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ARTIFICIAL ICING TEST ICE PHOBIC COATINGS ON UH-1H HELICOPTER ROTOR BLADES

FINAL REPORT

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

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The United States Army Aviation Engineering Flight Activity conducted a limited evaluation of the General Electric G697 compound and the Dow Corning E2460-40-1 substance to determine if either was useful as an ice phobic coating on UH-1H helicopter rotor blades. Testing was conducted at Spokane, Washington, from 9 January through 8 February 1978. During the tests 23.2 flight hours were accumulated of which 6.5 hours were in the icing environment. Within the scope of this test both the G697 and the E2460-40-1 aided in shedding ice accreted

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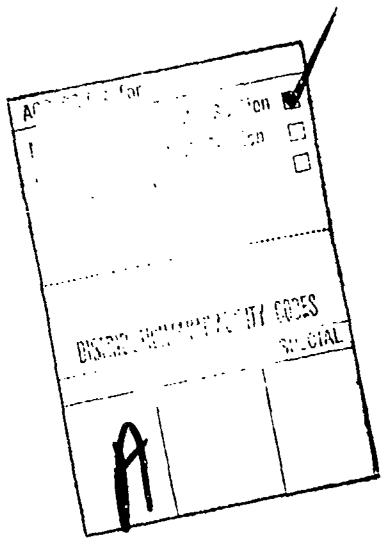
20. ABSTRACT

on the main rotor blades. A comparison between the G697 and the E2460-40-1 showed that the E2460-40-1 substance was significantly more effective and shows promise as an ice phobic coating. The E2460-40-1 aided ice shedding at -5°C and 0.5 gram per cubic meter (gm/m^3) liquid water content (LWC) and -10°C and 0.25 gm/m^3 LWC without reaching the incremental engine torque or airframe vibration test limit. It did not provide adequate protection at -15°C. Further development should be conducted to improve the ice shedding capabilities of the E2460-40-1 substance over a wider range of icing conditions.



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INTRODUCTION

BACKGOUND

1. Ice phobic coatings have been a subject of investigation for the past 20 years. Many attempts have been made to find a lightweight, inexpensive substance that can be easily applied to aerodynamic surfaces which would either prevent the formation of ice or reduce the surface adhesion force to the extent that aerodynamic and/or dynamic forces would remove the ice. Laboratory tests have indicated that silicone base compounds show promise for application on helicopter rotors, in that the ice adhesion forces are very low and the erosion properties of the coatings result in effectiveness for a useful period of time.

2. On 14 November 1977, the United States Army Aviation Research and Development Command (AVRADCOM) requested that the United States Army Aviation Engineering Flight Activity (USAAEFA) conduct icing tests of two ice phobic coatings (ref 1, app A).

TEST OBJECTIVES

3. The objectives of these artificial icing tests were:

a. Determine the ice shedding characteristics of main and tail rotor blades treated with the Dow Corning E2460-40-1 and General Electric (GE) G697 ice phobic coatings.

b. Determine the useful life of the ice phobic coatings when exposed to a supercooled liquid water environment.

c. Evaluate coating application techniques and the effect of these techniques on ice shedding characteristics and coating useful life.

d. Identify problem areas that may require additional development.

DESCRIPTION

4. The test aircraft was a standard UH-1H helicopter equipped with an electrically heated pilot windshield plus an isopropyl alcohol spray system attached to the lower edge of the pilot windshield. A detailed description of the helicopter is contained in the operator's manual (ref 2, app A). A detailed description of the electrically heated windshield and the isopropyl alcohol spray system is contained in appendix C.

5. The Dow Corning E2460-40-1 (redesignated E2978-46) ice phobic substance is a cationic silicone base oil with a viscosity comparable to that of SAE #10 oil. This substance with a proprietary composition was specifically developed by Dow Corning as an ice phobic coating. The numerical designation of this substance has been changed by Dow Corning since initial Army testing.

6. The GE G697 compound is a silicone base chemically inert grease that is used for corrosion prevention and for lubrication of unpainted threaded or nonthreaded ferrous metal surfaces. It is effective from -57 to 149°C and is a suggested rubber lubricant for low and medium swelling rubber components. The G697 compound meets military specification MIL-C-31567 requirements.

TEST SCOPE

7. The icing tests of the ice phobic substances applied to the rotor blades of the UH-1H helicopter were conducted in the vicinity of Spokane, Washington, from 9 January through 8 February 1978. A total of 19 icing test flights were conducted consisting of 23.2 hours, of which 6.5 hours were in the icing environment. Applied Technology Laboratory (ATL), Research and Technology Laboritories, AVRADCOM, Fort Eustis, Virginia, supplied the ice phobic coatings and provided technical assistance on their use. Flight restrictions and operating limitations were established by the operator's manual and modified by the airworthiness release issued by AVRADCOM (ref 3, app A). These tests were accomplished at an average gross weight of 7000 pounds, a mid center-of-gravity (cg) location of 138.0 inches, density altitudes from 6300 to 11,100 feet, 80 knots true airspeed (KTAS), and a rotor speed of 324 rpm. Icing was conducted at the test conditions contained in table 1.

TEST METHODOLOGY

8. Simulated icing flight tests of the ice phobics were conducted by flying a standard UH-1H helicopter with ice phobic protection on the main and tail rotor blades in a spray cloud generated by the JCH-47C helicopter icing spray system (HISS). A detailed description of the HISS is presented in references 4 and 5, appendix A, and in appendix B. A detailed discussion of the test sequence and procedures is contained in reference 6, appendix A, and in appendix D. Prior to entering the cloud, the test aircraft was stabilized at the predetermined test conditions and base-line trim data were recorded. The test aircraft was then immersed in the spray cloud. After each immersion the test aircraft was again stabilized outside the spray cloud at the initial trim airspeed and another data record taken. Ice accretion and shedding were documented photographically and visually. Steady-state autorotations were performed at predetermined test points to determine the effects of ice accretion on rotor speed. Immersion times were based on pilot judgment, vibrations, visual observations, HISS water supply exhaustion, engine torque rise, prior test results, and the limitations contained in the airworthiness release.

Table 1. Test Conditions.[1]

Average Gross Weight (lb)	Average Density Altitude (ft)	Average Outside Air Temperature (°C)	Total Time In Icing Cloud (min)	Programmed Liquid Water (gm/m^3)	Water Flow Rate (gpm)	Ice Phobic Material Evaluated
7000	10,200	-5.0	8	0.14	7	E-2460
6780	10,450	-5.0	28	0.14	7	E-2460
6760	10,500	-5.0	31	0.14 and 0.25	7 and 12	E-2460
6940	10,100	-5.0	20	0.25	12	E-2460
7060	8800	-15.0	13	0.14 and 0.25	7 and 12	E-2460[2]
7020	6900	-10.0	22	0.14 and 0.25	8 and 12	E-2460
6820	9000	-10.0	48	0.25	12	E-2460
6880	10,500	-10.0	27	0.14 and 0.25	7 and 12	None
6920	10,900	-10.0	27	0.25	12	None
6960	11,100	-10.0	20	0.50	24	None
6880	7500	-5.0	28	0.50	24	None[2]
6860	10,900	-10.0	32	0.25 and 0.50	12 and 24	GE 697
6830	9000	-5.0	42	0.50	24	GE 697
6850	9130	-10.0	40.5	0.50	24	E-2460
6850	6260	-5.0	48	0.50	24	E-2460
6800	9620	-10.0	60	0.25	12	E-2460

[1]Center of gravity: FS138.0 (mid range).
Rotor Speed: 324 rpm.
Trim airspeed: 80 KTAS.

[2]5 psi rise in torque observed during flight.

9. A USAAEFA-designed and fabricated visual ice accretion measuring device was used to observe the rate of ice accretion on the airframe. A detailed description of this device and the test instrumentation is provided in appendix C.

10. Test techniques and data analysis methods are presented in appendix D. A Vibration Rating Scale (VRS) and a Handling Qualities Rating Scale (HQRS) were used to augment pilot comments and are presented in appendix D. Methods used to establish liquid water content (LWC) in the test cloud are also contained in appendix D.

RESULTS AND DISCUSSION

GENERAL

11. The ice accretion and shedding characteristics and the useful life of two ice phobic coatings applied to UH-1H helicopter rotor blades were evaluated. Within the scope of this test, both the GE G697 compound and the Dow Corning E2460-40-1 substance aided in shedding ice accreted on the main rotor blades. A comparison between the G697 and the E2460-40-1 showed the E2460-40-1 substance was significantly more effective and shows promise as an ice phobic coating. The E2460-40-1 aided ice shedding at -5°C and 0.5 gram per cubic meter (gm/m^3) LWC and -10°C and 0.25 gm/m^3 LWC without reaching a test limit. More rigorous tests at colder temperatures and/or greater LWC's resulted in reaching the 5 psi test limit. Ice was not observed on the tail rotor during any of the flight tests. Further development should be conducted to improve the ice shedding capabilities of the E2460-40-1 substance over a wider range of icing conditions.

UNPROTECTED MAIN ROTOR BLADE ICE ACCRETION AND SHEDDING CHARACTERISTICS

General

12. Unprotected main rotor blade ice accretion and shedding characteristics data were recorded during 2.6 flight hours at the test conditions contained in table 1. These data were used as a base line for comparing the ice accretion and shedding characteristics data of the main rotor blades protected with ice phobic coatings. Test results are summarized in appendix E. At the time of this test, the two rotor blades had accumulated 800 and 1400 hours of flight time, respectively.

Ice Accretion and Shedding Characteristics at -5°C

13. Ice accretion and shedding characteristics of the unprotected main rotor blades were evaluated at -5°C and an LWC of 0.5 gm/m^3. Main rotor blade ice accretion was evidenced by a steady rise in engine torque as cumulative immersion time increased (table 4, app E). In-flight photographs showed ice accreted out to approximately 50 percent of the blade span with no significant asymmetry. Autorotation rotor speed was qualitatively checked after engine torque increases of 3.9 and 8.2 psi were experienced. A rotor speed degradation of 7 and 14 rpm was recorded for the respective torque increases. After 13 minutes of cumulative immersion time, frequent ice shedding occurred. This shedding was accompanied by moderate (VRS 4) one-per-rotor revolution (1/rev) lateral vibrations. These vibrations persisted less than 30 seconds and further shedding returned the aircraft to normal vibration levels. Ice was shed and struck the fuselage and windshield. The ice accreted on the main rotor blades at -5°C, required increased power for level flight, adversely affected autorotational performance, and shed randomly. These findings agree with previous icing test data (ref 7, app A).

Ice Accretion and Shedding Characteristics at -10°C

14. Ice accretion and shedding characteristics of the unprotected main rotor blades were evaluated at -10°C and an LWC of 0.5 gm/m^3. Similar to the -5°C flight, torque increased with cumulative immersion time (table 3, app E), indicating ice accretion on the main rotor blades. In-flight photographs showed ice accreted out to 69 percent of the blade span with no significant asymmetry. After 20 minutes of cumulative immersion time, an asymmetrical shed occurred. The ice shed was random and one piece struck the tail rotor. As shown in figure A, the incremental engine torque increases for the -10°C flight were smaller than those documented on the -5°C flight. These small engine torque increases did not give the pilot an adequate cue that a significant amount of ice was accreting on the main rotor blades. The first major indication of ice accretion was the asymmetrical shed which created a severe (VRS 8) 0.08g 1/rev lateral vibration. The test was terminated after the main rotor blades had the asymmetrical shed. The ice accreted on the main rotor blades at -10°C randomly shed, increased power required for level flight, caused severe lateral 1/rev vibrations, and damaged aircraft components. The findings agree with previous icing test data (ref 7, app A).

DOW CORNING ICE PHOBIC SUBSTANCE E2460-40-1 (REDESIGNATED E2978-46)

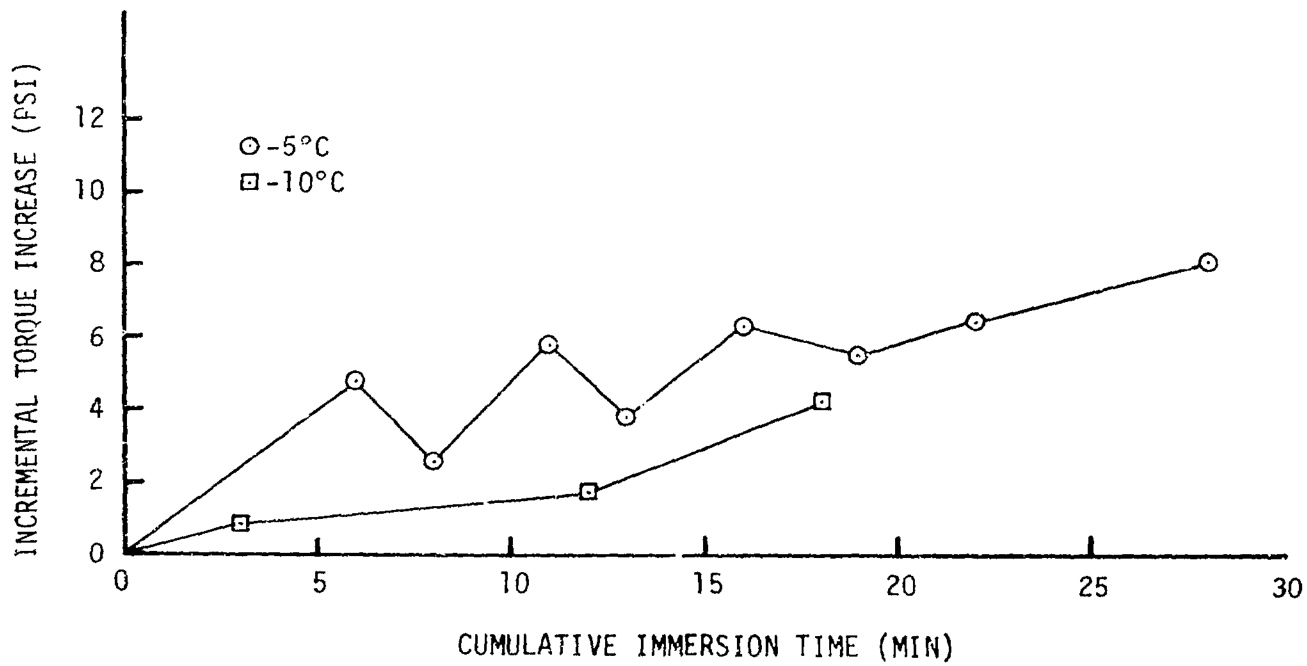
General

15. The E2460-40-1 ice phobic substance was supplied by the Dow Corning Corporation, Midland, Michigan. This substance is a cationic silicone base oil with a proprietary composition specifically developed by Dow Corning as an ice phobic coating. The substance has a viscosity comparable to that of SAE #10 oil. The E2460-40-1 substance (also referred to as E2460) was evaluated in 14.8 flight hours at the test conditions contained in table 1. The test results are summarized in appendix E. Another set of main rotor blades was used for this test and they had 1600 hours of flight time each. The E2460 aided ice shedding at -5°C and 0.5 gm/m^3 LWC and at -10°C and 0.25 gm/m^3 LWC. The E2460 shows promise as an ice phobic coating; however, further develpment should be conducted to improve the ice shedding capability of the E2460-40-1 substance over a wider range of icing conditions.

Application Technique

16. The application technique used for this substance was specified by Applied Technology Laboratory, Research and Technology Laboratories, AVRADCOM. The main and tail rotor blades were thoroughly cleaned with isopropyl alcohol prior to each application of the E2460. The main rotor blades were spray coated to 7 inches aft of the leading edge on the bottom surface and 5 inches aft of the leading edge on the top. The tail rotor blades were spray coated to 4 inches aft of the leading edge on both surfaces. The special equipment required for this technique was a Quixspray Polypropylene spray head attached to a can of Quixspray

FIGURE A
INCREMENTAL TORQUE INCREASE VS CUMULATIVE IMMERSION TIME - UNPROTECTED MAIN ROTOR BLADES



NOTE: 80 KTAS

Instant Areosol (Pierce Chemical Company, Rockford, Illinois). Personnel protective equipment required consisted of eye goggles and a vapor-proof breathing mask.

17. The applicator nozzle was held 4 to 6 inches from the rotor blade surface and the substance sprayed on with spanwise strokes. In winds greater than 10 knots, the spray was distorted and a uniform coating was not obtainable. In calm winds, even coatings were obtained easily, but the overspray caused eye irritation (para 36). The spray application technique was ineffective in winds greater than 10 knots, and generated an irritating mist. Because of limited time other application techniques were not evaluated. Future testing of the E2460-40-1 substance should include the evaluation of other application techniques.

Erosion and Flow Characteristics

18. The erosion and flow characteristics of the E2460 ice phobic substance were documented after each flight using a tape test. This test consisted of pressing a 2-inch strip of 1-inch masking tape to the rotor blade surface and qualitatively evaluating its adhesive strength. A rating was assigned to the coating in accordance with table 2.

Table 2. Adhesion Characteristics Ratings.

Rating	Properties
Excellent	(1) Blade surface oily to touch (2) Masking tape will not adhere to blade surface
Good	(1) Blade surface oily to touch (2) Masking tape has a partial adhesion to the blade surface
Poor	(1) Blade surface not oily to touch (2) Masking tape adheres to the blade surface similarly to a clean dry blade surface

19. The erosion and flow characteristics of the E2460 substance were essentially the same for all flights and figure B shows a sketch of typical patterns. After 3.9 flight hours on a single application of the E2460 substance, the erosion and flow characteristics of the inboard 70 percent of the rotor blade were rated excellent and the outboard 30 percent rated good. The coating had flowed outboard and toward the trailing edge. Within the scope of the test, the erosion and flow characteristics of the E2460 substance are acceptable.

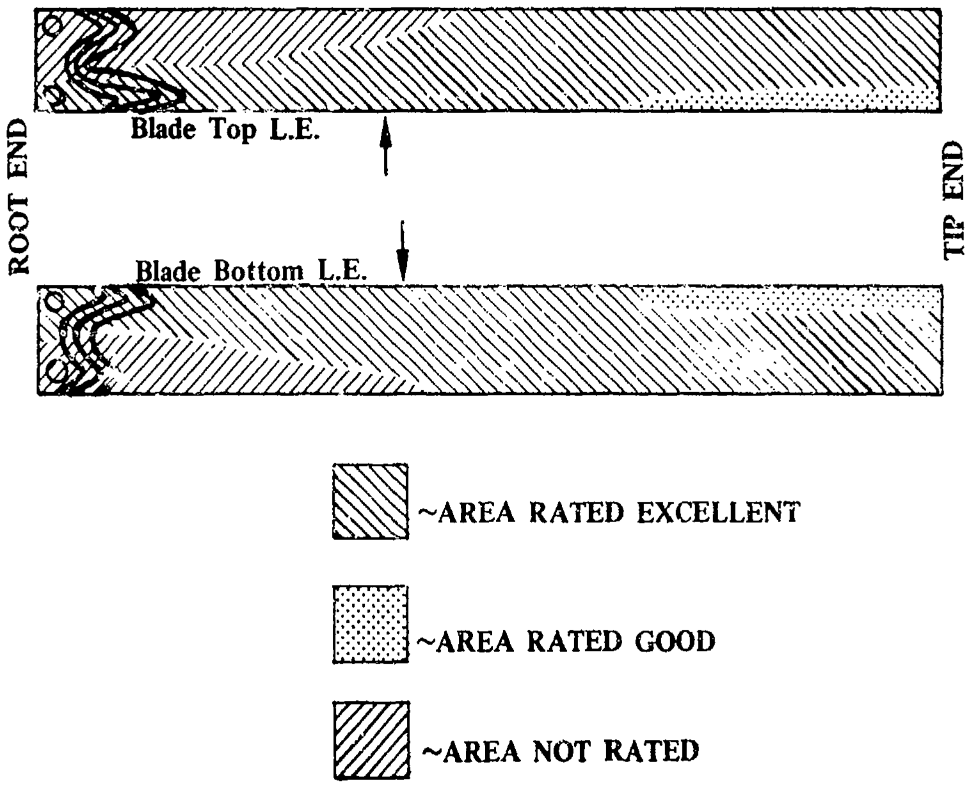


Figure B. Typical Erosion and Flow Pattern of E2460-40-1.

Ice Accretion and Shedding Characteristics at -5°C

20. The ice accretion and shedding characteristics of the main rotor blades with the E2460 substance were evaluated at -5°C during five flights resulting in 135 minutes of cumulative immersion time at LWC's from 0.14 to 0.5 gm/m^3. The maximum cumulative immersion time for a single application of E2460 was 79 minutes, which encompassed three flights. The maximum cumulative immersion time achieved during a single flight was 48 minutes at an LWC of 0.5 gm/m^3. No engine torque limits or vibration limits due to asymmetric ice shedding were noted during any of the flights. Incremental torque increases followed by decreases were typical of all flights at -5°C and indicated that ice was accreting and then shedding symmetrically since no abnormal airframe vibrations were noted. In-flight photographs of the main rotor blades showed symmetric sheds. The location of the sheds varied from 10 percent to approximately 50 percent of the blade span on both blades.

21. A comparison of the E2460 substance data at an LWC of 0.5 gm/m^3 to the same data for the unprotected blade data indicated a significant difference in total cumulative immersion time. The clean blade test was terminated at 28 minutes of immersion time due to an incremental torque increase of 8.2 psi. The E2460 substance test was terminated due to the exhaustion of the HISS water supply, at 48 minutes of immersion time with a maximum incremental torque increase of 3.7 psi.

22. The small incremental engine torque increases with periodic decreases, the absence of abnormal vibrations and the increase in cumulative immersion time indicates the E2460 coating aids in ice shedding and prevents the large accretions of ice seen during the unprotected blade test. Within the scope of this test, the ice shedding characteristics of rotor blades treated with E2460-40-1 show an improvement over that of the unprotected rotor system at -5°C.

Ice Accretion and Shedding Characteristics at -10°C

23. The ice accretion and shedding characteristics of the main rotor blades with the E2460 substance were evaluated at -10°C during three flights resulting in 130 minutes of cumulative immersion time at LWC's from 0.14 to 0.25 gm/m^3. The maximum cumulative immersion time for a single application of E2460 was 70 minutes, which encompassed two flights; the maximum cumulative immersion time achieved during a single flight was 60 minutes. No torque limits or asymmetric sheds were noted and the maximum incremental engine torque increase was 3.7 psi. Numerous small ice sheds occurred which were accompanied by short-term (1 to 2 seconds) 1/rev lateral vibrations (VRS 3). Photographs of the main rotor blades showed symmetrical shed locations ranging from 60 to 70 percent of the span. The small incremental engine torque increases followed by periodic decreases, the absence of abnormal vibrations, and the numerous observations of ice shedding indicate that rotor blades coated with the E2460 substance shed ice symmetrically prior to large accumulations of ice. Within the scope of this test, the E2460-40-1 ice phobic substance is effective in aiding symmetrical ice shedding at a temperature of -10°C and LWC's up to 0.25 gm/m^3.

24. A test was conducted at an LWC of 0.5 gm/m^3 and resulted in 40.5 minutes of cumulative immersion time. Two significant asymmetrical ice sheds occurred during this flight. The first shed occurred at 33 minutes of cumulative immersion time and caused a moderate (VRS 6) 1/rev lateral vibration of 0.05g measured at the pilot station. The increase in engine torque due to ice accretion was 2.7 psi. This vibration persisted for 4.5 minutes and was annoying to the crew; however, no difficulty was encountered in establishing an 80-KTAS level flight trim point and continued flight in instrument meteorological conditions (IMC) would be possible with minimal pilot compensation (HQRS 3). The second asymmetrical shed occurred at 40.5 minutes of cumulative immersion time and resulted in a severe (VRS 9) 1/rev lateral vibration of 0.12g measured at the pilot station. Photographs showed ice on the inboard 32 percent of one blade and the inboard 70 percent of the other. This vibration would prevent the reading of approach plates, and the writing of IFR clearances, require moderate pilot compensation (HQRS 5), and would necessitate termination of IMC flight.

25. A comparison of the E2460 substance data at an LWC of 0.5 gm/m^3 and -10°C to the same data for the unprotected blades showed a significant difference in cumulative immersion time. The clean blade test was terminated at 20 minutes of cumulative immersion time due to high 1/rev lateral vibrations caused by asymmetric ice shedding. The E2460 substance test was terminated at 40.5 minutes for the same reason. Within the scope of this test, the E2460-40-1 ice phobic coating demonstrates an increased rotor blade ice shedding capability at -10°C and an LWC of 0.5 gm/m^3.

Ice Accretion and Shedding Characteristics at -15°C

26. The ice accretion and shedding characteristics of the main rotor blades with the E2460 substance were evaluated at -15°C for 13 minutes of cumulative immersion time at an LWC of 0.25 gm/m^3. The flight was terminated due to an excessive engine torque increase. An autorotational descent showed a rotor speed degradation of 16 rpm. In-flight photographs showed ice accreted on 70 to 80 percent of the rotor blade span; however, no ice shedding was observed during the flight. The 7 psi engine torque increase in 13 minutes showed that the E2460 substance was not effective at -15°C. Within the scope of this test, the E2460-40-1 ice phobic substance did not aid ice shedding and did not provide adequate protection for a significant period of time at -15°C.

GENERAL ELECTRIC COMPOUND G697

General

27. The GE compound G697 (used as an ice phobic) was supplied by the Silicone Products Department, General Electric Company, Waterford, New York, and is a silicone grease used primarily for corrosion prevention and for lubrication. The G697 compound was evaluated during 3.1 flight hours at the test conditions

contained in table 1. Test results documenting ice accretion and shedding characteristics are summarized in appendix E. The rotor blades used for the unprotected blade testing were also used to test the G697 compound (para 12).

Application Techniques

General:

28. A mixture of ice phobic compound G697 and toluene, hereafter called G697 compound, was applied 5 inches aft of the leading edge on the top and bottom of the main rotor blades using a spray technique and a wipe technique. Both techniques used the same mix ratio (1:1) as recommended by ATL, and, prior to application, the blades were cleaned with toluene. Special equipment used for the spray technique was the Quixspray propellant system, protective eye goggles, and a vapor-proof breathing mask (para 20). A disposable paper towel was used for the wipe technique.

Spray Technique:

29. The G697 compound was sprayed on the main rotor blades using a spanwise stroke. The width of the spray was approximately 3/4 inch when the sprayhead was held approximately 6 inches from the surface. Difficulty was experienced in determining when an adequate coating had been applied because of the light reflectivity of the substance. This difficulty resulted in an increase of application time. The spray technique for applying the G697 compound requires excessive application time and critical ambient light conditions and is unsatisfactory.

Wipe Technique:

30. The G697 compound was wiped on the main rotor blades using a spanwise stroke. This technique used one paper towel and took 6 to 8 minutes to coat one blade. Each stroke left a coating approximately 1/32 inch thick and 2 inches wide. Voids in the coating were minimal and easy to identify. Within the scope of this test, the wipe technique for applying the G697 compound to the main rotor blades was satisfactory.

Erosion and Flow Characteristics

31. The erosion and flow characteristics of the G697 compound were documented after each flight using the tape test discussed in paragraph 18. These characteristics were the same on all flights and typical erosion and flow patterns are shown in figure C. After 1.5 hours of flying the inboard 40 percent of blade span was rated excellent and the outboard 60 percent rated poor (table 2). Within the scope of this test, the erosion characteristics of the G697 coating are unsatisfactory for use as an ice phobic compound.

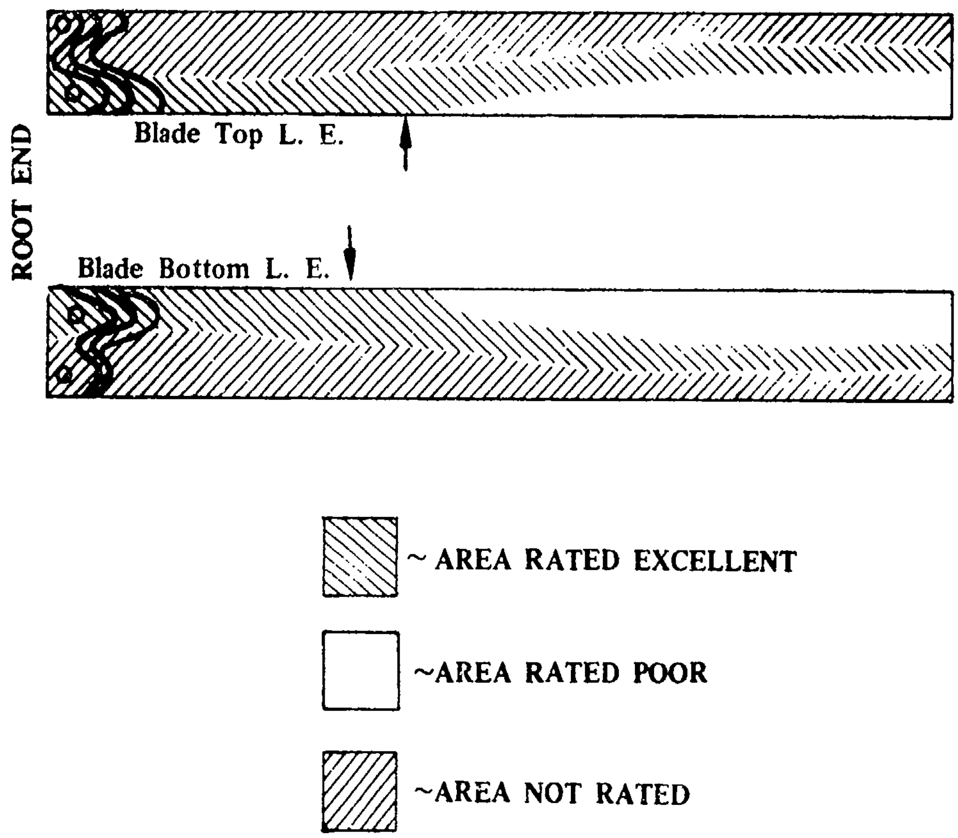


Figure C. Typical Erosion and Flow Pattern of G697.

Ice Accretion and Shedding Characteristics at -5°C

32. Ice accretion and shedding characteristics of the main rotor blades with the G697 compound were evaluated at -5°C and an LWC of 0.5 gm/m^3 during a cumulative time of 42 minutes in the spray cloud. The evaluation consisted of 14 3-minute immersions with data recorded in stabilized flight between immersions. Level flight trim power required increased with cumulative immersion time and periodic decreases were noted, indicating ice shedding. After 7 minutes of cumulative immersion time, frequent ice shedding occurred. Initially the ice shedding was symmetrical; however, after 12 minutes of cumulative immersion time, repeated 1/rev moderate lateral vibrations (VRS 4) were noted, indicating asymmetric ice shedding. The vibrations lasted less than 15 seconds and further shedding returned the aircraft to normal vibration levels. Ice was shed at random azimuths. Testing was terminated at 42 minutes of cumulative immersion time due to the exhaustion of the HISS water supply.

33. A comparison of the G697 compound data at an LWC of 0.5 gm/m^3 to the same data for the unprotected blades shows a 14-minute increase in cumulative immersion time. Similar incremental engine torque increases were noted and both tests exceeded the 5 psi test incremental engine torque limit. Within the scope of this test, the G697 compound demonstrated an increased rotor blade ice shedding capability at -5°C but does not provide adequate protection.

Ice Accretion and Shedding Characteristics at -10°C

34. Ice accretion and shedding characteristics of the main rotor blades with the G697 compound were evaluated at -10°C and LWC's of 0.25 and 0.5 gm/m^3 during a cumulative total of 32 minutes in the spray cloud. The evaluation consisted of 2 4-minute immersions at an LWC of 0.25 gm/m^3 and 8 3-minute immersions at an LWC of 0.5 gm/m^3. After 17 minutes of cumulative immersion time, periodic ice shedding was observed. At 29 minutes of cumulative immersion time, a moderate (VRS 4) 1/rev lateral vibration occurred. Photographs showed ice accretion to 38 percent of blade span on one blade and 57 percent of blade span on the other. The vibration remained constant for 3 minutes and then increased to a severe (VRS 7) 1/rev lateral vibration (0.07g measured at the pilot station) which caused termination of the flight.

35. A comparison of the G697 compound data at an LWC of 0.5 gm/m^3 to the same data for the unprotected blades shows a 12-minute increase in culululative immersion time. Similar incremental torque increases were noted and both tests were terminated due to severe vibrations. Within the scope of this test, the G697 compound demonstrated an increased rotor blade ice shedding capability at -10°C and an LWC of 0.5 gm/m^3 but does not provide adequate protection.

HUMAN FACTORS

36. Personnel applying the E2460 coating with no protective equipment experienced eye and throat irritation. On subsequent applications, personnel wore

clear unvented protective eye goggles and a vapor-proof breathing mask to prevent these irritations. The protective mask that proved qualitatively effective during spray applications was a model AR700 with an R21 chemical cartridge and was manufactured by the Wilson Products Division, ESB Incorporated, of Reading, Pennsylvania. Within the scope of this test, it was determined that the E2460-40-1 substance caused personnel discomfort and required the use of protective equipment. Further testing should be conducted to identify and eliminate the characteristics of the E2460-40-1 substance that caused personnel discomfort.

CONCLUSIONS

GENERAL

37. A comparison between the G697 compound and the E2460-40-1 substance showed the E2460-40-1 substance was significantly more effective and shows promise as an ice phobic coating. Ice was not observed on the tail rotor during any of the flight tests (para 11).

SPECIFIC

38. The following specific conclusions pertaining to E2460-40-1 were determined:

a. The spray application technique is ineffective in winds greater than 10 knots and generates an irritating mist (para 17).

b. The erosion and flow characteristics are acceptable (para 19).

c. The ice shedding characteristics show an improvement over that of the unprotected rotor system at -5°C (para 22).

d. It is effective in aiding symmetrical ice shedding at 10°C and LWC's up to 0.25 gm/m^3 (para 23).

e. It demonstrated an increased rotor blade ice shedding capability at -10°C and an LWC of 0.5 gm/m^3 (para 25).

f. It did not aid ice shedding and did not provide adequate protection for a significant period of time at -15°C (para 26).

g. It caused personnel discomfort and required the use of protective equipment (para 36).

39. The following specific conclusions pertaining to G697 were determined.

a. The spray technique required excessive application time and critical ambient light conditions and was unsatisfactory (para 30).

b. The wipe technique was satisfactory (para 30).

c. The erosion characteristics are considered unsatisfactory for use as an ice phobic compound (para 31).

d. It demonstrates an increased rotor blade ice shedding capability at -5°C but does not provide adequate protection (para 33).

e. It demonstrates an increased rotor blade ice shedding capability at -10°C and an LWC of 0.5 gm/m^3 but does not provide adequate protection (para 35).

RECOMMENDATIONS

40. Further development should be conducted to improve the ice shedding capabilities of the E2460-40-1 substance over a wider range of icing conditions (para 15).

41. Future testing of the E2460-40-1 substance should include the evaluation of the other application techniques (para 17).

42. Further testing should be conducted to identify and eliminate the characteristics of the E2460-40-1 substance that caused personnel discomfort (para 36).

APPENDIX A. REFERENCES

1. Letter, AVRADCOM, DRDAV-EQI, 14 November 1977, subject: Simulated Icing Flight Test of Ice Phobic Coatings, AVRADCOM/AEFA Test Request. Project No. 77-30.

2. Technical Manual, TM 55-1520-210-10, *Operator's Manual, Army Model UH-1D/H Helicopters*, 25 August 1971, with Change 18.

3. Letter, AVRADCOM, DRDAV-EQ, 29 December 1977, subject: Airworthiness Release for Ice Phobic Coating Evaluation Flight Test.

4. Handbook, All American Engineering Company, SM280B, *Installation, Operation, and Maintenance Instructions, with List of Parts, Helicopter Icing Spray System (HISS)*, 12 November 1973, revised 15 July 1976.

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

6. Test Plan, USAAEFA, Project No. 77-30, *Artificial Icing Tests, Ice-Phobic Coatings on UH-1H Helicopter*, December 1977.

7. Final Report, USAAEFA, Project No. 73-04-4, *Artificial Icing Tests, UH-1H Helicopter, Part 1*, January 1974.

8. Technical Report, Environment Research and Technology, Inc., *Characteristics of a Spray Plume*, April 1976.

9. Final Report, US Army Aviation Systems Test Activity, Project No. 73-04-4, *Artificial Icing Test, UH-1H Helicopters, Part II, Heated Glass Windshield*, January 1974.

10. Final Report, USAAEFA, Project No. 66-04, *Engineering Flight Test, YUH-1H Helicopter, Phase D*, November 1970.

APPENDIX B. DESCRIPTION

HELICOPTER ICING SPRAY SYSTEM DESCRIPTION

1. The HISS is carried on a CH-47C aircraft. The icing spray system equipment consists of a spray boom, boom supports, boom hydraulic actuators, an 1800-gallon unpressurized water tank, and operator control equipment (fig. 1). The spray boom consists of two 27-foot center sections and two 16.5-foot outer sections. The total weight of the system is approximately 4700 pounds empty. With the boom fully extended, the upper center section is located in a horizontal plane 17 feet below the aircraft and the lower center section 20 feet below. The booms are jettisonable and the water supply (1800 gallons) can be dumped in approximately 10 seconds with the boom in any position. A total of 172 nozzle locations are provided on the spray boom. During these tests, nozzles were installed at 39 of these locations, as shown in figure 2. A bleed air supply from the aircraft engines is used to atomize the water at the nozzles. For a more detailed description of the icing spray system, see reference 3, appendix A.

2. The LWC and water droplet size distribution of the spray cloud are controlled by varying the water flow rate and the distance of the test aircraft behind the spray aircraft. Controls and indicators for the water flow rate and bleed air pressure are located on the water supply tank. The methods used to establish the desired LWC are presented in appendix D. A detailed description of the spray cloud characteristics is contained in reference 8, appendix A.

TEST HELICOPTER DESCRIPTION

General

3. The test aircraft, a UH-1H utility helicopter, serial number 67-17145, was manufactured by Bell Helicopter Textron. A detailed description of the UH-1H may be found in the operator's manual. Special equipment installed on the airframe to assist in the evaluation included pilot heated glass windshield, an ice accretion indicator probe (visual probe) mounted on the cabin roof above the pilot overhead plexiglass panel, a heated total-temperature probe located 4 inches aft of the copilot chin bubble, and a windshield isopropyl alcohol spray system attached to the lower edge of the pilot windshield. A bracket was also added to the FM antennae mount in order to rotate the FM antennae an additional 15-degree away from the plane of rotation of the tail rotor.

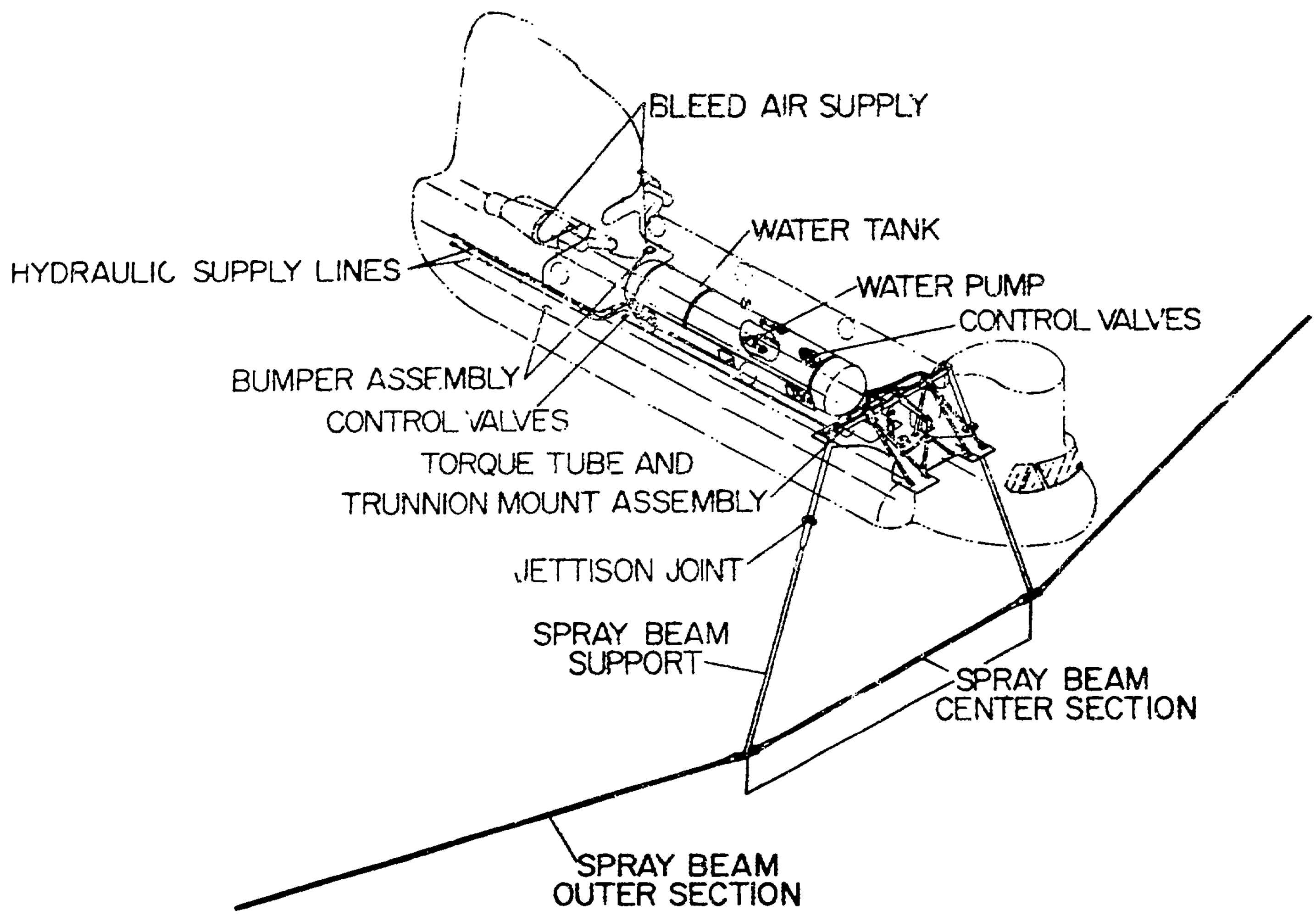


Figure 1. Helicopter Icing Spray System Schematic.

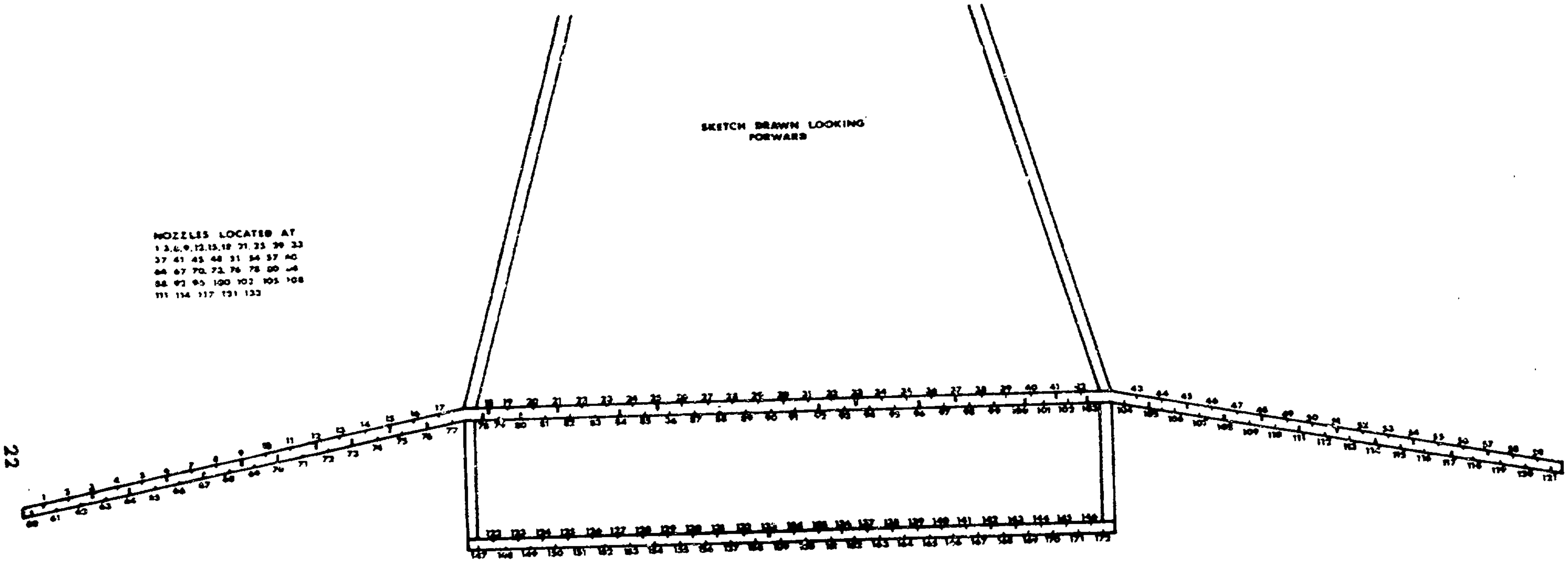


Figure 2. Hiss Nozzle Locations.

APPENDIX C. INSTRUMENTATION AND SPECIAL EQUIPMENT

INSTRUMENTATION

1. Instrumentation was installed in the test aircraft by USAAEFA personnel prior to the start of the icing test program and is shown in photo 1. Calibrated test indicators were installed in place of and in addition to normal cockpit flight indicators. Special test instrumentation was located in the cockpit to monitor the following parameters:

Pilot Panel

Airspeed
Altitude

Copilot/Engineer Panel

Airspeed
Altitude
Rotor speed
Engine torque pressure
Outside air temperature

2. An FM data recording system was used to record the following:

Pilot collective control position
Engine torque pressure
Pilot station vibration - triaxial accelerometer (WL 22, BL 22, FS 50)
Copilot station vibration - triaxial accelerometer (WL 22, BL 22, FS 50)
Aircraft cg vibration - triaxial accelerometer (WL 22, BL 0, FS 131)

3. The following parameters were hand-recorded from test instrumentation installed in the CH-47C spray aircraft:

Airspeed
Altitude
Outside air temperature
Dew point
Water flow rate (spray system)
Bleed air pressure (to the spray system)
Test aircraft separation distance from aircraft

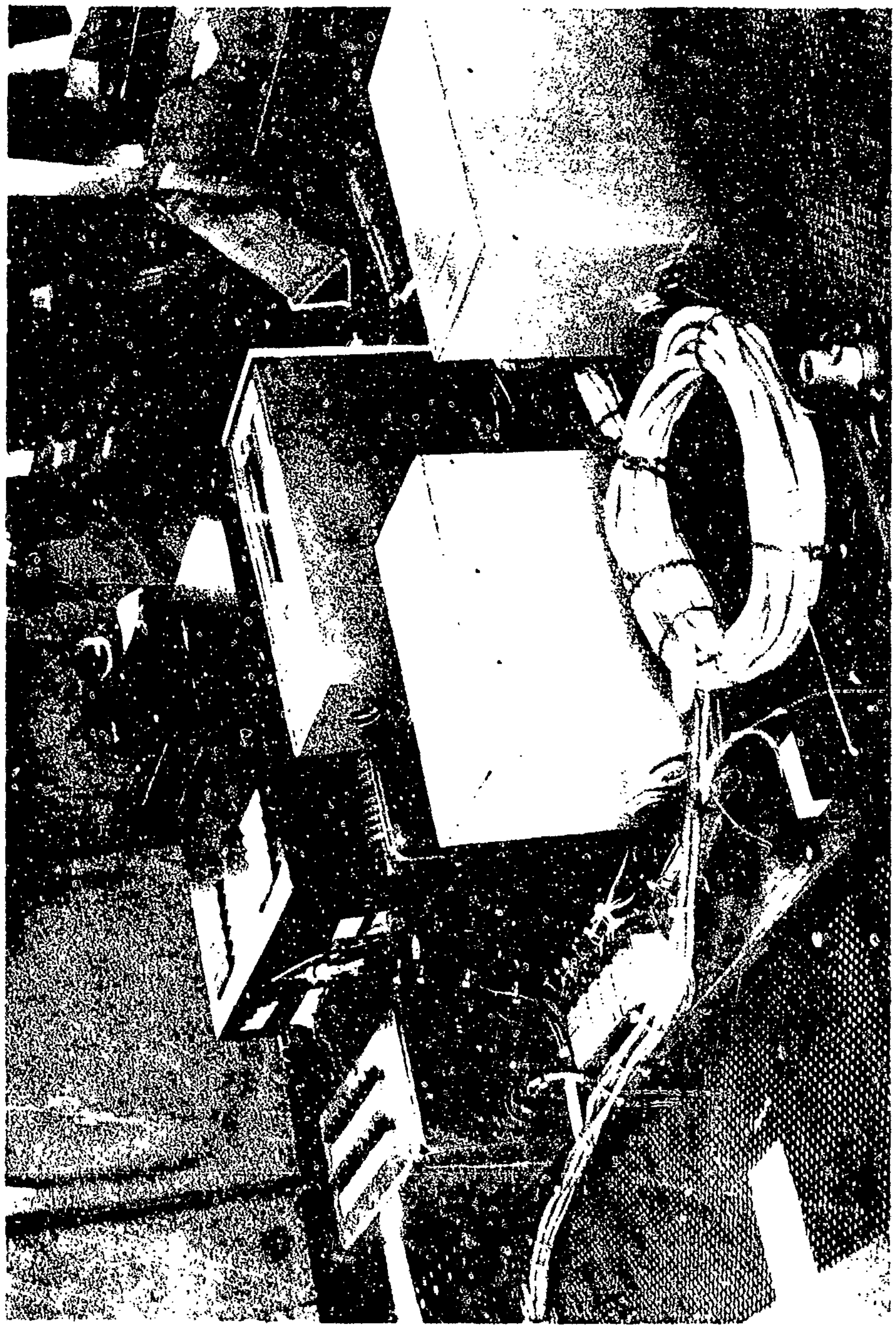


Photo 1. Instrumentation Package.

SPECIAL EQUIPMENT

Windshield Anti-Ice System

4. Windshield anti-icing on the pilot side (right side) of the test helicopter was accomplished using an alcohol spray system in conjunction with an electrically heated section of the windshield. The heated glass windshield was manufactured by Pittsburgh Plate Glass (PPG) Industries. Heating elements were provided to deice a viewing area of approximately 10 x 34 inches in the center of the windshield. A detailed description of the heated windshield system is contained in reference 9, appendix A. The alcohol spray system consisted of a 5-gallon tank, a 28VDC electric pump, flexible hose (photo 2) and an aluminum emitter tube with 0.024-inch diameter holes every 2 inches along the 20-inch inboard span of the tube. The outboard 17 inches of the tube had no holes. Alcohol was pumped to the emitter tube which was mounted to the lower pilot windshield frame (photo 3). Fluid flow was adjustable in flight.

Ice Accretion Indicator Probe

5. An ice accretion indicator probe (photo 4) was designed, fabricated, and mounted on the test aircraft by USAAEFA personnel and was used to give the pilot a visual cue to ice buildup on the the helicopter. It was composed of a small symmetrical airfoil (OH-6A tail rotor blade section) with a 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 1/4-inch wide black and white stripes to provide a reference for ice thickness estimation. The unit was mounted 13 inches above the top window on the pilot side facing forward and was visible to the pilot throughout testing.

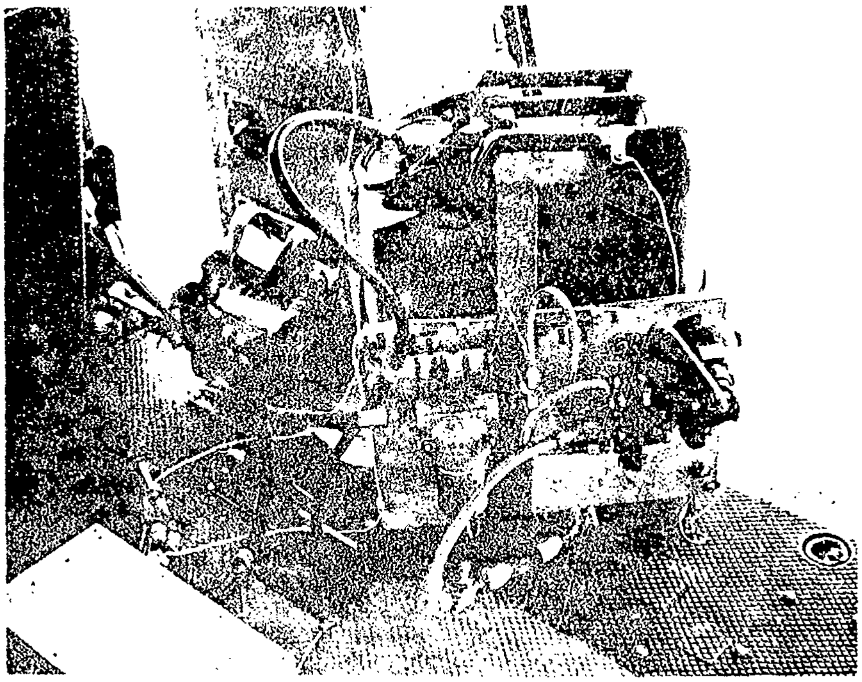


Photo 2. Windshield Anti-Ice System.

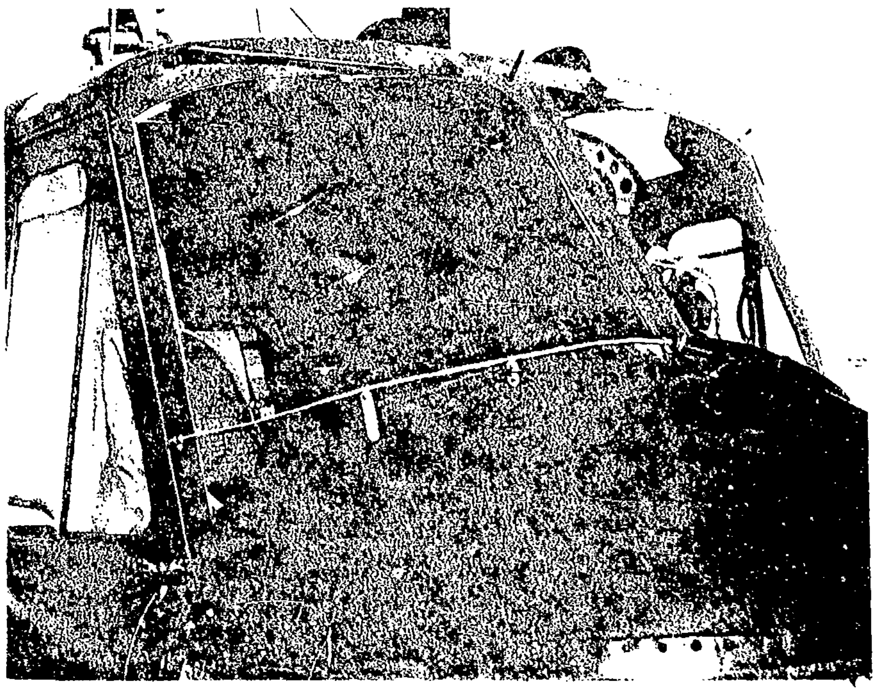


Photo 3. Windshield Anti-Ice Dispensing System.

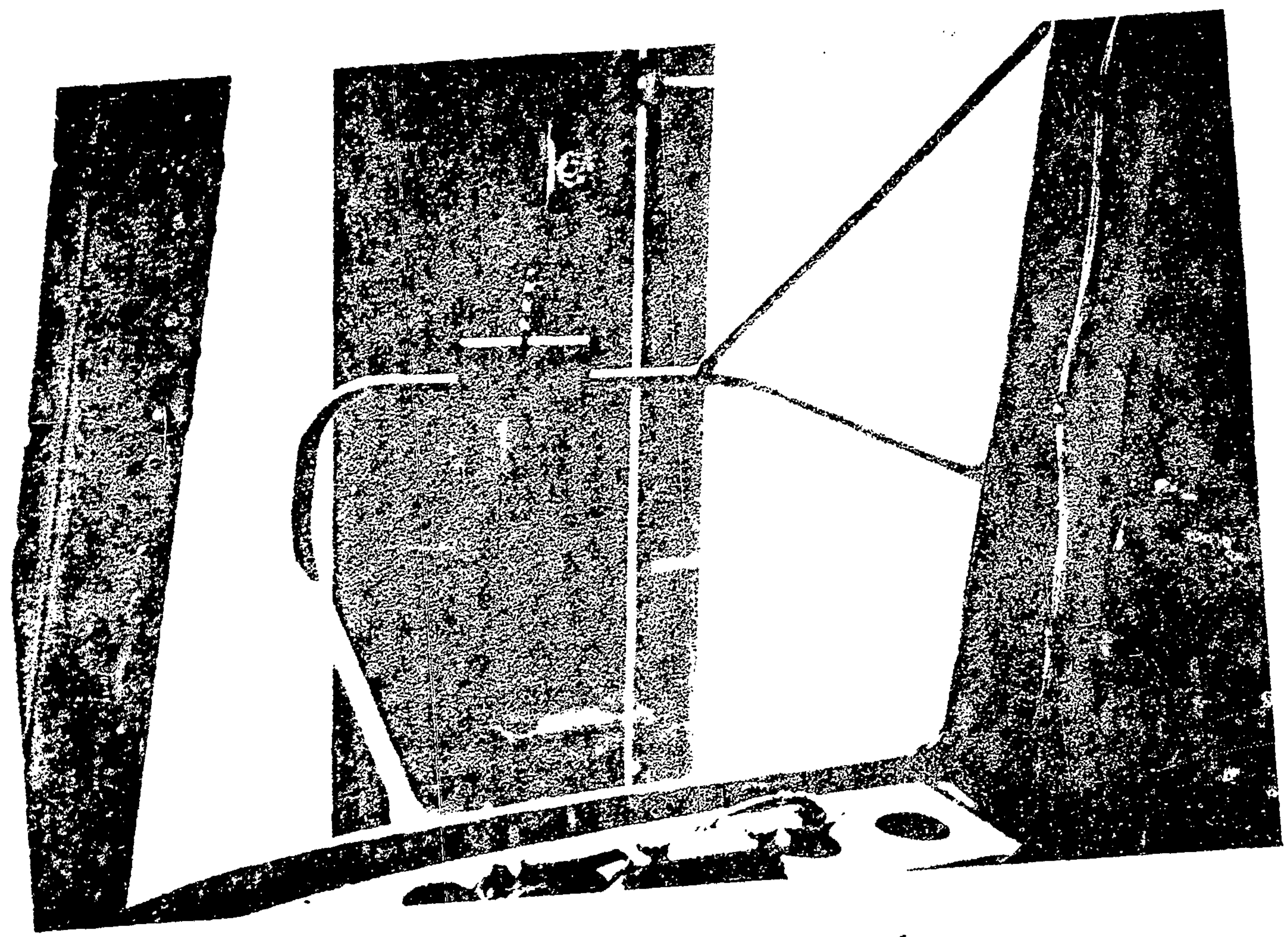


Photo 4. Ice Accretion Indicator Probe.

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. The following procedure was used to accumulate ice on the rotor system of the test aircraft. Upon reaching the altitude required for the specified test temperature, the HISS was stabilized in level flight at 80 KTAS and began spraying water at a flow rate established according to the procedures discussed in paragraphs 11 through 13 of this appendix. The test aircraft simultaneously recorded a level flight trim point at 80 KTAS. All standard and special anti-ice/deice systems were activated prior to entering the spray cloud. The test helicopter entered the spray cloud from a position below and approximately 200 feet behind the spray aircraft. The maximum time intervals used were calculated prior to each flight using the relationship of LWC and time shown in figure 1. After each immersion, a level flight trim point at 80 KTAS was recorded to assess changes in power required due to ice accretion.

ICE ACCRETION

2. Ice accretion was monitored in flight using an ice accretion indicator probe. Previous USAAEFA tests (ref 7, app A) have shown good correlation between the amount of ice seen on the probe and that observed on the rotor blades. High-speed motion picture photography and 35mm still photos shot from the rear of the spray aircraft were used to determine the extent of blade area covered with ice.

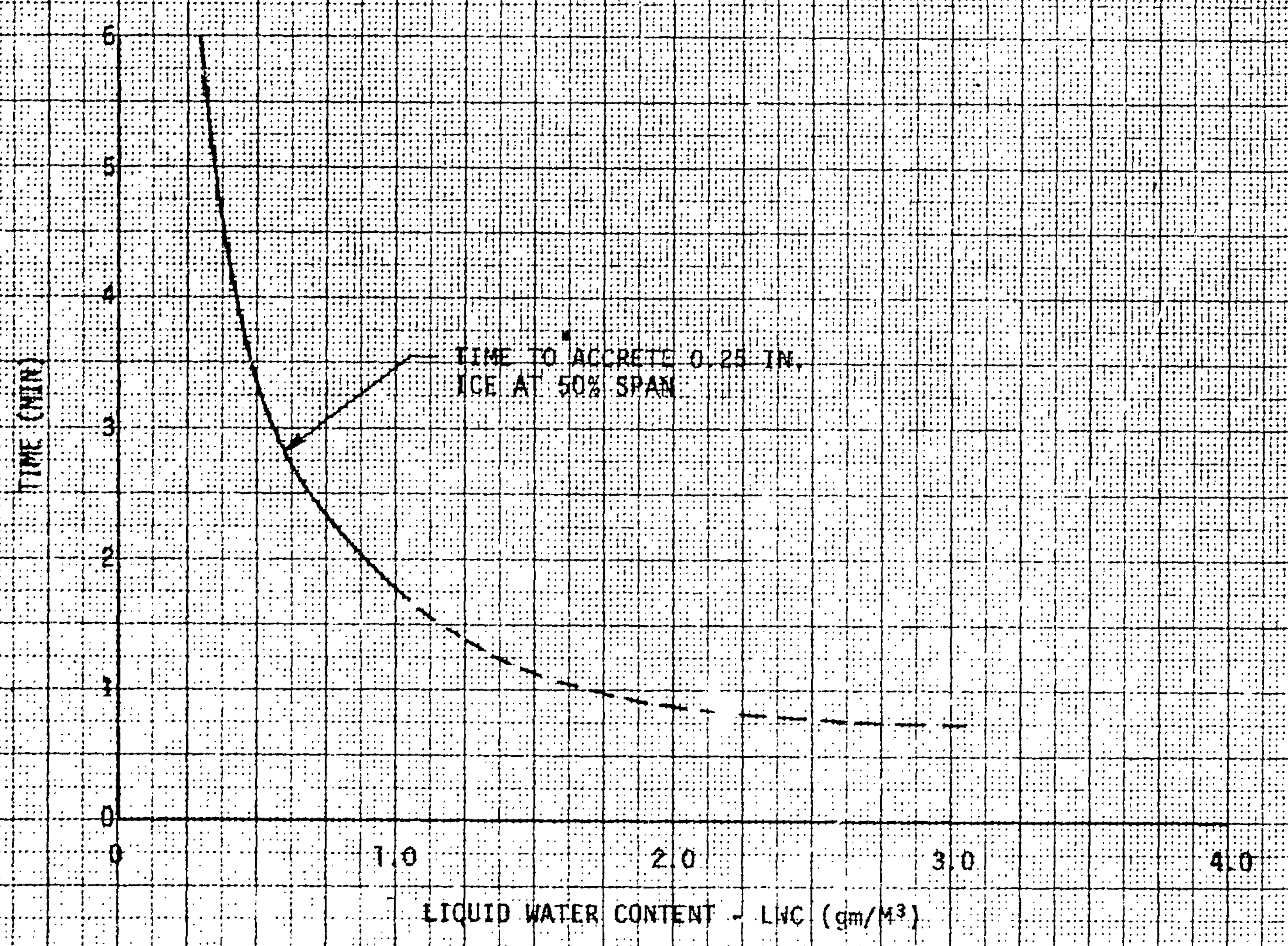
3. Lines were painted on each of the main rotor blades to provide a reference (fig. 2). A 5-inch diameter spot was painted on the top side of one rotor blade near the trailing edge at the root end. The spot was used to differentiate the rotor blades from each other when photographing the rotor disc from above.

4. Testing was conducted in three phases for each substance. The limit conditions for each phase were stipulated by an airworthiness release and were defined as follows:

a. Phase I - During Phase I tests, the temperature will be no lower than -10°C and the LWC no greater than 0.25 gm/m^3. Immersion time will be determined from figure 2. Test conditions will not be changed during Phase I testing.

b. Phase II - During Phase II tests the total icing immersion time will be increased until a predetermined limit (*ie*, limit torque increase to maintain a level flight trim, autorotational rotor speed limit, vibration limit, EGT limit, test or spray aircraft fuel or water endurance) is reached. The cumulative immersion time to reach a limit will be considered to be the usable life of the substance. Phase II

FIGURE 1. ICE ACCRETION AT 50 PERCENT BLADE SPAN



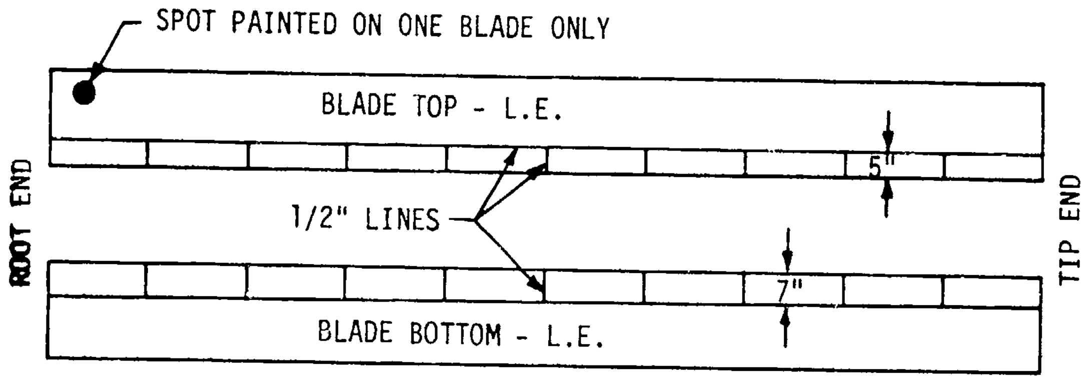


FIGURE 2. MAIN ROTOR BLADE REFERENCE MARKINGS

tests will be conducted at temperatures no lower than -20°C and LWC no greater than 0.75 gm/m^3. LWC may be increased during a Phase II flight test and maximum immersion time will be determined from figure 2.

c. Phase III - During Phae III testing, test flights will be at the same conditions as Phase II. However, the maximum continuous icing immersion time will be equal to one-half the usable life defined by the Phase II test.

d. Phase I and II tests may be conducted during a single flight.

e. Testing will be suspended if:

(1) Engine torque pressure required to maintain a level flight trim is increased by 5 psi or greater.

(2) Excessive vibration levels are encountered.

(3) It appears that ice impingement or shedding would be of sufficient magnitude to cause structural damage.

(4) Unacceptable performance or handling qualities are encountered.

LEVEL FLIGHT PERFORMANCE

5. Level flight performance data were obtained by establishing trim level flight at the test airspeed, altitude, and outside air temperature. Data were recorded before icing the test helicopter and again after each icing immersion was completed. The same trim true airspeed (80 KTAS) was used throughout the flight testing.

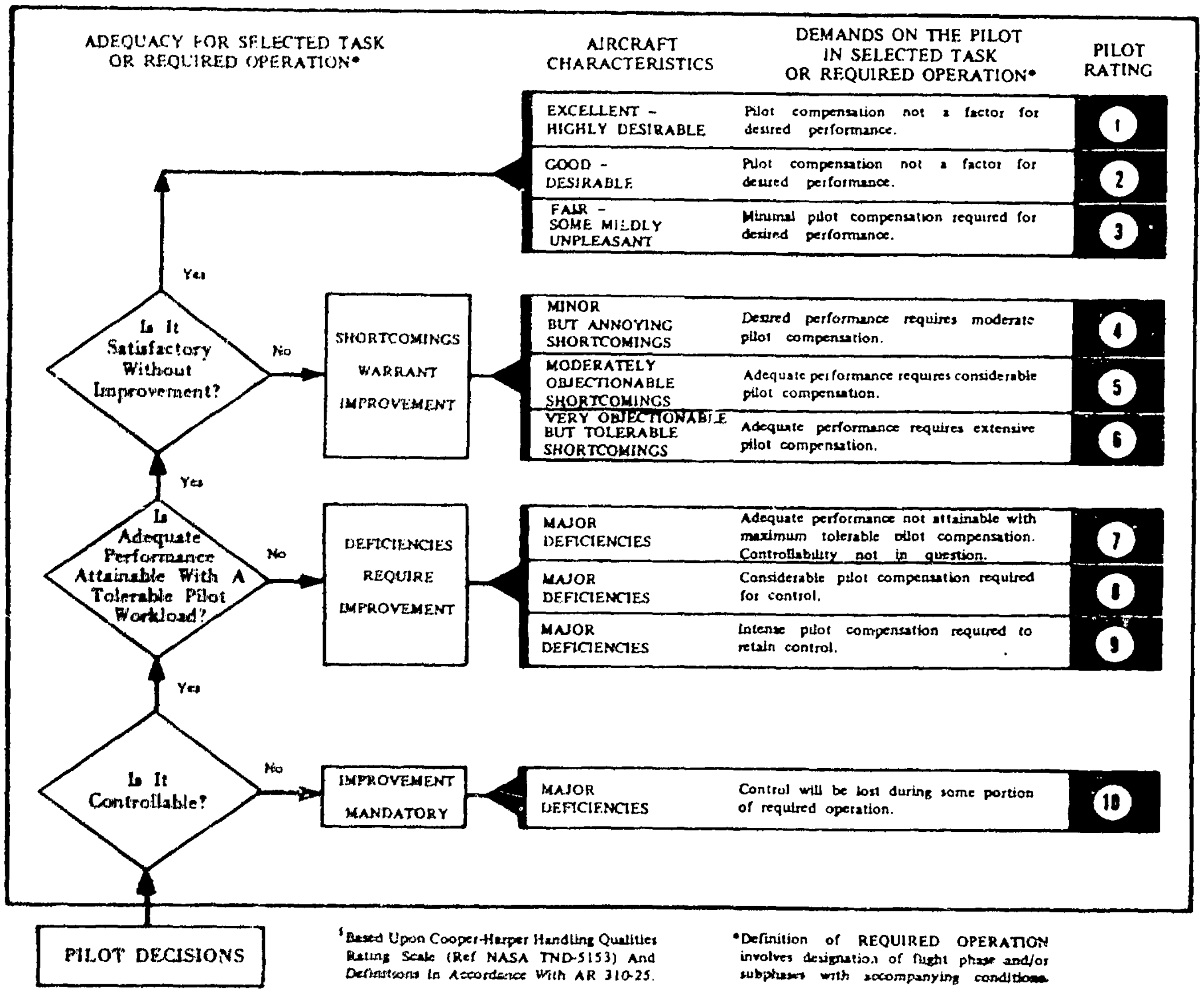
6. Level flight performance degradation due to ice accretion was assessed by comparing the engine power required to maintain constant airspeed and altitude before and after icing. Power required was corrected for fuel burn-off by using the nondimensional level flight performance carpet plot (fig. 67, ref 10, app A) for a standard "H" model helicopter.

AUTOROTATIONAL DESCENT PERFORMANCE

7. Limited autorotational descent performance was evaluated at the operator's manual recommended airspeed for minimum rate of descent (70 KIAS). Base-line autorotational descents were accomplished prior to icing and were used as comparison for autorotational descents with ice accumulation.

HANDLING QUALITIES

8. The effects of ice accretion on the test aircraft handling qualities were qualitatively assessed by the pilot. A Handling Qualities Rating Scale (HQRS) was used to augment pilot comments and is presented as figure 3.



[1] Based Upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TND-5153) And Definitions In Accordance With AR 310-25.

*Definition of REQUIRED OPERATION involves designation of flight phase and/or subphases with accompanying conditions.

Figure 3. Handling Qualities Rating Scale.

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, Boscome Down, England.

Figure 4. Vibration Rating Scale.

VIBRATION

9. Aircraft vibrations were qualitatively evaluated by the test crew and were quantified using the FM data system. Data tapes from the on-board FM data system were analyzed using a Spectral Dynamics 301 real time spectral analyzer and a Spectral Dynamics 302B ensemble averager. Data were plotted with acceleration as a function of frequency and are presented in appendix F for comparative analysis. A vibration rating scale (VRS) was used to augment pilot comments and is presented as figure 4.

WEIGHT AND BALANCE

10. Test aircraft weight and balance were determined by weighing the aircraft prior to the start of testing with all airframe modifications and test instrumentation installations complete.

HISS FLOW RATE CALCULATION METHOD

11. HISS water flow rates required to establish desired LWC for each flight were determined using the following procedure. Calibrated instruments were used to establish airspeed, altitude, and static air temperature for the required test conditions. The frost point was then obtained using a Cambridge thermoelectric dew point hygrometer installed in the spray aircraft. The frost point was then converted to a dew point using table 1. Saturation vapor pressure in millibars for the dew point and static air temperature was then determined using table 2. Relative humidity was then computed using the values obtained from table 2 and equation 1.

$$Rh = \frac{P_{VS}}{P_W} \times 100 \qquad (1)$$

Where:

Rh = Relative humidity (percent)

P_{VS} = Saturation vapor pressure for dew point (millibars)

P_W = Saturation vapor pressure for static air temperature (millibars)

12. The decay LWC, which is the spray cloud evaporation rate, was then computed using equation 2.

$$LWC_D = \frac{G(100 - Rh)}{4.5G_0} \qquad (2)$$

Table 1. Cambridge Thermoelectric Dew Point

Frost Point	Dew Point
-0.0	-0.1
-0.5	-0.7
-1.0	-1.2
-1.5	-1.8
-2.0	-2.3
-2.5	-2.9
-3.0	-3.4
-3.5	-4.0
-4.0	-4.5
-4.5	-5.1
-5.0	-5.6
-5.5	-6.2
-6.0	-6.7
-6.5	-7.3
-7.0	-7.9
-7.5	-8.4
-8.0	-9.0
-8.5	-9.5
-9.0	-10.1
-9.5	-10.6
-10.0	-11.2
-10.5	-11.7
-11.0	-12.3
-11.5	-12.8
-12.0	-13.4
-12.5	-13.9
-13.0	-14.5
-13.5	-15.0
-14.0	-15.6
-14.5	-16.2
-15.0	-16.7
-15.5	-17.3
-16.0	-17.8
-16.5	-18.4
-17.0	-18.9
-17.5	-19.5
-18.0	-20.0
-18.5	-20.6
-19.0	-21.1
-19.5	-21.1
-20.0	-22.2
-20.5	-22.8
-21.0	-23.3
-21.5	-23.9
-22.0	-24.5
-22.5	-25.0
-23.0	-25.6
-23.5	-26.1
-24.0	-26.7
-24.5	-27.2
-25.0	-27.8
-25.5	-28.3

Table 2. Saturation Vapor Pressure Over Water.
(Millibars)

Temperature °C	.0	.1	.2	3	4	.5	.6	.7	.8	.9
-50	0.06356									
-49	0.07124	0.07044	0.06964	0.06885	0.06807	0.06730	0.06654	0.06578	0.06503	0.06429
-48	0.07975	0.07886	0.07797	0.07710	0.07624	0.07538	0.07453	0.07370	0.07287	0.07205
-47	0.08918	0.08819	0.08722	0.08625	0.08530	0.08435	0.08341	0.08248	0.08156	0.08065
-46	0.09961	0.09852	0.09744	0.09637	0.09531	0.09426	0.09322	0.09220	0.09118	0.09017
-45	0.1111	0.1099	0.1087	0.1075	0.1063	0.1052	0.1041	0.1930	0.1018	0.1007
-44	0.1239	0.1226	0.1213	0.1200	0.1187	0.1174	0.1161	0.1149	0.1136	0.1123
-43	0.1379	0.1364	0.1350	0.1335	0.1321	0.1307	0.1293	0.1279	0.1266	0.1252
-42	0.1534	0.1518	0.1502	0.1486	0.1470	0.1455	0.1440	0.1424	0.1409	0.1394
-41	0.1704	0.1686	0.1669	0.1651	0.1634	0.1617	0.1600	0.1583	0.1567	0.1550
-40	0.1891	0.1872	0.1852	0.1833	0.1815	0.1796	0.1777	0.1759	0.1740	0.1722
-39	0.2097	0.2076	0.2054	0.2033	0.2013	0.1992	0.1971	0.1951	0.1931	0.1911
-38	0.2323	0.2299	0.2276	0.2253	0.2230	0.2207	0.2185	0.2162	0.2140	0.2119
-37	0.2571	0.2545	0.2520	0.2494	0.2469	0.2444	0.2419	0.2395	0.2371	0.2347
-36	0.2842	0.2814	0.2786	0.2758	0.2730	0.2703	0.2676	0.2649	0.2623	0.2597
-35	0.3139	0.3108	0.3077	0.3047	0.3017	0.2987	0.2957	0.2928	0.2899	0.2870
-34	0.3463	0.3429	0.3396	0.3362	0.3330	0.3297	0.3265	0.3233	0.3201	0.3170
-33	0.3818	0.3781	0.3745	0.3708	0.3673	0.3637	0.3602	0.3567	0.3532	0.3497
-32	0.4205	0.4165	0.4125	0.4085	0.4046	0.4007	0.3968	0.3930	0.3893	0.3855
-31	0.4628	0.4584	0.4541	0.4497	0.4454	0.4412	0.4370	0.4328	0.4287	0.4246
-30	0.5088	0.5040	0.4993	0.4946	0.4899	0.4853	0.4807	0.4762	0.4717	0.4672
-29	0.5589	0.5537	0.5485	0.5434	0.5383	0.5333	0.5283	0.5234	0.5185	0.5136
-28	0.6134	0.6077	0.6021	0.5966	0.5911	0.5856	0.5802	0.5748	0.5694	0.5642
-27	0.6727	0.6666	0.6605	0.6544	0.6484	0.6425	0.6366	0.6307	0.6249	0.6191
-26	0.7371	0.7304	0.7238	0.7172	0.7107	0.7042	0.6978	0.6914	0.6851	0.6789
-25	0.8070	0.7997	0.7926	0.7854	0.7783	0.7713	0.7643	0.7574	0.7506	0.7438
-24	0.882[illegible]	0.8748	0.8671	0.8593	0.8517	0.8441	0.8366	0.8291	0.8217	0.8143
-23	0.9649	0.9564	0.9479	0.9396	0.9313	0.9230	0.9148	0.9067	0.8986	0.8906
-22	1.0538	1.0446	1.0354	1.0264	1.0173	1.0084	0.9995	0.9908	0.9821	0.9734
-21	1.1500	1.1400	1.1301	1.1203	1.1106	1.1[illegible]	1.0913	1.0818	1.0724	1.0631
-20	1.2540	1.2432	1.2325	1.2219	1.2114	1.20[illegible]	1.1906	1.1804	1.1702	1.1600
-19	1.3664	1.3548	1.3432	1.3318	1.3204	1.3091	1.2979	1.2868	1.2758	1.2648
-18	1.4877	1.4751	1.4627	1.4503	1.4381	1.4259	1.4138	1.4018	1.3899	1.3781
-17	1.6186	1.6051	1.5916	1.5783	1.5650	1.5519	1.5389	1.5259	1.5131	1.5003
-16	1.7597	1.7451	1.7306	1.7163	1.7020	1.6879	1.6738	1.6599	1.6460	1.6323
-15	1.9118	1.8961	1.8805	1.8650	1.8496	1.8343	1.8191	1.8041	1.7892	1.7744
-14	2.0755	2.0586	2.0418	2.0251	2.0085	1.9921	1.9758	1.9596	1.9435	1.9276
-13	2.2515	2.2333	2.2153	2.1973	2.1795	2.1619	2.1444	2.1270	2.1097	2.0925
-12	2.4409	2.4213	2.4019	2.3826	2.3635	2.3445	2.3256	2.3069	2.2883	2.2698
-11	2.6443	2.6233	2.6024	2.5817	2.5612	2.5408	2.5205	2.5004	2.4806	2.4606
-10	2.8627	2.8402	2.8178	2.7956	2.7735	2.7516	2.7298	2.7082	2.6868	2.6655
-9	3.0971	3.0729	3.0489	3.0250	3.0013	2.9778	2.9544	2.9313	2.9082	2.8854
-8	3.3484	3.3225	3.2967	3.2711	3.2457	3.2205	3.1955	3.1706	3.1459	3.1214
-7	3.6177	3.5899	3.5623	3.5349	3.5077	3.4807	3.4539	3.4272	3.4008	3.3745
-6	3.9061	3.8764	3.8468	3.8175	3.7883	3.7594	3.7307	3.7021	3.6738	3.6456
-5	4.2148	4.1830	4.1514	4.1200	4.0888	4.0579	4.0271	3.9966	3.9662	3.9361
-4	4.5451	4.5111	4.4773	4.4437	4.4103	4.3772	4.3443	4.3116	4.2791	4.2468
-3	4.8981	4.8617	4.8256	4.7897	4.7541	4.7187	4.6835	4.6486	4.6136	4.5794
-2	5.2753	5.2364	5.1979	5.1595	5.1214	5.0836	5.0460	5.0087	4.9716	4.9347
-1	5.6780	5.6365	5.5953	5.5544	5.5138	5.4734	5.4333	5.3934	5.3538	5.3144
-0	6.1078	6.0636	6.0196	5.9759	5.9325	5.8894	5.8466	5.8040	5.7617	5.7197

Where :

LWC_D = Decay liquid water content (percent/second)

G = Thermodynamic function (centimeter^2/second)

Rh = Relative humidity (percent) obtained from equation 1

G_O = 60 X 100^{-8} centimeter^2/second (constant)

The value for the thermodynamic function G used in equation 2 was obtained from figure 5 using the total air temperature indicated by the HISS aircraft. Pressure dependence of G is small, so that values for 1000 millibars given in figure 5 were satisfactory for the test altitudes. The programmed LWC based on the desired test condition was then corrected for evaporation using the decay LWC calculated above and equation 3.

$$LWC_C = \left(\frac{LWC_D}{100}\right) \left(\frac{D}{1.6889V_T}\right) (LWC_P) + LWC_P \tag{3}$$

Where:

LWC_C = Corrected liquid water content (gm/m^3)

LWC_D = Decay liquid water content (percent/second)

D = 200 feet (constant distance between test and spray aircraft maintained during this test)

1.6889 = Conversion factor (ft/sec/kt)

V_T = 80 knots (constant test time airspeed)

LWC_P = Programmed liquid water content (gm/m^3)

13. The corrected LWC and figure 6 were then used to determine the required water flow rate. The flow rate obtained from figure 6 and a constant bleed air pressure of 15 pounds per square inch at the nozzles (gauge) were used to establish the spray cloud.

FIGURE 5. VARIATION OF THERMODYNAMIC FUNCTION WITH TEMPERATURE AT 1000 MILLIBARS

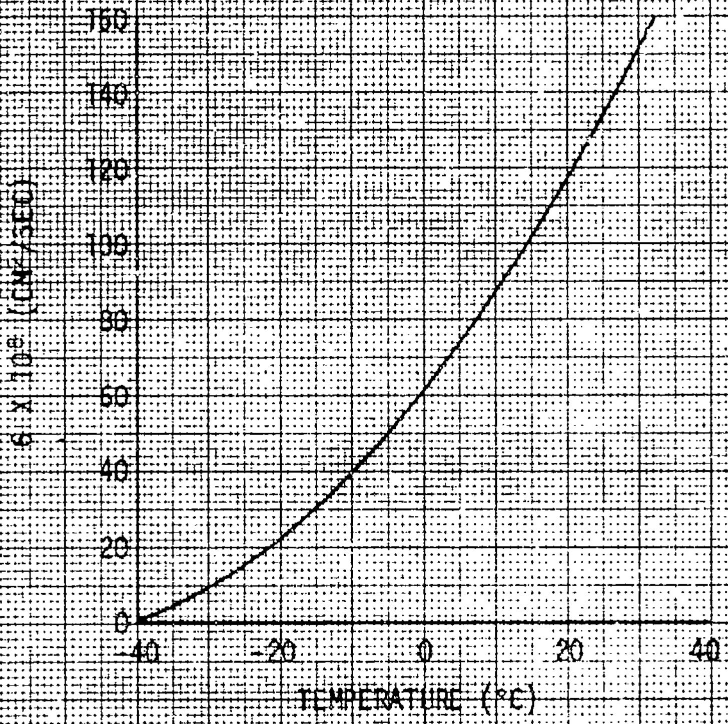
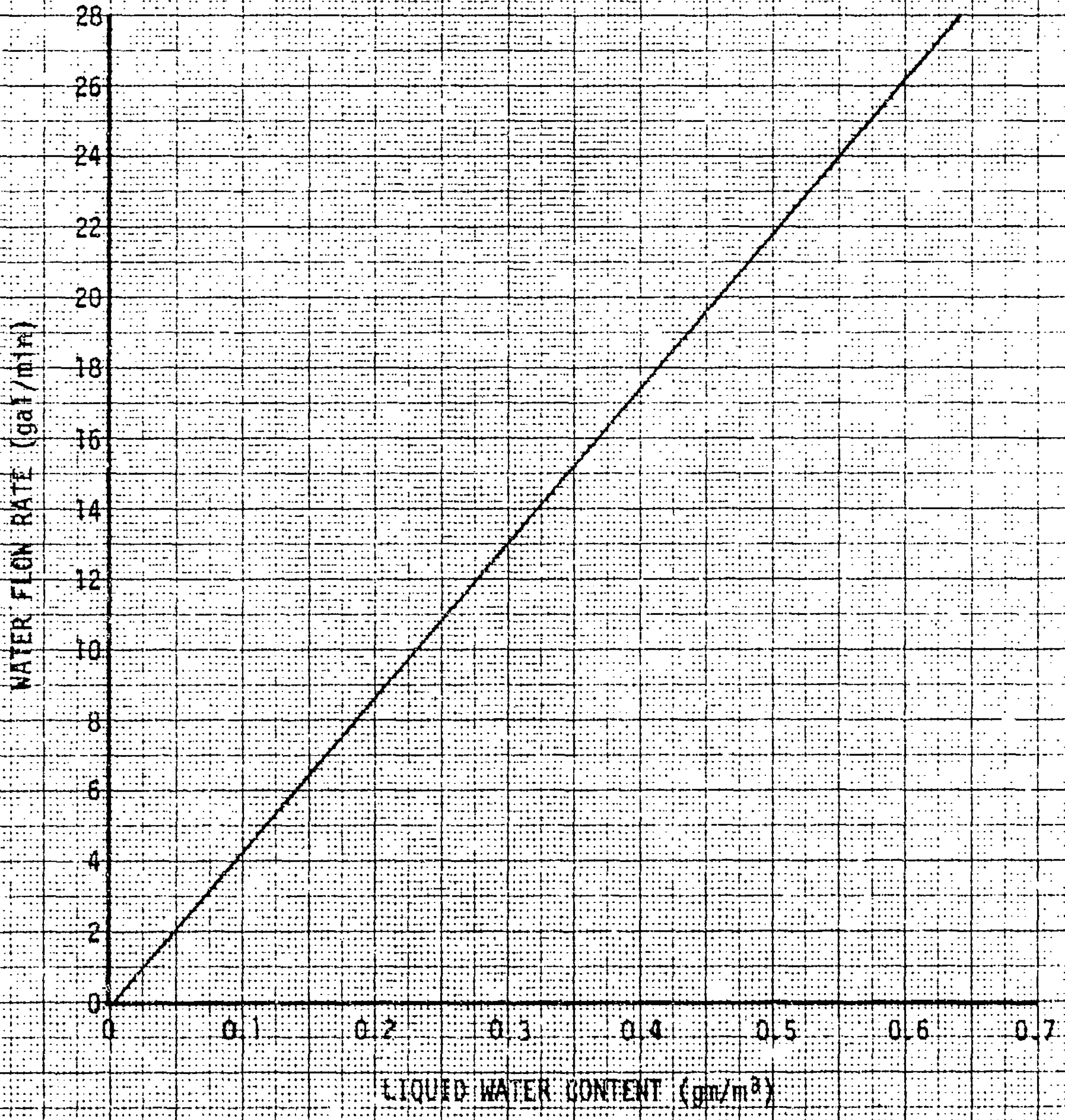


FIGURE 6
HISS WATER FLOW RATE CHART

NOTE:

1. THIS CHART USED FOR TESTS IN SPOKANE, WASHINGTON JANUARY-FEBRUARY 1978.
2. HISS CONFIGURED FOR SINGLE BOOM SPRAYING WITH 38 NOZZLES ACROSS TOP BOOM AND 1 NOZZLE AT CENTER LOWER BOOM
3. STANDOFF DISTANCE = 150 FEET
4. ASSUMED CLOUD THICKNESS = 12.0 FEET



APPENDIX E. TEST DATA

INDEX

Icing Test Flight Summaries

Spectral Analysis Plots

Table 1. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m²)	Hiss Water Flow Rate (gpm)
13	30 Jan 78	6880	138.0 (Mid)	10,500	80	-10.0	0.14; 0.25	7; 12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	4	4	4	3	3	3	3	3									27
Δ torque pressure (psi)	0.1		0		0.2	0.1		0.7									

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested None
3. Application technique N/A
4. Dry air blade time (min) N/A
5. Small amount of ice visible on windshield, lower front fuselage and synchronized elevator. Ice thickness on the visual probe was 0.50 in. after 27 min. Photos showed trace amounts of ice on the main rotor blades after approximately 15 min in cloud which extended from 10% to 60% blade radius.
6. Aircraft vibration levels were normal throughout this flight.
7. First 3 immersions (4 min each) were at an LWC of 0.14 gm/m³. The rest of the flight was at an LWC of .25 gm/m³.
8. Small amount of ice seen this flight attributed to position of test A/C (too high) in the icing cloud.

Table 2. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
14	30 Jan 78	6920	138.0 (Mid)	10,900	80	-10.0	0.25	12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	3	3	3	3	3	3	3								27
Δ torque pressure (psi)			1.8		1.8				2.0								

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested None
3. Application technique N/A
4. Dry air blade time (min) N/A
5. Ice visible in flight on windshield, stationary controls, and synchronized elevator. Ice thickness on visual probe was 0.5 in. after 27 min. Photos showed small amount of ice on the main rotor blades which extended from 10% to 72% blade radius.
6. Postflight ice remaining on the rotor blades was 0.25 in. thick and extended from blade roots to 21% and 22% blade radius.
7. Aircraft vibration levels were normal throughout this flight.

Table 3. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
15	3 Feb 78	6960	138.0 (Mid)	11,100	80	-10.0	0.5	24

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	3	3	3	3	2										20
Δ torque pressure (psi)	1.0			1.9		4.3											

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.

2. Substance tested None

3. Application technique N/A

4. Dry air blade time (min) N/A

5. Ice visible in flight on windshield, stationary controls, and synchronized elevator. Ice thickness on the visual probe was 7/16 in. after 20 min. Photos showed ice from blade root to 67 and 69% blade radius after 20 min. During the 7th immersion in the icing cloud (after 20 min of icing), ice was shed from one blade to 58% blade radius. Ice remained on the blades with shed points at 69% and 58% blade raduis for 3.5 min. Ice shed and hit the tail rotor. A dent was found on one tail rotor Blade after landing.

6. Ground temperature was above freezing and no ice remained on the rotor blades after landing.

7. Aircraft vibration levels were normal until the 7th immersion in the icing cloud. During this immersion (after 20 min of icing) a lateral vibration at the 1/rev freq. was suddenly felt. The test A/C was flown out of the cloud and descended. After 3.5 min, at an altitude (Hp) of 10,000 ft, the vibration stopped and aircraft vibration levels returned to normal and remained normal until landing. The maximum 1/rev lateral vibration was 0.08g measured at the pilot seat.

Table 4. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
16	3 Feb 78	6880	138.0 (Mid)	7500	80	-5.0	0.5	24

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	2	3	2	3	3	3	3	3							28
Δ torque pressure (psi)		4.8	2.7	5.9	3.9	6.3	5.6	6.4		8.2							

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested None
3. Application technique N/A
4. Dry air blade time (min) N/A
5. Ice was visible in flight on the windshield, stationary controls, and synchronized elevator. Ice on the visual probe was 7/8 in. after 28 min. Photos showed the rotor blade ice shed points changed several times during the flight. Ice shed points remained between 35% to 48% blade radius, with no significant asymmetry to the ice accumulations noted.
6. Ground temperature was above freezing and no ice remained on the rotor blades after landing.
7. Light, lateral, 1/rev vibrations were noted several times while in the icing cloud. These vibrations were first noted after 21 min. of icing and persisted for the duration of icing flight (28 min total).

Table 5. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
3	9 Jan 78	7000	138.0 (Mid)	10,200	80	-5.0	0.14	7

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	4	4															8
Δ torque pressure (psi)	0.3	0.5															

Comments:

1. Torque pressure corrected for fuel burnoff u 'ng figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 72
5. Small amount of ice visible in flight on rotor hub and nonrotating controls. Ice thickness on visual probe was 1/8 in. after 4 min and 3/16 in. after 8 min. Ice shed point could not be determined due to small amount of ice on main rotor blades.
6. Ground temperature was above freezing and no ice remained on the test aircraft on landing.
7. Aircraft vibration levels were normal throughout the flight.

Table 6. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m²)	Hiss Water Flow Rate (gpm)
4	10 Jan 78	6780	138.0 (Mid)	10,450	80	-5.0	0.14	7

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	4	4	4	4	4	4	4										28
Δ torque pressure (psi)	3.2	3.9	2.0	1.5	3.0	3.1	3.9										

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 79
5. Small amount of ice visible in flight on stationary controls and synchronized elevator. Ice thickness on visual probe was 1/2 in. after 28 min.
6. Ground temperature was above freezing and no ice remained on the test helicopter on landing.
7. Aircraft vibration levels were normal throughout the flight.

Table 7. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m²)	Hiss Water Flow Rate (gpm)
5	10 Jan 78	6760	138.0 (Mid)	10,500	80	-5.0	0.14/0.25	7; 12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	4	2	2	2	2	2	2	3	3	3	3	3					31
Δ torque pressure (psi)	0	0.7	2.1	3.5	4.4	3.5	3.7	3.0	2.4	3.6	3.8	1.7					

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested F2460
3. Application technique Spray
4. Dry air blade time (min) 89
5. Ice visible in flight on stationary controls, windshield, and synchronized elevator. Ice thickness on visual probe was 3/8 in after 31 minutes.
6. Ground temperature was above freezing and no ice remained on the test helicopter on landing.
7. Aircraft vibration levels were normal throughout the flight.
8. First immersion (4 min) was an LWC of 0.14 gm/m^3. All other immersions were at 0.25 gm/m^3 LWC.
9. Autorotational descent after 31 min in cloud showed approximate 15 rpm decrease as compared to base-line autorotation accomplished at beginning of flight (650 lb change in GW from baseline autorotation to autorotation with ice on rotor blade).

Table 8. Icing Test Flight Summary.

Flight Conditions								
Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
6	13 Jan 78	6940	138.0 (Mid)	10,100	80	-5.0	0.25	12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	2	3	3	3	3										20
Δ torque pressure (psi)		0.9			0.3		1.4										

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 82
5. Ice visible in flight on stationary controls, windshield, and synchronized elevator. Ice thickness on visual probe was 3/8 in. after 20 min. Photos showed rotor blade ice shed point at 48% to 50% blade span for both blades.
6. Postflight ice remaining on rotor blades was 1/8 in. thick and extended from blade roots to 8% and 22% blade radius.
7. Aircraft vibration levels were normal throughout the flight.

Table 9. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
9	22 Jan 78	7060	138.0 (Mid)	8800	80	-15.0	0.14; 0.25	7; 12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	4	3	3	3													13
Δ torque pressure (psi)		5.6	6.1	7.0													

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 43
5. Ice visible in flight on windshield, stationary controls, and synchronized elevator. Ice thickness on visual probe was 3/8 in. thick after 13 min. Photos showed ice from 8% on both blades to shed points at 73% and 75% blade radius.
6. Postflight ice remaining on rotor blades was 0.15 in. thick and extended from blade roots to 12% and 15% radius. Ice chunks fell off the rotor blades on shutdown and were measured to be .25 in. thick.
7. Aircraft vibration levels were normal throughout the flight.
8. Autorotational descent after 13 minutes in cloud showed approximate 6 rpm decrease in rotor speed as compared to base-line autorotation of flt 5.

Table 10. Icing Test Flight Summary.

Flight Conditions								
Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
10	22 Jan 78	7020	138.0 (Mid)	6900	80	-10.0	0.14; 0.25	8; 12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	4	3	3	3	3	3										22
Δ torque pressure (psi)		0.9	0.7		3.6	3.2	1.2										

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 43
5. Ice visible in flight on windshield, stationary controls, and synchronized elevator. Ice thickness on visual probe was 5/8 in. after 20 min. Photos showed ice out to 60% blade radius with shed points not clearly defined.
6. Postflight ice remaining on rotor blades was 0.15 in. thick and extended from blade roots to 22% and 24% blade radius.
7. Aircraft vibration levels were normal throughout the flight.
8. After approximately 10 min in the cloud a thump on the airframe was noted by the test crew which was suspected to be caused by ice shedding from the main rotor.

Table 11. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
12	23 Jan 78	6820	138.0 (Mid)	9000	80	-10.0	0.25	12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	48
Δ torque pressure (psi)		0.2		1.3		1.6		0.8					1.5	3.7		1.8	

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 72
5. Ice visible in flight on windshield, stationary controls, and synchronized elevator. Ice thickness on the visual probe was 1.0 in. after 48 min. Photos showed ice extending from blade root to abrupt shed point at 72% and 73% blade radius at maximum.
6. Postflight ice remaining on rotor blades was 0.12 in. thick and extended from blade roots to 8% and 12% blade radius. The ice extended 1.5 in. aft of the leading edges.
7. Several instances of ice shedding from the main rotor blades and rotating controls. Test crew experienced short duration (1-2 sec.) light, lateral 1/rev vibrations.

Table 12 Icing Test Flight Summary.

Flight Conditions								
Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
19	8 Feb 78	6850	138.0 (Mid)	9130	80	-10.0	0.5	24

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	1.5			40.5
Δ torque pressure (psi)		0		3.1	1.5			2.6		2.7	2.7			2.8			

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 65.5
5. Ice was visible in flight on the windshield, stationary controls, and synchronized elevator. Ice thickness on the visual probe was 1 in. after 40.5 min. Photos showed rotor blade ice shed points varied from 47% to 55% blade radius. Additional shedding occurred inboard of the outboard shed points after 40.5 min. of icing. An asymmetrical shedding of ice occurred with the shed points at 32% and 70% blade radius.
6. Ground temperature was above freezing and no ice remained on the rotor blades after landing.
7. Aircraft vibration levels were normal during the first 33 min of icing. Light lateral 1/rev vibrations were noted several times during the remainder of the icing flight. During the 14th immersion, a severe 1/rev vibration started and the test was terminated.

Table 13 Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
20	8 Feb 78	6850	138.0 (Mid)	6260	80	-5.0	0.5	24

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	48
Δ torque pressure (psi)		1.4		0.7			2.1		2.7			2.5				3.7	

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 50
5. Ice was visible in flight on the windshield, stationary controls, and synchronized elevator. Ice thickness on the visual probe was 2 1/4 inches after 48 min. Photos showed ice shed points symmetrical between the two blades throughout the flight varying from 10% to 30% blade radius.
6. Ground temperature was above freezing and no ice remained on the rotor blades after landing.
7. Aircraft vibration levels were normal except for minor, short-time duration, lateral shaking caused by ice shedding symmetrically.

Table 14 Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
21	8 Feb 78	6800	138.0 (Mid)	9620	80	-10.0	0.25	12

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	20	20	20														60
Δ torque pressure (psi)	0.9	0.3	1.1														

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested E2460
3. Application technique Spray
4. Dry air blade time (min) 53
5. Ice was visible in flight on the windshield, stationary controls, and synchronized elevator. Ice thickness on the visual probe was 3/4 in. after 60 min. Photos showed rotor blade ice shed points symmetrical between the tow blades at 65% blade radius.
6. Ground temperature was above freezing and no ice remained on the rotor blades after landing.
7. Aircraft vibration levels were normal throughout the flight.

Table 15. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
17	6 Feb 78	6860	138.0 (Mid)	10,900	80	-10.0	0.25; 0.5	12; 24

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	4	4	3	3	3	3	3	3	3	3							32
Δ torque pressure (psi)		1.5		0.4			1.8			4.2							

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested GE 697
3. Application technique Wipe
4. Dry air blade time (min) 72
5. Ice was visible in flight on the windshield, stationary controls, and synchronized elevator. Ice thickness on the visual probe was 1/2 in. after 32 min. Photos showed ice shed point varying between 42% and 54% blade radius after 12 min of icing. Blade ice shed points remained symmetrical between the two blades (within 2% of each other) throughout the icing immersions. An asymmetrical shedding of rotor ice occurred after the 10th immersion while the test A/C was setting up a level flight trim point. Ice shed points were at 38% and 57% blade radius for this point.
6. Ground temperature was above freezing and no ice remained on the rotor blades after landing.
7. Aircraft vibration levels were normal during the first 29 min of icing. Light lateral vibrations at 1/rev freq were noted during the last 3 min immersion. During set-up for a level flight trim out of the cloud after 32 min of icing, a severe 0.07g 1/rev lateral vibration started and the test was terminated. The vibrations continued as the test aircraft descended for approximately 4.5 min. Normal aircraft vibration levels were restored at an altitude (Hp) of 7500 ft and an OAT of -2.5°C.
8. An autorotational descent was conducted after icing for 32 min with moderate lateral 1/rev vibrations.

Table 16. Icing Test Flight Summary.

Flight Conditions

Flight Number	Date of Flight	Average Gross Weight (lb)	Average Longitudinal Center of Gravity (FS)	Average Density Altitude (ft)	Trim True Airspeed (kt)	Average Outside Air Temperature (°C)	Liquid Water Content (gm/m^2)	Hiss Water Flow Rate (gpm)
18	7 Feb 78	6830	138.0 (Mid)	9000	80	-5.0	0.5	24

Icing Immersion Synopsis

Immersion number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Immersion time (min)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	42
Δ torque pressure (psi)		3.0	2.9		2.6			5.5			4.3			5.7			

Comments:

1. Torque pressure corrected for fuel burnoff using figure 67, reference 10, appendix A.
2. Substance tested GE 697
3. Application technique Wipe
4. Dry air blade time (min) 64
5. Ice was visible in flight on the windshield, stationary controls and synchronized elevator. Ice thickness on the visual probe was 7/8 in. after 42 min. Photos showed rotor blade ice shed points varying from blade root to 65% blade radius and remaining symmetrical between the two blades for the duration of the flight.
6. Ground temperature was above freezing and no rotor blade ice remained after landing.
7. Aircraft vibration levels were normal during the first 3 immersions (9 min). Light 1/rev lateral vibrations were randomly felt for the duration of the icing flight. Typical 1/rev lateral vibrations experienced during this flight were 0.02g.

FIGURE [illegible]

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17146

LOCATION PILOT SEAT

AXIS LATERAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
6800	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN

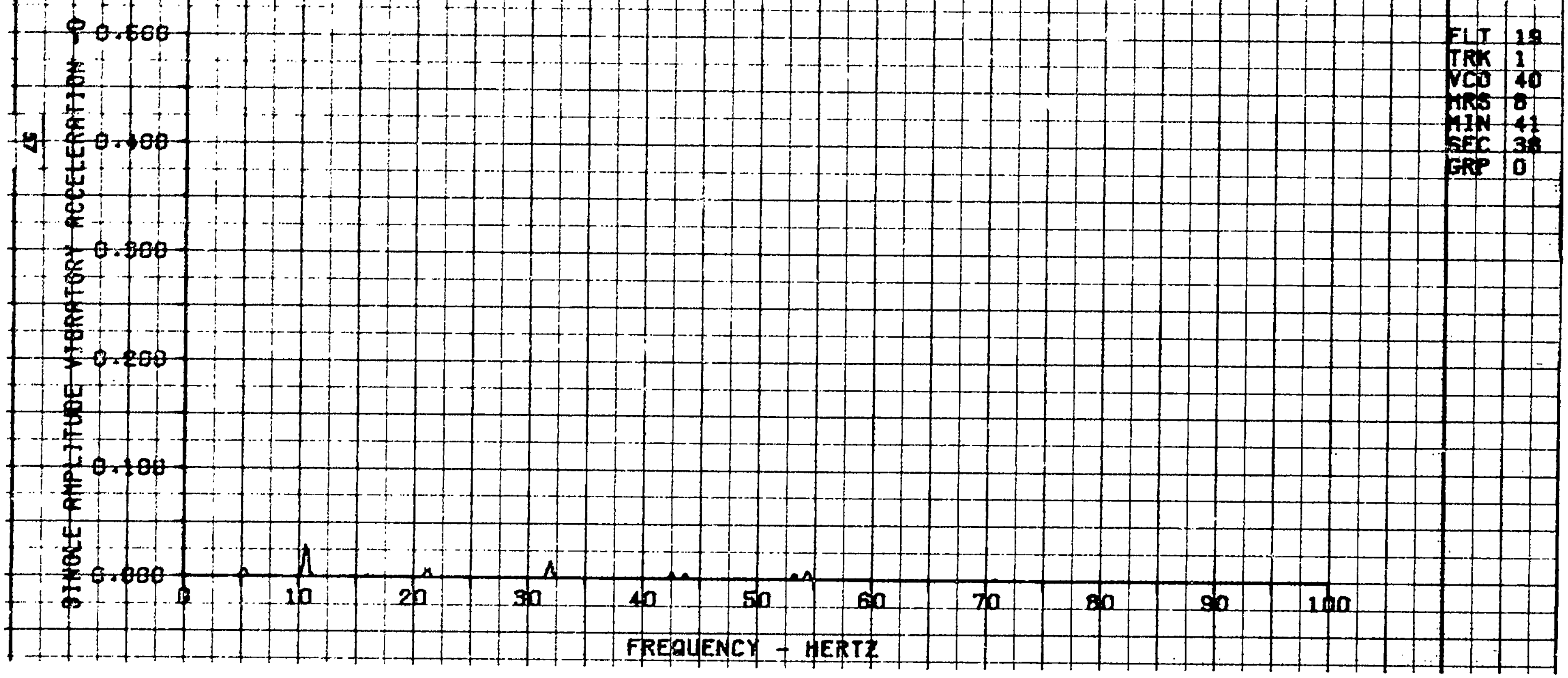


FIGURE 2

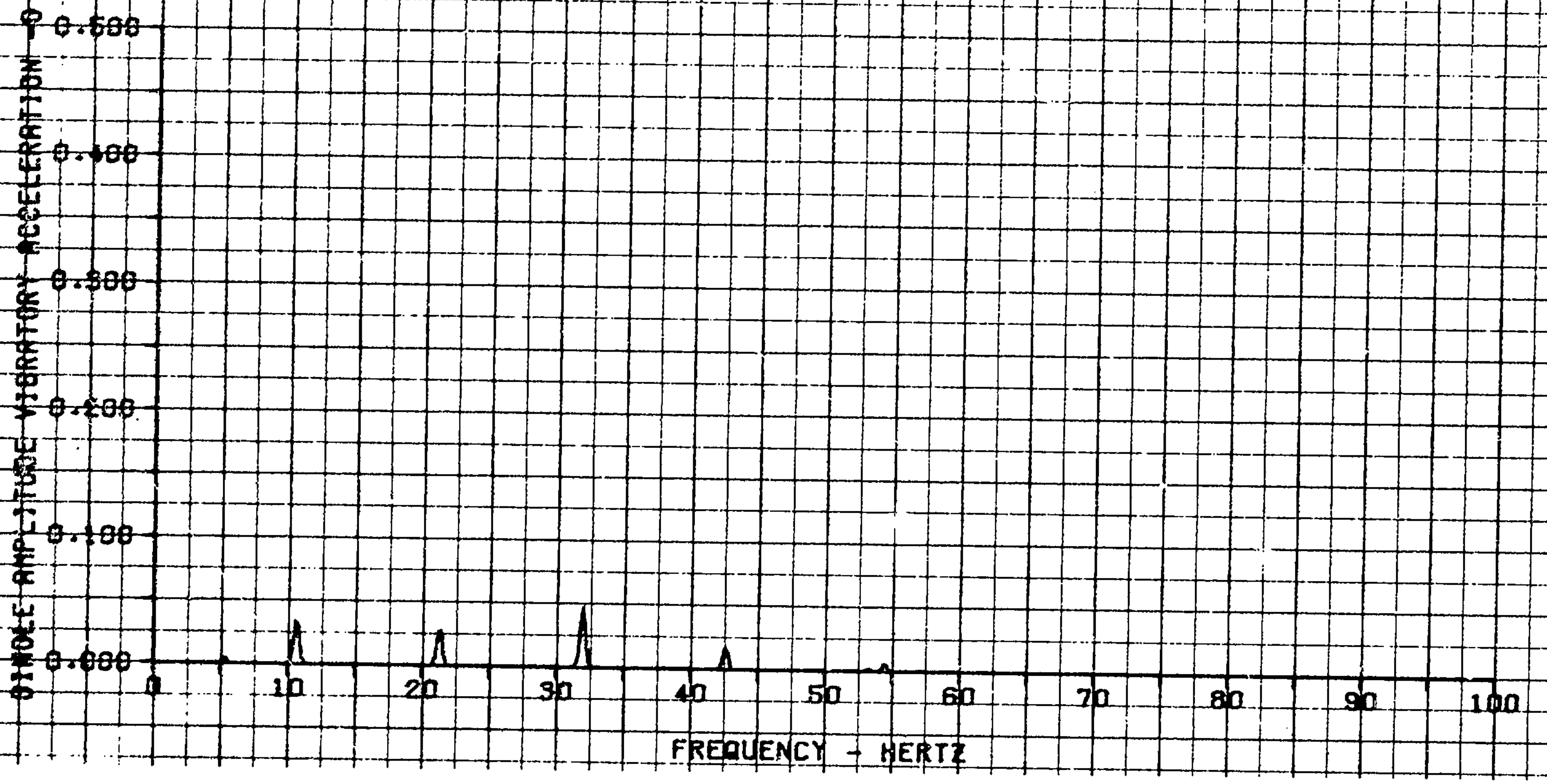
VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION PILOT SEAT
AXIS VERTICAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5800	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT	19
TRK	1
VCO	55
HRS	8
MIN	41
SEC	38
GRP	0

FIGURE 3

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION PILOT SEAT

AXIS LONGITUDINAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
7000	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN

FLT	19
TRK	2
VCO	100
HRS	8
MIN	32
SEC	41
GRP	0

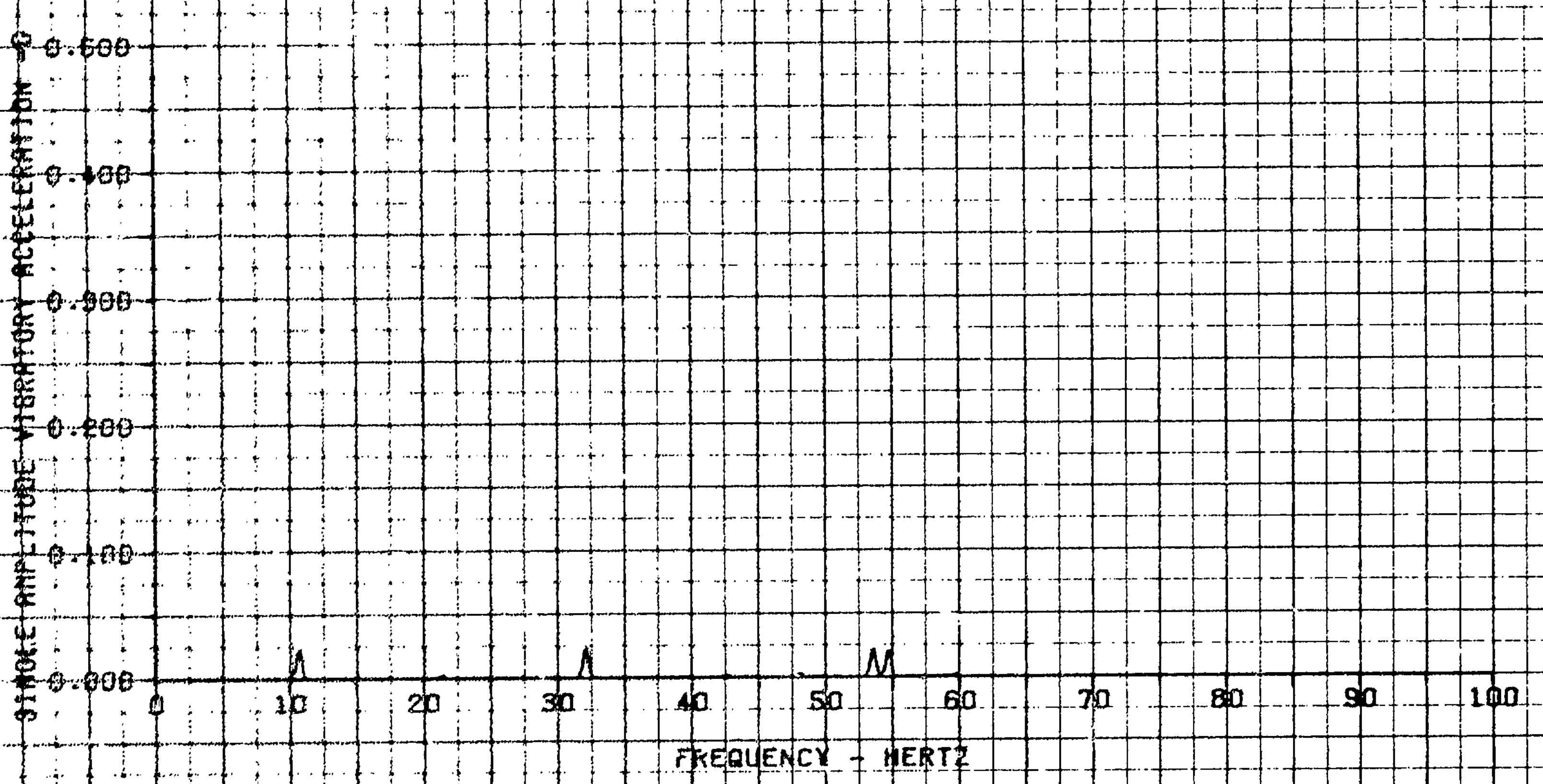


FIGURE 4

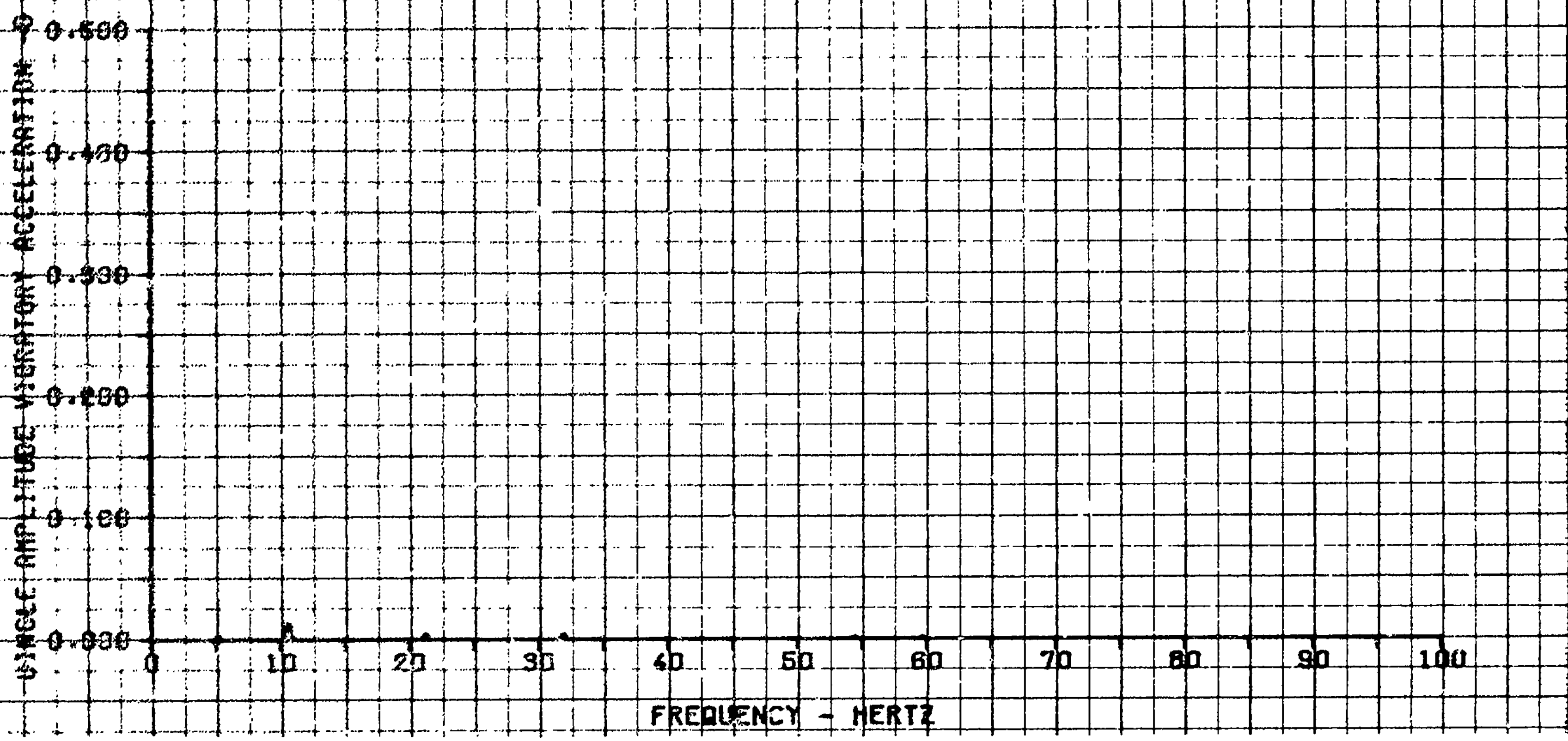
VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION COPILOT SEAT
AXIS LATERAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
6800	138.0	0.0	8150	-10.0	324	80	LF TRIM	CLEAN



FLT 19
TRK 2
VCO 70
HRS 8
MIN 41
SEC 38
GRP 0

FIGURE 3

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION COPILOT SEAT
AXIS VERTICAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
6300	136.0	0.0	8150	-10.0	324	80	LF TRIM	CLEAN

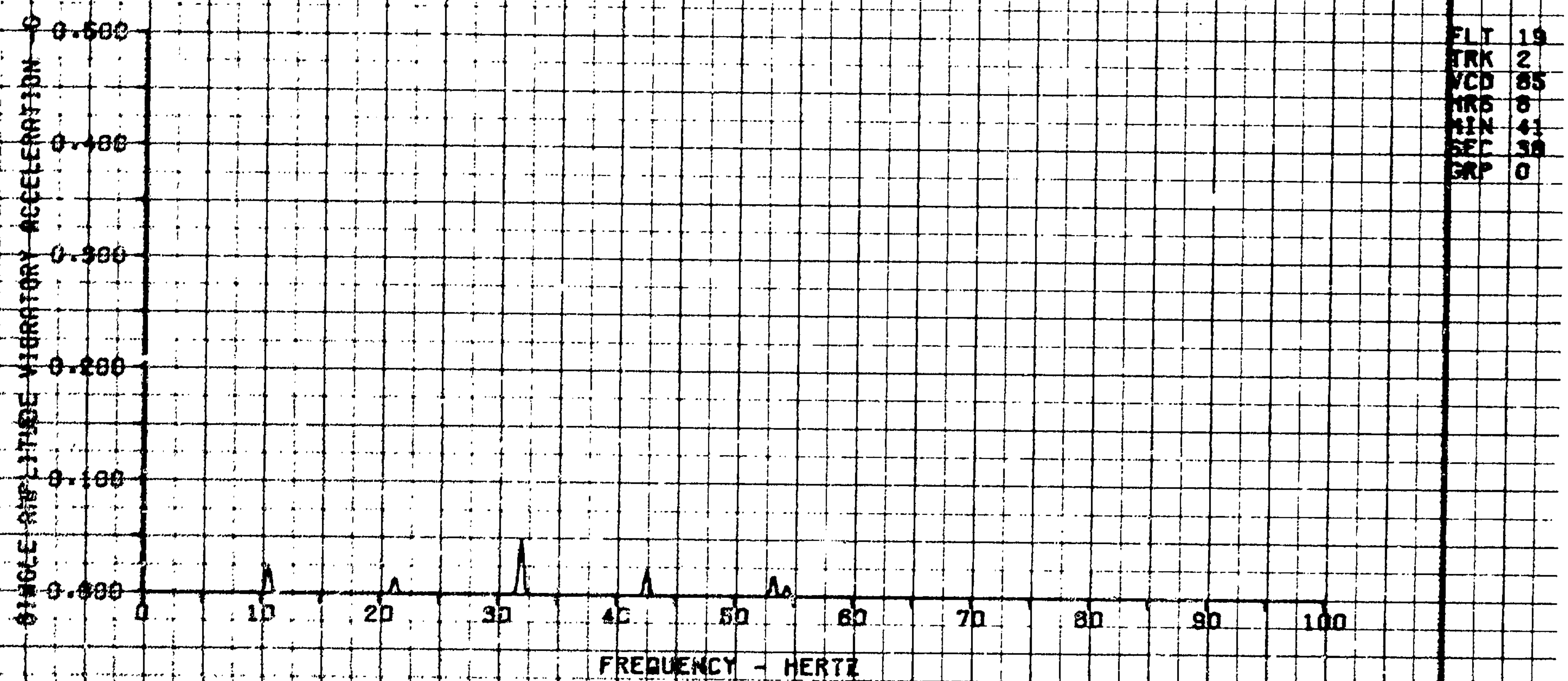


FIGURE 6

VIBRATION CHARACTERISTICS

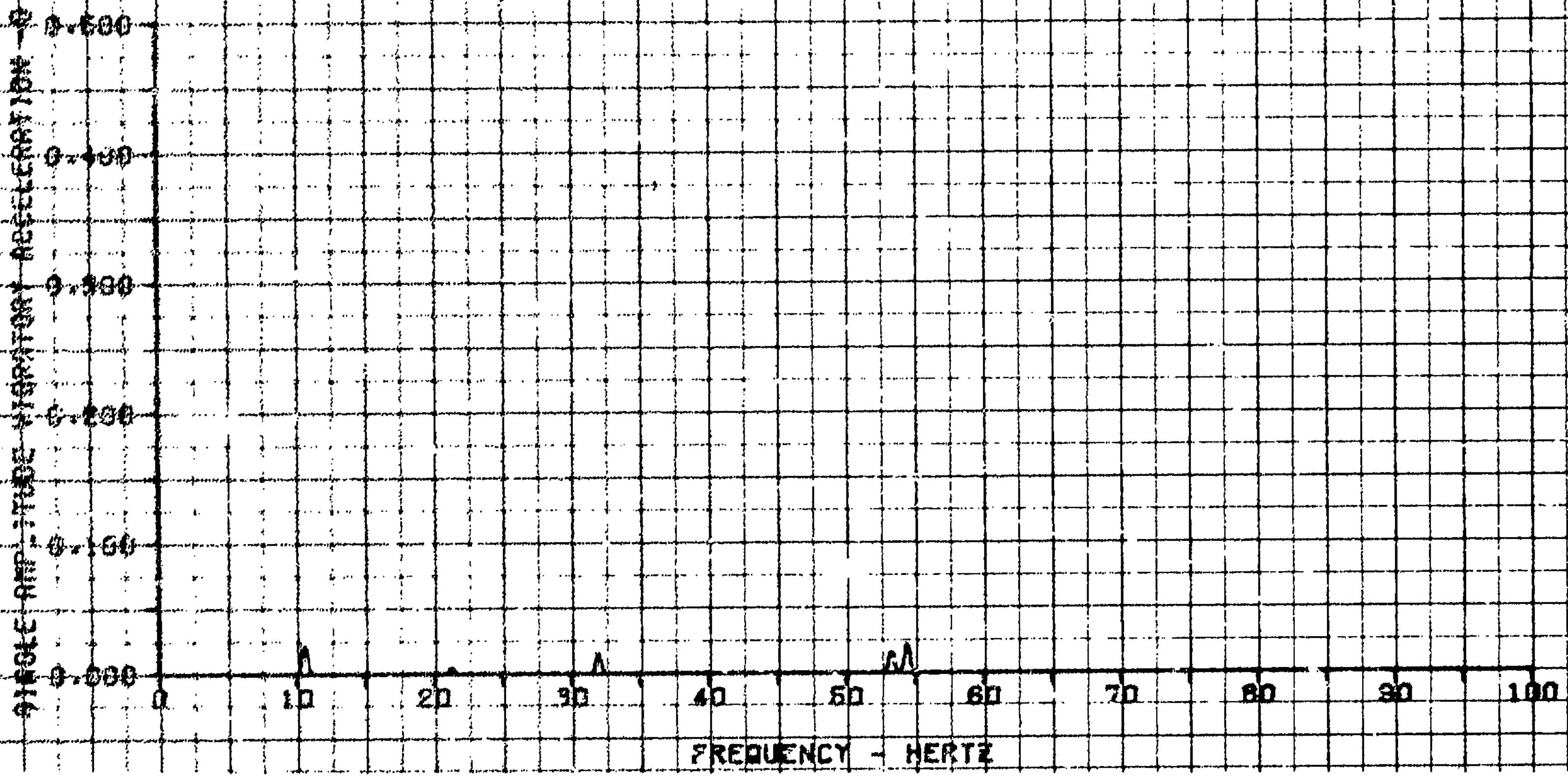
UH-1H USA S/N 67-17145

LOCATION COPILOT SEAT

AXIS LONGITUDINAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
8800	138.0	5.0	8150	-10.0	324	80	LF TRIM	CLEAN



FLT
TRK
VCD
HRS
MIN
SEC
GRP

FIGURE 7

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION A/C CENTER OF GRAVITY
AXIS LATERAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
6800	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN

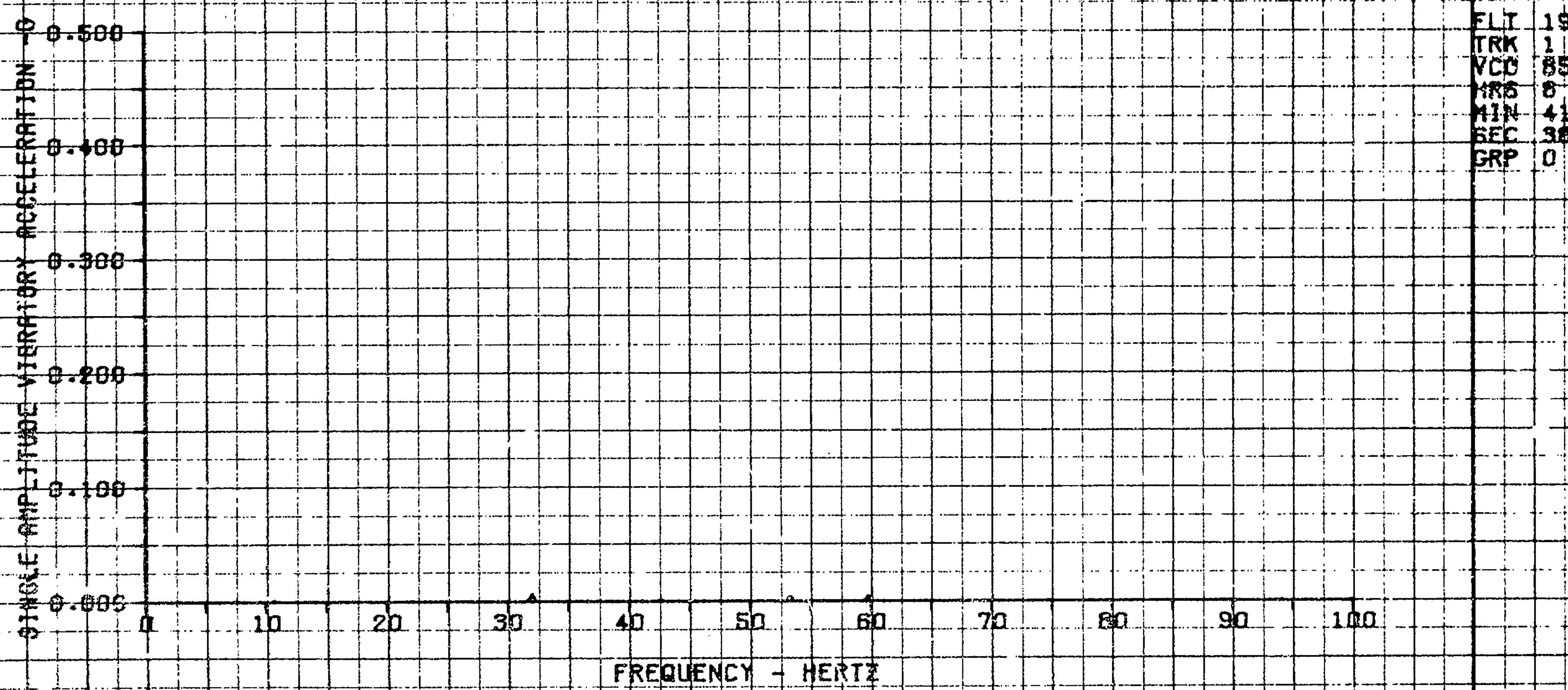


FIGURE 8

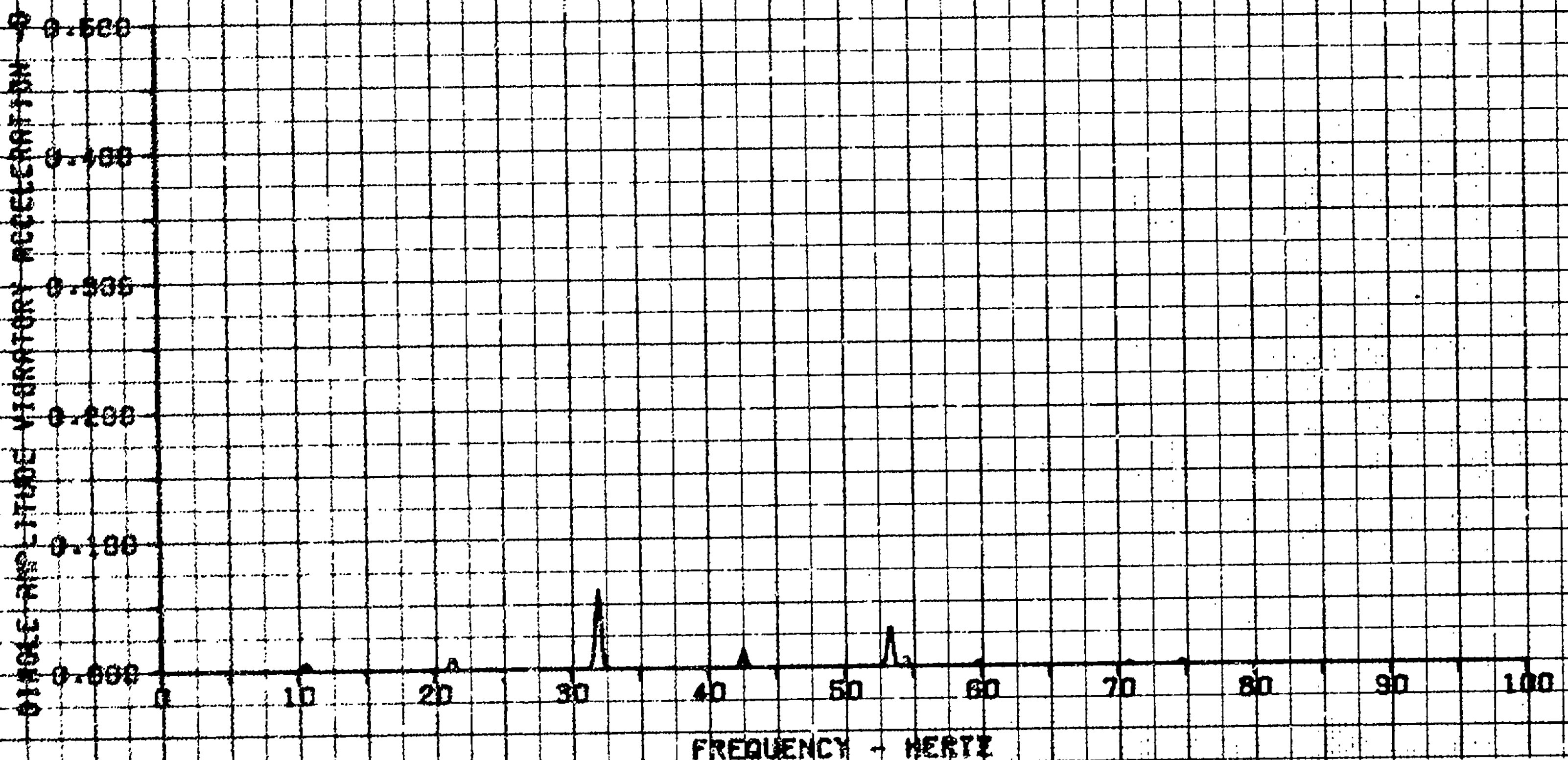
VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION A/C CENTER OF GRAVITY
AXIS VERTICAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
8000	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT 19
TRK 1
VCD 100
HRS 8
MIN 41
SEC 38
GRP 0

FIGURE 9

VIBRATION CHARACTERISTICS

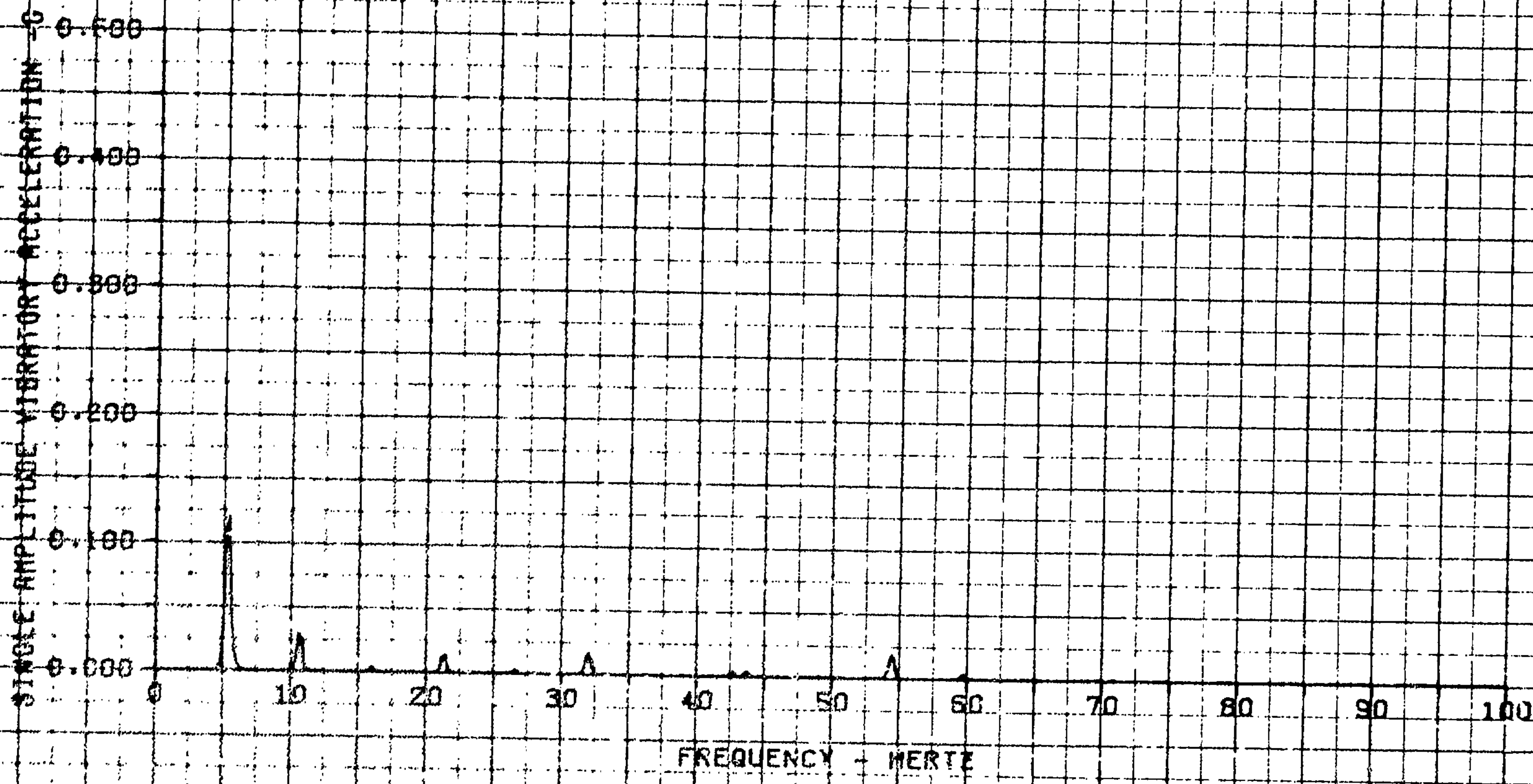
UH-1H USA S/N 67-17145

LOCATION PILOT SEAT

AXIS LATERAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT 19
TRK 1
VCO 40
MRS 9
MIN 27
SEC 20
GRP 0

FIGURE 10

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION PILOT SEAT

AXIS VERTICAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
6650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN

FLT	19
TRK	1
VCO	65
HRS	9
MIN	27
SEC	20
GRP	0

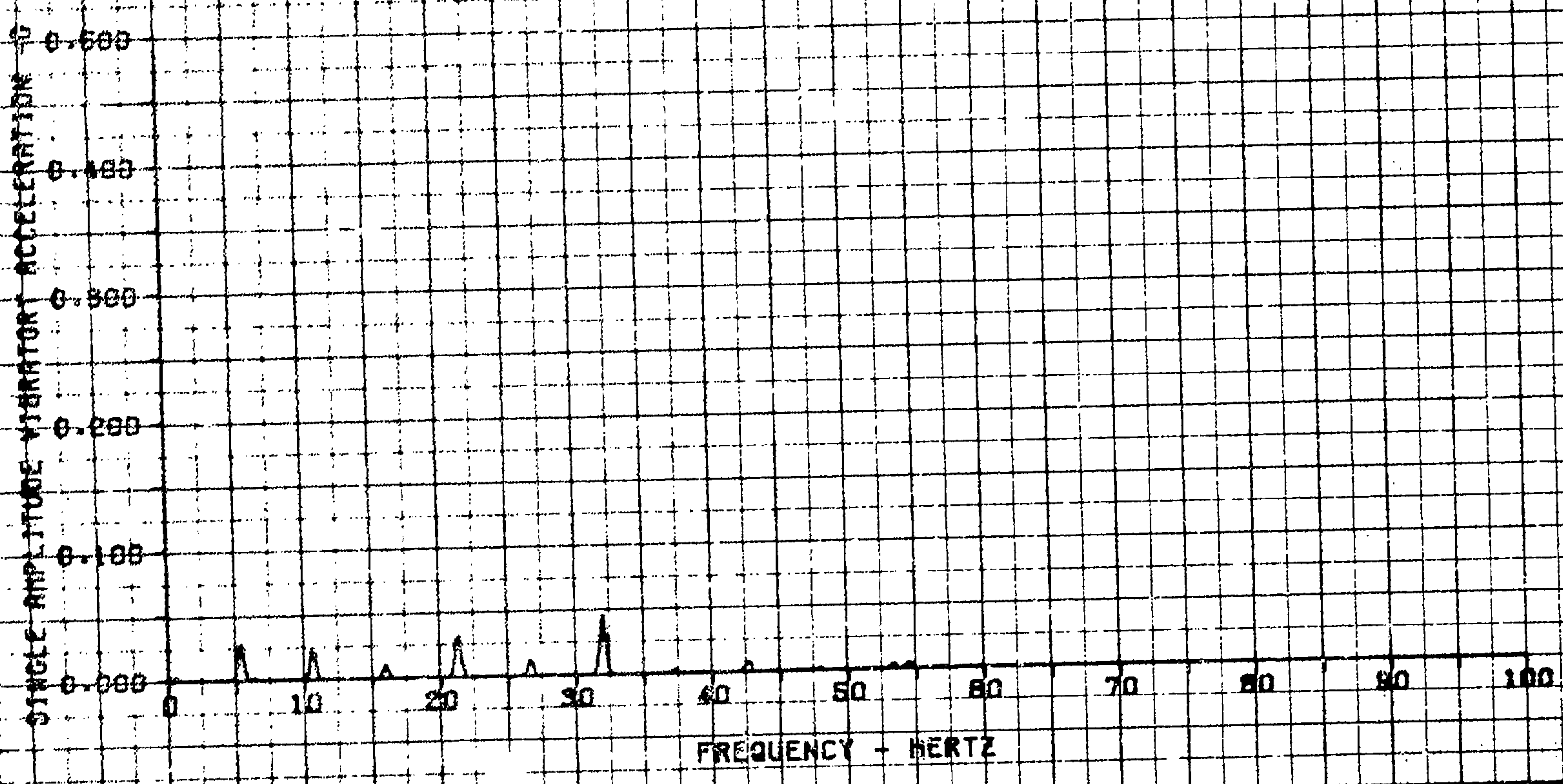


FIGURE 11

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION PILOT SEAT
AXIS LONGITUDINAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN

FLT 19
TRK 2
VCO 100
HRS 9
MIN 27
SEC 20
GRP 0

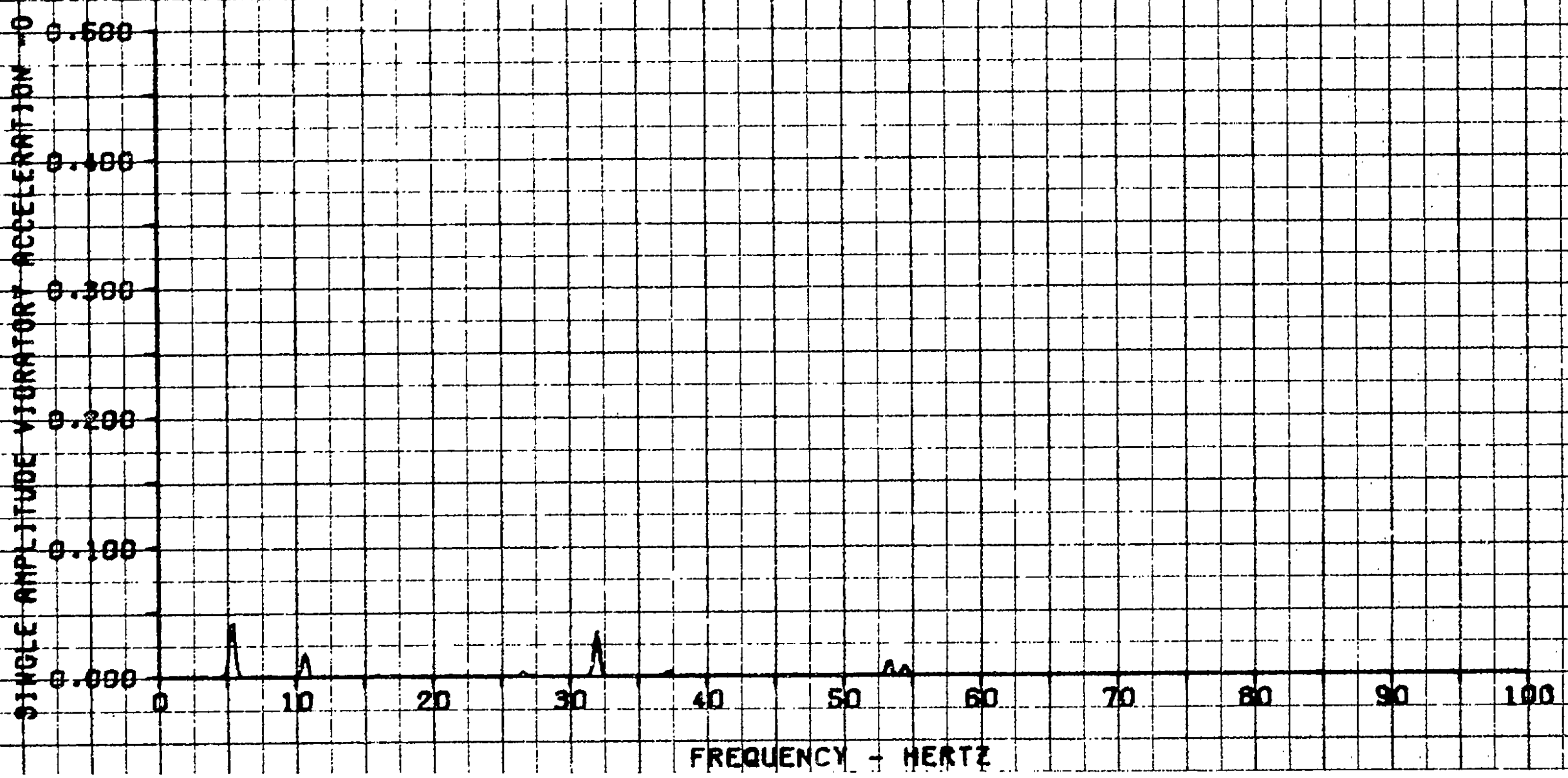


FIGURE 12

VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION COPILOT SEAT
AXIS LATERAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN

FLT	19
TRK	2
VCO	70
HRS	9
MIN	27
SEC	20
GRP	0

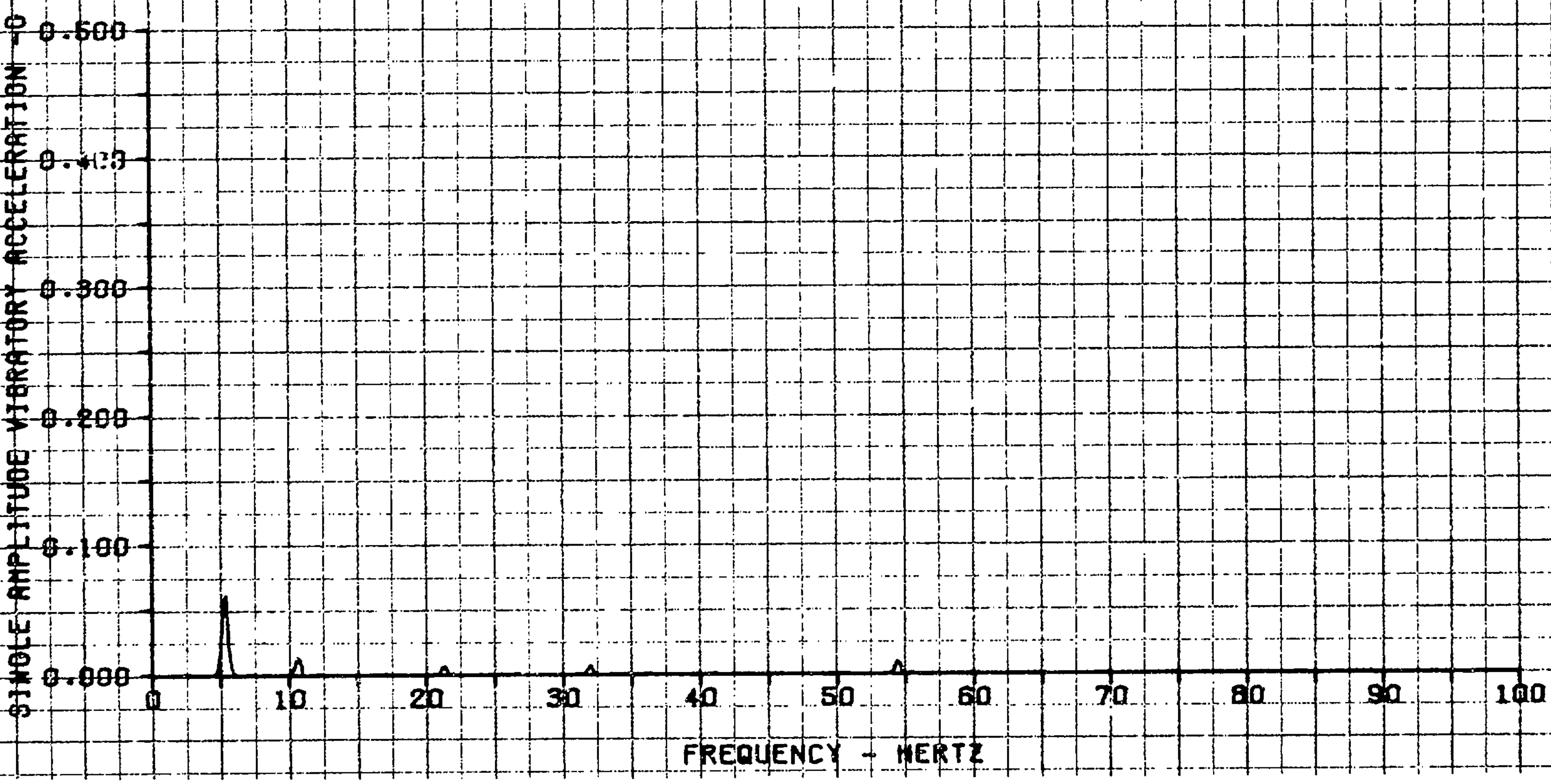


FIGURE 13

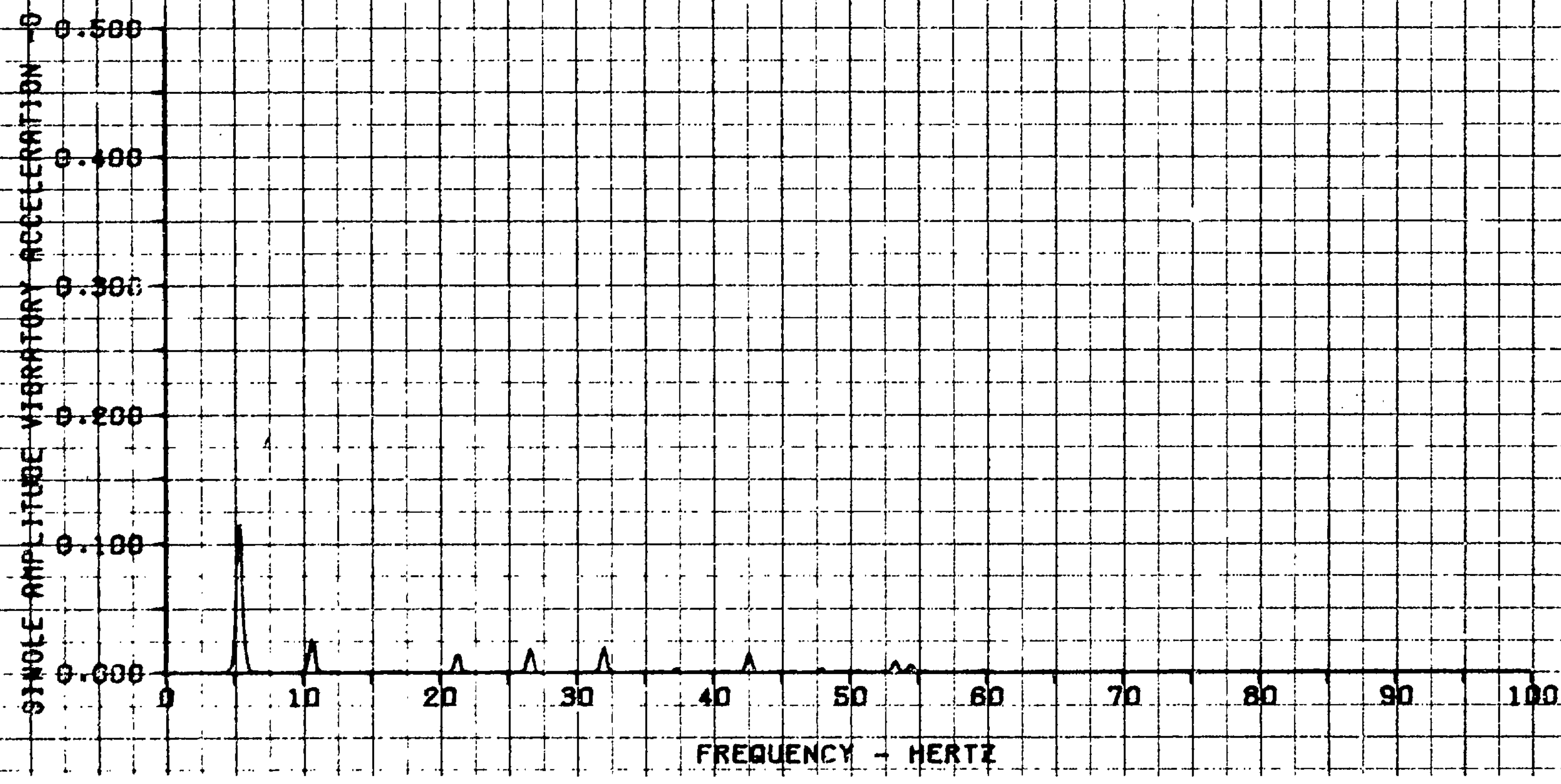
VIBRATION CHARACTERISTICS

UH 1H USA S/N 67-17145

LOCATION COPILOT SEAT
AXIS VERTICAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT 19
TRK 2
VCD 85
HRS 9
MIN 27
SEC 20
GRP 0

69

FIGURE 14

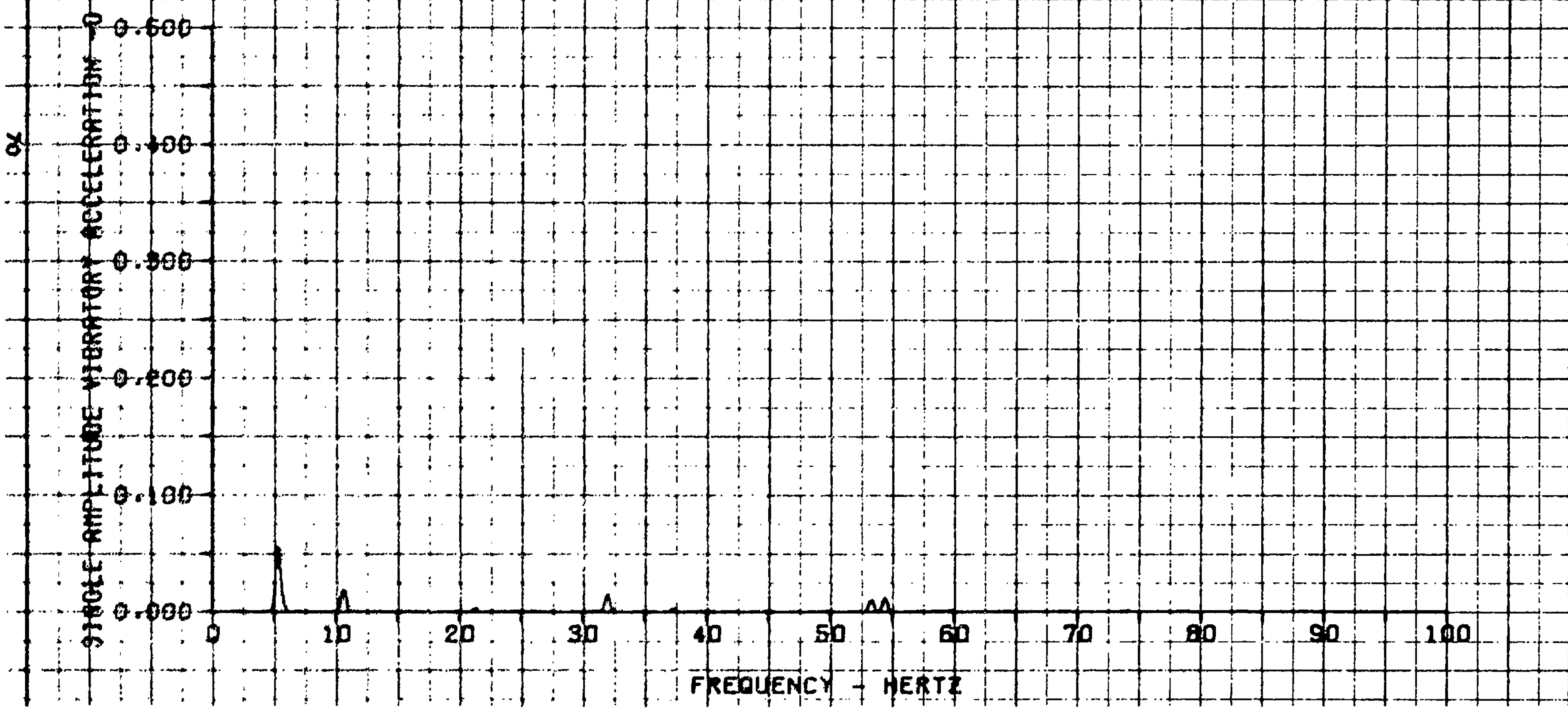
VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION COPILOT SEAT
AXIS LONGITUDINAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT 15
TRK 2
VCO 55
HRS 9
MIN 27
SEC 20
GRP 0

FIGURE 15

VIBRATION CHARACTERISTICS

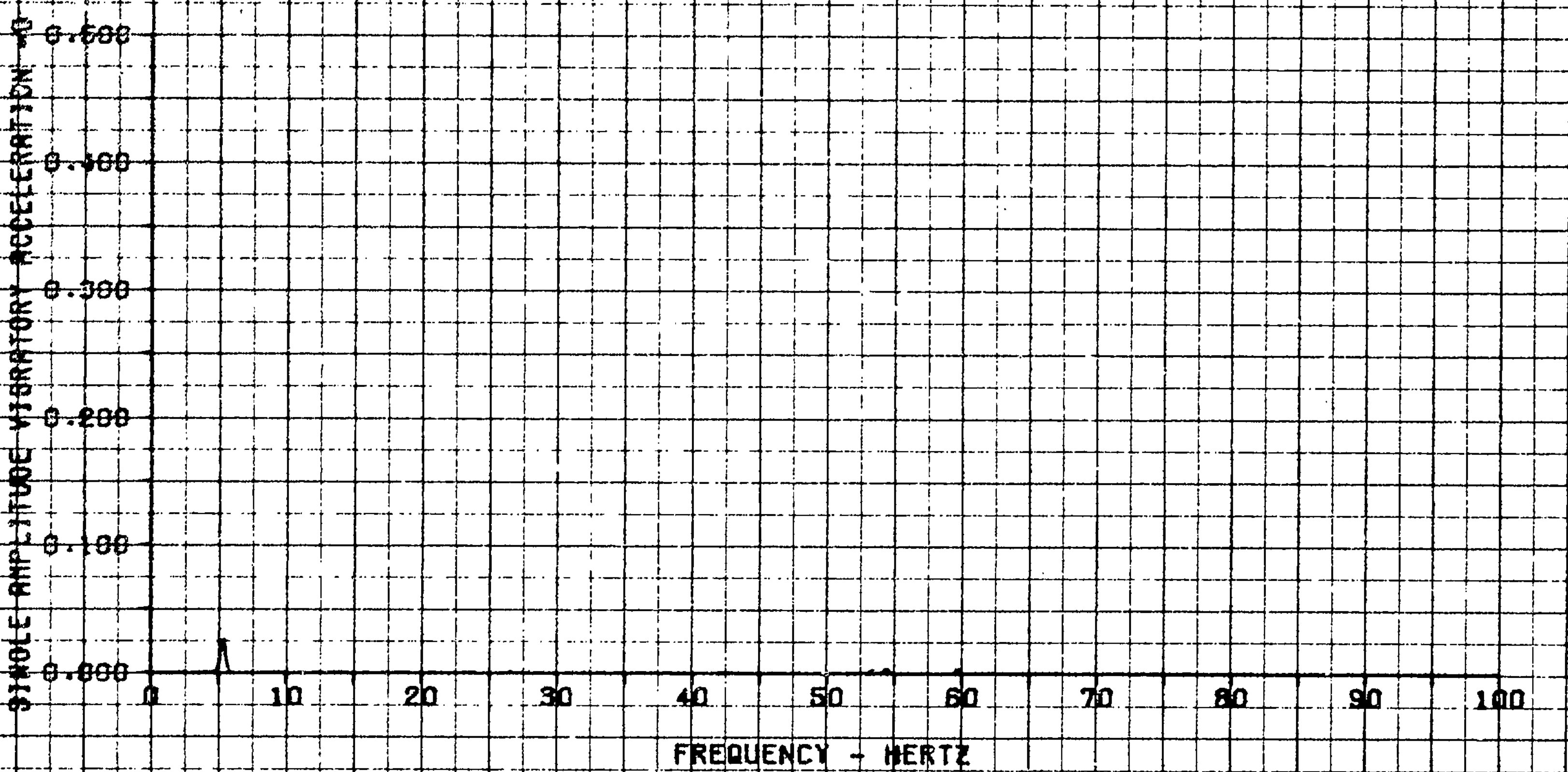
UH-1H USA S/N 67-17146

LOCATION A/C CENTER OF GRAVITY

AXIS LATERAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
6650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT
TRK
VCO
HRS
MIN
SEC
GRP

71

FIGURE 16

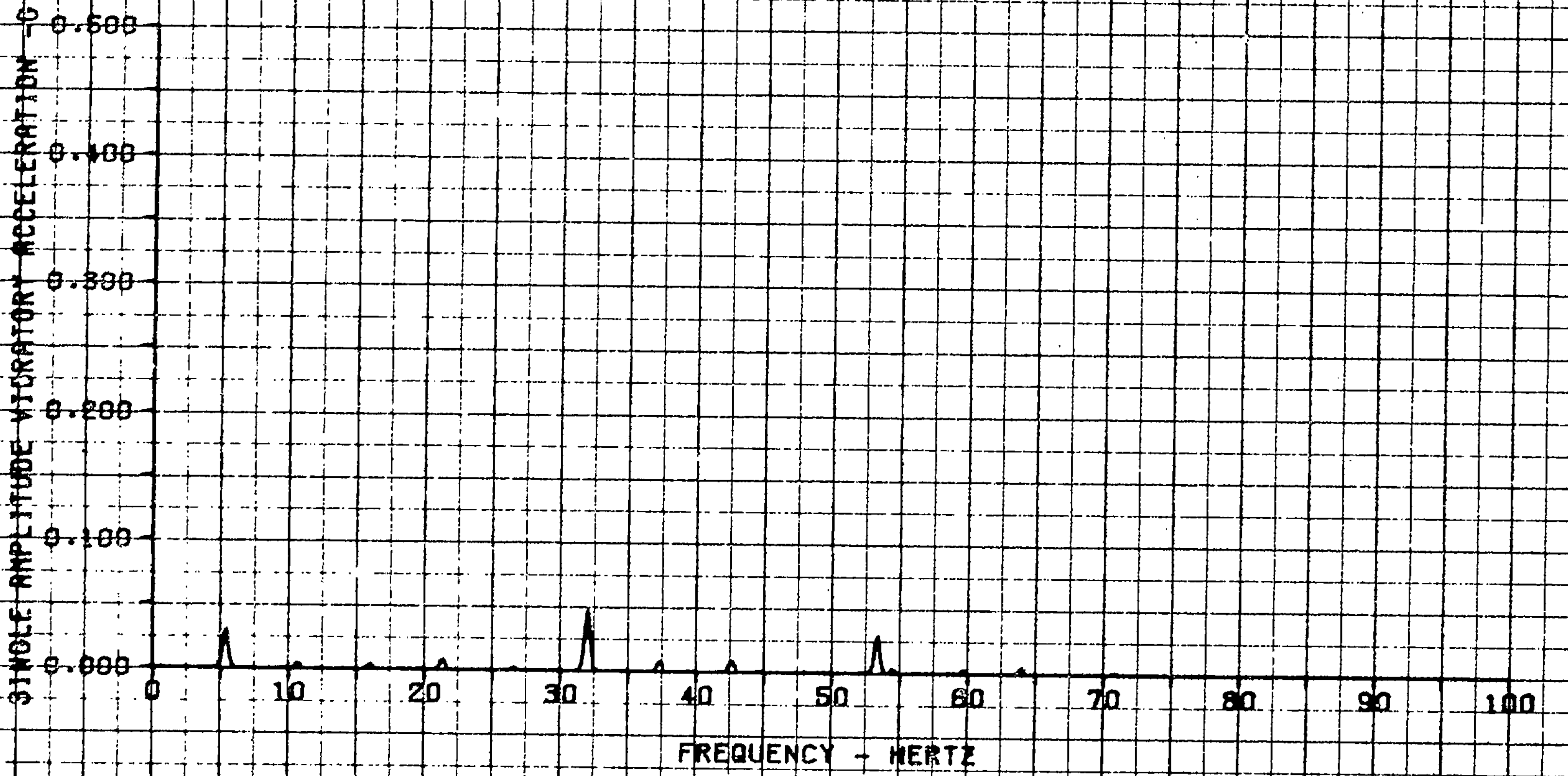
VIBRATION CHARACTERISTICS

UH-1H USA S/N 67-17145

LOCATION A/C CENTER OF GRAVITY
AXIS VERTICAL

FUNDAMENTAL FREQUENCY IS 5.40 HZ

AVG GROSS WEIGHT LB	LONG CG FS IN	LAT CG BL IN	AVG DENSITY ALTITUDE FT	AVG OUTSIDE AIR TEMPERATURE DEG C	ROTOR SPEED RPM	TRIM TRUE AIRSPEED KTS	FLIGHT CONDITION	CONFIGURATION
5650	138.0	0.0	9150	-10.0	324	80	LF TRIM	CLEAN



FLT 19
TRK 1
VCO 100
HRS 9
MIN 27
SEC 20
GRP 0

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