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EVALUATION OF THE IMPROVED OV-1D ANTI-ICING SYSTEM

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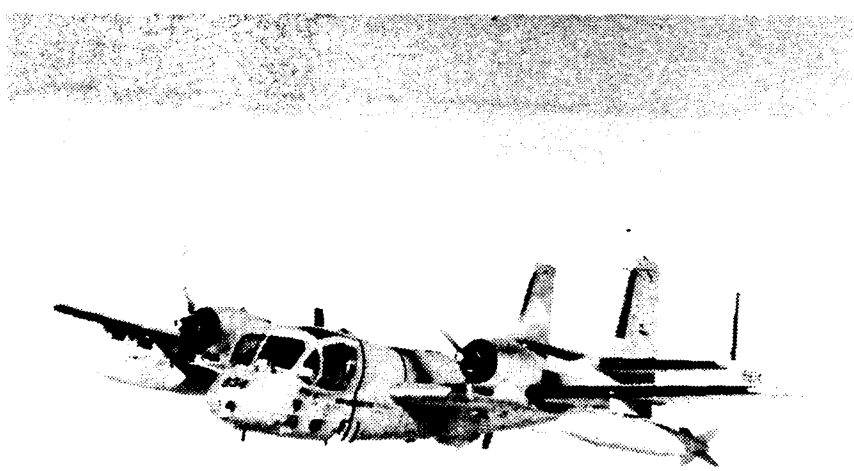
Final Report



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The U.S. Army Aviation Engineering Flight Activity evaluated the improved OV-1D anti-icing system from 28 January to 21 February 1988 at Duluth, Minnesota. Ten flights (6.5 hours cloud immersion) in artificial conditions and four flights (5.8 hours cloud immersion) in natural conditions were conducted. One enhancing characteristic, nine deficiencies, and three shortcomings were identified. The windshield anti-ice system, when working, enhances safe mission accomplishment. The nine deficiencies were: the inability of the pneumatic deicing system to remove wing and empennage leading edge ice accumulations; the excessive number of AC generator drive shaft failures; the ice accretion characteristics of the engine inlet cowl at temperatures colder than -15 degrees C; the ice accretion and shedding characteristics of the propeller spinner afterbody; the numerous dropouts of one or both windshield anti-ice systems and lack of failure warning to the pilot; the numerous dropouts of the AC generators during flight, the increased pilot workload required to reset them and the distraction caused by illumination of the Master Caution light; the numerous converter dropouts during normal operations, the increased pilot workload required to reset them, and the resulting pilot distractions caused by illumination of the Master Caution light; the numerous inverter dropouts and the ensuing delay and actions required to reestablish flight essential and normal inverter loads; the fact that an anti-ice controller may not be functioning properly and still pass its Operational Readiness Test. The shortcomings were: the ice accretion characteristics of the propellers and the

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damage caused by their shedding characteristics; the illumination of the Master Caution light during anti-ice system activation; the reverse sensing and mislabeled engine anti-ice switch. The deficiencies should be corrected as soon as possible.

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INTRODUCTION

BACKGROUND

1. The U.S. Army Aviation Engineering Flight Activity (AEFA) Project Nos. 80-16 and 81-21 (refs 1 and 2, app A) identified two deficiencies and seven shortcomings with the currently operational OV/RV-1D anti-icing system. The deficiencies were:

a. Ice accretion characteristics of the engine nose cowling assembly, propeller, propeller spinner, and propeller spinner afterbody which may result in engine damage. These deficiencies were predicated on field experience including accidents caused by the ingestion of ice into the engine, and damage incurred during previous icing tests.

b. Failure of the windshield ice protection system to clear the windshield sufficiently to provide an adequate forward field of view after encountering icing conditions

2. Grumman Aircraft Corporation (GAC) developed an improved anti-icing system for the OV/RV-1D aircraft. The U.S. Army Aviation Systems Command directed AEFA to evaluate the improved system in artificial and natural icing conditions (ref 3). Testing was conducted in accordance with the approved test plan (ref 4).

TEST OBJECTIVE

3. The primary objective of this test was to determine ice accretion characteristics of the OV-1D engine, cowling assembly, propeller spinner, propeller spinner afterbody, and cockpit windshield with the improved anti-icing system in moderate icing conditions. A secondary objective was to determine the reliability, maintainability, and failure/troubleshooting indications provided by the system.

DESCRIPTION

4. The test aircraft was an OV-1D(C), S/N 68-15934. The OV-1 is a two-place, twin turboprop aircraft with a midwing design, triple vertical stabilizers and tricycle landing gear. A more complete description of the OV-1 is contained in the operator's manual (ref 5). The test aircraft was modified with an improved AC electrical and anti-ice system using 3 phase AC electric power provided by new 24 Kilo Volt-Ampere AC generators. A detailed description of the improved AC electrical and anti-ice system is presented in appendix B.

TEST SCOPE

5. The OV/RV-1D improved anti-ice system was evaluated in the Duluth, Minnesota area from 28 January to 21 February 1988 in artificial and natural icing conditions. Ten flights were conducted in artificial icing conditions totaling 15.0 flight hours of which 6.5 hours were accumulated during actual immersion in the artificial cloud. Detailed artificial icing test conditions are presented in table 1 located in the Results and

Discussion section. After satisfactory completion of the artificial icing tests, the improved system was evaluated in natural icing conditions. Four flights were conducted in natural icing conditions totaling 5.8 hours of actual cloud immersion. Detailed natural icing test conditions are presented in table 2 located in the Results and Discussion section. Operating limitations contained in the operator's manual and in the airworthiness release (ref 6, app A) were observed during the test.

TEST METHODOLOGY

6. Artificial icing tests were conducted by immersing one-half of the aircraft in the artificial icing cloud generated by the Helicopter Icing Spray System (HISS) which is configured on a JCH-47C helicopter. A more detailed description of the HISS is presented in appendix C. The cloud conditions were documented by a U-21 aircraft configured with cloud measuring equipment. This equipment is further described in appendix D. The test aircraft was flown at 120 knots true airspeed (KTAS) with one-half of the aircraft in the artificial cloud for approximately 45 minutes for each test condition. Photographic data and qualitative ice accretion characteristics were obtained from observers onboard the JCH-47, U-21, and the OV-1D aircraft.

7. During the natural icing tests, the OV-1 was flown in the cruise configuration (gear and flaps up) at cruise power (60 percent torque and 1450 rpm) which resulted in an airspeed of approximately 190 KTAS. The U-21 equipped with the cloud measuring equipment documented the test conditions and provided air-to-air photo documentation after the icing encounter. Natural icing test techniques are further discussed in appendix D.

RESULTS AND DISCUSSION

GENERAL

8. The evaluation of the OV-1 Improved Anti-Ice System was conducted first in artificial icing conditions and then in natural icing conditions. The ice accretion characteristics were evaluated at the conditions in tables 1 and 2. Documentation is presented in figures E-1 through E-16. For artificial icing conditions, one half of the aircraft was immersed in the HISS cloud for approximately 45 minutes at 120 KTAS for each test point using a standoff distance of 150 feet. Once it was determined that the improved system could handle moderate icing in the artificial environment, the system was evaluated in natural conditions.

9. Ten flights were conducted behind the HISS of which only 8 flights were productive. The unproductive flights were the result of inoperative or improperly functioning anti-ice system components. Natural icing flights were conducted when that test condition or a more severe condition was completed in artificial conditions. Four flights totaling 5.8 hours of cloud immersion were conducted in natural conditions. The accretion characteristics of the OV-1 were essentially the same in both artificial and natural conditions.

ENGINE INLET COWL

10. The engine inlet cowls are protected by an anti-ice system (see app B). The engine inlet cowl typically started accreting ice at the junction of the fixed and removable cowl joints as shown in figure E-1. At temperatures colder than -15 degrees C, the joints had a greater accumulation of ice than the remaining engine cowl and ice accumulated inside the inlet lip at these junctures (fig. E-1). Ice accretion inside of the cowl leading edge was more a function of outside air temperature than liquid water content (LWC). After approximately 45 minutes in the cloud, either natural or artificial, at temperatures colder than -15 degrees C, there were 3 to 4 randomly located ice build-ups approximately 3/8 inches thick and 1 inch in diameter inside in the inlet (figs. E-2 through E-5). These accretions were located from 2 to 8 inches aft of the leading edge. At temperatures colder than -15 degrees C there were also some accretions from runback and refreeze on the aft side of the cowl struts, most often at the 4 and 7 o'clock positions. These accretions were up to 3/8 inch thick and up to 2 inches long. These accretions are a potential engine ingestion hazard. The ice accretion characteristics of the engine inlet cowl at temperatures colder than -15 degrees C are a deficiency. Ice accreted on the outside of the engine inlet cowl starting aft of the juncture of the heated and unheated portions of the cowl due to runback. This accretion gradually built forward, but never over the leading edge lip and was not an ingestion hazard to the engine except at the joints of the fixed and removable cowls. These ice formations would occasionally break away without causing any apparent damage.

Table 1. Artificial Icing Tests

Flight Number	Outside Air Temperature (Deg)	Average Liquid Water Content (gm/m³)	Median Volumetric Diameter (microns)	Relative Humidity (percent)	Time In Cloud (hour)	Average Pressure Altitude (ft)	Equivalent Icing Condition	Remarks
1	-6.0	.55	31	55	0.6	4650	Moderate	Rt side imnmersed, EMER mode, generator dropped off-line, could not reset
2	-20.0	.60	28	19	0.5	5360	Moderate	Rt side immersed, NORM mode, aborted due to #2 engine chip light.
3	-21.0	.29	37	18	0.75	7170	Light	Rt side immersed, EMER and NORM mode, numerous components went off-line.
4	-19.0	.63	39	61	0.75	6365	Moderate	Rt side anti-ice conroller changed. Windshield powered by inverter.
5a	-17.1	.34	N/A	39	0.5	5240	Light	Rt side immersed, EMER, then NORM modes.
5b	-16.8	.60	32	36	0.5	5383	Moderate	Lt side immersed, EMER mode.
7	-9.7	.67	32	33	0.75	7449	Moderate	Rt side immersed, generator shaft sheared.
8	-8.7	.78	38	24	0.63	7448	Moderate	Lt side immersed, generator shaft sheared.
11a	-21.9	.65	25	47	0.62	5030	Moderate	Rt side immersed, modified controller used.
11b	-21.9	.63	25	47	0.58	5260	Moderate	Lt side immersed, unmodified controller used.

Table 2. Natural Icing Tests

Flight Number	Outside Air Temperature (Deg)	Average Liquid Water Content (gm/m^3)	Median Volumetric Diameter (microns)	Time In Cloud (hour)	Average Pressure Altitude (ft)	Equivalent Icing Condition	Remarks
6	-20.0	.10	14	0.75	11000	Trace	
9	-11.5	.43	16	2.0	7150	Light	1500 psi shear section generator shaft installed.
10	-4.5	.40	12	2.0	3500	Light	1500 psi shear section generator shaft in #1 engine sheared
12	-5.0	.25	N/A	1.0	4000	Light	Both generator shafts sheared during flight.

PROPELLER BLADES AND PLATEAUS

11. The propeller blades and plateaus are protected by a deice system (see app B). At temperatures colder than -15 degrees C, the propellers accreted ice to approximately three quarters of an inch. Ice accreted on the plateaus to approximately one-half inch radially out from the plateaus. When these components deiced, airframe vibration would increase and chunks of ice would impact the side of the fuselage and drop tanks causing slight damage (fig. E-6 and E-7). The ice accretion characteristics of the propellers and damage caused by their shedding characteristics are a shortcoming.

PROPELLER NOSE AND SPINNER

12. The propeller spinner nose was anti-iced at the aluminum cap only (fig. E-8). During artificial and natural tests, the spinner accreted ice in a donut or crown shape which was observed during one shed to go down through the propeller and away from the engine inlet area. Spine type splinter ice formations started growing on the spinner portion just aft of the "crown" and accumulated to a depth of 1/2 to 1 inch with the higher (0.5) LWC's and lower (-15 degrees C) temperatures (fig. E-8). Grumman analysis showed that any accretions on the spinner aft of the aluminum cap would be thrown out of the engine inlet area by centrifugal force and, therefore, was not considered to be an ingestion hazard to the engine. No ice from the propeller nose and spinner was observed being ingested by the engine.

PROPELLER SPINNER AFTERBODY

13. Spine shaped ice accreted on the spinner afterbody on the bottom portion from the 4 to 8 o'clock positions from the leading edge of the afterbody to approximately 6 inches aft (fig. E-9). During a natural icing encounter, ice accreted at the leading edge of the afterbody and grew forward to the point where it was impacted by the rotating propeller blade shank. When a section of the accretion was impacted by the propeller blade shank, it broke off and was ingested into the inlet and, therefore, is an ingestion hazard to the engine. The ice accretion and shedding characteristics of the propeller spinner afterbody in light and moderate icing conditions are a deficiency.

ICE DETECTOR PROBE AND TEMPERATURE SENSOR

14. Ice accumulated on the leading edge of both the ice detector probe and the temperature sensor, figures E-10 and E-11. The accretion did not appear to affect the operation of the system. The ice accretion characteristics of the ice detector probe and the temperature sensor are satisfactory.

OIL COOLER SCOOP AND SPLITTER

15. The engine oil cooler inlet anti-ice boots were removed for the improved system. The area accreted a significant amount of ice, however, no deteriorated engine oil cooling conditions were noted. The engine oil cooler inlet has a splitter which provides cooling air to the area between the exhaust pipe and the wing. A study conducted by GAC showed that there was no significant increase in wing temperature under the exhaust pipe with the air duct clogged when operating in icing conditions. The ice accretion characteristics of the engine oil cooler inlet area are satisfactory.

WINDSHIELD ANTI-ICE

16. The windshield anti-ice system kept the windshield clear for all conditions tested except during dropouts. There was a small segment on the outboard portion of each windshield that was not heated and did accrete a small amount of ice, however, this accretion caused no problem. The windshield anti-ice system is satisfactory and enhances safe mission accomplishment. However, the unreliability of the system was undesirable.

17. Numerous dropouts occurred on one or both windshield anti-ice systems. There is no indication to the pilot other than a frosty or foggy windshield that one or both windshield anti-ice systems is inoperative. On occasion, when normal descents from altitude to landing were made, the windshield fogged up on short final. If the pilot knew the windshield anti-ice system was inoperative, he could prepare for a fogged windshield by recycling the system or by increasing the amount of hot air directed to the windshield. The numerous dropouts of one or both windshield anti-ice systems and lack of failure warning to the pilot are a deficiency.

PERFORMANCE AND FLYING QUALITIES

18. Performance degradations were noted for each icing condition evaluated. The most notable degradation was in natural icing conditions at .43gm/m3 LWC and -11.5 degrees C with mean volumetric diameters ranging from 14 to 17 microns. The icing condition was entered at 185 (knots indicated airspeed) KIAS at a cruise power setting of 1450 rpm and 60% torque. After 30 minutes in the icing environment, airspeed decreased to 135 KIAS with a power setting of 80% torque. The wing deice boots were activated after approximately 1/2 inch of ice had accreted on the wing leading edge, but the boots were ineffective in removing the ice from the leading edges of the wings and vertical and horizontal stabilizers (fig. E-8). After the airspeed had decreased to 135 KIAS and intermittent stall buffet was encountered, a large increment of drag, presumably an ice shape, departed the aircraft and the airspeed increased rapidly to 195 KIAS. The inability of the pneumatic deicing system to remove wing and empennage leading edge ice accumulations in a moderate icing environment is a deficiency and will degrade mission accomplishment. The following warning should be placed in the operator's manual:

WARNING

When flying in icing conditions, if the indicated airspeed decreases as much as 15 knots within a 5 minute period or decreases to 145 knots with a power setting for maximum range airspeed, the airframe ice protection system may become ineffective and the icing conditions should be exited immediately.

ENGINE DAMAGE

19. The engine was visually inspected after each flight. There was no evidence of engine damage during either artificial or natural icing tests.

AIRFRAME DAMAGE

20. Propeller ice sheds occurred in all of the icing conditions tested. Ice departing the blades frequently hit the fuselage empennage or fuel drop tanks. Figure E-6 depicts fuselage damage resulting from propeller ice sheds. Dents as large as 3/8 inch deep and 4 inches in diameter were observed on one drop tank (fig. E-7). Airframe and stores damage caused by ice shedding from the propellers is a shortcoming as discussed in paragraph 11.

PROPELLER DAMAGE

21. During a flight in natural icing conditions, a large chunk of ice, approximately 2 inches by 5 inches was observed to shed from the right windshield wiper arm and go through the right propeller, causing impact damage to one of the blades. The propeller blade damage is shown in figures E-12 and E-13. Ice accumulation on the left windshield wiper is shown in figure E-14.

MISCELLANEOUS

22. The following electrical and anti-ice system component malfunctions and/or operating characteristics were unsatisfactory:

Electrical System

23. The anti-ice AC generators dropped off-line numerous times in flight. The generators could always be reactivated by resetting the generator ON-OFF switch. If N1 speed was reduced to flight idle, the AC generators would drop off-line more frequently, and would always drop off-line when power was reduced to ground-idle. The numerous

drop outs of the AC generators during flight, the increased pilot workload required to reset them, and the distraction of the Master Caution light are a deficiency.

Converter Operation

24. The AC converters dropped off-line more frequently than did the AC generators. Each time a dropout occurred, a Master Caution light illuminated and a manual reset of the converter was required. Any time the power levers were reduced to flight idle, the converters dropped off-line. During test flights in icing conditions, there were numerous converter dropouts. It was necessary to conduct the flights with the converters off, powering the windshield anti-ice by the inverter. There were significantly fewer windshield anti-ice dropouts when the windshield anti-ice system was powered by the inverter. The converters dropped off-line when power was reduced to ground idle during landing with resultant illumination of the Master Caution light. The numerous converter drop outs during normal operations, the increased pilot workload required to reset them, and the resulting pilot distractions caused by illumination of the Master Caution light are a deficiency.

Inverter Operation

25. There were numerous occasions when the inverter dropped off-line with the resultant loss of AC instrument power. When the inverter drops off-line or if the pilot needs to go to the BACKUP position to power the converter bus, he must wait several seconds with the inverter switch in the OFF position before the switch can be reset back to ON or to BACKUP. This is an extreme nuisance during instrument conditions. There is another approximately 5 second delay prior to restoration of AC instrument power after the switch is positioned. The numerous inverter dropouts and the ensuing delays and actions required to re-establish flight essential and normal inverter loads are a deficiency.

Engine Anti-Ice Switch

26. The engine anti-ice switch is labeled so that the normal position is down, the center position is off and the up position is EMER. The normal sensing for all other switches is for the normal position to be up. The EMER position should be labeled "BACK-UP" due to the implication that there is an emergency if the switch is in that position. The position simply bypasses the ice detector and turns the system on. Normal temperature sensing and control is still operational through the engine inlet sensors. The reverse sensing and mislabeled engine anti-ice switch is a shortcoming.

RELIABILITY AND MAINTAINABILITY

27. The following components failed one or more times during the evaluation.

Ice Detector

28. The ice detector system, which controls the operation of the anti-ice/deice system when operating in the normal mode, would not operate the system during the first several

flights. The system had to be operated in the emergency position which bypasses the ice detector system. After the third flight, a complete electrical check was performed. A relay in the ice detector was found to be not grounded. Further investigation uncovered a terminal lug with a loose crimp which caused an intermittent connection. Once the correct electrical connections were completed, the system operated satisfactorily. When the ice detector system senses ice it turns the system ON. The system then starts through an Operational Readiness Test (ORT) with resultant illumination of the Master Caution Light and the #1 and #2 ANTI-ICE segment light. The lights go out in 10 seconds if the system passes the ORT and turns the system ON. However, the illumination of the Master Caution light during anti-ice system activation is a nuisance to the pilot and is a shortcoming. Activation of the anti-ice system by the ice detector should be an advisory only.

AC Generators/Drive Shafts

29. During the artificial and natural icing flight tests, a total of five AC generator drive shafts were sheared. This is the short shaft that connects the generator drive to the hydraulic pump drive shaft. Test Incidence Reports were submitted and a copy of each is included in appendix F. Figure E-15 shows the damaged shafts. GAC engineering believes the shafts to be too brittle to withstand the cycling loads imposed by the improved anti-ice system. The excessive number of AC generator drive shaft failures is a deficiency.

Anti-Ice Temperature Controller

30. During the third flight, after the ice detector problem had been fixed, it became obvious that the anti-ice system temperature controller was not functioning properly for the right side, even though it passed the ORT prior to flight. The controller for the left and right side were interchanged and the right side of the system then functioned properly, keeping the ice build-up to a minimum. A new controller was installed on the left side with the result that both systems worked properly. The fact that an anti-ice controller may not be functioning properly and still pass its ORT is a deficiency.

31. When test results showed that ice was accreting at the joints of the fixed and removable cowls and in the inlet at temperatures colder than -15 degrees C, Cox Inc. modified a controller to heat the inlet to a higher temperature. This controller was flown in artificial and natural icing side by side with an unmodified controller. No improvement was noted. The reason for no improvement at the colder temperatures may have been that the system was already operating full time at full power without delivering a higher inlet temperature.

CONCLUSIONS

GENERAL

32. Nine deficiencies and three shortcomings were identified during the Improved OV-1 Anti-Icing System evaluation. The inlet area ice accretions, though still presenting potential engine ice ingestion damage are much less than accetion on the standard OV-1 inlet.

ENHANCING CHARACTERISTICS

33. The windshield anti-ice system, when working, enhances safe mission accomplishments (para 16).

DEFICIENCIES

34. The following deficiencies are listed in order of importance:

a. The inability of the pneumatic deicing system to remove wing and empennage leading edge ice accumulations (para 18).

b. The excessive number of AC generator drive shaft failures (para 29).

c. The ice accretion characteristics of the engine inlet cowl at temperatures colder than -15 degrees C (para 10).

d. The ice accretion and shedding characteristics of the propeller spinner afterbody (para 13).

e. The numerous dropouts of one or both windshield anti-ice systems and lack of failure warning to the pilot (para 17).

f. The numerous dropouts of one or both windshield anti-ice systems and lack of failure warning to the pilot (para 17).

g. The numerous converter dropouts during normal operations, the increased pilot workload required to reset them, and the resulting pilot distractions caused by illumination of the Master Caution light (para 24).

h. The numerous inverter dropouts and the ensuing delay and actions required to reestablish flight essential and normal inverter loads (para 25).

i. The fact that an anti-ice controller may not be functioning properly and still pass is ORT (para 30).

SHORTCOMINGS

35. The following shortcomings are listed in order of importance:

a. The ice accretion characteristics of the propellers and the damage caused by their shedding characteristics (paras 11 and 20).

b. The illumination of the Master Caution Light during anti-ice system activation (para 28).

c. The reverse sensing and mislabeled engine anti-ice switch (para 26).

RECOMMENDATIONS

36. The deficiencies and shortcomings listed in the conclusion should be corrected as soon as practical.

37. The following **WARNING** should be placed in the operator's manual.

WARNING

> When flying in icing conditions, if the indicated airspeed decreases as much as 15 knots within a 5 minutes period or decreases to 145 knots with a power setting for maximum range airspeed, the airframe ice protection system may become ineffective and the icing conditions should be exited immediately.

38. Activation of the anti-ice system by the ice detector should be an advisory only (para 28).

39. The EMER position should be labeled "BACK-UP" due to the implication that there is an emergency if the switch is in that position.

APPENDIX A. REFERENCES

1. Letter, AEFA, DAVTE-TB, July 1981, subject: Report, Limited Artificial Icing Tests of the OV-1D.

2. Final Report, AEFA Project No. 81-21, *Limited Artificial and Natural Icing Tests of the OV-1D (Re-Evaluation)*, June 1982.

3. Letter, AVSCOM, AMSAV-8, 25 November 19878, subject: Evaluation of the Improved OV-1D Anti-Icing System (Test Request).

4. Test Plan, AEFA Project No. 87-25, *Evaluation of the Improved OV-1D Anti-Icing System*, August 1987.

5. Technical Manual, TM 55-1510-213-10, *Improved Electrical Anti-Icing and AC Electrical Systems for A/C 67-15934, OV-1D(C) Mohawk Aircraft, Prototype Flight, Operator's Manual*, 4 August 1978.

6. Letter, AVSCOM, AMCPM-AE, 19 January 1988 with revision 1, 1 February 1988, subject: Airworthiness Release for OV-1D(C), S/N 68-15934, for AEFA Project No. 87-25, Evaluation of the OV-1D Improved Anti-Icing System.

7. Letter, USAAEFA, DAVTE-TI, 22 June 1982, subject: USAAEFA Project No. 80-04-02, Helicopter Icing Spray System (HISS) Evaluation and Improvements.

8. Advance copy, AEFA Project No. 83-10, *Verification of U-21A Cloud Parameter Measurement Equipment and Comparison of Natural and Artificial Ice Accretion Characteristics on Rotor Blade Airfoil Sections*, May 1987.

9. Technical Manual, TM 55-1510-10, *Operator's Manual OV/RV-1D Aircraft*, 4 August 1978.

APPENDIX B. DESCRIPTION OF THE OV-1D IMPROVED ANTI-ICE SYSTEM

GENERAL

1. A description of the ice protection system currently installed on operational aircraft is contained in reference 8, appendix A. For the U.S. Army Aviation Engineering Flight Activity Project 87-25 evaluation, aircraft OV-1D(C) serial number 68-15934, was modified with an Improved Anti-Ice System using three-phase AC electric power provided by two new 24 Kilo-volt-Ampere (KVA) AC generators. A photo of the propeller and engine inlet is shown in figure E-16.

AC ELECTRICAL POWER

2. The AC power system was modified by a preliminary engineering change proposal GR-OV-334 and consists of the following changes:

OLD SYSTEM:

(2) 6.5 KVA 115V variable frequency AC electrical generator system

(1) 750 VA rotary inverter

(1) 2500 VA rotary inverter

NEW SYSTEM:

(2) 24 KVA 115V 400 Hz nominal variable frequency 306 to 480 Hz generator

(2) 10 KVA 115VA 400 Hz converter

(1) 10 KVA 115V 400 Hz static inverter

A schematic of the new AC electrical system is shown in figure B-1.

3. The AC system contains two AC buses; an inverter bus and a converter bus. The inverter/converter bus crossover relay (K77) will automatically combine the two buses through the weight on wheels switch. This is required because the converter output will be cut off when its respective AC generator speed is reduced below 9200 rpm. The 10 KVA inverater will supply mission loads to the converter bus through the inverter/converter bus crossover relay to provide pre-flight operations to the mission equipment. Failure of the inverter for any reason, such as an undervoltage condition not corrected within 4 seconds, will cause the inverter output relay (K76) to de-energize. The inverter input relay (K11) will de-energize, taking the inverter off line. Whenever the output relay (K76) de-energizes, it will automatically energize the inverter/converter bus crossover relay (K77) through normally closed contacts.

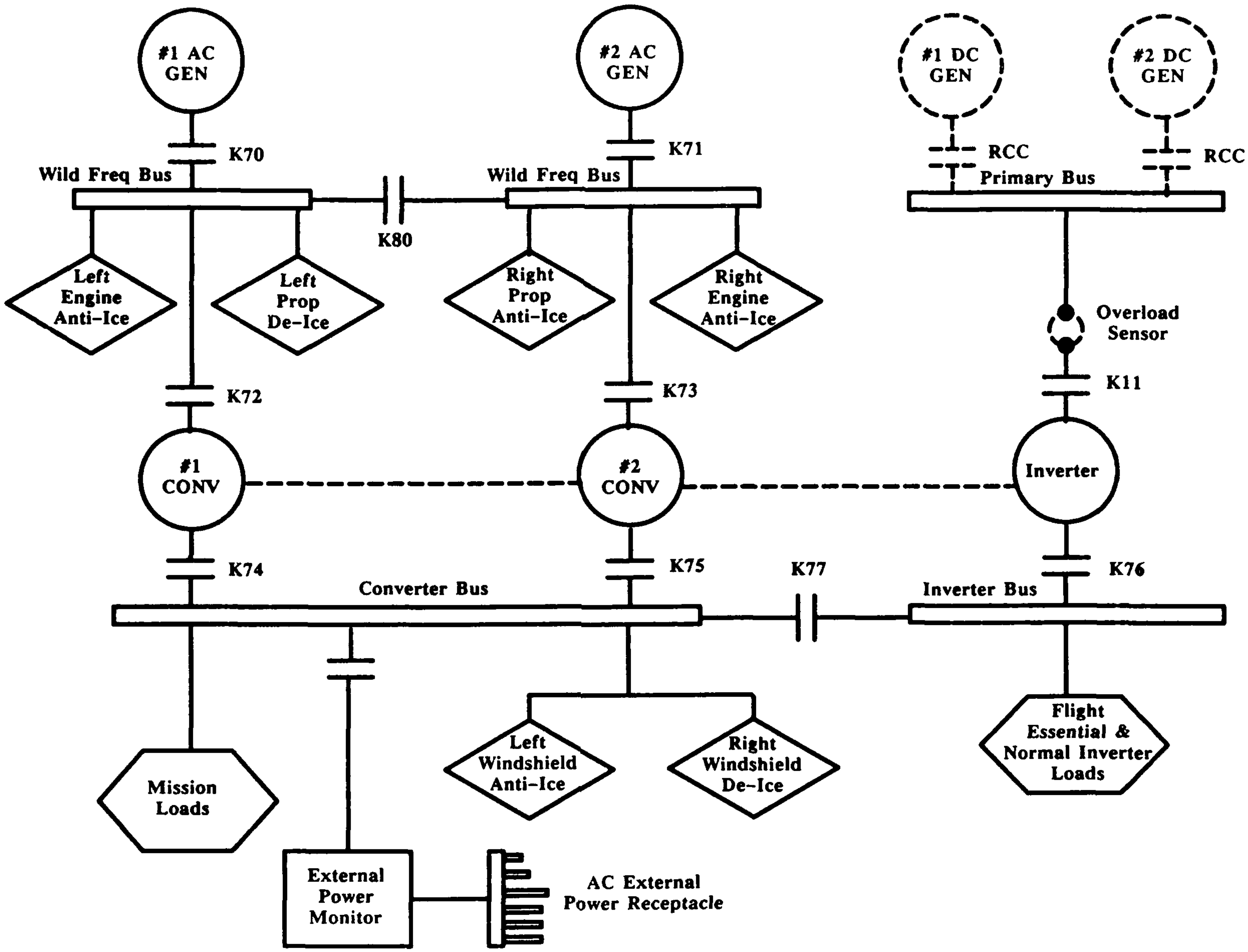

Figure B-1. AC Electrical System Schematic

4. The pilot can manually energize the crossover relay to provide inverter power to the converter bus by moving the inverter selector switch to the backup mode. If the converters are lost, the inverter will provide power to the windshield anti–ice system as well as the flight essential loads through the inverter/converter crossover relay contacts.

AC Generators

5. The AC generators are manufactured by Leland Electrosystems, Inc. and each provide 24 KVA, three–phase power of 115/200 volts, variable frequency (400 Hz nominal) to its respective left or right 10 KVA converter at 11200 rpm. At lower speeds, the generator output is gradually reduced to 12.5 KVA at 8900 rpm. Below 8900 rpm, the AC generators will cut off. During normal operations, the No. 1 AC generator supplies the left side of the anti-ice/deice system and also the No. 1 converter. The No. 2 AC generator supplies the right side of the anti-ice/deice system and the No. 2 converter. In the event of a loss of either generator, a warning light will illuminate in the cockpit indicating failure.

6. The pilot can manually activate an AC generator crossover bus relay (K80) which permits one AC generator to power the total anti-ice/deice system and both converters. The AC generator crossover bus relay is normally open. Upon failure of either generator in icing conditions, the pilot would dump the mission loads and energize the AC generator crossover bus relay (K80), allowing one generator to feed both converters which would supply windshield anti-ice. Further, this switching action prevents the possibility of paralleling the generators together which would result in an overcurrent condition.

7. The following warning light indicators are available within the cockpit for pilot:

#1 AC GEN

#2 AC GEN

#1 CONV

#2 CONV

INV

#1 ANTI-ICE

#2 ANTI-ICE

8. Each AC generator is protected by its respective Generator Control Unit (GCU), which is located in the lower nacelle area. The GCU senses over/undervoltage, underspeed, short circuit, overcurrent, overtemperature, and feeder faults. An underspeed fault will reset automatically whenever the generator speed falls below 8750 rpm or increases above 8900 rpm. Manual reset is accomplished by positioning the appropriate AC GEN switch to OFF and then back to ON. The system will only reset if the fault is cleared.

10 KVA Converters

9. Two 10 KVA converters, manufactured by Leland Electrosystems, Inc., have been provided to convert 115/200V, wild frequency (nominal 400 Hz), from the AC generators and convert it to a regulated 115/200V AC precise 400 Hz output. The two 10 KVA converters normally operate in parallel to a common bus and provide power to the camera systems, side looking airborne radar set or the infrared set (IR) and the windshield anti-ice system. The converters are located in the top of the equipment bays above the KD-76 camera, fuselage station (FS) 204, and the aft KA-60 camera, FS 248. Each converter weighs approximately 90 lb.

10. The converter assembly is divided into two major power stages: AC-DC Stage, and DC-AC Stage. These stages, when combined, produce regulated 400 Hz power.

First Stage: AC-DC Stage takes 115/200V AC wild frequency from the AC generator, and rectifies and filters it to produce an unregulated ±135 VOLTS DC.

Second Stage: Converts ±135 VOLTS DC into a regulated 115/200V AC precise 400 Hz using Sinusoidal Pulse-Width Modulation Technique. This technique switches the ±135V DC into positive and negative half cycles of 400 Hz by driving the output with sine-weighted pulses.

11. A microcontroller is constantly monitoring the converter input/output and also synchronization/load sharing conditions. It will respond to the following failure conditions: Input Over/Undervoltage; Output Over/Undervoltage; Output Over/Under Frequency; Overtemperature; Short Circuit; Wave Form Distortion; Input Under Frequency.

12. The converters have a rated output of 10 KVA continuous, 15 KVA overload for five seconds and 12.5 KVA overload for five minutes with an efficiency of approximately 80%. The converters are controlled by the AC CONV No. 1 and No. 2 switches on the left pilot's overhead panel. The ON position enables the converter to perform normal regulatory and monitoring functions. The OFF position disables the converter and establishes a reset. The converter requires that its respective AC generator be on-line (unless K-80 relay is operational) and above 9200 rpm. There are no conditions in which the converter will automatically reset after a fault has occurred.

13. The failure of one 10 KVA converter does not present a problem, the remaining converter can supply the entire mission and windshield anti-ice load. Failure of both converters will cause mission load to be lost, however, the 10 KVA inverter can power mission equipment for this condition by energizing the inverter/converter bus crossover relay (K77).

Static Inverter

14. The AC power generation system utilizes one static inverter which is manufactured by Leland and supplies power to operate flight essential instrumentation and normal inverter loads. The inverter's function is to take input 28 volts DC from the primary bus

and generate 115/200V AC. It is capable of operating individually or in conjunction with two converters to supply a common three phase AC bus. The inverter and converter have identical microcomputer-controlled DC-AC power inverter stages and are designed to precisely load share, however, the inverter has a ten second time delay built-in before output power is provided.

15. The normal rated output of the inverter is 10 KVA. The inverter has built-in protection for the following fault conditions: overtemperature; wave form distortion; over/under frequency condition; over/under input and output voltage condition. It is also protected by an overload sensing control in the 28 VDC primary bus input. Excess input current through the overload sensing control results in shutdown of the inverter with illumination of the INV annunciator and master caution light. All of the above failures require a manual reset by positioning the INV switch to OFF and then back to NORMAL. The system will only reset if the fault has been cleared. If the inverter fails with the INV switch in the NORMAL position, the converter bus power is automatically connected to the inverter bus through K-77 relay. The inverter bus will be powered by the converter bus if the inverter fails in the OFF or BACKUP mode. If both converters fail, the inverter switch needs to be placed to the OFF position for 5 seconds, then to BACKUP. The inverter will provide sufficient AC power to operate normal aircraft systems and windshield anti-ice. If the inverter fails while both converters are failed, no backup AC source and no engine or propeller ant-ice/deice is available.

AC External Power

16. The AC system includes provisions for connecting an external source of regulated, three-phase, 115/200 V, 400-cycle AC power to the converter bus. The AC external power receptacle is located on the left side of the equipment compartment No. 4. The AC receptacle has provisions for protection from overvoltage, undervoltage, overfrequency and reverse phase rotation. Therefore, any anti-ice/deice system function requiring wild frequency AC power will not receive ground power through the AC external receptacle but the windshield anti-ice and mission loads can receive ground external power.

ANTI-ICE/DEICING SYSTEM DESCRIPTION

General

17. Grumman Aircraft Corporation designed and installed an improved electrical anti-ice system. The existing method of ice prevention of the cowl inlet and spinner on the Mohawk OV-1D utilize two 6.5 KVA AC deicing generators. The heating elements are energized by single phase 115V AC. The new anti-ice/deice system contains two 24 KVA AC generators which anti-ice the cowl inlet and spinner. The pneumatic deice system was not altered. The design used NASA Lewis' environmental wind tunnel test results to establish baseline data. New wiring provisions were installed and the pilot's overhead panel was redesigned to include new anti-ice switching. An analytic propeller performance evaluation was conducted by propulsion engineering. Newly designed power

takeoff gears were provided by Western Gear Ind. and installed by Corpus Christi Army Depot personnel. The Improved Electrical Anti-Icing system is comprised of two segments on each side of the aircraft: (1) engine/propeller anti-ice/deice and (2) windshield anti-ice. The difference between an anti-ice and deice system is that ice is permitted to form on a surface which is then removed by a cycled deice system. In an anti-ice system, ice is prevented from forming on the surface which is continually electrically heated.

Cowl Spinner Anti-Ice/Deice System

18. Engine anti-ice/deice consists of heating elements installed on the spinner highlight, spinner plateaus, and propeller blades, all of which have a protective metal covering, plus fixed and removable engine nacelle cowls, cowl split-lines, and cowl struts. A detailed design of the cowl and strut heater elements is shown in figure B-2. The No. 1 AC generator normally supplies three-phase wild frequency power to the left anti-ice/deice resistive load and No. 2 AC generator supplies the right side. Each side of the anti-ice/deice system block diagram is shown in figure B-3.

19. The anti-ice/deice system contains the following caution/warning lights located on the caution annunciator panel.

a. "#1 ANTI-ICE "

b. "#2 ANTI-ICE"

c. "ANTI-ICE On"

20. The anti-ice caution/warning lights illuminate to indicate a failure of the No. 1 and/or No. 2 anti-ice/deice system. The "ANTI-ICE ON" is an advisory light which indicates that system is activated. This advisory light illuminates only on the ground, with the aircraft's weight on wheels and the anti-ice/deice system "ON".

21. The anti-ice/deice system may be energized manually by turning the anti-ice switch to either the "NORM" (normal) or "EMER" (emergency) position. The engine anti-ice switch is located on the left overhead panel. The "EMER" position of operation directly controls 28V DC power to the anti-ice/deice system. In the "NORM" position, the anti-ice position, the anti-ice switch supplies 28V DC to the ice detector which operates in conjunction with an anti-ice relay. The ice detector consists of a probe which senses the presence of ice and provides an output to activate the aircraft's anti-ice/deice equipment only in the "normal" mode of operation.

22. The ice detector is comprised of two oscillators. The magnetostrictive oscillator (probe) without icing condition oscillates in the range of 40.0 KHZ, while the crystal reference oscillator oscillates at 40.2 KHZ. A mixer compares the difference in the frequency of both oscillators. As the ice build-up on the probe increases, a decrease occurs in the operating frequency of mixer. If the delta frequency is between 5 and 350 Hz, the ice detector is "off". Above 350 Hz, the ice detector will energize an anti-ice relay which supplies 28V DC power to the anti-ice/deice controllers. The output remains

Area	Wrap Distance From Highlight – (Inches)	Power Density – W/In²
1.	-2.0 to -1.5	8.5
2.	-1.5 to -0.5	11.0
3.	-0.5 t0 0.5	12.5
4.	0.5 to 1.5	11.0
5.	1.5 to 3.5	9.0
6.	3.5 to 4.5	8.0
7.	4.5 to 9.0	7.0
8.	9.0 to 10.0	6.0
9.	10.0 to 12.0	5.0
10.	12.0 to 13.75	3.5

Cowl Power – 7500W (nominal)
Struts and Splitline – 700W
Total Cowl Anti-Icing System Power – 8200W (nominal)

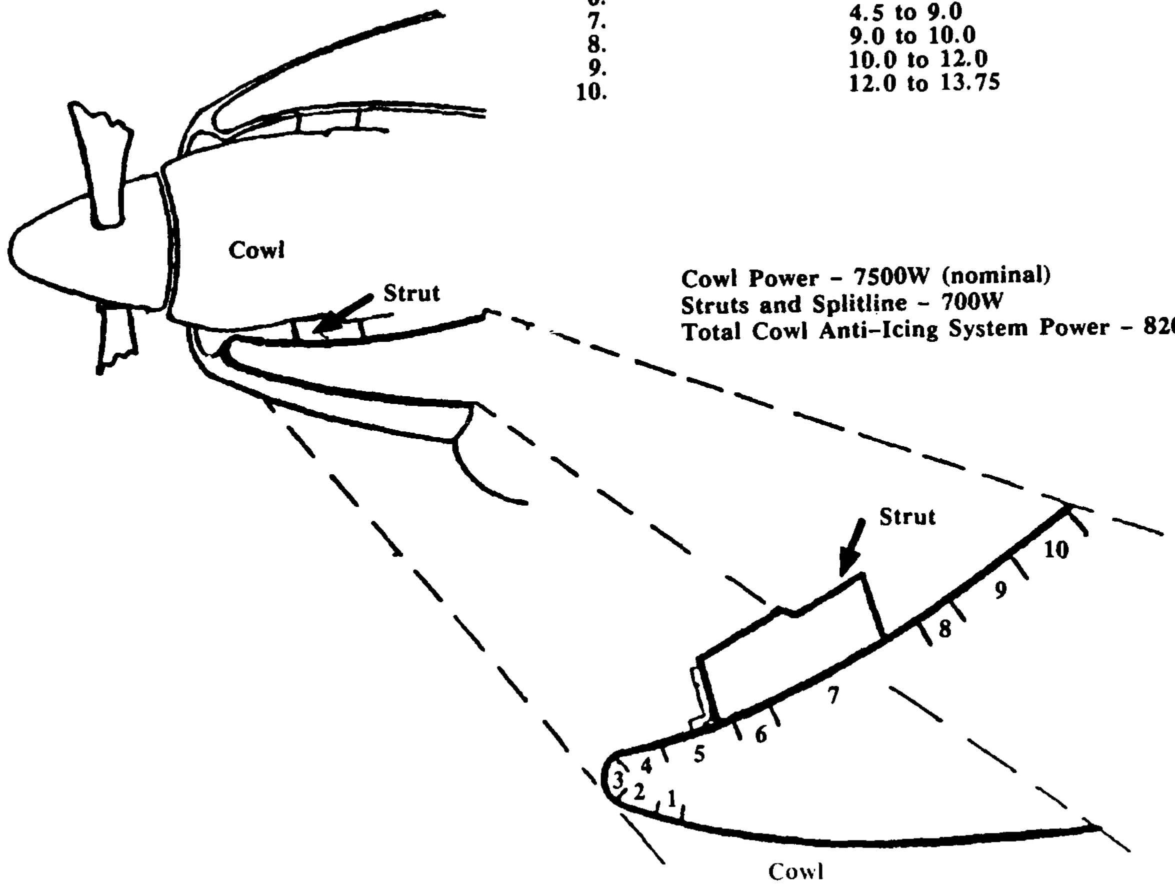

Figure B-2. Location and Power Densities of the Cowl and Strut Heater Elements

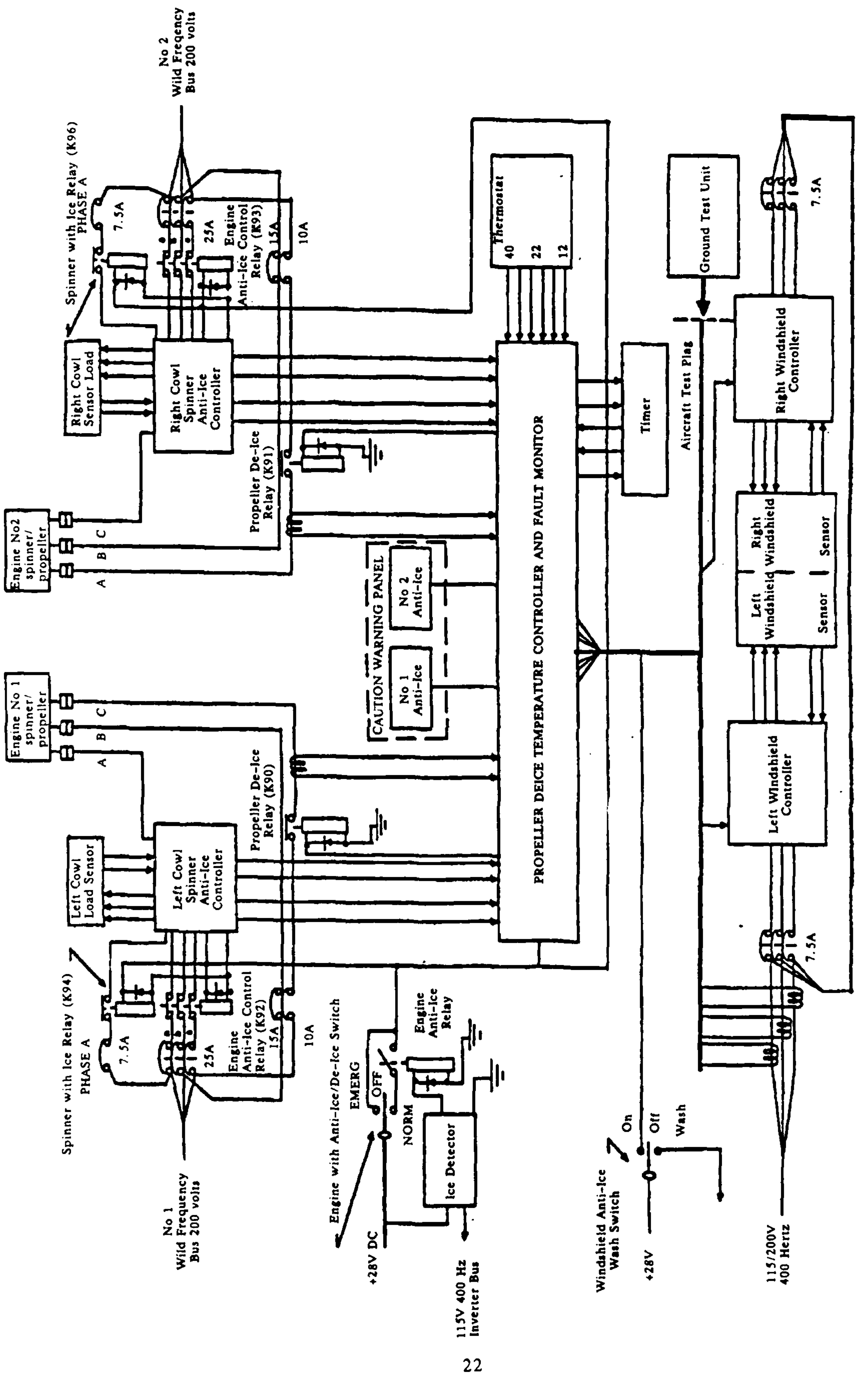

Figure B-3. Anti-Ice System Block Diagram on for 60 seconds after icing conditions are sensed. A second voltage remains on for 5 seconds after ice is sensed which activates an internal heater that deices the probe.

23. The anti-ice system contains two microprocessor temperature controllers. The main functions of the microprocessor temperature controller are: temperature sensing, power switching, self-test, fault detection, and signaling. The temperature controllers control AC power to the spinner and cowl anti-ice heating elements to maintain an ice free engine inlet. Both temperature controllers can operate continuously or intermittently without any adjustments required from the pilot.

24. The temperature controller interfaces with two temperature sensors per nacelle. One temperature sensor is located in the fixed section of the cowl, the other in the removable cowl section. The temperature controller possesses the capability, such that, should one sensor fail the remaining sensor controls the anti-ice system. The pilot anti-ice caution/warning light will illuminate for an open or shorted sensor. If both sensors fail, the temperature controller fails "safe", that is, power is maintained to the heater elements. In flight without icing conditions, the temperature generated by the cowl heater elements cannot cause structural damage to the engine cowl. A correlating coefficient between the power demand of the cowl and spinner is stored in an erasable programmable read only memory. The spinner anti-ice heating elements can, therefore, be controlled from the cowl thermal sensors through a correlation of the cowl temperature control signal. The microprocessor thus develops a power control signal for the single phase power switch of the controller which supplies power to the spinner heater. No temperature sensors are located within the spinner. The spinner heating element remaining energized without icing will cause blistering of the spinner until the heater elements burnout. The anti-ice system is lost to engine No. 1 spinner highlight but the engine anti-ice remains operational.

25. The spinner-cowl temperature controller contains a built-in test capability which includes an on-board operational readiness test (ORT) and failure detection/isolation capability. The ORT checks out all phases of the spinner-cowl temperature controller and determines the operational readiness of the heating system. The ORT is activated for less than 10 seconds of elapsed time from power up, and then returns to its normal operating mode. During this test, 11 fault signals are inhibited and the anti-ice caution/warning light is illuminated. If the anti-ice warning light fails to extinguish after an ORT test, a fault exists somewhere within the anti-ice system. During the ORT test, the two heater elements are tested sequentially at moderate duty cycles to maintain average system power below 25% or maximum power. The ORT test is capable of being performed on the ground or during flight. The pilot can manually initiate the ORT with a switch located within the cockpit. This switch is in the ice protection circuit breaker panel (sloping console).

26. Fault detection and isolation are implemented by the microprocessor through software checks and special sensors and circuitry to monitor the various voltage and currents at critical points in the heater power flow. The following system faults can be detected:

d. input power loss

e. input voltage dropout or imbalance exceeding 10%

f. open or shorted power switch

g. open or shorted heater elements

h. open or shorted sensors

i. under/overtemperature

27. The microprocessor temperature controller contains a watchdog timer which automatically resets the controller if it becomes lost in a program as a result of an isolated "hiccup" or a momentary power loss. The processors and other critical circuit components are buffered and isolated from the sensors, heater firing circuits, and other signals. This prevents a fault in one heater or sensor circuit from propagating and causing damage throughout the controller and also protects the processing section of the controller.

28. If a fault occurs, a fault signal is developed which illuminates the anti-ice caution/warning light. This light informs the pilot that a fault has occurred within the anti-ice/deice system. Four additional fault signals trip fault indicators (flags) in the fault monitor to identify the nature and area of failure.

29. Detected faults that present safety hazards will cause external relays that supply primary power to the system to be de-energized. The controller will remove power within 2 seconds of fault occurrence for dropouts and imbalance levels exceeding 10%. The voltage at the output of each of the solid state passive elements is also monitored and compared to its input. A shorted or open input pass element will trip the fault monitor flag and then primary power will be removed. The current is also monitored through each phase of each channel. A shorted or open heater circuit will be detected and power to that load will be removed. Open or shorted temperature sensors and under/overtemperature conditions will be sensed by comparators which will signal the microprocessor of the fault. The controller signals the appropriate fault line and if necessary removes power from a particular load.

30. The spinner-cowl temperature controller contains a support equipment connector on its front panel to facilitate diagnosis of the anti-ice system failures. Production plans are for a computer controlled type of bench test equipment which will be plugged into this connector to perform function checkout of the system and isolate failures to the module/submodule level of the system.

Fault Monitor and Deice Controller

31. The deice system contains one fault monitor and deice temperature controller which controls deicing for both engines. The fault monitor and deice controller perform the following major functions:

j. Monitoring and fault display of the propeller deice system.

k. Display faults provided from both spinner-cowl temperature controllers.

l. Provides interface for the anti-ice spinner-cowl temperature controllers and for the deice timer and three setpoint thermostat.

m. The system provides an ORT for the propeller deice system, windshield anti-ice system, fault monitor interface circuits, and the caution panel anti-ice display when used with an anti-ice ground test set.

32. The system uses 200V AC to energize the heating elements on these surfaces. A timer establishes three different time periods to energize heater elements which are dependent on thermostat settings. Above 4.4 degrees C ambient temperature, the propeller timer and thermostat circuitry provide an inhibit of propeller deicing. A three element thermostat (mercury columns) is used which selects one of the three timer cycles for the propeller deice system. The timer cycles are: between 4.4 and -5.6 degrees C, a 5 second "on" - 60 second "off" cycle; between -11.1 degrees C, a 10 second "on" - 60 second "off" cycle; below -11.1 degrees C, a 20 second "on" - 60 second "off" cycle. The output from the propeller timer is used to control the propeller fault monitor during the "on" portion of each cycle. A cockpit test connector is provided which allows ground testing to be performed on this part of the propeller deice control system. During flight, continuous fault monitoring is provided for cowls, spinner, and propellers. A current transformer is located in each of the two propeller power lines to the propeller heating element. The current transformers sense the input power and compares its signal with a reference level. If a difference in signal is detected, one of the fault indicator flags trip and the anti-ice caution/warning light will illuminate. The windshield anti-ice system can only be checked with a ground test set, no fault monitor provision exists during flight.

33. The fault monitor system identifies the following fault conditions and provides displays on the fault unit by individual fault indicators (flags):

n. loss of input primary power

o. cowl heater and sensor faults

p. spinner load faults

q. controller faults

r. deice propeller faults

34. The presence of any of these faults will trip a fault indicator flag on the unit and also illuminate the anti-ice caution/warning light on the caution annunciator panel. If the fault should clear, the warning light will extinguish automatically, however, the fault indicator will remain tripped and can only be reset by use of a ground test set. The fault monitor contains circuitry for a one second test signal for ORT of the propeller and windshield fault test.

Windshield Anti-Ice System

35. The existing method of deicing operational aircraft windshields is by spraying a mixture of alcohol and water on the windshield through one restrictor. The duration of fluid during the deicing cycle is approximately 10 to 15 minutes. This windshield ice protection system does not always clear the windshield sufficiently. The new windshield anti-ice system electrically heats both the pilot's and observer's windshield. Each windshield anti-ice system load is approximately 2 KVA. The windshield heating elements consist of a layer of electrically conductive metal oxide (nesatron) with integral bus bars which are applied to the interior surface of the outboard layer glass.

36. The electrically heated windshield interfaces with a windshield heater controller and a thermal sensor. The windshield anti-icing system contains two windshield heater controllers which are both operated by one "on-off-wash" switch located on the left overhead panel. The windshield heater controller is a device which senses and controls three-phase AC converter power into the windshield and attempts to maintain a 110 degrees F setting. The No. 1 controller controls power to the pilot's windshield heater elements, the No. 2 controller to the observer's heater elements. The windshield controller operates in a closed loop with two temperature sensors connected in parallel. These temperature sensors are embedded in the interlayer of the windshield and have a positive temperature/resistance characteristic. The controller turns "on" when the resistance of the two sensors in parallel decreases to 168 ($\pm$1.0 ohms above the 168 ohm turn "on" value). If either sensor develops short circuit fault, the controller is designed to automatically open the power circuit. The controller also turns off for loss of DC power. The windshield controller contains a fail safe provision which de-energizes the heater elements for internal controller failures (i.e., shorted controller output power switch). This feature precludes overheating the windshield which could cause delamination or structural failure.

37. Two 10 KVA converters supply regulated three phase 400 Hz power to the converters mission bus. The windshield anti-ice power is normally supplied from the converters mission bus for AC generator shaft speeds above 9200 rpm. For loss of both converters or AC generator speeds below 9200 rpm, the windshield system can be powered from the DC sourced 10 KVA inverter by moving the inverter switch to its backup position.

38. The pilot's and observer's windshields are independently controlled by separate windshield controllers. Loss of the pilot's windshield controller, sensor or heater elements will not affect the anti-ice operation of the observer's windshield and vice-versa.

39. During the flight, there is no fault indication to the pilot if either side of the windshield system is lost. The pilot can determine by observation if either side of the windshield anti-ice system is lost or by sensing if the windshield is warm. After failure of one side or the entire windshield anti-ice system there exists no means of restoring the windshield system. If icing conditions exist, the pilot will be forced to attempt using his side window to land the aircraft.

40. The windshield anti-ice system utilizes three current transformers to monitor each of the input three-phase circuits. This power input sense signal is compared to a reference level. No warning signal or fault signal is tripped if the fault occurs during flight. The windshield system can only be checked with use of a ground test set, which is plugged into a test jack located in the cockpit.

APPENDIX C. HELICOPTER ICING SPRAY SYSTEM DESCRIPTION

1. The Helicopter Icing Spray System (HISS) is installed in a modified CH-47C helicopter and consists of an internally mounted 1800-gallon water tank and an external spray boom assembly suspended 19 ft beneath the aircraft from a cross-tube through the cargo compartment. A schematic is shown in figure C-1, and a detailed description is given in reference 7, appendix A. Hydraulic actuators rotate the cross-tube to raise and lower the boom assembly. Both the external assembly and water supply can be jettisoned in an emergency.

2. The spray boom consists of two 27 ft center sections, vertically separated by 5 ft, and two 17.6 ft outriggers attached to the upper center section. When lowered, the outriggers are swept aft 20 degrees and angled down 10 degrees giving a tip to tip boom width of 60 ft. The boom is assembled of concentric metal pipe; the inner pipe (1-1/2 in. diameter) acts as the water supply and leads to 30 manifolds spaced approximately 3 ft apart along the boom exterior; the outer pipe (4 in. diameter) contains bleed air from the aircraft engines and bleed air auxiliary power unit (APU), and is fitted with a total of 172 nozzle receptacles on the boom surface. These nozzle receptacles are spaced at one foot intervals along the top and bottom of the boom and are staggered to provide alternating upward and downward ejection ports every six inches.

3. A Solar T-62T-40C2 APU is installed in the HISS aircraft bolted to the trunnion assembly between fuselage station (FS) 160 and FS 200. For purposes of safety and noise reduction, the unit is enclosed in a stainless steel box with fiberglass sound proofing. Bleed air from the APU is ducted to a flow mixer which combines aircraft engine bleed air with APU bleed air. The combined APU and engine bleed air enters the boom through flexible tubing leading to the boom air intake pipes on either side of the cabin. Electrically-operated valves which are actuated from a single control panel are installed in the system to control both bleed air and water flow rates.

4. A calibrated air temperature probe and a Cambridge dew point hygrometer provide accurate ambient temperature and humidity measurement. A radar altimeter with aft-facing antenna is mounted on the CH-47 to allow positioning the test aircraft at a known standoff distance. The radar altimeter is wired to red and yellow station-keeping lights to provide a visual indication to the test aircraft for maintaining the proper standoff distance.

5. Because of gross weight limitations, only 1425 gallons of water are carried. To facilitate photographic documentation during icing tests, a non-toxic, biodegradable chemical with coloration properties similar to sea marker dye is added to the water to impart a yellow color to the ice.

6. At the 150 foot standoff distance used for icing tests, the size of the visible spray cloud is approximately 8 feet high by 36 feet wide. Water flow rates to provide a desired liquid water content (LWC) are established based on a theoretically derived formula assuming mass conservation (no evaporation). The spray cloud is then sampled to determine the actual LWC by a fixed-wing, chase/calibration aircraft equipped with particle-measuring devices. The flow rate is adjusted and the cloud is sampled until the desired average LWC is attained.

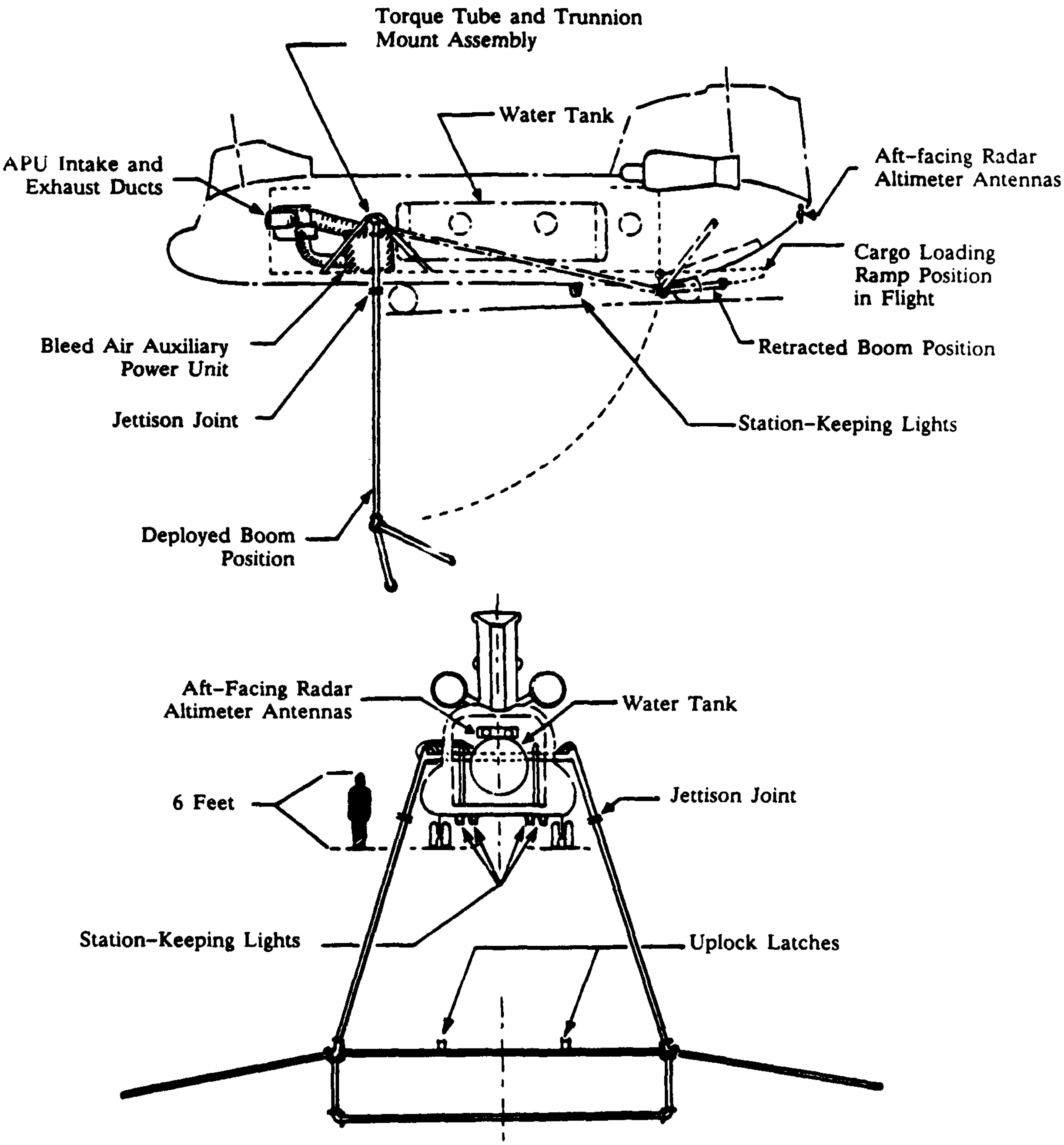

Figure C-1. Helicopter Icing Spray System Side and Rear View Schematic

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

ARTIFICIAL ICING

1. An artificial icing cloud was generated by a CH-47C helicopter equipped with a Helicopter Icing Spray System. The test conditions liquid water content (LWC), droplet size, humidity, and air temperature were documented by a U-21 equipped with a cloud measuring and recording system (described below). The OV-1 test aircraft flew at 120 knots true airspeed (KTAS) with half of the aircraft immersed in the cloud for approximately 30 to 45 minutes. Visual observation and comments as well as photographic documentation were obtained from personnel on the rear ramp of the CH-47. This was the best location for obtaining ice accretion characteristics in the engine inlet. Observation and comments were also obtained from the U-21 chase aircraft flying alongside the test aircraft. The observer in the right seat of the OV-1 also supplied comments and photographic documentation. The observer was in excellent location to identify ice building up on the engine cowl ring and propeller spinner. Normally, the test would terminate directly over a landing area and a rapid descent and landing would be made for further documentation of locations and quantities of ice build-up. The ground observations allowed actual measurement of ice thickness and pinpointed locations of ice building upside the engine inlet.

2. A major advantage of this type of test was the safety element of not exposing both power plants to the ice environment. If ice accretion characteristics had caused engine damage, the aircraft could easily have flown to Duluth Airport for a safe landing.

NATURAL ICING

3. A U-21A scout/chase aircraft equipped with a cloud particle measuring system was used to locate and document the icing conditions. The U-21 was also configured with a bubble photographic window installed in the cabin and was used as a photographic platform to provide documentation of the ice accreted on the test aircraft. The scout/chase aircraft would locate the desired icing conditions and radio the location and icing conditions to the test aircraft before it entered the icing environment. The U-21 would then exit the icing conditions and loiter in the area to facilitate a rapid in flight join-up with the test aircraft after it exited the cloud for photographic documentation. The OV-1 was flown in the icing environment in a clean configuration initially with cruise power (60% torque and 1450 rpm) which produced approximately 190 KTAS. The test aircraft's anti-ice and deice equipment was used while in the icing conditions.

CLOUD SAMPLING EQUIPMENT

4. For cloud measurements in the natural environment, the U.S. Army Aviation Engineering Flight Activity employs a JU-21A fixed-wing aircraft, U.S. Army S/N

66–18008, equipped with a cloud measurement package. The cloud measurement package consists of the following equipment: a Particle Measuring Systems, Inc. (PMS) Forward Scattering Spectrometer Probe (Model FSSP-100), a PMS optical array cloud droplet spectrometer probe (model OAP-200X), Rosemount total temperature sensor and display, Cambridge model 137 chilled mirror dew point hygrometer and display, Leigh Mk 12 ice detector unit, Cloud Technology Inc., model LWH-1 (Johnson Williams type) LWC indicator system, Small Intelligent Icing Data System (SIIDS), and two visual accretion devices: Aeroplane & Armament Experimental Establishment's Vernier Accretion Meter (Harvey-Smith) and a Small Airfoil Section probe (OH-6 tail rotor section). Figures D-1 and D-2 show the exterior of the aircraft with the probes in place, while figure D-3 shows the exterior instrumentation rack with displays.

5. Each PMS probe projects a collimated helium–neon laser beam normal to the airflow across a small sample area. In forward flight, particles passing through the beam (sample area) are counted and measured into 15 size channels per probe, each probe operating over a different size range. While these probes are primarily intended as particle sizing devices, an LWC can be calculated from the drop size measurement and number count within the sample volume relative to airspeed.

6. The FSSP-100 determines particle size by measuring the amount of light scattered into the collecting optics aperture as the particles pass through the laser beam. A pulse height analyzer compares the maximum amplitude of the scattering signal pulses with a reference voltage derived from from a separate measurement of the illuminating light signal. The pulse height analyzer output is encoded to give the particle size in binary code, and resolves particle sizes from 2 to 27 μm into 15 equally spaced increments 3 μm wide. It is capable of sizing particles having velocities of 20 to 125 meters/sec (39 to 243 knots). A gate output signal provides a measure of particle transit time, and a velocity averaging counter and control system determines an average transit time. The system automatically rejects particles with transit times less than average since these are susceptible to edge effect errors which result from particles passing through regions of less than maximum intensity. A laser beam width of 0.186 mm and depth of field of 2.76 mm provides a total sample area of 0.513 mm^2 (before velocity reject).

7. The OAP-200X determines particle size using a linear array of photodiodes to sense the shadowing of array elements. Particles passing through the field of view illuminated by its laser area imaged as shadowgraphs on the array and a flip–flop memory element is set if the photodiode elements are darkened. Size is given by the number of elements set by a particle's passage, the size of each array element, and the optical magnification. Magnification is set for a size range of 20 to 30 μm, and 24 active photodiode elements divide particles into 15 size channels, each 20 μm wide. It is capable of sizing particles with velocities of 5 to 100 meters/sec (10 to 194 knots). Depth of field, effective array width, and sample area vary with sensed particle size to a maximum of 61 mm, 0.44mm and 18.3mm^2, respectively.

8. The SIIDS was designed by Meteorological Research Inc. and is a data acquisition system programmed specifically for icing studies. A more complete description appears in reference 8, appendix A. It consists of four main components: a microprocessor, Techtran data cassette recorder, Axiom printer, and an operator control panel. The

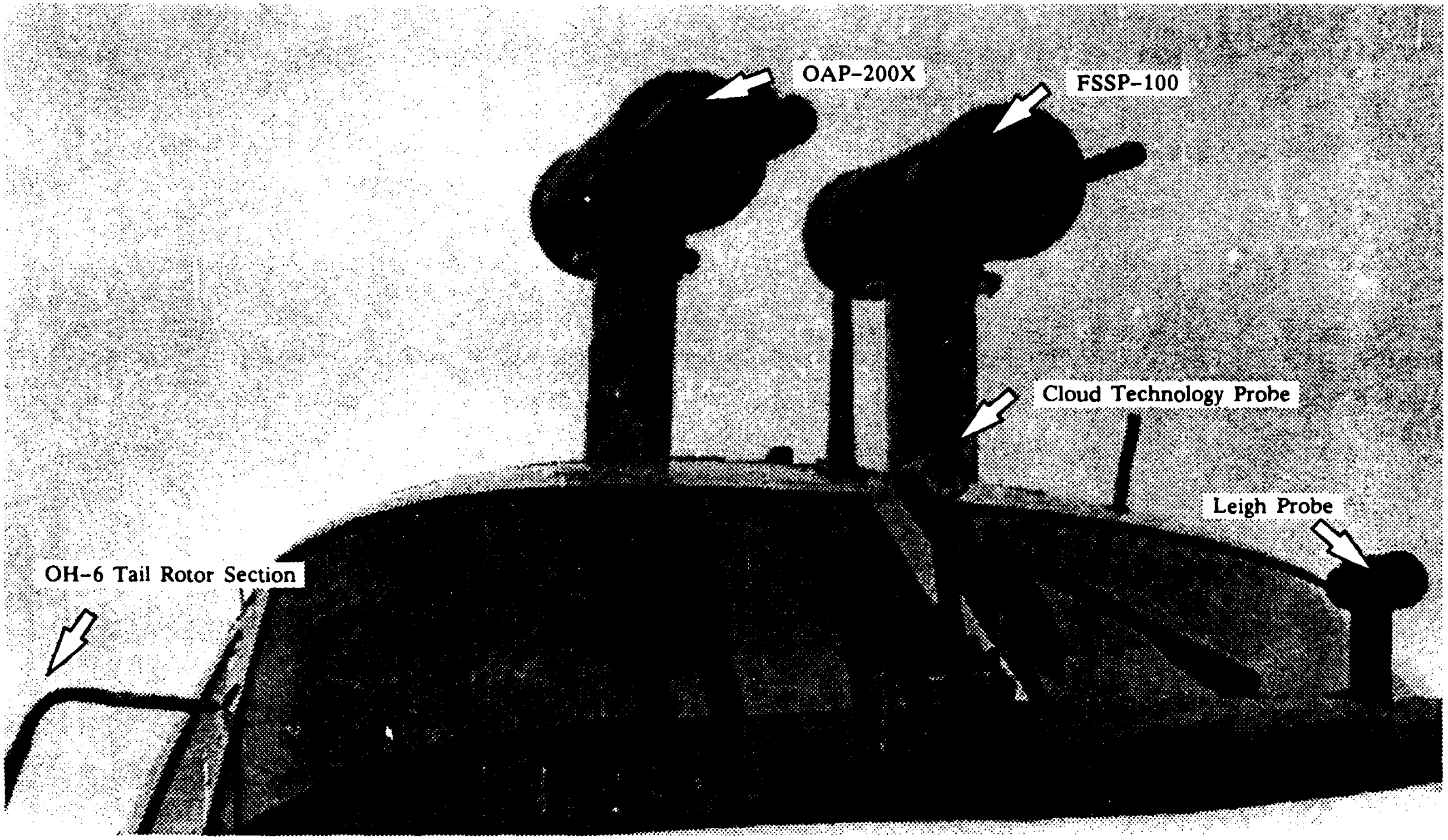

Figure D-1. JU-21A Aircraft - Nose and Cabin Top View

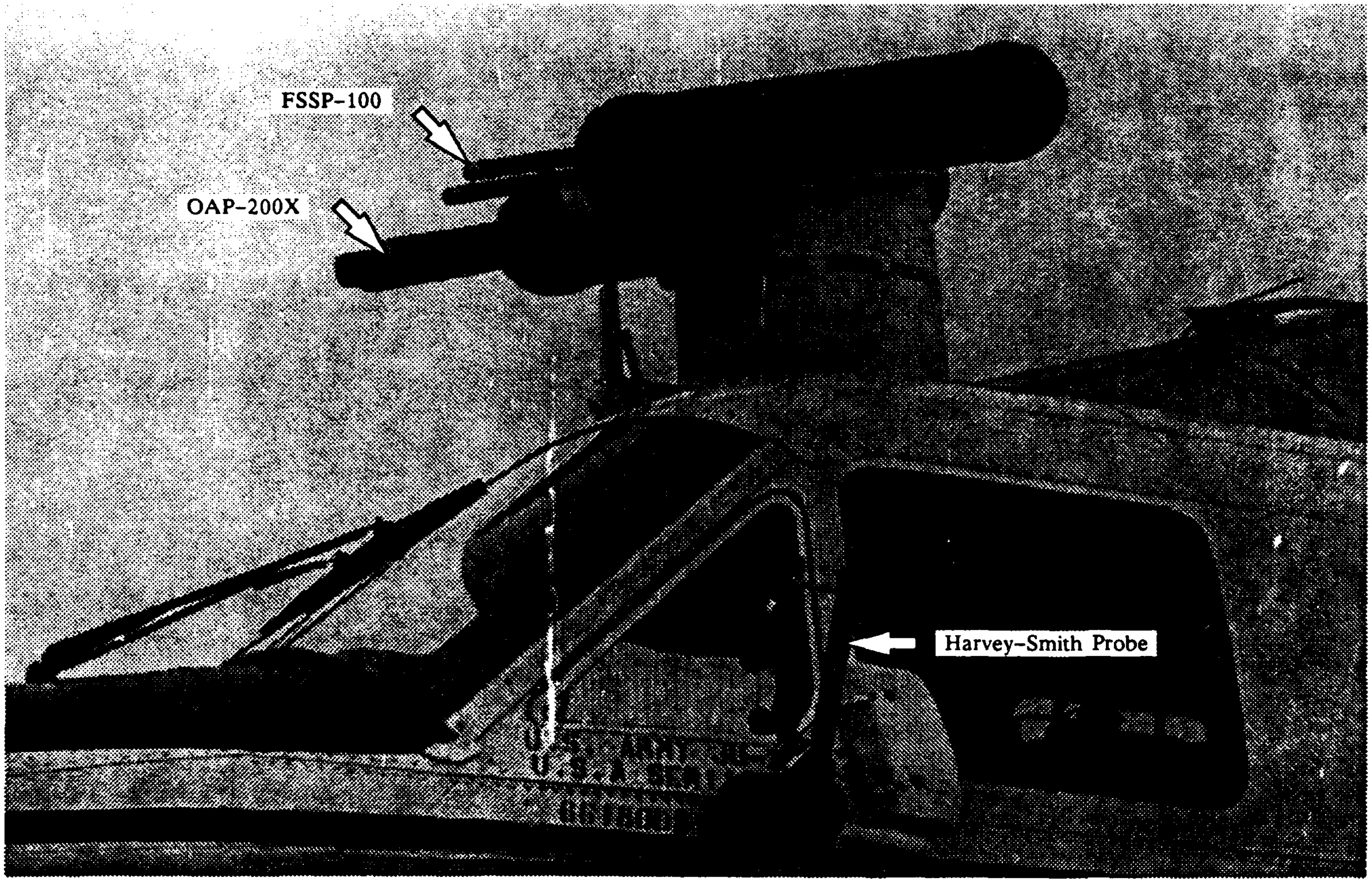

Figure D-2. JU-21 Aircraft - Left Side View

Figure D-3. JU-21A Aircraft - Interior Instrumentaion Rack

SIIDS has three operational modes: (1) data acquisition, in which averaged raw data are recorded on cassette tape and engineering units are displayed on the printer, (2) a playback mode in which raw averaged data read from the cassette are converted to engineering units displayed on the printer, and (3) a monitor mode used to set the calendar clock and alter programmed constants. During data acquisitions, the operator may select an averaging period of 1/2, 1, 2, 5, or 10 seconds. The following parameters are displayed on the SIIDS printer in engineering units.

a. calendar: year, month, day, hour, minute and second

b. pressure altitude (feet)

c. airspeed (knots)

d. outside air temperature (degree C)

e. dew point (degree C)

f. total LWC observed by the FSSP (gm/m^3)

g. total LWC observed by both FSSP and OAP (gm/m^3)

h. median volumetric diameter (μm)

i. amount of LWC observed for each channel (total 30) of both probes (gm/m^3)

9. The Cloud Technology ice detector has a calibrated resistance wire which is mounted in the airstream and connected as one branch of a balanced bridge circuit This wire is heated by an electric current. As the water droplets in the cloud strike the wire, they are evaporated, cooling the wire and decreasing its resistance. The change in resistance causes the bridge to become unbalanced. The degree of unbalance is a function of the LWC of the cloud. A second resistance wire, mounted with its axis parallel to the airstream direction and hence not subject to water-drop impingement, is connected as an adjacent branch of the bridge becomes unbalanced only in the presence of water droplets. The output of the bridge is proportional to the rate of impingement of water on the sensing wire. This signal is converted to concentration of water per unit volume of air by means of an adjustment for true airspeed.

10. The Mark 12 ice detector draws in ambient air by means of an aspirator. During icing conditions, ice builds up on the sensor probe at a rate proportional to the LWC of the ambient air. This ice, accreted on the probe, occludes an infrared light beam crossing the central area of the probe at an oblique angle. The degree of occlusion reaches a predetermined level, representing maximum permitted ice thickness, a heating cycle is initiated to remove ice from the probe. The shedding of built-up ice restores the original light path conditions, the heating cycle is terminated and the accretion operation is resumed. The time taken to accrete ice between two predefined levels is used as a measure of the icing rate from which the LWC can be calculated.

DEFINITIONS

11. Results were categorized as deficiencies or shortcomings in accordance with the following definitions.

Deficiency: A defect or malfunction discovered during the life cycle of an item of equipment that constitutes a safety hazard to personnel; will result in serious damage to the equipment if operation is continued or indicates improper design or other cause of an item or part, which seriously impairs the equipment's operational capability.

Shortcoming: An imperfection or malfunction occurring during the life cycle of equipment, which must be reported and which should be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation or materially reduce the usability of the material or end product.

APPENDIX E. PHOTOGRAPHS

PHOTOGRAPHS	PHOTOGRAPH NO.
Right Engine	E-1
Right Engine Cowl	E-2, E-3, E-4 and E-5
Fuselage Damage	E-6
Left Drop Tank	E-7
Right Engine	E-8
Spinner Afterbody	E-9
Ice Detector Probe	E-10
Temperature Sensor	E-11
Propeller Damage	E-12 and E-13
Left Windshield Wiper	E-14
AC Generator Shafts	E-15
Propeller and Engine Inlet	E-16

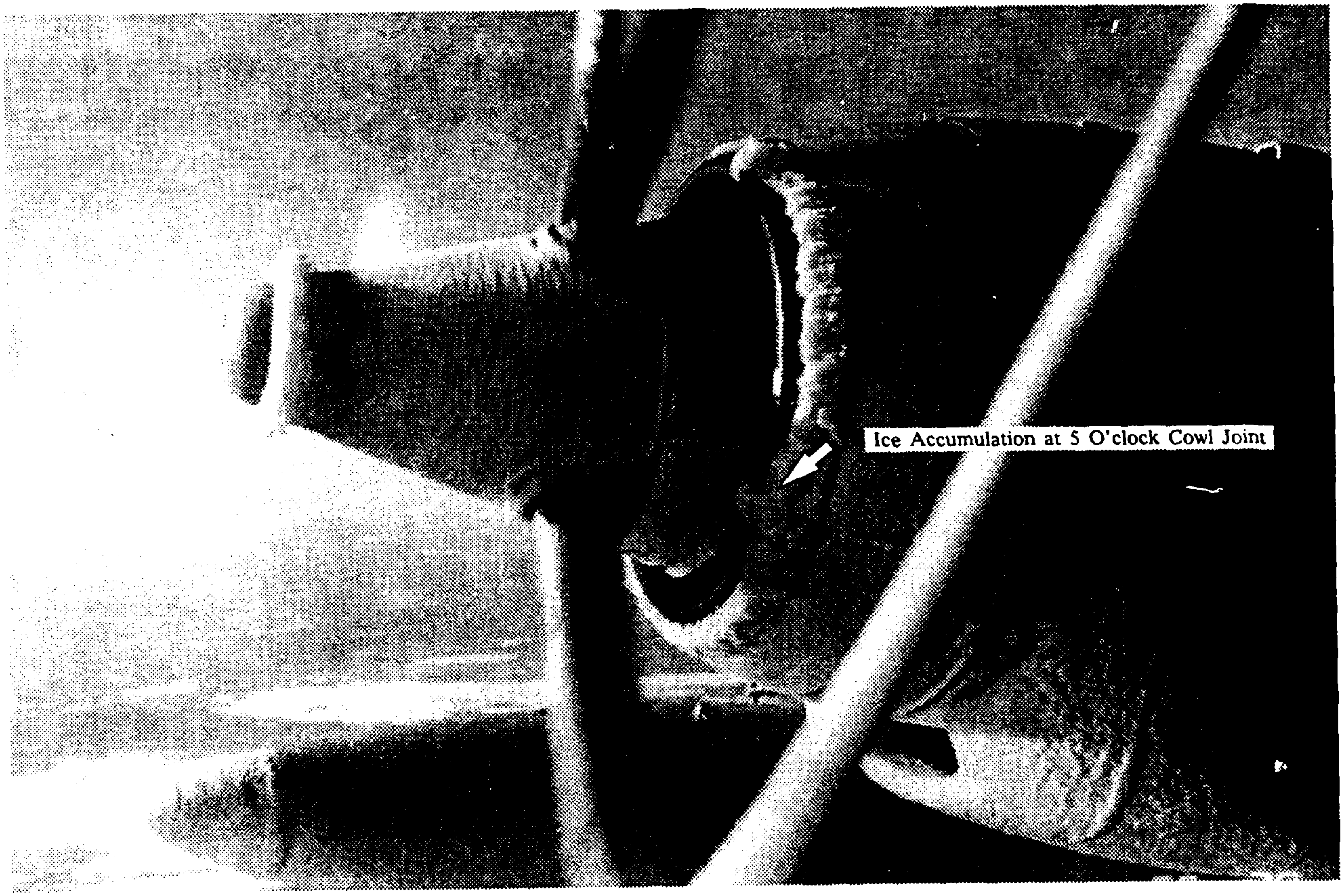

Figure E-1. Right Engine
Conditions: Avg LWC = 0.63 gm/m^3
Avg OAT = −19.0 DEG C

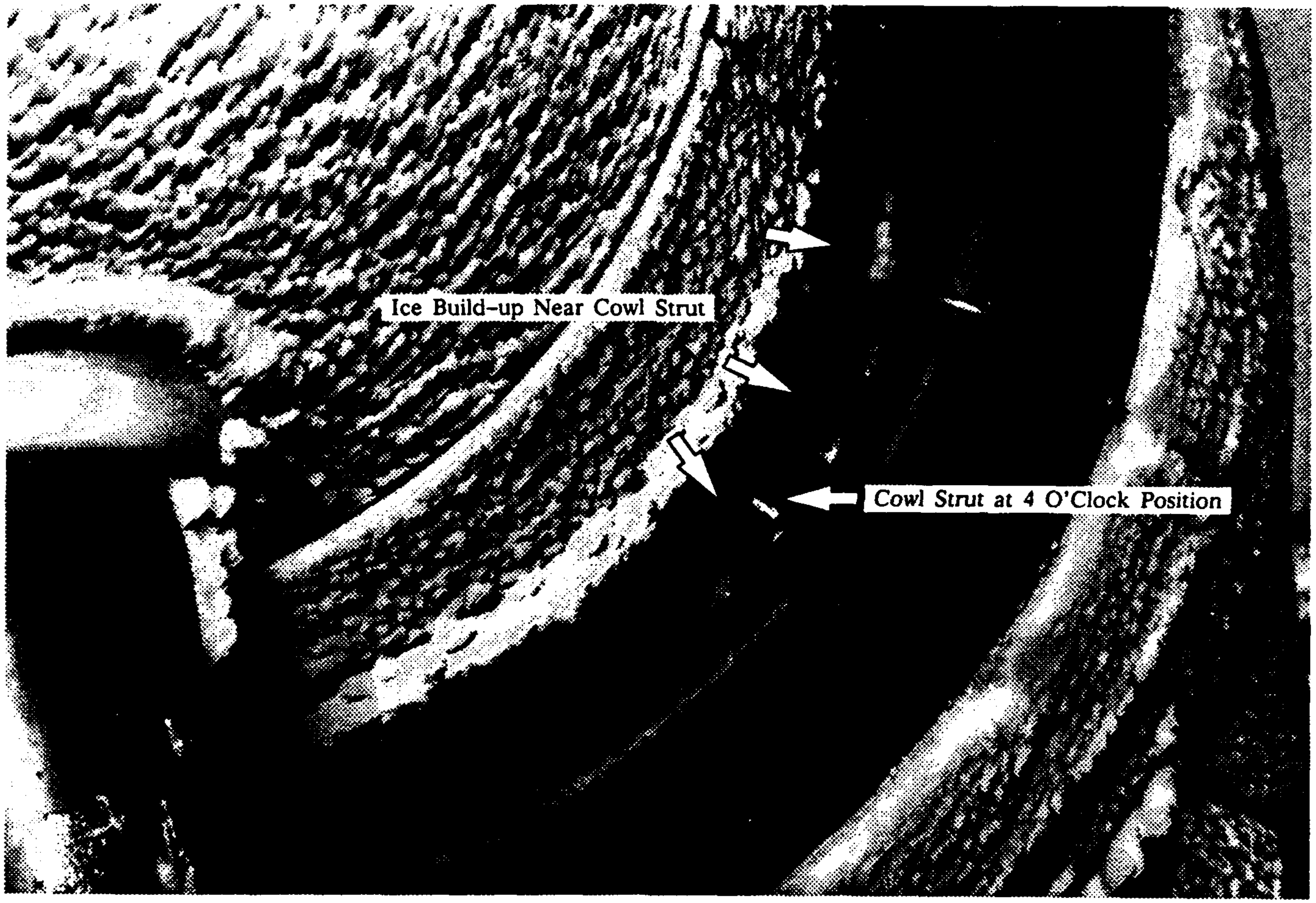

Figure E-2. Right Engine Cowl
Conditions: Avg LWC=0.63 gm/m³
Avg OAT= -19.0 DEG C

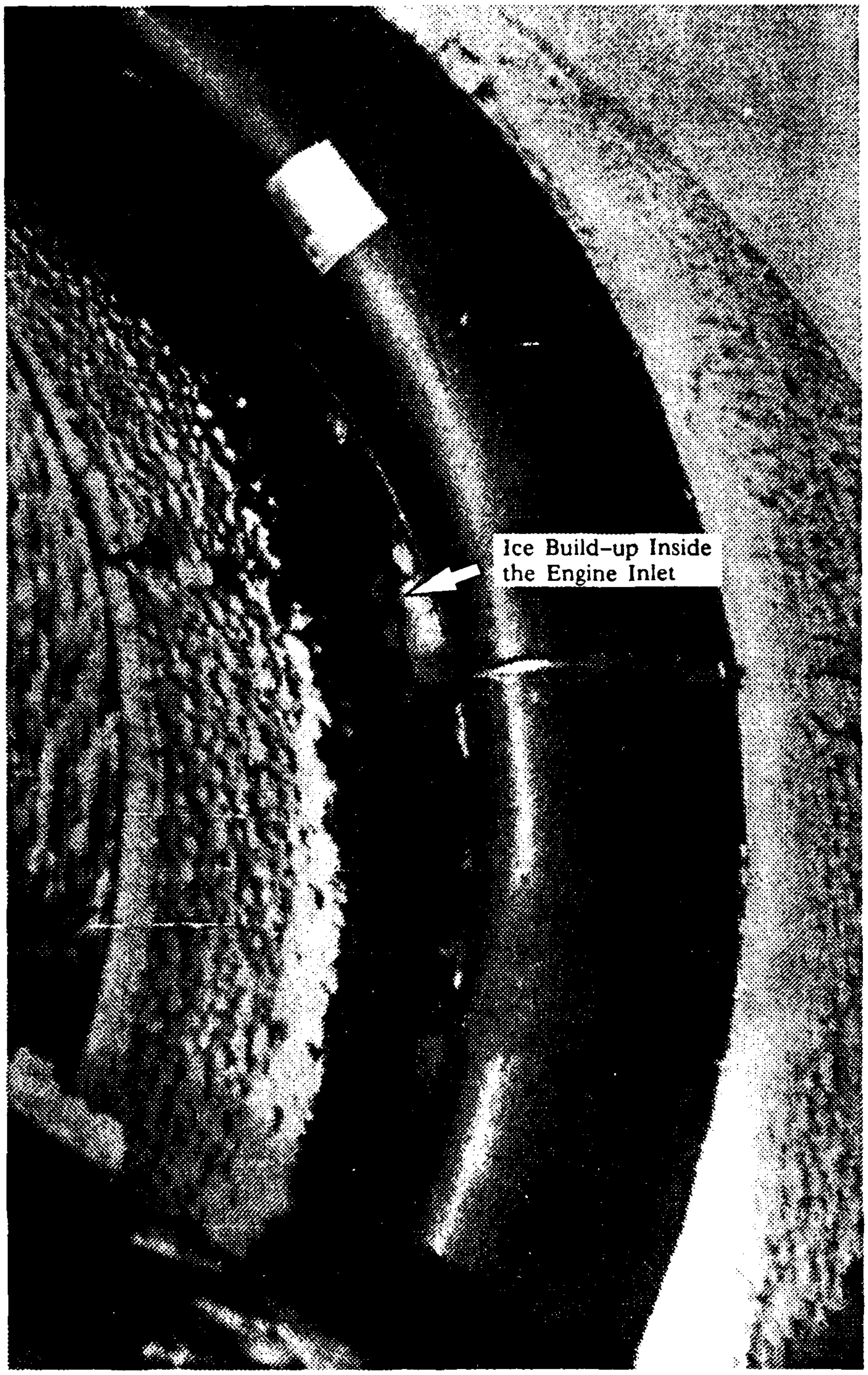

Figure E-3. Right Engine Cowl
Conditions: Avg LWC = 0.63 gm/m³
Avg OAT = -19.0 DEG C

Figure E-4. Right Engine Cowl
Conditions: Avg LWC = 0.63 gm/m^3
Avg OAT = -19.0 DEG C

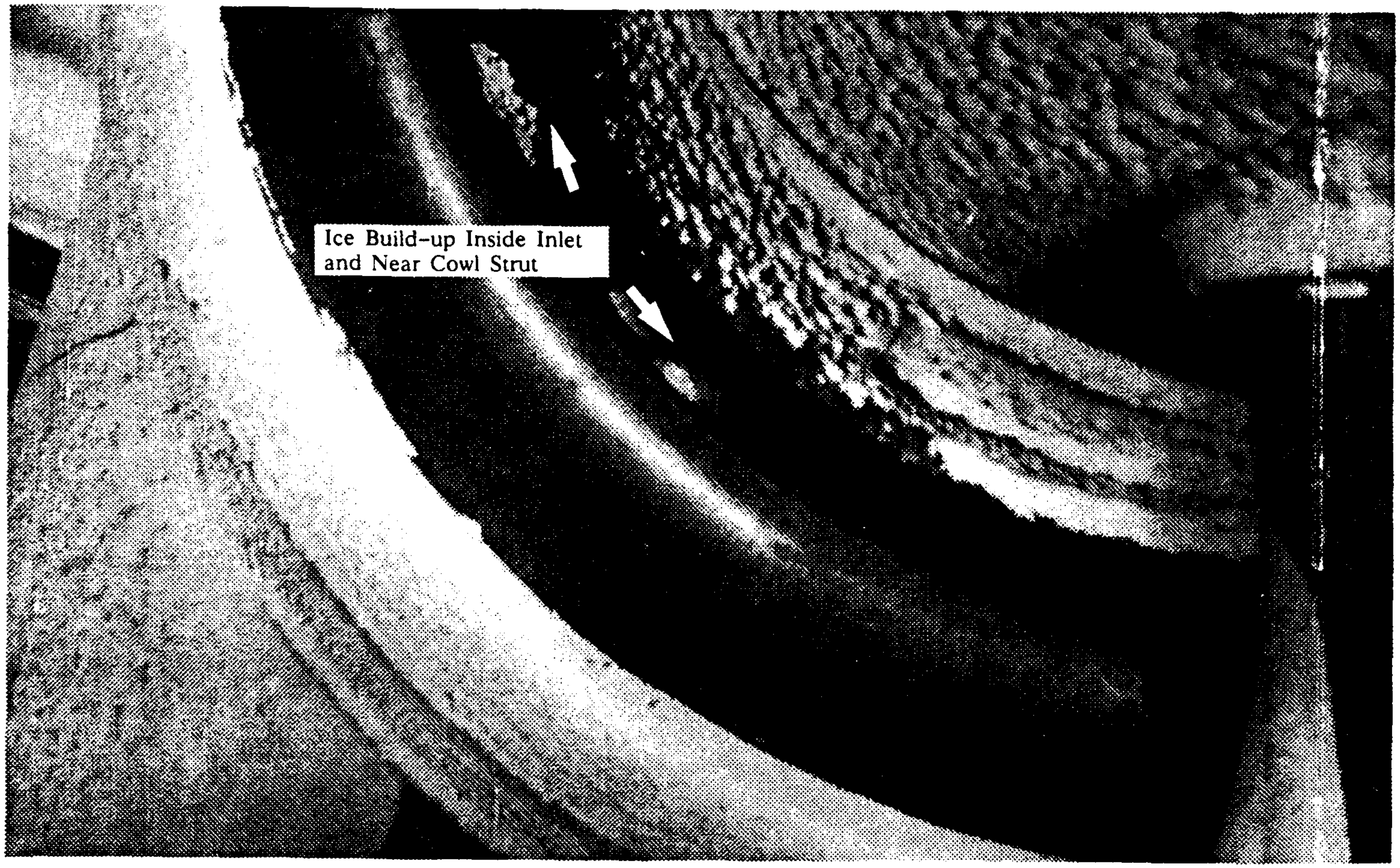

Figure E-5. Right Engine Cowl
Conditions: Avg LWC = 0.63 gm/m^3
Avg OAT = -19.0 DEG C

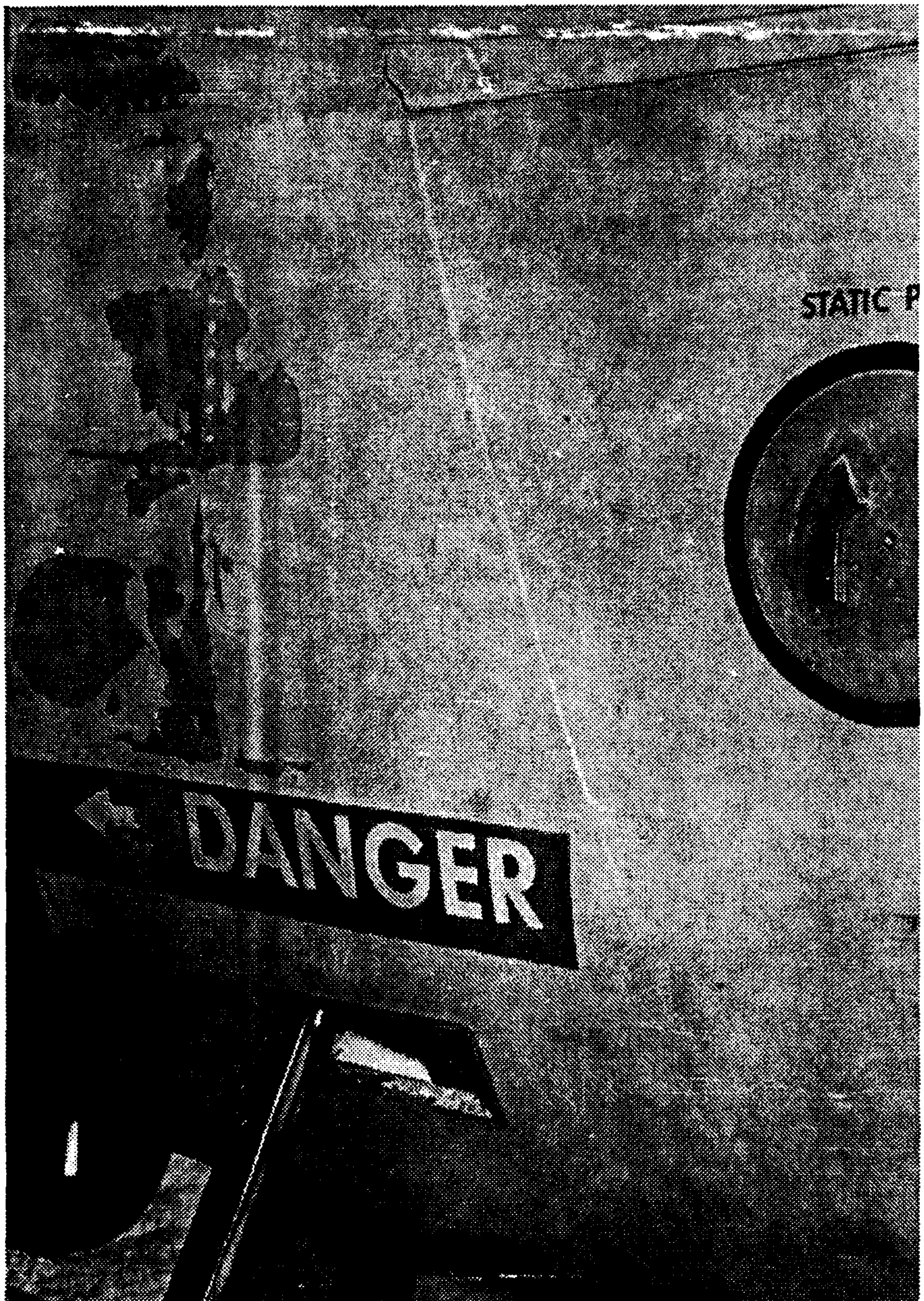

Figure E-6. Fuselage Damage from Ice Shedding

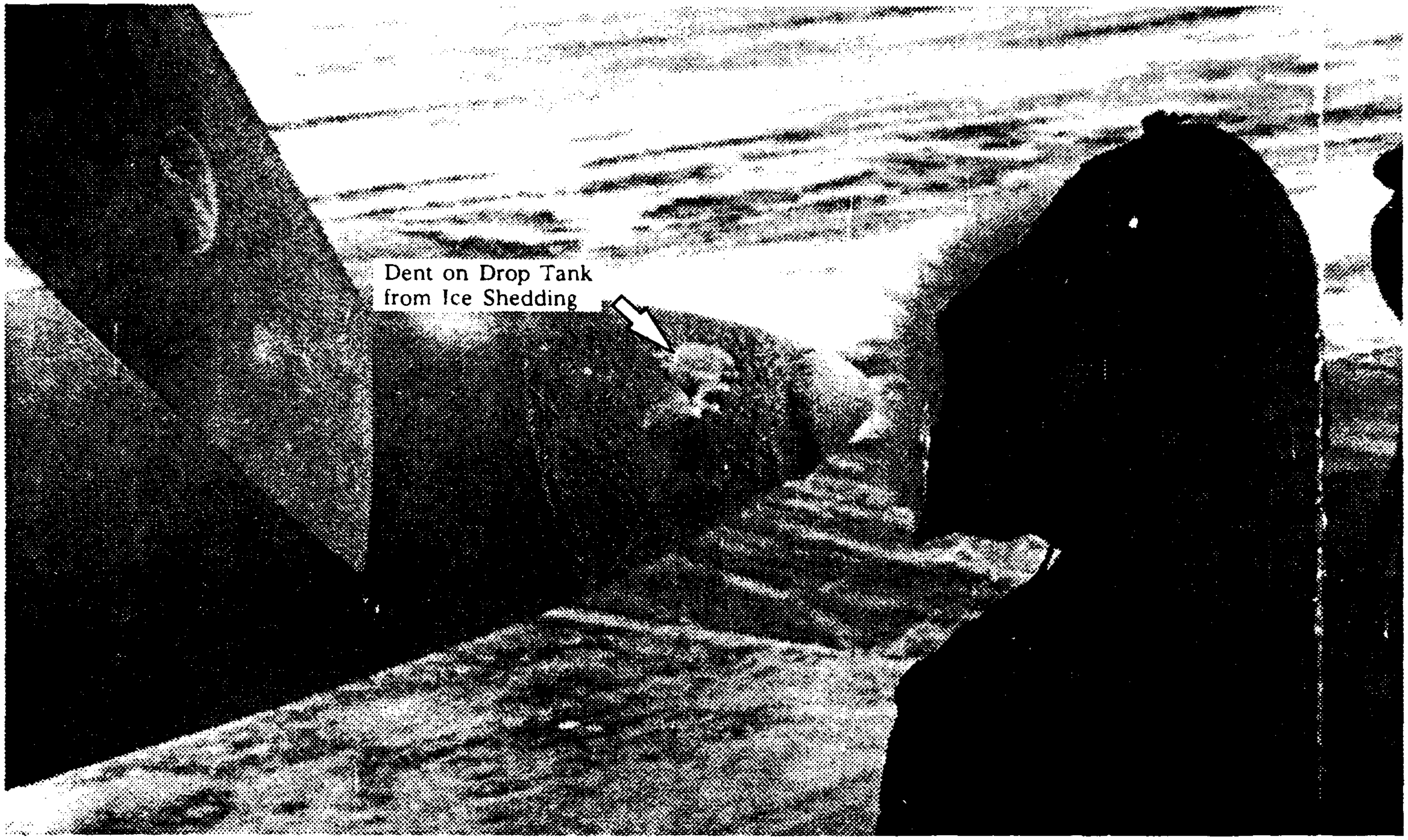

Figure E-7. Left Drop Tank

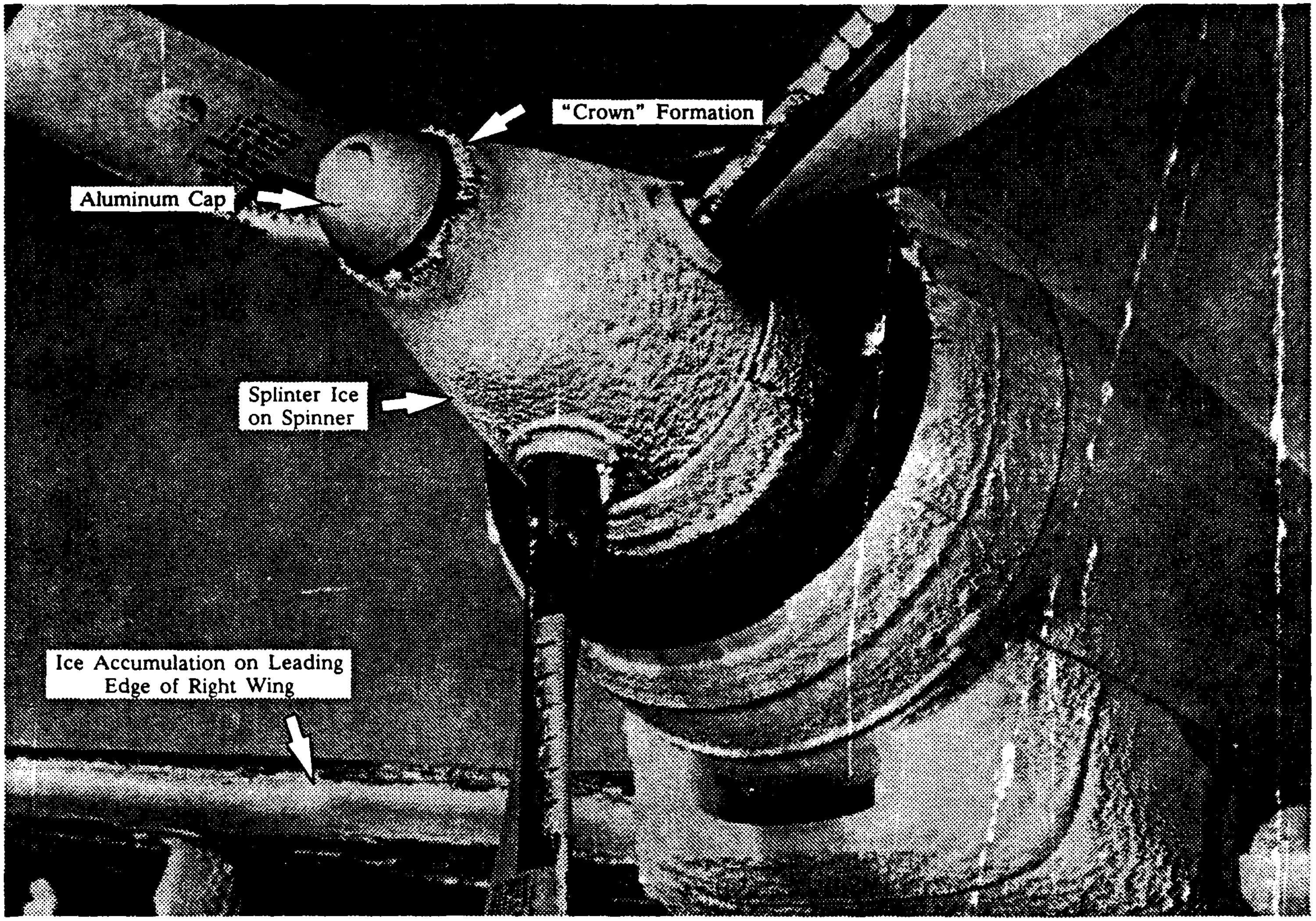

Figure E-8. Right Engine
Conditions: Avg LWC = 63 gm/m³
Avg OAT = -19.0 DEG C

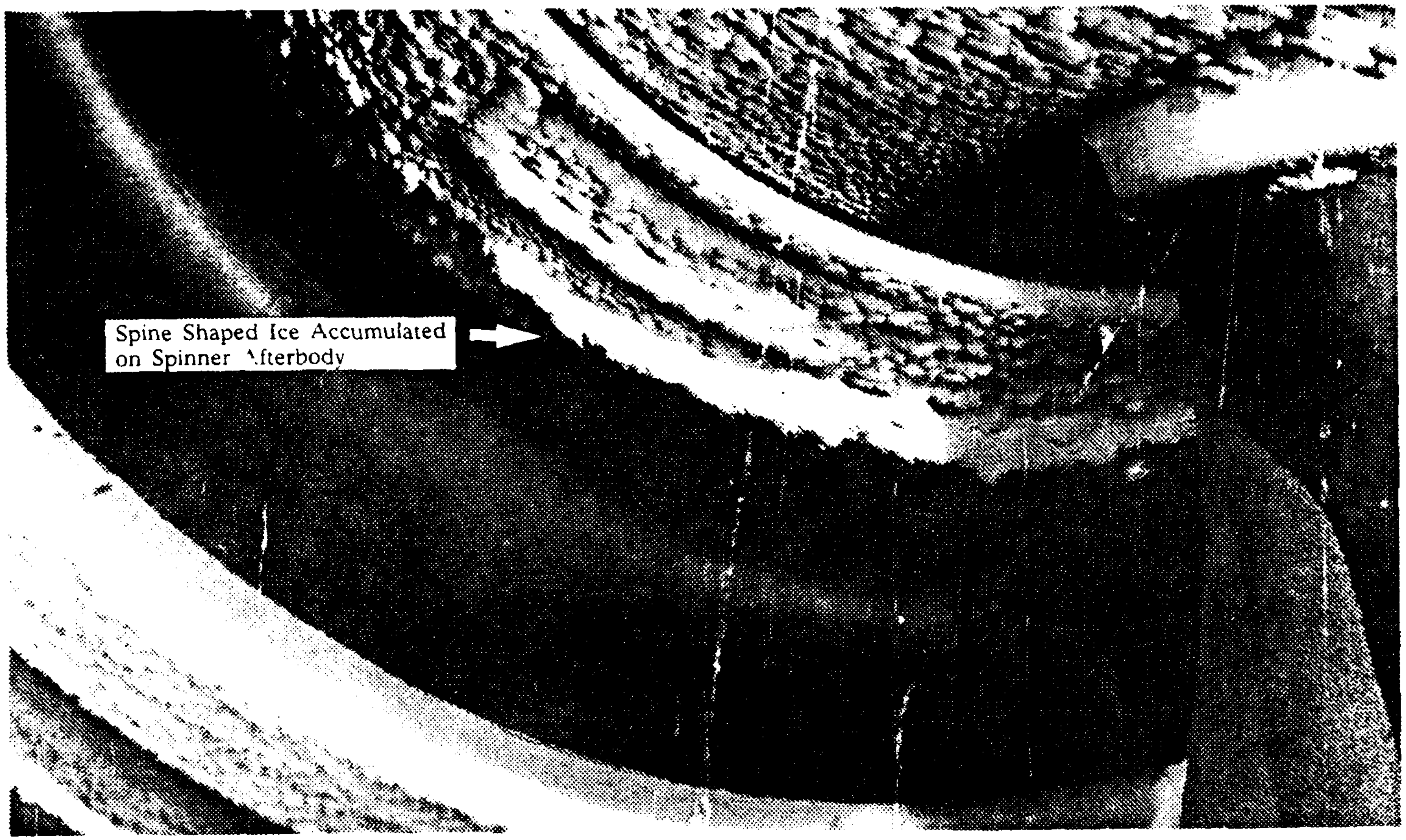

Figure E-9. Spinner Afterbody of Right Engine
Conditions: Avg LWC = 0.63 gm/m^3
Avg OAT = -19.0 DEG C

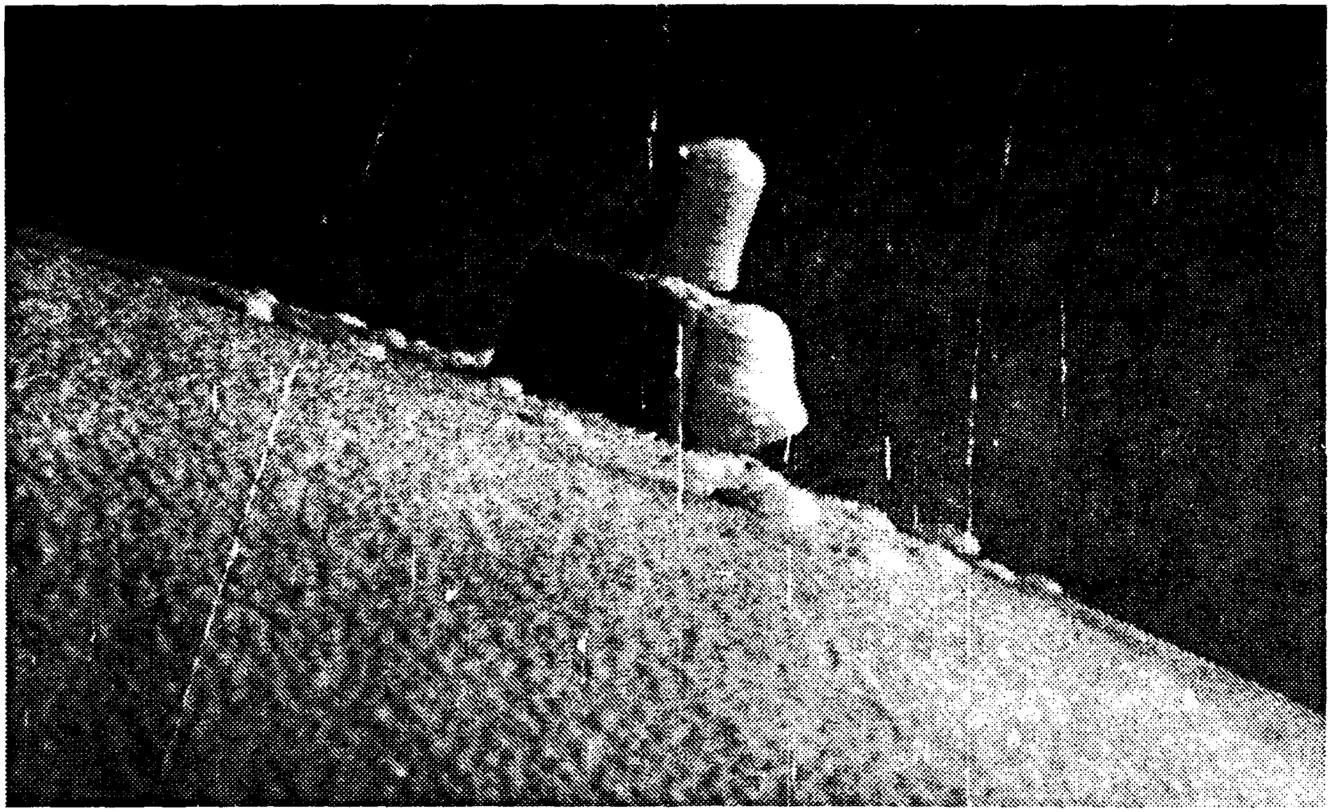

Figure E-10. Ice Accumulation on the Ice Detector Probe

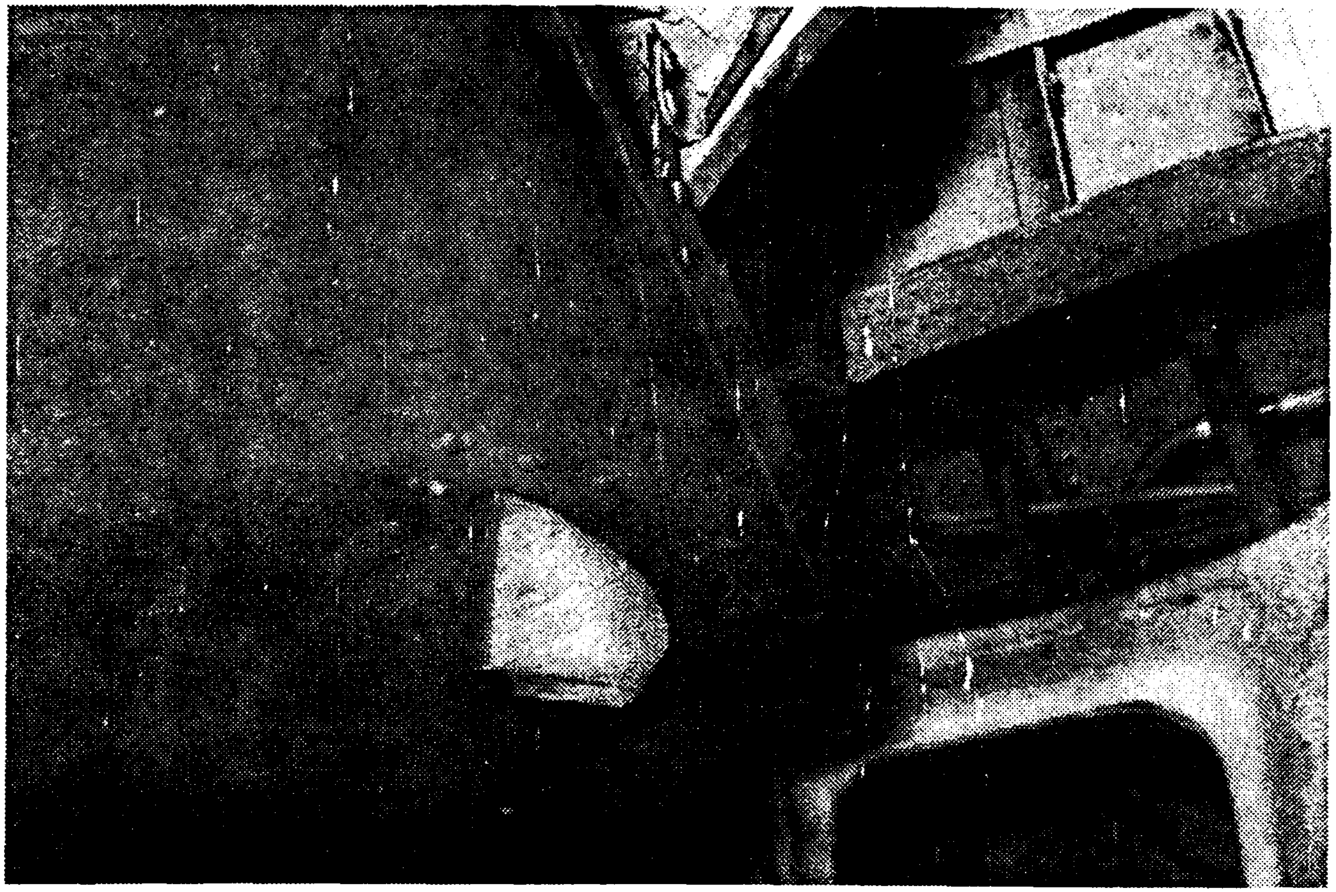

Figure E-11. Ice Accumulation on the Temperature Sensor

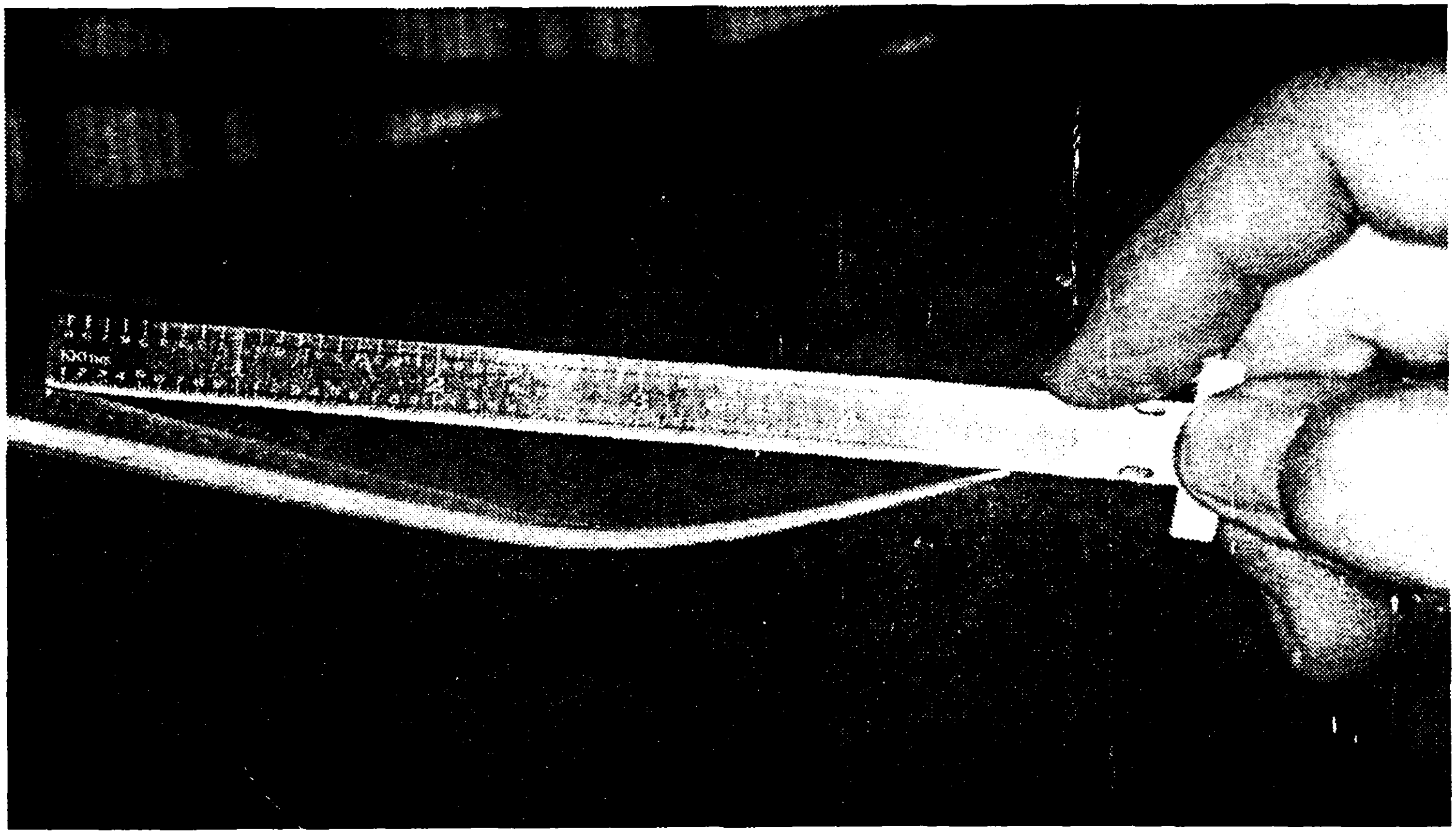

Figure E-12. Propeller Damage

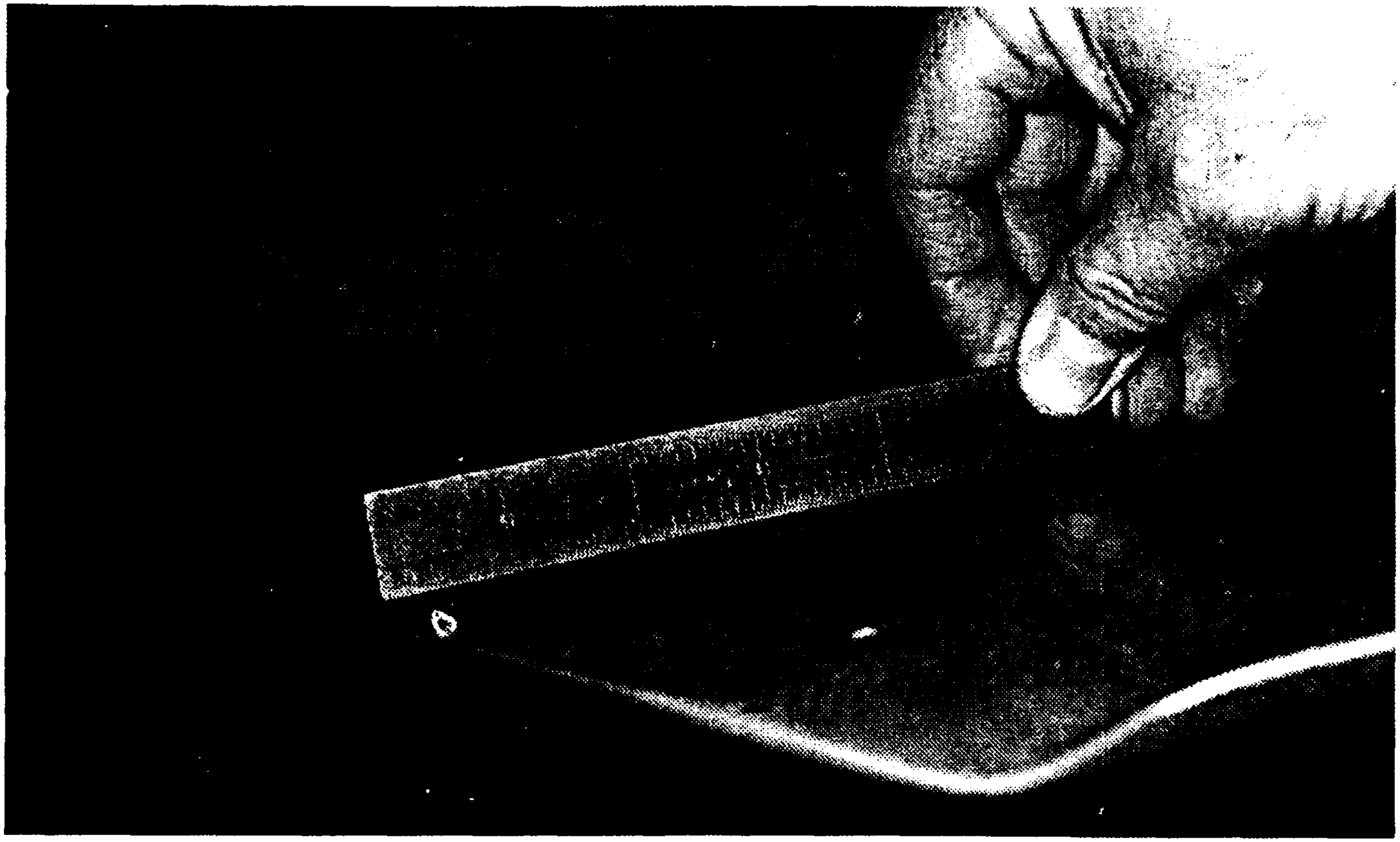

Figure E-13. Propeller Damage

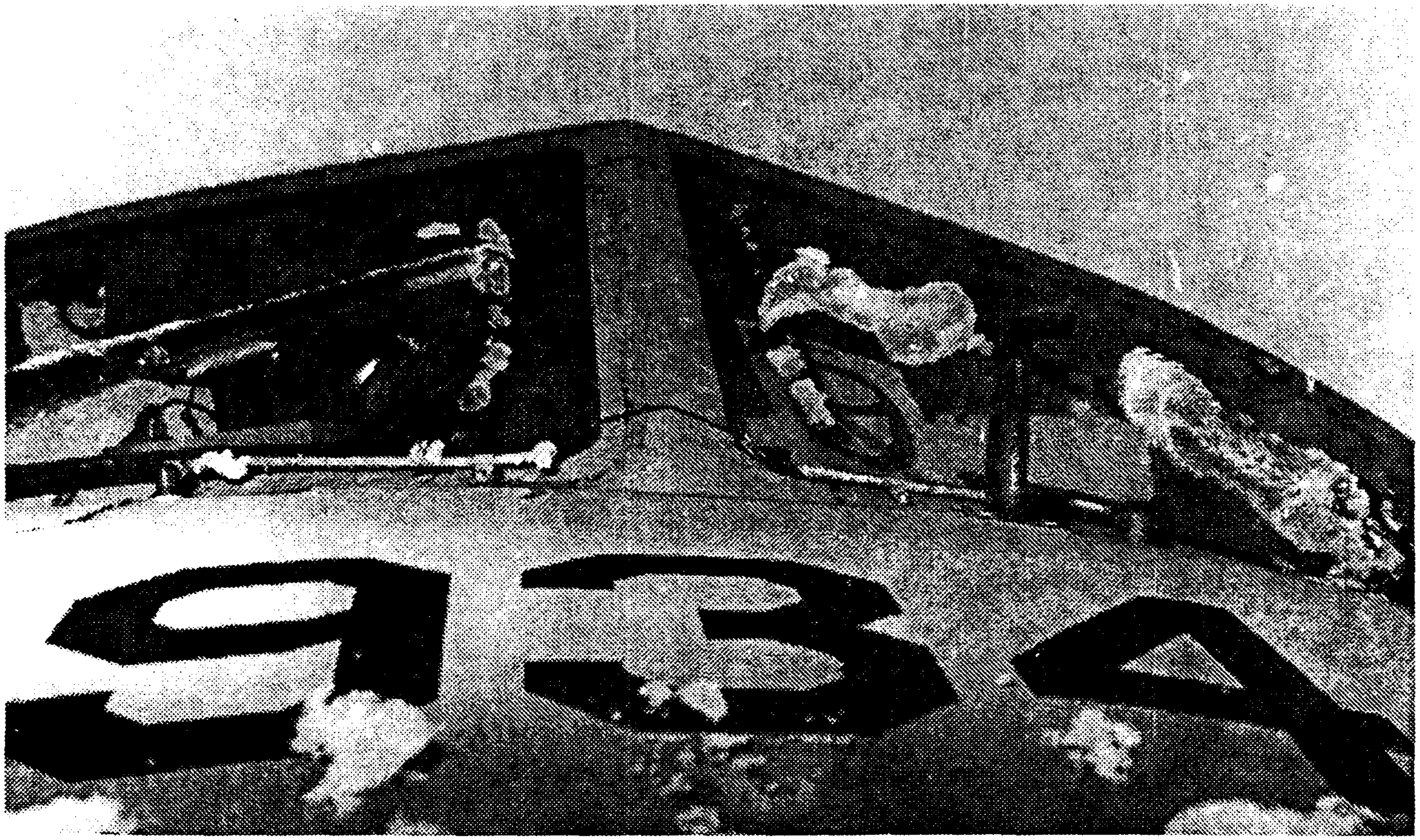

Figure E-14. Ice Accumulation of the Left Windshield Wiper

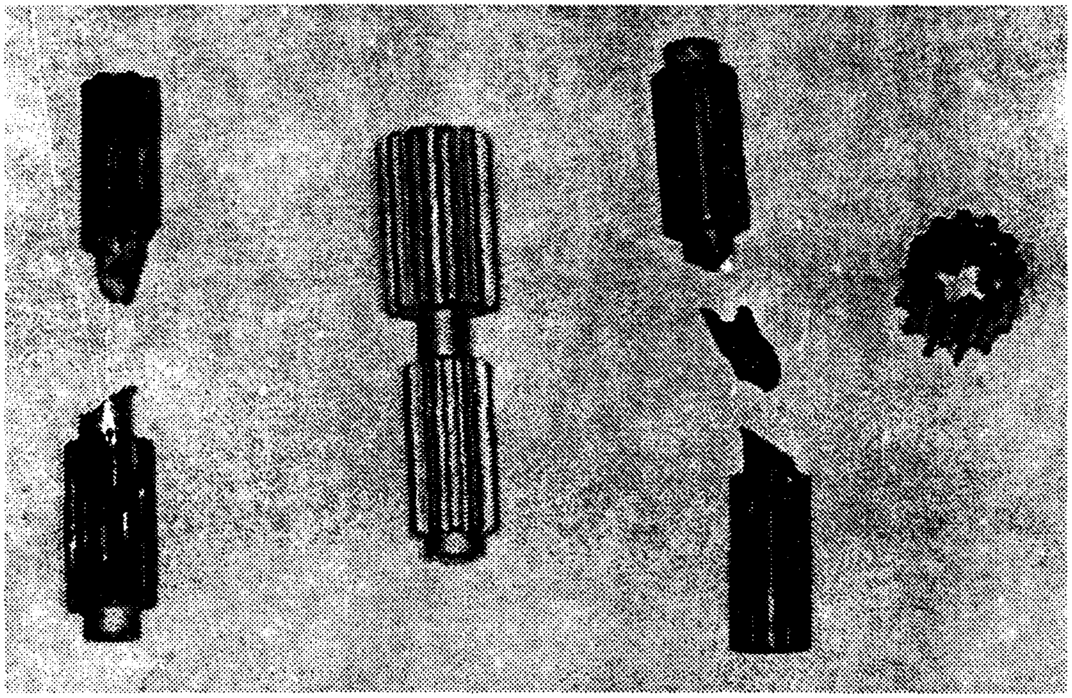

Figure E-15. Comparison of Damaged and Undamaged AC Generator Drive Shafts

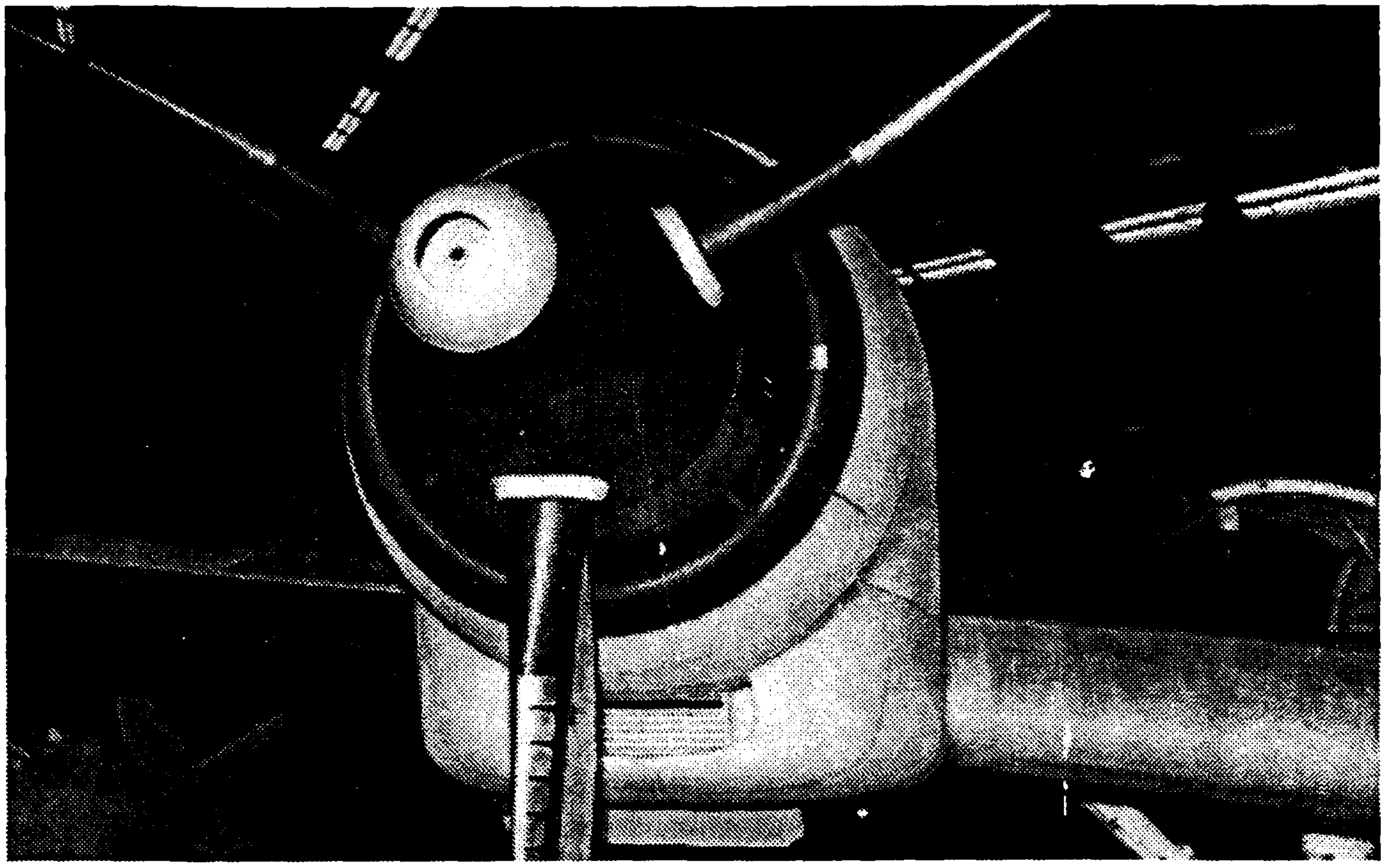

Figure E-16. Propeller and Engine Inlet

APPENDIX F. TEST INCIDENT REPORTS

TEST INCIDENT REPORT (AMCR 70-13) | 1. Release Date: 4 FEB 88

2. Test Title: EVALUATION OF THE IMPROVED OV-1D ANTI-ICING SYSTEM | 3. Test Project#: 87-25 | 4. TIR#: EJ-A-8725-1

5. Test Agency: USAAEFA | 6. Test Sponsor: AVSCOM

I MAJOR ITEM DATA

10. Model: AGH 789-1 25KVA Gen
11. Serial#: NA
12. USA#: NA
13. Mfr: Leland
14. Contract#: USAAVSCOM DAAK 50-G-0004 D.O. 0001, 15 Dec 83

Test Life: Units:
21. 36.8 Hrs
22. NA
23. NA
24. (Not Used)

II INCIDENT DATA

30. Title: 24KVA AC Gen Failure
31. Subsystem: OV-1D
32. Incident Class: Major Incident
33. Category: RAM
34. Observed During: Icing Tests
35. Action Taken: Changed Generators

40. Date & Time: 29 Jan 1988 11:10
41. FD/SC Step#: NA
42. FD/SC Class: NA
43. Chargeability: Hardware
44. Preliminary CA Status: OPen
45. Asgd Resp: Material Developer

48. Test Environment: Artificial icing test in cloud.
49. Defective Materiel: Returned to Grumman.

III INCIDENT SUBJECT DATA

50. Name: AC Generator
51. Serial#: None
52. FSN/NSN: None
53. Mfr: Leland
54. Mfr Part#: AHG-739-1
55. Drawing#: 134SCAV262
56. Quantity: One
57. Action: Replaced drive shaft

60. FGC: OV-1D 68-15934
61. LSA#: NA
Part Life: Units: UNK
63. NA
64. NA
65. NA
66. Next Assy: OV-1 aircraft engine
67. Serial#: 68-15934

IV MAINTENANCE DATA

70. Diagnostic Clockhours: NA
71. Diagnostic Manhours: 3
72. Active Maint Clockhours: NA
73. Active Maint Manhours: NA

80. Type: Unscheduled
81. Level Used: AVUM
82. Level Prsc: None
83. Level Recm: AVUM

V INCIDENT DESCRIPTION

Full Description of Incident:

90. Anti-ice gen light illuminated while in ARTIFICIAL cloud. Trouble shooting revealed that the short shaft between the hydraulic pump and the AC generator sheared.

98. Name, Title & Phone of Preparer: JOSEPH MIESS, CW4 AV 527-4986

99. FOR THE COMMANDER: AUSTIN R. OMLIE, MAJ, CH, PLANS & PROGRAM OFFICE

TEST INCIDENT REPORT (AMCR 70-13)	1. Release Date: 5 Feb 1988	
Test Title: 2. OV-1 IMPROVED ANTI-ICE SYSTEM	Test Project#: 3. 87-25	TIR#: EJ-A-8725-2
5. Test Agency: USAAEFA	6. Test Sponsor: AVSCOM (SEMA)	

I MAJOR ITEM DATA

10. Model: Anti-ice Controller	Test Life: Units:
11. Serial#: 134SCAV277	21. 36.8 Hrs
12. USA#: NA	22. NA
13. Mfr: Cox & Co.	23. NA
14. Contract#: DAAJQ9-05GA030	24. (Not Used)

II INCIDENT DATA

30. Title: Temperature Controller Anti-ice	40. Date & Time: 5 Feb 88 10:45
31. Subsystem: OV-1D	41. FD/SC Step#: NA
32. Incident Class: Major	42. FD/SC Class: NA
33. Category: RAM	43. Chargeability: Hardware
34. Observed During: Icing tests	44. Preliminary CA Status: Open
35. Action Taken: Changed controllers	45. Asgd Resp: Material Developer

48. Test Environment: Artificial icing tests (-5°C)
49. Defective Materiel: Returned to Cox & Co.

III INCIDENT SUBJECT DATA

50. Name: Temperature Controller (anti-ice)	60. FGC: OV-1D 68-15934
51. Serial#: 005	61. LSA#: NA
52. FSN/NSN: NA	Part Life: Units: NA
53. Mfr: Cox & Co.	63. NA
54. Mfr Part#: FSC 98085	64. NA
55. Drawing#: NA	65. NA
56. Quantity: One	66. Next Assy: OV-1 Aircraft
57. Action: Diagnose and repair	67. Serial#: 68-15934

IV MAINTENANCE DATA

70. Diagnostic Clockhours: NA	80. Type: Unscheduled
71. Diagnostic Manhours: 3	81. Level Used: AVUM
72. Active Maint Clockhours: NA	82. Level Prsc: None
73. Active Maint Manhours: NA	83. Level Recm: AVUM

V INCIDENT DESCRIPTION

Full Description of Incident:

90. Anti-ice controller not preventing ice accretion.

Name, Title & Phone of Preparer:	FOR THE COMMANDER:
98. JOSEPH MIESS, CW4 PROJECT OFFICER, AV 527-4986	99. AUSTIN R. OMLIE, MAJ, AV, CHIEF PLANS & PROGRAMS OFFICE

TEST INCIDENT REPORT (AMCR 70-13)	1. Release Date: 14 Feb 1988	
Test Title: 2. EVALUATION OF OV-1D IMPROVED ANTI-ICE SYSTEM	Test Project#: 3. 87-25	TIR#: 4. EJ-A-8725-3
5. Test Agency: USAAEFA	6. Test Sponsor: AVSCOM (SEMA)	

I MAJOR ITEM DATA

10. Model: AGH 789-1 24KVA Generator	Test Life: Units:
11. Serial#: PB 501	21. 3.5 Hrs.
12. USA#: NA	22. NA
13. Mfr: Leland	23. NA
14. Contract#: DAAK 50-83-G-0004-0001	24. (Not Used)

II INCIDENT DATA

30. Title: Generator, AC	40. Date & Time: 14 Feb 88, 0900
31. Subsystem: OV-1D	41. FD/SC Step#: NA
32. Incident Class: Major	42. FD/SC Class: NA
33. Category: RAM	43. Chargeability: Hardware
34. Observed During: Icing tests	44. Preliminary CA Status: Open
35. Action Taken: Replaced generator	45. Asgd Resp: Material Developer

48. Test Environment: Artificial icing tests

49. Defective Materiel: Returned to Grumman.

III INCIDENT SUBJECT DATA

50. Name: AC Generator	60. FGC: OV-1D 68-15934
51. Serial#: PB501	61. LSA#: NA
52. FSN/NSN: NA	Part Life: Units: NA
53. Mfr: Leland	63. NA
54. Mfr Part#: 07639-AGH 789-1	64. NA
55. Drawing#: NA	65. NA
56. Quantity: One	66. Next Assy: OV-1 Aircraft engine
57. Action: Diagnose and repair	67. Serial#: 68-15934

IV MAINTENANCE DATA

70. Diagnostic Clockhours: NA	80. Type: Unscheduled
71. Diagnostic Manhours: 0.1	81. Level Used: AVUM
72. Active Maint Clockhours: NA	82. Level Prsc: None
73. Active Maint Manhours: NA	83. Level Recm: AVUM

V INCIDENT DESCRIPTION

Full Description of Incident:

90. Aircraft had just completed 45 minutes in cloud. Anti-ice generator light illuminated, could not be reset. On landing generator fan turned freely. AC generator shaft had sheared.

Name, Title & Phone of Preparer:	FOR THE COMMANDER:
98. JOSEPH MIESS, CW4 PROJECT OFFICER, AV 527-3986	99. AUSTIN R. OMLIE, MAJ, AV, CHIEF, PLANS & PROGRAMS OFFICE

TEST INCIDENT REPORT (AMCR 70-13)	1. Release Date: 16 Feb 1988	
2. Test Title: EVALUATION OF OV-1D IMPROVED ANTI-ICE SYSTEM	3. Test Project#: 87-25	TIR#: 4EJ-A-8725-4
5. Test Agency: USAAEFA	6. Test Sponsor: AVSCOM (SEMA)	

I MAJOR ITEM DATA

10. Model: AGH 789-1-125KVA	Test Life: Units:
11. Serial#: TB 506	21. 2.0 Hrs.
12. USA#: NA	22. NA
13. Mfr: Leland	23. NA
14. Contract#: DAAK50-83-G-0004-0001	24. (Not Used)

II INCIDENT DATA

30. Title: Generator, AC	40. Date & Time: 14 Feb 88, 0900
31. Subsystem: OV-1D	41. FD/SC Step#: NA
32. Incident Class: Major	42. FD/SC Class: NA
33. Category: RAM	43. Chargeability: Hardware
34. Observed During: Icing Tests	44. Preliminary CA Status: Open
35. Action Taken: Replaced generator	45. Asgd Resp: Material Developer

48. Test Environment: Artificial icing tests.
49. Defective Materiel: Returned to Grumman

III INCIDENT SUBJECT DATA

50. Name: AC generator	60. FGC: OV-1D 68-15934
51. Serial#: TB 506	61. LSA#: NA
52. FSN/NSN: NA	Part Life: Units: NA
53. Mfr: Leland	63. NA
54. Mfr Part#: 07639-AGH 789-1	64. NA
55. Drawing#: NA	65. NA
56. Quantity: One	66. Next Assy: OV-1 aircraft engine
57. Action: Diagnose and repair	67. Serial#: 68-15934

IV MAINTENANCE DATA

70. Diagnostic Clockhours: NA	80. Type: Unscheduled
71. Diagnostic Manhours: 0.1	81. Level Used: AVUM
72. Active Maint Clockhours: NA	82. Level Prsc: None
73. Active Maint Manhours: NA	83. Level Recm: AVUM

V INCIDENT DESCRIPTION

Full Description of Incident:

90. Aircraft had completed 38 minutes in cloud when AC generator light illuminated and could not be reset. AC generator shaft had sheared.

Name, Title & Phone of Preparer: JOSEPH MIESS, CW4	FOR THE COMMANDER:
98. PROJECT OFFICER, AV 527-3986	99. AUSTIN R. OMLIE, MAJ, AV, CHIEF PLANS & PROGRAMS OFFICE

TEST INCIDENT REPORT (AMCR 70-13) | 1. Release Date: 18 Feb 88

2. Test Title: EVALUATION OF IMPROVED OV-1D ANTI-ICE SYSTEM | 3. Test Project#: 87-25 | TIR#: 4EJ-A-8725-5

5. Test Agency: USAAEFA | 6. Test Sponsor: AVSCOM

I MAJOR ITEM DATA

10. Model: AGH 789-1 24KVA Generator	Test Life: Units: NA
11. Serial#: NA	21. 4.0
12. USA#: NA	22. NA
13. Mfr: Leland	23. NA
14. Contract#: USAAVSCOM DAAK50-G-0004-D.O.-0001 15 Dec 83	24. (Not Used)

II INCIDENT DATA

30. Title: 24KVA AC Generator failure	40. Date & Time: 18 Feb 88, 1300
31. Subsystem: OV-1D	41. FD/SC Step#: NA
32. Incident Class: Major incident	42. FD/SC Class: NA
33. Category: RAM	43. Chargeability: Hardware
34. Observed During: Icing tests	44. Preliminary CA Status: Open
35. Action Taken: Replaced drive shaft	45. Asgd Resp: Material developer

48. Test Environment: Natural icing environment.

49. Defective Materiel: Returned to Grumman

III INCIDENT SUBJECT DATA

50. Name: AC Generator	60. FGC: OV-1D 68-15934
51. Serial#: None	61. LSA#: NA
52. FSN/NSN: None	Part Life: Units: UNK
53. Mfr: Leland	63. NA
54. Mfr Part#: AHG-789-1	64. NA
55. Drawing#: 1345CAV262	65. NA
56. Quantity: One	66. Next Assy: OV-1 Aircraft engine
57. Action: Replaced shaft.	67. Serial#: 68-15934

IV MAINTENANCE DATA

70. Diagnostic Clockhours: NA	80. Type: Unscheduled
71. Diagnostic Manhours: 0.3	81. Level Used: AVUM
72. Active Maint Clockhours: NA	82. Level Prsc: None
73. Active Maint Manhours: NA	83. Level Recm: AVUM

V INCIDENT DESCRIPTION

90. Full Description of Incident:
AC generator light illuminated while in natural icing conditions. Short shaft between hydraulic pump and AC generator had sheared. This was a heavier duty shaft, the same type that had been used in 6.5 KVA generator.

Name, Title & Phone of Preparer:

92. JOSEPH MIESS, CW4
PROJECT OFFICER, AV 527-4986

FOR THE COMMANDER:

99. AUSTIN R. OMLIE, MAJ, AV, CHIEF,
PLANS & PROGRAMS OFFICE

TEST INCIDENT REPORT (AMCR 70-13)

1. Release Date: 21 Feb 1988

2. Test Title: EVALUATION OF IMPROVED OV-1D ANTI-ICE SYSTEM

3. Test Project#: 87-25

4. TIR#: EJ-A-87256

5. Test Agency: USAAEFA

6. Test Sponsor: AVSCOM

I MAJOR ITEM DATA

10. Model: AGH 789-1 24 KVA Generator	Test Life: Units:
11. Serial#: NA	21 3.0
12. USA#: NA	22 NA
13. Mfr: Leland	23 NA
14. Contract#: USAAVSCOM DAAK 50-G-0004 D.O.-0001, 15 Dec 83	24. (Not Used)

II INCIDENT DATA

30. Title: 24 KVA AC generator failure	40. Date & Time: 18 Feb 88, 1010
31. Subsystem: OV-1D	41. FD/SC Step#: NA
32. Incident Class: Major incident	42. FD/SC Class: NA
33. Category: RAM	43. Chargeability: Hardware
34. Observed During: Icing tests	44. Preliminary CA Status: Open
35. Action Taken: Replaced drive shaft	45. Asgd Resp: Material developer

48. Test Environment: Natural icing environment

49. Defective Materiel: Returned to Grumman

III INCIDENT SUBJECT DATA

50. Name: AC generator	60. FGC: OV-1D 68-15934
51. Serial#: None	61. LSA#: NA
52. FSN/NSN: None	Part Life: Units: UNK
53. Mfr: Leland	63. NA
54. Mfr Part#: AHG-789-1	64. NA
55. Drawing#: 1345CAV262	65. NA
56. Quantity: Two	66. Next Assy: OV-1 aircraft engine
57. Action: Replaced shafts	67. Serial#: 68-15934

IV MAINTENANCE DATA

70. Diagnostic Clockhours: 0.0	80. Type: Unscheduled
71. Diagnostic Manhours: 0.0	81. Level Used: AVUM
72. Active Maint Clockhours: NA	82. Level Prsc: None
73. Active Maint Manhours: NA	83. Level Recm: AVUM

V INCIDENT DESCRIPTION

Full Description of Incident:

90. During flight in icing conditions, AC generator light illuminated. Short shafts between hydraulic pumps and AC generators had sheared. These were heavy duty shafts that had been used in 6.5 KVA generators.

Name, Title & Phone of Preparer:

98 JOSEPH MIESS, CW4 60
PROJECT OFFICER, AV 527-2986

FOR THE COMMANDER:

99. AUSTIN R. OMLIE, MAJ, AV, CHIEF
PLANS & PROGRAMS OFFICE

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US Army Aviation Research and Technology Activity (AVSCOM Propulsion Directorate (SAVRT-PN-D)	1
Defense Technical Information Center (FDAC)	2
US Military Academy, Department of Mechanics (Aero Group Director)	1
ASD/AFXT, ASD/ENF	2
US Army Aviation Development Test Activity (STEBG-CT)	2
Assistant Technical Director for Projects, Code: CT-24 (Mr. Joseph Dunn)	2
6520 Test Group (ENML)	1
Commander, Naval Air Systems Command (AIR 5115B, AIR 5301)	3
Defense Intelligence Agency (DIA-DT-2D)	1
School of Aerospace Engineering (Dr. Daniel P. Schrage)	1
Headquarters United States Army Aviation Center and Fort Rucker (ATZQ-ESO-L)	1