 1. The autorotative rpm was not checked after those immersions when the IPS was activated due to unacceptable vibrations. The comparison of increases in power required and autorotative rpm degradation shows that coated blades were superior to clean blades. Power increases of greater than 5 psi torque were experienced twice with coated blades and seven times with clean blades. Autorotative rpm degradation greater than 15 rotor rpm was experienced once with coated blades and five times with clean blades.

24. Based upon comparison of the results of testing behind the HISS with coated and with clean blades, the ice phobic coating did not significantly affect the capability of the UH-1H to fly in icing conditions. The vibrations encountered as a result of asymmetric ice sheds were worse with coated blades, but the increases in power required and the degradation in autorotative rpm were worse with clean blades. No further testing of the G661 ice phobic compound is recommended.

CAPABILITY FOR FLIGHT IN ICING CONDITIONS

25. The capability of the UH-1H to operate in icing conditions was investigated in artificial icing behind the HISS and during three flights in natural icing conditions. Test results of primary interest were: vibrations as a result of asymmetric shedding of ice from the rotor; increases in power required and degradation of autorotative rpm due to ice accretion; capability of the heating and ventilation system to keep the windshields ice free; and damage to the test helicopter as a result of being struck by ice shed from the rotor system.

26. Vibrations due to asymmetric ice sheds from the main rotor during flights behind the HISS were discussed in paragraphs 21 and 22. Moderate vibrations were experienced during the flights at -15°C and 0.25 gm/m^3 LWC with clean blades and with coated blades. Moderate vibrations were also experienced during the flights at -5°C and 0.75 gm/m^3 LWC and -20°C and 0.25 gm/m^3 LWC with clean blades. An intolerable vibration was experienced during the flight at -15°C and 0.75 gm/m^3 LWC with clean blades. Severe vibrations were experienced during all remaining flights behind the HISS. The vibrations experienced during the flight at -5°C and 0.75 gm/m^3 LWC with clean blades were at the top of the moderate range. Severe vibrations adversely affect the pilot's work load and would degrade his instrument flight performance. In addition to degraded crew performance, severe vibrations cause concern for aircraft structural integrity. An immediate autorotative descent

was the instinctive reaction of the test helicopter crew when first exposed to a severe vibration. If an aircrew encounters severe vibrations while in instrument conditions, the likely result will be immediate termination of the mission.

27. Increases in power required and degradation in autorotative rpm are shown in table 1 and were discussed previously. Power increases of the magnitude experienced represent a significant reduction in aircraft range and endurance. The degradation in autorotative rpm experienced on several immersions would significantly affect the capability to accomplish a safe autorotative landing following an engine failure.

28. Ice accretion on and asymmetric sheds from the tail rotor did not appear to be a significant problem. One asymmetric ice shed from the tail rotor was experienced at -15°C and 0.75 gm/m^3 LWC with clean blades. The resulting vibration, though readily apparent, was not severe enough to affect crew performance. A precautionary landing was made because the onset of the vibration coincided with a report from observers aboard the HISS that a piece of ice from a main rotor shed had struck the tail rotor. After landing, it was determined that the vibration was the result of an asymmetric ice shed and not a damaged tail rotor. Ice accretion on the tail rotor was experienced at -20°C and 0.50 gm/m^3 LWC with clean blades, but did not cause any unusual vibrations or noticeable degradation of aircraft stability and control or performance. Ice accretion on the tail rotor was not noted for any of the other conditions tested.

29. Natural icing flights to verify the HISS results were flown when natural icing was present in the vicinitiy of the icing test site. The natural icing flights were in less severe conditions than any of the HISS testing; therefore, test conditions were not duplicated. Figure 1 depicts the approximate icing test conditions and HISS testing boundary. Although the natural icing results cannot be used to verify the HISS results, the two are consistent. Moderate vibrations were experienced during the 67 minute natural icing flight with clean blades at -6°C and an LWC range from approximately 0.25 to 0.50 gm/m^3. Vibrations with clean blades behind the HISS were moderate during 60 minutes at -5°C and 0.75 gm/m^3 LWC and at the lower end of the severe range after approximately 21 at -10°C and 0.50 gm/m^3 LWC. Light vibrations were noted during the 70 minute natural icing flight with coated blades at -9°C and less than 0.25 gm/m^3 LWC. Vibrations with coated blades behind the HISS were moderate during 60 minutes at -15°C and 0.25 gm/m^3 LWC and severe during 60 minutes at -10°C and 0.50 gm/m^3 LWC. No vibrations were noted during the 20 minute natural icing flight with clean blades at -5°C and less than 0.25 gm/m^3 LWC. The only significant increase in power required noted during the natural icing flights was during the 67 minute flight with clean blades at -6°C and an LWC range from approximately 0.25 to 0.50 gm/m^3. Although the exact magnitude of the increase was not determined because a portion occurred due to ice accretion during the climb to test altitude, the increase required a reduction of cruise airspeed from 90 KIAS to 70 KIAS. Power increases exceeding 5 psi torque were noted with clean blades behind the HISS during 60 minutes at -5°C and 0.75 gm/m^3 LWC and -10°C and 0.50 gm/m^3 LWC. Autorotative rpm was not checked during the natural icing flights.

30. The natural icing flights were alternately flown with electric heat off for the pilot's or copilot's windshield to evaluate the capability of the aircraft heating and ventilating system to keep the windshields free of ice. No ice accretion was noted on either windshield during the natural icing flights; however, ice might have accreted during more severe conditions.

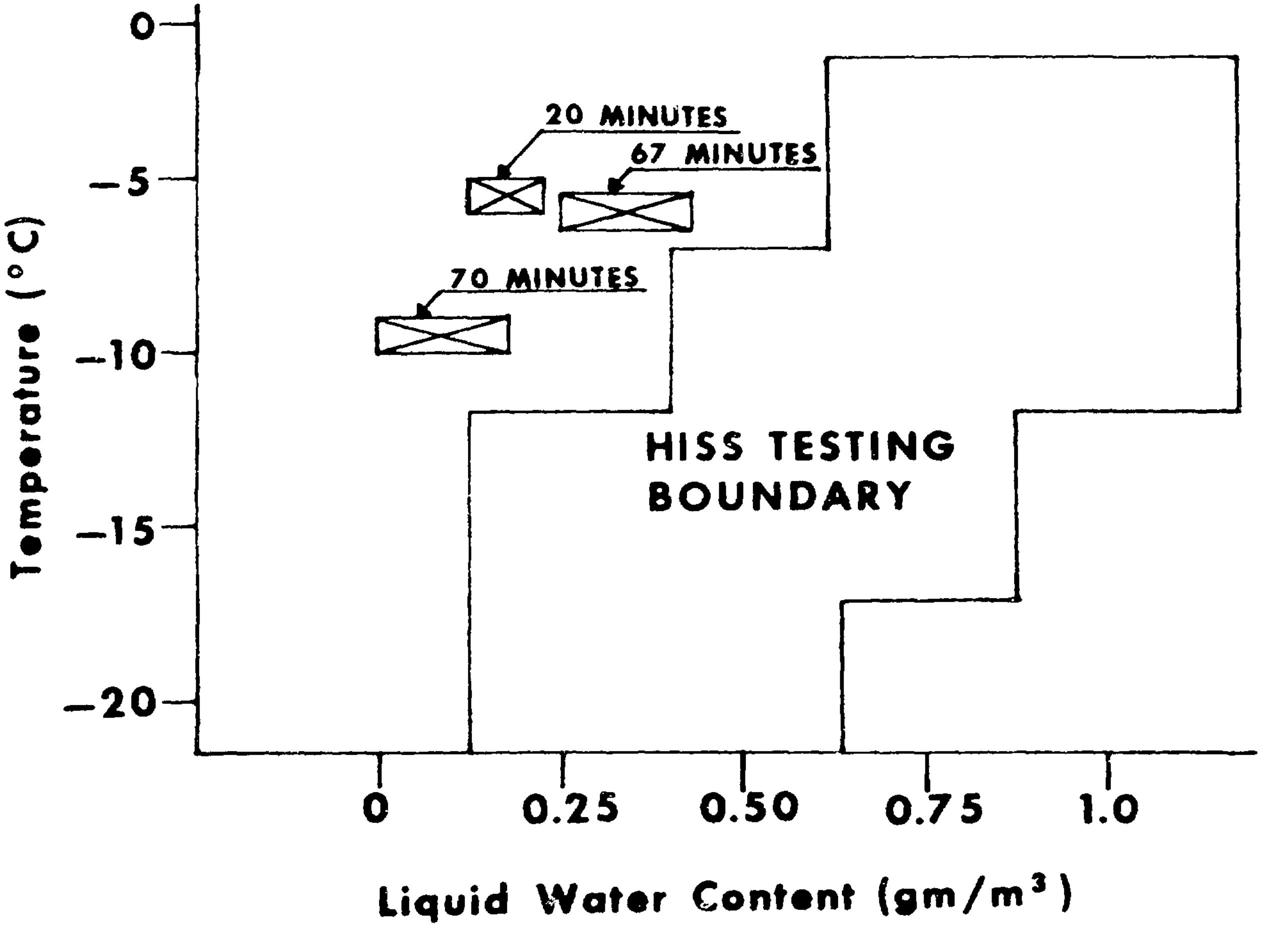


FIGURE 1. NATURAL ICING TEST CONDITIONS

31. The test helicopter was struck by pieces of ice shed from the main rotor on numerous occasions as evidenced by dents in main and tail rotor blades and the aircraft fuselage, particularly the tail rotor drive shaft covers. Icing conditions that resulted in main and/or tail rotor ice strike damage are shown in table 1. Ice striking the main rotor resulted in one dent that would have required replacement of the main rotor blade; however, the airworthiness release (ref 9) was modified (ref 12) to allow continued use during the remainder of the test program. Ice striking the tail rotor resulted in dents requiring replacement of both tail rotor blades one time and replacement of one tail rotor blade another time. According to the aircraft maintenance manual (ref 13), the complete tail rotor drive train also required replacement; however, continued use until completion of the test program was authorized (ref 14). Ice strikes on the aircraft and rotor system during ice sheds from the main rotor would result in a significant added maintenance work load and repair parts cost for the operational unit, in addition to added overhaul costs at the depot maintenance level.

32. The capability of the UH-1H to operate satisfactorily in icing conditions is adversely impacted by; the vibration encountered as a result of asymmetric ice sheds from the main rotor; increases in power required and degradation of autorotative rpm due to ice accretion; and increased maintenance requirements because of ice striking the helicopter during an ice shed. Prolonged flight (over 10-15 minutes) into light icing is not recommended and flight into moderate or higher intensity icing should be prohibited. An icing severity level indication system should be provided for all UH-1H aircraft in order to utilize the aircraft to its fullest potential. Flight into light icing should only be attempted with caution and only when conditions provide an option to vacate the icing condition due to the inadequacies of forecasting icing intensities.

FAA R&D EVALUATIONS

33. Data to meet the FAA R&D requirements were obtained throughout the artificial and natural icing flights and are presented in the MRI report (ref 11). Specifically, the following data were obtained:

a. Cloud droplet size

b. Cloud LWC

c. Relative humidity

d. Solar radiation

e. Ice crystal content

Data regarding ice shape and thickness, ice impingement limits including runback, and ice formation type were limited because the camera for photographing the main rotor blades did not function properly. Photographic coverage from the HISS and the chase helicopters is presented in photos 1 through 3.

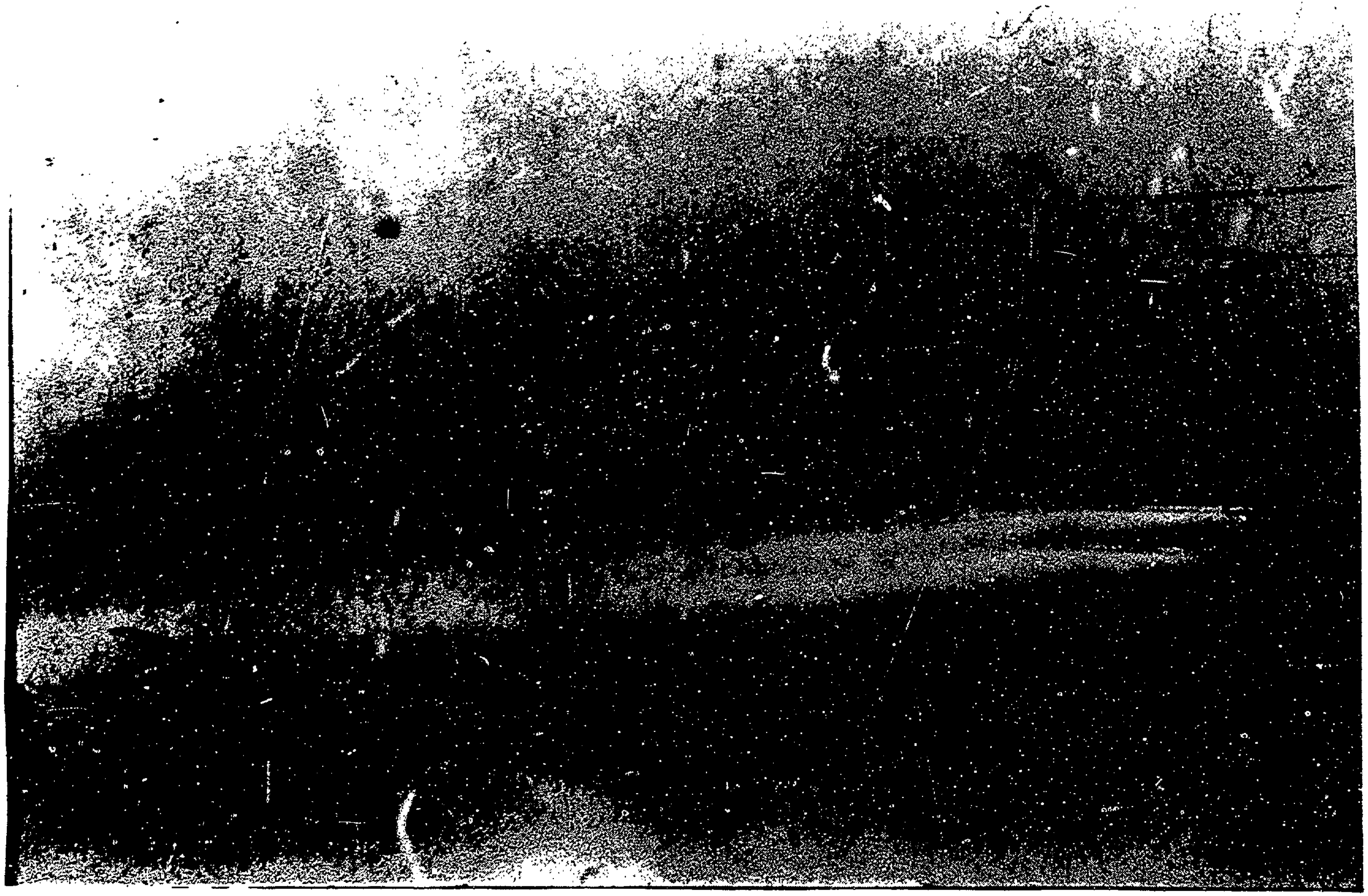


Photo 1. Test and HSS Helicopters from the Chase.

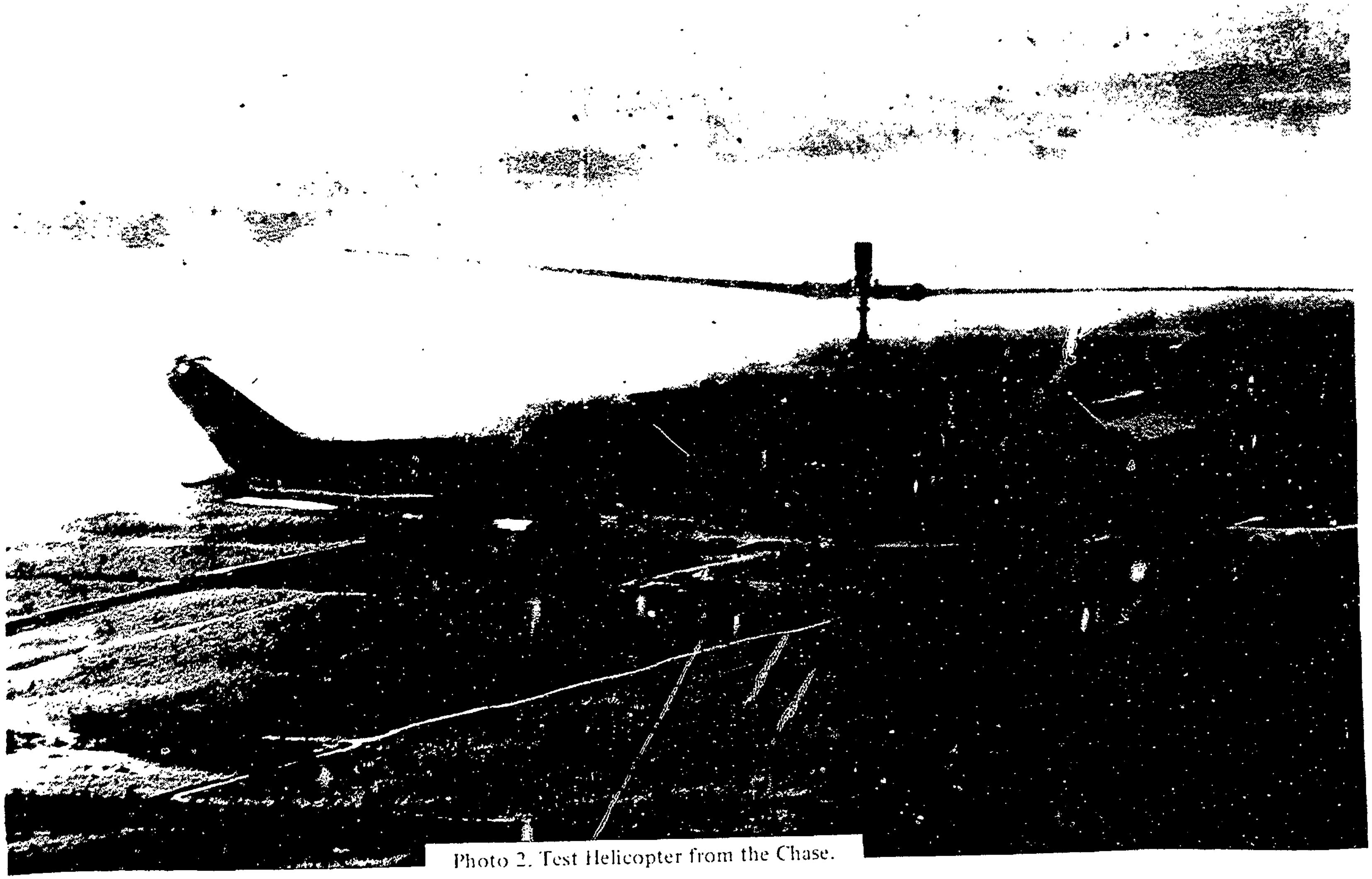


Photo 2. Test Helicopter from the Chase.

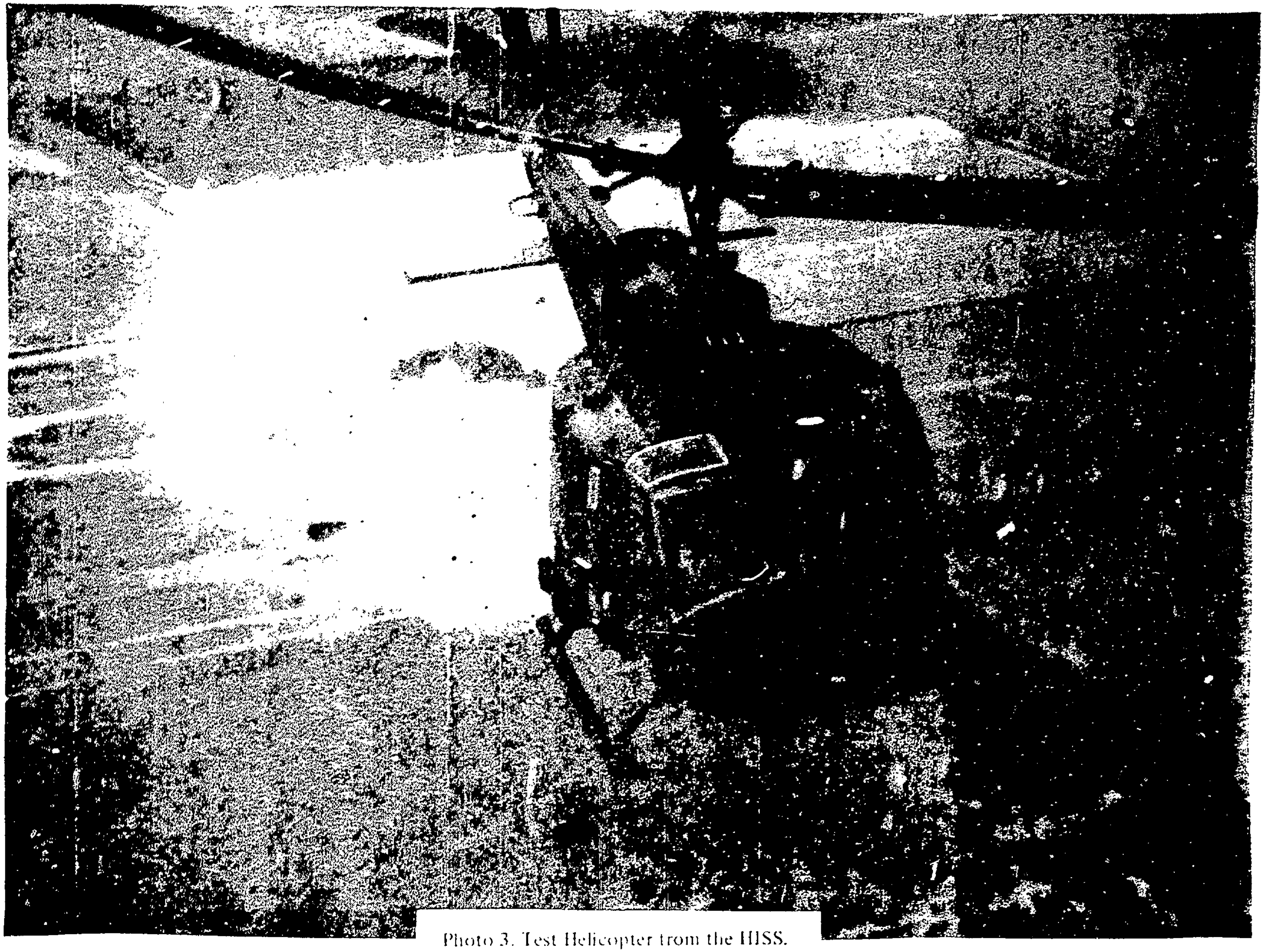


Photo 3. Test Helicopter from the HISS.

CONCLUSIONS

34. The GE G661 ice phobic coating did not significantly affect the capability of the UH-1H to operate in icing conditions (par 24).

35. The vibrations resulting from asymmetric ice sheds, the increase in power required, the degradation of autorotative rpm due to ice accretion and the increased maintenance requirements because of damage by ice striking the helicopter during ice sheds prevent safe operation of the UH-1H in moderate or higher intensity icing and prolonged (10-15 minutes) light icing (para 32).

RECOMMENDATIONS

36. No further testing of the G661 ice phobic compound is recommended (par 24).

37. Prolonged flight (over 10-15 minutes) into light icing is not recommded (par 32).

38. Flight in the UH-1H into moderate or higher intensity icing should be prohibited (par 32).

39. Icing severity level indication system for the UH-1H in order to utilize the aircraft to its fullest potential.

APPENDIX A. REFERENCES

1. Test Request, USAAEFA Project 80-13, *HISS Calibration, Ice Phobics, and FAA R&D Evaluations,* 16 September 1980.

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

3. Test Request, USAAEFA Project No. 80-04, *HISS Evaluation and Improvements,* 6 June 1980.

4. Interagency Agreement DTFA03-80-A-00199 between US Department of Transportation, Federal Aviation Administration, and US Army Aviation Research and Development Command.

5. Final Report, USAAEFA Project No. 74-13, *Artificial Icing Test Lockheed Advanced Ice Protection System Installed on a UH-1H Helicopter,* June 1975.

6. Final Report, USAAEFA Project No. 78-21-2, *Microphysical Properties of Artificial and Natural Clouds and Their Effect on UH-1H Helicopter Icing,* August 1979.

7. Technical Manual, TM 55-1520-210-10, *Operator's Manual, Army Models UH-1D/1H and EH-1H Helicopters,* 18 May 1979.

8. Supplement to Technical Manual, TM 55-1520-210-10, *Operator's Manual, UH-1H Helicopter, Serial No. 70-16318, Incorporating an Advanced Ice Protection System and UH-1H Kit A Ice Protection,* 19 July 1978.

9. Letter, DRDAV-DI, 24 December 1980, subject: Airworthiness Release for USAAEFA Project No. 80-13, HISS Calibration, Ice Phobics and FAA R&D Evaluation.

10. Test Plan, USAAEFA Project 80-13, *HISS Calibration, Ice Phobics, and FAA R&D Evaluation,* December 1980.

11. (MRI Report)

12. Letter, DRDAV-DI, 19 February 1981, subject: JUH-1H, S/N 70-16318 Main Rotor Blade Dent.

13. Technical Manual, TM55-1520-210-23, *Aviation Unit and Intermediate Maintenance Instructions, Army Model UH-1D/H/EH-1H Helicopters,* 20 February 1979.

14 Message, CDR TSARCOM, DRSTS-MEA, 022015Z MAR 81, subject: JUH-1H, S/N 70-16318, Tail Rotor Blade and Drive System Icing Tests Inspection Requirements.

15. Final Report, USAASTA, Project No. 66-04, *Engineering Flight Test, YUH-1H Helicopter,* November 1970.

16. Technical Manual, TM55-1500-219-MTF, *Maintenance Test Flight Manual, Army Model UH-1 Helicopter,* 28 February 1979

APPENDIX B. DESCRIPTION

GENERAL

1. In addition to the ice protection provided a basic UH-1H helicopter (pitot-static tube and engine air inlet), the test helicopter incorporated an ice protection system (IPS). The IPS provided protection for the main rotor blades, stabilizer bar/tip weights, pilot/copilot windshields, and tail rotor blades (not operational for this test). Nonstandard features are shown in figure 1.

ICE PROTECTION SYSTEM (IPS)

Power System

2. To supply electrical power to the IPS, the existing direct current (DC) generator had been replaced by a 30 kilovolt-ampere (KVA), 400 hertz alternating current (AC) generator. The AC generator was mounted on the forward accessory pad of the main transmission. Because of the elimination of the main DC generator, the primary source of DC power was the engine-driven starter/generator. A 200 ampere transformer-rectifier to convert AC to DC power was installed as a standby DC system.

System Operation

3. The IPS operation was controlled through the IPS panel (fig. 2), IPS control unit (fig. 3), and IPS controller (fig. 4), all located on the center console. Windshield anti-icing was controlled manually from the IPS panel. Stabilizer bar/tip weights anti-ice was controlled manually from the IPS control unit. Main and tail rotor blade de-ice was controlled semi-automatically from the combined operation of the IPS controller and IPS control unit.

a. Automatic mode: In the automatic mode, icing severity signals from the MK 10 ice detector and Lewis outside air temperature (OAT) probe scheduled the operation of main and tail rotor blade heater elements according to predetermined OAT and ice accretion level parameters. The variables involved were individual heater element ON time and dwell time (system OFF time between cycles). The IPS control unit provided an indication (ICING light) when icing conditions were encountered. An icing severity signal from the ice detector and a below freezing OAT signal were required to permit power to be applied to the rotor blades in the automatic mode. The automatic mode was not operational during this test program.

b. Semiautomatic mode: In the semiautomatic mode, the liquid water content (LWC) and OAT inputs to the IPS controller were selected by the flight crew through the IPS control unit. This in turn controlled the ON time of the deicer heating elements. Manual ground adjustments were also provided to vary heater parameters during optimization of the system.

4. The IPS control unit provided operational control and adjustment capability for the main and tail rotor blade de-ice and stabilizer bar/tip weight anti-ice through switches located on the control unit head.

5. The IPS controller was an automatic processor which accepted automatic data from the MK 10 ice detector and Lewis OAT probe, or manual data inputs

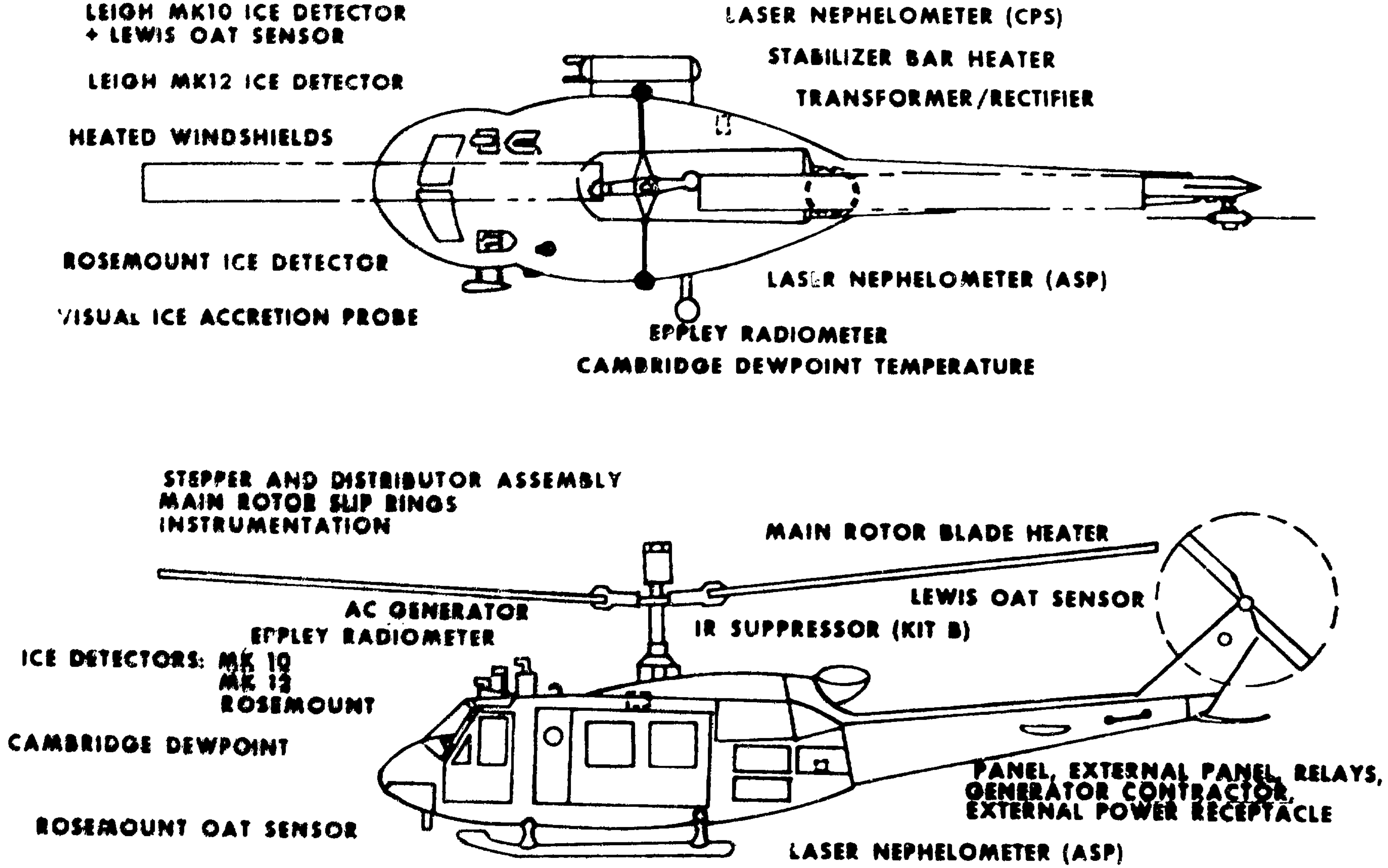
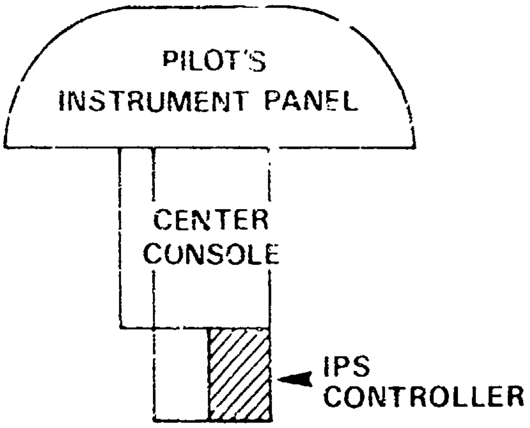
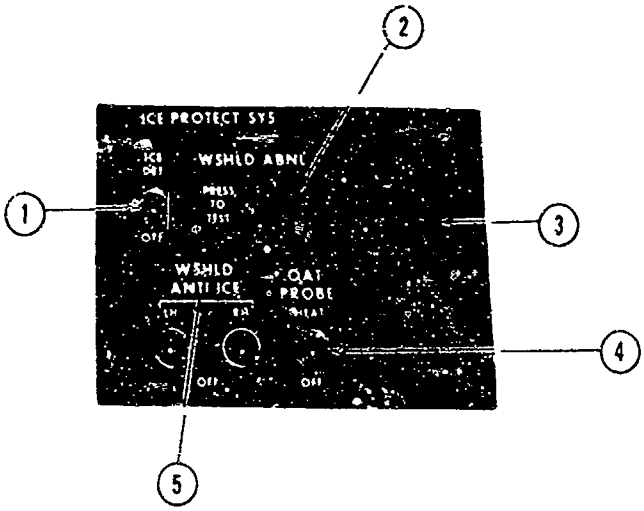


FIGURE 1. NON-STANDARD FEATURES





KIT A. ICE PROTECTION SYSTEM PANEL

INDEX	SWITCH OR INDICATOR	FUNCTION
1	Ice Det. On-Off	Turns on the Rosemount Ice Detector
2	WSHLD ABNL	Warning lights innunicate "Left" or "Right" heated glass window abnormal conditions
3	Total Air Temperature Gage	Displays outside air temperature digitally in degrees centigrade
4	OAT Probe Heat On-Off	Provides on-off control of anti-ice heaters on the Rosemount total air temperature probe (Model 102). (Not used in conjunction with non-deiced model 172 temperature probe.)
5	WSHLD Anti-ice On-Off left and right	Turns on the automatic windshield deice heater controls

FIGURE 2. IPS CONTROL PANEL

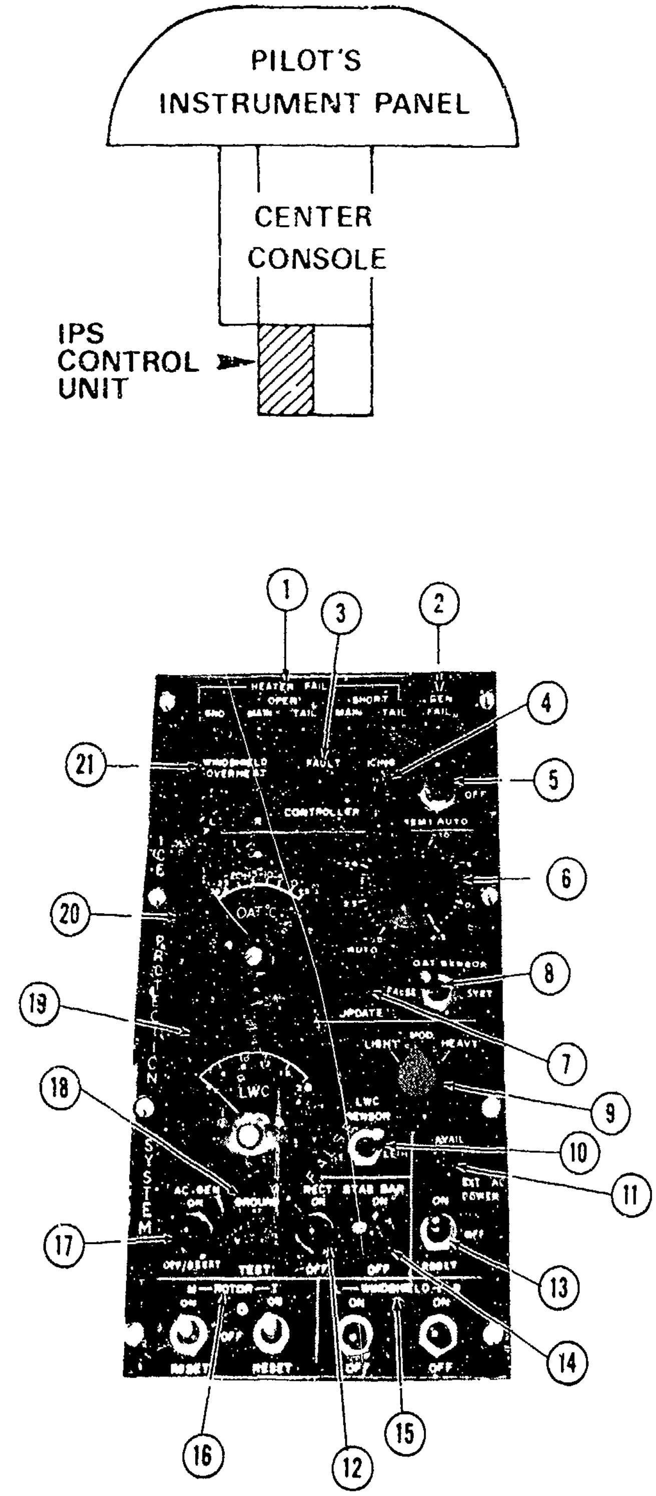


FIGURE 3. IPS CONTROL UNIT

INDEX	SWITCH OR INDICATOR	FUNCTION
1	HEATER FAIL	Provides warning of any line-to-ground leakage in the generator system or in the wiring of the main or tail rotor deicing system, such as a rotor blade element shorting to ground
	OPEN MAIN TAIL	Provides warning of an open element or open line for main or tail rotor deicing system NOTE The OPEN MAIN/TAIL lamp lights if the MASTER POWER switch on the deicing controller is ON and corresponding ROTOR switch on control unit is ON with AC GEN switch OFF.
	SHORT MAIN TAIL	Provides indication when current is excessive for main or tail rotor on any power phase
	SHORT MAIN	Also provides indication that power synchronization
2	AC GEN FAIL	Deactivated
3	FAULT CONTROLLER	Provides indication when main rotor power doesn't follow time control but stays on
4	ICING	Provides indication that icing conditions are present outside the helicopter when MASTER POWER switch on deicing controller is ON and icing conditions are encountered or a false signal is introduced to simulate icing
5	MODE SWITCH	Allows selection of automatic or semiautomatic operation of ice protection control system. Detented to prevent inadvertent operation. Automatic mode was inoperational
6	OAT SELECTOR	Allows setting outside all temperature into deicing system in semiautomatic mode
7	AUTO UPDATE	Allows initiation of main rotor timer operation. Resets all timers for normal operation to begin again (with zone 1 for main rotor)
8	OAT SENSOR	Allows selection of FALSE or SYST OAT sensor for display on OAT meter and input to the deicing controller

INDEX	SWITCH OR INDICATOR	FUNCTION
9	LWC SELECTOR (LIGHT/MOD/HEAVY)	Allow setting LWC icing condition into system in semiautomatic mode to control OFF times
10	LWC SENSOR	Allows selection of FALSE or LEIGH MARK 10 LWC sensor for display on LWC meter and input to the controller
11	EXT AC PWR AVAIL LAMP	Provides indication that AC external power is available
12	RECT ON/OFF	Deactivated
13	EXT AC PWR ON/OFF RESET SWITCH	Allows external AC power to be applied to the helicopter
14	STAB BAR ON/OFF	Allows power to be applied to stabilizer bar heating blanket. Detented to prevent inadvertent operation
15	L-WINDSHIELD-R ON/OFF	Deactivated. Use Kit A Panel
16	M-MOTOR-T ON/OFF	Allows power to be applied to either or both main and tail rotor heater elements
	RESET	Allows resetting BITE circuits
17	AC GEN ON OFF/RESET	Deactivated. Use Kit A panel
18	GROUND TEST	Allows overriding of normal timing circuits by a test oscillator to test rotor heating cycle. With normal loads, the main rotor blades will have one operational sequence; and the tail rotor blades will have one power on period. The test oscillator is turned off at the end of the main rotor blade sequence
19	LWC METER	Provides indication of outside liquid water content (LWC) when MASTER POWER switch is ON
20	OAT METER	Provides indication of outside air temperature when MASTER POWER switch is ON
21	WINDSHIELD OVER HEAT L R	Deactivated. Use Kit A panel

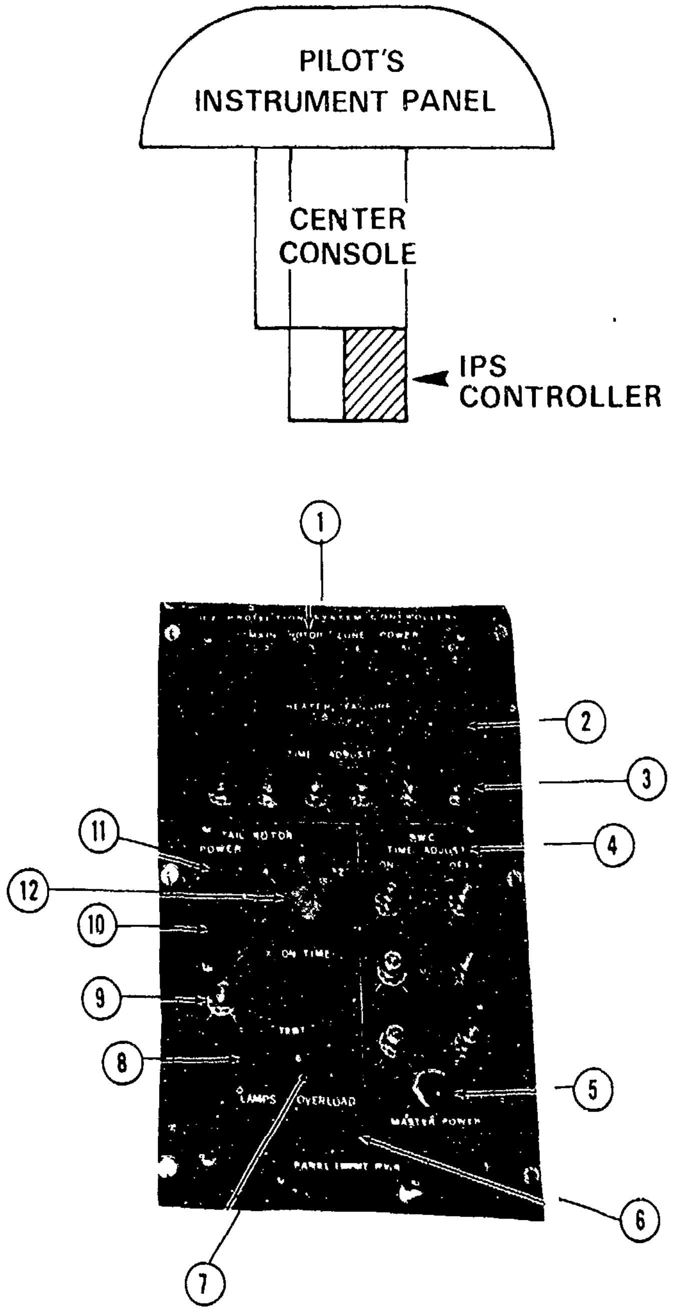


FIGURE 4. IPS CONTROLLER

INDEX	SWITCH OR INDICATOR	FUNCTION
1	MAIN ROTOR ZONE POWER	Provides indications when power is being applied to each of the six main rotor heated areas. As power is programmed to the main rotor heated areas, indicators come on and go off in sequence
2	MAIN ROTOR HEATER FAILURE BITE	Provides indication of failure of one of the six main rotor Heater elements
3	MAIN ROTOR TIME ADJUST	Provides for individual adjustment of the heater-on time for each of the six main rotor heater elements. Locking nuts are provided to secure the settings
4	LWC TIME ADJUST	Provides for the simultaneous adjustments of the time periods that all main and tail rotor heaters are off for light, moderate and heavy voltage settings
5	MASTER POWER	Provides master power control for the ice protection system. Detented to prevent inadvertent operations. Must be cycled OFF, then ON to unlatch any failure lamps. Master power switch is used to activate the blade deice cycle when in the semi-automatic mode
6	PANEL INPUT BREAKER	Controls 28 vdc power to the system. Provides protection against excessive current
7	TEST OVERLOAD	Provides simulation of overload condition for preflight checkout of fault protection circuit
8	TEST LAMPS	Provides test of all lamps on ice protection system control panel only
9	TAIL ROTOR TIME ADJUST	Provides for adjustment of the heater-on time for the tail rotor heater elements
10	TAIL ROTOR HTR FAIL BITE	Provides indication of a failure in the tail rotor deicing system
11	TAIL ROTOR POWER	Provides indication that power is being applied to tail rotor heaters
12	TAIL ROTOR OFF-TIME	Provides selection of tail rotor heater element off-time as 4, 8 or 12 times the heater element on-time

from the IPS control unit. It provided the means for adjusting the heat ON/OFF time of the main rotor and provided system fail indications for main and tail rotor blade heater failure.

Windshield Anti-Icing

6. The pilot and copilot windshields were anti-iced by supplying electrical power to a transparent metallic conductive coating bonded between the laminations of the windshield. Windshield heating was controlled by independent ON/ OFF switches located on the IPS panel. Control of windshield temperature was automatic after windshield anti-ice switches were turned on. Three phase AC power was used for heating with a single phase heating each third of the windshield. A temperature sensor located in each windshield provided temperature input to maintain a predetermined temperature range for proportional control of power to the heating elements.

Stabilizer Bar and Tip Weights

7. The stabilizer bar and tip weights were covered with electric heater blankets interconnected through flat braided wires to provide AC power for anti-icing. Stabilizer bar and tip weight heating was controlled by an ON/OFF switch on the IPS control unit with amperage monitoring provided by an ammeter located on the left center console.

Main Rotor Blade Deicing

8. The electrothermal de-icing system of the main rotor blades used sequentially supplied AC electric heating elements in the leading edges of the blades. The heated area was divided into six spanwise zones, each with its own heater element. Corresponding zones in both blades were heated simultaneously to provide symmetrical ice shedding. Heating began at the blade tip zone and progressed sequentially to the root. The heater elements were covered with a stainless steel erosion shield bonded to the leading edge of the blades and were controlled by a switch located on the IPS control unit. The main rotor blade de-icing system was activated by the master power switch on the IPS controller when operating in the semi-automatic mode on the IPS control unit.

Ice Detectors

9. The IPS system incorporated a Leigh Instruments MK 10 ice detector mounted on a 12-inch streamlined mast on the cabin roof (photo 1). The detector operated on the infrared occlusion principle, and consisted of a light emitting diode/photo transistor assembly which provided an optical path that was partially occluded by the accretion of ice on the probe. The assembly was encased in an annular duct and ejection nozzle which was supplied with engine bleed air to induce high velocity air flow over the ice collection probe and provide anti-icing. When the ice accumulation on the probe reached a preset level, the probe was automatically electrically de-iced and the cycle was repeated. The icing signals were displayed by lights and icing severity meters located in the cockpit. The signal was also routed to the IPS controller and integrating rate unit (IRU), for automatic control of main and

tail rotor blade de-ice operation. The tail rotor de-ice system was disconnected and automatic control of main rotor blade de-ice was not operational.

10. A Leigh MK 12 ice detector (photo 1) was located on the cabin roof at the pilot's air inlet. The MK 12 detector, like the MK 10, operated on the infrared occlusions principle and requires bleed air. Icing signals from the MK 12 were routed to a distinct integrating rate unit (Model IRU-2) located in the crew compartment. An LWC display in grams per cubic meter (gm/m^3) was also provided.

11. An ultrasonic-type ice detector manufactured by Rosemount Engineering Inc. was attached to the copilot's air inlet on the cabin roof (photo 1). The detector utilized a vibrating probe which was excited at its natural frequency by a magnetostrictive oscillator mounted on the end of the probe. As the probe accreted ice, the natural frequency was reduced and the change was detected as an ice accretion rate. When the ice thickness reached a predetermined value the probe was housed in an electrically heated aspirator shroud which used engine bleed air to induce flow over the probe during low airspeeds. The icing signal was displayed on an LWC indicator located on the center console. The LWC indicator incorporated a manual selector knob which provided 5 damping levels to reduce needle oscillations.

Integrating Rate Unit (IRU)

12. An IRU (Model IRU-4) (photo 2), manufactured by Leigh Instruments, Ltd., accepted the icing signal from the Leigh MK 10 ice detector and calculated this rate of ice accretion to indicate the amount of ice accreted up to the point where a new sample had been taken. The IRU accumulated the integrated blocks of accretion data and compared the total to a quantity which was preselected via thumbwheel switches. When the accumulated total exceeds that selected, a signal was produced which could be used to illuminate a light on the IRU panel located in the crew compartment. An LWC display in gm/m^3 was also provided on the IRU panel.

13. The IRU (Model IRU-5) accepted the icing signal from Leigh MK 12 ice detector and calculated this rate to indicate the amount of ice accreted. Ice accretion was displayed on an LWC indicator on the IRU located in the crew compartment.

Outside Air Temperature Sensors

14. A Lewis OAT sensor was located flush mounted on the 12-inch streamlined mast on the cabin roof (colocated with MK 10 ice detector). This sensor provided temperature signals to a dial indicator located on the IPS control unit and, when combined with LWC signals from the MK 10 ice detector, provided an indication of icing encounter by illuminating an ICING light on the IPS control unit. In addition, the signals were routed to the IPS controller for automatic blade de-icing control; however, the automatic mode was not operational.

15. A second Lewis OAT sensor was located on the left hand side of the vertical tail fin in the vicinity of tail rotor. This sensor provided signals to a cockpit display and to the PCM tape system.

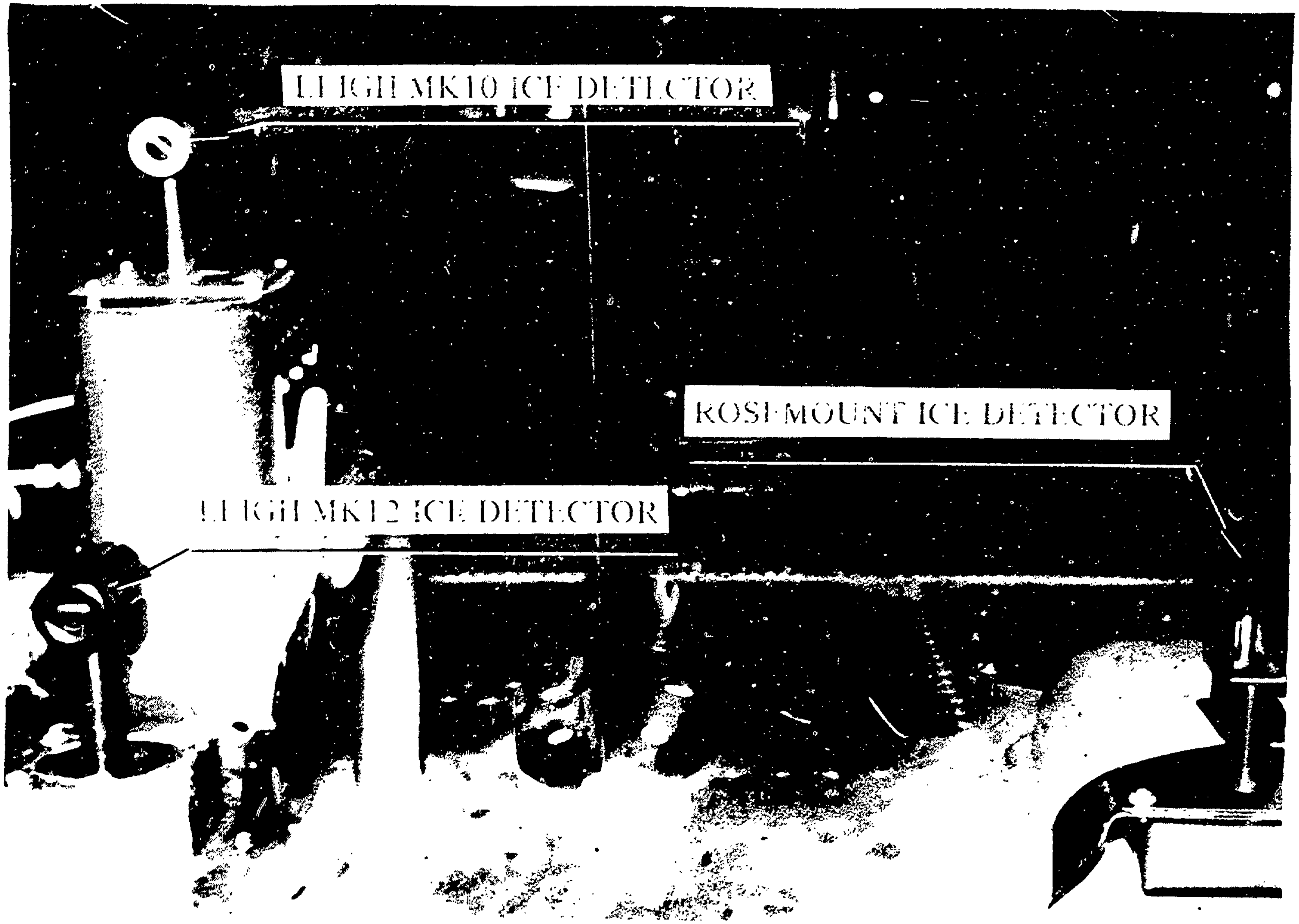


Photo 1. Ice Detectors

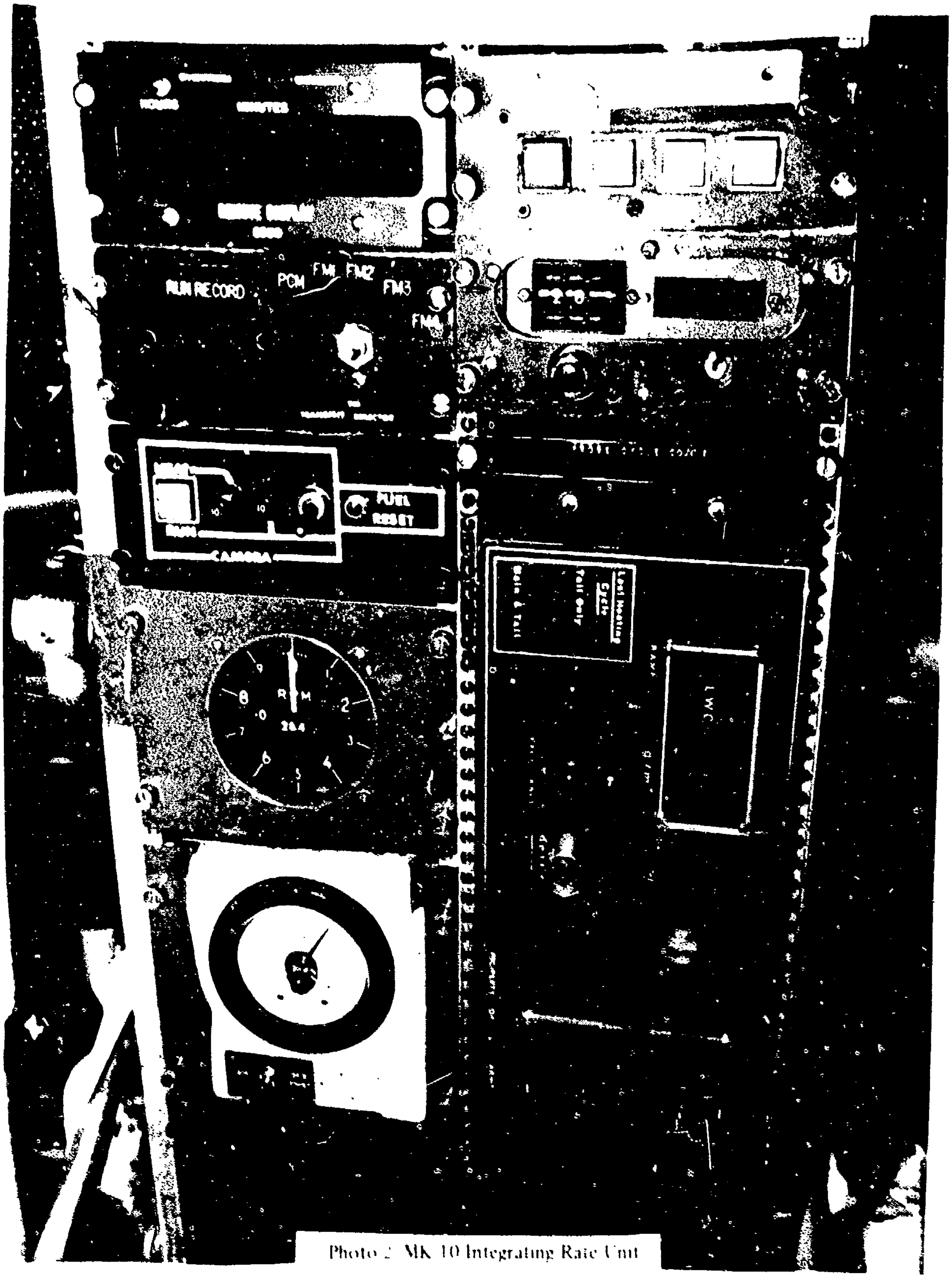


Photo 2 MK 10 Integrating Rate Unit

16. A Rosemount OAT sensor was located below the avionics compartment door on the nose of the aircraft. The sensor's sole purpose was to provide an additional signal which was displayed on the IPS panel OAT digital indicator.

APPENDIX C. INSTRUMENTATION AND SPECIAL EQUIPMENT

Instrumentation

1. The test instrumentation was installed, calibrated, and maintained by US Army Aviation Engineering Flight Activity (USAAEFA). Digital and analog data were obtained calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. The digital instrumentation system consisted of various transducers, signal condition units, an eight-bit pulse code modulation (PCM) encoder, and an Ampex AR 700 tape recorder. Time correlation was accomplished with a pilot/engineer event switch and on-board recorded and displayed Inter-Range Instrumentation Group B time. Analog data were recorded on one track of the AR 700 recorder through the use of a voltage control oscillator. Various specialized test indicators displayed data to the crew continuously during the flight.

2. In addition to standard ship's instruments, the following parameters were displayed on calibrated test instruments in the cockpit:

Pilot's Panel

Airspeed (ship's)
Altitude (ship's)
Fuel flow
Fuel used
Engine torque
Engine inlet screen differential pressure
Rosemount outside air temperature (OAT)
Rosemount liquid water content (LWC)
Leigh Mark 12 LWC
Leight Mark 12 integrating rate unit (IRU)

Engineer's Panel

Main rotor speed
Leigh Mark 10 LWC
Leigh Mark 10 IRU
Vertical tail fin OAT
Cambridge dew point temperature
Leigh ice detector bleed air pressure
Rosemount ice detector bleed air pressure

3. The following parameters were recorded on magnetic tape.

PCM Parameters

Control position:
    Longitudinal
    Lateral
    Directional
    Collective
Engine torque
Fuel flow
Fuel used

- Airspeed (ship's)
- Altitude (ship's)
- Main rotor speed
- Engine inlet screen differential pressure
- Aircraft attitude:
  - Pitch
  - Roll
  - Yaw
- Aircraft rates:
  - Pitch
  - Roll
  - Yaw
  - Oat
- Rosemount LWC
- Leigh Mark 10 LWC
- Lewis OAT (vertical tail fin)
- Cambridge dew point temperature
- Normal acceleration Center-of-gravity
- Leigh Mark 10 IRU present sum
- Leigh Mark 10 IRU last sum
- Leigh Mark 12 LWC
- Leigh Mark 12 IRU ice units
- Main rotor temperatures at the following stations:
  - Station 257.11 (zone 1)
  - Station 110 (zone 4)
  - Station 55 (zone 6)

Frequency Modulated

- CG lateral acceleration
- Pilot seat acceleration
  - Lateral
  - Vertical
- Main rotor pitch link axial load
- Tail rotor pitch link axial load

SPECIAL EQUIPMENT

Dew Point Meter

4. A Cambridge Model 137 chilled mirror dew point hygrometer was located on the left hinged panel door. This device sampled airflow and indicated a corresponding dew point temperature to a cockpit display and to the PCM tape system.

Strobe Camera

5. A 16mm stop action camera was mounted on the inside of the right hinged panel door. A strobe light was incorporated in the design to allow photographing a single main rotor blade throughout the flight. This strobe camera was intended to provide inflight photographic coverage to quantify main rotor blade ice accumulation and shedding.

Ice Accretion Indicator Probe

6. A visual ice accretion indicator (photo 1) was mounted on the test aircraft to give the copilot a visual cue of ice buildup on the helicopter. It was composed of a small symmetrical air foil (OH-6A tail rotor blade section) with 3/16-inch diameter steel rod protruding 1-1/2 inches out from the leading edge at the center. The protruding rod was painted with multi-colored 0.2 inch stripes to provide a reference for ice thickness estimation. The unit was mounted on the copilot's door facing forward.

Meteorological Research Incorporated (MRI) Equipment

7. The test objectives requiring cloud parameter data (LWC and droplet size distribution) were obtained through MRI instrumentation. The following equipment was installed on the test aircraft: an axially scattering probe (ASP) (photo 2), a cloud particle spectrometer (CPS) (photo 3) and associated recording equipment (photo 4).

8. The ASP sized particles by measuring the amount of light scattered into the collecting optics apperture during particle interaction through a focused laser beam. The signal pulses were alternating current coupled to a pulse height detector which compared their maximum amplitude with a reference voltage derived from a separate measurement of the direct current light signal illuminating particles. The system was capable of sizing particles from 2 to 30-microns diameter having velocities from 10 to 125 meters per second (20 to 240 knots).

9. In the CPS, particles were sized using a linear array of photodiodes to sense the shadowing of array elements were particles passing through its field of view. Particles were illuminated by a helium-neon laser. As shadowing of each photodiode element became dark enough, a flip-flop memory element was set. The particle size was determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system.

10. Two different CPS probes were used during this evaluation. One probe contained 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns. The other probe contained 20 photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 140 to 2100 microns.

11. More detailed descriptions of the ASP and CPS are contained in reference 11, appendix A.

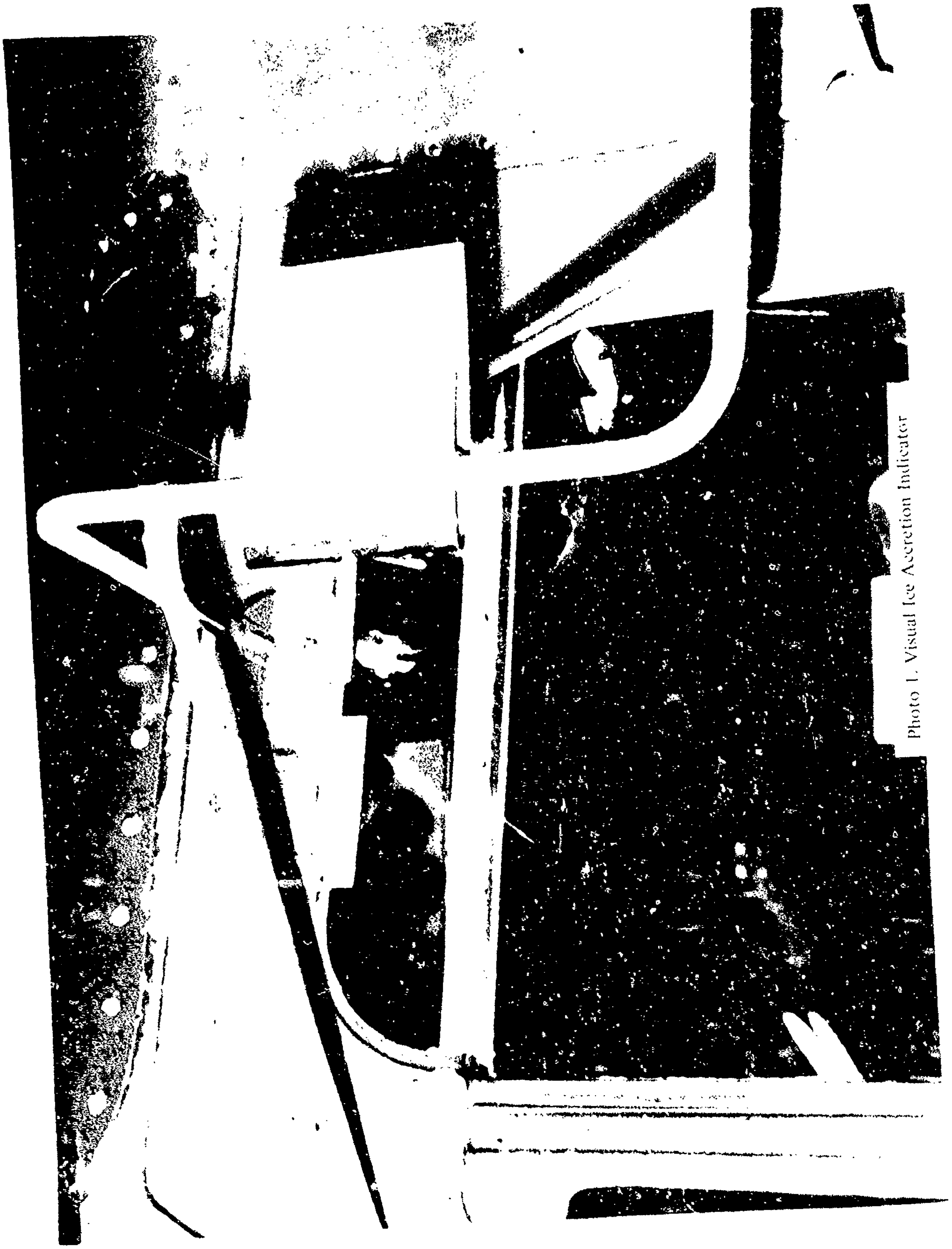


Photo 1. Visual Ice Accretion Indicator

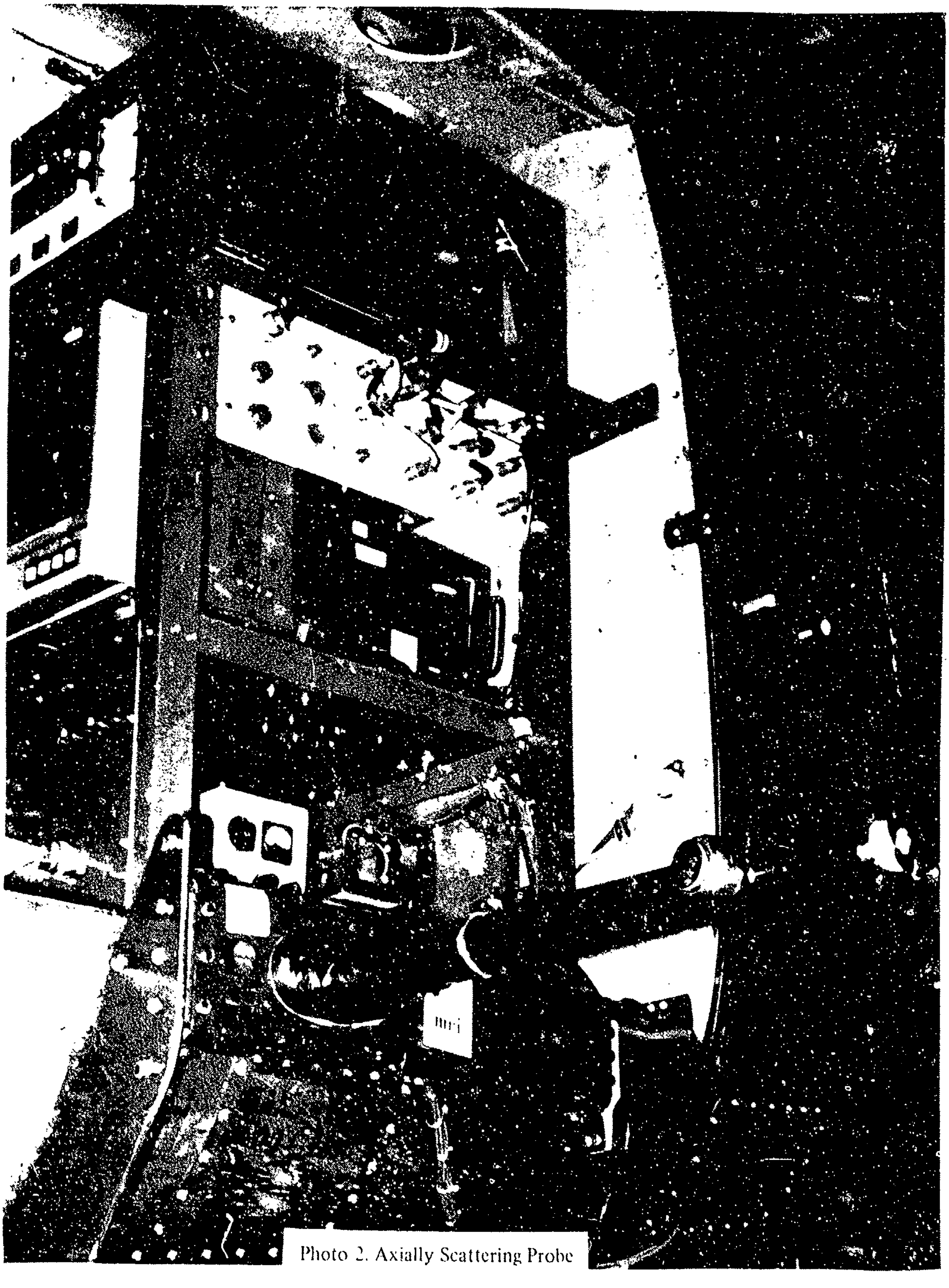


Photo 2. Axially Scattering Probe

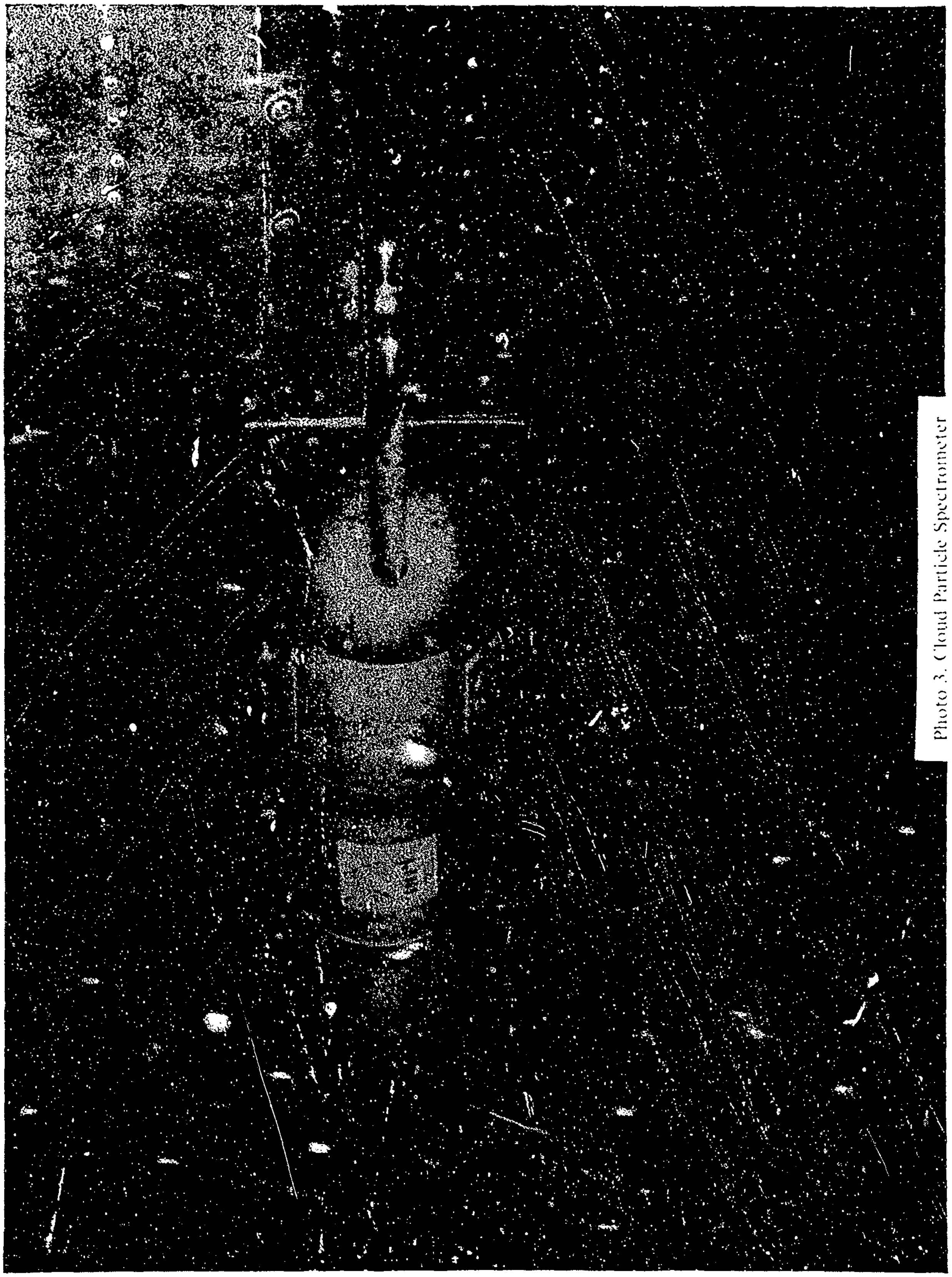


Photo 3. Cloud Particle Spectrometer

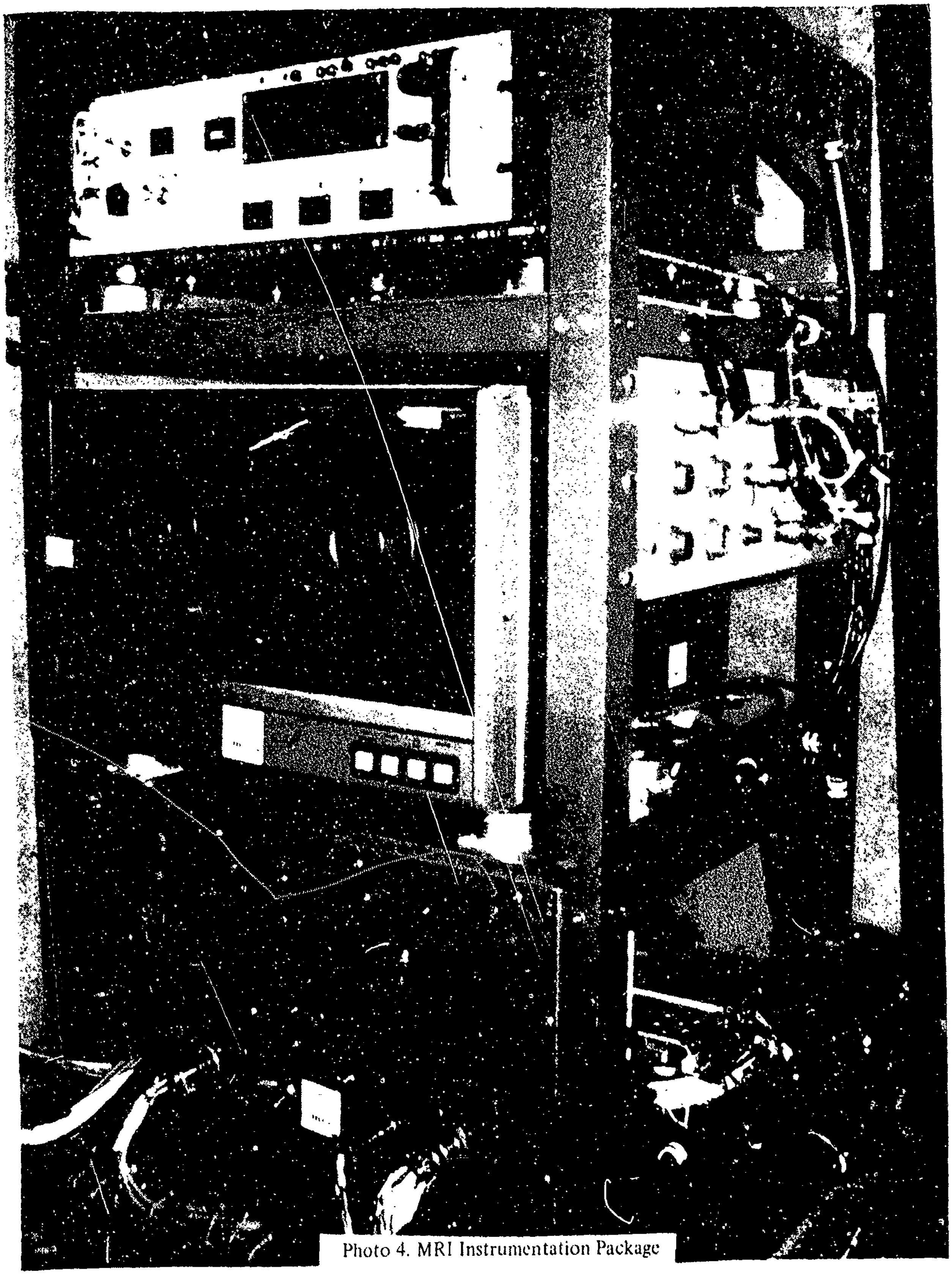


Photo 4. MRI Instrumentation Package

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. Testing was conducted in two phases: artificial icing behind the helicopter icing spray system (HISS) and natural icing. For artificial icing tests, all anti-ice systems were activated while enroute to the test area. After reaching the altitude required for the specified test temperature, baseline level flight performance and autorotational data were obtained. The test aircraft then entered the spray cloud from a position below and approximately 150 feet behind the HISS. Test aircraft and HISS separation distance was maintained during the icing flight by information relayed from a radar altimeter mounted on the HISS. Test airspeed and outside air temperature (OAT) were established with the calibrated systems of the HISS. All artificial icing flights were flown with a predetermined liquid water content (LWC) and outside air temperature.

2. For natural icing tests, all anti-ice systems except the windshields were activated prior to entering expected icing conditions. After entering the cloud, altitude was varied until icing indications were obtained on the instrumentation. Once established on the test altitude, baseline level flight performance data were obtained.

3. The aircraft was flown in the icing cloud (artificial or natural) until a predetermined torque increase was noted or vibration levels increased because of main or tail rotor asymmetric ice sheds.

Ice Accretion

4. Ice accretion was monitored in flight by the copilot using the visual ice accretion indicator probe. The engineer monitored time in cloud, LWC indications, and integrating rate unit counts to correlate accretion rates.

5. An attempt was made to document main rotor blade ice accretions by use of a stop-action strobe camera mounted inside the aircraft cabin. Because of numerous camera mechanical failures, strobe light failures, and icing of the door window, no useable data were obtained from this camera. Therefore, photographic documentation could only be obtained by using high speed motion picture cameras to photograph the test aircraft from both the chase and spray aircraft.

Level Flight Performance

6. Level flight performance data were obtained by establishing trim level flight at the test airspeed (90 knots true airspeed), altitude, and OAT using the test aircraft calibrated instruments. Data were recorded before and after the cloud immersion.

7. Level flight performance degradation due to ice accretion was assessed by comparing the engine power required to maintain constant airspeed and altitude before and after icing. Power required was corrected for fuel burn-off by using the nondimensional level flight performance carpet plot (ref 15, app A) for a standard UH-1H.

8. Engine inlet screen differential pressure was monitored during the icing flights to determine the effects of ice accretion on the inlets.

Autorotational Descent Performance

9. Autorotational descent performance was qualitatively evaluated throughout the tests at 90 knots indicated airspeed. Stabilized autorotational rotor speed data were obtained prior to cloud entry and compared to post-immersion data to determine rotor speed degradation.

Weight and Balance

10. Prior to testing, the aircraft gross weight and longitudinal center-of-gravity (cg) were determined by using calibrated scales. The longitudinal cg was calculated by a summation of moments about a reference datum line (fuselage station 0.0). Additional equipment/instrumentation installed in the aircraft was weighed and the fuselage station determined to calculate a moment. These moments and weight were then used to calculate the actual aircraft gross weight and cg.

Vibration Rating Scale

11. The Vibration Rating Scale (VRS), present in figure 1, was used to augment crew comments on aircraft vibration levels during main rotor asymmetric ice sheds.

HISS Flow Rate Calculation Method

12. Calibrated instruments aboard the HISS were used to establish airspeed, altitude, and static temperature for the required test conditions. HISS water flow rates required to establish desired LWC for each flight were determined using the following equation:

$$\mathrm{WFR} = \frac{\mathrm{LWC_D} \times V_T \times A}{1320.057611} \qquad (1)$$

Where: WFR = water flow rate (gal/min)

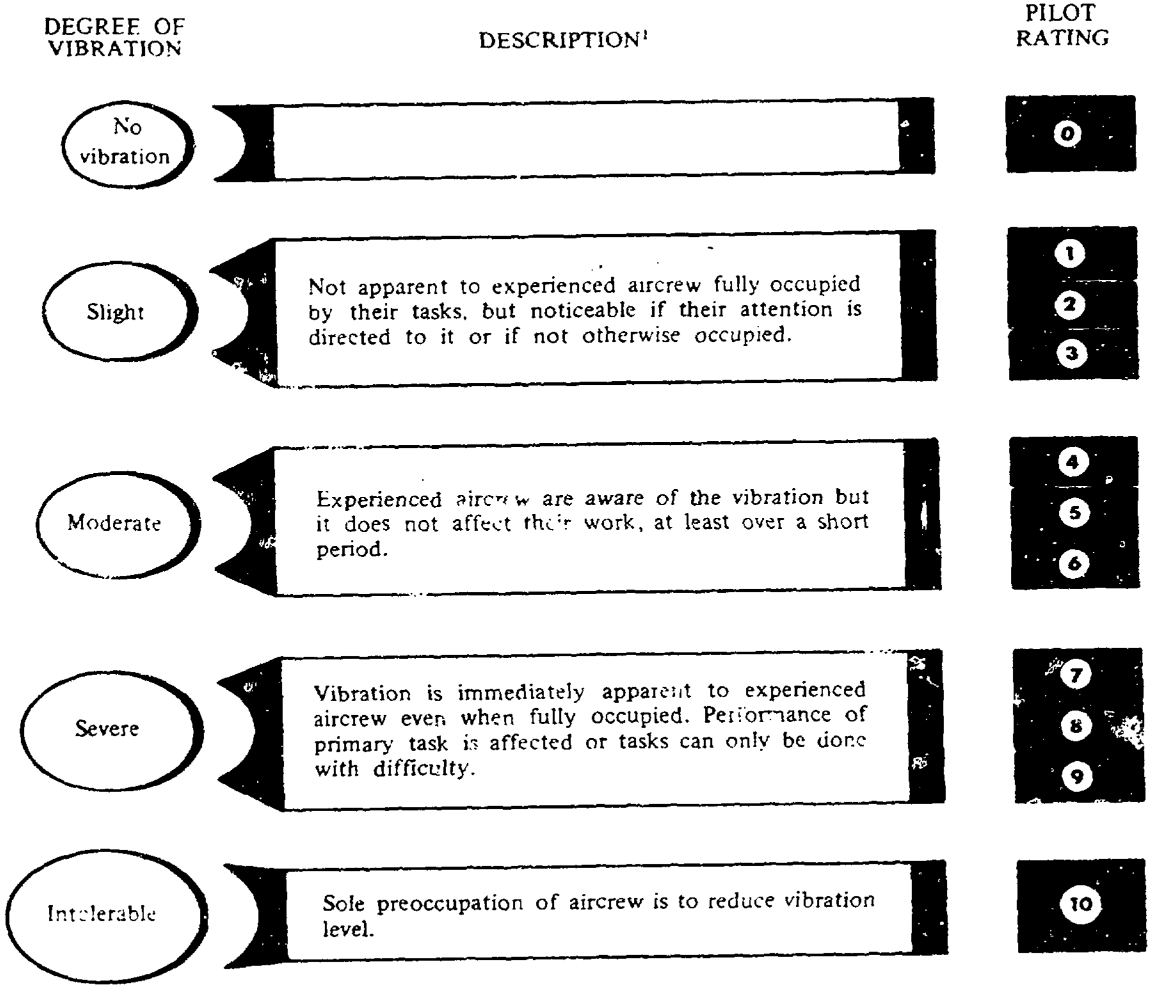
$\mathrm{LWC_D}$ = desired liquid water content (gm/m^3)

V_T = test true airspeed (knots)

A = cross-sectional area of spray cloud = 288 feet^2 (for assumed 8 feet by 36 feet cloud)

1320.057611 = conversion factor $\left(\frac{\mathrm{ft^2\text{-}gm\text{-}kt\text{-}min}}{\mathrm{m^3\text{-}gal}}\right)$

The above equation assumes no loss of liquid water through evaporation. However, based on previous cloud calibration data, it is useful for providing an average LWC over the entire cloud cross-sectional area.



DEGREE OF VIBRATION	DESCRIPTION[1]	PILOT RATING
No vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1 2 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4 5 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty.	7 8 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration level.	10

[1] Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

Figure 1. Vibration Rating Scale

MRI CALCULATION OF LWC

13. The outputs from the ASP and CPS were in terms of the number of particles in each size channel. These data were then used to calculate the LWC of each sample point by the following equation:

$$\text{LWC} = w\frac{4\pi}{3}\sum_{i=1}^{n}(D_i/2)^3 N_i \qquad (2)$$

Where: w = density of liquid water

D_i = mean diameter for the ith channel

N_i = the number of droplets in the ith channel

n = number of channels

Mass distribution is the droplet concentration weighted by the mass of the droplet of the appropriate size,

$$m_i = \frac{\pi}{6} D_i^3 \times w \qquad (3)$$

then

$$M_i = P_i \times m_i \qquad (4)$$

where

M_i = quantity plotted as droplet mass

P_i = droplet concentration

m_i = mass of droplet of size observed in channel i

APPENDIX E. TEST DATA

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Table 1. HISS Cloud Measurements[1]

Flight No	Date	Pressure Altitude (ft)	OAT (°C)	Relative Humidity (%)	Actual Flow Rate (gal/min)	Sample Start Time	Sample Length (sec)	Avg LWC (gm/m^3)	Standard Deviation of LWC	Median Volumetric Diameter (μm)	Standard Deviation of MVD
12	6 Feb 81	4700	-11.5	56	5	15:43:39	68	0.05	0.03	19	7
					10	15:41:19	22	0.06	0.03	19	5
					15	15:36:29	64	0.38	0.19	31	9
					20	14:46:24	10	0.54	0.26	39	8
13	9 Feb 81	6600	-16.5	29	5	13:32:06	26	0.27	0.09	43	16
					5	13:32:50	14	0.23	0.08	45	16
					10	13:28:43	64	0.27	0.13	35	14
					15	13:20:26	38	0.33	0.11	28	4
					20	13:23:19	63	0.83	0.32	40	17
16	2 Mar 81	3400	-11.0	75	5	16:02:09	54	0.11	0.04	19	3
					10	15:59:45	65	0.25	0.11	23	4
					15	15:57:13	59	0.44	0.20	36	16
					20	15:53:54	66	0.55	0.25	37	12
19	4 Mar 81	2360	-5	90	5	10:36:09	8	0.10	0.02	16	1
					5	10:36:20	16	0.08	0.03	16	1
					10	10:38:54	14	0.11	0.04	15	2
					10	10:39:26	13	0.08	0.02	16	3
					15	10:41:17	9	0.19	0.08	21	2
					15	10:41:31	45	0.15	0.10	19	4
					20	10:43:57	50	0.22	0.17	24	4
20	6 Mar 81	9160	-18.5	36	5	08:39:56	64	0.13	0.04	23	3
					10	08:37:04	65	0.17	0.05	28	7
					15	08:34:21	68	0.28	0.12	33	8
					20	08:31:23	70	0.28	0.17	32	11

NOTE:

[1] Data taken at 90 KTAS during stable immersions centered in the spray cloud. Measurements made with an Axially Scattering Probe and Cloud Particle Spectrometer furnished by MRI.

[2] Engineering analysis indicates low confidence in these values.

Figure 1. Vertical Variation of HISS Cloud LWC

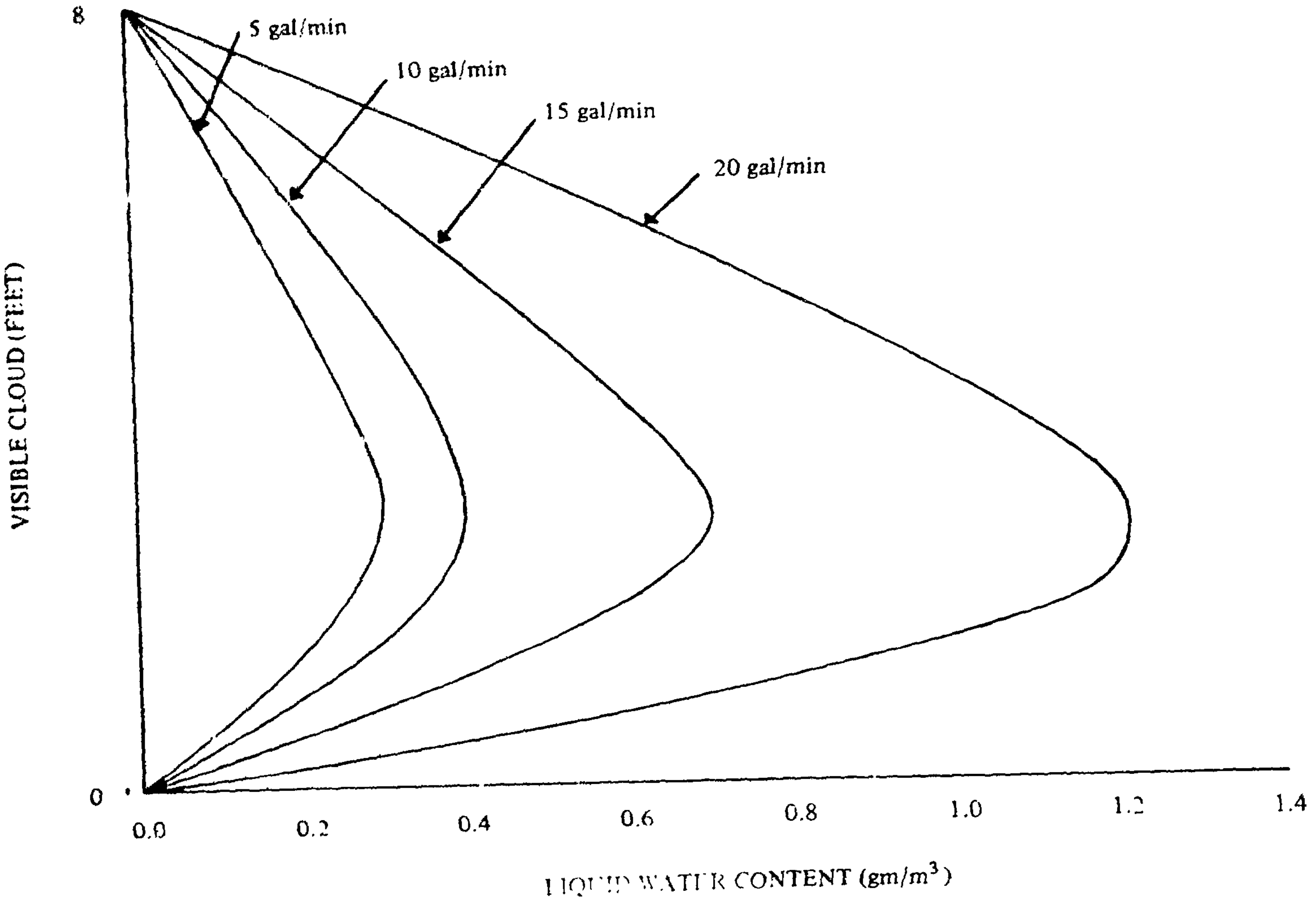
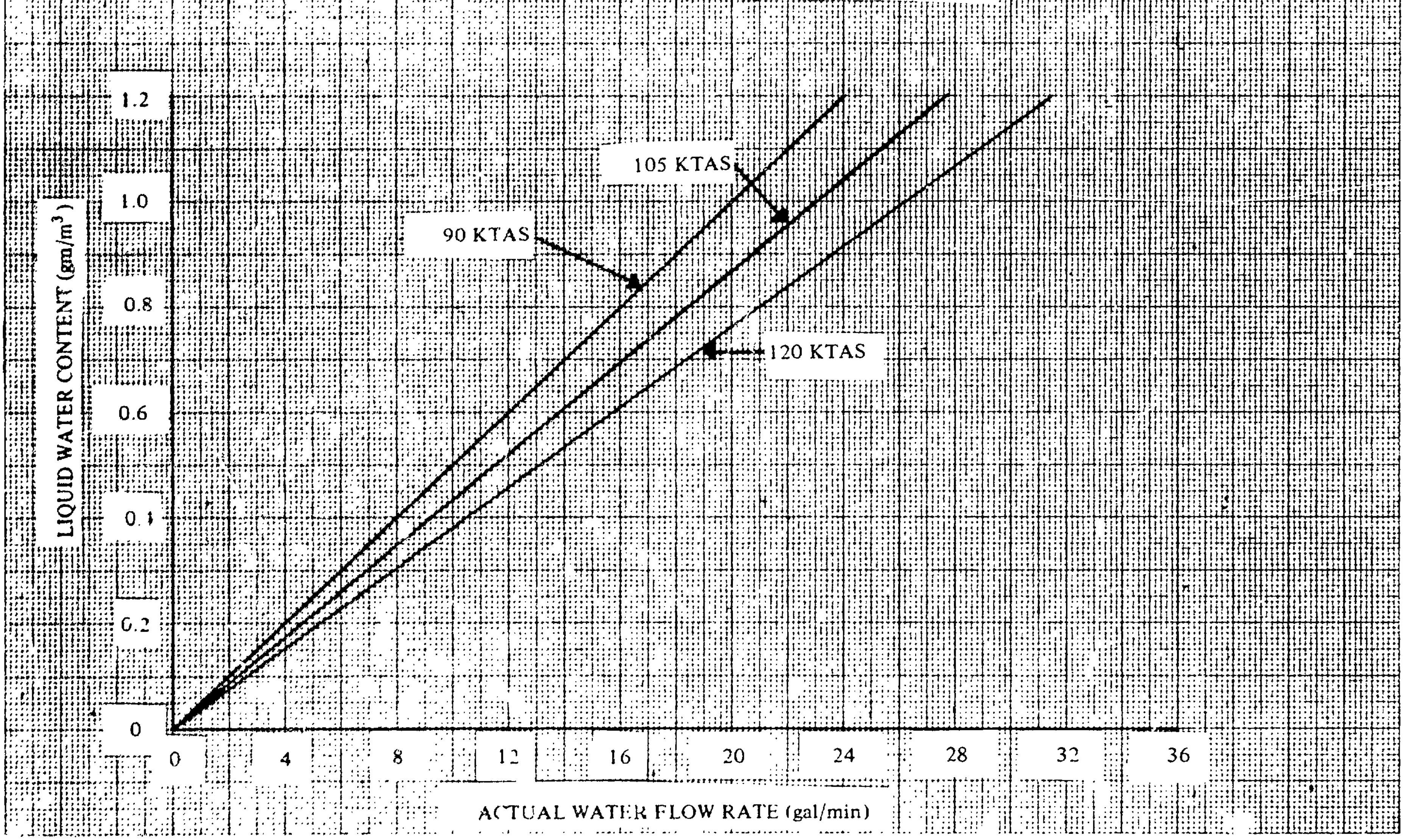


Figure 2. Calculated HISS Flow Rates for Spray Cloud LWC



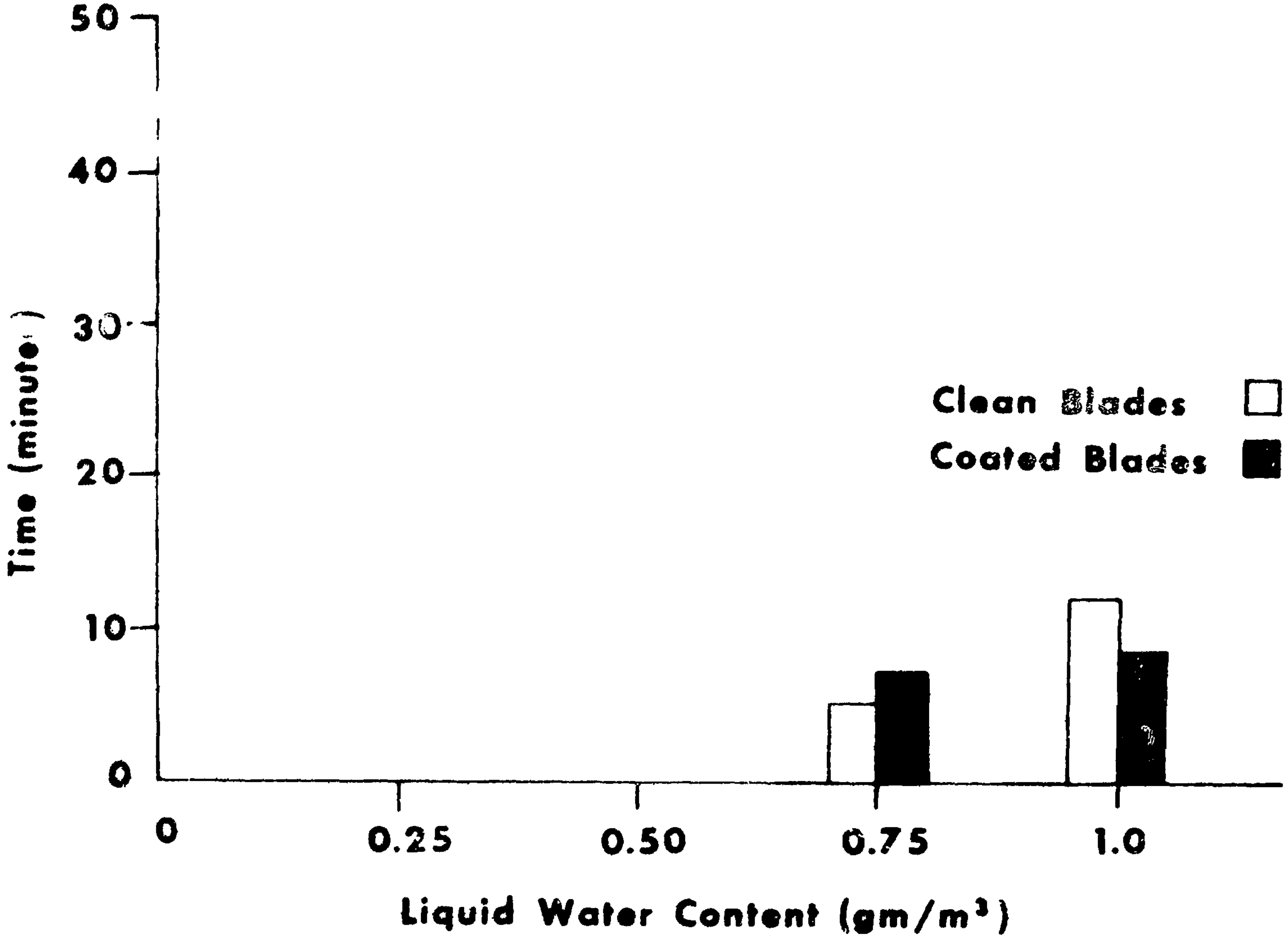


FIGURE 3. TIME TO FIRST MODERATE VIBRATION AT −5°C

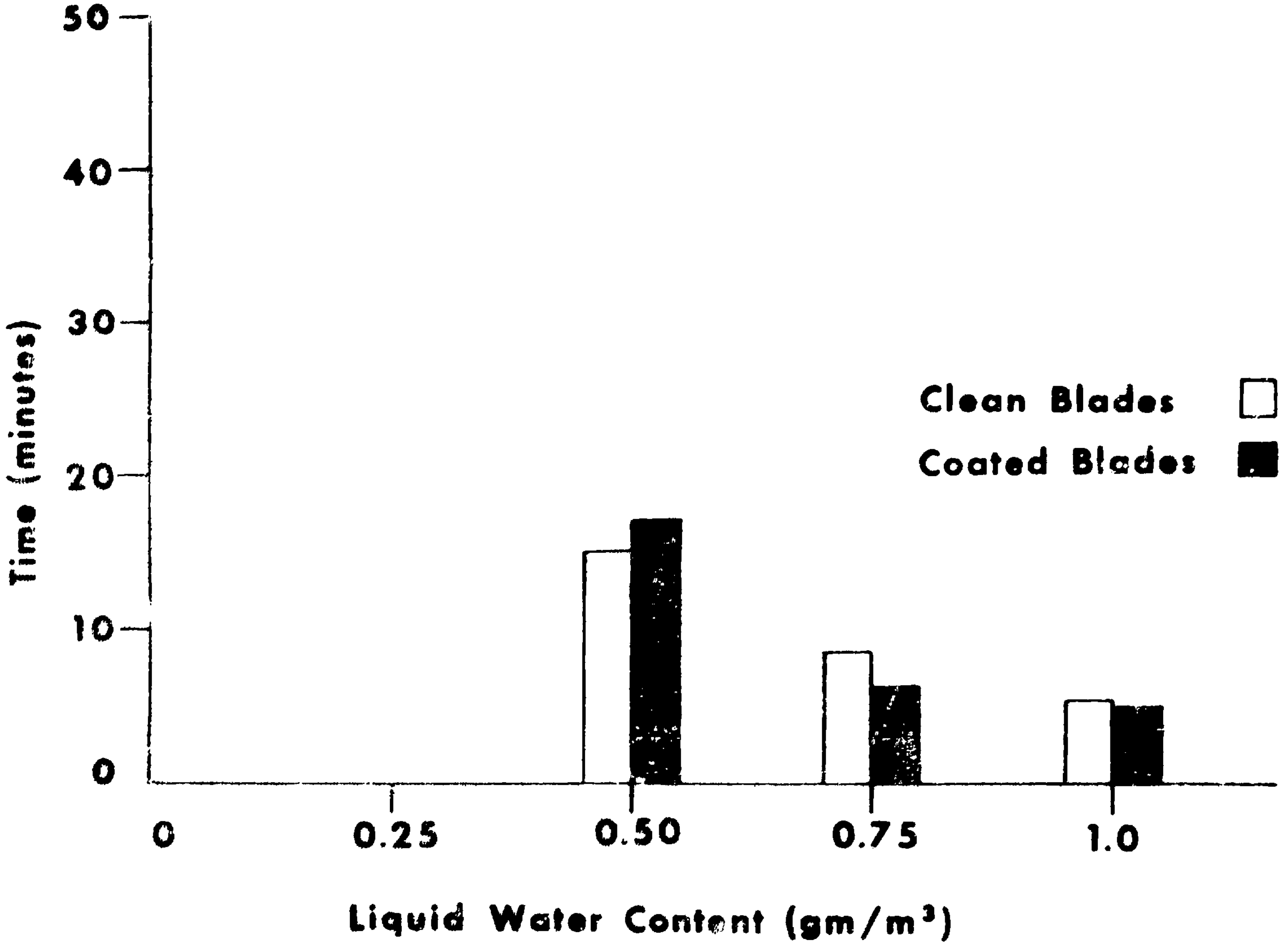


FIGURE 4. TIME TO FIRST MODERATE VIBRATION AT −10°C

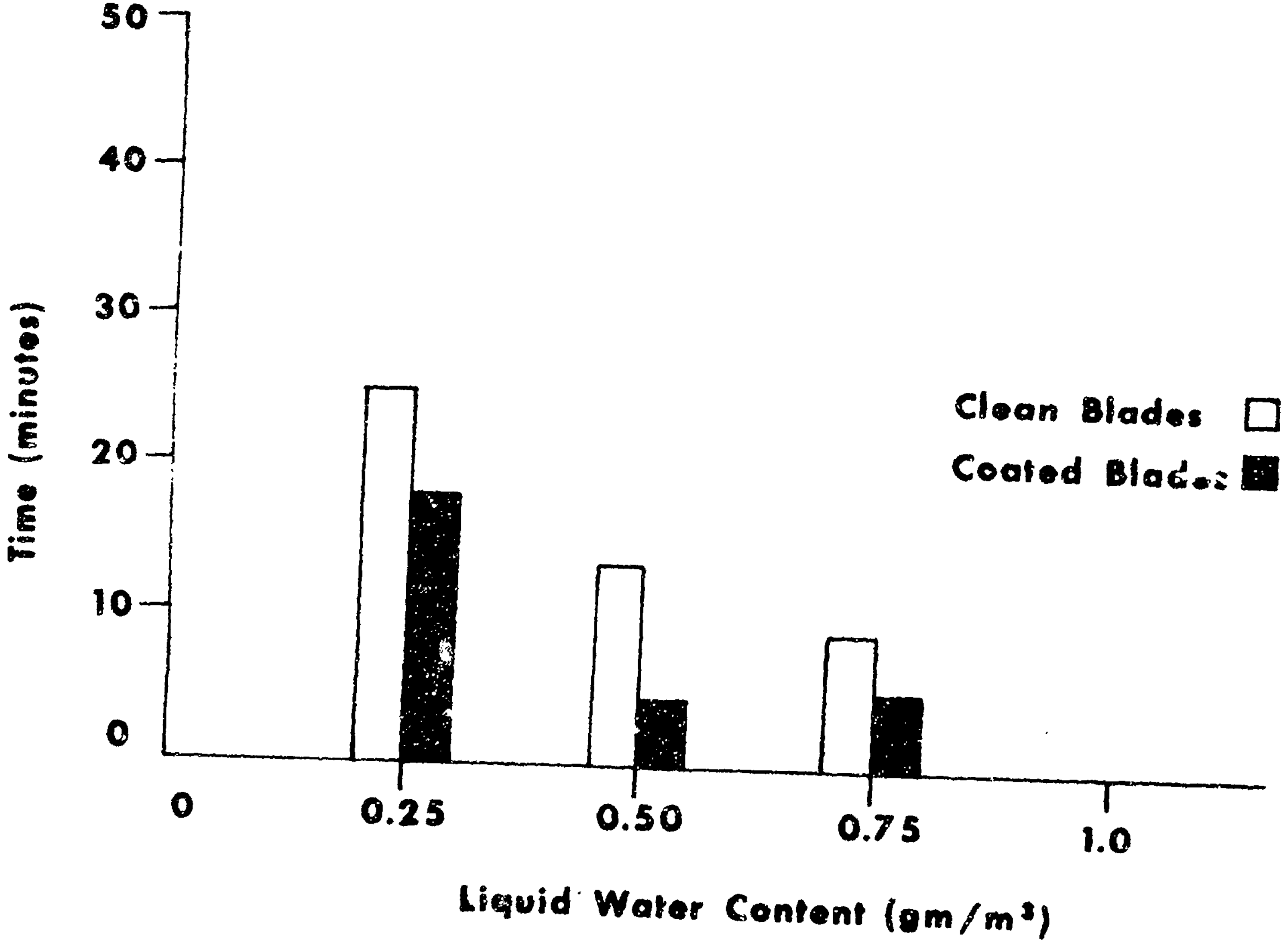


FIGURE 5. TIME TO FIRST MODERATE VIBRATION AT −15°C

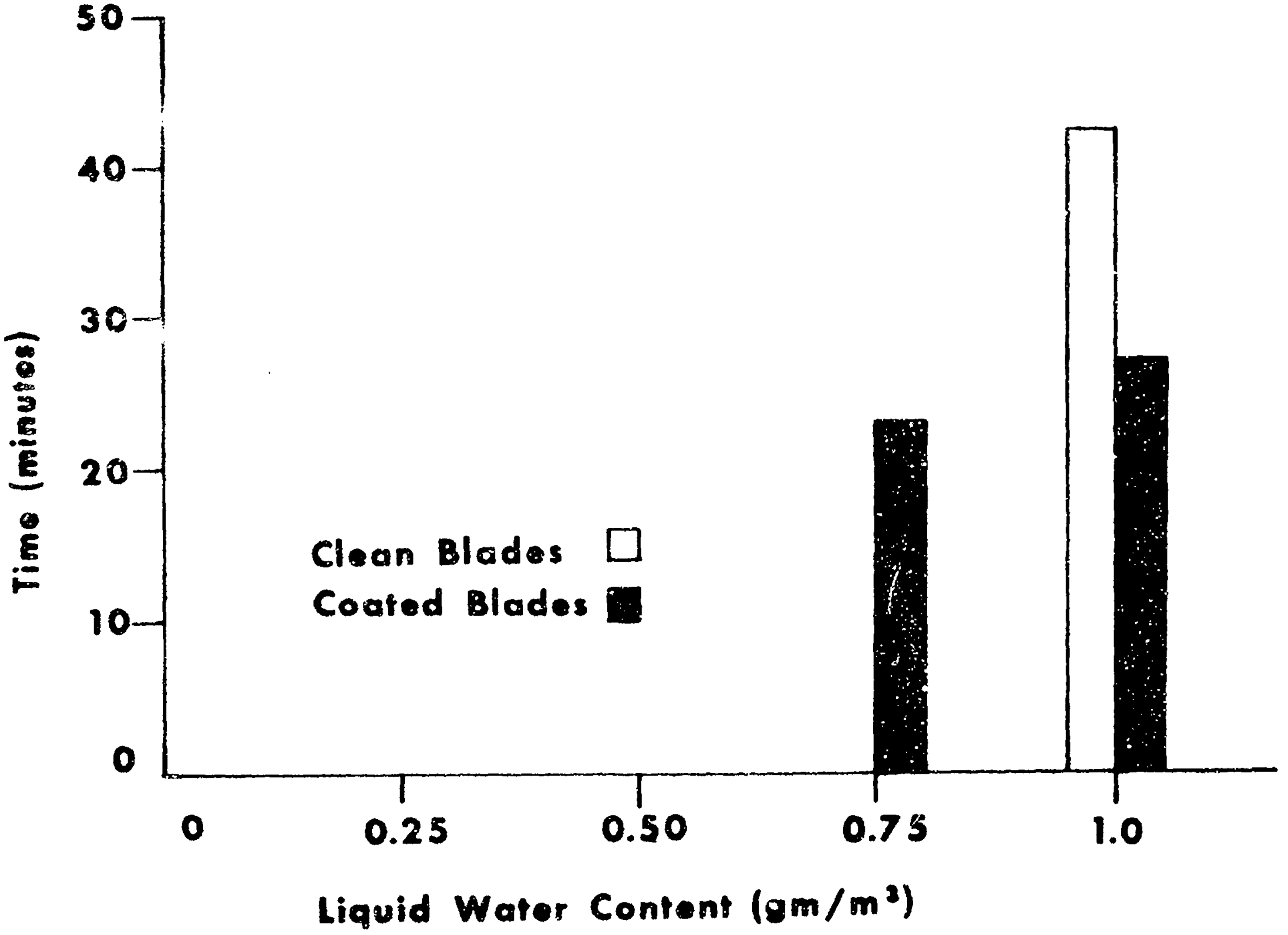


FIGURE 6. TIME TO FIRST SEVERE VIBRATION AT –5°C

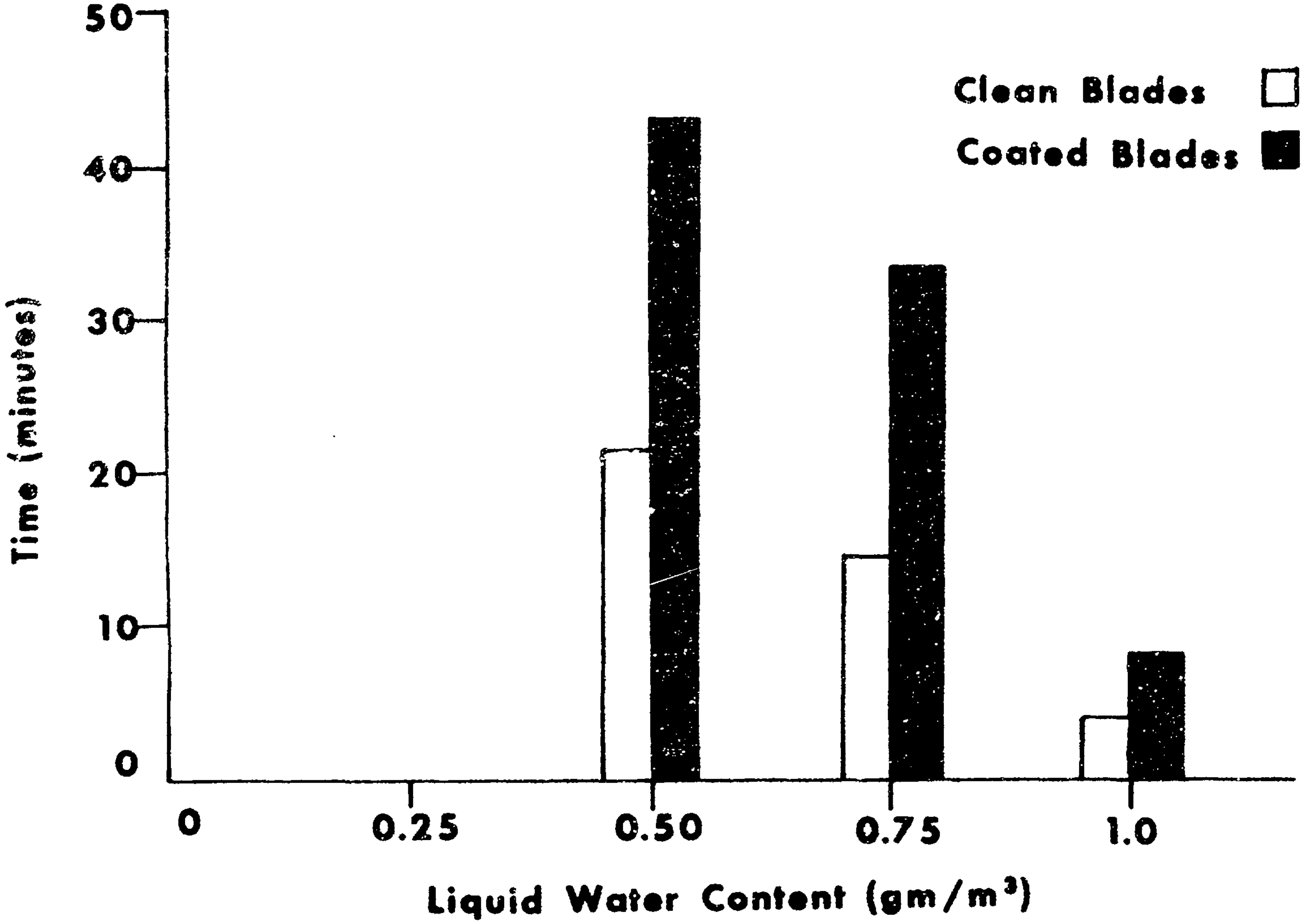


FIGURE 7. TIME TO FIRST SEVERE VIBRATION AT –10°C

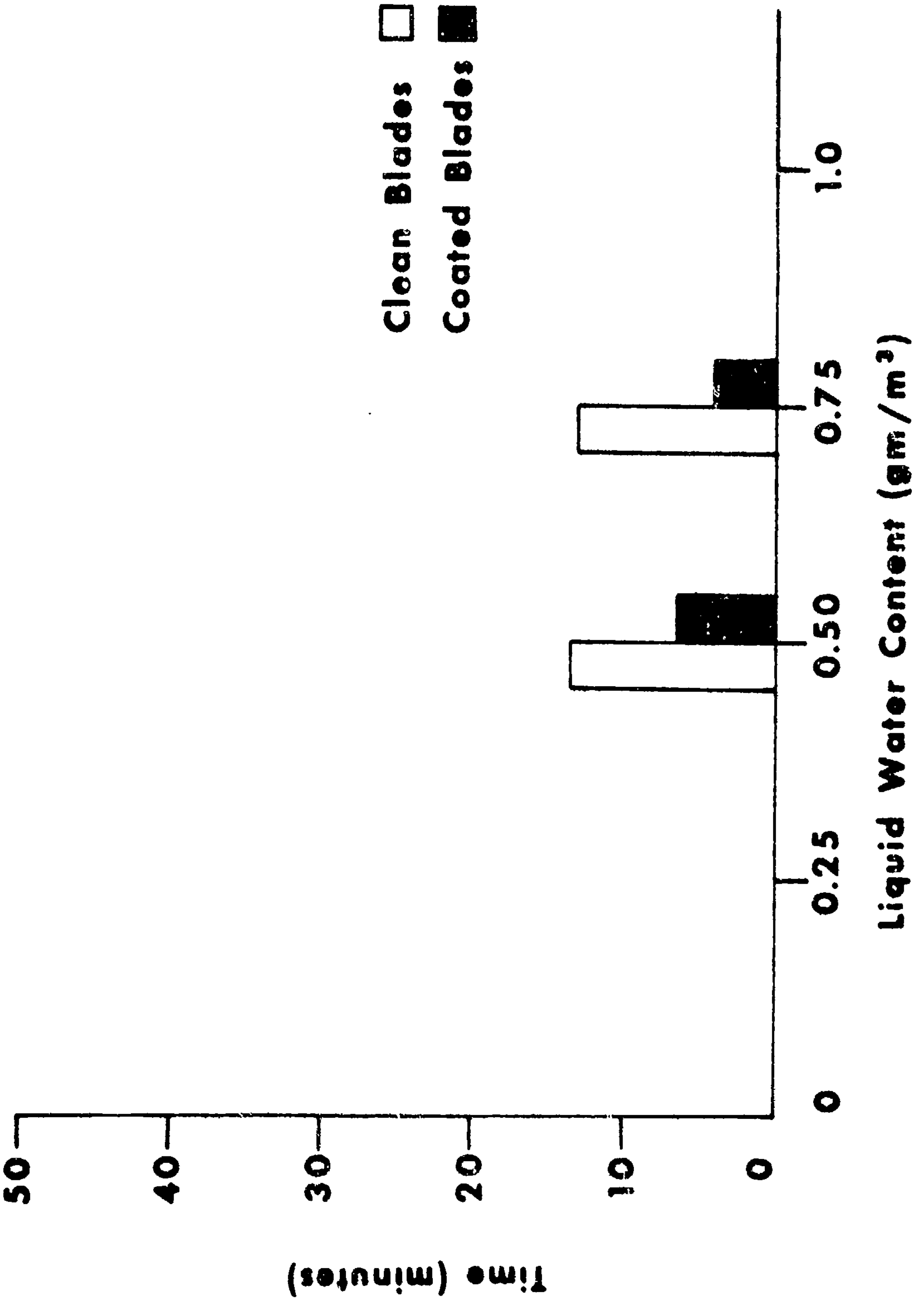
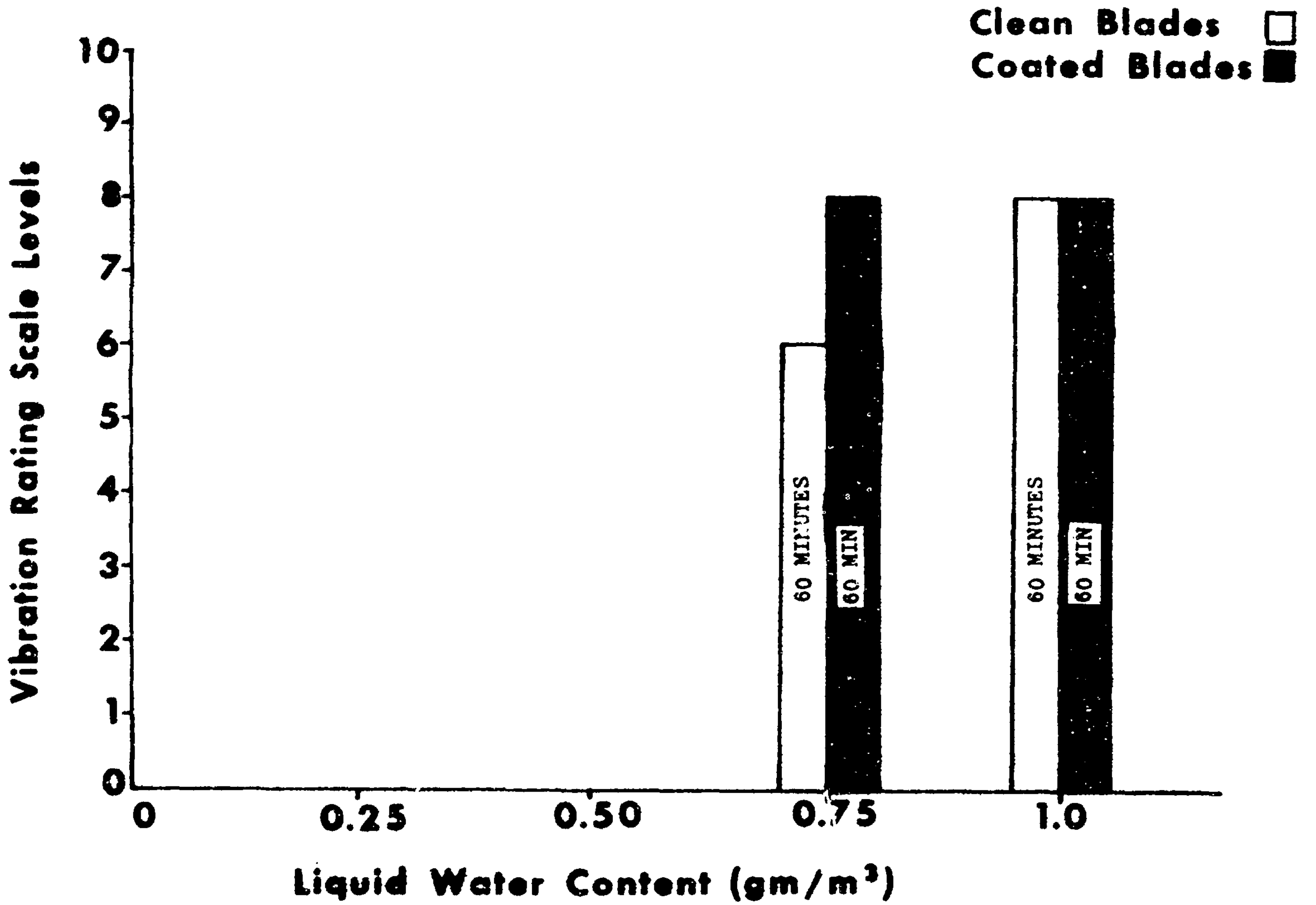
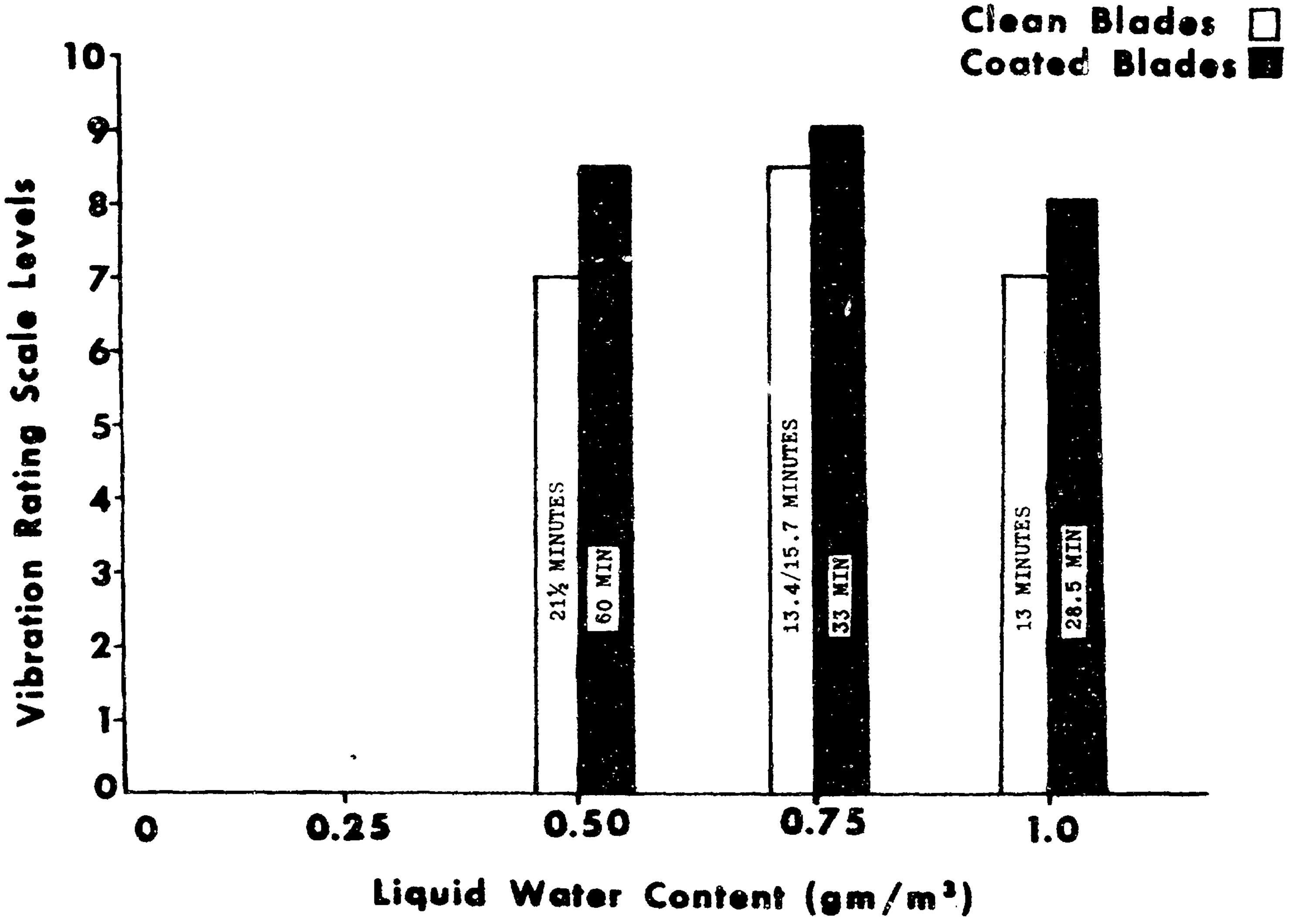


FIGURE 8. TIME TO FIRST SEVERE VIBRATION AT −15°C



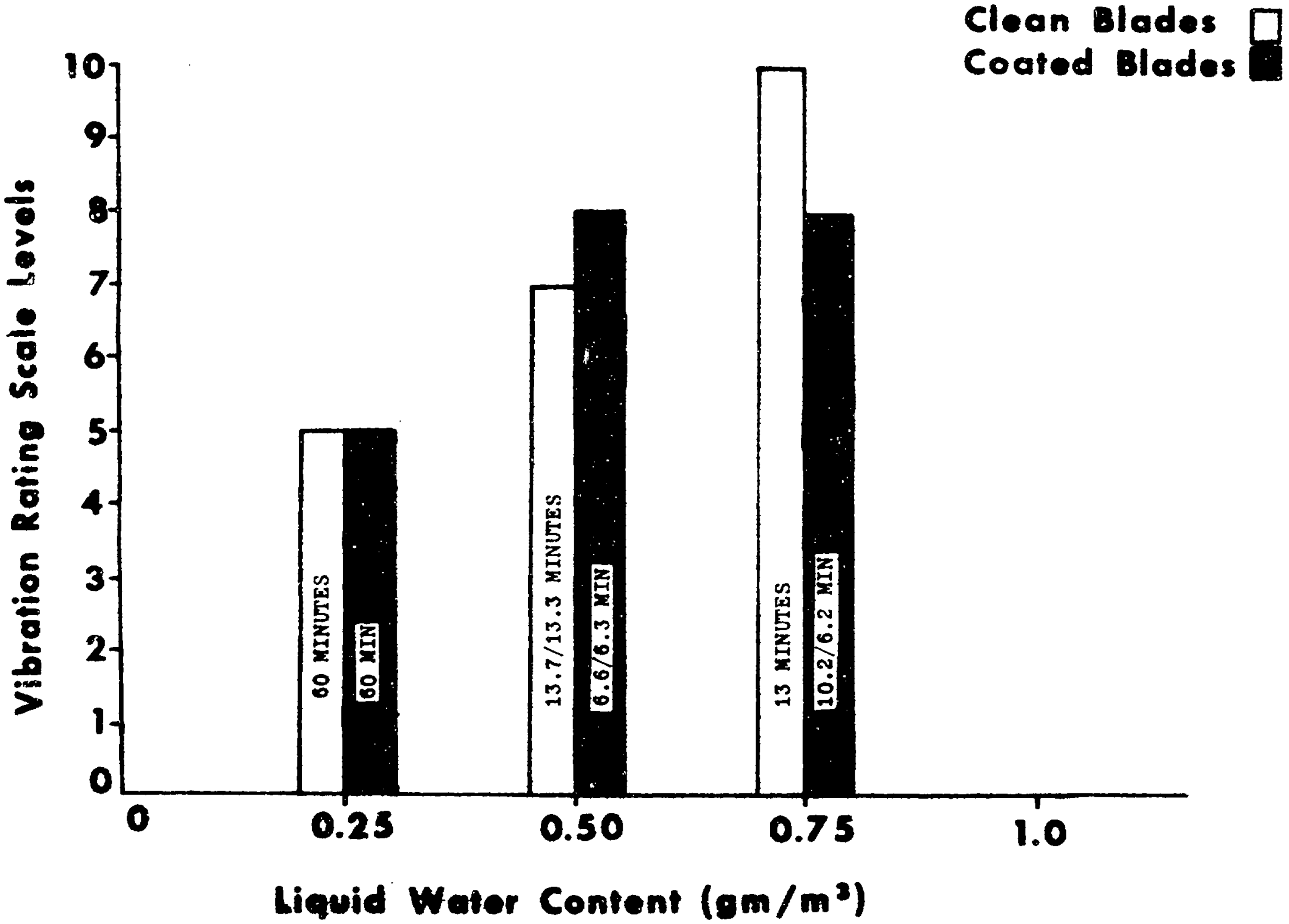
Note: Times denote immersion time to cloud exit

FIGURE 9. WORST VIBRATION LEVELS ENCOUNTERED AT —5°C



Note: Times denote immersion time to cloud exit

FIGURE 10. WORST VIBRATION LEVELS ENCOUNTERED AT −10°C



Note: Times denote immersion time to cloud exit

FIGURE 11. WORST VIBRATION LEVELS ENCOUNTERED AT −15°C

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