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LIMITED ARTIFICIAL AND NATURAL ICING TESTS OF THE
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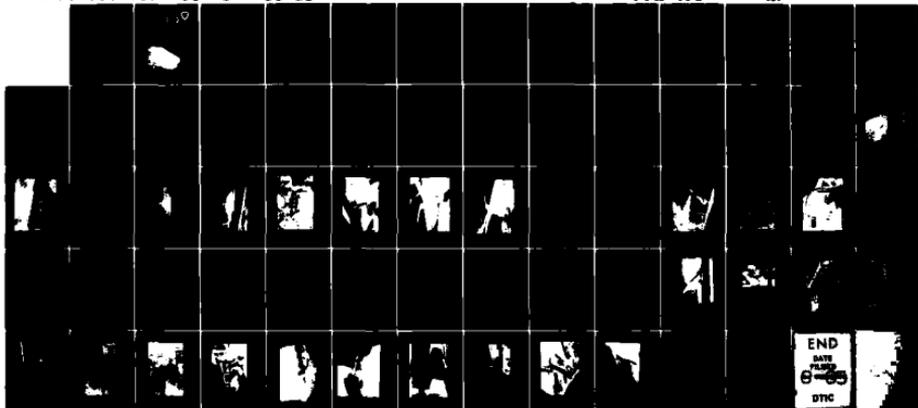
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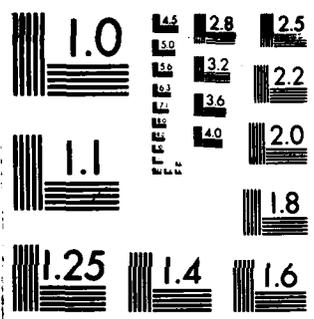
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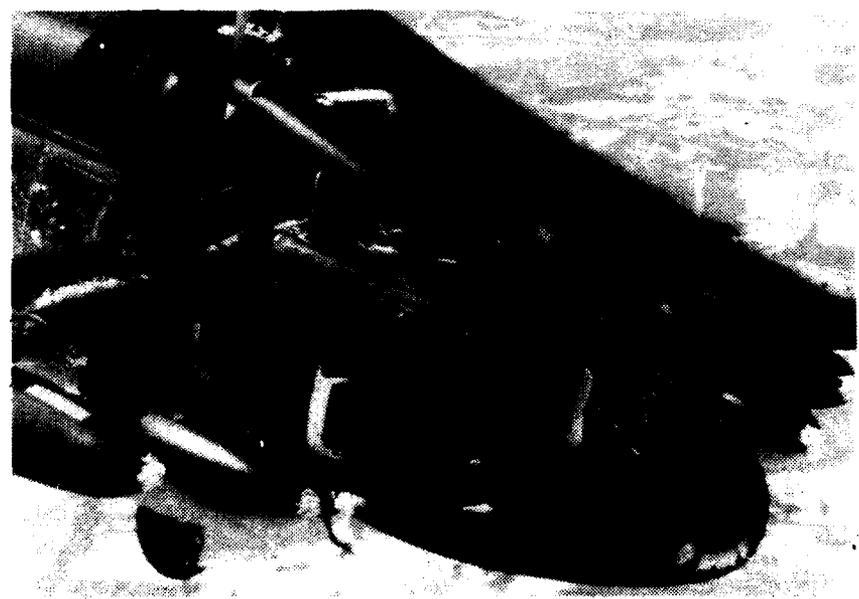
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**LIMITED ARTIFICIAL AND NATURAL ICING TESTS
OF THE EXTERNAL STORES SUPPORT SYSTEM
(ESSS) INSTALLED ON A UH - 60A AIRCRAFT**

**MARVIN L. HANKS
MAJ, AV
PROJECT OFFICER / PILOT**

**RALPH WORATSCHEK
PROJECT ENGINEER**

**JUNE 1984
FINAL REPORT**



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

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A limited artificial and natural icing evaluation of the production UH-60A Black Hawk helicopter equipped with an External Stores Support System (ESSS) and selected components of a prototype Wire Strike Protection System (WSPS) was conducted to determine the capability to operate safely in a moderate icing environment. Flight tests were conducted at Duluth, Minnesota, from 20 February through 29 March 1984. Testing was performed by the United States Army Aviation Engineering Flight Activity and consisted of 23.6 productive flight hours. The UH-60A helicopter configured with the ESSS can safely		

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operate in icing conditions through the moderate level of intensity. The probability of rotating component foreign object damage (FOD), due to impact with shed ice particles, is increased with the installation of the WSPS. The probability of engine FOD, due to ice ingestion, is increased with the installation of the improved airspeed system pitot-static tube support strut fairings or wedges. Three major shortcomings were identified: (1) the large ice accretions on the WSPS components which subsequently shed and cause FOD to the aircraft; (2) the large ice accretions on the forward portion of the improved airspeed system pitotstatic tube support strut fairings or wedges; (3) the inadequate anti-ice provisions on the pitot-static tube support struts as installed with the improved airspeed system fairings or wedges. The two shortcomings associated with the improved airspeed system should be corrected prior to release of any UH-60A aircraft configured with the improved airspeed system for flight in icing conditions. The shortcoming associated with the WSPS should be corrected prior to release of UH-60 helicopters equipped with the WSPS for flight in icing conditions.

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REPLY TO
ATTENTION OF

DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY AVIATION SYSTEMS COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120-1798

AMSAV-E

SUBJECT: Directorate for Engineering Position on the Final Report of USAAEFA Project No. 83-22, Limited Artificial and Natural Icing Tests of the External Stores Support System (ESSS) Installed on a UH-60A Aircraft

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1. The purpose of this letter is to establish the Directorate for Engineering position on the subject report. The objective of the icing tests was to evaluate the UH-60A with the ESSS installed to insure satisfactory operation consistent with the moderate icing envelope capability of the basic UH-60A. In addition to the ESSS, the test UH-60A also incorporated an improved airspeed system, a Wire Strike Protection System (WSPS) and fixed provision fairings which are installed when the ESSS is removed. Although the additional preceding installed items were designed to reduce ice accretion and shedding, it still occurred, thereby increasing Foreign Object Damage (FOD) to the airframe, rotating components and the engines.

2. This Directorate agrees with the report conclusions and recommendations and the following additional comments are provided. Comments are directed to the paragraph of the report as indicated below:

a. Paragraphs 22a, 22b, and 22c. The shortcomings in these paragraphs related to actual and potential FOD caused by shed ice cannot be easily corrected through redesign. Of major concern is the engine damage in which FOD represents 52% of all engine removals. Shed ice FOD represents one half of this total and presents a serious safety problem as well as degraded maintainability and cost. The BLACK HAWK Project Manager has requested Sikorsky Aircraft provide a formal design proposal for an ice protection screen for the engines. The screen would provide FOD protection in an icing and non-icing environment. Until the screen is available, shed airframe ice will result in negative safety, maintainability and cost impacts.

b. Paragraphs 23a through 23g: The shortcomings listed in these paragraphs were previously addressed in the referenced reports.

c. Paragraph 24: Correction of the WSPS design is being evaluated. However, it may require changes which degrade the protection afforded by the WSPS under non-icing conditions. The best overall protection appears to be the engine FOD screen.

AMSAV-E

SUBJECT: Directorate for Engineering Position on the Final Report of USAAEFA
Project No. 83-22, Limited Artificial and Natural Icing Tests of the
External Stores Support System (ESSS) Installed on a UH-60A Aircraft

d. Paragraph 25: The new improved airspeed system pitot-static tube support strut fairings or wedges degraded the safe operation of the UH-60A in icing conditions. The designs of the preceding are being evaluated for corrective changes; however, as with the WSPS, the engine FOD screen appears to be the best overall protection.

e. Paragraph 26a through 26d: These recommendations are being evaluated for incorporation in the Operator's Manual as appropriate. Relabeling of the Windshield Anti-ice Copilot and Pilot switches is also being evaluated. However, there have been no complaints from the field relative to the labeling of these switches.

3. The report prepared by the US Army Aviation Engineering Flight Activity (USAAEFA) provides excellent documentation of the significant safety and cost impacts caused by accreted and shed ice relative to minor as well as major external configuration changes. Any such changes necessitate evaluation of the design to consider accreted and shed ice in terms of FOD which causes degradation in safety and maintainability. In the case of the UH-60A with the improved airspeed pitot static system and WSPS, any changes to correct the reported shortcomings will require re-evaluation in moderate icing conditions, particularly if an engine FOD screen is incorporated.

FOR THE COMMANDER:

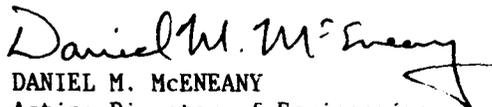

DANIEL M. McENEANY
Acting Director of Engineering

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INTRODUCTION

BACKGROUND

1. The UH-60A helicopter with the production deicing kit installed has undergone natural and artificial icing airworthiness qualification flight tests (refs 1 through 3, app A) and has been cleared for flight into moderate icing conditions. The External Stores Support System (ESSS) is designed to meet a requirement for a self-deployment capability for the UH-60A. The ESSS allows the UH-60A to operate over long distances with auxiliary fuel by externally mounting a 450 gallon and a 230 gallon fuel tank on each side of the helicopter. Artificial and natural icing tests were required to qualify this configuration for flight in moderate icing. The US Army Aviation Systems Command (AVSCOM) requested the US Army Aviation Engineering Flight Activity (USAAEFA) conduct artificial and natural icing tests on the ESSS configured UH-60A during the winter of 1983-84 (ref 4). Testing was conducted in accordance with the approved test plan (ref 5).

TEST OBJECTIVE

2. The objective of this test was to conduct limited artificial and natural icing flight tests to provide AVSCOM the basis for establishing a moderate icing envelope for a UH-60A configured with the ESSS.

DESCRIPTION

3. The ESSS is a modification of the UH-60A helicopter designed to provide the capability for performing extended range missions and self-deployment. The test aircraft, UH-60A USA Serial Number 79-23352, is a twin-turbine single main rotor helicopter capable of day or night operations in visual or instrument meteorological conditions (IMC). The main and tail rotors are both four-bladed with a capability of manual main rotor blade and tail rotor pylon folding. A horizontal stabilator is located on the tail rotor pylon. The deicing kit installed incorporates a main and tail rotor deicing system and an ice detection system as well as anti-ice provisions for the main rotor droop stops, the pilot and copilot windshields, pitot-static tubes and their support struts, engines, and engine inlets (ref 2, app A). The ESSS for the UH-60A consists of airframe fixed provisions and external stores subsystems. The airframe fixed provisions include permanent structural modifications, attachment points, fuel and pneumatic lines and electrical harnesses. The external stores subsystem is comprised of a horizontal stores support, two support struts, and two vertical stores pylons for each side of the aircraft.

The pylons are designed to accommodate a 450 gallon fuel tank on the inboard station and a 230 gallon tank on the outboard station. All stores stations are designed to permit jettison of loads. The ESSS installed on the test aircraft was a prototype design fully capable of stores jettison and fuel transfer. An improved airspeed system was installed which consisted of reoriented pitot-static tubes and fairing around the base of these tubes. Selected mock-up components of a prototype Wire Strike Protection System (WSPS) were also installed on the test aircraft. A more detailed description of the standard UH-60A is contained in the operator's manual (ref 6, app A). A description of the ESSS is included in USAAEFA report number 82-14 (ref 7) and appendix B. A brief description of the Helicopter Icing Spray System (HISS) is presented in appendix C. A more detailed description of the HISS and a description of the JU-21A configured with the cloud particle measuring system, used to document the icing environment in which the test aircraft was flown, are presented in reference 8, appendix A.

TEST SCOPE

4. In-flight artificial and natural icing tests were conducted in the vicinity of Duluth, Minnesota from 20 February to 29 March 1984. A total of 18 icing flights were conducted totaling 38.3 hours. Seven artificial icing flights totaling 5.0 productive hours, and 11 natural icing flights, totaling 18.6 productive hours were conducted. Maintenance, quality assurance control, and logistical support for the test aircraft was provided by the US Army Aviation Development Test Activity. The test aircraft was flown in three different configurations: fixed provisions (the normal utility configuration with ESSS mounting provisions enclosed by fairings); ESSS with two-230 gallon tanks mounted on the outboard store stations; and ESSS with four tanks mounted. Tests were conducted at the range of conditions shown in table 1. Anti-ice and deice systems were operated continuously while in the icing environment. A summary of specific test conditions is presented in table 1, appendix F. Flight limitations contained in the operator's manual and the airworthiness release (ref 9, app A) were observed during testing.

TEST METHODOLOGY

5. Artificial icing was conducted by flying in a spray cloud generated by the HISS. The JU-21A configured with the cloud particle measuring system was used to document the HISS cloud and provide visual chase and photographic documentation while the

Table 1. Test Conditions

Number of Flights	Icing Environment	Configuration	Average Outside Air Temperature (°C)	Average Liquid Water Content (gm/m ³)	Average True Airspeed (knots)	Total Time in Cloud (hours)
2	Artificial	Fixed Provisions	-4.5 and -20	0.96 and 1.00	120	1.6
3	Natural		-8.0 to -16.0	0.15 to 0.30	123 to 134	3.2
1	Artificial	ESSS, 2-tank	-15.5	1.03	120	0.8
1	Natural		-13.0	0.05	135	0.5
4	Artificial	ESSS, 4-tank	-5.5 to -20	0.95 to 1.05	120	2.6
7	Natural		-3 to -21	0.05 to 0.36	107 to 125	14.9

NOTES:

Range of average gross weights; 12,180 to 18,530 lb

Range of center-of-gravity; FS 349.0 to FS 363.3

Range of density altitudes; 80 to 7960 feet

Average rotor speed: 258 rpm (100 percent)

test aircraft was in the artificial cloud. Ice accretion was also documented on the ground following icing encounters. The UH-60A was immersed in the cloud for the maximum time attainable (limited by HISS fuel and water capacities). A detailed discussion of the test sequence and procedures is contained in reference 5, appendix A.

6. Natural icing tests were conducted by flying in IMC icing conditions under instrument flight rules (IFR). The JU-21A chase aircraft configured with the cloud particle measuring system was used to locate and document the icing conditions. Photographs were taken in-flight from the JU-21A after the test aircraft exited the icing environment. Close coordination with air traffic control, the chase, and test aircraft crews was required to find and stay in the icing environment and to implement in-flight aircraft join-up for photographic documentation. A combination of radar vectoring, navigational aid holding, and block airspace assignment were used to control natural icing flights. Time in the clouds was limited by the availability of natural icing conditions and aircraft IFR fuel requirements.

7. A description of special equipment and instrumentation used to document icing conditions and ice accretion is presented in appendix D. Test techniques, data analysis methods, methods used to determine cloud parameters, and definitions of icing types and severities are presented in appendix E.

RESULTS AND DISCUSSION

GENERAL

8. Artificial and natural icing flight tests were conducted on a UH-60A helicopter configured with the ESSS and selected components of a prototype WSPS. The aircraft was tested in the fixed provision configuration as well as the two (230 gallon outboard) external fuel tank and four (two-230 gallon outboard and two-450 gallon inboard) external fuel tank configurations. Anti-ice capabilities, ice accretion and ice shedding characteristics were documented. A summary of the specific test conditions for each flight is presented in table 1, appendix F. Additionally, a graphic presentation of the artificial and natural icing test conditions is shown in figures 1 and 2, appendix F, respectively. The UH-60A helicopter configured with the ESSS can safely operate in icing conditions through the moderate level of intensity. The probability of rotating component foreign object damage (FOD), due to impact with shed ice particles, is increased with the installation of the WSPS. The probability of engine FOD, due to ice ingestion, is increased with the installation of the improved airspeed system pitot-static tube support strut fairings or wedges. Three major shortcomings were identified: (1) the large ice accretions on the WSPS components which subsequently shed and cause FOD to the aircraft; (2) the large ice accretions on the forward portion of the improved airspeed system pitot-static tube support strut fairings or wedges; (3) the inadequate anti-ice provisions on the pitot-static tube support struts as installed with the improved airspeed system fairings or wedges. The two shortcomings associated with the improved airspeed system should be corrected prior to release of any UH-60A aircraft configured with the improved airspeed system for flight in icing conditions. The shortcoming associated with the WSPS should be corrected prior to release of UH-60 helicopters equipped with the WSPS for flight in icing conditions.

ANTI-ICE SYSTEMS OPERATION

General

9. The anti-ice systems installed on the test aircraft were identical to the systems previously tested (ref 3, app A) except for the improved main rotor droop stops (P/N 70105-08151-045, photo 4, app B). All anti-ice systems were activated prior to entering the icing environment and were operational for all icing flights. Observed anti-ice system operational characteristics were identical to previous tests except as noted in the following paragraphs. The inadequate anti-ice provisions on the pitot-static struts as installed with the improved airspeed system fairings or wedges was identified as a shortcoming.

Pitot-Static Tube Struts

10. Pitot-static tube strut anti-ice characteristics were evaluated throughout these tests. Specific test conditions are presented in table 1, appendix F. The test aircraft was equipped with the improved airspeed system (para 7, app B). The pitot-static tube is fully anti-iced, while only the leading edge of the support strut is anti-iced. The improved airspeed system was tested with an aerodynamic fairing and with wedges installed (photos 7 and 8, app B). Large ice accretions were observed to form on the unheated aft, outboard, lower portions of both pitot-static tube struts at most of the conditions tested (artificial and natural). An example of these ice formations is shown in photo 1, appendix G. These ice accretions were larger with increased icing exposure (liquid water content (LWC) or time) and were characterized by clear globular formations. These characteristics are typical of runback ice formations indicating that the pitot-static tube strut anti-ice capabilities were exceeded. The location of the ice formation, directly in front of the engine inlet, increases the probability of engine FOD, although none was noted during 23.6 hours of icing condition flight. Since previous testing on UH-60 aircraft without the improved airspeed system installation fairing or wedge did not encounter this problem, it is expected that the size and shape of the improved airspeed system installation fairing or wedge was responsible for these ice formations. The inadequate anti-ice provisions on the pitot-static tube support struts as installed with the improved airspeed system fairings or wedges is a shortcoming. The inadequate anti-ice capabilities of the pitot-static tube support struts should be improved prior to release into icing conditions of any UH-60 aircraft configured with the improved airspeed system.

Droop Stops

11. The anti-ice characteristics of the improved droop stops were evaluated at the specific test conditions shown in table 1, appendix F. The improved droop stops (P/N 70105-08151-045, photo 2, app G) installed on the test aircraft were electrically anti-iced and differed slightly in design from the droop stops previously tested (ref 3, app A). Following all tests, the improved anti-iced droop stops returned to the retracted position, fully seated, and incurred no damage. The improved anti-iced droop stops operated satisfactorily through moderate icing conditions.

FLIGHT CONTROL SURFACE ICE ACCRETION AND SHEDDING CHARACTERISTICS

General

12. The flight control surface ice accretion and shedding characteristics were evaluated at the specific test conditions listed in table 1, appendix F. No changes were incorporated in the test aircraft main or tail rotor deice systems that had not been previously tested (refs 2 and 3, app A). Ice accretion and shedding characteristics of the main rotor, tail rotor, stabilator and vertical stabilizer were identical to previous results. The flight control surface ice accretion and shedding characteristics of the ESSS configured UH-60A helicopter were satisfactory.

AIRFRAME ICE ACCRETION AND SHEDDING CHARACTERISTICS

General

13. The airframe ice accretion and shedding characteristics of the ESSS configured UH-60A helicopter were evaluated in three configurations the fixed provisions only, the two (230 gallon) external fuel tank and the four (two-230 gallon and two-450 gallon) external fuel tank configurations at the specific test conditions shown in table 1, appendix F. The test conditions are shown graphically for the artificial and natural icing environments in figures 1 and 2, respectively. The test aircraft was also configured with the improved airspeed system and a portion of a prototype WSPS. In-flight photographic documentation from a chase aircraft as well as onboard photography were utilized. A typical in-flight photo of the helicopter with ice accreted, photo 3 and 4, appendix G was taken immediately after exiting natural icing conditions. The ice accretions depicted in this photo were indicative of all natural icing encounters in this configuration during the evaluation. Ice formed on all stagnation areas and sharp protrusions from the airframe, ESSS and external fuel tanks. Two shortcomings were documented which were associated with the ESSS configured UH-60 helicopter as tested with the prototype WSPS and improved airspeed system installed. The probability of rotating component FOD, due to impact with shed ice particles, is increased with the installation of the WSPS. The probability of engine FOD, due to ice ingestion, is increased with the installation of the improved airspeed system pitot-static tube support strut fairings or wedges.

Pitot-Static Tube Mounts

14. The ice accretion and shedding characteristics of the improved airspeed system pitot-static tube mounts were evaluated at the specific conditions shown in table 1, appendix F. A fairing was installed around the base plate of the standard UH-60A pitot-static tube support as a result of the improved airspeed system modification. Details of the fairings installation is contained in appendix B. An example of an ice accretion on these fairings is shown in photo 5, appendix G. This in-flight photo shows the relative position of this accretion to the engine inlet. Although a few instances of natural ice accretion shedding were observed, no engine FOD was noted. An alternate metal wedge pitot-static strut installation was tested with similar results. The large ice accretion and location of the formation relative to the engine inlet combined to increase the probability of engine FOD. The large ice accretions on the forward portion of the improved airspeed system pitot-static tube support strut fairings or wedges is a shortcoming. The pitot-static tube support strut mounting should be redesigned to minimize or eliminate ice accretion prior to release into icing conditions of any UH-60 aircraft configured with the improved airspeed system.

Fixed Provision Fairings

15. The ice accretion and shedding characteristics of the fixed provision fairings were evaluated at the specific test conditions shown in table 1, appendix F. Artificial and natural icing condition flights were conducted with the aircraft configured with fixed provision fairings. All icing flights were conducted with the prototype wing root fairings except for two flights where the right prototype wing root fairings (smooth surface) were replaced with production wing root fairings (ribbed surface). A detailed description of these fairings with photos is contained in appendix B. Photos 6 and 7, appendix G, document typical ice accretions on the right (production) fairing and left (prototype) fairing, respectively. These photos show small ice accretions (approximately 1/2 inch thick) on the wing root fairings and a larger buildup of ice (approximately 3 inches thick) on the outboard portions of the fixed provision fairings. The area directly in front of the engine inlet accumulated only a small quantity of ice, and no engine or aircraft damage was documented when these formations shed. The ice accretion and shedding characteristics of the fixed provision fairings (combined with either the prototype or production wing root fairings) were satisfactory.

External Stores Support System External Fuel Tank Configuration

16. The ice accretion and shedding characteristics of the UH-60A helicopter configured with an ESSS and external fuel tanks were evaluated at the specific test conditions shown in table 1, appendix F. Thirteen of the eighteen icing flights were conducted with the ESSS wing and fuel tanks installed. Eleven flights were flown with four external fuel tanks installed and two were conducted with the two-230 gallon outboard tanks installed. A typical ice accretion is shown in photo 8, appendix G. The ESS installed on the test aircraft was an operable external fuel system and fuel was transferred during icing condition flight with ice accretions on the tanks and supports. As much as four inches of ice was accreted on the stagnation regions of the horizontal and vertical supports, and the nose of the fuel tanks. Larger accretions (approximately six inches thick) were observed on the wing struts due to their higher catch efficiency. On several occasions the aircraft descended below the freezing level and these ice formations were shed. These ice sheds were observed from the chase aircraft and documented on video tape. In all cases the shed ice particles passed well clear of rotating components. No evidence of aircraft damage due to shedding of these ice accretions was documented. The ice accretion and shedding characteristics of the ESSS with either two (230 gallon) or four (two-230 gallon and two-450 gallon) external fuel tanks installed were satisfactory.

Vertical Stores Pylon Jettison Racks

17. The stores jettison capability of the wing pylon stores racks was evaluated at the specific test conditions shown in table 1, appendix F. Ice accreted on the forward end of both the inboard and outboard stores jettison racks in the area between the external fuel tanks and the vertical pylon fairings. Photos of the outboard wing pylon stores jettison rack with ice accreted are shown in photos 9 and 10, appendix G, respectively. The manual release mechanism lever must move forward approximately 1/2 inch for the outboard jettison rack to fully release. Static (rotors stopped on the ground) jettison tests were satisfactorily accomplished with ice accretions which restricted the motion of the manual release lever. The inboard vertical pylon jettison rack is of a different construction and has no components restricted by ice accretions. No other ice accretion or shedding characteristics were observed which should effect aircraft operation or stores jettison. The stores jettison capability with ice accretion on the ESSS vertical pylon jettison racks was satisfactory.

Wire Strike Protection System

18. Ice accretion and shedding characteristics of selected portions of a prototype WSPS were evaluated at the specific test conditions listed in table 1, appendix F. Two upper wire cutters and several wire deflectors were installed. The test installation included only the components considered to have an icing hazard potential. A full description of these WSPS selected components is contained in appendix B. A typical ice accretion can be seen in the large scale aircraft photograph (photo 3, app G). Close-up pictures of the WSPS peculiar accretions are shown in photos 11 through 14, appendix G. Large ice accretions (as much as five inches in thickness) were observed both from the chase aircraft and as residual ice formations after landing. On several occasions observers reported large pieces of ice departing these components and striking various fixed and rotating components of the test aircraft. Ice from the upper wire cutter was seen striking the pitch change links of the main rotor blades and fragmenting into the main and tail rotors. The location of these components near the aircraft centerline and forward of the rotating components contribute to the potential for FOD. Following several flights, in which the ice was naturally shed from the WSPS components, main and/or tail rotor blade damage was noted on the post-flight inspection. One such FOD occurrence (flight 17, average OAT of -7.0°C , average LWC of 0.36 gm/m^3) resulted in dents to three main rotor blade lower skin surfaces. One dent (0.086 inches deep at approximately two-thirds span) was cause for blade rejection. Another dent found on the tail rotor red blade skin approached blade paddle replacement criteria. Lesser damage to other main and tail rotor blades and tip caps were documented throughout these tests. No damage to the main rotor pitch change links was noted. The large ice accretions on the WSPS components which subsequently shed and cause FOD damage to the aircraft is a shortcoming. A design effort should be undertaken to minimize the ice accretion and/or ice shedding FOD associated with the WSPS prior to issuing a clearance for flight in icing conditions for aircraft so equipped.

MISCELLANEOUS

19. No corrective action was accomplished for several of the previously identified (refs 2 and 3, app A) shortcomings on the UH-60A in icing conditions. The following discrepancies remain:

- a. The failure of the anti-flapping restrainers to return to the shutdown position with ice accumulation on the rotor head.

b. The large increase in power required with ice accumulation on the rotor system.

c. The large decrease in power available with engine and engine inlet anti-ice systems ON.

d. The poor location of the deice system circuit breakers.

e. The inadequate water tightness of the cockpit.

f. The ice accumulation on the cockpit steps.

g. The ice accumulation on the FM homing antennas which interferes with cockpit door opening.

20. The following recommendations still apply from previous UH-60 icing tests since no corrective action has been accomplished or the corrective action taken was inadequate to warrant deletion of the previous (refs 2 and 3, app A) recommendation:

a. The Windshield Anti-Ice Copilot and Pilot switches should be labeled to indicate the reset feature of the OFF position.

b. The following CAUTION should be placed in the operator's manual immediately:

CAUTION

Continued use of a faulty windshield anti-ice system may result in structural damage (delamination and/or cracking) to the windshield.

c. The following CAUTION should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment.

CAUTION

If ice accumulates on one or more sections of the anti-iced windshields, with the windshield anti-ice system ON, the respective windshield should be turned OFF and the icing conditions exited due to the possibility of engine foreign object damage if the ice should shed from the windshield.

d. The following NOTE should be placed in the operator's manual as soon as possible:

NOTE

During operation in cold weather, particularly when snow or moisture is present, the tail wheel locking indicating system may give erroneous cockpit indications.

CONCLUSIONS

GENERAL

21. The UH-60A helicopter configured with the ESSS can safely operate in icing conditions through the moderate level of intensity. The probability of rotating component FOD, due to impact with shed ice particles, is increased with the installation of the Wire Strike Protection System. The probability of engine FOD, due to ice ingestion, is increased with the installation of the Improved airspeed system pitot-static tube support strut fairings or wedges.

SHORTCOMINGS

22. The following shortcomings were identified and are listed in decreasing order of importance.

a. The large ice accretions on the WSPS components which subsequently shed and cause FOD to the aircraft (para 18).

b. The large ice accretions on the forward portion of the improved airspeed system pitot-static tube support strut fairings or wedges (para 14).

c. The inadequate anti-ice provisions on the pitot-static tube support struts as installed with the improved airspeed system fairings or wedges (para 10).

23. The following previously identified (from previous UH-60 icing tests) icing related shortcomings remain (para 19).

a. The failure of the anti-flapping restrainers to return to the shutdown position with ice accumulation on the rotor head.

b. The large increase in power required with ice accumulation on the rotor system.

c. The large decrease in power available with engine and engine inlet anti-ice systems ON.

d. The poor location of the deice system circuit breakers

e. The inadequate water tightness of the cockpit.

f. The ice accumulation on the cockpit steps.

g. The ice accumulation on the FM homing antennas which interferes with cockpit door opening.

RECOMMENDATIONS

24. The shortcoming listed in paragraph 22a should be corrected prior to release of any UH-60 aircraft, equipped with a WSPS, to operate in icing conditions (para 18).

25. The shortcomings listed in paragraph 22b and c should be corrected prior to release into icing conditions of any UH-60 aircraft, equipped with the improved airspeed system pitot-static tube support strut fairings or wedges (paras 10 and 14).

26. The following recommendations still apply from previous UH-60 icing tests since no corrective action has been accomplished or the corrective action taken was inadequate to warrant deletion of the previous (refs 2 and 3, app A) recommendation (para 20).

a. The Windshield Anti-Ice Copilot and Pilot switches should be labeled to indicate the reset feature of the OFF position.

b. The following CAUTION should be placed in the operator's manual immediately:

CAUTION

Continued use of a faulty windshield anti-ice system may result in structural damage (delamination and/or cracking) to the windshield.

c. The following CAUTION should be placed in the operator's manual prior to release of the aircraft for operation in an icing environment.

CAUTION

If ice accumulates on one or more sections of the anti-iced windshields, with the windshield anti-ice system ON, the respective windshield should be turned OFF and the icing conditions exited due to the possibility of engine foreign object damage if the ice should shed from the windshield.

d. The following NOTE should be placed in the operator's manual as soon as possible:

APPENDIX A. REFERENCES

1. Letter, USAAFEA, SAVTF-TB, 12 October 1979, subject: Report, Artificial and Natural Icing Tests, Production UH-60A Helicopter, USAAFEA Project No. 78-05.
2. Final Report, USAAFEA Report No. 79-19, *Artificial and Natural Icing Tests Production UH-60A Helicopter*, June 1980.
3. Final Report, USAAFEA Report No. 80-14, *Limited Artificial and Natural Icing Tests Production UH-60A Helicopter (Re-evaluation)*, August 1981.
4. Letter, AVRADCOM, DRDAV-DI, 9 September 1983, with revision dated 3 October 1983, subject: Limited Artificial and Natural Icing Tests of the External Stores Support System (ESSS) Installed on a UH-60A Aircraft.
5. Test Plan, USAAFEA, Project No. 83-22, *Artificial and Natural Icing Tests, Production UH-60A Helicopter Configured with the External Stores Support System (ESSS)*, October 1983.
6. Technical Manual, TM 55-1520-237-10, *Operator's Manual, UH-60A Helicopter*, 21 May 1979 through change 21 dated 12 August 1983.
7. Final Report, USAAFEA Project No. 82-14, *Preliminary Airworthiness Evaluation of the UH-60A Configured with the External Stores Support System (ESSS)*, March 1983.
8. Letter, USAAFEA, DAVTE-TI, 22 June 1982, subject: USAAFEA Project No. 80-04-2, Helicopter Icing Spray System (HISS) Evaluation and Improvements.
9. Letter, AVSCOM, DPSAV-E, 10 February 1984, subject: Airworthiness Release for UH-60A Helicopter, S/N 79-23352 Configured with the External Stores Support System (ESSS) to Conduct Artificial and Natural Icing Tests, with revision 1 dated 12 March 1984.

APPENDIX B. DESCRIPTION

1. The UH-60A is a twin engine, single main rotor helicopter with nonretractable wheel-type landing gear. A movable horizontal stabilator is located on the lower portion of the tail rotor pylon. The main and tail rotor are both four-bladed with a capability of manual main rotor blade and tail pylon folding. The cross-beam tail rotor with composite blades is attached to the right side of the pylon. The tail rotor shaft is canted 20 degrees upward from the horizontal. Primary mission gross weight is 16,260 pounds and maximum alternate gross weight is 20,250 pounds. The UH-60A is powered by two General Electric T700-GE-700 turboshaft engines having an installed thermodynamic rating (30 minute) of 1553 shaft horsepower (SHP) (power turbine speed of 20,900 RPM) each at sea level, standard-day static conditions. Installed dual-engine power is transmission limited to 2828 SHP. The aircraft also has an automatic flight control and a command instrument system. The test helicopter, UH-60A US Army S/N 79-23352 was manufactured by Sikorsky Aircraft.

2. The test aircraft was modified for installation of the External Stores Support System (ESSS) in accordance with Sikorsky assembly drawing 70082-00075-041. The UH-60A ESSS fuel system installation is defined on assembly drawing 70307-42400. Additional modifications are as follows.

- a. 450 gallon auxiliary tanks per drawing X7006-18003-042
- b. 230 gallon auxiliary tanks per drawing X7006-18003-041
- c. left and right cockpit door vents per DEO 01763
- d. pitot-static probe orientation per DEO 060163 (includes DEO 18437, 18438, and 18439)
- e. pitot tube support and fairing installation per drawing 70219-02141
- f. Wire Strike Protection System (WSPS) icing test installation per drawing X7006-26780.

EXTERNAL STORES SUPPORT SYSTEM (ESSS)

3. The ESSS provides a means of carrying a variety of external stores, including external extended range fuel tanks. The ESSS consists of fixed and removable provisions. Fixed provisions include upper fuselage fixed fittings for attaching the horizontal stores support (HSS) subsystems, and lower fuselage strut support fittings for attaching two struts for each HSS. The fixed

provision fittings are enclosed by fairings when the aircraft is flown without the removable provisions. Two types of wing root fairings were installed on the test aircraft during the icing evaluation, prototype wing root fairings (photo 1) and production wing root fairings (photo 2).

4. The removable external stores subsystem (fig. 1) consists of the horizontal store support which is a composite boxed I-beam structure, the support struts (two on each wing) and the vertical stores pylons (two on each wing) all of which are enclosed with thin aluminum fairings. Ejector racks were mounted on the vertical stores pylons at a 4° nose up angle with reference to the aircraft water line.

5. The test aircraft was configured with various portions of the external extended range fuel system, which included two-230 gallon external fuel tanks on the outboard pylons and a combination of the two-230 gallon tanks with two-450 gallon fuel tanks on the inboard pylons (photo 3 and 4).

IMPROVED DROOP STOPS

6. The droop stops installed on the test aircraft were referred to as improved droop stops (FSN 70105-08151-045, photo 5) and differed from the previously tested (ref 3, app A) production droop stops (FSN 70105-08151-041). The improved droop stops have shortened and thickened counterweight attachment arms to improve thermal conductivity and the rubber bumpers and tungsten washer have been removed. The improved droop stops utilized electrically heated rods to provide anti-ice protection. These rods were equipped with quick disconnect cannon plugs.

PITOT TUBE INSTALLATION

7. During previous icing tests of the UH-60A (refs 2 and 3, app A), the aircraft had been configured with the standard production airspeed system (photo 6). For this evaluation, the aircraft was configured with the improved airspeed system, either with a fairing (photo 7) or with a wedge and no fairing (photo 8).

WIRE STRIKE PROTECTION SYSTEM (WSPS)

8. A partial non-structural WSPS was installed for icing test purposes (fig. 2). The installation included upper fuselage components considered to have an icing hazard potential and



Photo 1. Prototype Wing Root Fairing

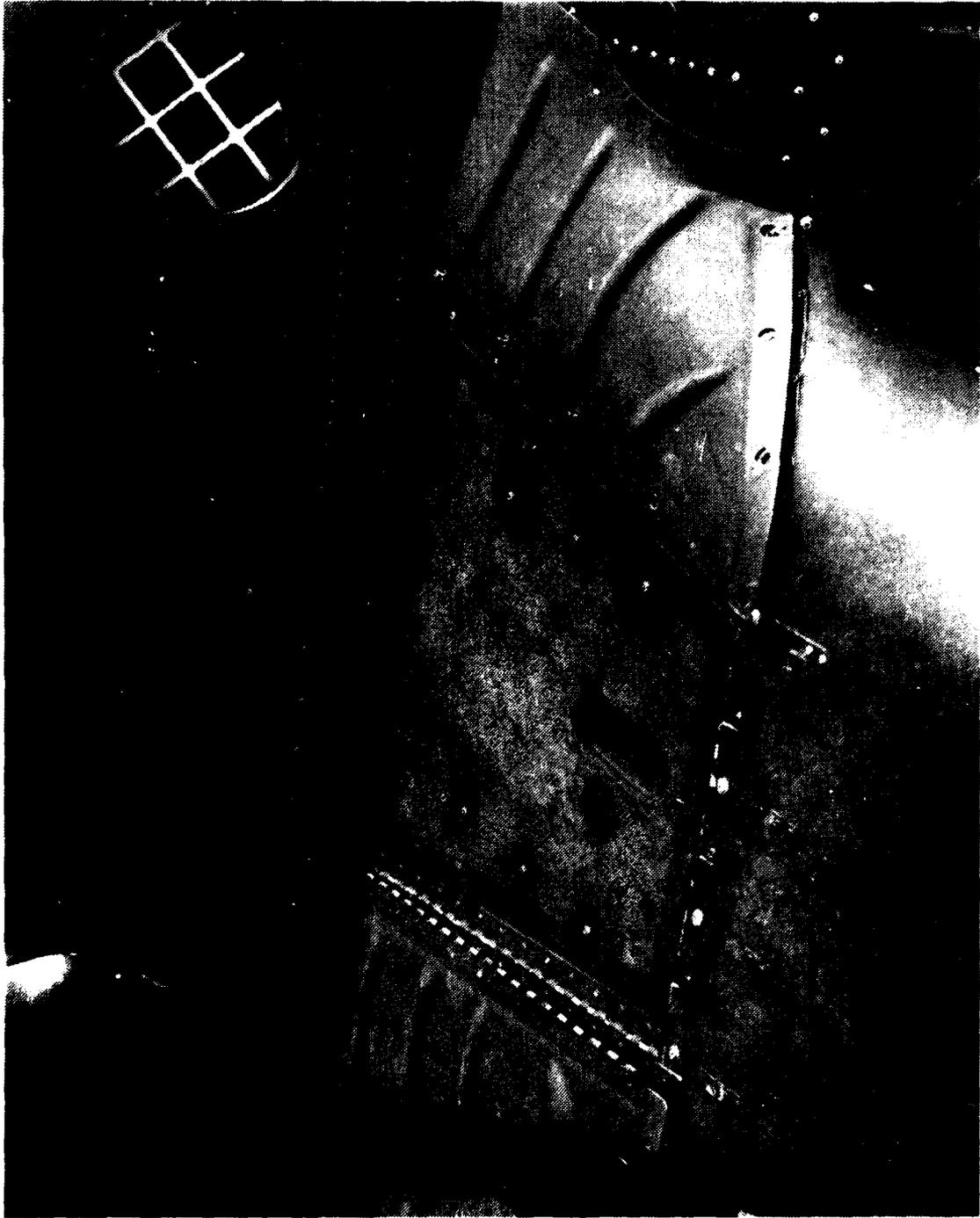


Photo 2. Production Wing Root Fairing

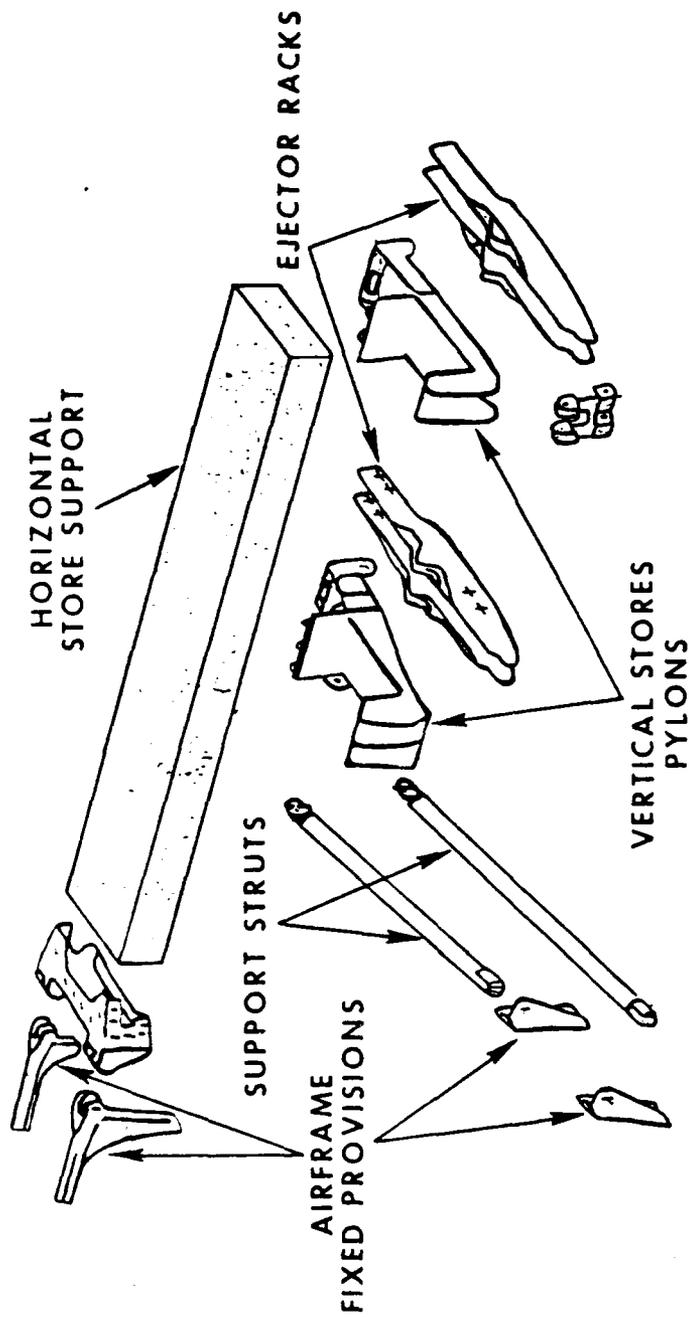


Figure 1. ESSS Structural Components

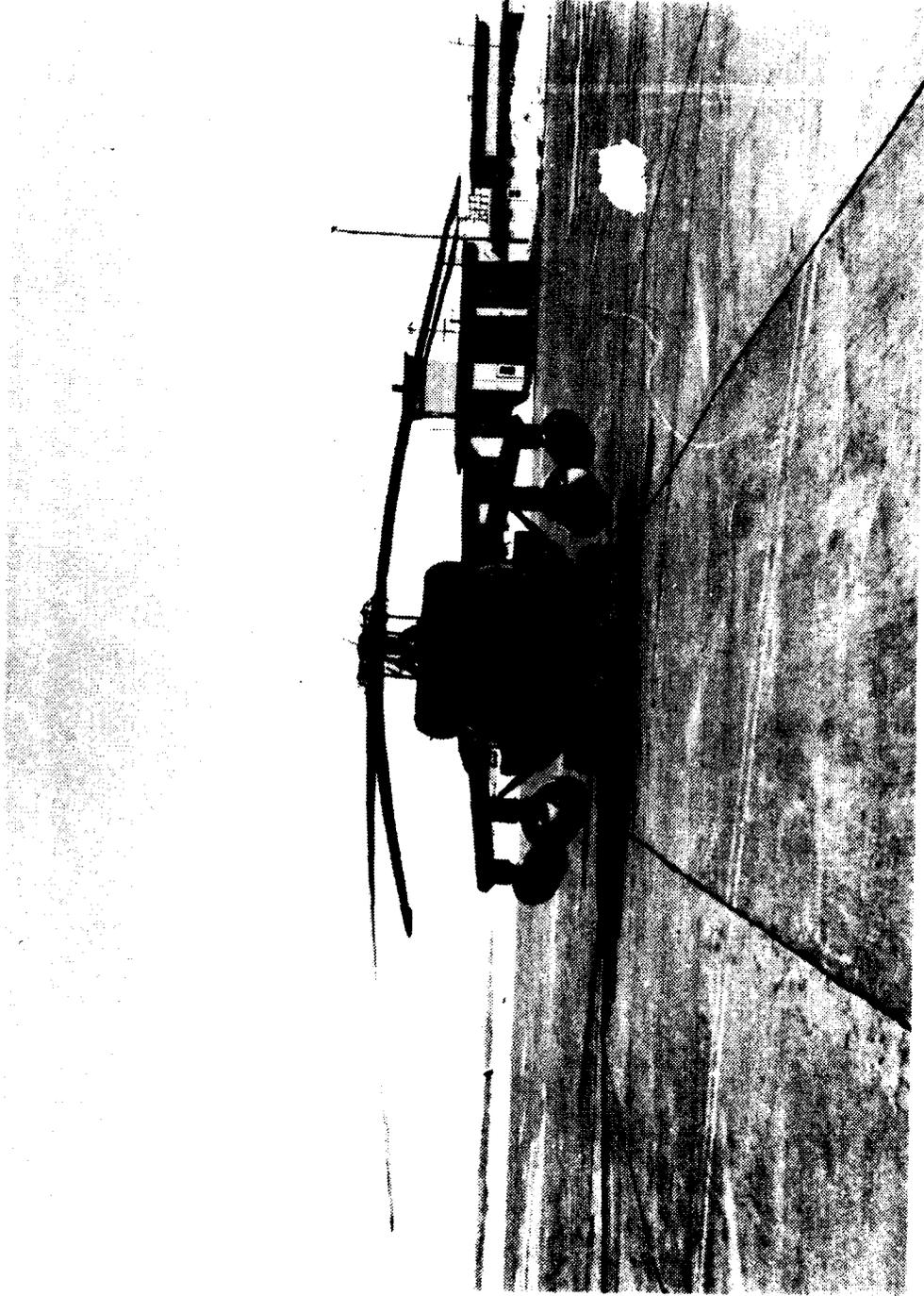


Photo 3. ESSS Four-Tank Configuration, Front View



Photo 4. ESSS Four-Tank Configuration, Right Front View

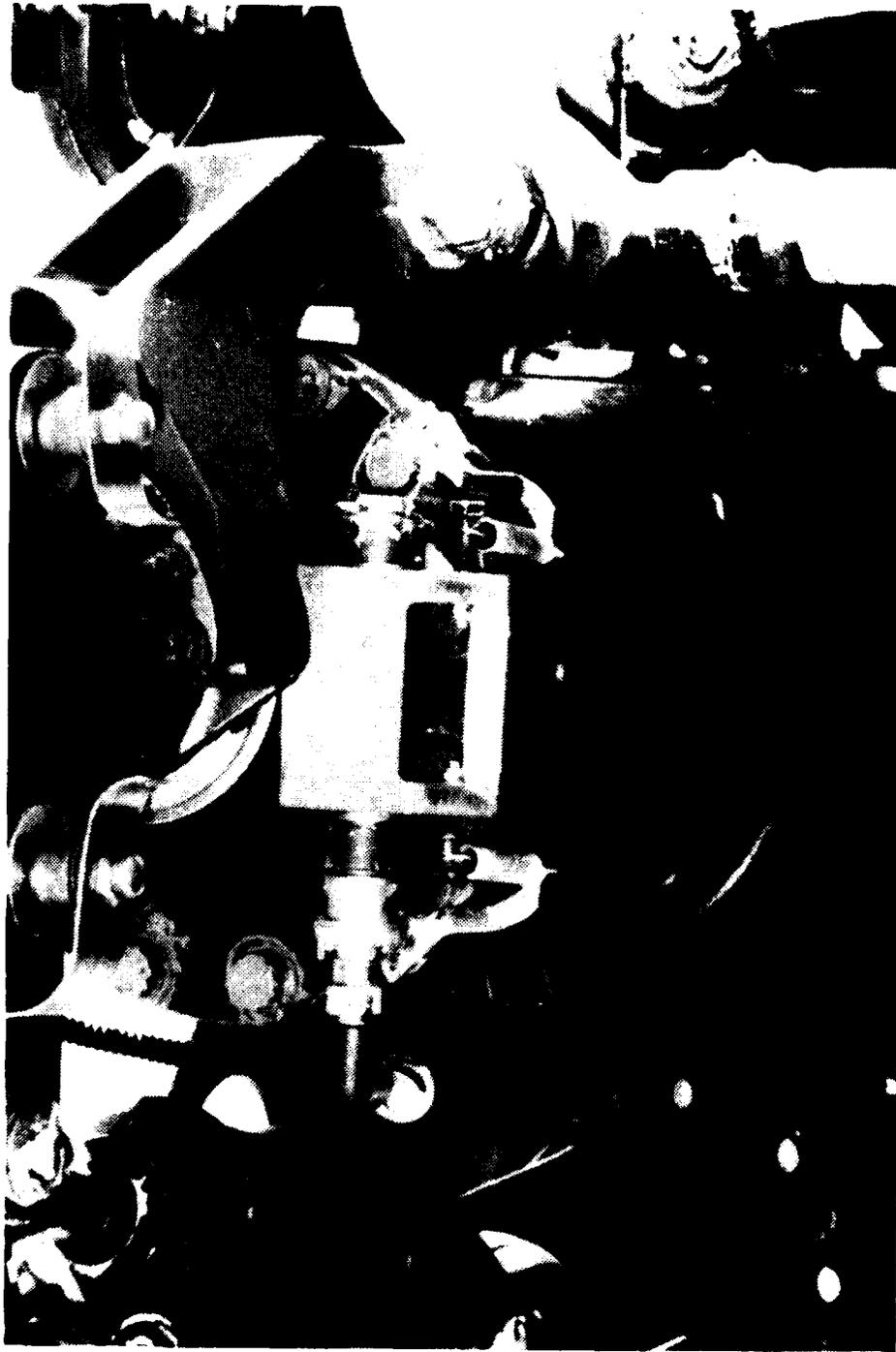


Photo 5. Improved Droop Stop Installation



Photo 6. Standard Production Airspeed System



Photo 7. Improved Airspeed System with Fairing

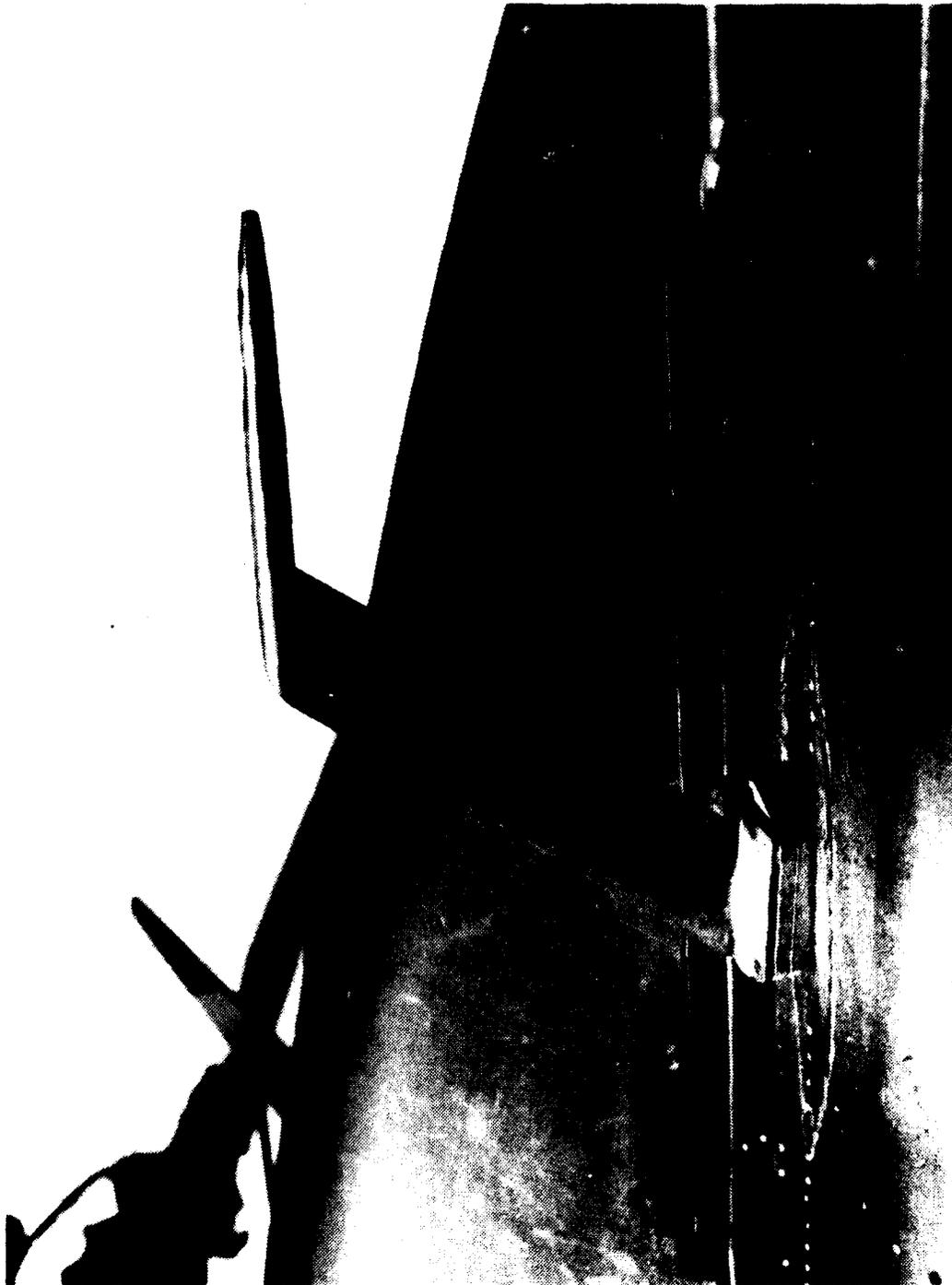


Photo 8. Improved Airspeed System with Wedge

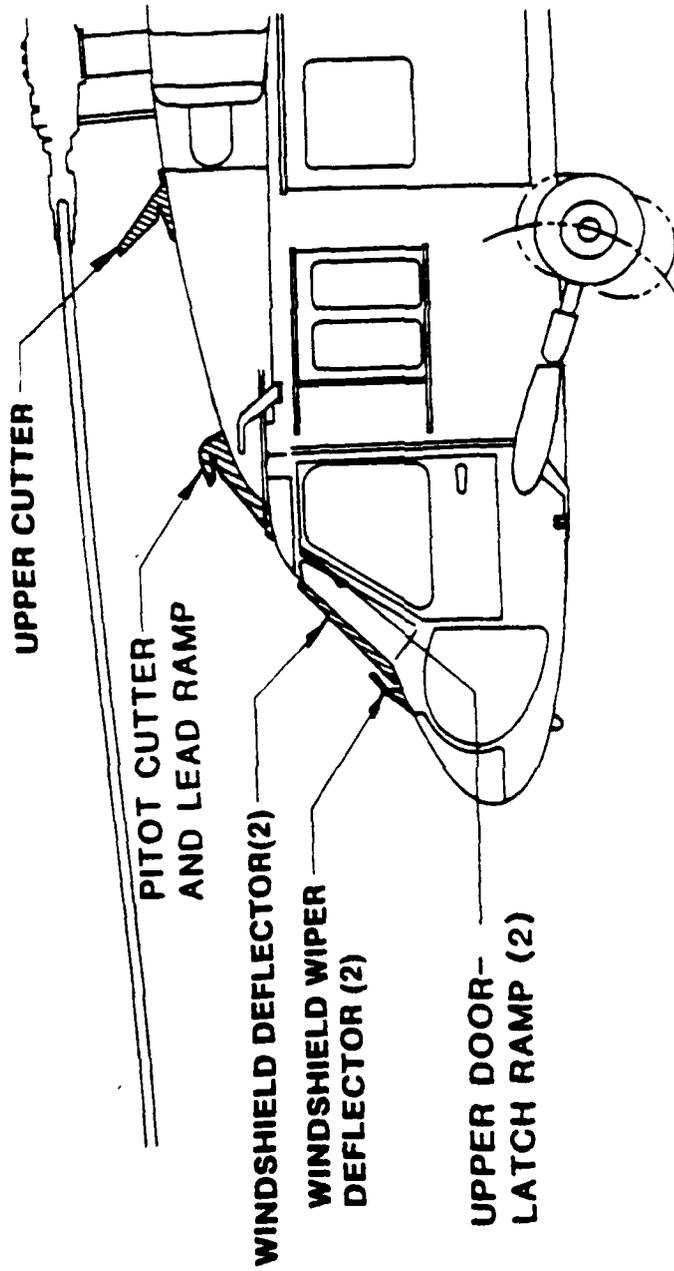


Figure 2. Wire Strike Protection System Icing Test Installation

was made in accordance with drawing X7006-26780. The major components included the upper cutter (photo 9), pitot cutter and lead ramp (photo 10), two windshield wiper deflectors, two windshield deflectors, and two upper door latch ramps (photo 11).

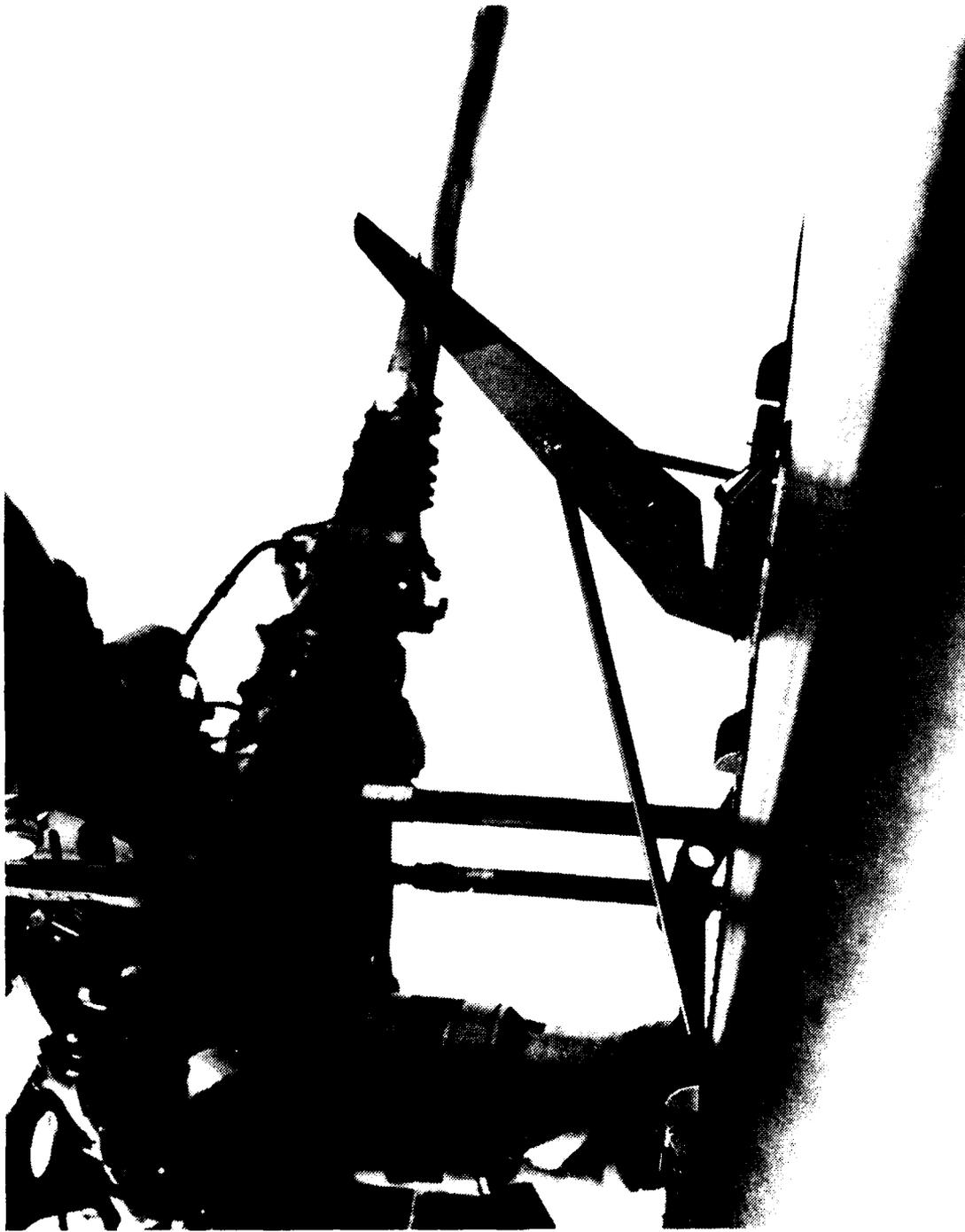


Photo 9. WSPS Upper Cutter

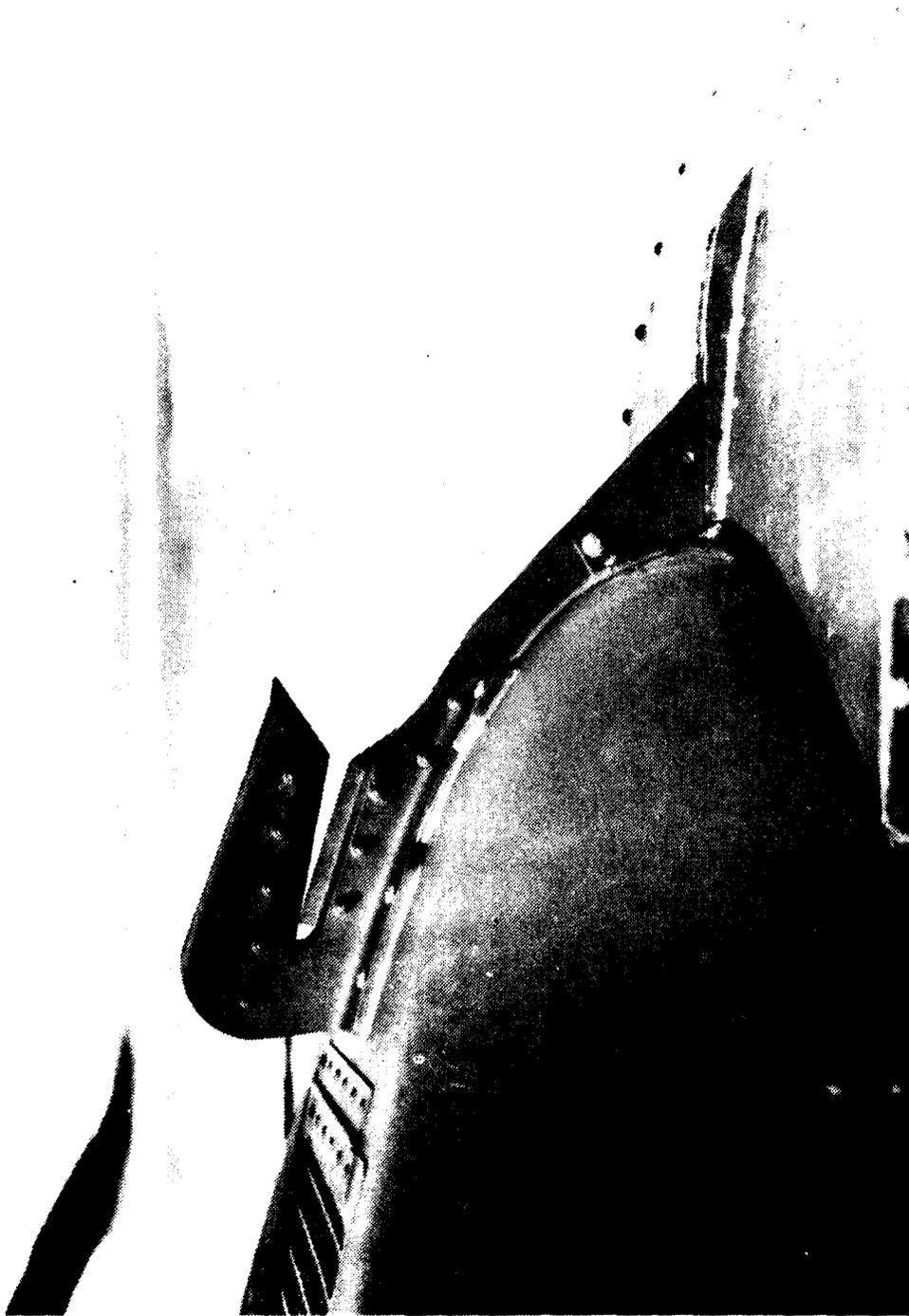
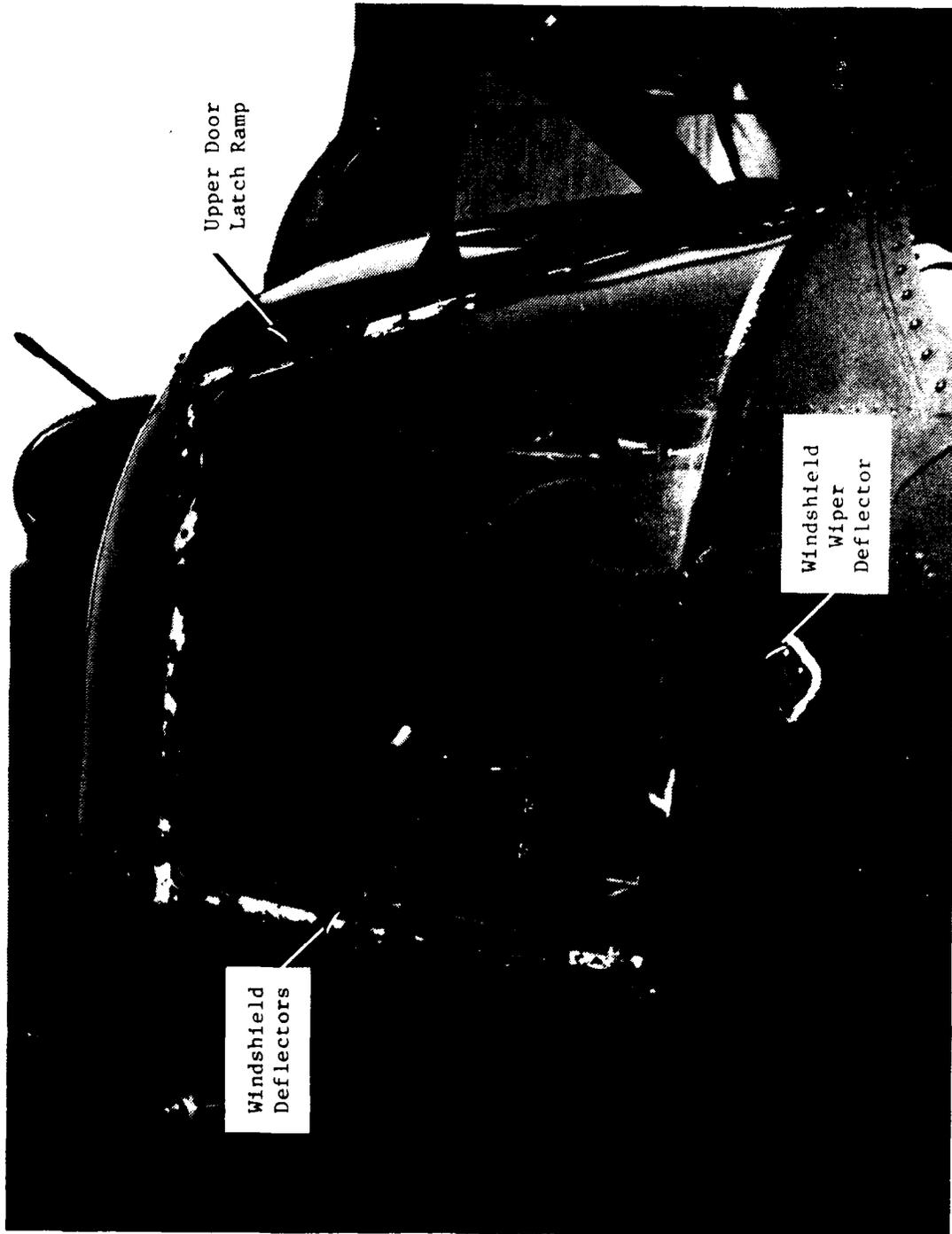


Photo 10. WSPS Pitot Cutter and Lead Ramp



Upper Door
Latch Ramp

Windshield
Wiper
Deflector

Windshield
Deflectors

Photo 11. WSPS Windshield Wiper Deflector, Windshield Deflectors,
and Upper Door Latch Ramp

APPENDIX C. HELICOPTER ICING SPRAY SYSTEM (HISS) DESCRIPTION

1. The 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 feet beneath the aircraft from a cross-tube through the cargo compartment. A schematic is shown in figure 1, and a detailed description is given in reference 8, appendix A. Hydraulic actuators rotate the cross-tube to raise and lower the boom assembly. Both the external boom assembly and water supply can be jettisoned in an emergency. The spray boom consists of two 27-foot center sections, vertically separated by 5 feet, and two 17.6-foot outriggers. The outriggers are swept back 20 degrees and angled downward 10 degrees giving a tip to tip boom width of 60 feet. A total of 97 Sonic Development Corporation Sonicore Model 125-HB nozzles are installed on the two center sections. The spray cloud is generated by pumping water at known flow rates from the tank to the nozzles on the boom assembly, using bleed air from the aircraft engines and an auxiliary power unit to atomize the water.

2. A calibrated outside air temperature probe and a dew point hygrometer provide accurate 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 on the underside of the CH-47. These lights provide a visual indication to the test aircraft for maintaining the proper stand-off distance. Because of gross weight limitations, only 1400 gallons of water are carried. To facilitate photographic documentation during icing tests, a chemical is added to the water to impart a yellow color to the ice.

3. 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 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 sampled until the desired average LWC is attained.

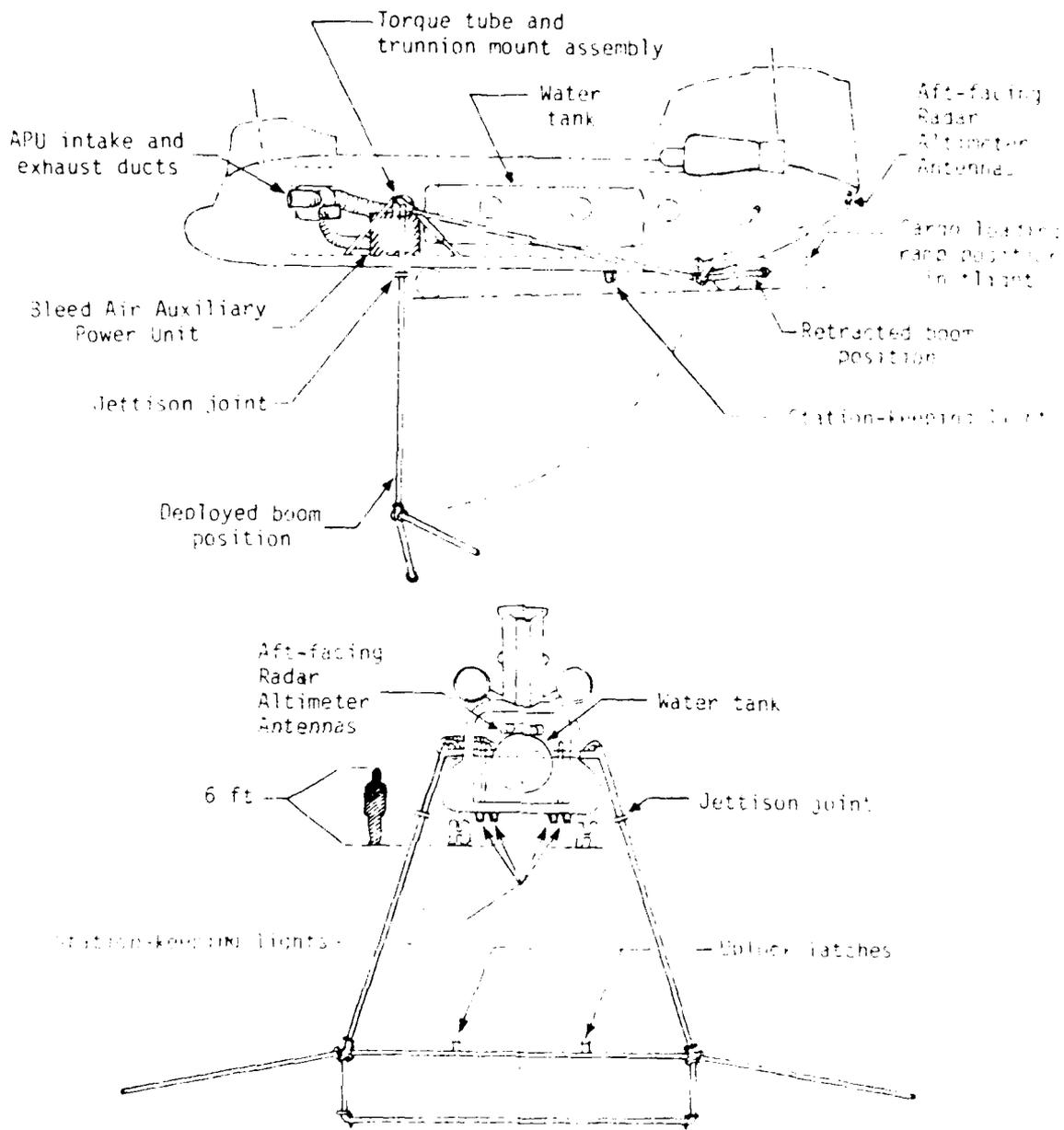


Figure 1. Helicopter Icing Spray System
Side and Rear View Schematic

APPENDIX D. INSTRUMENTATION AND SPECIAL EQUIPMENT

CAMERA SYSTEMS

1. A video camera and a 16mm motion picture camera were located onboard the chase and Helicopter Icing Spray System aircraft and were used to document the test aircraft both in the spray cloud and after exit from icing encounters. Single lens reflex 35mm cameras were used for still photo (color prints and slides) documentation both in the air and on the ground following icing flights.

CLOUD SAMPLING EQUIPMENT

2. For cloud measurements in both the natural and artificial environments, USAAEFA employs a JU-21A fixed-wing aircraft, US Army S/N 66-18008, equipped with a cloud measurement package. This package consists of the following equipment: a Particle Measuring System (PMS), forward scattering spectrometer probe (model FSSP-100), a PMS optical array cloud droplet spectrometer probe (model OAP-200X), Rosemount outside air temperature sensor and display, Cambridge model 137 chilled mirror dew point hygrometer and display, Leigh Mk 10 ice detector unit with digital display, cloud technology ice detector unit, and a Small Intelligent Icing Data System (SIIDS).

3. The FSSP-100 sizes particles by measuring the amount of light scattered into the collecting optics aperture during particle interaction through a focused helium-neon high order, multimode laser beam. The signal pulses are alternating current coupled to a pulse height analyzer which compares their maximum amplitude with a reference voltage derived from a separate measurement of the direct current light signal illuminating the particles. The output of the pulse height analyzer is encoded to give the particle size in binary code. The probe is set up to size particles from 2 to 47 microns having velocities between 20 and 125 m/sec (39 to 243 knots).

4. The OAP-200X sizes using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field-of-view. Particles are illuminated by a helium-neon laser and imaged as shadowgraphs on the photodiode array. If the shadowing of each photodiode element is dark enough a flip-flop element is set. The particle size is determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system. This probe contains 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns.

5. The SIIDS is a compact data acquisition system designed and programmed specifically for icing studies. It consists of four main components: a microprocessor, Techtran data cassette recorder, Axiom printer, and an operator control panel. The SIIDS has three operational modes: (1) data acquisition, in which averaged raw data are recorded on cassette tape and averaged engineering units are displayed on the printer, (2) a playback mode in which raw averaged data read from the cassette are converted to average engineering units which are displayed on the printer, (3) monitor mode used to set the calendar clock and alter programmed constants. During data acquisition, the operator may select an averaging period of 1/2, 1, 2, 5, or 10 seconds.

6. 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 ($^{\circ}\text{C}$)
- e. dew point ($^{\circ}\text{C}$)
- f. total liquid water content observed by the FSSP (g/m^3)
- g. total liquid water content observed by both the FSSP and OAP (g/m^3)
- h. median volumetric diameter (μm)
- i. amount of liquid water content observed for each channel (total 30) of both probes (g/m^3)

APPENDIX E. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. All anti-ice systems (i.e., pitot heat, windshield anti-ice, engine, and engine air induction system anti-ice) were activated while enroute to the test area. For artificial icing the test aircraft then entered the artificial spray cloud from a position below and approximately 150 feet behind the spray aircraft. Test and spray aircraft separation distance was maintained during the icing flight by observing yellow (greater than 160 feet) and red (closer than 140 feet) lights mounted on the bottom of the spray aircraft. The visual indications were supplemented as required by information relayed from the spray aircraft. Airspeed and outside air temperature (OAT), were established with the calibrated instrumentation system of the spray aircraft. All artificial flights were flown with a predetermined liquid water content (LWC) and OAT. Flight continued in the cloud condition until the spray aircraft water limit was reached. For natural icing the JU-21A would locate and document the icing condition and radio the data back to the test aircraft before it entered the icing environment. The JU-21A would then loiter in the area to facilitate a post-immersion rapid in-flight join-up with the test aircraft for photographic documentation. The LWC, particle size in the icing cloud, OAT, and relative humidity were documented by the JU-21A chase/scout aircraft configured with the particle measuring system instrumentation. The Rosemount icing rate meter in the test aircraft was also used to monitor LWC in natural clouds.

ICE ACCRETION AND SHEDDING

2. Ice accretion on the test aircraft was documented using hand-held video and high-speed motion picture cameras photographing from both the chase aircraft and spray aircraft. Post-flight photographs were made to document the ice remaining on the individual components of the airframe and rotors.

3. Ice shedding characteristics were qualitatively assessed by crew members in the test, spray, and chase aircraft.

DEFINITIONS

4. Icing characteristics were described using the following definitions of icing severity. These definitions may be found in FM 1-30 and the UH-60A operator's manual.

a. Trace icing: Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though deicing equipment is not used, unless encountered for an extended period of time (over 1 hour). Commonly 0 to 0.15 gm/m³ LWC for the UH-60A helicopter.

b. Light icing: The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used. Commonly 0.15 to 0.5 gm/m³ LWC for the UH-60A helicopter.

c. Moderate icing. The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary. Commonly 0.5 to 1.0 gm/m³ LWC for the UH-60A helicopter.

d. Severe/heavy icing. The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary. Commonly greater than 1.0 gm/m³ LWC for the UH-60A helicopter.

5. 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 equipments 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 F. TEST DATA

<u>Table</u>	<u>Table No.</u>
Specific Test Conditions	1
<u>Figure</u>	<u>Figure No.</u>
Artificial Icing Test Conditions	1
Natural Icing Test Conditions	2

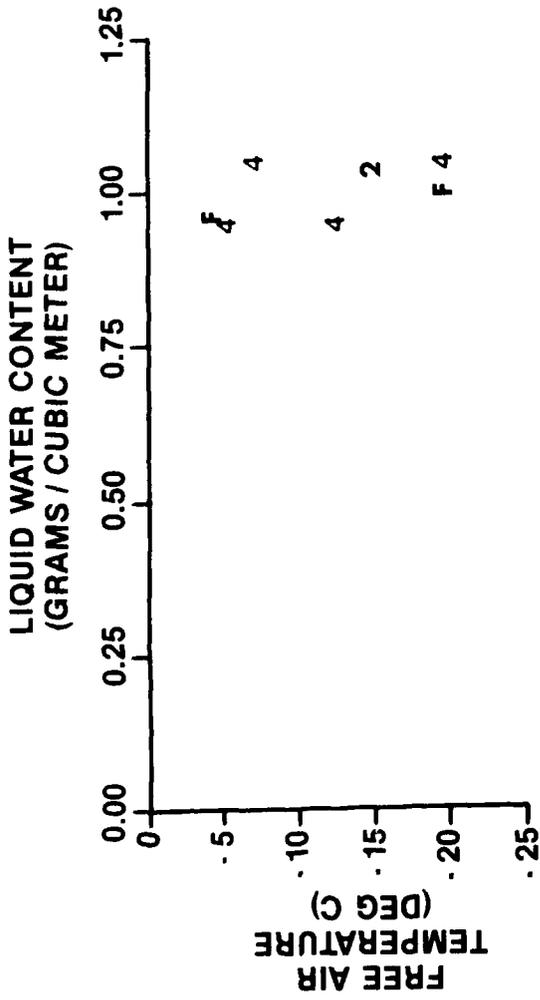
Table 1. Specific Test Conditions

Plt No.	Icing Environment	ESSS Configuration	Average Gross Weight (lb)	Average Longitudinal CG (PS)	Average Density Altitude (ft)	Average OAT (°C)	Average IWC (cm/m ³)	Median Volumetric Diffractometer (µm)	Average True Airspeed (kts)	Total Time in cloud (min)
1	Artificial	4-tank	13,747	356.8	4800	-7.5	1.05	62	120	49
2	Natural	4-tank	13,550	356.5	3100	-4.0				
3	Natural	4-tank	16,150	351.8	2020	-3.0	0.25	18	125	50
4	Artificial	4-tank	16,830	351.3	2730	-12.0	0.25	15	123	62
5	Artificial	4-tank	15,240	356.4	4840	-13.0	0.95	55	120	22
6	Artificial	Fixed Provisions	12,180	362.3	7180	-20.0	1.05	65	120	45
7	Natural	Fixed Provisions	12,400	362.3	6600	-20.0	1.00	55	120	53
8	Natural	4-tank	16,570	354.6	2030	-16.0	0.15	12	123	32
9	Natural	2-tank	15,700	358.4	7960	-21.0	0.05	10	120	75
10	Natural	4-tank	15,540	353.9	5100	-13.0	0.05	10	135	30
11	Natural	4-tank	16,010	355.9	5200	-5.5	0.25	26	107	142
12	Artificial	2-tank	13,300	359.5	5490	-8.0	0.20	18	115	150
13	Artificial	4-tank	13,970	358.8	80	-15.5	1.03	67	120	45
14	Artificial	Fixed Provisions	13,320	362.9	2650	-5.5	0.95	63	120	41
15	Natural	Fixed Provisions	13,124	362.0	1810	-4.5	0.96	46	120	45
16	Natural	Fixed Provisions	17,080	361.4	6,730	-9.5	0.25	25	134	72
17	Natural	4-tank	18,530	362.0	7440	-8.0	0.30	NA ²	132	91
18	Natural	4-tank	17,090	352.6	970	-7.0	0.36	19	108	168
					3560	-13.5	0.29	NA	108	245

NOTES:

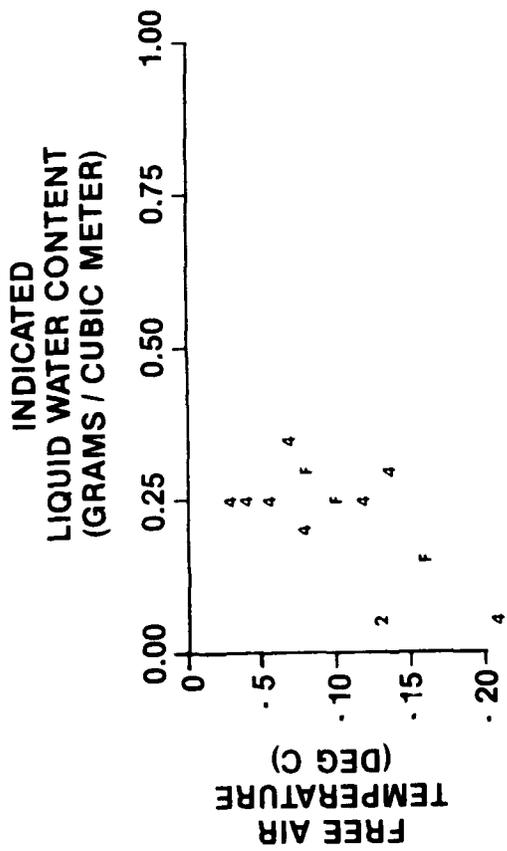
¹Main rotor speed = 258 rpm, mid lateral cg location

²NA = not available



- NOTE:
- 2. ESSS, 2-TANK CONFIGURATION
 AVERAGE GROSS WEIGHT = 13,300 lb
 AVERAGE LONGITUDINAL CG LOCATION = FS 359.5
 AVERAGE DENSITY ALTITUDE = 80 FT
 - 4. ESSS, 4-TANK CONFIGURATION
 AVERAGE GROSS WEIGHT = 14,940 lb
 AVERAGE LONGITUDINAL CG LOCATION = FS 355.8 (MID)
 AVERAGE DENSITY ALTITUDE = 4870
 - F. FIXED DPROVISIONS
 AVERAGE GROSS WEIGHT = 12,250 lb
 AVERAGE LONGITUDINAL CG LOCATION = FS 362.6 (AFT)
 AVERAGE DENSITY ALTITUDE = 4200 FT

Figure 1
 Artificial Icing Test Conditions



NOTE: 2. ESSS, 2-TANK CONFIGURATION
 AVERAGE GROSS WEIGHT = 15,700 lb
 AVERAGE LONGITUDINAL CG LOCATION = FS 356.4 (MID)
 AVERAGE DENSITY ALTITUDE = 5100 FT

4. ESSS, 4-TANK CONFIGURATION
 AVERAGE GROSS WEIGHT = 16,190 lb
 AVERAGE LONGITUDINAL CG LOCATION = FS 353.5 (MID)
 AVERAGE DENSITY ALTITUDE = 3880

F. FIXED DPROVISIONS
 AVERAGE GROSS WEIGHT = 12,200 lb
 AVERAGE LONGITUDINAL CG LOCATION = FS 362.2 (AFT)
 AVERAGE DENSITY ALTITUDE = 5230 FT

Figure 2
 Natural Icing Test Conditions

APPENDIX G. PHOTOGRAPHS

1. Pitot-Static Tube Strut Ice Accretion
2. Improved Droop Stop Ice Accretion
3. Typical Four External Fuel Tank Ice Accretion
4. Typical Four External Fuel Tank Ice Accretion (Alt Fuselage)
5. Pitot-Static Probe Mounting Ice Accretion
6. Production Wing Root Fairing Ice Accretion
7. Prototype Wing Root Fairing Ice Accretion
8. Four Tank ESSS Typical Ice Accretion
9. Outboard Jettison Rack Configuration
10. Outboard Jettison Rack Ice Accretion
11. Upper Wire Cutter Ice Accretion
12. Pitot-Static Probe Wire Cutter Ice Accretion
13. Windshield Wiper Wire Deflector Ice Accretion
14. Upper Cockpit Door Latch Wire Deflector Ice Accretion



Photo 1. Pitot-Static Tube Strut Ice Accretion

Conditions: Environment - Natural
Configuration - 4-Tank
Flight - 17

Avg FAT - -7.0°C
Avg LWC - 0.36 gm/m^3
Time in Cloud - 168 minutes



Photo 2. Improved Droop Stop Ice Accretion

Conditions:	Environment - Natural	Avg FAT - -12.0°C
	Configuration - 4-Tank	Avg LWC - 0.25 gm/m^3
	Flight - 3	Time in Cloud - 62 minutes

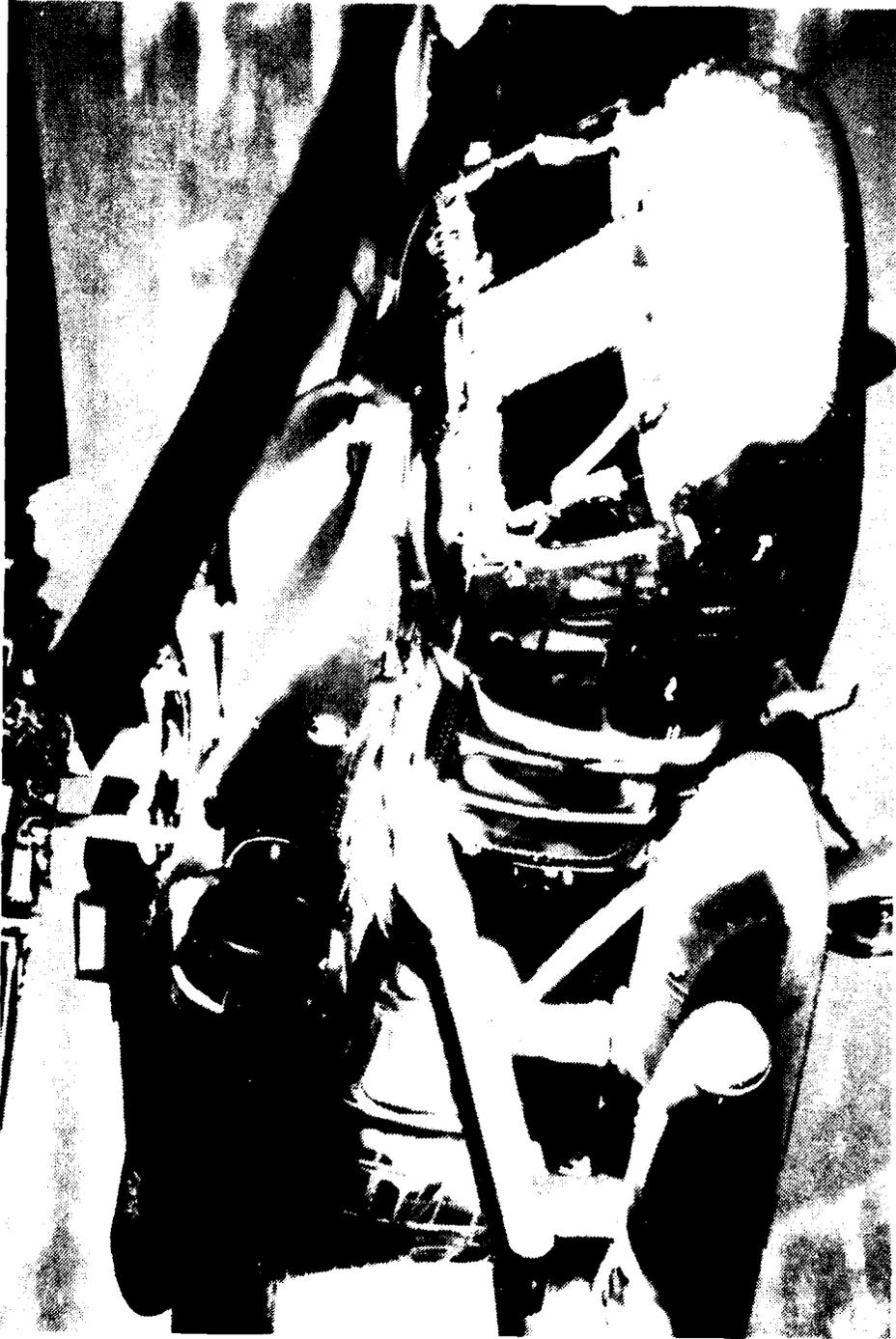


Photo 3. Typical Four External Tank Ice Accretion (Forward Fuselage)

Conditions: Environment - Artificial Avg FAT - 20.0°C
Configuration - 4-Tank Avg IWC - 1.05 gm/m³
Flight - 5 Time in Cloud - 45 minutes



Photo 4. Typical Four External Fuel Tank Ice Accretion (Aft Fuselage)

Conditions: Environment - Artificial Avg FAT - 20.0°C
Configuration - 4-Tank Avg LWC - 1.05 gm/m³
Flight - 5 Time in Cloud - 45 minutes



Photo 5. Pitot-Static Probe Mount Fairing Ice Accretion

Conditions: Environment - Natural Avg FAT - -8.0°C
Configuration - 4-Tank Avg LWC - 0.20 gm/m^3
Flight - 11 Time in Cloud - 150 minutes

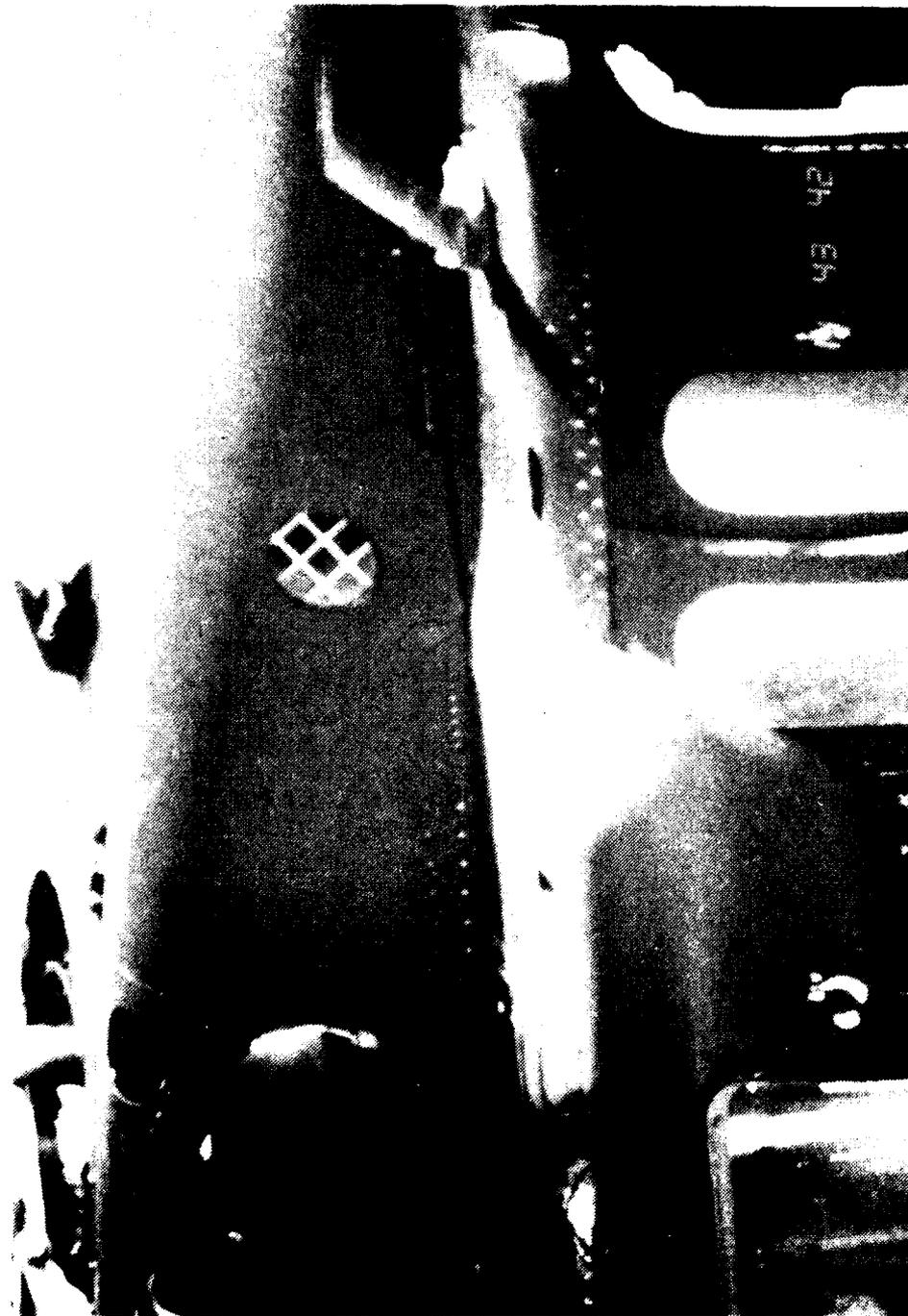


Photo 6. Production Wing Root Fairing Ice Accretion;

Conditions: Environment - Natural Avg FAT - -8.0°C
Configuration - Fixed Provisions Avg LWC - 0.30 gm/m^3
Flight - 16 Time in Cloud - 132 minutes



Photo 7. Prototype Wing Root Fairing Ice Accretion

Conditions:	Environment - Natural	AVG FAT - -8.0°C
	Configuration - Fixed Provisions	AVG LWC - 0.30 gm/m^3
	Flight - 16	Time in Cloud - 132 minutes

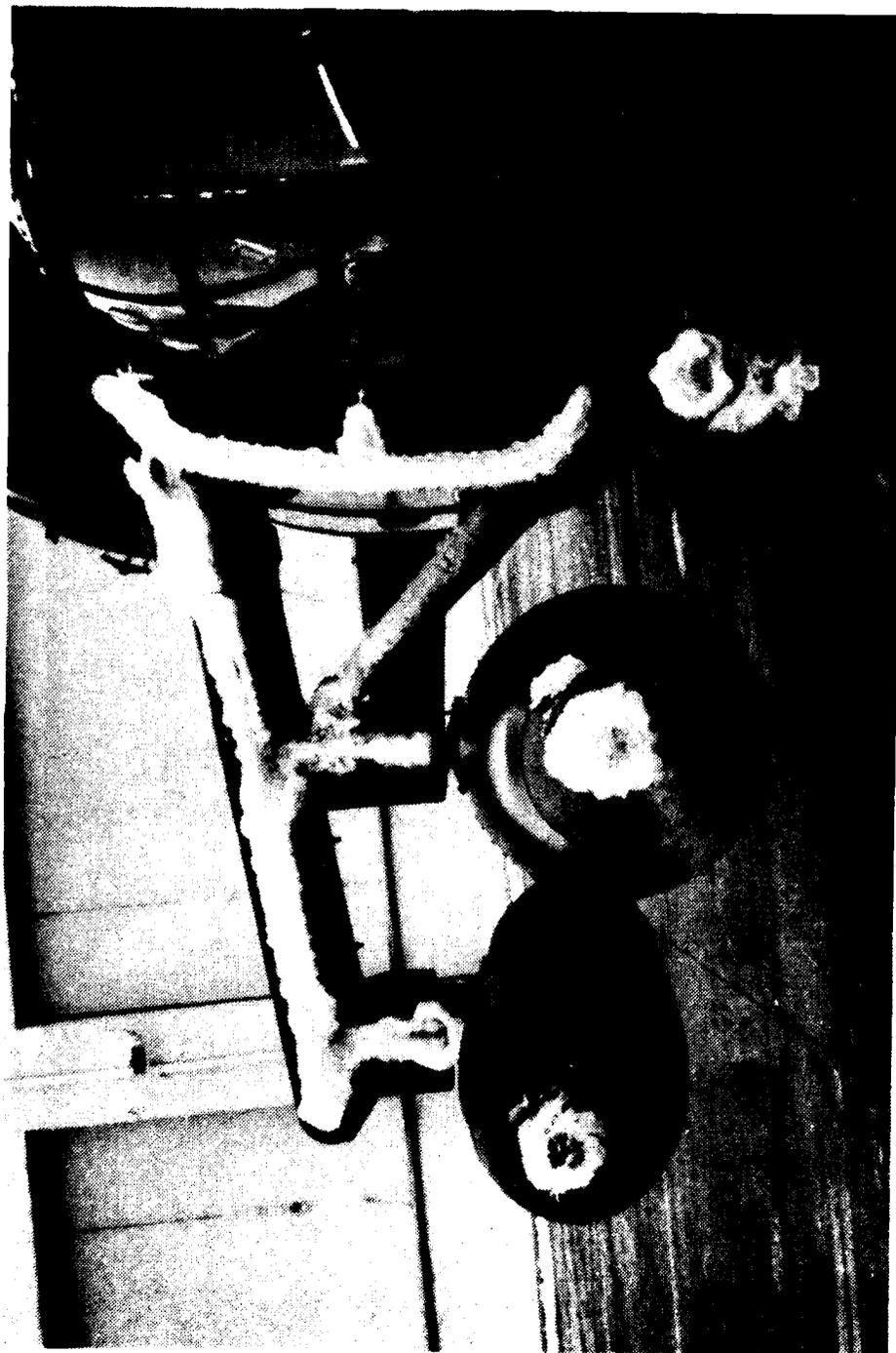


Photo 8. Four Tank ESSS Typical Ice Accretion

Conditions: Environment - Natural
Configuration - 4-Tank
Flight - 10

Avg FAT - -5.5°C
Avg LWC - 0.25 gm/m^3
Time in Cloud - 142 minutes



Photo 9. Outboard Jettison Rack Configuration



Photo 10. Outboard Jettison Rack Ice Accretion

Conditions: Environment - Natural
Configuration - 4-Tank
Flight - II

Avg FAT - -8.0°C
Avg LWC - 0.20 gm/m^3
Time in Cloud - 150 minutes

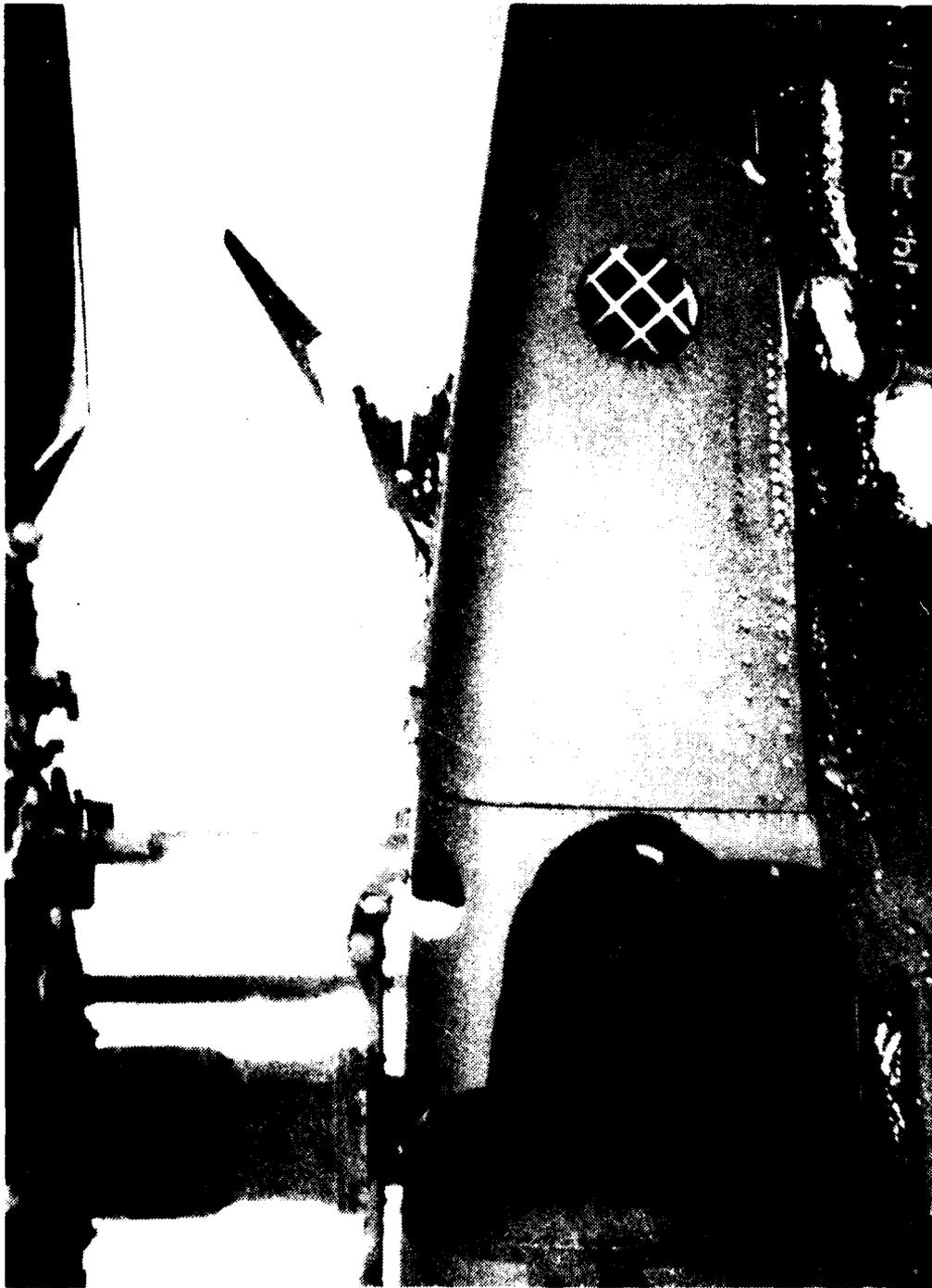


Photo 11. Upper Wire Cutter Ice Accretion

Conditions: Environment - Natural
Configuration - 4-Tank
Flight - 11

Avg FAT - -8.0°C
Avg LWC - 0.20 gm/m^3
Time in Cloud - 150 minutes



Photo 12. Pitot-Static Probe Wire Cutter Ice Accretion

Conditions: Environment - Natural
Configuration - 4-Tank
Flight - 18

Avg FAT - -13.5°C
Avg LWC - 0.29 gm/m^3
Time in Cloud - 245 minutes



Photo 13. Windshield Wiper Wire Deflector Ice Accretion

Conditions: Environment - Artificial Avg FAT - -13.0°C
Configuration - 4-Tank Avg LMC - $0.95 \mu\text{m}/\text{m}^3$
Flight - 4 Time in Cloud - 22 minutes



Photo 14. Upper Cockpit Door Latch Wire Deflector Ice Accretion

Conditions: Environment - Natural
Configuration - 4-Tank
Flight - 10

Avg FAT - -5.5°C
Avg LWC - 0.25 gm/m^3
Time in Cloud - 142 minutes

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