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ICING EVALUATION. U-21A AIRPLANE WITH LOW REFLECTIVE PAINT.(U)  
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USAAEFA PROJECT NO. 77-05



**ICING EVALUATION  
U-21A AIRPLANE WITH  
LOW REFLECTIVE PAINT**

FINAL REPORT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The United States Army Aviation Engineering Flight Activity conducted an evaluation of the icing characteristics of a U-21A airplane painted with low reflective paint. The flight tests were conducted in natural icing conditions at the Seattle, Washington area from 24 February through 10 March 1977. Test flights were made in trace, light, and moderate icing conditions. During these tests four shortcomings were noted. The shortcomings were ineffectiveness of the deice boots with rime (continued)		

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20. Abstract

ice accumulation, inability of the engine air inlet anti-ice system to prevent formation of ice in the engine air inlet, lack of an engine inlet lip boot anti-ice system preflight test, and lack of anti-ice/deice capability for the wing area outboard of the pneumatic boots. From the evaluation it was concluded that the low reflective paint does not significantly affect the ice accumulation characteristics of the U-21A airplane, and also that, regardless of the type paint, in moderate icing conditions at constant power, airspeed will be reduced by 20 to 30 knots.

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# TABLE OF CONTENTS

	Page
INTRODUCTION	
Background . . . . .	2
Test Objective . . . . .	2
Description . . . . .	2
Test Scope . . . . .	2
Test Methodology . . . . .	3
RESULTS AND DISCUSSION	
General . . . . .	4
Airspeed/Power Effects . . . . .	4
Anti-Ice/Deice Equipment . . . . .	5
Ice Accumulation Characteristics . . . . .	6
CONCLUSIONS	
General . . . . .	8
Shortcomings . . . . .	8
RECOMMENDATIONS . . . . .	9
APPENDIXES	
A. References . . . . .	10
B. Photographs . . . . .	11
C. Icing Severity Definitions . . . . .	25
D. Instrumentation and Special Equipment . . . . .	26
DISTRIBUTION	

# INTRODUCTION

## BACKGROUND

1. Based upon an Equipment Improvement Report (EIR) submitted in February 1977 (ref 1, app A), the Department of the Army has expressed concern about the capability of U-21 aircraft painted with low reflective (LR) paint to safely operate in an icing environment. In response to the EIR, the United States Army Aviation Engineering Flight Activity (USAAEFA) was requested by the United States Army Aviation Systems Command (AVSCOM) to conduct a safety-of-flight evaluation of the icing characteristics of a U-21A airplane painted with LR paint (ref 2).

## TEST OBJECTIVE

2. The objective of the evaluation was to compare ice accretion and shedding characteristics of a U-21 airplane painted with LR paint as compared with a U-21 airplane painted with high gloss paint. This was a preliminary test to determine if a comprehensive icing evaluation was necessary.

## DESCRIPTION

3. The test U-21A aircraft, SN 66-18008 (photos 1 and 2, app B), was painted with LR paint (MIL-L-46159) at Sharpe Army Depot, California, in June 1975. The aircraft used for comparison was a JU-21D aircraft, SN 68-18107 (photos 3 and 4). The comparison aircraft was painted with high gloss lacquer (MIL-C-81773). With the exception of the paint, both aircraft external configurations were essentially the same. A detailed description of the U-21 aircraft is contained in the operator's manual (ref 3, app A).

## TEST SCOPE

4. The icing tests of the U-21 aircraft were conducted in natural icing conditions at the Seattle, Washington, area from 24 February through 10 March 1977. Twenty test flights consisting of 8.1 productive flight hours were conducted during the evaluation. Test flights were made in trace, light, and moderate icing conditions. Definitions of icing severity levels are contained in appendix C.

### TEST METHODOLOGY

5. The two aircraft were flown at the same altitude and airspeed in a trail formation with a 3-mile separation maintained between aircraft to ensure exposure of both aircraft to the same icing conditions. The 3-mile separation was accomplished with the assistance of a radar controller on the ground and the installed TACAN navigational radio (AN/ARN-103) in each aircraft.

6. Photographic documentation of ice accumulation and use of aircraft deicing equipment was coordinated by radio. Flight test data were recorded on a magnetic tape voice recorder and on hand-held data forms. A detailed description of test instrumentation and special equipment is contained in appendix D. Photos 5 and 6, appendix B, show the Rosemount ice accretion indicators and sensitive outside air temperature indicators. Use of the anti-icing equipment was in accordance with the operator's manual.

## RESULTS AND DISCUSSION

### GENERAL

7. A limited comparative evaluation of two U-21 airplanes in natural icing conditions was conducted. Ice accumulation characteristics were evaluated to determine if there was a significant difference in ice accumulation between an aircraft painted with LR paint and one painted with high gloss lacquer. Operation of the anti-ice/deice equipment on both aircraft was also evaluated.

8. The icing tests revealed no discernible difference in ice accumulation or the effects of ice accumulation between the two aircraft. The U-21 airplane can be safely flown in trace, light, and moderate icing conditions. At constant power an airspeed loss of 20 to 30 knots should be expected with flight in moderate icing conditions regardless of paint configuration. Four shortcomings were identified: ineffectiveness of the deice boots with rime ice accumulation; inability of the engine air inlet anti-ice system to prevent formation of ice on the lip boots; lack of a preflight test for the engine inlet anti-ice system; and lack of anti-ice/deice capability for the wing area outboard of the pneumatic boots. The operator's manual should be amended so that pilots are aware of the characteristic airspeed loss and the large ice accumulation on the wing tips. Future tests should evaluate engine performance with inlet ice accumulation and use of the landing lights to anti-ice/deice the wing area outboard of the pneumatic deicing boots.

### AIRSPPEED/POWER EFFECTS

9. The two U-21 aircraft were flown in trace, light, and moderate icing conditions at entry airspeeds of 140 and 170 knots calibrated airspeed (KCAS). At 140 KCAS power was increased to prevent airspeed from decreasing further and the pneumatic deicing boots activated to clear the ice on the leading edges of the wings. The tests at 170 KCAS were performed using two methods. Initially, power was added to maintain 170 KCAS. On a second test, airspeed was allowed to decrease while holding power constant.

10. With constant power for 170 KCAS in level flight, an ice accumulation of 0.5 to 1 inch on the leading edges of the deicing boots resulted in a 20- to 30-knot loss in airspeed. At this same ice accumulation level, 170 KCAS could be maintained with full power applied to both engines. Photos 7 and 8, appendix B, show an ice accumulation of approximately 1 inch on the leading edges of the pneumatic deicing boots. After activation of the boots, the power required for level flight was reduced. The effectiveness of the deicing boots is further discussed in paragraph 13. To prevent unnecessary concern on the part of the flight crew the following NOTE should be incorporated in the operator's manual:



#### NOTE

At constant power an airspeed loss of 20 to 30 knots can be expected with flight in moderate icing conditions.

#### ANTI-ICE/DEICE EQUIPMENT

11. The U-21 incorporates electrothermal systems for anti-icing and deicing the windshield, pitot tube, stall warning vane, propeller blades, engine air inlet lip boots, and fuel vents. Pneumatic boots are incorporated for deicing the leading edges of the outer wing (outboard of the engine nacelle to 30 inches short of the wing tips), and the vertical and horizontal stabilizers.

12. During the tests, the procedure used for anti-icing and deicing was to turn on all electrical anti-ice and propeller deice switches prior to entering icing conditions. For test purposes the pneumatic boots were used at different stages of ice accumulation. In one test the boots were activated when ice accumulation had reached approximately 0.5 inch, and in another test the boots were not used until airspeed (140 KCAS) could not be maintained with maximum allowable power from both engines (approximately 2 inches of ice accumulation on the leading edge of the wing).

13. The effectiveness of the pneumatic boots differed with the type of ice that accumulated on the wing. With rime icing the boots did not adequately clear the ice. Photo 9, appendix B, depicts rime ice accumulation prior to activation of the boots. Photo 10 shows the wing after the boots were activated. Repeated use of the boots (six attempts) did not significantly clear more ice. With clear or mixed icing the boots were effective and ice was cleared by one application of the boots. The landing lights were used in one attempt (approximately 1 minute) to clear the large ice build-up on the wing tip. In the short period the landing light was used the ice did not shed from the wing tip. In any future U-21 icing tests, the possibility of anti-icing/deicing the wing area outboard of the boots by use of the landing lights should be investigated. The ineffectiveness of the deice boots with rime ice accumulation is a shortcoming.

14. Photos 11 and 12, appendix B, show ice accumulation at the engine air inlet lip boots. Although this area incorporates electrothermal deicing and was in use at the time this photograph was taken, ice still formed on the lip boots. The air inlet boots were checked by maintenance personnel and found to be operational. Ice formation on the engine air inlet lip boots was typical for both aircraft. The inability of the engine air inlet anti-ice system to prevent formation of ice on the inlet lip boots is a shortcoming.



15. The lack of a preflight test capability for the engine air inlet lip boot anti-ice system could result in flight into icing conditions without anti-icing of the inlet lip. The lack of an engine lip boot anti-ice system preflight test is a shortcoming.

16. Ice accumulation and patterns of accumulation were the same for both aircraft except for ice formation on the windshields. The IR-painted aircraft incorporated a windshield electrothermal anti-ice system. The JU-21D with high gloss paint had an unheated windshield and could only use defrost air to prevent windshield icing. With use of the electrothermal system only a small amount of ice formed on the windshield (photos 13 and 14, app B), and most of this ice was in the area of the windshield wipers. Although considerably more ice formed on the unheated windshield, the defrost air did maintain an area of the windshield clear that was sufficient for landing the aircraft. One test was conducted after application of ice-phobic material to the windshield. The purpose of this test was to determine if ice-phobic material would prevent ice from forming on the windshield or enhance natural shedding. Although icing conditions were not encountered on this flight, further use of the ice-phobic material was discontinued when the pilot complained of reduced visibility and distortion.

17. When ice accumulation reached an approximate depth of 2 inches, the aircraft could not maintain level flight at 140 KCAS with maximum power. Photo 15, appendix B, depicts the aircraft with an ice accumulation of 2 inches. After the pneumatic boots were activated power requirements were greatly reduced. However, because of the ice build-up on surfaces that do not have an anti-ice/defice capability, the power required after activation of the pneumatic boots was still increased over that for the initial entry conditions.

#### ICE ACCUMULATION CHARACTERISTICS

18. The aircraft surfaces that collected ice during the tests were generally leading edges, *ie*, leading edge of wings, propeller spinners, radome, and radio antennas. Photos 16 through 23, appendix B, depict the areas of the majority of ice accumulation. There was some ice accumulation inside the engine inlet (photo 24). This photograph was taken after the aircraft had landed and shut down, approximately 20 minutes after leaving freezing temperature conditions. Because of the time delay, an unknown quantity of ice had melted before the photograph was taken. Since ice vanes are incorporated to prevent ice from entering the engine, the problem of ice formation may be one of reduced airflow, rather than ice ingestion. Further testing should be accomplished to determine the effects of ice accumulation inside the engine inlet and to determine the effectiveness of the ice vanes in preventing foreign object damage.

19. A substantial amount of ice (approximately 6 inches thick and 6 inches high) accumulated outboard of the pneumatic boots. This large build-up of ice is shown in photos 25 and 26, appendix B. Throughout the tests this large block of ice fell from the aircraft prior to landing. Should such a large piece of ice fall in a populated area, the result could be damage to property and/or bodily injury. The lack of anti-ice/deice capability for the wing area outboard of the pneumatic boots is a shortcoming.

20. On one occasion a small amount of ice formed in streaks behind the wing pneumatic boots. The small streaks were a result of runback caused by flying in freezing rain. Because of the small area and amount of runback, the clear ice streaks are considered insignificant. Runback is a characteristic of freezing rain which generally does not exist for long periods, is usually confined to small geographic areas, and is normally predictable (ref 4, app A); therefore, no further study of runback was made.

## **CONCLUSIONS**

### **GENERAL**

21. The U-21A airplane with LR paint can be safely flown in light to moderate icing conditions.
22. The LR paint does not significantly affect the ice accumulation characteristics of the U-21 airplane.
23. In moderate icing conditions at constant power, airspeed will be reduced by 20 to 30 knots.
24. Four shortcomings were identified.

### **SHORTCOMINGS**

25. The following shortcomings were identified:
  - a. Ineffectiveness of the deice boots with rime ice accumulation (para 13).
  - b. Inability of the engine air inlet anti-ice system to prevent formation of ice on the engine inlet (para 14).
  - c. Lack of an engine inlet lip boot anti-ice system preflight test (para 15).
  - d. Lack of anti-ice/deice capability for the wing area outboard of the pneumatic boots (para 9).

## **RECOMMENDATIONS**

26. The shortcomings should be corrected.
27. Future U-21 icing tests should investigate the use of landing lights for anti-icing or deicing the wing area outboard of the pneumatic boots (para 8).
28. Conduct further testing to determine the effects of ice accumulation inside engine inlets and determine the effectiveness of the engine ice vanes in preventing foreign object damage (para 18).
29. Incorporate the following NOTE in the operator's manual (para 10):

### **NOTE**

At constant power an airspeed loss of 20 to 30 knots can be expected with flight in moderate icing conditions.

## APPENDIX A. REFERENCES

1. Equipment Improvement Report, 56th Aviation Company, APO NY 09028, No. 748987, subject: U-21 IR Painted Icing.
2. Message, AVSCOM, DRSAV-EQI, 112035Z February 1977, subject: Test Request No. 77-05, Low Reflective IR Painted U-21 Icing Evaluation.
3. Technical Manual, TM 55-1510-209-10/1, *Operator's Manual, Army Model U-21A, RU-21A, and RU-21D Aircraft*, 1 August 1972.
4. Technical Report, US Army Air Mobility Research and Development Laboratory, Report No. 7338, *Ice Protection Investigation for Advanced Rotary Wing Aircraft*, August 1973.

## APPENDIX B. PHOTOGRAPHS



Photo 1. U-21A Test Aircraft SN 66-18008.



Photo 2. Right-Side Rear Quarter View, U-21A Test Aircraft.



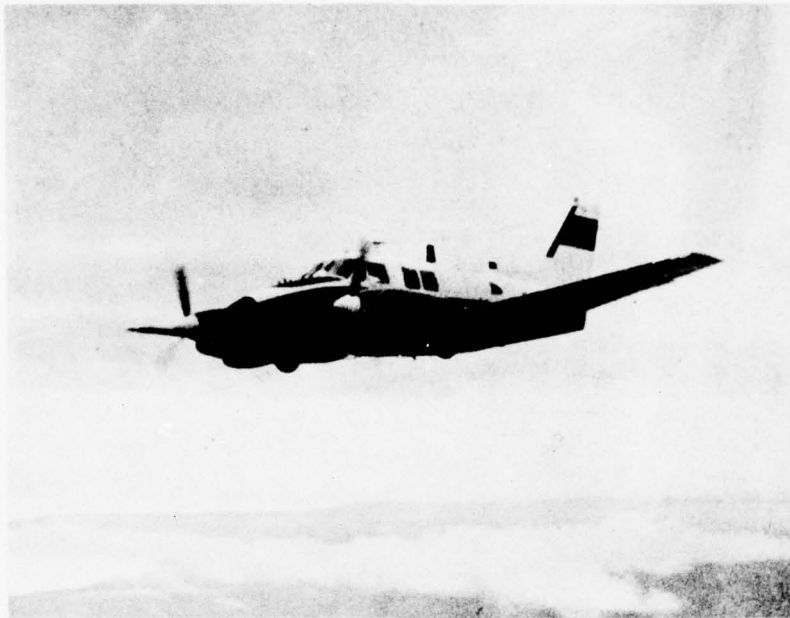
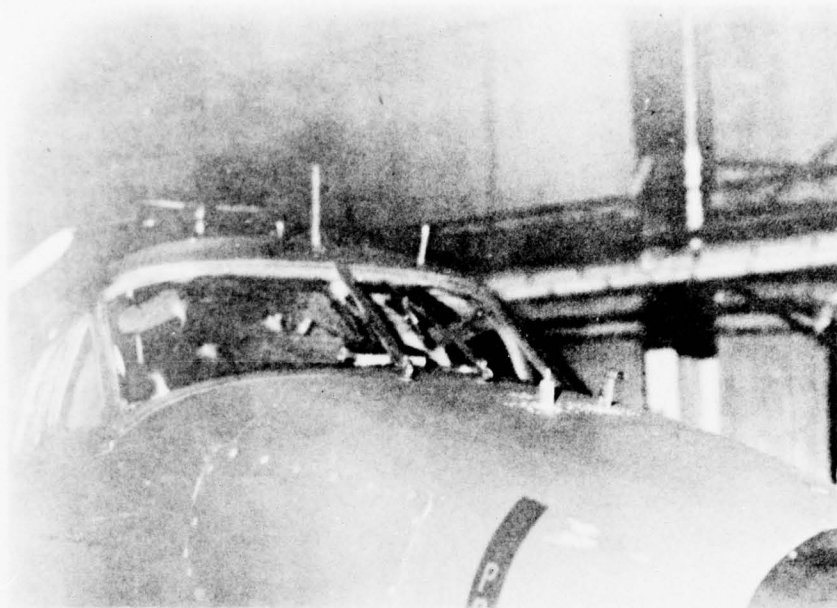


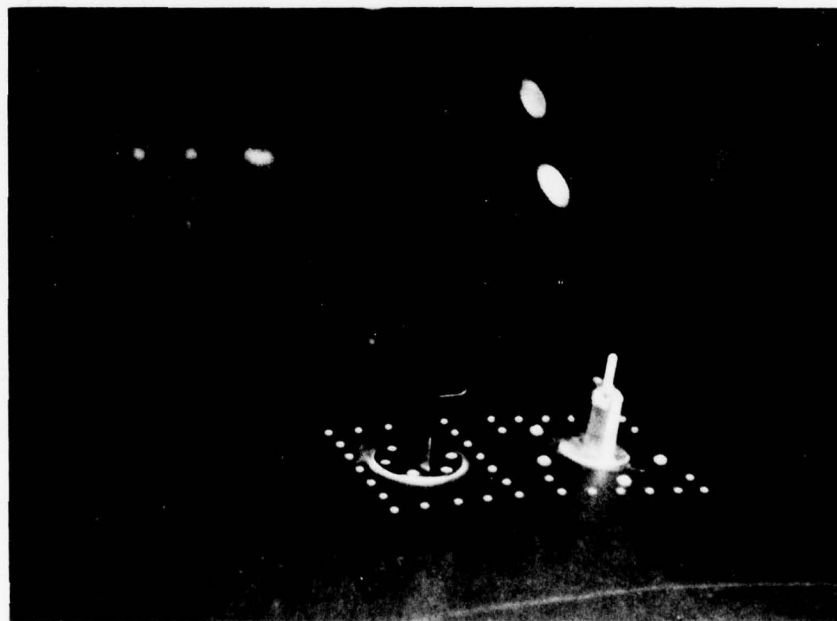
Photo 3. Left-Side Front Quarter View, JU-21D Aircraft.



Photo 4. Left-Side Rear Quarter View, JU-21D Aircraft.



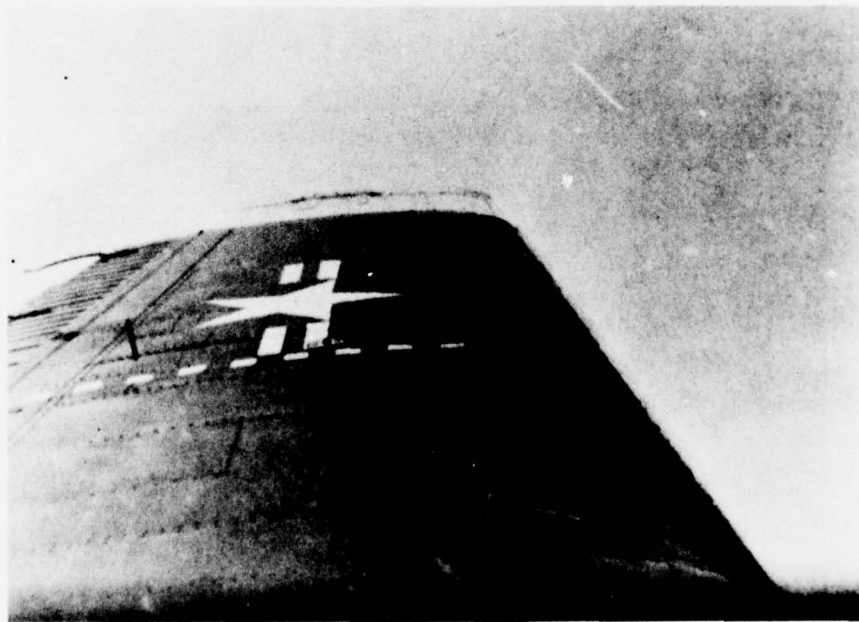
**Photo 5. Ice Detector and OAT Probe Mounted on Nose of Test Aircraft.**



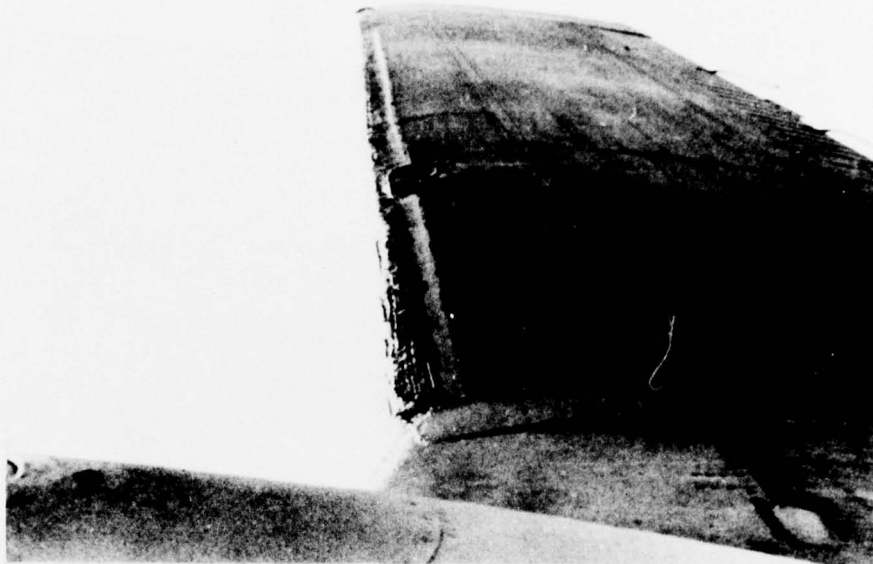
**Photo 6. Rosemount Ice Detector and OAT Probe.**



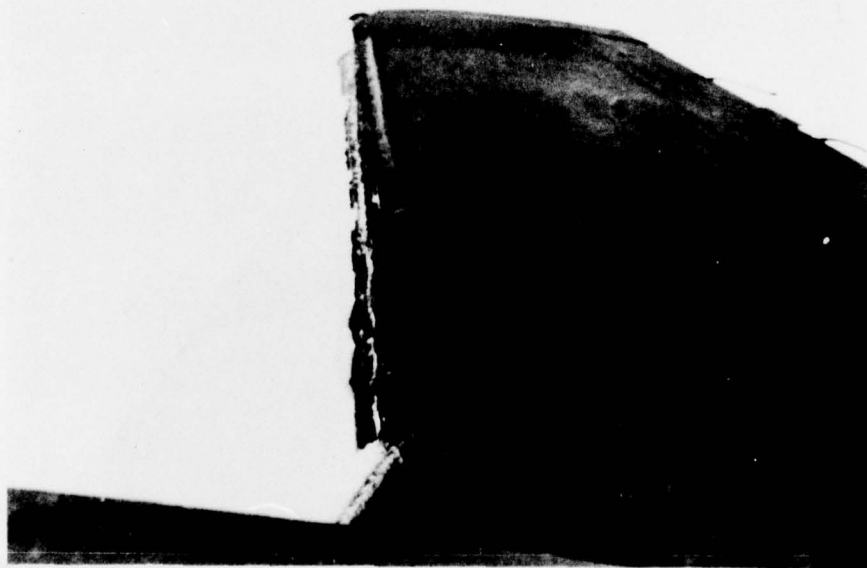
**Photo 7.** Approximately One Inch of Ice Accumulated on Leading Edge of Wing of Test Aircraft.



**Photo 8.** Approximately One Inch of Ice Accumulated on Leading Edge of Wing of Standard Aircraft.



**Photo 9. Approximately Two Inches of Rime Ice Accumulation on Leading Edge of Test Aircraft.**



**Photo 10. Rime Ice After Activation of Wing Deicer Boots.**

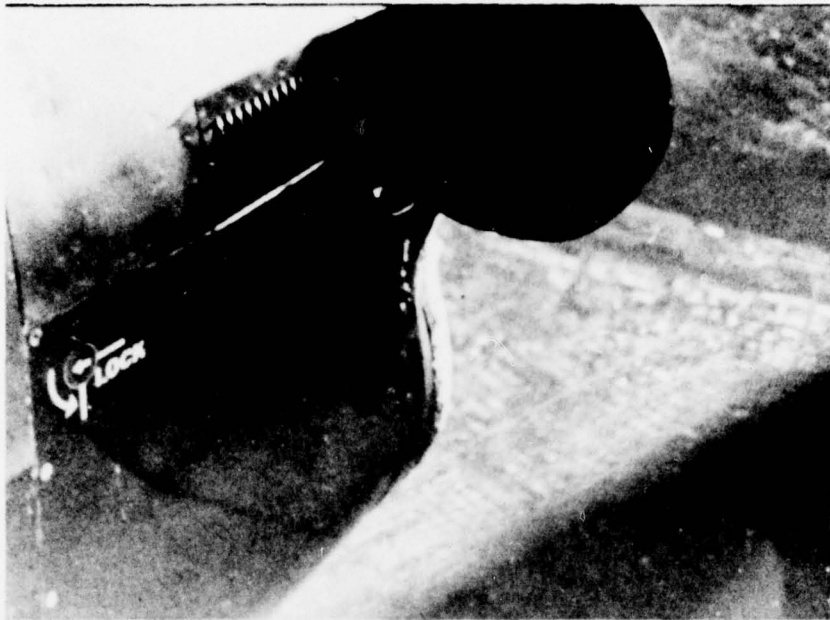


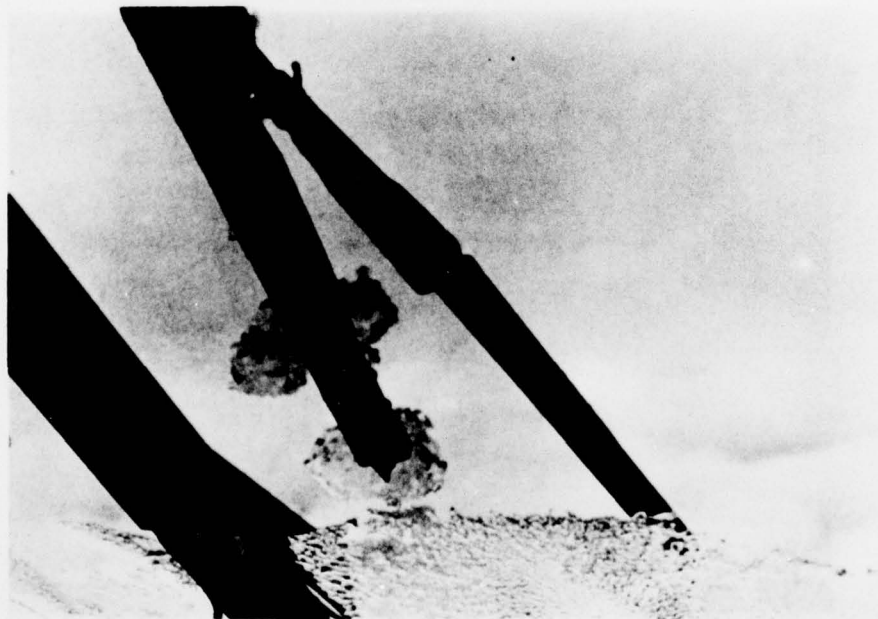
Photo 11. Rime Ice Accumulation on Engine Air Inlet Anti-ice Lip Boot.



Photo 12. Glime Ice Accumulation on Engine Air Inlet Lip Boot.

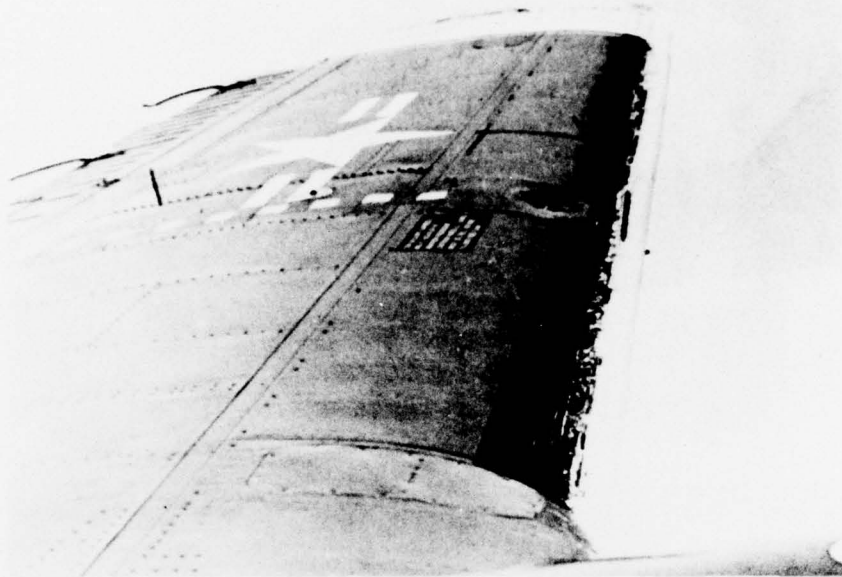


**Photo 13. Windshield and Windshield Wiper Icing on Test Aircraft.**



**Photo 14. Windshield and Windshield Wiper Icing on Test Aircraft.**





**Photo 15. Approximately Two Inches of Glime Ice Accumulation  
on Leading Edge of Standard Aircraft.**



**Photo 16. Right-Side Front Quarter View of Test Aircraft  
with Rime Ice Accumulation.**



**Photo 17. Right-Side View of Test Aircraft  
with Glime Ice Accumulation.**



**Photo 18. Right-Side Nose-Section View of Test Aircraft  
with Glime Ice Accumulation.**



Photo 19. Right-Wing Leading Edge of Test Aircraft  
with Glime Ice Accumulation.

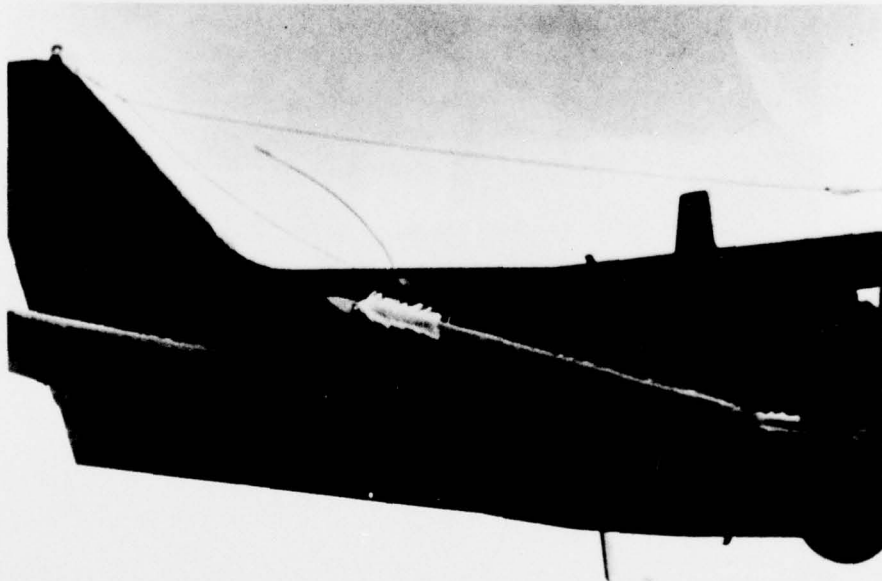
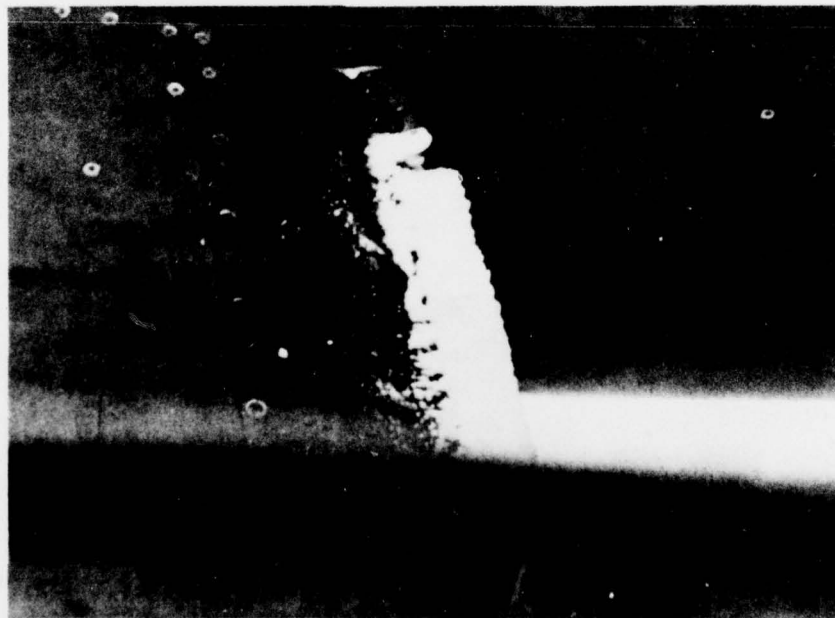


Photo 20. Right-Wing and Empennage of Test Aircraft  
with Glime Ice Accumulation.



**Photo 21. Leading Edge of Right Horizontal Stabilizer of Test Aircraft with Glime Ice Accumulation.**



**Photo 22. Left-Wing Center Section of Test Aircraft with Glime Ice Accumulation.**



Photo 23. Environmental Control Ram Air Inlet of Test Aircraft with Ice Accumulation.

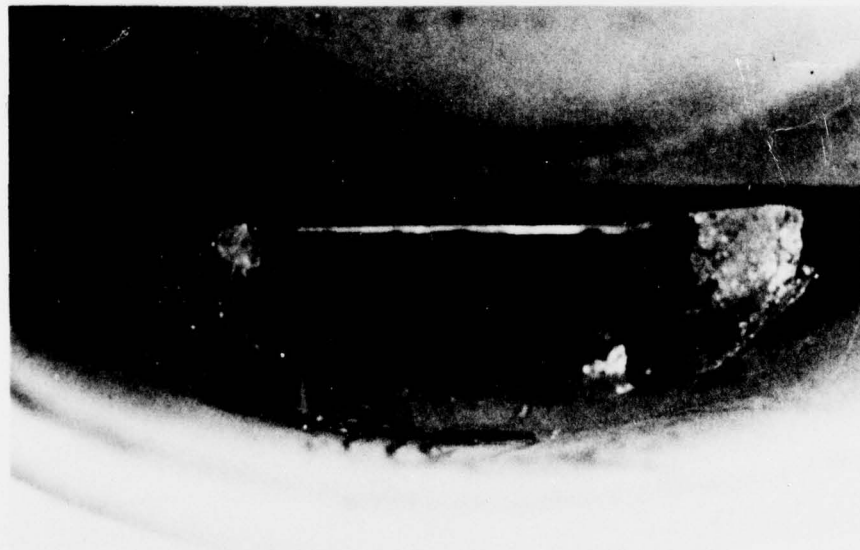


Photo 24. Engine Air Inlet Duct of Test Aircraft with Ice Accumulation.

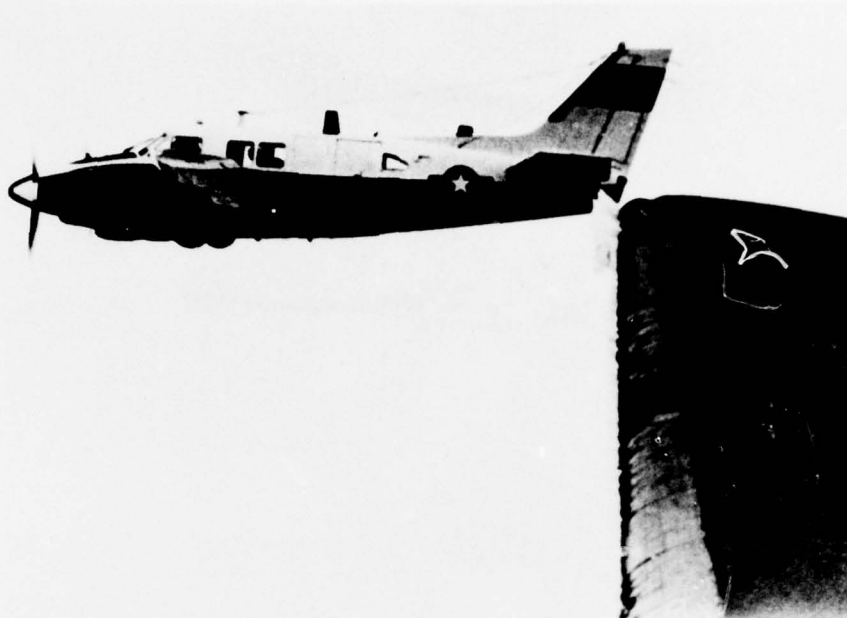


Photo 25. Wingtip of Test Aircraft with Rime Ice Accumulation.

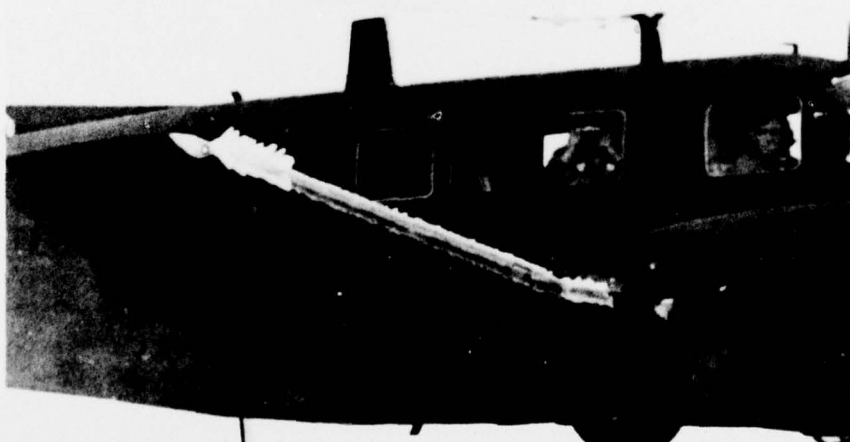


Photo 26. Wingtip of Test Aircraft with Rime Ice Accumulation.



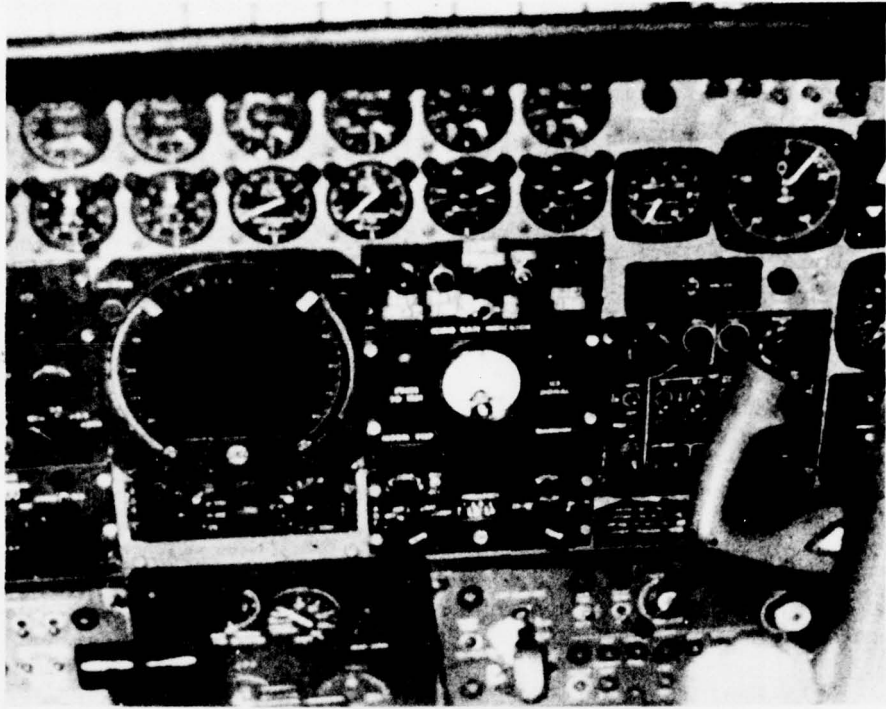


Photo 27. Rosemount Ice Rate Indicator.

## **APPENDIX C. ICING SEVERITY DEFINITION**

1. **Trace Icing:** The presence of ice can be visually detected on airframe projections with the rate of accretion nearly balanced by the rate of sublimation. Not considered hazardous unless encountered for an extended period of time. The use of anti-ice equipment is necessary and the use of deicing equipment is unnecessary.
2. **Light Icing:** The rate of ice accretion is sufficient to create a hazard if flight is prolonged, but insufficient to make diversionary action necessary. The use of anti-ice equipment is necessary and the occasional use of deicing equipment may be necessary.
3. **Moderate Icing:** A condition where the rate of ice accretion is excessive, making even short encounters under these conditions hazardous. Immediate diversion is necessary or the use of anti-icing and deicing equipment is mandatory.
4. **Heavy Icing:** Under these conditions the anti-icing and deicing equipment fail to reduce or control the ice accretion hazard and an immediate exit from the icing condition is mandatory.
5. **Rime:** An opaque ice formed by the instantaneous freezing of small supercooled droplets.
6. **Clear:** A semitransparent ice formed by the slower freezing of larger supercooled droplets.
7. **Glime:** A mixture of clear ice and rime ice which is very common.
8. **Ice-Phobic Material:** A chemical substance that is used to reduce the adhesion of ice to the coated surface of aircraft.

## **APPENDIX D. INSTRUMENTATION AND SPECIAL EQUIPMENT**

### **INSTRUMENTATION**

1. The test aircraft instrumentation which replaced or augmented the standard aircraft instrumentation is listed below. In addition to the special instrumentation, selected standard instrumentation such as engine torque, propeller speed, etc. was calibrated prior to the start of the evaluation. *All instrumentation was installed and maintained by USAAEFA.* The sensitive total temperature probe and ice detector element are shown in photos 4 and 5, appendix B.

- Airspeed (ship's system)
- Altitude (ship's system)
- Total air temperature (heated test system)
- Ice detection system

### **SPECIAL EQUIPMENT**

2. Both aircraft were equipped with the Rosemount series 871 ice detectors. The system was used to measure the ice severity rate, such as trace, light, etc. and not accretion. The series 871 ice detector uses an axially vibrating sensing element frequency sensitive to mass (ice) buildup. When ice builds on the sensing element, the added mass decreases the reference resonant frequency. This frequency is compared with a stable reference frequency and when the frequency shift reaches a preset level an icing rate signal is given. When the icing signal is given, the element is heated, deiced, and a new cycle is started. The frequency of the cycle is directly related to the rate of icing intensity or severity. The system was calibrated by Rosemount in their icing wind tunnel prior to the evaluation. The cockpit-mounted icing rate indicator is shown in photo 27 of appendix B.

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