

NRC Publications Archive Archives des publications du CNRC

Helicopter icing and de-icing flight trials on a bristol sycamore type 171, MK.3

Heines, J.M.H.; Bailey, D.L.; Stallabross, J.R.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:

<https://doi.org/10.4224/40004024>

Aeronautical Report (National Research Council Canada. National Aeronautical Establishment); no. LR-221, 1958-05

NRC Publications Archive Record / Notice des Archives des publications du CNRC :

<https://nrc-publications.canada.ca/eng/view/object/?id=fffc4b58-e2fa-4b46-ac4d-f6ec2e0434fe>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=fffc4b58-e2fa-4b46-ac4d-f6ec2e0434fe>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

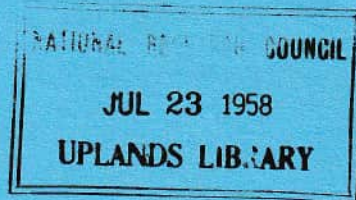
Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

NATIONAL AERONAUTICAL ESTABLISHMENT
CANADA

LABORATORY REPORT LR-221



HELICOPTER ICING AND DE-ICING FLIGHT TRIALS
ON A BRISTOL SYCAMORE TYPE 171, MK. 3

BY

J. M. H. HEINES, D. L. BAILEY AND J. R. STALLABRASS

CLASSIFIED DOCUMENT — CONDITIONS OF RELEASE

1. This information is disclosed for the official use, in Canada only, of the recipient organization and members of its staff as may be authorized under seal of classification.
2. The transmission outside Canada or revelation of the information in any manner to an unauthorized person would be a breach of the security regulations of the Government of Canada.

OTTAWA

MAY 1958

THIS REPORT MAY NOT BE PUBLISHED IN WHOLE OR
IN PART WITHOUT THE WRITTEN CONSENT OF THE
NATIONAL AERONAUTICAL ESTABLISHMENT.

27832

NATIONAL AERONAUTICAL ESTABLISHMENT

Canada

LABORATORY REPORT

Low Temperature Laboratory

Pages - Preface - 5
Text - 16
App. - 7
Tables - 6
Figures - 44

CONFIDENTIAL

Laboratory Report: LR-221

Date: May 1958

Lab. Order: 11876A

File: CM4-A3-R26

For: Ministry of Supply.

Reference: Letter from M. O. S. dated 7 April 1955.

Subject: HELICOPTER ICING AND DE-ICING FLIGHT TRIALS ON A
BRISTOL SYCAMORE TYPE 171, MK. 3

Submitted by: J. J. Samolewicz
Section Head

Authors: J. M. H. Heines
D. L. Bailey
J. R. Stallabrass

Approved by: D. C. MacPhail
Director

SUMMARY

A Sycamore helicopter fitted with an electro-thermal de-icing system was tested under different simulated conditions of icing severity over a wide range of temperatures. The effect of icing on handling and performance was assessed and power requirement for clean shedding was determined.

The de-icer pads had a low fatigue life due to the flexibility of the main rotor blades. Flexing caused creasing of the erosion shield and cracking of the nichrome heater elements.

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	(i)
LIST OF TABLES	(iii)
LIST OF ILLUSTRATIONS	(iv)
1.0 INTRODUCTION	1
2.0 PURPOSE OF TESTS	1
3.0 TEST EQUIPMENT	2
3.1 Aircraft	2
3.2 Additional Aircraft Instrumentation	2
3.3 Spray Rig Installation	2
3.4 De-Icer Pads	2
3.5 Windscreen Anti-Icing System	2
3.6 Communication	2
4.0 TEST PROCEDURES	3
4.1 Preliminary Flight Tests	3
4.2 Icing Flights	3
4.3 De-Icing Flights	3
4.4 Windscreen Anti-Icing	3
5.0 RESULTS	4
5.1 Icing Flights	4
5.2 De-Icing Flights	5
5.3 Flights in Simulated Freezing Rain	6
5.4 Windscreen Anti-Icing System	6
5.5 Handling and Performance	7
6.0 DISCUSSION	7
6.1 Icing Flights	7
6.2 De-Icing System Performance	10
6.3 Flights in Simulated Freezing Rain	12
6.4 De-Icer Pads	12
6.5 Instrumentation and Control Equipment	13
7.0 CONCLUSIONS	14
8.0 REFERENCES	16

TABLE OF CONTENTS (Cont'd)

APPENDIX A: Engineering and Performance Data for
 Bristol Sycamore Type 171

APPENDIX B: Effect of Icing and De-Icing on Aircraft Handling
 from Pilot's Viewpoint

APPENDIX C: De-Icer Pad Failure

LIST OF TABLES

	<u>Table</u>
Icing Flights - Distribution over Temperature Range	I
Icing Flight Results:	
Temperature Range 0° C to -10° C	IIa
Temperature Range -10° C to -20° C	IIb
Temperature Range -20° C to -30° C	IIc
De-Icing Flights - Distribution over Temperature Range	III
De-Icing Flight Results:	
Temperature Range 0° C to -10° C	IVa
Temperature Range -10° C to -20° C	IVb
Temperature Range -20° C to -30° C	IVc
Flights in Simulated Freezing Rain	V
Windscreen Anti-Icing and De-Icing in Simulated Freezing Rain	VI

LIST OF ILLUSTRATIONS

	<u>Figure</u>
Bristol Sycamore Type 171, Mk. 3	1
Main Rotor Blades Used During Trials	2
Cyclic Switch Installed on Aircraft	3
Snatch Plug Arrangement for External Power Supply	4
Diagram of Power and Control Wiring on Helicopter and in Control Hut	5
Shielded Temperature Bulb on Top of Cabin	6
Helicopter During Icing Flights	7
Ice Profile Mould and Camera	8
Layout of De-Icer Pads	9
Main Rotor with De-Icer Pads Installed	10
Typical Accretion Collected During Icing Flights with Standard Blades	11
Self-Shedding of Ice Accretions on Protected Blade	12
Ice Extent on Tail Cone	13
Icing of Air Inlets	14
Component Icing	15
Ice Accretion on Side Windows	16
Icing on Rotor Head at -16°C O. A. T.	17
Variation of Power-On Time with Ambient Air Temperature	18
Minimum Specific Energy to Shed Ice Along Span of Main Rotor at Various Specific Power Densities and Ambient Temperatures	19
Simulated Zone Failures	20
Accretions Collected in Simulated Freezing Rain	21
Diagram of Windscreen Anti-Icing System	22
Chordwise Extent of Ice Accretions on Main Rotor De-Icer Pads	23

LIST OF ILLUSTRATIONS (Cont'd)

	<u>Figure</u>
Maximum Ice Thickness Observed for a 4-minute Accretion at Different Ambient Temperatures	24
Maximum Spanwise Extent at Stagnation Line and Calculated Ice Accretion Characteristics for Liquid Water Content = 0.3 gm./m. ³	25
Maximum Spanwise Extent at Stagnation Line and Calculated Ice Accretion Characteristics for Liquid Water Content = 0.7 gm./m. ³	26
Maximum Spanwise Extent at Stagnation Line and Calculated Ice Accretion Characteristics for Liquid Water Content = 1.5 gm./m. ³	27
Typical Examples of Tail Rotor Self-Shedding	28
Tail Rotor Self-Shedding, Calculated and Observed Values	29
Examples of Run-Back Ice	30
Windscreen Thermal Anti-Icing	31
Windscreen Anti-Icing with Alcohol and Wiper Action	32
Typical Records Obtained from Ice Profile Moulds	33
C. G. and Loading Diagram	A1
Alvis Leonides 173.02 Engine Performance Chart at Sea Level	A2
Variation of Linear Blade Velocity and Radial Acceleration Along the Blade Radius of the Main Rotor at Various R. P. M.	A3
Chord Length and Thickness of Main Rotor Blades	A4
Variation of Linear Velocity and Radial Acceleration Along the Tail Rotor Blade at Various R. P. M.	A5
Chord Length and Thickness of Tail Rotor Blade	A6
Pilot's View from Aircraft During Icing Flight	B1
De-Icer Pad Deterioration	C1
De-Icer Pad Failure	C2
Damage to Wooden Blade Due to Short Circuit	C3
Repairs to Main Rotor De-Icer Pad	C4

HELICOPTER ICING AND DE-ICING FLIGHT TRIALS ON A BRISTOL SYCAMORE TYPE 171, MK. 3

1.0 INTRODUCTION

During the winter season 1956-57, at the request of the Ministry of Supply, a Bristol Sycamore helicopter Type 171, Mk. 3 (Fig. 1), equipped with a main rotor electro-thermal de-icing system was tested for icing and de-icing performance. The M. O. S. supplied the aircraft, pilot and maintenance crew, while the National Research Council was responsible for conducting the flight trials. Grateful acknowledgement is made to the R. C. N. for making a second pilot available to assist in the completion of the tests.

Tests were made to cover the meteorological conditions laid down by the test schedule of Reference 1. Two sets of rotor blades were used, standard blades not equipped for de-icing, and a second set having de-icing pads installed along the leading edge (Fig. 2).

The effect of icing on handling and performance was assessed, and an appropriate time decided upon during which ice could accumulate to a thickness sufficient to give efficient shedding. A series of de-icing tests determined the power requirements for clean shedding. Other phenomena such as run-back and impingement extents, with their effects on performance and handling of the aircraft, were noted. Icing of other components was also observed.

Flights in the icing cloud up to 1 hour 40 minutes were made and the system was tested for a total of approximately 200 cycles. An airspeed of 30 m. p. h. was the maximum allowable due to the wind loading limitation on the spray rig described in Reference 2.

2.0 PURPOSE OF TESTS

- 2.1 To obtain information on the performance and handling of the protected and unprotected aircraft under icing conditions, including freezing rain.
- 2.2 To test the efficiency of the installed de-icing system for the meteorological conditions specified in Reference 1 and from the results to select a shedding cycle consistent with an acceptable deterioration of flight performance.
- 2.3 To determine limits of impingement areas and the effect of run-back ice.
- 2.4 To assess the effects of ice accretions on secondary components - air intakes, control linkages, and tail rotor, etc.
- 2.5 To test the windshield anti-icing systems.
- 2.6 To check the effect of simulated system failures on aircraft handling.

3.0 TEST EQUIPMENT

3.1 Aircraft

The helicopter (details in Appendix A) was equipped to test a main rotor electro-thermal de-icing system. De-icer pads were installed along the leading edge of the protected blades, power being supplied via a slipping unit and controlled by a selector switch mounted on the rotor head (Fig. 3). A 3-phase 60 c/s a-c. variable power supply installed in the test hut supplied power to the aircraft system through a trailing cable which was connected to the aircraft by means of a snatch plug (Fig. 4). Figure 5 shows details of the power installation. The variable electronic timer controlled the shedding cycle.

3.2 Additional Aircraft Instrumentation

In addition to the standard instrumentation, an automatic observer was installed on the rear seat mounting and was controlled from a unit beside the observer's seat. The recorder photographed a duplicate set of flight instruments. A shielded resistance thermometer was installed on the top of the aircraft cabin (Fig. 6) and a record of ambient temperature was kept by the auto observer.

3.3 Spray Rig Installation

The spray rig described in Reference 2 and shown in Figure 7 was used to produce the icing cloud. Instrumentation at the test site recorded windspeed, temperature, and humidity.

The ice profile camera and moulds were used to obtain ice profile records at four stations along the blade. These are shown in Figure 8 and their use is described in Reference 3.

3.4 De-Icer Pads

The pads were of sandwich construction and were cemented to the leading edge of the rotor blades. Figures 9 and 10 give full details of pad construction and rotor coverage.

3.5 Windscreen Anti-Icing System

In addition to the standard windscreen alcohol anti-icing system an electro-thermal system was installed in the port windscreen. An area of 156 sq. in. was electrically heated by embedded resistance wires with a sensing element providing temperature control. Power for the system was provided through the trailing cable.

3.6 Communication

To ensure a safe and satisfactory test programme two-way communication

between air and ground is essential. Two methods were available, VHF radio and a telephone cable within the trailing cable. Radio communication with the aircraft in the cloud was only fair due to static and the telephone cable had to be abandoned because of interference from the de-icing system electrical equipment.

4.0 TEST PROCEDURES

4.1 Preliminary Flight Tests

Performance flights were made in clear air with both standard and protected blades to obtain a datum for deterioration of performance due to icing. All tests were made with the main rotor speed constant at 265 r. p. m. , power requirements being controlled by variations of manifold pressure.

4.2 Icing Flights

The aircraft was flown in the icing cloud to investigate any change in performance and handling characteristics resulting from ice build-up. Ice thickness and extent of impingement data were recorded after the flights. Tests were also made in simulated freezing rain.

The purpose of the flights with standard blades was to obtain information on the effect of icing on an unprotected aircraft. With the protected blades, impingement data and determination of suitable "power-off" time under different conditions of liquid water content and temperature were the main objects. The maximum power-off or accretion time allowable was dependent on three main factors:

- (1) acceptable decrease in performance,
- (2) allowable vibration level because of asymmetrical self-shedding,
- (3) possibility of damage due to pieces of thrown ice.

4.3 De-Icing Flights

Ice was allowed to build up on the main rotor for a suitable power-off time as determined by the icing flights. The aircraft was landed and the accretion inspected and recorded. The aircraft then hovered in clear air and a de-icing cycle was initiated, at the completion of which the aircraft was again landed and the shedding inspected. The object was to find combinations of specific power density and power-on time which gave satisfactory shedding. Tests were also made to investigate the effects of run-back and simulated system failures.

4.4 Windscreen Anti-Icing

The aircraft was subjected to conditions of simulated freezing rain, and tests were made to find necessary power requirements in the case of the electro-thermal system, and to test the effectiveness of the alcohol system.

5.0 RESULTS

5.1 Icing Flights

Fifty-three flights were made totalling 6 hours, $2\frac{1}{2}$ hours flying time using standard blades, and $3\frac{1}{2}$ hours using protected blades. Temperatures ranged from -2°C to -26°C and tests were made at light, medium, and heavy icing conditions. Tables I and II give full details.

5.1.1 Standard Blades

The standard blades had 4-inch brass nose caps over the leading edge of the blade (Fig. 2), and this plus the high flexibility of the blades used on the Sycamore resulted in considerable self-shedding. With temperatures down to -20°C the aircraft was able to fly without any drastic reduction in performance. The shedding was not always symmetrical and this induced vibration, but not to an unacceptable level. Below -20°C the accretion did not bridge the gaps between the 4-inch nose caps and separate accretions were formed on each. Large accretions could accumulate with no self-shedding until maximum power was attained. Figure 11 shows typical accretions collected during these tests.

5.1.2 Protected Blades

The protected blades were not as flexible as the standard blades and had no gaps at which stress in the ice was concentrated, so that self-shedding was not so pronounced. The maximum chordwise impingement on the top surface of the blade was $1\frac{1}{8}$ inches and on the lower surface $3\frac{1}{2}$ inches. Four minutes in the icing cloud appeared to be an acceptable over-all power-off time to allow accretion of a suitable formation for efficient shedding.

The actual extent of self-shedding was almost impossible to determine because, when the rotor was slowing down, the pronounced droop of the rotor blades cracked the ice accretion and more self-shedding took place than would occur in normal flight. Examples of self-shedding with the protected blades are shown in Figure 12.

5.1.3 Tail Rotor Icing

Tail rotor icing occurred in a manner similar to that on the main rotor, but rate of icing and susceptibility to self-shedding were greater. This self-shedding was often asymmetrical and caused vibration. At no time was the tail rotor control mechanism affected. See Table II for details of thickness of accretion and extent.

5.1.4 Airframe and Secondary Icing Effects

Airframe icing had little effect although accretions did form on the various projections on the aircraft.

Some nodules of ice formed on the tail cone (Fig. 13), but were not large enough to create a problem. This accretion was largely caused by rotor downwash.

The engine intake crossbars collected ice, and some ice formed within the engine bay and on the carburettor air intake filter; but these gave no trouble. No carburettor icing was observed and the warm air shutter worked successfully. Figure 14 shows typical accretions.

Ice accumulated on the aerial (Fig. 15) and it vibrated considerably. Pitot heating was sufficient although ice remained on the rear part of the tube.

Ice formed on the side windows and doors, especially at lower temperatures (Fig. 16), and restricted vision. Flights in freezing rain caused almost complete icing of windows, and on one occasion difficulty was experienced in opening the door from the inside.

Typical rotor head ice accretions are shown in Figure 17.

The pilot noted little interference with the control mechanisms other than a slight stiffening which was probably caused by solidifying of the grease at lower temperatures. Ice collecting on the centrifugal bob weights decreased their cut-in r. p. m., and difficulty was experienced in engaging all but the first step. At lower temperatures they were very sluggish but a little stick stir usually was enough to assist them to engage.

5.2 De-Icing Flights

A total of 93 flights were made to test the de-icing system and to determine the specific energy required to give clean shedding over a full range of temperatures. Details are given in Tables III and IV. Shedding was attempted at 15, 20, 25, and 30 watts/sq. in. and Figure 18 shows the power-on time required to shed cleanly to Station 63. Figure 19 shows these points transposed to show energy vs. ambient temperature.

The zones were heated in different sequences to check the effect of shedding performance and run-back. Variation from the numerical sequence shown in Figure 9 showed an increase in power requirements. Zone 6 was omitted as it was outside the impingement area found during the icing flights. During the later tests zones 7 and 8 became inoperative because of failure.

Various accretion times were used; in general, 4 minutes was found to give an adequate accretion for efficient shedding without serious deterioration in flight performance over the complete temperature range. No airframe damage due to ice shed from the rotor was noted.

5.2.1 Simulated Failures

To investigate the effect of failure of either individual zones or a complete

pad a number of failures were simulated. Such failures may be attributed to the switch gear or to the pads themselves.

As mentioned in Section 5.2, zone 6 had already been eliminated from the heater sequence and towards the end of the programme zones 7 and 8 were removed because they became open circuited. Since these zones were nearly always outside the impingement limit no effect was noticed, although, with higher all-up weight, clean shedding was not obtained because of ice remaining on zone 7. Figure 20 shows the secondary ice left after shedding. Failures of zones 2 and 4 were also simulated because they were considered to be of special interest. With zone 2 inoperative little effect was noticed during continuous cycling, apart from a slight increase in vibration level. The ice on the outer section of zone 2 shed if zone 1 was heated and the ridge left on the inner section of the blade (Fig. 20b) caused no noticeable deterioration in performance.

In the case of zone 4, an increase in run-back was noted when that zone was not energized.

In the case of one blade failing to shed, the magnitude of vibration was dependent upon size of the accretion. A 2-minute accretion resulted in moderate vibration but it was still acceptable. Unfortunately, as these tests were carried out at higher temperatures, the accretion self-shed before the vibration reached a level where the flight had to be discontinued.

5.3 Flights in Simulated Freezing Rain

These tests were made in conjunction with the windscreen anti-icing tests. The ice accretions were similar but heavier and slightly more extensive than those under normal icing conditions. Figure 21a shows the accretion collected during a ground run with zero pitch, while Figure 21b shows the accretion collected during Flight VIII-1. Two sheddings were attempted with satisfactory results. Table V gives details.

Little effect was noted on control linkages and centrifugal weights of the droop stops. A 1/32-inch accretion formed on the tail cone.

5.4 Windscreen Anti-Icing System

During the icing and de-icing trials little windscreen icing was noticed. This was partially due to the practice of flying just below the cloud so that the main rotor was enveloped while the windscreen remained clear, but was also due to low relative speed and the large scale of the fuselage.

Windscreen tests, therefore, were made under simulated conditions of freezing rain at -15°C . Both systems worked satisfactorily and the results of the different tests are given in Table VI. Figure 22 shows details of the electro-thermal system.

5.5 Handling and Performance

The handling of the aircraft showed little change with icing and the aircraft behaved satisfactorily.

The major effect was the increase in profile drag of the main rotor blades and the necessary increase in power to overcome it. After effective shedding the power setting reverted close to its original value.

During the shedding process a slight increase in vibration was noted, and this was more pronounced if the shedding was asymmetric. These vibrations were not fed back into the pilot's cyclic control.

6.0 DISCUSSION

6.1 Icing Flights

6.1.1 General

Tests were carried out over a range of temperatures from -2°C to -26.5°C . As nature determines the test temperature, 36 of the 53 flights made were in the ranges -5°C to -15°C . Table I shows the distribution of flights over the temperature range. It will be noted that no tests at low liquid water content were possible below -20°C . Low values of water content can be obtained only at high windspeed and this usually does not occur at very low temperatures.

The true time in the icing cloud is affected by such factors as turbulence and the ability of the pilot to keep the rotor enveloped in the cloud. Therefore, a corrected time is shown in column 8 of Table II. At low windspeeds the cloud was sucked down through the main rotor and little or no tail rotor icing took place (Fig. 7b).

Although self-shedding did occur, it was usually possible to define the point of maximum extent of the ice as it had often begun to reform along the blade. The accretion at this point was usually quite thin, and it was unaffected by the self-shedding which took place as the main rotor slowed down and the blades took on the pronounced droop which is a feature of the Sycamore.

6.1.2 Standard Blades

Flights with the standard blades were made to investigate the effect of icing on the unprotected aircraft. The aircraft was flown for periods of up to 30 minutes in icing without exceeding the maximum power. This was possible because self-shedding occurred readily with the highly flexible standard blades. Concentration of stress in the ice over the gaps between the 4-inch nose caps caused it to crack at these points and facilitated shedding.

Self-shedding gave the Sycamore good performance in icing conditions;

but the shedding was uncontrolled, and if asymmetric, caused airframe vibration which could reach a serious level at lower temperatures when accretions are larger. It is therefore not considered a satisfactory means of protection below temperatures of about -3°C .

6.1.3 Protected Blades

The protected blades were not as flexible as the standard blades and did not self-shed as readily. The fact that the metal cover presented a continuous surface to ice and so had no tendency to concentrate stress in it may also have been a factor.

The main objects of these tests, however, were to collect impingement data, to determine the chordwise coverage required on the main rotor blades, and to determine, also, a suitable accretion time which would give efficient shedding. This accretion time necessarily was a compromise between increase in engine power required to overcome the increased blade profile drag and obtaining a suitable accretion with resulting higher centrifugal forces to assist shedding. A 4-minute accretion time seemed to satisfy this requirement over the range of temperatures and liquid water contents tested.

The impingement data collected show that the installed pads are wider than necessary. Zones 6 and 8 could be removed without affecting shedding performance. Extent of impingement for the various temperature ranges is shown in Figure 2. For a given water content and time of accretion, the maximum ice thickness along the blade varied linearly with temperature. Figure 24 shows this relationship particularly well defined for the condition of high liquid water content. The effect is less clear at lower water concentrations because of the difficulty of exact measurement of liquid water content.

Figures 25, 26 and 27 show the maximum spanwise extent noted during the trials compared with the theoretical curves for different liquid water contents. The theoretical changeover points for different types of ice are also shown, but these points were never well defined although the type of ice did vary along the span in accordance with the theoretical calculations. The inboard end of the blade did not produce the streamline ice expected, but rather a large double ridge shaped rime accretion which can be seen in Figure 17.

Impingement data collected for both sets of blades were very similar.

6.1.4 Tail Rotor Icing

Tail rotor icing occurred in a manner similar to that on the main rotor. The fact that it has a higher collection efficiency and centrifugal forces five times greater than the main rotor caused the tail rotor to shed more frequently. This shedding was often asymmetric and could result in severe airframe vibration. The unbalance does not appear to be fed back into the pilot's control. Examples of self-shedding are shown in Figure 28. The observed extent of self-shedding compared with the calculated values is shown in Figure 29.

One case of severe vibration occurred. After an icing flight the aircraft was landed to inspect the accretions. While it was standing, the sun warmed one blade; upon starting up again, this blade shed and the vibration was so severe that take-off had to be abandoned. The ice was removed by hand from the other blades and testing was continued.

Some form of tail rotor protection is essential, not only to limit vibration but also because the accretions which self-shed are thrown into the path of the main rotor, causing damage to the main rotor de-icer pads in the tip region (see Fig. C4(b), Appendix C).

This protection may take the form of anti-icing or de-icing. If de-icing is chosen, it would be advisable to select a shorter accretion time for the tail rotor than for the main rotor. Due to the higher centrifugal forces, lower power densities are feasible for effective de-icing.

At no time did the tail rotor control mechanism appear to be affected.

6.1.5 Effect on Secondary Components

The effect of icing on secondary components was small.

The rotor head and controls collected ice but never to a point where it created a serious problem. Ice did form on the bob weights of the droop stops, increasing their centrifugal weight, and so decreased the r. p. m. at which they cut in. This meant that it was seldom possible to get the main rotor blades on to any but the first step. On longer flights at higher forward speeds the larger accretions which would result might begin to have an effect and require that some form of protective cover be provided.

Tailcone icing was the result of rotor downwash; at no time did it have any effect on the handling of the aircraft. It is possible with higher forward speeds that the accretion would be extensive enough to cause a significant change in weight and centre of gravity and require consideration.

Intake icing created no problems and no cases of carburettor icing were noted. The warm air shutter arrangement worked satisfactorily.

Ice formed on all projections of the aircraft and in only one case was any effect noted. After a flight in freezing rain the pilot's door could not be opened from the inside. This could have serious results in an emergency.

6.1.6 Handling Changes

Handling changes were small. Other than the need to close the throttle quickly when the ice shed and so prevent a surge in rotor r. p. m. , the only effect was the increase in airframe vibration caused by asymmetric shedding of the main and tail rotors. A summary of the pilot report on the handling of the aircraft during the trials is given in Appendix B.

6.2 De-Icing System Performance

6.2.1 De-Icing Flights

A total of 93 flights were made to test the de-icing system; the full details are given in Table IV. Table III shows the distribution of the de-icing flights over the temperature range. Because zone 6 was outside the impingement area found during the icing flights, it was decided to eliminate it from the de-icing cycle. The zone sequence was therefore 1, 2, 3, 4, 5, 7, 8, except during the latter part of the tests when zones 7 and 8 were removed from the sequence because of unserviceability. Other sequences were tried, and although it was possible to obtain successful shedding, the energy requirement increased, as did run-back.

For efficient de-icing it is essential that an adequate accretion be formed before de-icing is attempted. Too thin an accretion results in melting and run-back rather than in clean shedding. The effect of run-back was of considerable interest as it might upset the mass balance of the blades. Low power densities requiring long power-on times increased run-back, especially at lower temperatures (Fig. 30), but at no time was it excessive. It usually occurred over the inboard third of the blade where it has least effect. A series of consecutive cycles within the cloud showed no appreciable increase in run-back, and in fact it usually disappeared after several heating cycles.

De-icing was normally attempted as a single heating cycle outside of the cloud as this is the more severe condition. The aircraft then landed and the extent of the shedding was noted. This method of testing is necessarily a lengthy procedure as several flights may be required to establish the minimum power-on time for a particular combination of power density and temperature. Shedding was attempted at specific power densities of 15, 20, 25 and 30 watts/sq. in. over the full range of temperatures. Shedding was accepted as successful if ice shed cleanly to Station 63, and the corresponding power-on times were plotted in Figure 18. It will be seen that power-on time increases linearly with the decrease in ambient temperature.

The variation of power-on time with temperature indicates that a temperature controlled variable power-on time system is desirable. Failing this, a two- or three-step system may be satisfactory. A controlled system will prevent pad overheating which will occur at higher ambient temperatures if a fixed power-on time is used.

Figure 19 shows the energy required for shedding at various power densities over a range of temperatures. A power density of 25 watts/sq. in. gave satisfactory performance down to -25°C . This power density seems to be, therefore, a good compromise between shedding performance and the size of the alternator required.

Spanwise shedding proved to be a satisfactory method of de-icing.

6.2.2 Simulated Failures

A limited number of system failures were simulated at higher temperatures. These were restricted to failure of zones considered likely to have the most effect on performance and to asymmetric shedding brought about by the failure of the de-icing equipment of one blade.

6.2.2.1 Zone Failures

Failure of zone 2 was considered to be the most serious zone failure as any accretion left would form a ridge of ice and cause a turbulent flow over the upper side of the blade. Under the test conditions this expectation did not materialize. The ice on the outer part of zone 2 shed when zone 1 was heated, and that left on the inner part of the blade had little effect.

Zone 4 was omitted from the heating sequence to see whether it could be permanently removed along with zone 6 (Section 5.2). Although it was sometimes outside of the impingement area an increase in run-back was noted when it was not energized.

Zones 7 and 8 did become inoperative during the tests, so that this failure was not a simulated one. Figure 20a shows the accretion left on these inoperative zones after a shedding cycle.

6.2.2.2 Asymmetrical Shedding

The magnitude of the vibration brought about by the failure of one blade to shed is dependent upon the size of the accretion. Asymmetric sheddings were attempted with 1- and 2-minute accretions, and although they resulted in an increase in vibration the level was not unacceptable. Because these tests were made at higher ambient temperatures, any further increase in accretion time was not possible as self-shedding took place. This prevented an attempt to determine the size of accretion which would cause vibration so severe that the flight would have to be discontinued. At lower temperatures this point in all probability could be reached, and some form of protective device is therefore considered necessary to disconnect the power in the event of failure of some part of the de-icer system that would result in asymmetric shedding. A steady decrease in performance is considered preferable to the vibration resulting from unbalanced shedding at these temperatures.

6.2.3 Windscreen Anti-Icing

Little icing of windscreens was noted. This is explained by the low speed and the large scale of the fuselage, plus the fact that most of the flying was done with the windscreen clear of the cloud because of the necessity for visual reference. However, under conditions of simulated freezing rain when severe icing occurred, the two protective systems with which the aircraft was equipped both worked successfully.

The electro-thermal system appears adequate when operated at 2 watts/sq. in. It was possible to keep the windscreen clear at lower power densities, but if the heater was switched on after the accretion had formed clearance took several minutes. If the wiper was used to assist clearance the time required was reduced. Figure 31 shows the system in operation. The heated area was inconveniently positioned, and it should be arranged that the edge is parallel to the horizon so that it may be used as a flight reference. The area should be increased to give the pilot a better field of view.

The alcohol system worked successfully, particularly if it was switched on before an accretion had formed; otherwise it took a considerable time to clear. The nozzle arrangement gives poor distribution and is wasteful of alcohol. Consequently it dripped down over the lower vision panels distorting view and producing a noxious smell within the cockpit. Figure 32 shows the clearance produced by the alcohol system and the way in which the fluid ran down over the lower panels leaving a mushy accretion. Some type of collection channel would have conserved the alcohol supply. The controls on this particular aircraft required considerable effort to put the system into operation.

6.3 Flights in Simulated Freezing Rain

In conjunction with the windscreen anti-icing tests, under conditions of freezing rain, a number of flights were made to investigate the impingement and de-icing performance of the aircraft. It had been hoped that these tests could be made under natural conditions, but unfortunately these did not occur during the duration of the trials. The condition was therefore simulated but at a temperature lower than that at which freezing rain would be expected to occur normally.

The aircraft was first run on the ground to check the extent and type of accretion on the rotors and the effect of glaze ice on the control mechanism. The accretion was heavier and more extensive than under normal icing conditions. The results of this ground run can be seen in Figure 21a. Flights were then made as detailed in Table V. Performance decreased progressively and in a manner similar to that experienced in other tests under icing conditions. De-icing was also similar to previous tests. Little adverse effect on handling was noted, apart from airframe vibration caused mainly by self-shedding of ice from the tail rotor.

The effect on control linkages and on the centrifugal droop stops was small, but the accretion can be expected to increase with higher forward speeds. The high density glaze ice on the tail cone can be expected on longer flights to have an influence on the position of the centre of gravity.

Little self-shedding took place at this temperature (-15°C) but at higher temperatures, around -4°C , the amount can be expected to increase especially with standard blades.

6.4 De-Icer Pads

As the Sycamore trials were the first complete full scale tests of a

helicopter rotor protection system, there was no available standard for comparison of the thermal performance. When compared with results of tests made with sample pads of various construction on a whirling rig in a cold chamber, the power-on times required were greater. Since this time, however, further full scale testing has been completed and the power-on times required for shedding on the Sycamore compare favourably. The thermal performance of these pads is therefore considered acceptable. The performance could be improved, however, by smaller gaps between heater passes and by reducing the thickness of the outer insulating layer, but with the present method of construction and materials used the limit appears to have been reached.

The mechanical behaviour of the pads was poor, a fact which was accentuated by the extreme flexibility of main rotor blades used on the Sycamore. The short life of the pads points to the fact that development of helicopter de-icers is not merely a case of adapting the existing pads used on fixed wing aircraft. Provision must be made for the flexing action of the blade and also for thermal expansion of the heater elements during the power-on time. With the long heater passes used in the spanwise layout (226 inches on the Sycamore), this expansion was sufficient to cause local delamination between the base insulation and the element.

Another possible source of failure is the ice thrown from the tail rotor into the path of the main rotor blades, causing dents in the metal cover. These can be seen in Figure C4. Due to the resilience of the neoprene insulation, the stainless steel cover gets little support and local stretching occurs upon impact. Consequently, the insulation below the dent is thin and highly stressed. A more rigid insulating material will provide better support for the metal cover.

Failure of the pads and details of the repair schemes tried are given in Appendix C.

6.5 Instrumentation and Control Equipment

6.5.1 Airborne

Little instrumentation other than the standard flight instruments was used. The automatic observer which photographed a duplicate set of relevant flight instruments and the O. A. T. gauge was the main installation. The camera was controlled by a unit which allowed time intervals of 1, 2, 3 and 6 seconds to be selected. The auto observer worked satisfactorily in temperatures down to -20°C when the film transport mechanism stopped operating because no cabin heating was provided.

Additional instruments which would have provided records to improve analysis of the icing problem are:

- (1) Pitch-angle indicator
- (2) Torque measuring equipment for main and tail rotors
- (3) Vibration recording equipment
- (4) De-icer pad surface temperature gauges.

Operation of the snatch plug arrangement was never necessary during the tests, but it did work satisfactorily during a trial run. Provision should be made for a release mechanism controlled by the pilot rather than use the drag of the cable to disconnect in event of an emergency.

After the incident of the short circuit which developed in one heater mat during a flight (described in Appendix C), it was decided to provide a contactor in the power cable and give the flight observer over-riding control of the power to the heater mats. This would increase safety and possibly minimize damage, as with the power control on the ground and the poor radio communication which existed for the majority of the test, considerable time elapsed before preventive action could be taken from the ground.

6.5.2 Ground

The instrumentation at the test site for recording windspeed, temperature, and humidity operated satisfactorily throughout the winter.

The mould technique was used for profile ice measurement at four stations along the blade. These records, samples of which are shown in Figure 33, are particularly useful in analysing the problems of rotor blade icing.

The time range of the electronic timer was limited to 6 seconds maximum and should be extended. During the test, times in excess of 6 seconds had to be controlled manually with the aid of a stop-watch.

7.0 CONCLUSIONS

7.1 The de-icing performance of the system was satisfactory. A good average optimum power density is shown to be 25 watts/sq. in. , which requires a power-on time of 13 seconds at -25°C (Fig. 18).

7.2 Shedding times vary inversely as ambient temperature at all power densities tested (Fig. 18).

7.3 Run-back reduced as power densities increased. It was always present to some extent at 15 watts/sq. in. It occurred over the inner third of the blade only, over both the upper and lower surfaces in parallel streaks 1 to $1\frac{1}{2}$ inches long.

7.4 If present after the first de-icing cycle, run-back disappeared after subsequent cycles and gave no reason for concern.

7.5 The installed de-icer pad was wider than necessary, and impingement tests showed that zones 6 and 8 can be deleted. Zones 4 and 7 can also be deleted over the outer third of the blade. Spanwise shedding gave good results and a smooth shedding. The numerical heating sequence specified (see Fig. 9) gave slightly better performance with less run-back than other sequences tried.

7.6 Performance and handling of the aircraft under icing conditions were good. A progressive increase of engine power is required to overcome the increased blade drag.

7.7 A 4-minute accretion time was found satisfactory and gave effective shedding over the whole range of ambient temperatures and liquid water contents without undue aerodynamic deterioration.

7.8 The de-icing and control systems worked satisfactorily with the external power supply.

7.9 The thermodynamic performance of the pads was good, but its mechanical behaviour on the flexing blades rather poor. The stainless steel outer cover developed creases and finally cracks. Under some of these cracks, failures developed in the heater strips. Ice thrown off the tail rotor into the path of the main rotor created impact dents in the steel cover, and it is recommended that a more rigid insulating material be used to provide adequate support for the metal cover.

7.10 Simulated failures conducted at higher temperatures only, gave no trouble. However, asymmetrical shedding may produce excessive vibrations at lower temperatures, and a protective device is desirable.

7.11 Self-shedding does occur both on the standard and on protected blades. The ice sheds more readily from the standard blades which are more flexible. It occurs usually symmetrically but it is possible to occur asymmetrically to an extent which is unacceptable for flight. Self-shedding can only be accepted as protection against icing down to about -3°C .

7.12 Icing protection is considered essential for the tail rotor. It should either be anti-iced or, if de-iced, be cycled more frequently than the main rotor.

7.13 Some protection might be required for the rotor head mechanism and this can take the form of covers, baffles, etc.

7.14 No noticeable effect resulted from icing on the tail cone, although at higher forward speeds changes in weight and centre of gravity may require consideration.

7.15 Power densities of up to 2 watts/sq. in. were adequate for electrical windscreen anti-icing under the test conditions. The heated area should be increased and located horizontally so that it acts as a flight reference.

The alcohol spray system gave adequate protection providing it was turned on as soon as ice commenced to form. Better spray distribution is desirable.

7.16 The electro-thermal de-icing method has proved, in principle, to be a satisfactory, attractive, and safe method against icing, but further technological development work is necessary on the de-icer pads to improve serviceability.

8.0 REFERENCES

1. Stephenson, L. R. Test Schedule for Bristol Type 171 Helicopter No. WT. 933 at the N. A. E. Icing Rig, Ottawa, Canada.
Bristol Aircraft Limited, AIR-ICE/HELI/LRS/28, 6 October 1956.
2. Bailey, D. L. Description of the Spray Rig Used to Study Icing on Helicopters in Flight.
NAE Laboratory Report LR-186, January 1957.
3. Stallabrass, J. R. Icing Flight Trials of a Bell HTL-4 Helicopter.
NAE Laboratory Report LR-197, July 1957.

/LES

TABLE I
ICING FLIGHTS

Main Rotor r.p.m.: 265

Hovering Height: 50 ft.

Liquid Water Content mm./m.3	Ambient Air Temperature Range °C					
	0° - 5°	-5° - 10°	-10° - 15°	-15° - 20°	-20° - 25°	-25° - 30°
0.3	I-1 I-2	II-1 II-2s II-3s II-4s II-5s II-6	III-1	IV-1		
0.7	I-3	II-7 II-8 II-9 II-10 II-11s II-12 II-13s	III-2 III-3 III-4 III-5 III-6	IV-2	V-1 V-2 V-3 V-4	VI-1s VI-2s
1.5	I-4	II-14s II-15s II-16 II-17 II-18s II-19 II-20	III-7 III-8s III-9s III-10s III-11 III-12 III-13 III-14 III-15 III-16	IV-3	V-5	VI-3s VI-4s VI-5s
	Details Table IIa		Details Table IIb		Details Table IIc	

m. Denotes flights with standard blades.

TOTAL FLIGHTS - 53

TABLE II a-c
ICING FLIGHTS RESULTS

Ambient Temperature: (0°C to -10°C)

Icing Flight	Ambient Temp.	True Air Speed (average)	L.W.C.		Droplet Size (MVDS)	Time in Icing Cloud		Max. Ice Accretion	Blade Station of Max. Accretion	Spanwise Extent			Self Shedding up to Blade Station	Chordwise Extent of Max. Accretion		Maximum Tail Rotor Accretion	Spanwise Icing Extent on Tail Rotor	Engine Manifold Pressure Variation			Collective Pitch Angle Indicator (Average)	Aircraft Weight
			Estimated (Rig setting)	Calculated		Uncorrected	Corrected			On Top	Stagnation Line	Bottom		Upper Surface	Lower Surface			No Ice	With Ice	After Shed.		
I-1	-3.3	18	0.3	> 0.3	20	4	4	3/64	90	215	165	180*	1/8 in. accretion up to Sta. 90	1	1 1/4	3/32	Sta. 34	34	36.5		6.5	4950
I-2	-3.3	16	0.3	> 0.3	20	4	4	1/16	80	230	170	190	1/16 in. accretion up to Sta. 60	1	1 1/4	1/16	Sta. 35	33.5	36.5		6.0	4900
I-3	-2.0	10	0.7	~ 0.7	20	10	2 x 4	3/64	70	160	135	145*		1	1 1/2	1/32	Sta. 20	35	37		7.0	4850
I-4	-2.0	10	1.5	~ 1.5	20	15	3 x 4	1/16	70	155	142	146*		1	1 1/2	1/32	Sta. 20	35	37	35	7.0	4850
II-1	-7.5	25	0.3		20	2	2	1/16	128	240	235	238	230	1 1/8	1 1/4	3/32	Sta. 45	32.5	34		5.5	4800
II-2e	-8.0	7	0.3	0.3	20	5	4	1/8	130	248	242	244		7/8	1 1/2	3/16	Sta. 50	35	37		8.5	4900
II-3e	-8.0	5	0.3		20	5	4	1/8	125	247	244	246*	2	2	3/16	Sta. 50	34.5	37		8.5	4850	
II-4e	-8.0	6	0.3		20	10	2 x 4	3/16	130	247	243	245*	1	1 3/4	3/8	Sta. 52	34.5	37		8.0	4800	
II-5e	-9.5	4	0.3	0.3	20	15	15	1/2	155	265	260	263*	7/8	7/8	1/2	Sta. 55	36	39	37	9.0	4900	
II-6	-10.0	15	0.3	0.3	20	5	4	5/32	165	268	262	264*	230	1	1/4	full span	34	35.5		5.5	4700	
II-7	-7.0	16	0.7		20	2	2	3/64	140	248	245	245	7/8	1 7/8	3/32	Sta. 50	33.5	36		6.0	4900	
II-8	-7.0	18	0.7		20	2	2	3/64	140	248	245	245	7/8	2	3/32	Sta. 50	32	34		5.5	4850	
II-9	-7.5	21	0.7	0.7	20	5	4	1/8	140	265	255	258	1	1 7/8	3/16	Sta. 55	32.5	35		5.5	4800	
II-10	-7.5	18	0.7	0.7	20	5	4	1/8	155	260	253	256	1 1/8	2	1/8	Sta. 60	32	34		5.5	4800	
II-11e	-8.0	9	0.7		20	5	4	5/32	145	262	250	260*	215	7/8	2 1/4	3/16	Sta. 55	34	36		7.5	4850
II-12	-8.0	3	0.7		20	3	2	1/16	140	258	252	256	7/8	2 1/8	3/32	Sta. 55	36.5	38		9.5	4950	
II-12e	-8.0	3	0.7		20	30	30	7/8	160	290	285	287*	115	7/8	2	1	full span				9.0	4900
II-13e	-9.0	3	0.7	0.7	20	30	30	7/8	160	290	285	287*	115	7/8	2	3/16	Sta. 55	35	37		8.0	4900
II-14e	-6.5	10	1.5	1.5	20	5	4	3/16	110	252	240	245*	180	1	2	3/32	Sta. 55	35	37		8.0	4875
II-15e	-7.0	8	1.5		20	10	8	5/16	115	258	250	254*	115	1	2	3/32	Sta. 55	35	37		6.0	4950
II-16	-7.0	23	1.5		20	3	2	1/32	120	245	240	240	1	1 7/8	3/64	full span	33	36.5		5.0	4800	
II-17	-7.0	25	1.5		20	5	4	1/16	125	245	240	245	1 1/8	2	3/32	full span	33	36.5		8.5	4900	
II-18a	-8.5	3	1.5		20	25	25	3/4	130	258	250	254*	140	1	1 7/8	1	full span	37	42	39	7.0	4950
II-19	-10.0	12	1.5	< 1.5	20	4	4	3/16	130	273	262	268	1	1 7/8	5/16	full span	36	38		8.5	4950	
II-20	-10.0	7	1.5	< 1.5	20	5	4	1/4	130	275	265	270	1	2	5/16	full span	36	38		8.5	4950	

Ambient Temperature: (-10°C to -20°C)

III-1	-11.0	12	0.3	~ 0.3	20	5	4	1/8	160	268	268	266		7/8	1 1/2	3/16	full span	32	34.5		6.0	4750
III-2	-10.1	10	0.7		20	4	4	3/16	150	273	270	271		1	1 3/4	1/4	self shed to Sta. 35	35	37		7.5	4900
III-3	-11.0	10	0.7	~ 0.7	20	5	4	3/16	160	274	275	275*	260	1	1 1/2	1/4	self shed to Sta. 40	36.5	38.5		7.5	4950
III-4	-11.5	10	0.7		20	10	10	5/16	160	280	278	278*	250	1	1 1/4	7/16	self shed to Sta. 30	36	43	38.5	7.0	4900
III-5	-13.0	9	0.7		20	2	2	1/8	180	287	286	288		1	1 3/4	3/16	full span	36.5	38		8.0	4950
III-6	-13.0	10	0.7	~ 0.7	20	5	4	1/4	176	290	290	290		1	2	5/16	self shed to Sta. 40	34	36.5		6.5	4800
III-7	-10.5	10	1.5		20	10	10	5/16	170	275	270	270*	240	1	2	7/16	self shed to Sta. 20	37	39		7.5	4950
III-8e	-11.0	5	1.5	~ 1.5	20	10	10	5/16	165	278	275	272*	230	3/4	1 1/2		self shed to Sta. 25	37	39	37.5	9.0	4950
III-9e	-11.0		1.5	~ 1.5	20	20	20	3/8	170	279	275	275*	230	3/4	1 3/4		self shed to Sta. 15	37	39	37.5	8.5	4900
III-10e	-11.0	7	1.5	~ 1.5	20	30	30	7/16	170	280	275	275*	220 (shed to 100 on the ground)	3/4	1 7/8		self shed to Sta. 10	36	39	37	7.5	4800
III-11	-11.1	7	1.5		20	10	10	5/16	170	280	277	277*	238	1	2	3/8	self shed to Sta. 30	35	38		8.5	4950
III-12	-12.0	15	1.5		20	10	10	1/4	170	285	285	285*	260	7/8	1 7/8	1/4	self shed to Sta. 40	35	37		6.5	4950
III-13	-12.5	15	1.5	< 1.5	20	5	4	1/4	180	290	290	290*	265	3/4	1 1/2	1/4	full span	34.5	37		6.5	4950
III-14	-13.0	2	1.5		20	3	2	1/8	185	full span	full span	full span		1	2	1/4	self shed to Sta. 45	36	38		9.0	4950
III-15	-13.0	7	1.5	< 1.5	20	4	4	5/16	195	full span	full span	full span		1	2	3/8	self shed to Sta. 35	36	38.5		8.0	4900
III-16	-14.0	15	1.5		20	5	4	3/8	210	full span	full span	full span*	260	1	1 7/8	7/16	self shed to Sta. 30	34	36.5		6.0	4900
IV-1	-15.0	20	0.3	< 0.3	20	5	4	3/16	170	full span	full span	full span		3/4	1 7/8	5/16	full span	34.5	37		6.0	4950
IV-2	-17.0	10	0.7	< 0.7	20	5	4	1/4	205	full span	full span	full span		1	2	7/16	self shed to Sta. 35	34.5	37.5		6.5	4800
IV-3	-16.0	12	1.5	< 1.5	20	5	4	3/8	210	full span	full span	full span		1	2	7/16	self shed to Sta. 35	33.5	36.5		6.5	4850

Ambient Temperature: (-20°C to -30°C)

V-1	-25.0	15	0.7	< 0.7	20	3	2	1/8	230	full span	full span	full span		3/4	1 1/2	1/4	full span	34.5	36.5		6.5	4950
V-2	-25.0	15	0.7	< 0.7	20	5	4	1/4	240	full span	full span	full span		7/8	1 1/2	3/8	full span	33	36.5		6.5	4900
V-3	-25.0	15	0.7		20	3	2	1/8	230	full span	full span	full span		1	1 3/4	3/8	full span	33.5	35.5		6.0	4850
V-4	-25.0	14	0.7		20	3	2	1/8	235	full span	full span	full span		1	1 1/2	1/4	full span	32.5	35		6.0	4800
V-5	-23.0	3	1.5	< 1.5	20	5	4	9/16	205	full span	full span	full span		1	2 1/4	1/2	full span	35	38.5		9.0	4850
VI-1e	-26.2	9	0.7	0.7	20	10	10	7/8	230	full span	full span	full span		1	2	1	self shed to Sta. 30	34.5	38.5		6.5	4750
VI-2e	-26.0	9	0.7	< 0.7	20	5	4	1/2	220	full span	full span	full span		1	2 1/4	11/16	full span	34	37.5		6.0	4700
VI-3e	-26.5	10	1.5		20	5	4	11/16	175	full span	full span	full span		1	3	1 1/8	self shed to Sta. 30	35	38.5		7.5	4900
VI-4e	-26.5	9	1.5	< 1.5	20	5	4	5/8	170	full span	full span	full span		1	3 1/4	1	self shed to Sta. 30	34.5	38.5		7.0	4800
VI-5e	-25.5	10	1.5		20	10	8	1	170	full span	full span	full span		1	3 1/2	1 1/2	self shed to Sta. 20	37.5	41		9.5	5400

* Ice started to reform to this point after self shedding main accretion.

TABLE III

DE-ICING FLIGHTS

Main Rotor r.p.m.: 265

Hovering Height: 50 ft.

Liquid Water Content gm./m. 5	Power Density w/sq. in.	Ambient Air Temperature Range °C					
		0° - 5°	-5° - 10°	-10° - 15°	-15° - 20°	-20° - 25°	-25° - 30°
0.3	15	D-I-1	D-II-1	D-III-1,2	D-IV-1		
0.3	20	D-I-2	D-II-2,3	D-III-3			
0.3	25	D-I-3,4	D-II-4,5	D-III-4,5,6			
0.3	30			D-III-7			
0.7	15	D-I-5	D-II-6		D-IV-2,3,4		
0.7	20	D-I-6,7,8	D-II-7,8,9,10	D-III-8,9,10,11, 12,13,14	D-IV-5,6,7,8,9		
0.7	25	D-I-9	D-II-11,12,13	D-III-15,16,17, 18,19	D-IV-10	D-V-1,2,3	
0.7	30					D-V-4,5	
1.5	15		D-II-14,15		D-IV-11		
1.5	20	D-I-10,11,12, 13	D-II-16*,17,18, 19,20,21*	D-III-20,21,22, 23,24,25, 26	D-IV-12	D-V-6,7	
1.5	25	D-I-14	D-II-22	D-III-27,28*,29, 30,31,32, 33,34,35	D-IV-13		
1.5	30		D-II-23		D-IV-14		
		Details Table IVa		Details Table IVb		Details Table IVc	

Table III
R-221

* De-icing inside the cloud.

TOTAL FLIGHTS - 93

TABLE IVa
DE-ICING FLIGHT RESULTS

Ambient Temperature: (0°C to -10°C)

De-Icing Flight	Ambient Air Temp.	True Airspeed (average)	Liquid Water Content	Accretion Time	Maximum Ice Accretion	Spanwise Extent (Blade Station)			Specific Power Density	Power On Time	Specific Shedding Energy	Zone Heating Sequence (see Fig. 10)	Runback in Streaks Over Inner 1/3 Blade	Engine Manifold Pressure Variation			Collective Pitch Angle Indicator	Aircraft Weight	Results of De-Icing Cycle(s) and Remarks
						On Top	Stagnation Line	Bottom						No Ice	With Ice	After Shed.			
No.	°C	m.p.h.	gm./m. ³	min.	in.	in.	in.	in.	w/sq.in.	sec.	Joules/sq.in.			in. Hg			deg.	lb.	
D-I-1	- 3.3	18	0.3	4	1/16	230	168	180	15	3	45	1,2,3,4,5	Little	34.0	36.5		6.5	4950	Clean shedding, de-icing after Flight I-2.
D-I-2	- 3.3	17	0.3	4	1/16	235	165	180	20	1	20	1,2,3,4,5	Little	33	36	33.5	6.0	4900	Shedding marginal. Estimated 1.5 sec. required for clean shedding.
D-I-3	- 3.3	22	0.3	2	1/32				25	1	25	1,2,3,4,5	Very slight	33	34.5	33	5.5	4900	Partial shedding, thickness inadequate. Estimated 1.2 sec. required for clean shedding.
D-I-4	- 3.3	20	0.3	4	1/16	235	160	180	25	1	25	1,2,3,4,5	Very little	33	34.5	33	5.5	4850	Shedding marginal. Estimated 1.2 sec. required. Vibration.
D-I-5	- 3.3	17	0.7	4	5/64	235	168	190	15	3	45	1,2,3,4,5	Little	33.5	36	34	6.0	4950	Clean shedding.
D-I-6	- 5	17	0.7	4 x 4	3/32	225	190	198	20	3	60	1,2,3,4,5	Slight	34	36	34	6.0	4950	Asymmetric shedding. Clean shedding on two blades. 4 cycles.
D-I-7	- 5	16	0.7	5 x 4	3/32				20	3	60	1,2,3,4,5	Slight	34	36	34	6.0	4900	Clean shedding. 5 cycles outside cloud.
D-I-8	- 5	12	0.7	4	1/16				20	3	60	1,2,3,4,5	Slight on lower surface	32	34	32	6.5	4850	Clean shedding.
D-I-9	- 3.0	15	0.7	4	1/16	275	168	190	25	1	25	1,2,3,4,5	No runback	33	36	33.5	6.0	4800	Clean shedding.
D-I-10	- 3.0	16	1.5	4	3/16	230	173	190	20	6	120	1,2,3,4,5	Slight	34	36.5	34	6.0	4900	Longer "Power on Time" check for runback.
D-I-11	- 3.1	11	1.5	2 x 4	3/32				20	6	120	1,2,3,4,5	Slight	35	37.5	35.5	7.5	4950	Longer "Power on Time" check for runback.
D-I-12	- 3.2	15	1.5	4	1/8	240	178	195	20	2	40	1,2,3,4,5	Slight	33	35.5	33	6.0	4850	Clean shedding of smaller accretion.
D-I-13	- 5	11	1.5	2 x 4	3/32	250	230	240	20	3	60	1,2,3,4,5	Slight	34	36.5	34	6.5	4800	Clean shedding.
D-I-14	- 3.3	17	1.5	4	1/16	218	178	195	25	1	25	1,2,3,4,5	No runback	33	35.5	33	6.0	4900	Marginal shedding. Estimated 1.2 sec. required for clean shedding.
D-II-1	- 6.5	15	0.3	4	3/32	235	200	215	15	6	90	1,2,3,4,5	Moderate	34	37	34	6.0	4800	Shedding marginal. Estimated 6 1/2 sec. required for clean shedding.
D-II-2	- 7.5	19	0.3	2	1/32	245	230	238	20	4	80	4,2,1,3,5,7,8	Moderate	32	34	32	5.5	4800	Patchy ice left. No shedding, larger accretion required for shedding.
D-II-3	- 7.5	20	0.3	5 x 2	1/32	248	235	240	20	4	80	4,2,1,3,5,7,8	Slight	32	34	32	5.0	4700	5 de-icing cycles. Ice shed up to 100 in.
D-II-4	- 6.0	15	0.3	4	1/8	240	230	235	25	2	50	1,2,3,4,5	Slight				6.0	4800	Marginal. Estimated 2 1/2 sec. required for clean shedding.
D-II-5	-10.0	15	0.3	4	1/8	270	262	263	25	6	150	1,2,3,4,5	Slight	34.0	35.5	34.0	5.5	4700	Clean shedding; too much input energy. Estimated 5 sec. required for clean shedding.
D-II-6	- 7.5	12	0.7	4	1/8	258	250	253	15	8	120	1,2,3,4,5	Moderate	35	37	35	6.5	4850	Clean shedding.
D-II-7	- 6	12	0.7	4 x 2	3/64				20	4	80	2,1,3,5,7,8	Slight over zone 4	35	36.5	35	7.0	4900	Opaque ice on windshield. 4 cycles in cloud. Zone 4 should be included in de-icing cycle due to runback.
D-II-8	- 7	18	0.7	2	3/64	248	243	242	20	3	60	4,2,1,3,5,7,8	Slight	35	36.5	35	6.0	4950	Inadequate shedding, patchy ice left, de-icing after Flight II-7.
D-II-9	- 7	20	0.7	2	3/64	248	245	245	20	4	80	4,2,1,3,5,7,8	Slight	31.5	34	32	5.5	4900	Clean shedding (marginal) de-icing after Flight II-8.
D-II-10	- 7.5	22	0.7	4	1/8	250	248	249	20	4	80	4,2,1,3,5,7,8	Slight	32	34	32	5.0	4750	Shedding up to 80 in. De-icing flight after Flight II-10.
D-II-11	- 7.5	23	0.7	4	1/8	255	255	258	25	3	75	4,2,1,3,5,7,8	Very slight	32	35	33	5.0	4800	Shedding up to 85 in., de-icing after Flight II-9.
D-II-12	- 7.5	19	0.7	4	1/8				25	4	100	4,2,1,3,5,7,8	Very slight	32	34	32	5.0	4750	Clean shedding, too much energy, 3 1/2 sec. is adequate.
D-II-13	- 8.8	17	0.7	5 x 4	3/16	273	260	265	25	5	125	1,3,4,5	No runback	35.0	37	35	6.0	4900	Zone 2 out. Marginal shedding (thin accretion).
D-II-14	-10	12	1.5	4	3/16	273	262	268	15	10	150	1,2,3,4,5	Moderate	35	37	35	7.0	4950	Incomplete shedding. Estimated 11 sec. required for complete shedding. De-icing after Flight II-19.
D-II-15	-10	17	1.5	4	1/4	275	268	270	15	11	165	1,2,3,4,5	Moderate	32	34	32	5.5	4750	Clean shedding.
D-II-16	- 6.5	20	1.5	5 x 4	3/16				20	4	80	4,2,1,3,5,7,8	No runback	33	35.5	33	6.0	4950	5 cycles in cloud to check build up of runback. Clean shedding after flight.
D-II-17	- 7	23	1.5	4	3/16	245	240	244	20	3	60	4,2,1,3,5,7,8	Very slight	32	35	33.5	5.0	4800	Incomplete shedding. Sheds up to 110 in. De-icing after Flight II-17.
D-II-18	- 7	18	1.5	4	3/16	260	252	255	20	4	80	4,2,1,3,5,7,8	Slight	32	34.5	32	6.0	4850	Clean shedding (marginal).
D-II-19	- 7	20	1.5	5 x 4	3/16				20	4	80	4,2,1,3,5,7,8	No runback	32	34	32	5.5	4800	5 de-icing cycles outside cloud. Shed up to 60 in.
D-II-20	- 7.5	25	1.5	2	3/64	265	260	262	20	5	100	4,2,1,3,5,7,8	No runback	34	36	34	5.5	4950	Clean shedding. De-icing after Flight II-16.
D-II-21	- 9	18	1.5	8 x 2	1/8				20	4	80	1,2,3,4,5,7,8	No runback	33.5	35	33.5	6.0	4900	8 cycles in cloud to check build up of runback system. Clean shedding after flight. No traceable runback.
D-II-22	- 5.5	16	1.5	4	1/8	240	215	220	25	2	50	1,2,3,4,5	Very slight	34	37	35	6.0	4900	Marginal. Estimated 2 1/2 sec. required for clean shedding.
D-II-23	- 5.2	17	1.5	4	1/8	230	220	225	30	1	30	1,2,3,4,5	No runback	33	36	33.5	6.0	4850	Shedding up to 90 in. Estimated 1 1/2 sec. required for clean shedding.

TABLE IVb
DE-ICING FLIGHT RESULTS

Ambient Temperature: (-10°C to -20°C)

De-Icing Flight	Ambient Air Temp.	True Airspeed (average)	Liquid Water Content	Accretion Time	Maximum Ice Accretion	Spanwise Extent (Blade Station)			Specific Power Density	Power On Time	Specific Shedding Energy	Zone Heating Sequence (see Fig. 10)	Runback in Streaks over Inner 1/3 Blade	Engine Manifold Pressure Variation			Collective Pitch Angle Indicator	Aircraft Weight	Results of De-Icing Cycle(s) and Remarks
						On Top	Stagnation Line	Bottom						No Ice	With Ice	After Shed.			
No.	°C	m.p.h.	gm./m. ³	min.	in.	in.	in.	in.	w/sq.in.	sec.	joules/sq.in.			in. Hg			deg.	lb.	
D-III-1	-10.2	12	0.3	4	1/8	265	258	260	15	11	165	1,2,3,4,5	Moderate	35	37	35	6.5	4900	Marginal shedding.
D-III-2	-10.2	14	0.3	4	1/8	265	256	260	15	12	180	1,2,3,4,5	Moderate	35	36.5	35	6.5	4900	Clean shedding (too much energy input).
D-III-3	-11.0	15	0.3	4	3/16	280	270	270	20	8	160	1,2,3,4,5	Slight	34	35.5	33.5	6.0	4850	Clean shedding (too much energy, 7.5 sec. is adequate).
D-III-4	-11.0	12	0.3	2	1/16	275	268	270	25	5	125	1,2,3,4,5	Very slight	36	38	36	6.5	4900	Marginal shedding (5 1/2 sec. required for full and adequate shedding).
D-III-5	-15.0	18	0.3	4	1/4		full span		25	5	125	1,2,3,4,5	Slight	34	35.5	35	6.0	4850	Ice sheds up to 135 in.
D-III-6	-15.0	15	0.3	4	3/8		full span		25	6	150	1,2,3,4,5	Very slight				6.5	4900	Marginal shedding of large accretion.
D-III-7	-10.1	16	0.3	4	1/8	263	260	261	30	4	120	1,2,3,4,5		34	35.5	34.5	5.5	4800	Clean shedding.
D-III-8	-12.0	12	0.7	4	3/16	281	280	280	20	4	80	1,2,3,4,5	Slight	36	38	36.5	7	4900	Shed up to 150 in.
D-III-9	-12.0	11	0.7	2	3/16	287	288	288	20	6	120	1,2,3,4,5	Slight	35	37	35.5	7.0	4850	Shed up to 125 in., de-icing Flight III-5.
D-III-10	-12.0	3	0.7	2	1/16				20	6	120	1,2,3,4,5	Slight	36	38	36.5	8.5	4900	Shed up to 180 in.
D-III-11	-12.5	3	0.7	4	5/16				20	5	100	1,2,3,4,5		36.5	38.5	37	8.5	4900	Shed up to 150 in.
D-III-12	-12.5	3	0.7	4	3/16	286	285	285	20	6	120	1,2,3,4,5	Slight on top not on bottom	35.5	37.5	36	8.5	4850	Shed up to 130 in.
D-III-13	-12.5	3	0.7	2	1/16				20	4	80	1,2,3,4,5	Slight	36	38	37	9.0	4950	Shedding up to 80 in.
D-III-14	-12.5	3	0.7	4	3/16	276	275	275	20	8	160	1,2,3,4,5	Moderate	36	38	36	9.0	4900	Clean shedding.
D-III-15	-10.0	14	0.7	2	3/32	274	270	272	25	2	50	1,2,3,4,5	Very slight	34	36	34			Shedding up to 160 and 165 in.
D-III-16	-10.0	13	0.7	4	3/16	272	270	271	25	3	75	1,2,3,4,5	Very slight	35	37	35	6.5	4900	No shedding (de-icing system failure) cyclic switch U/S.
D-III-17	-10.0	15	0.7	4	3/16	273	270	271	25	5	125	1,2,3,4,5	Very slight	34	36	34	6.0	4900	Clean shedding.
D-III-18	-13.0	12	0.7	3 x 4	3/16	290	290	290	25	4	100	1,2,3,4,5	Slight	35	37	35	6.5	4900	Clean shedding. 3 cycles in cloud.
D-III-19	-13.5	14	0.7	4	3/16		full span		25	6	150	1,2,3,4,5	Very slight	34	36	34	6.0	4850	Marginal shedding (6 1/2 sec. required for full and clean shedding).
D-III-20	-10.0	7	1.5	4	3/16	270	265	269	20	4	80	1,2,3,4,5	Moderate	36.5	38.5	37	8.0	4900	Shedding up to 130 in.
D-III-21	-10.0	6	1.5	4	7/32				20	5	100	1,2,3,4,5	Moderate	36	38	36.5	8.5	4900	Shedding up to 120 in.
D-III-22	-10.0	7	1.5	4	7/32	270	269	269	20	6	120	1,2,3,4,5	Slight on top	36	38	36	8.0	4900	Marginal shedding (6 1/2 sec. required for clean shedding).
D-III-23	-10.0	8	1.5	4	3/16				20	6	120	1,2,3,4,5	Moderate	35.5	37	36	7.5	4850	Shed up to 85 in.
D-III-24	-10.0	9	1.5	4	3/16	270	270	269	20	7	140	1,2,3,4,5	Moderate	35.5	37	35.5	7.0	4850	Clean shedding (slightly too much energy).
D-III-25	-10.5	8	1.5	4	1/4				20	7	140	1,2,3,4,5	Moderate	36	38	36.5	8.5	4950	Ice left until 70 in.
D-III-26	-10.5	8	1.5	4	1/4	272	271	272	20	8	160	1,2,3,4,5	Moderate	36	38	36	8.0	4900	Clean shedding (too much energy).
D-III-27	-12.2	5	1.5	4	1/4				25	6	150	1,2,3,4,5	Slight		30		9.0	4950	Clean shedding on the ground (r.p.m. 180). Functional test.
D-III-28	-12.2	12	1.5	5 x 2	1/8	281	270	282	25	4	100	1,2,3,4,5	Slight	35	37	35.5	6.5	4900	5 cycles in cloud. Clean shedding after flight.
D-III-29	-12.3	13	1.5	4	1/4				25	3	75	1,2,3,4,5	Slight	35	37	36	7.0	4950	Shedding up to 160 in.
D-III-30	-12.3	18	1.5	4	1/4				25	4	100	1,2,3,4,5	Slight	34	36	35	6.0	4900	Shed up to 130 in.
D-III-31	-12.3	15	1.5	4	1/4	286	285	287	25	4	100	1,2,3,4,5	Very slight	34	36	35	6.0	4850	Zone 1 shed to 170 - 180 in.
D-III-32	-12.3	16	1.5	4	1/4				25	4	100	1,2,3,4,5		33	35	33	6.0	4850	Zone 2 - Little shedding on this zone, shedding down to 150 in.
D-III-33	-12.5	17	1.5	4	5/16	286	285	285	25	4	100	1,2,3,4,5	Slight	33	35	34	5.5	4800	Zone 3 - Shedding until 125 in.
D-III-34	-13.0	16	1.5	4	1/4				25	6	150	1,2,3,4,5	Very slight	34	36	34.5	6.0	4800	Zone 4 - Shed up to 100 in.
D-III-35	-13.5	16	1.5	4	5/16		full span		25	7	175	1,2,3,4,5	Slight	33	35.5	33	6.0	4850	Clean shedding (slightly too much energy).
D-IV-1	-15.0	15	0.3	4	3/16		full span		20	6	120	1,2,3,4,5	Moderate	34	37	37	6.5	4900	No shedding - de-icing system failure, cyclic switch.
D-IV-2	-15.0	8	0.7	4	1/4		full span		15	15	225	1,2,3,4,5	Moderate	36	38	36	8.5	4950	Clean shedding. Marginal (Estimated 16 sec. needed).
D-IV-3	-16.0	8	0.7	2	1/16		full span		15	25	375	1,2,3,4,5	Moderate	36	38	37	8.0	4900	Shedding up to 120 in. Ice melting. Check on long power on time.
D-IV-4	-17.0	9	0.7	2	1/16		full span		15	20	300	1,2,3,4,5	Moderate	36	38	36	7.5	4900	Shedding up to 180 in. Ice melting. Check on long power on time.
D-IV-5	-17.0	9	0.7	4	5/16		full span		20	10	200	1,2,3,4,5	Moderate	34	37	35	6.5	4800	Shed until 120, 125 in. Icing flight of Flight IV-2.
D-IV-6	-17.0	8	0.7	4	1/4		full span		20	12	240	1,2,3,4,5	Moderate	36	39	36	8.0	4950	Clean shedding (too much energy, estimated 11.5 sec. needed).
D-IV-7	-17.0	8	0.7	4	1/4		full span		20	14	280	1,2,3,4,5	Moderate	34.5	37		8.0	4900	No power for de-icing.
D-IV-8	-17.0	9	0.7	4	1/4		full span		20	15	300	1,2,3,4,5	Moderate	35	38	35	7.5	4900	Clean shedding. Check of runback with excessive power.
D-IV-9	-17.0	7	0.7	4	5/16		full span		20	11	220	1,2,3,4,5	Moderate	36	39	37	7.0	4850	Shedding up to 80 in.
D-IV-10	-15.0	7	0.7	4	1/4		full span		25	7	175	1,2,3,4,5	Very slight	35.5	38.5	35.5	8.0	4900	Clean shedding, marginal (estimated 7.5 sec. needed).
D-IV-11	-16.0	12	1.5	4	3/8		full span		15	16	240	1,2,3,4,5	Moderate	34	36	33.5	6.5	4850	Marginal shedding (estimated 16.5 sec. needed for adequate and clean shedding).
D-IV-12	-16.0	13	1.5	4	5/16		full span		20	11	220	1,2,3,4,5	Moderate	36	38.5	36	6.5	4900	Clean shedding.
D-IV-13	-16.0	7	1.5	4	5/16		full span		25	8	200	1,2,3,4,5	Very slight	37.5	40	36.5	8.5	4950	Clean shedding (marginal).
D-IV-14	-16.0	8	1.5	4	5/16		full span		30	7	210	1,2,3,4,5	None	36	39	35.5	7.5	4900	Clean shedding.

TABLE IVc
DE-ICING FLIGHT RESULTS
Ambient Temperature: (-20°C to -30°C)

De-icing Flight No.	Ambient Air Temp. °C	True Airspeed (average) m.p.h.	Liquid Water Content gm./m. ³	Accretion Time min.	Maximum Ice Accretion in.	Spanwise Extent (Blade Station) in.	Specific Power Density w/sq.in.	Power On Time sec.	Specific Shedding Energy joules/sq.in.	Zone Heating Sequence (see Fig. 10)	Runback in Streaks Over Inner 1/3 Blade	Engine Manifold Pressure Variation		Collective Pitch Angle Indicator deg.	Aircraft Weight lb.	Results of De-icing Cycle(s) and Remarks
												No. With Ice	After Shed.			
D-V-1	-25	18	0.7	4	1/4	full span	25	8	200	1,2,3,4,5	Slight	36	39	37	4900	Shedding up to 210, 215 in. De-icing after Flight V-2.
D-V-2	-25	15	0.7	4	5/16	full span	25	7	175	1,2,3,4,5	Slight	35.5	38	37.5	4850	Shedding up to 240 in.
D-V-3	-25	17	0.7	4	5/16	full span	25	10	250	1,2,3,4,5	Slight	36	39.5	37	4800	Shedding up to 150 in. Electrical failure of de-icer pad.
D-V-4	-25	15	0.7	4	5/16	full span	30	6	180	1,2,3,4,5	Slight	36	35	37	4950	Shedding up to 185 in.
D-V-5	-25	15	0.7	4	1/4	full span	30	11	330	1,2,3,4,5	Very slight	33.5	39.5	34	4900	Clean shedding.
D-V-6	-23	4	1.5	2	5/16	full span	20	10	200	1,2,3,4,5	Rather moderate	37	39.5	38	4950	Shedding to 200 in. - Zone 1.
D-V-7	-23	4	1.5	4	5/8	full span	20	10	200	1,2,3,4,5	More than moderate	35	36	36	4800	Shedding to 200 in. - Zones 2 and 3. De-icing after Flight V-5.

TABLE V
FLIGHTS IN SIMULATED FREEZING RAIN

Flight No.	Ambient Air Temp. °C	True Airspeed (average) m.p.h.	Droplet Size microns	Time in Freezing Rain min.	Ice Accretion Maximum in.	Ice Extent			Tail Rotor Icing in.	Specific Power Density w/sq.in.	Power On Time sec.	Power Variation in. Hg	Collective Pitch Angle Indicator deg.	Aircraft Weight lb.	Remarks
						Spanwise in.	Maximum Chordwise in.	Upper Lower in.							
VII-1	-13.0	10	1000 - 3000	4	1/8	full span	1	2 3/4	1/4			36,39	7	4900	Icing flight to check accretion.
VII-2	-13.0	10	1000 - 3000	4	1/8	full span	1	2 7/8	5/16	25	6	36.5, 39, 36	7	4900	Icing and de-icing flight outside the cloud. Clean shedding.
VII-3	-12.5	10	1000 - 3000	4	1/8	285	1	3	1/4	25	5	36, 39, 36	7	4900	Icing and de-icing flight outside the cloud. Clean shedding.

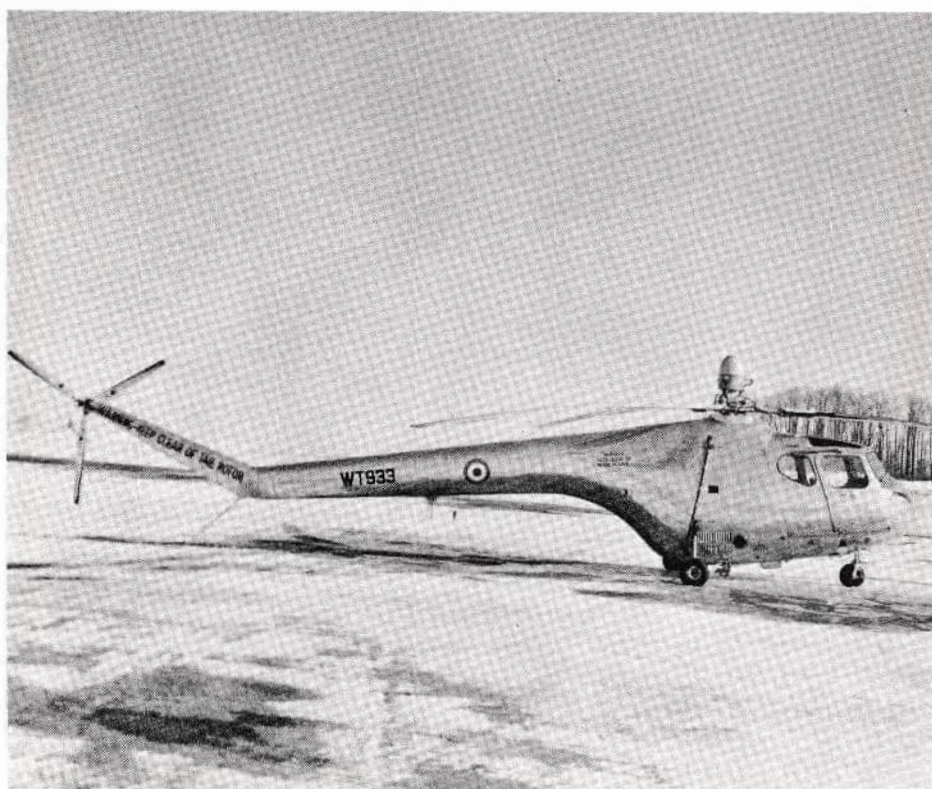
TABLE VI

WINDSCREEN ANTI-ICING AND DE-ICING IN SIMULATED FREEZING RAIN

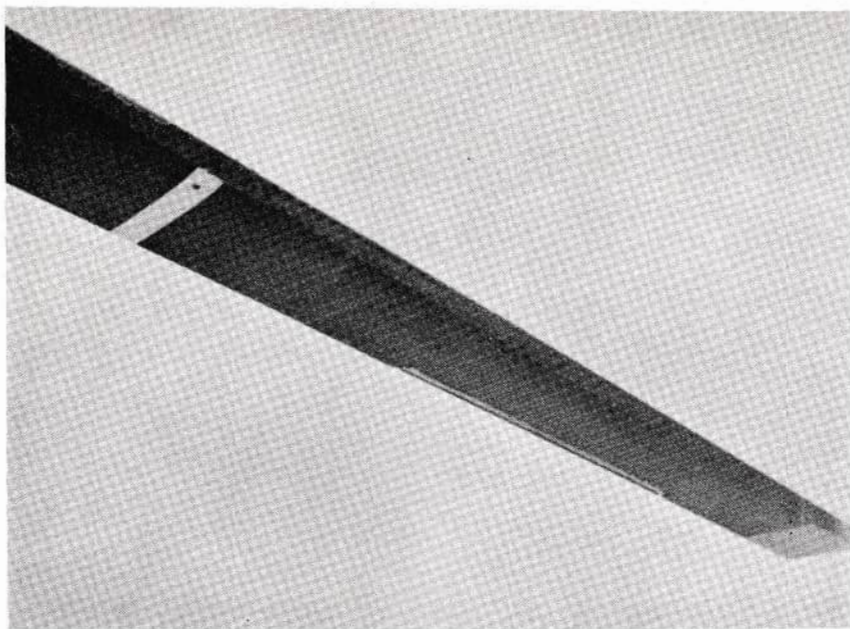
Test No.	Ambient Temp. °C	Droplet Size micron	Power Density w/sq. in.	Additional Equipment Used	Test Conditions	Results and Remarks
I	-15	1000 - 3000	0.75	Wipers off	On ground windspeed 5 m.p.h.	Ice accretion melts after 3 min. making an oval
II	-15	1000 - 3000	1.6	Wipers off	On ground windspeed 5 m.p.h.	30 sec. to start melting.
III	-15	1000 - 3000	1.6	Wipers off	On ground windspeed 5 m.p.h.	2 min. for clear vision.
IV	-13	1000 - 3000	1.6	Wipers on	On ground windspeed 5 m.p.h.	1 min. for clear vision.
V	-13	1000 - 3000	1.6	Wipers off	In air windspeed 10 m.p.h.	2 min. for clear vision. Vision maintained.
VI	-13	1000 - 3000	1.6	Wipers on. No alcohol	In air windspeed 10 m.p.h.	1 min. for clear vision.
VII	-13	1000 - 3000	-	Wipers on. With alcohol	In air windspeed 10 m.p.h.	Clear vision maintained. Mushy anti-icing.
VIII	-12	1000 - 3000	1.8*	No wipers. No alcohol	In air windspeed 10 m.p.h.	Clear vision in less than 1 min.

* During this run power density was reduced to 0.75 w/sq.in. and windscreen stayed clear of ice.

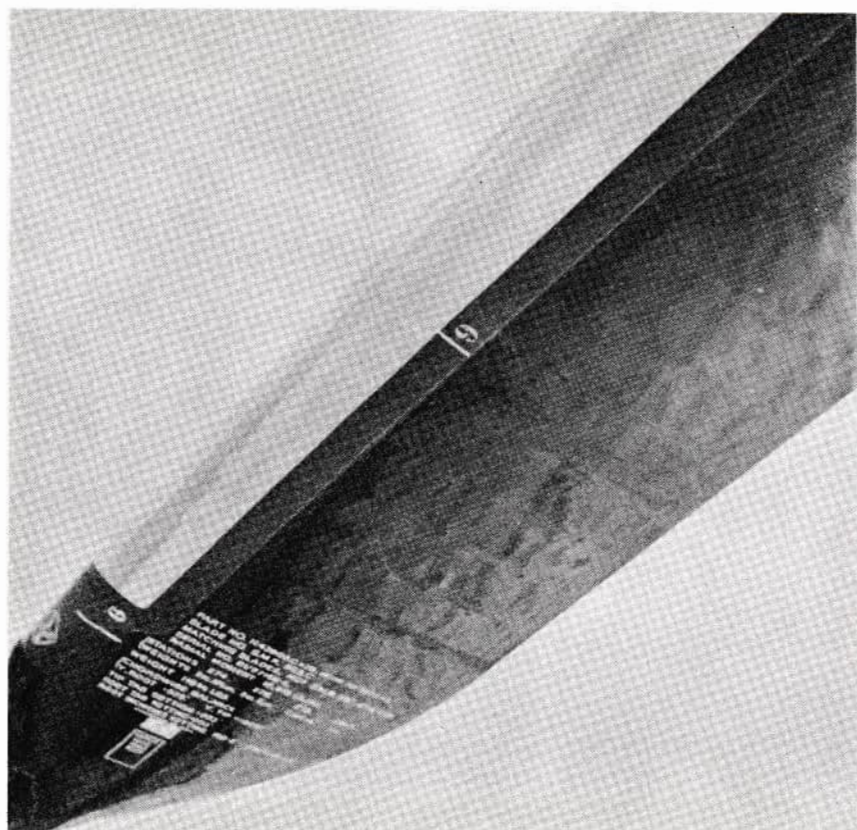
FIG. 1
LR-221



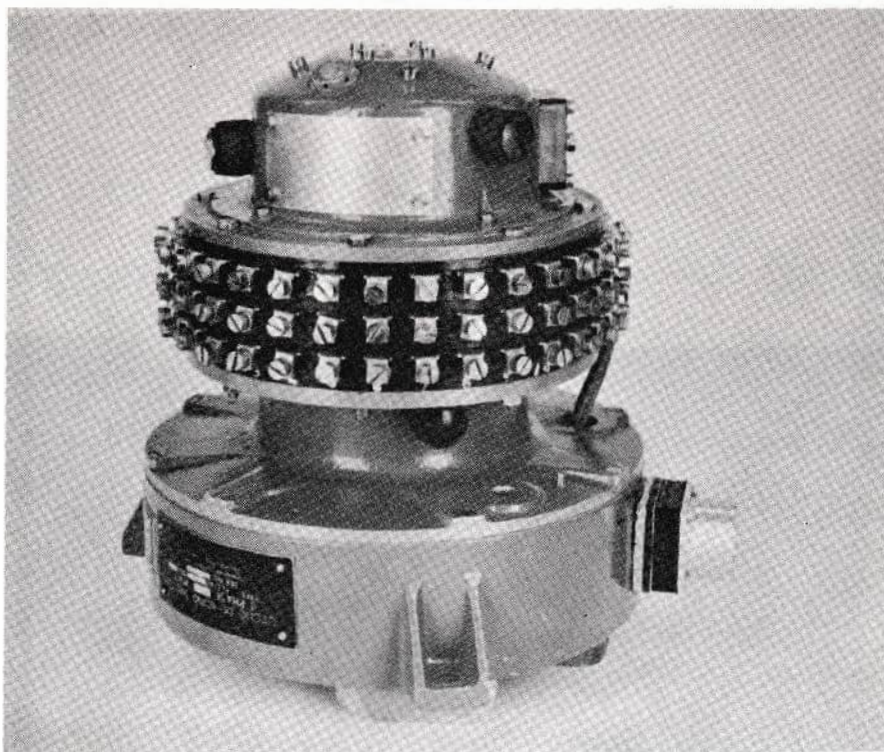
BRISTOL SYCAMORE TYPE 171, MK. 3
(WITH MAIN ROTOR DE-ICING EQUIPMENT)



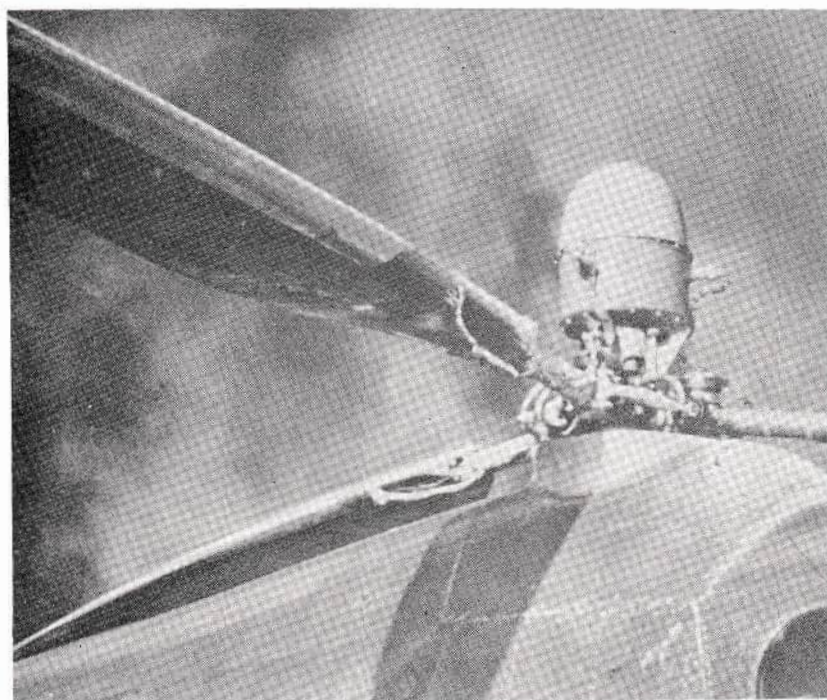
STANDARD ROTOR BLADE SHOWING 4-IN. BRASS STRIPS



ROTOR BLADE WITH DE-ICER PAD INSTALLED
MAIN ROTOR BLADES USED DURING TRIALS

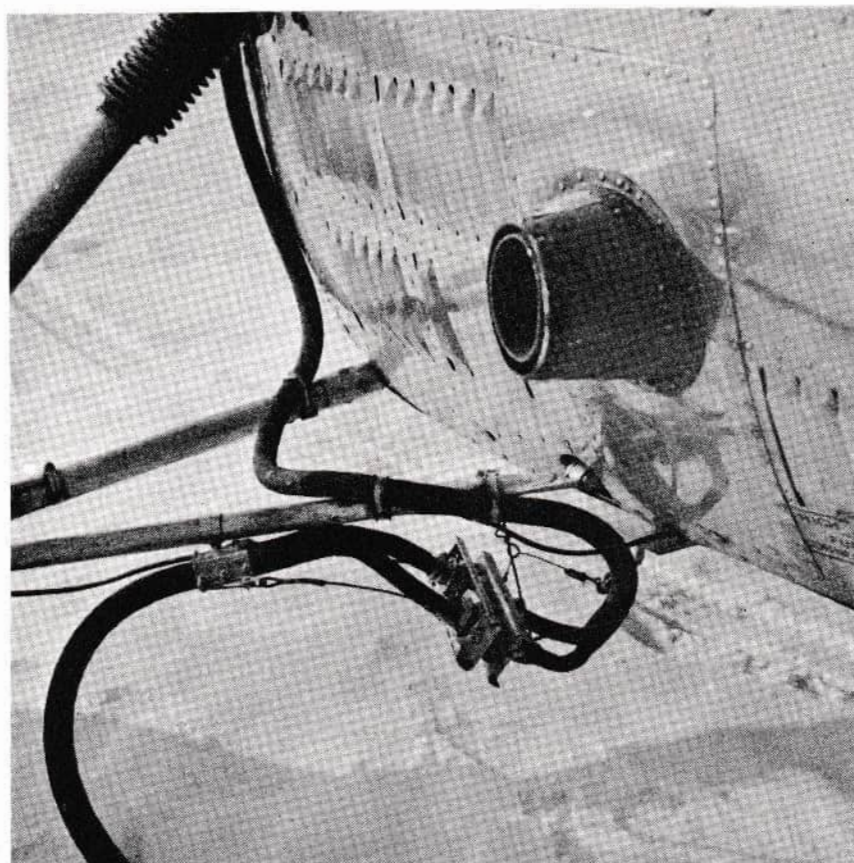


SLIPRING AND CYCLIC SWITCH MOUNTED ON ROTOR HUB



DOMES INSTALLATION WITH CYCLIC SWITCH INSIDE

CYCLIC SWITCH INSTALLED ON AIRCRAFT



SNATCH PLUG ARRANGEMENT FOR EXTERNAL POWER SUPPLY

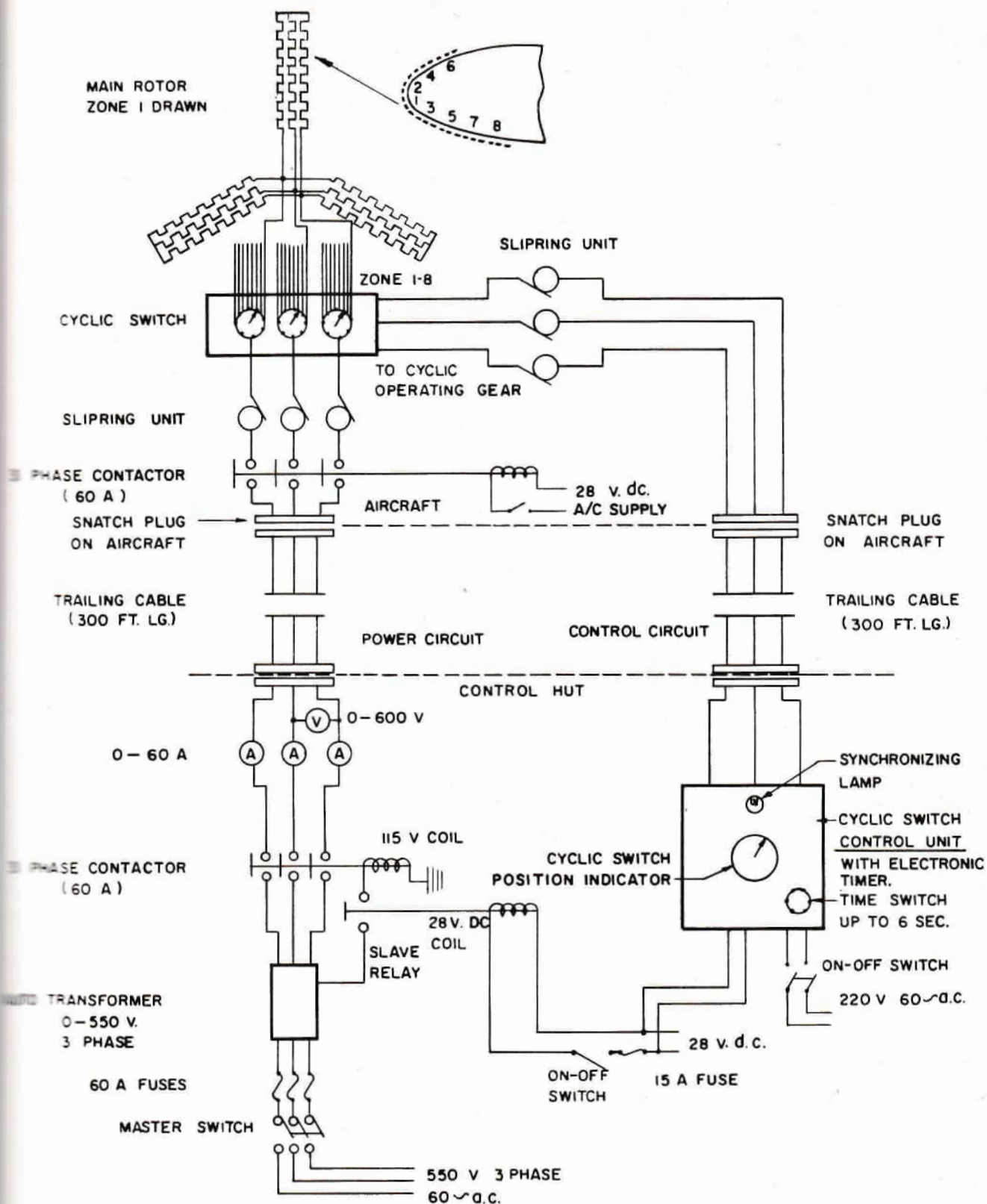
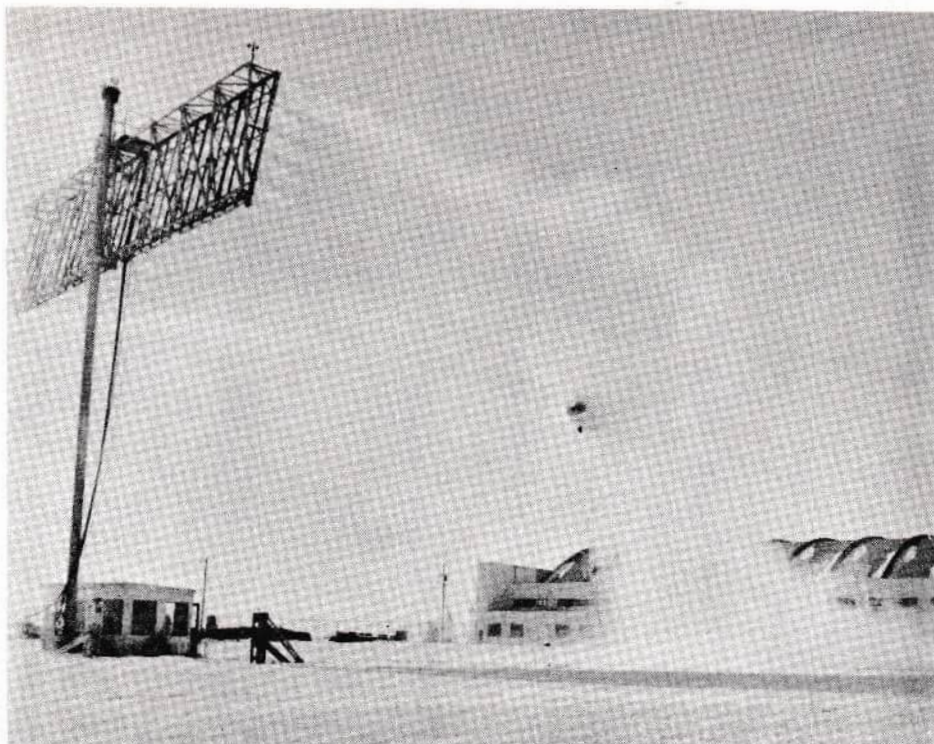


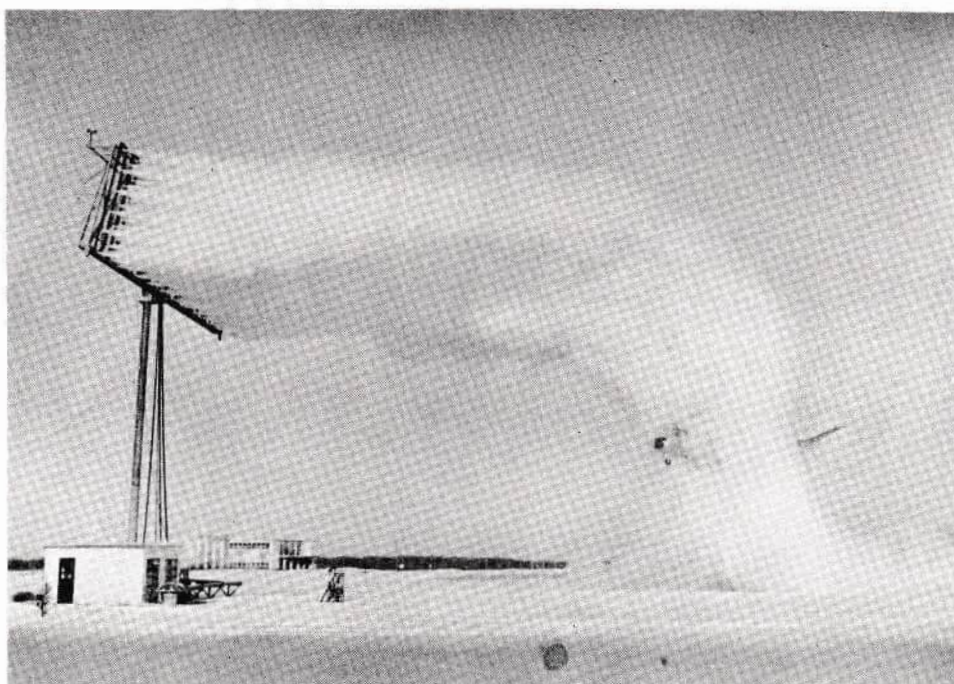
DIAGRAM OF POWER AND CONTROL WIRING
ON HELICOPTER AND IN CONTROL HUT



SHIELDED TEMPERATURE BULB ON TOP OF CABIN

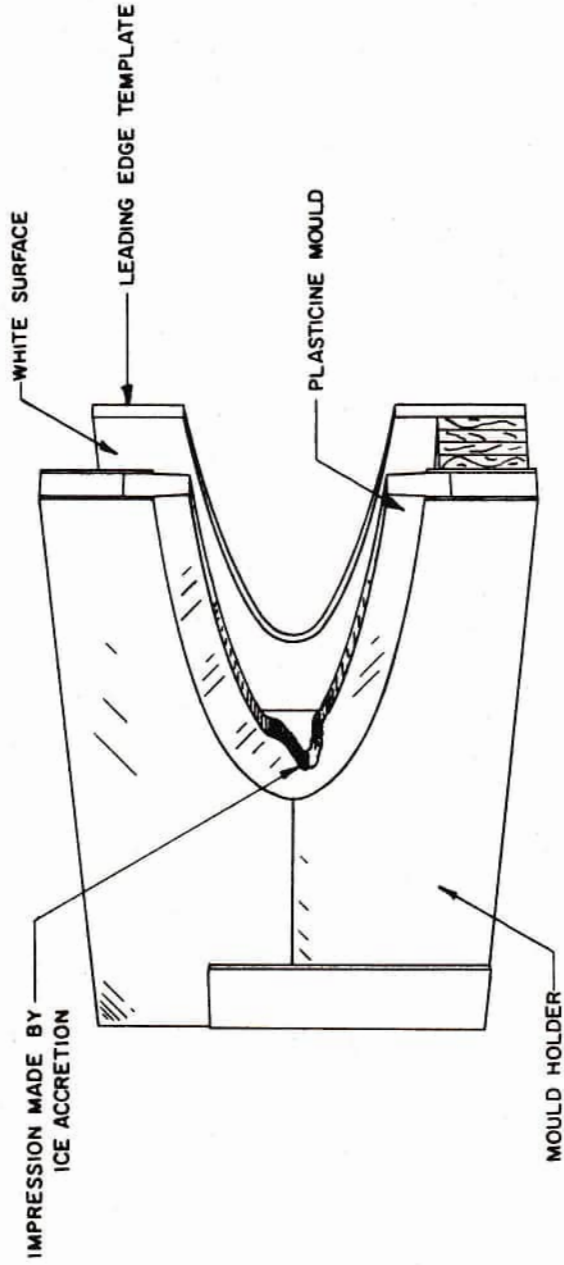
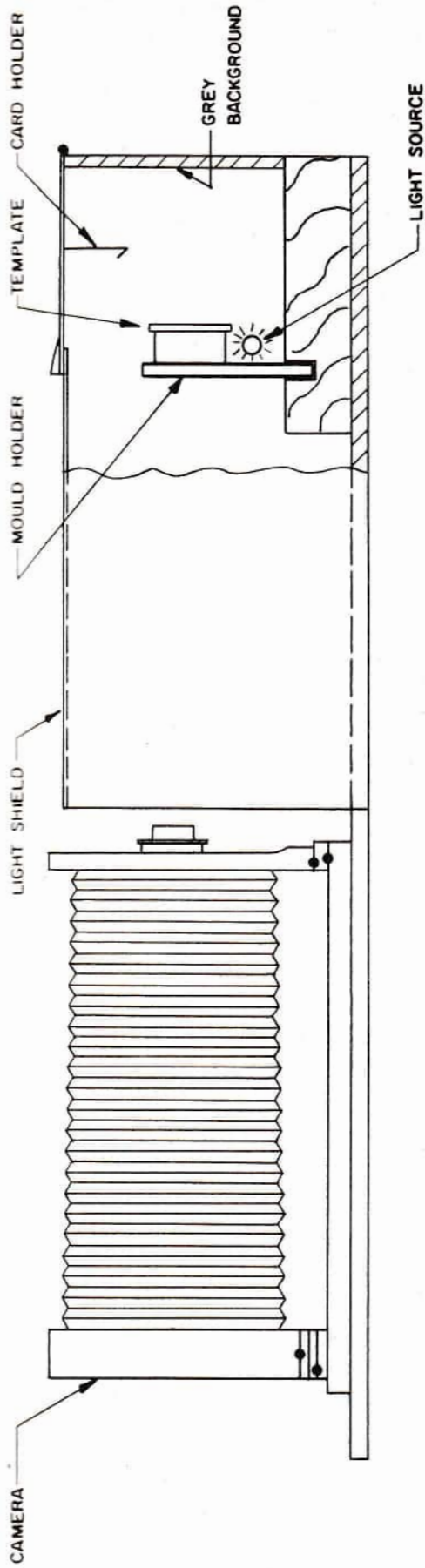


CORRECT AIRCRAFT POSITION FOR ICING FLIGHT

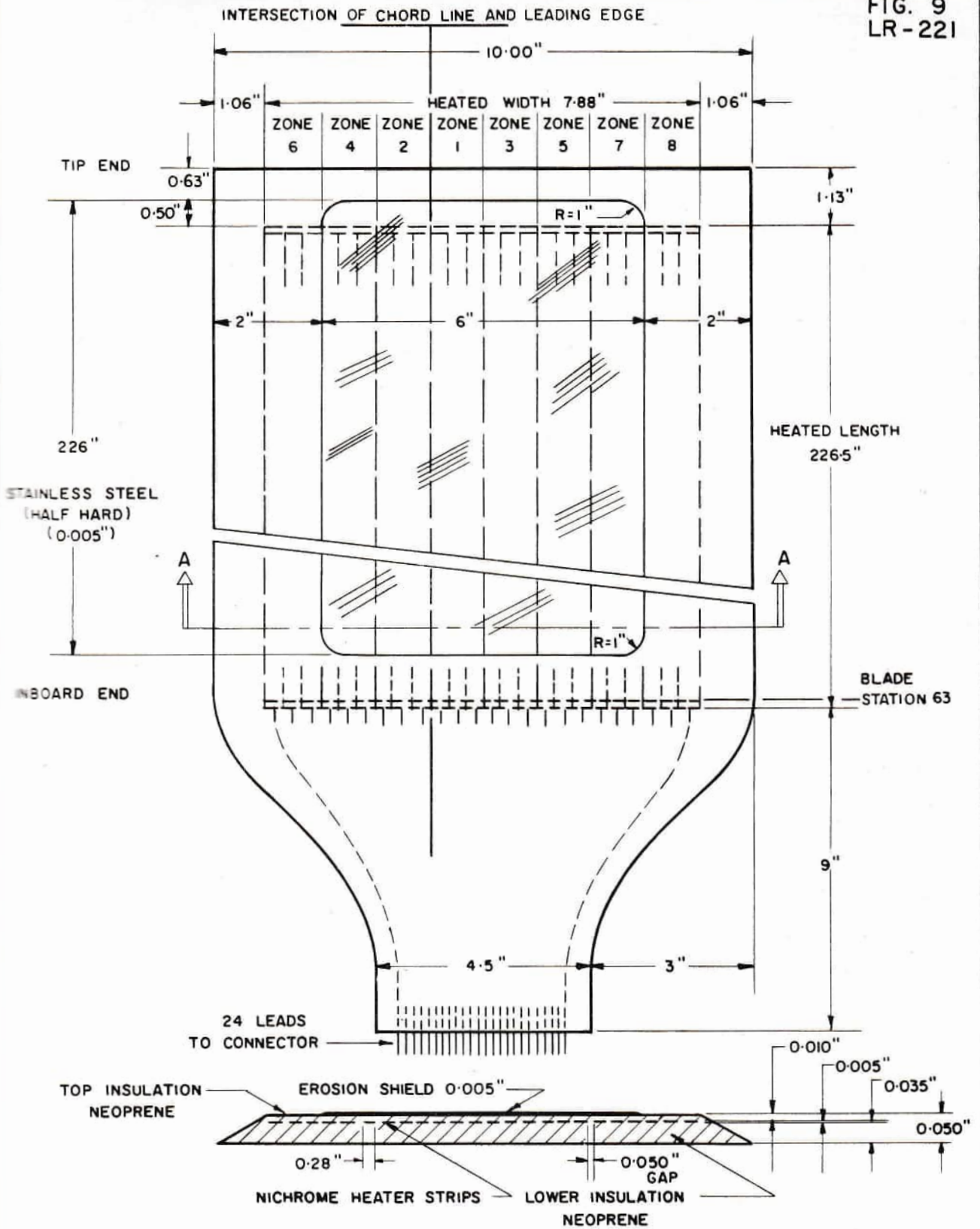


WINDSPEED IS SLIGHTLY TOO LOW (NO TAIL ROTOR ICING)

HELICOPTER DURING ICING FLIGHTS



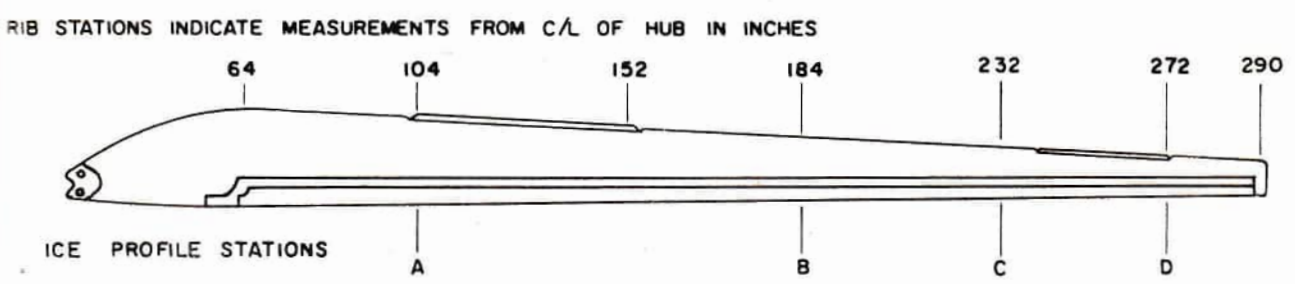
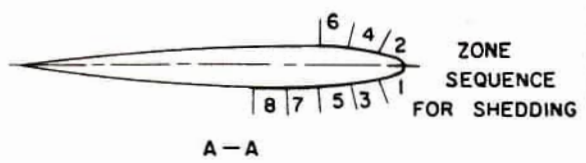
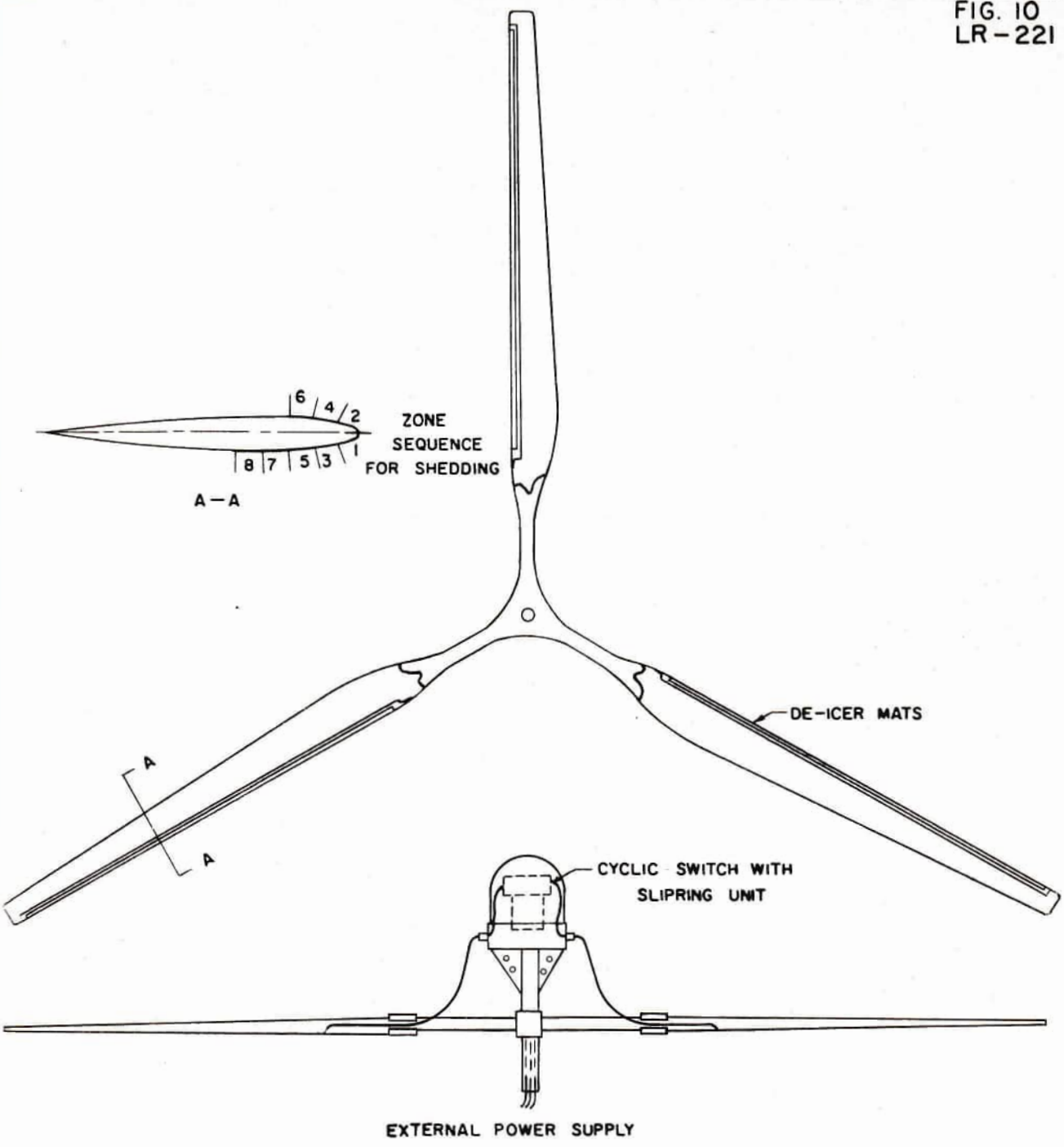
ICE PROFILE MOULD AND CAMERA.



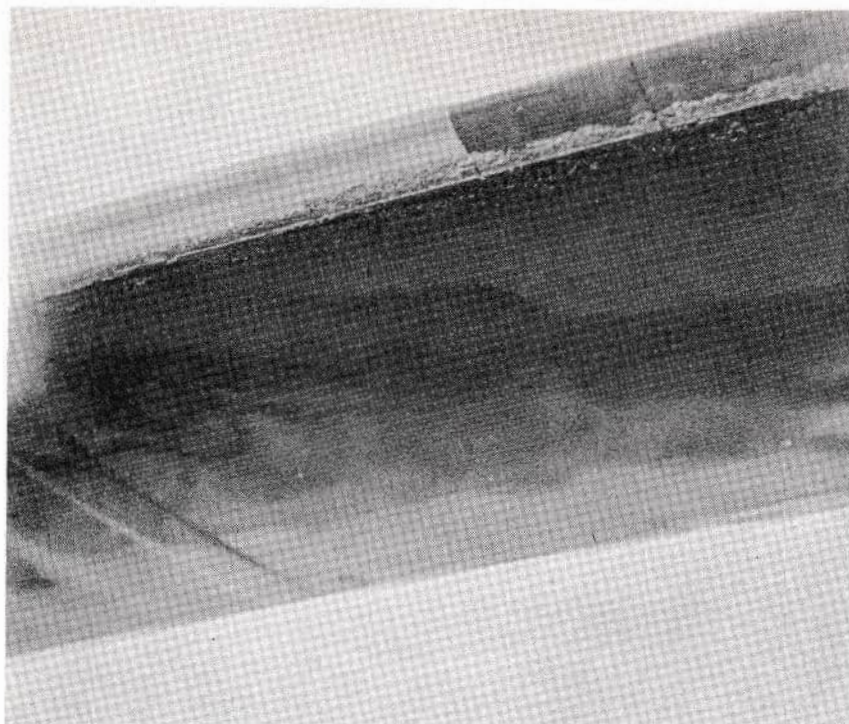
SECTION A-A

RESISTANCE OF EACH HEATER STRIP : $8.03 \Omega \pm 5\%$
 WEIGHT OF PADS : 9.9 lbs. (6 lbs./ft.²), 13.8 lbs. WITH LEADS (16 GA.)

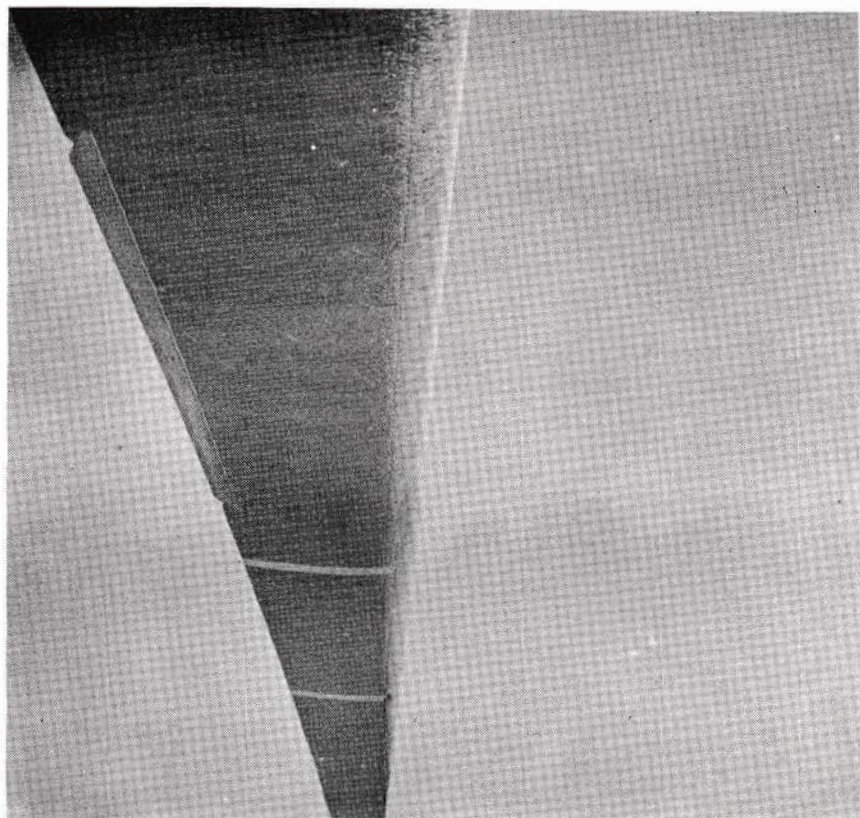
LAYOUT OF DE-ICER PADS



MAIN ROTOR WITH DE-ICER PADS INSTALLED



SELF-SHEDDING ON STANDARD BLADES (NOTE CRACKING
OF ICE ACCRETION OVER GAPS BETWEEN BRASS NOSE CAPS)



ICE ACCRETION COLLECTED DURING FLIGHT VI-5
TYPICAL ACCRETION COLLECTED DURING ICING
FLIGHTS WITH STANDARD BLADES



ICING FLIGHT II -13
SELF-SHEDDING UP TO STATION 115. ICE ACCRETION 7/8 IN.
AMBIENT AIR TEMPERATURE -9°C



ICING FLIGHT II -18
SELF-SHEDDING UP TO STATION 140. ICE ACCRETION 3/4 IN.
AMBIENT AIR TEMPERATURE -8.5°C
SELF-SHEDDING OF ICE ACCRETIONS ON PROTECTED BLADE

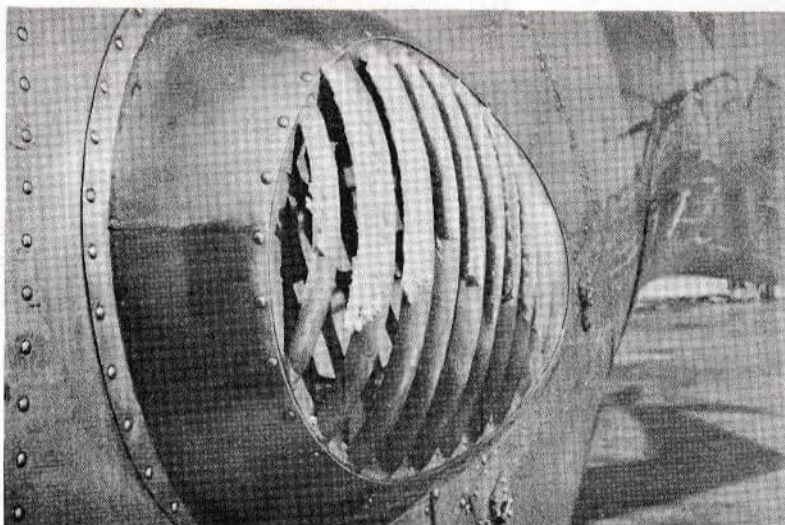


ISOLATED RIME FINGERS ON TAIL CONE

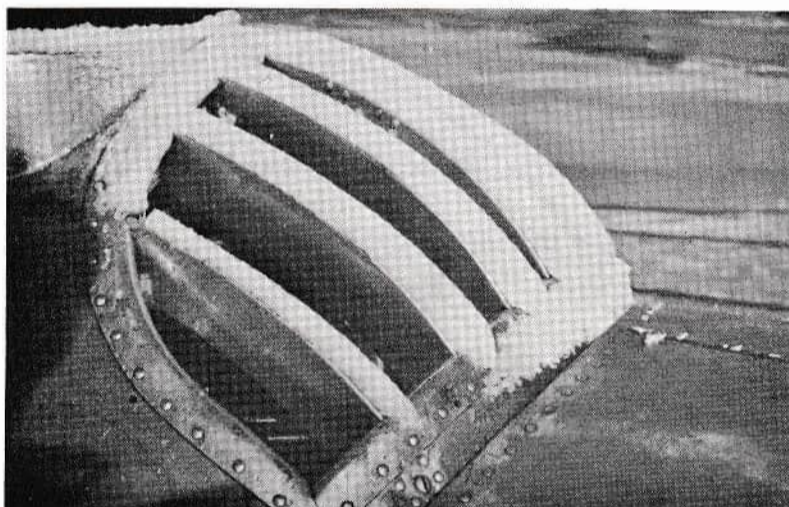


EXTENT OF ICE ON TAIL CONE AT -16°C

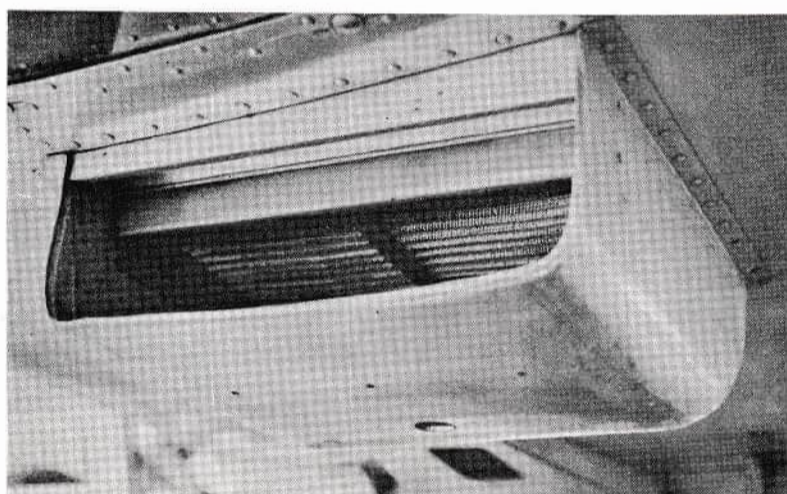
ICE EXTENT ON TAIL CONE



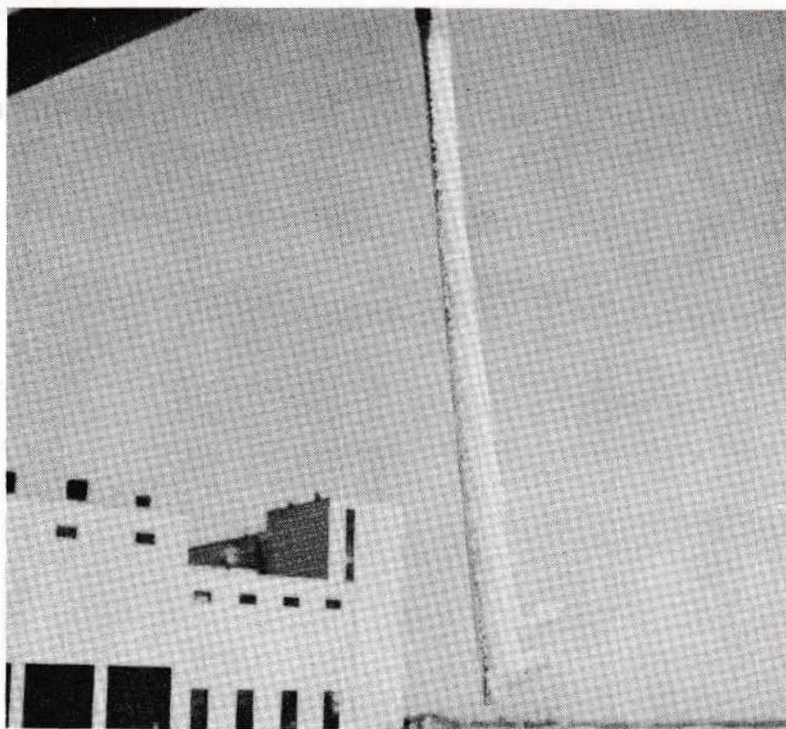
OIL COOLER GRID



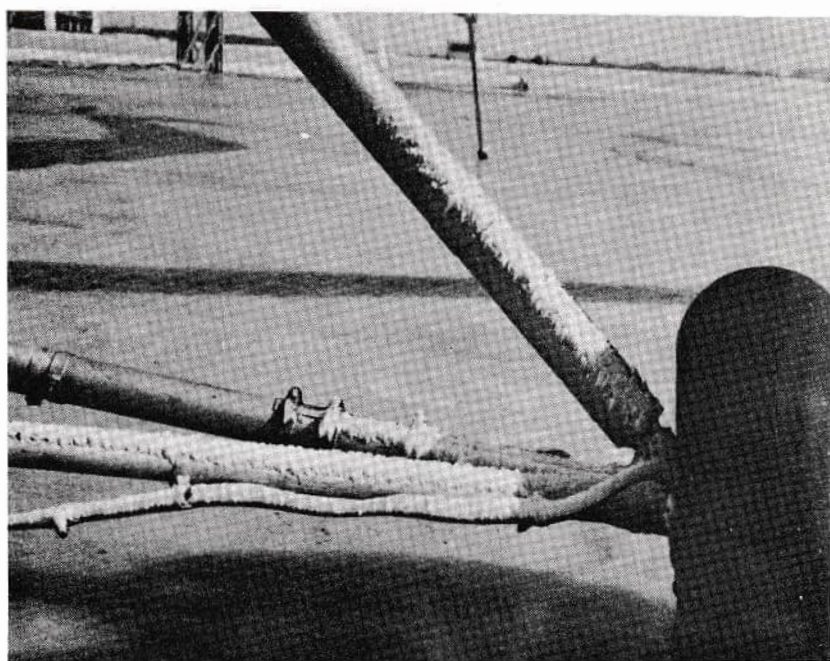
COOLING AIR INLET



ENGINE CARBURETTOR INTAKE WITH FILTER
ICING OF AIR INLETS



ICE ACCRETION ON AERIAL

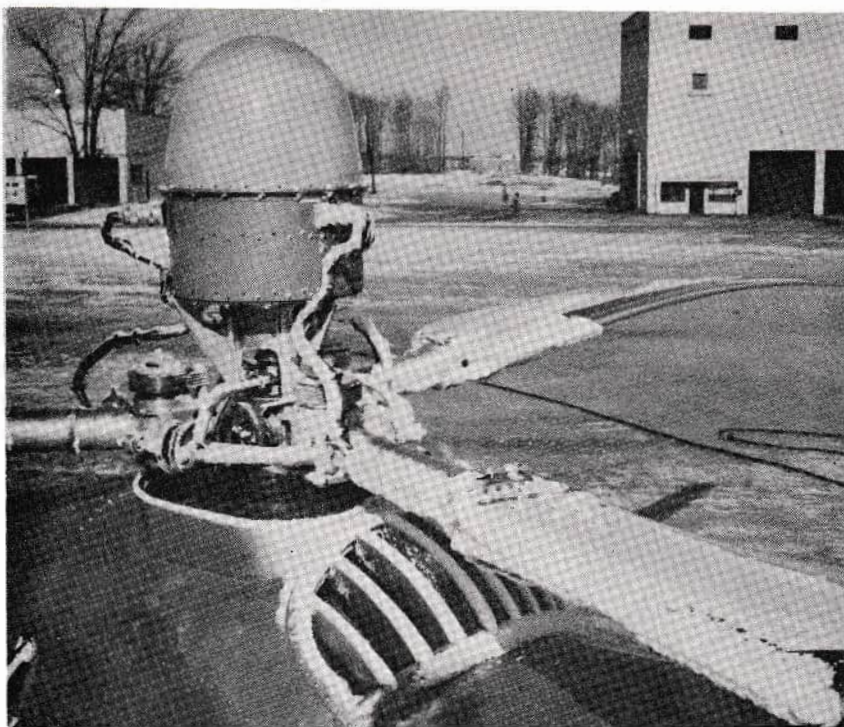


UNDERCARRIAGE ICING

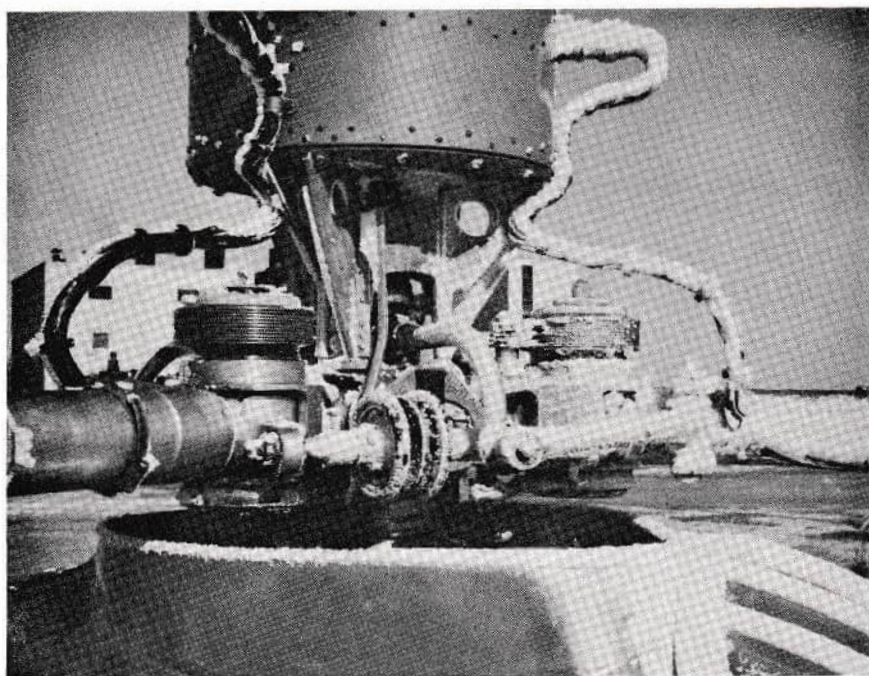
COMPONENT ICING



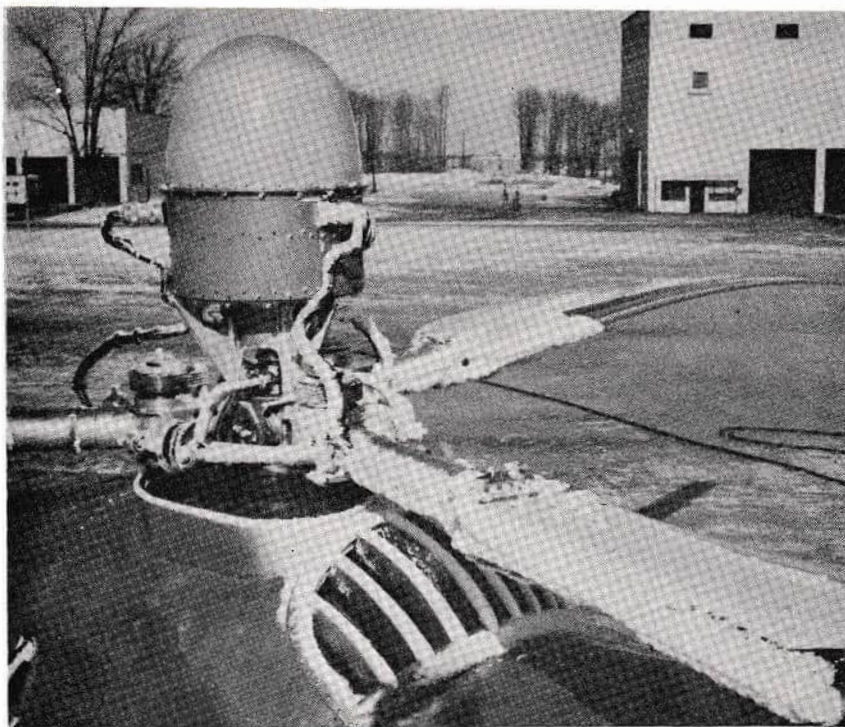
ICE ACCRETION ON SIDE WINDOWS



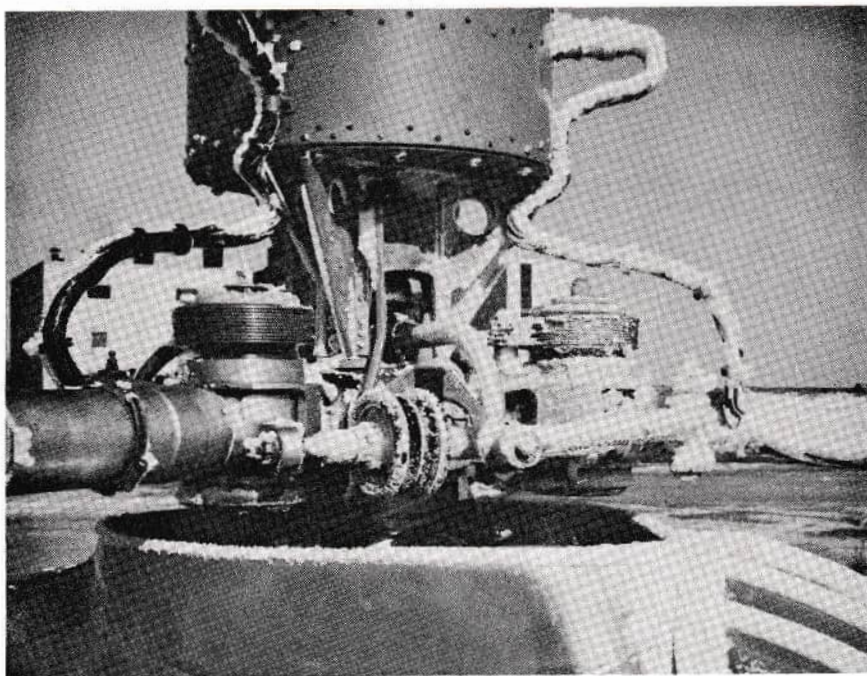
ICE ACCRETION ON UNPROTECTED PART OF ROTOR AND HUB MECHANISM



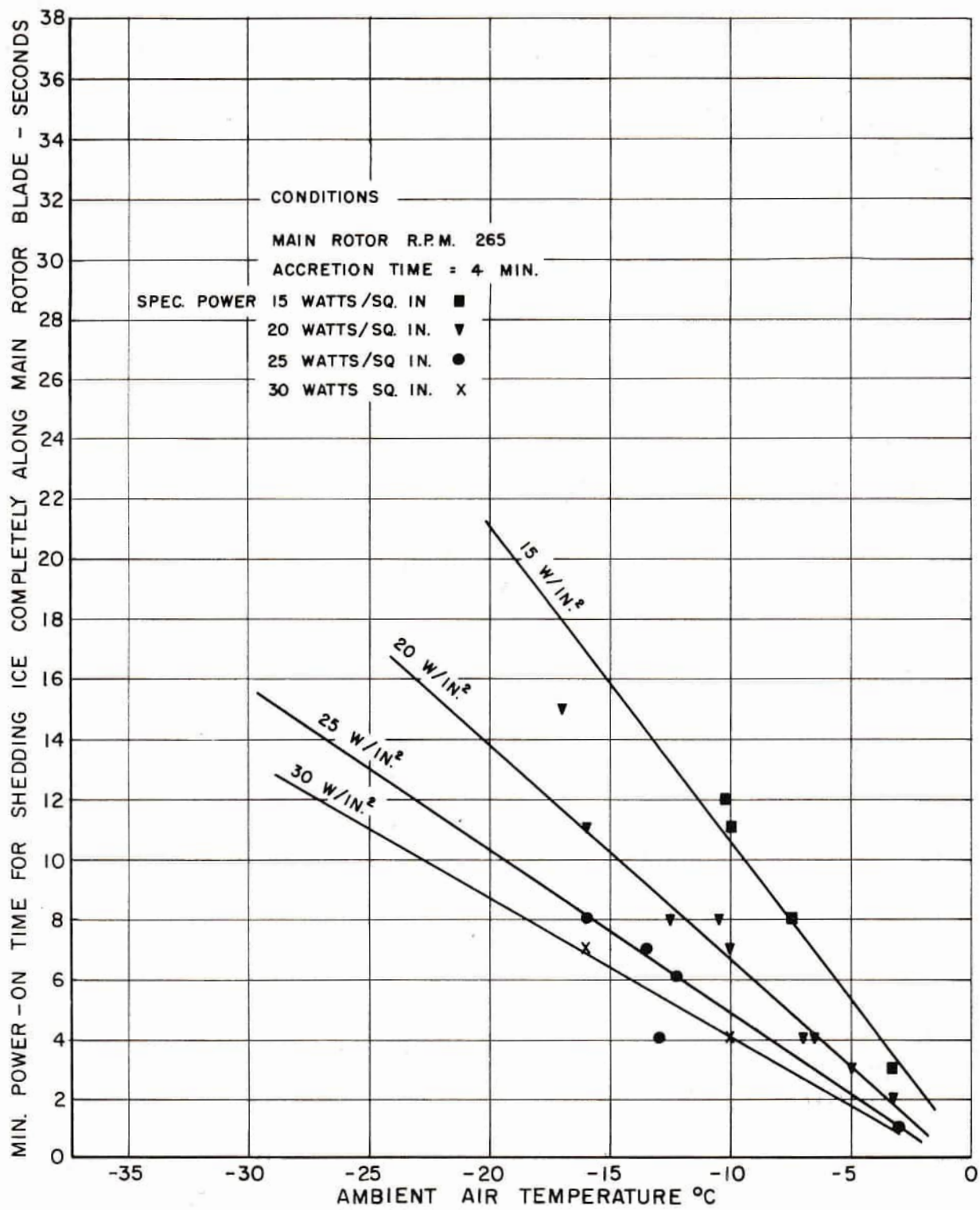
ICE ACCRETION ON CONTROL MECHANISM AND DAMPERS
ICING ON ROTOR HEAD AT -16°C O.A.T.



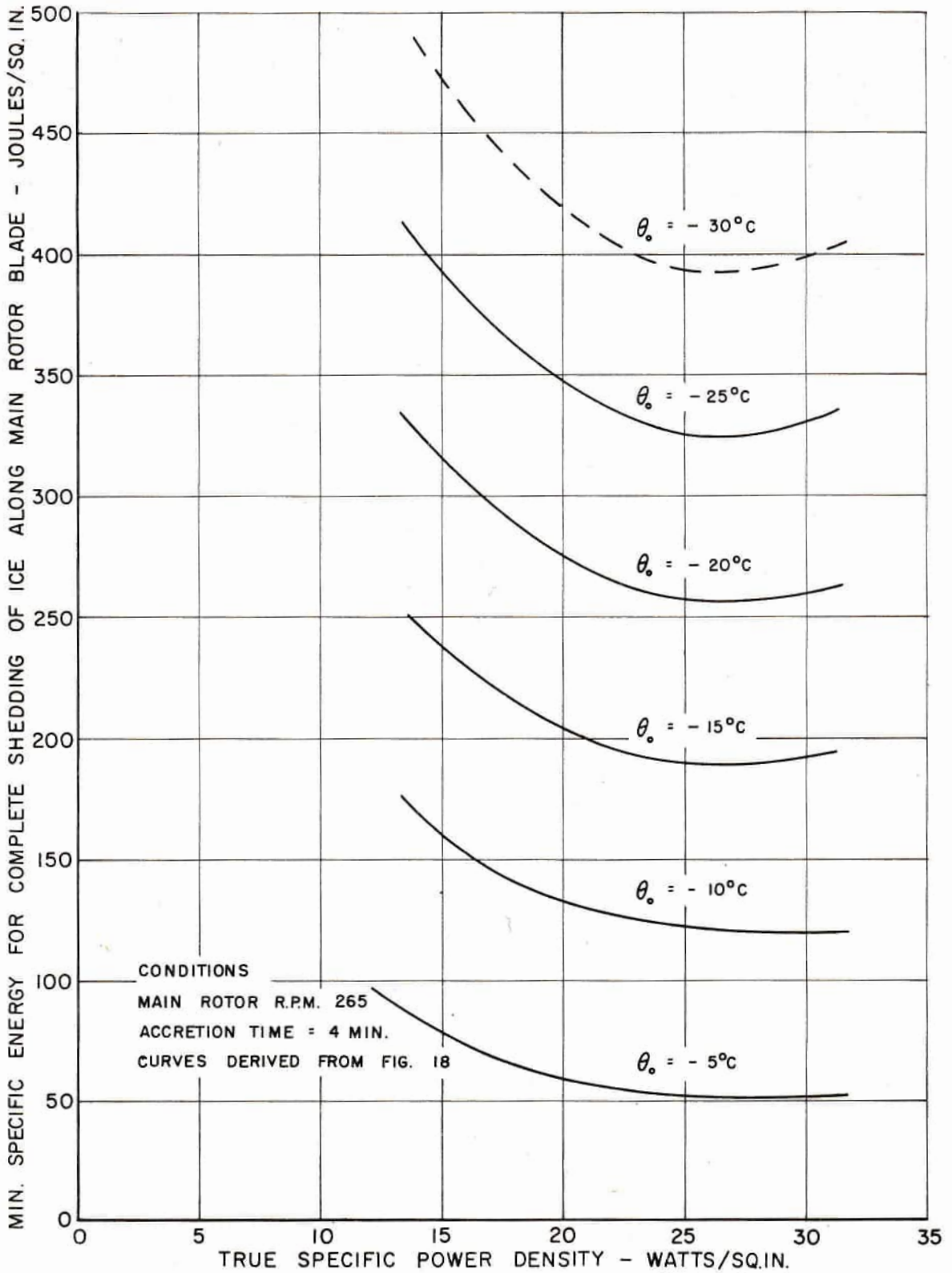
ICE ACCRETION ON UNPROTECTED PART OF ROTOR AND HUB MECHANISM



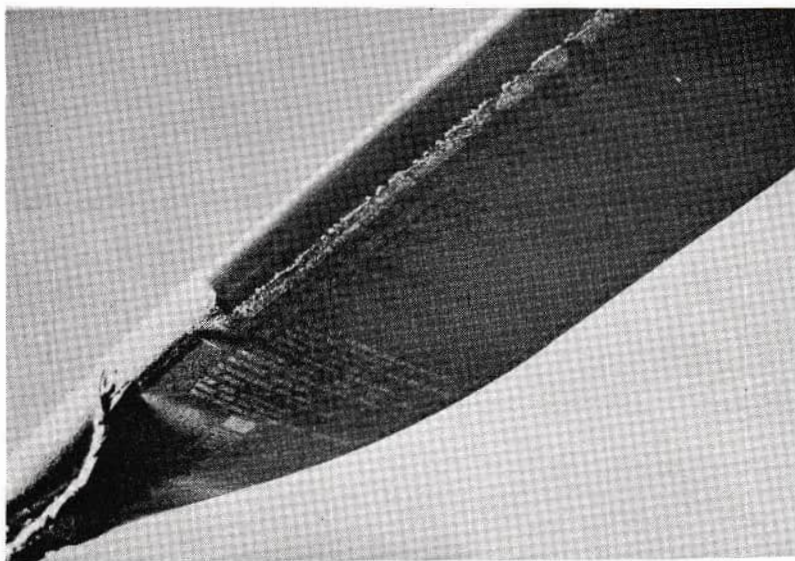
ICE ACCRETION ON CONTROL MECHANISM AND DAMPERS
ICING ON ROTOR HEAD AT -16°C O.A.T.



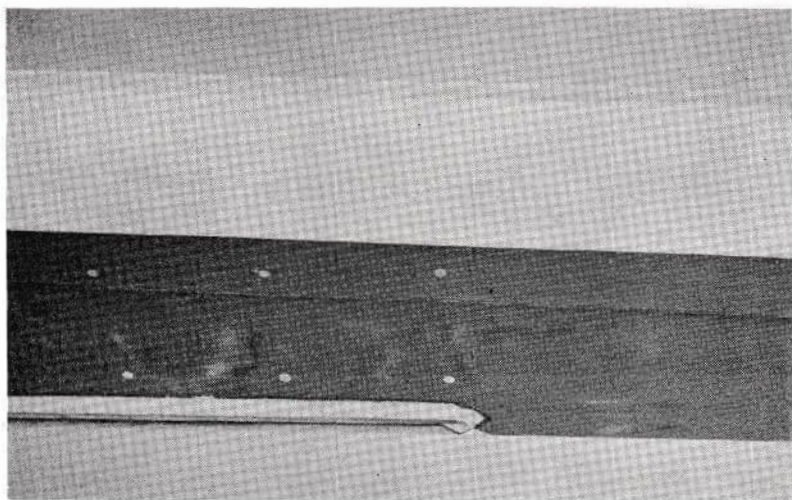
VARIATION OF POWER-ON TIME WITH AMBIENT AIR TEMPERATURE



MINIMUM SPECIFIC ENERGY TO SHED ICE ALONG
 SPAN OF MAIN ROTOR AT VARIOUS SPECIFIC
 POWER DENSITIES AND AMBIENT TEMPERATURES

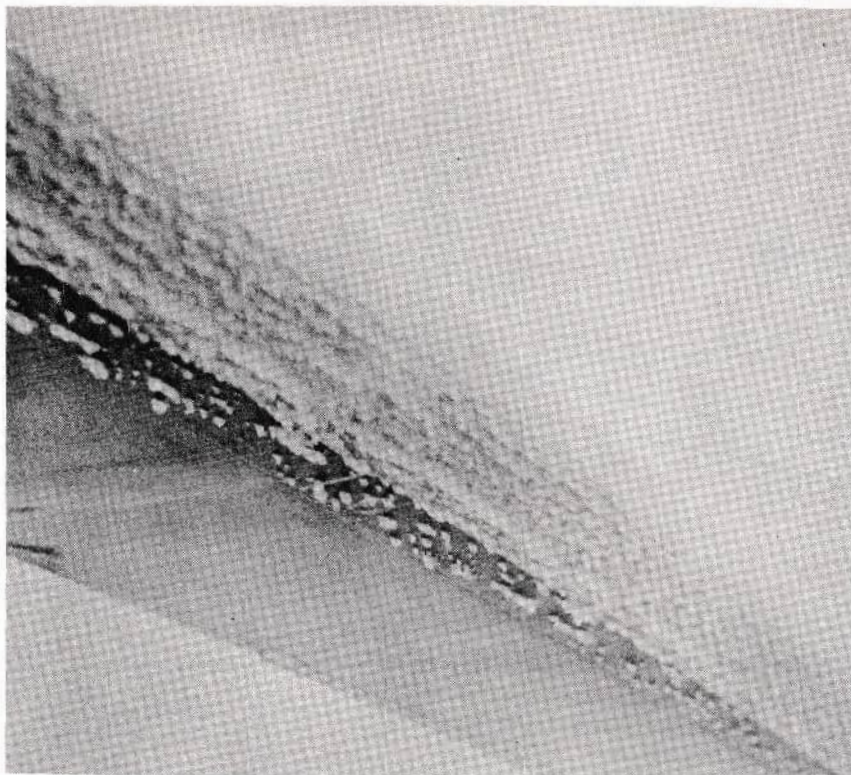


SIMULATED FAILURE OF ZONES 7 AND 8 AFTER SHEDDING

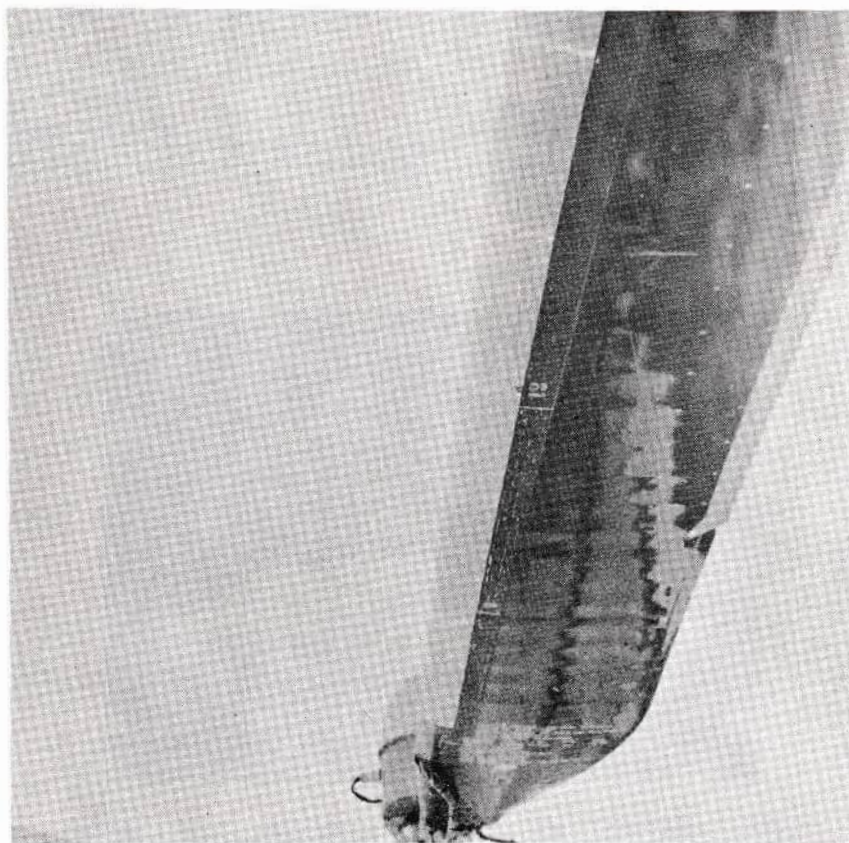


SIMULATED FAILURE OF ZONE 2 AFTER SHEDDING

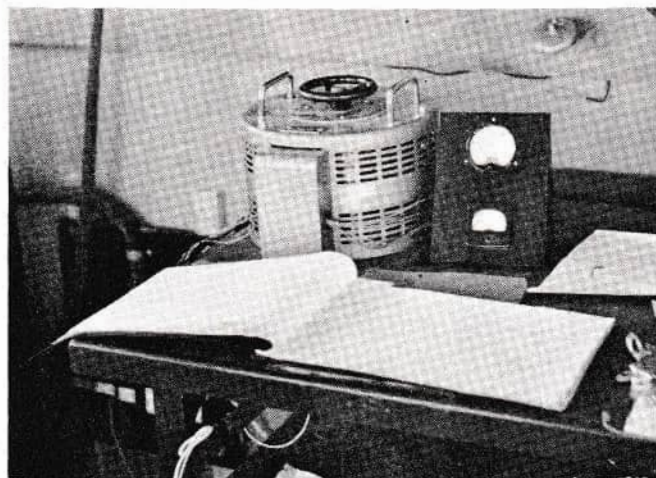
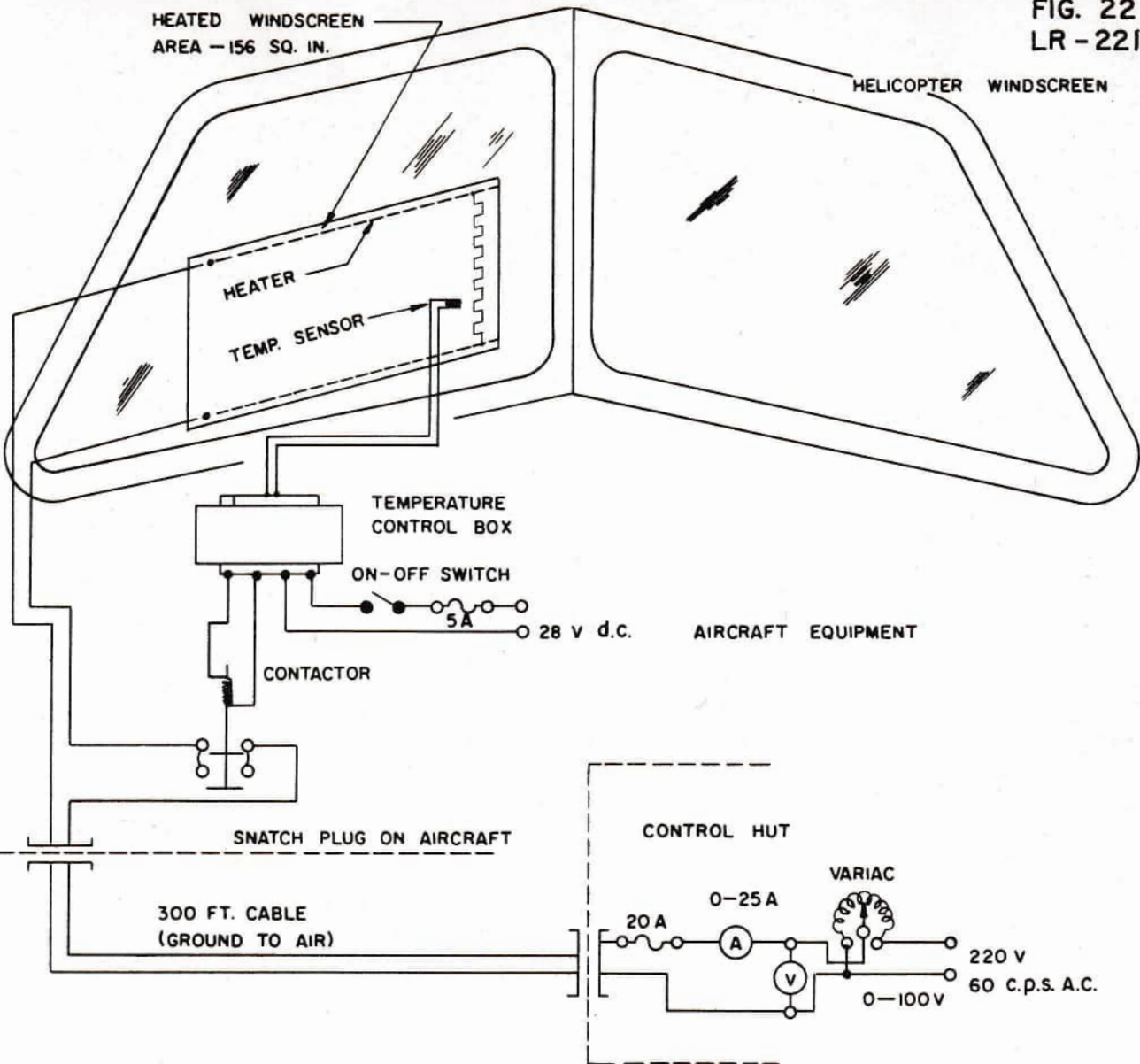
SIMULATED ZONE FAILURES



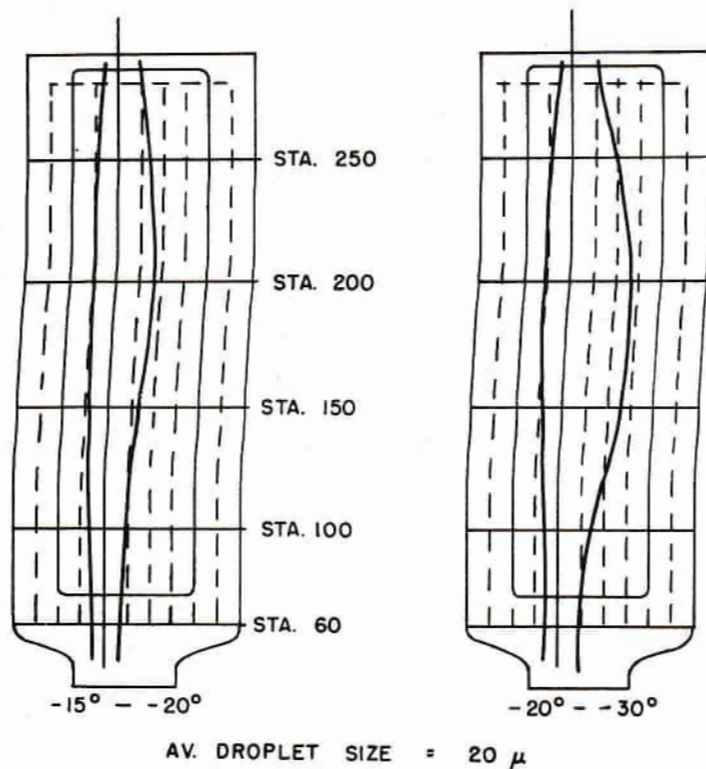
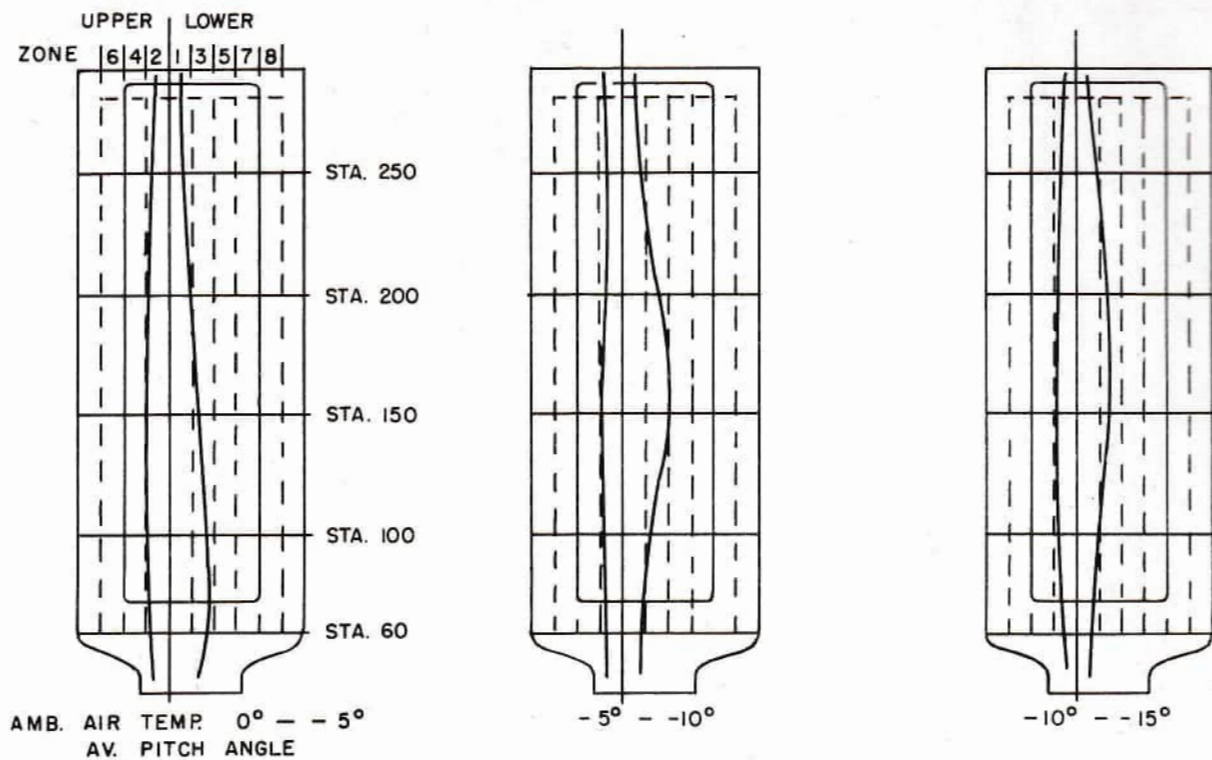
ACCRETION COLLECTED DURING GROUND RUN AT ZERO PITCH



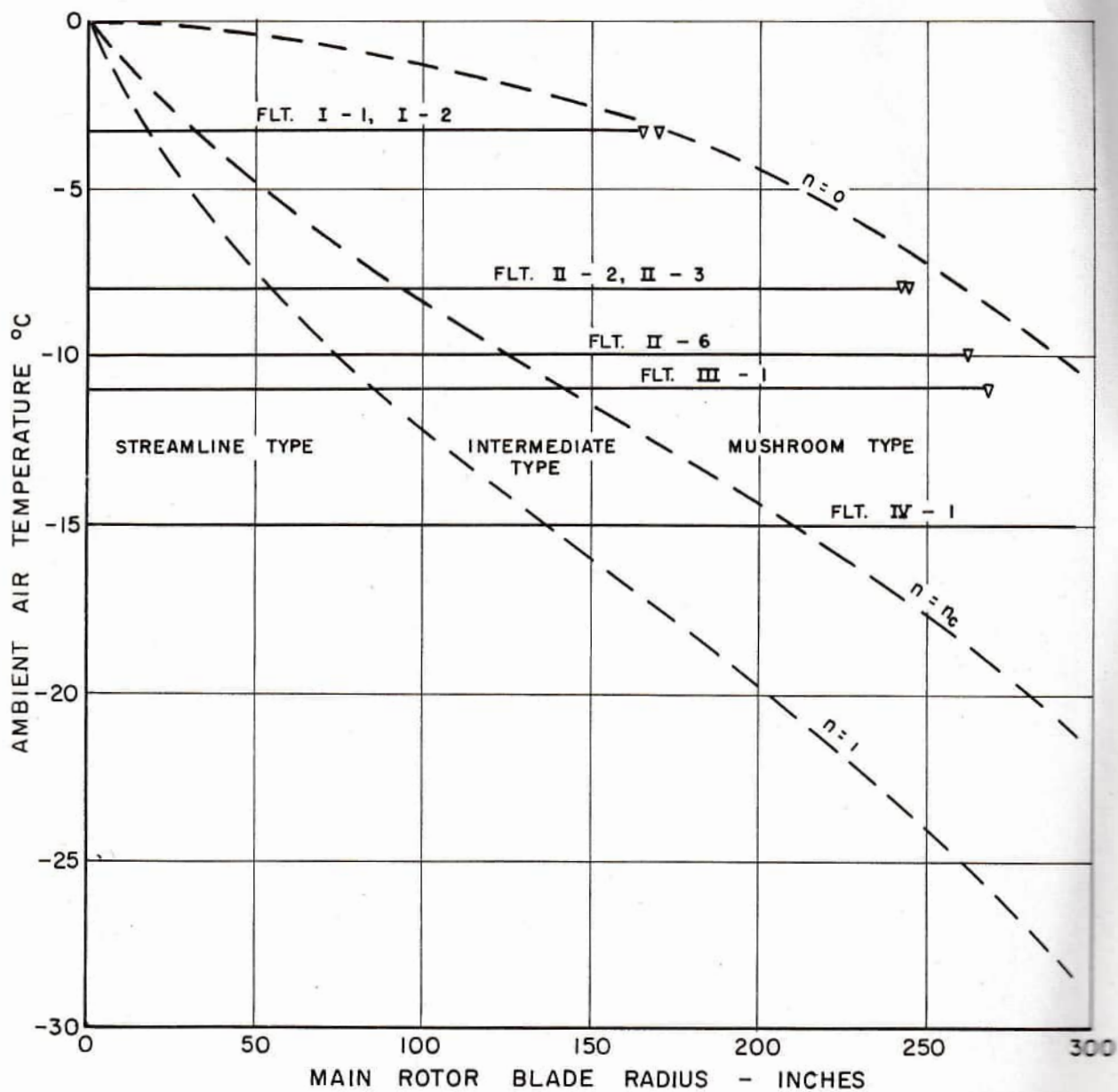
EXTENT OF ICING COLLECTED DURING FLIGHT VII-1
ACCRETIONS COLLECTED IN SIMULATED FREEZING RAIN



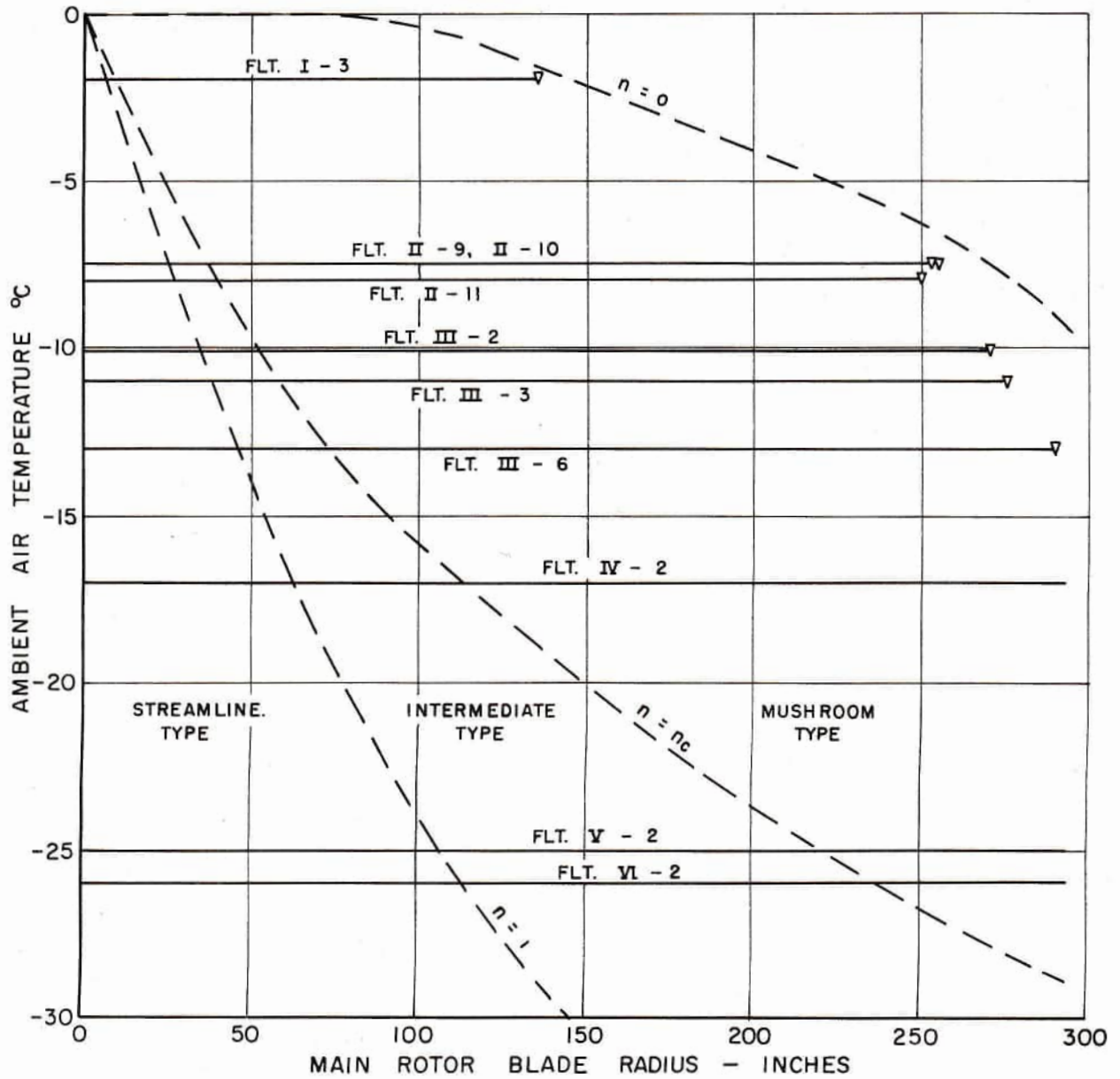
VARIAC AND INSTRUMENTATION IN CONTROL HUT
DIAGRAM OF WINDSCREEN ANTI-ICING SYSTEM



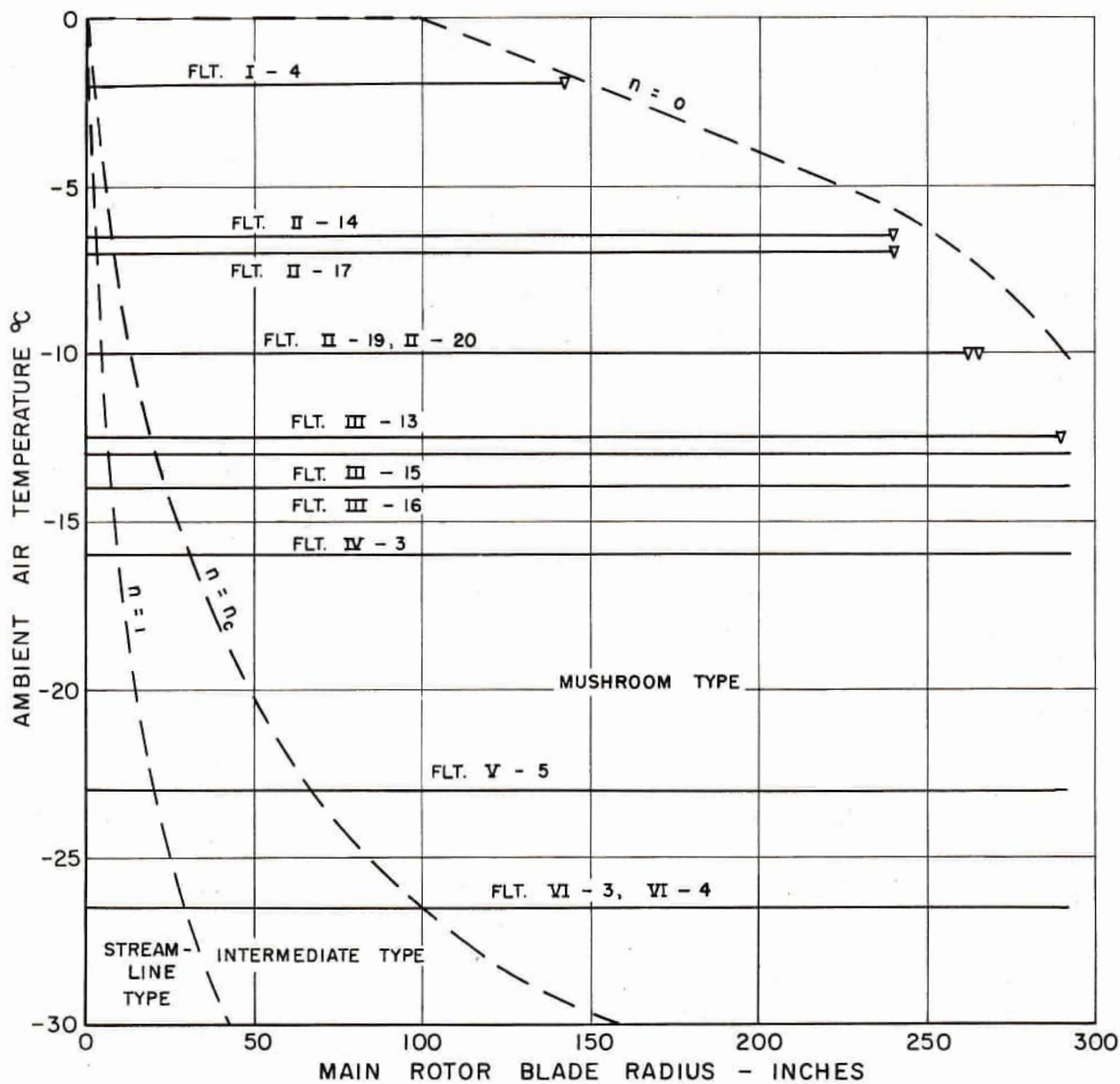
CHORDWISE EXTENT OF ICE ACCRETIONS
ON MAIN ROTOR DE-ICER PADS



MAXIMUM SPANWISE EXTENT AT STAGNATION LINE
AND CALCULATED ICE ACCRETION CHARACTERISTICS
FOR L.W.C. = 0.3 GM./M.³

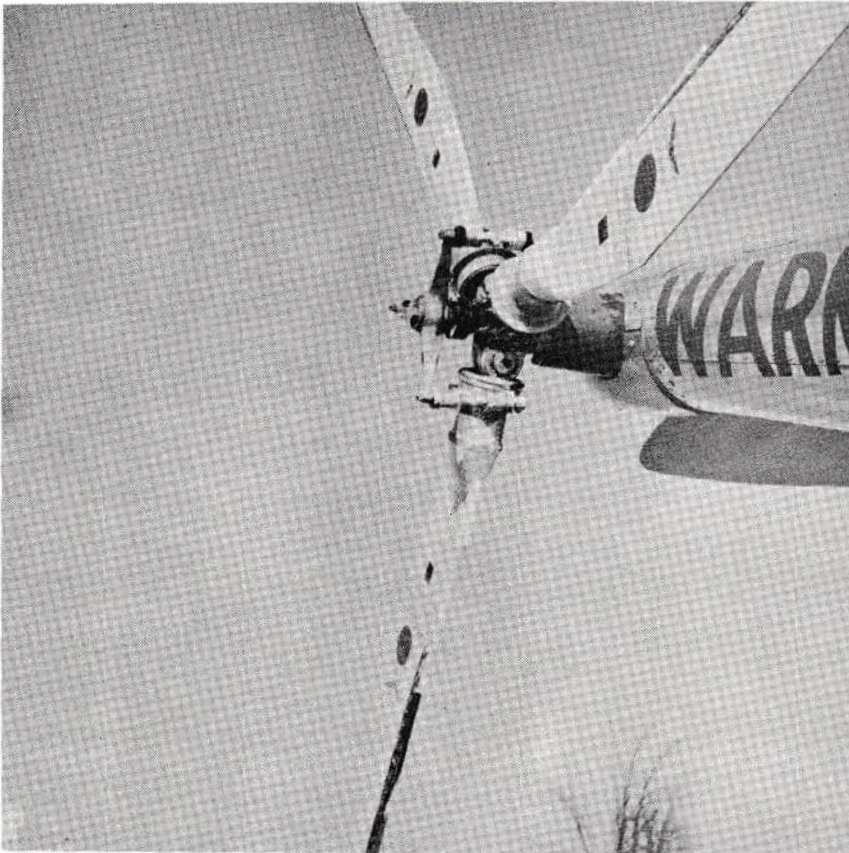
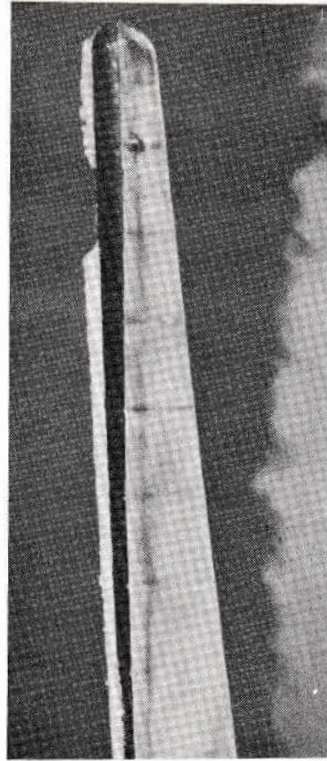
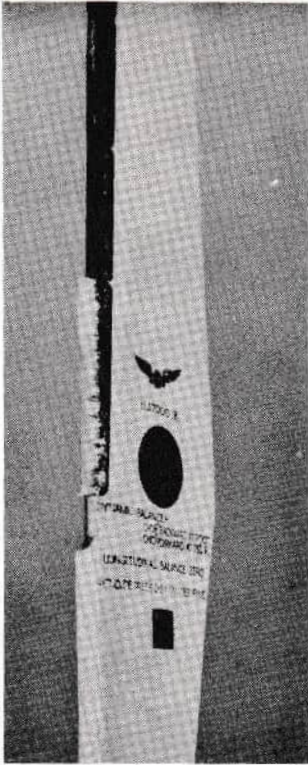


MAXIMUM SPANWISE EXTENT AT STAGNATION LINE
AND CALCULATED ICE ACCRETION CHARACTERISTICS
FOR L.W.C. = 0.7 GM./M.³

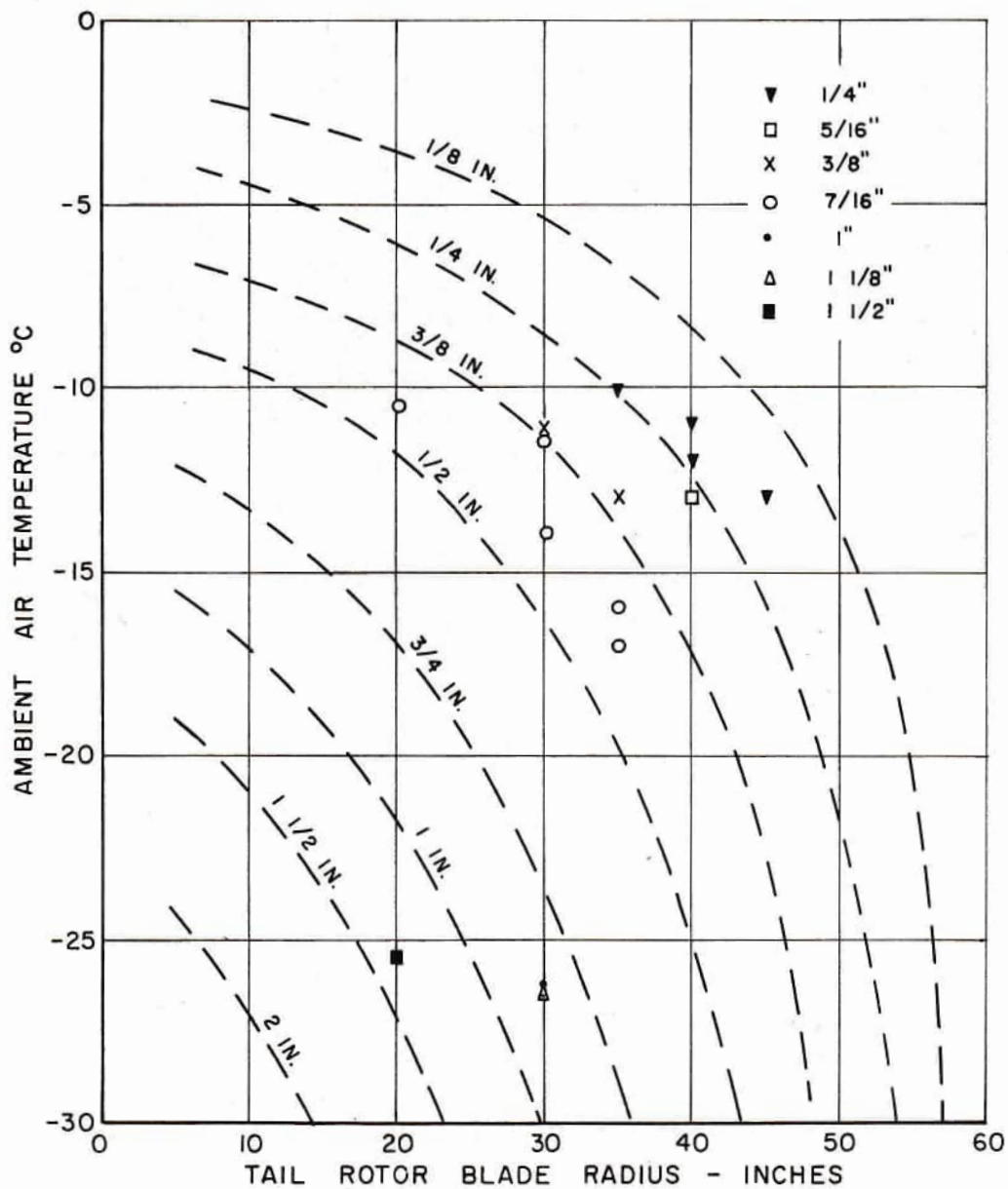


MAXIMUM SPANWISE EXTENT AT STAGNATION LINE
AND CALCULATED ICE ACCRETION CHARACTERISTICS
FOR L.W.C. = 1.5 GM./M.³

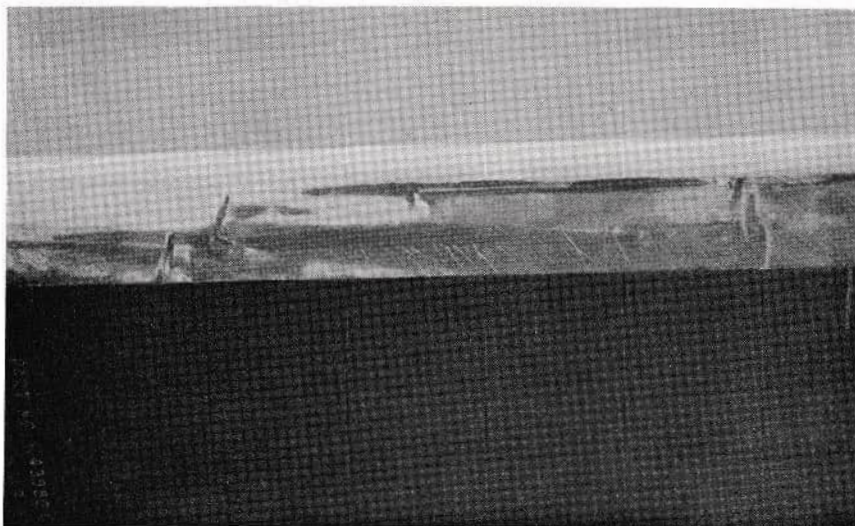
FIG. 28
LR-221



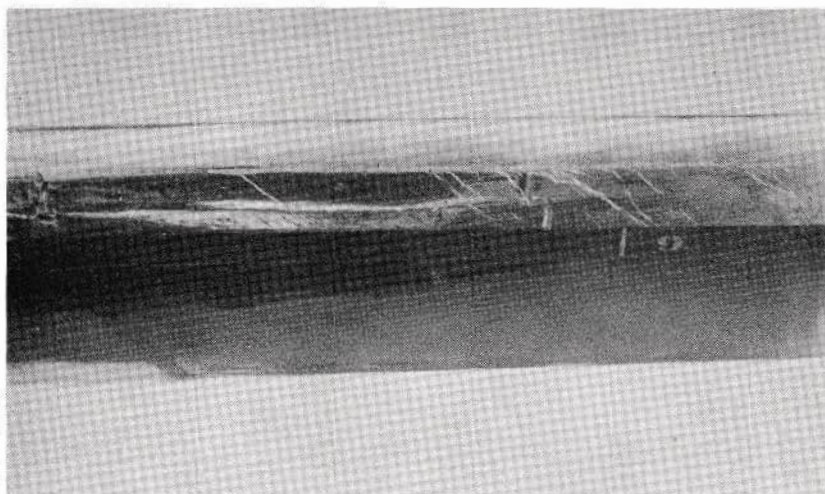
TYPICAL EXAMPLES OF TAIL ROTOR SELF-SHEDDING



TAIL ROTOR SELF-SHEDDING
CALCULATED AND OBSERVED VALUES



MELTING OF SECONDARY ACCRETION AND RESULTING RUN-BACK
AFTER FLIGHT DI-3. MAIN ACCRETION DID NOT SHED.



RUN-BACK NOTED AFTER FLIGHT DII-2

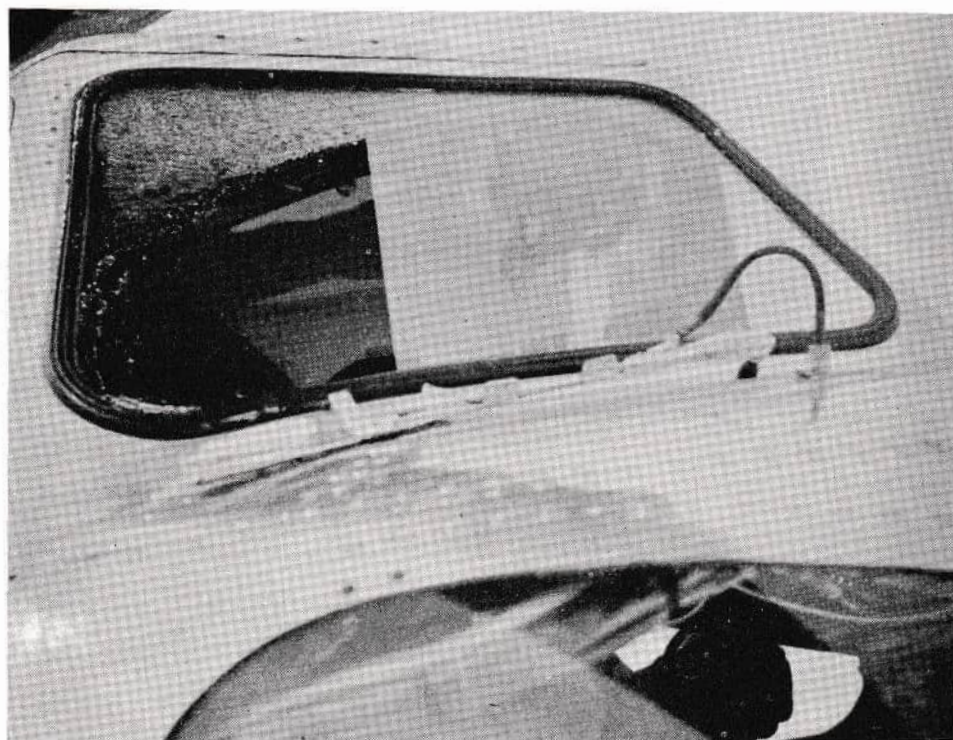
EXAMPLES OF RUN-BACK ICE



FREEZING RAIN ICE ACCRETION AT 15 M.P.H. T.A.S.
SHOWING HEATED WINDSCREEN AREA
WINDSCREEN THERMAL ANTI-ICING

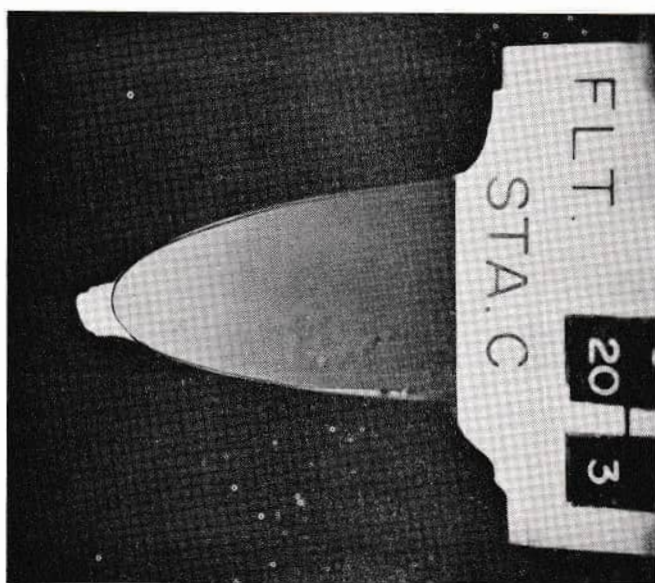
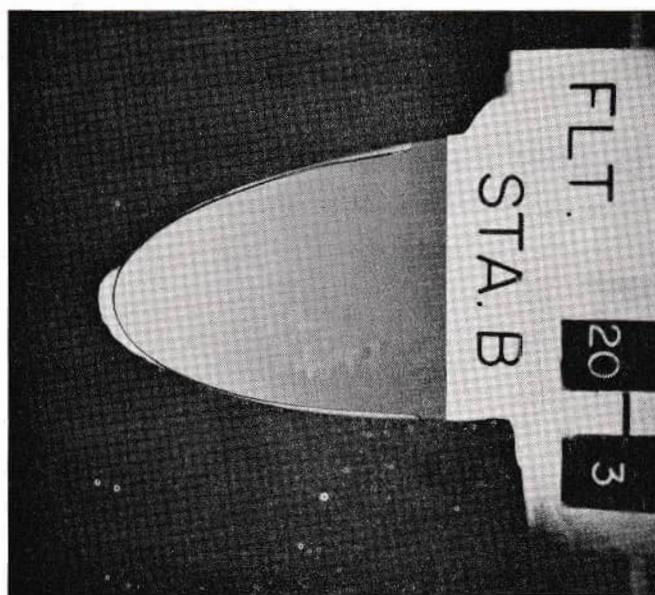


MUSHY ICE ON LOWER VISION PANELS



WINDSCREEN ANTI-ICING WITH ALCOHOL AND WIPER ACTION

FIG. 33
LR-221



TYPICAL RECORDS OBTAINED FROM ICE PROFILE MOULDS

APPENDIX A

ENGINEERING AND PERFORMANCE DATA FOR
BRISTOL SYCAMORE TYPE 171

Leading Particulars

Engine

Make - Alvis
Model - Leonides Mk. 173-02
Type - 9 cylinder air-cooled radial 550 b. hp.

Dimensions

Over-all length (blade folded)	46 ft. 2 in.
Over-all height (to top of tail rotor disc)	14 ft. 7 in.
Nominal fuselage ground clearance	1 ft. 7 in.
Wheel base	8 ft. 10 in.

Main Rotor

Diameter	48 ft. 7 in.
Disc area	1,860 sq. ft.
Gear ratio (engine to rotor)	11.15:1
Range of permissible rotor revolutions	Power on - 245-287 r. p. m. Power off - 210-287 r. p. m.

Tail Rotor

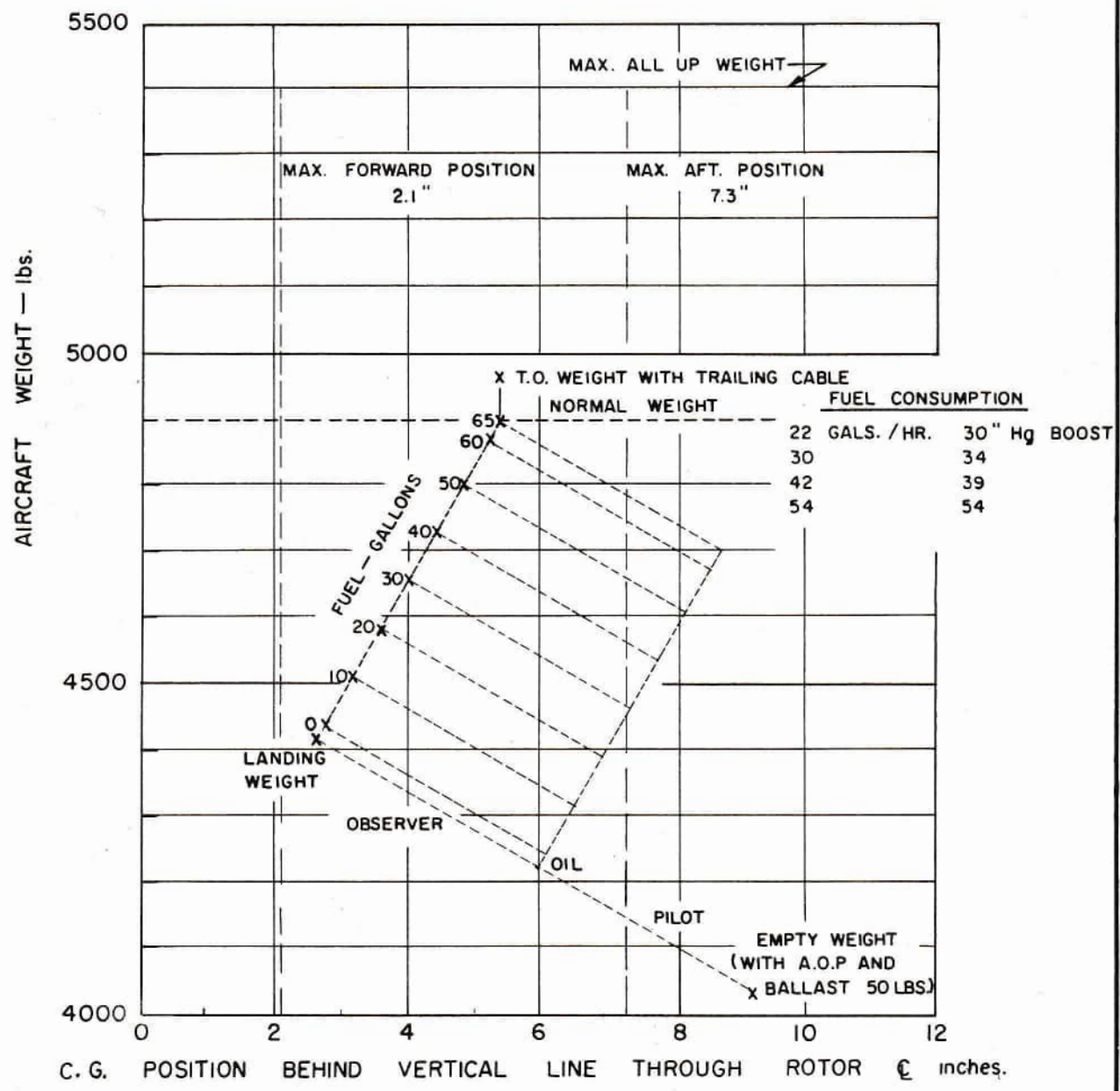
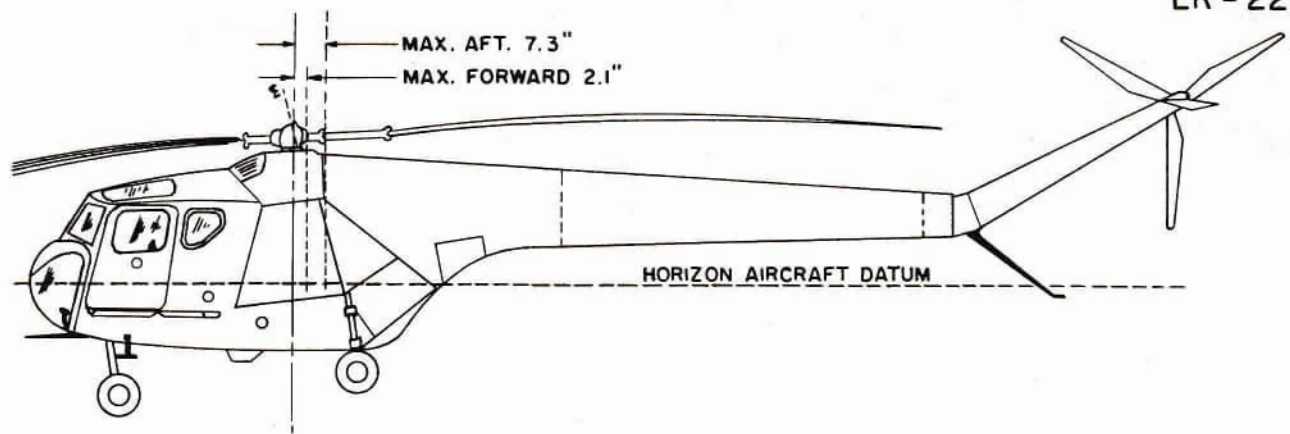
Diameter	9 ft. 7 in.
Disc area	73 sq. ft.
Gear ratio (engine to tail)	2.41:1

General

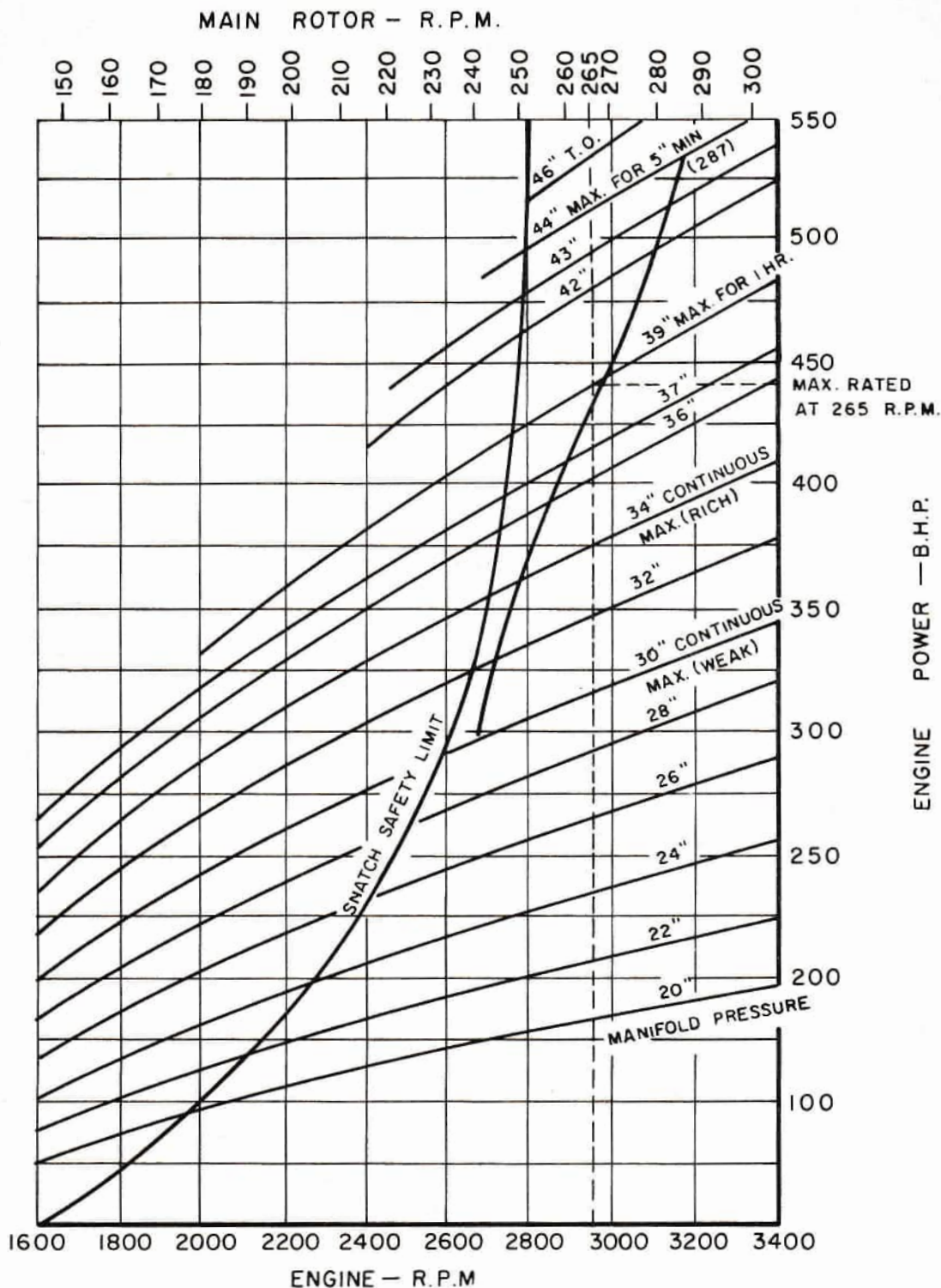
Maximum all-up weight	5,400 lb.
Maximum range - economical cruise	Normal fuel (65 gal.) 233 nautical miles

See also Figures A1 to A6.

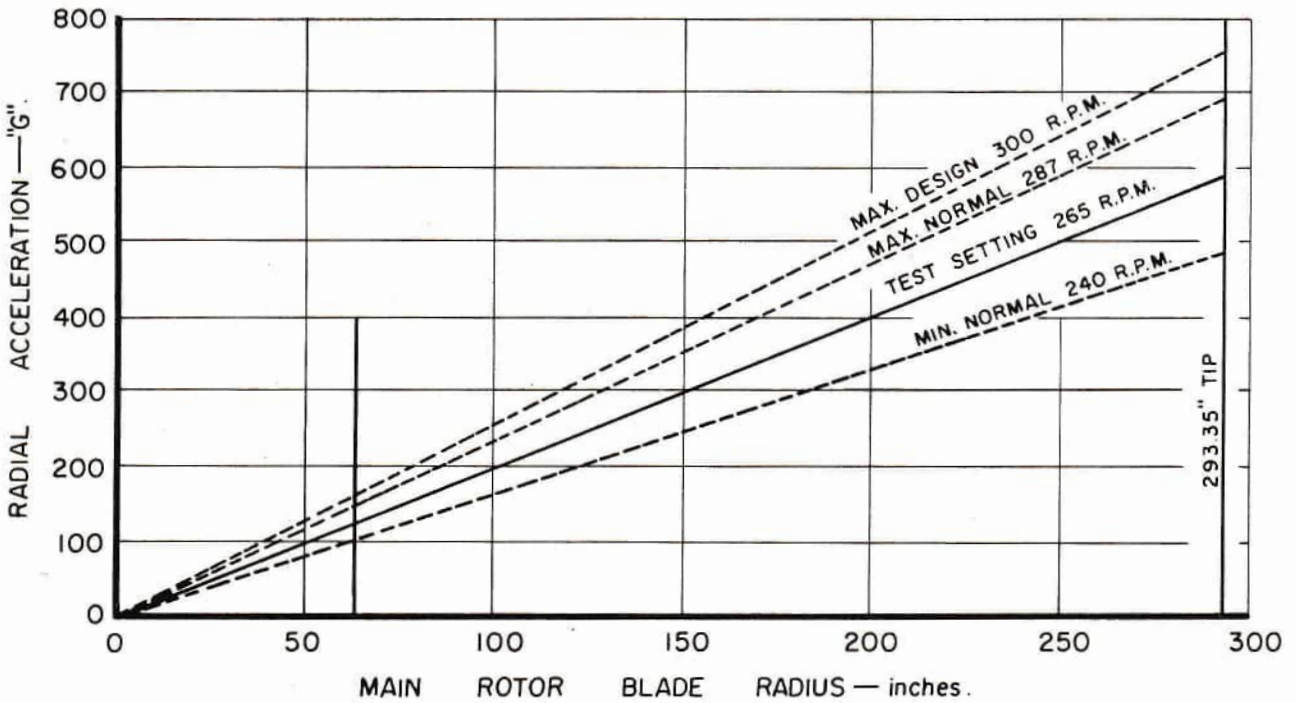
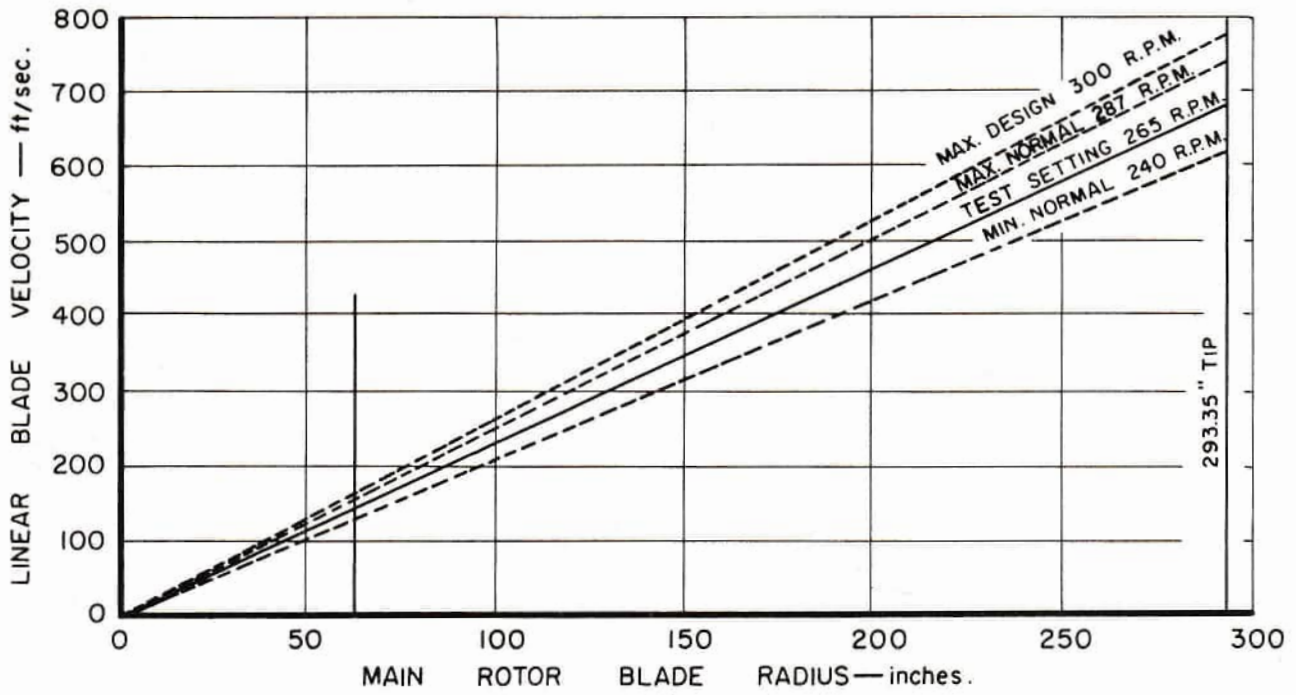
FIG. A1
LR-221



C. G. AND LOADING DIAGRAM

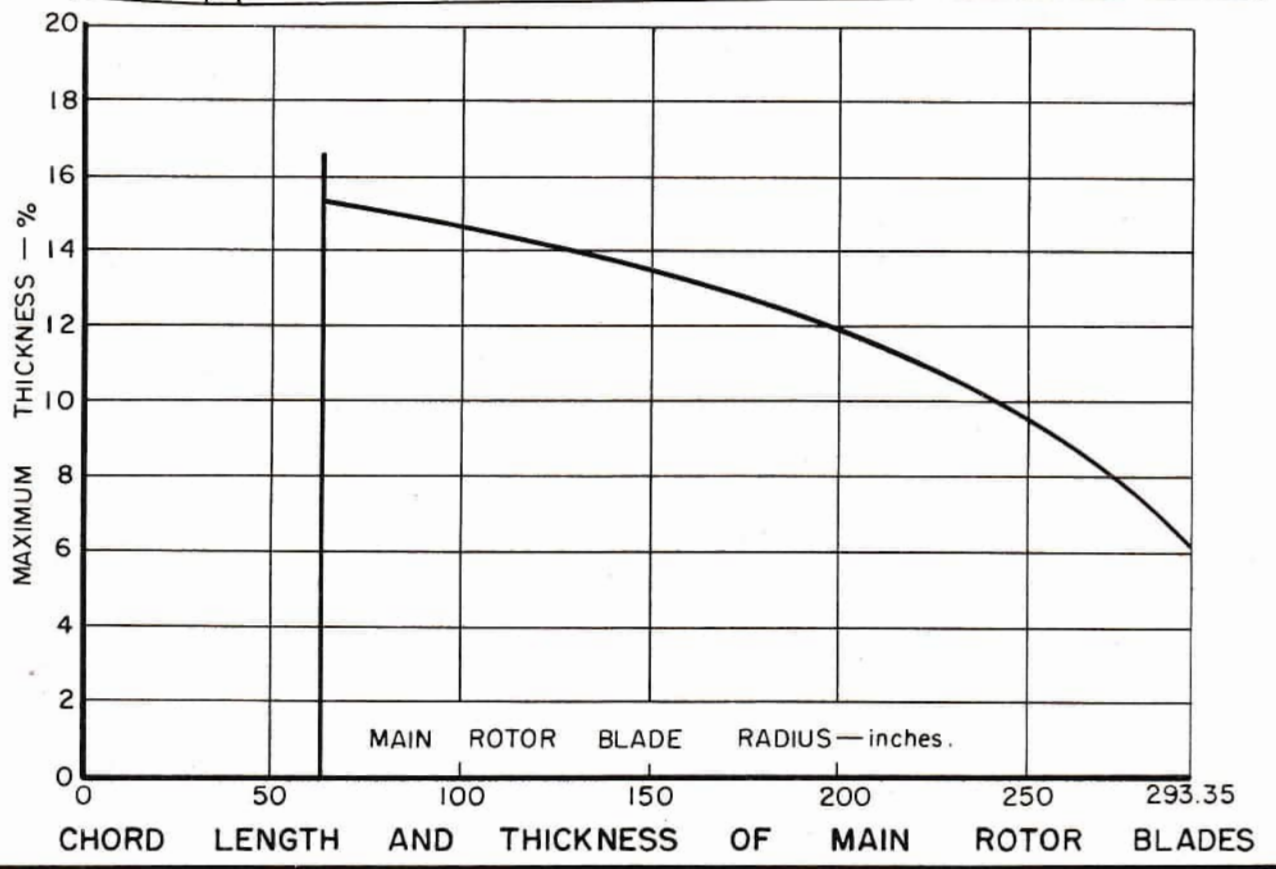
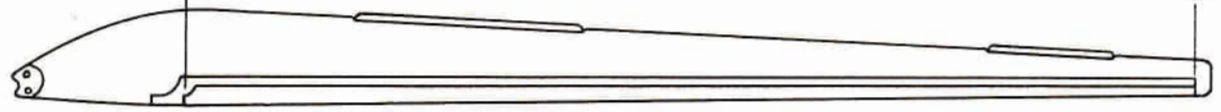
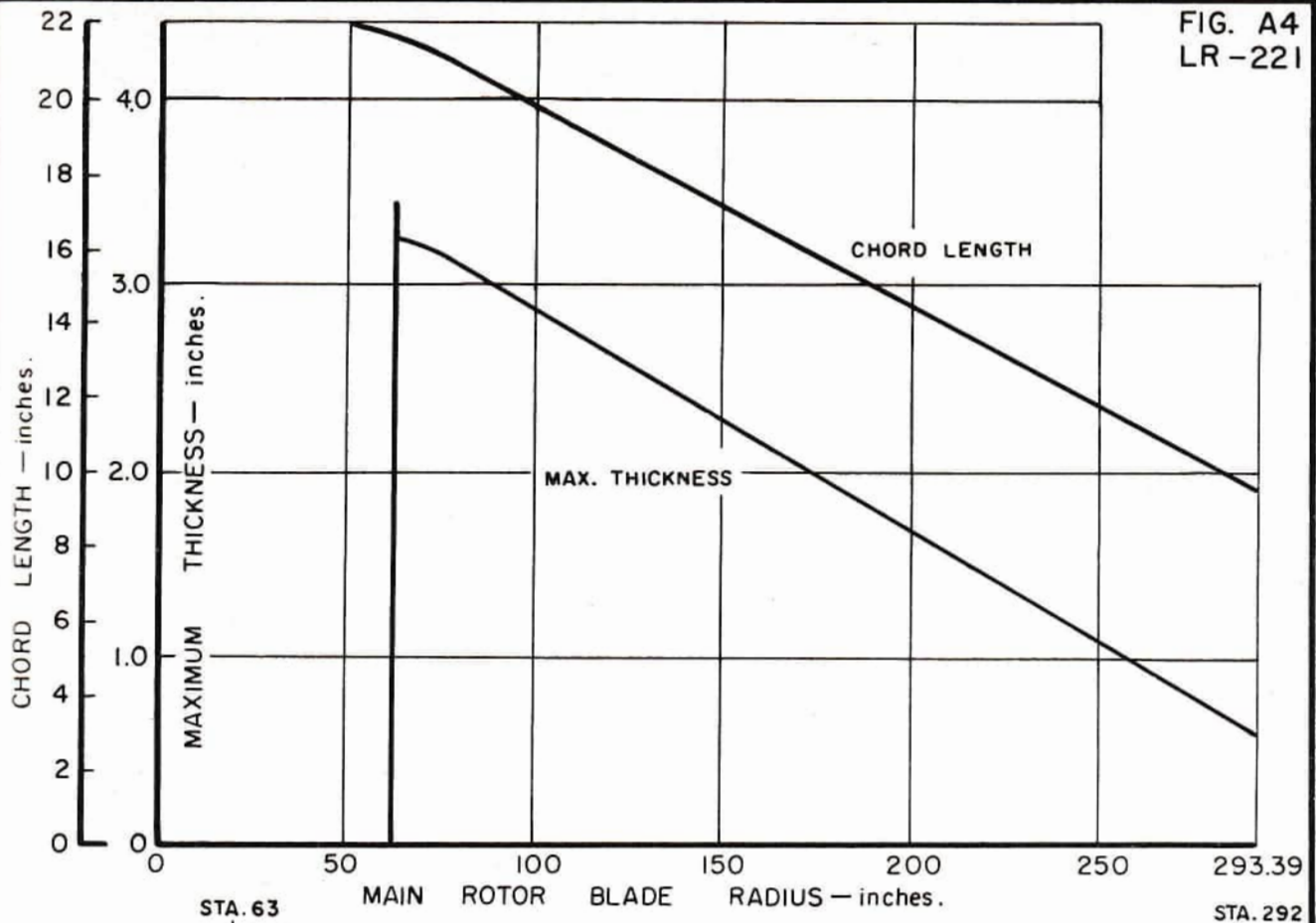


ALVIS LEONIDES 173.02 ENGINE PERFORMANCE
CHART AT SEA LEVEL

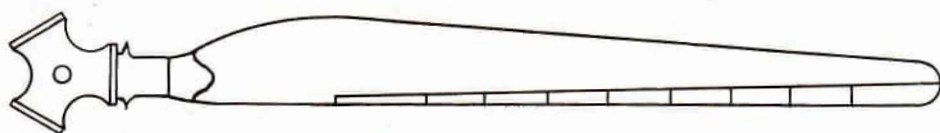


VARIATION OF LINEAR BLADE VELOCITY AND RADIAL ACCELERATION ALONG THE BLADE RADIUS OF THE MAIN ROTOR AT VARIOUS R.P.M.

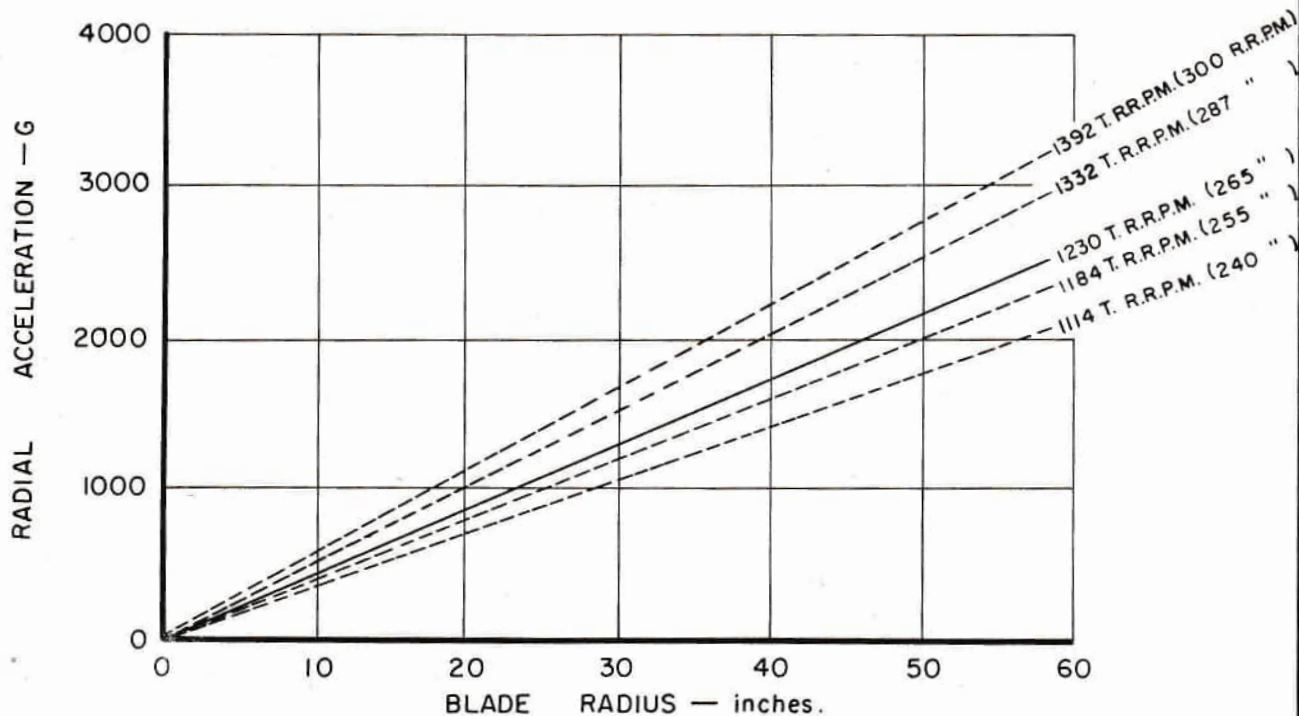
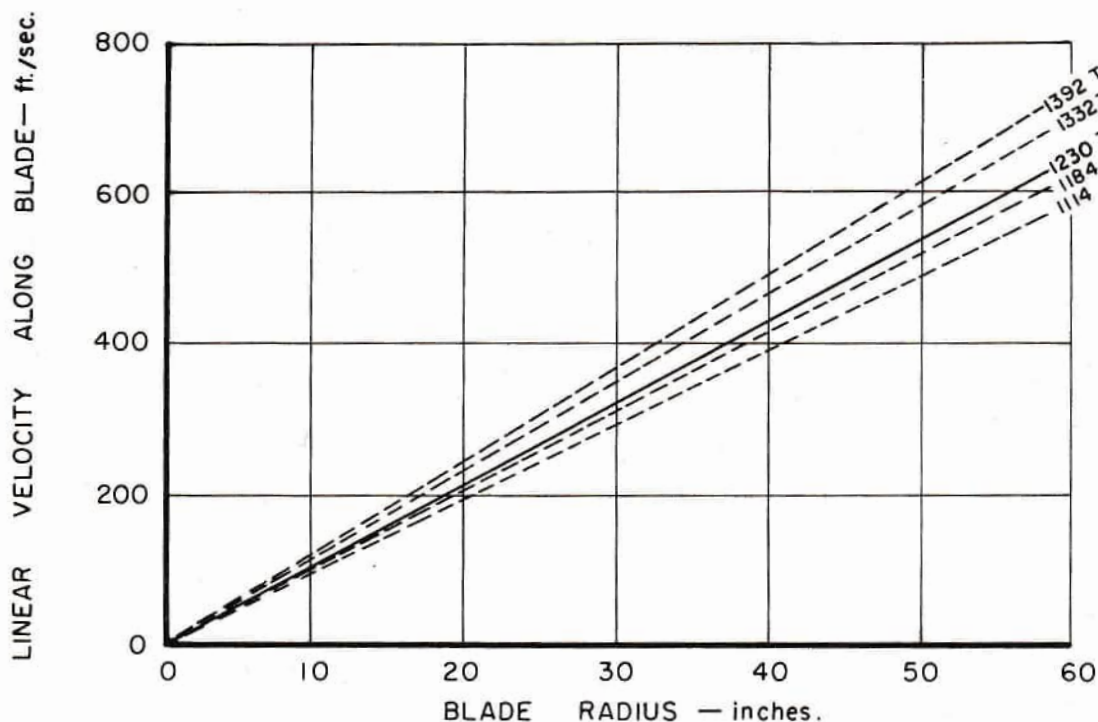
FIG. A4
LR-221



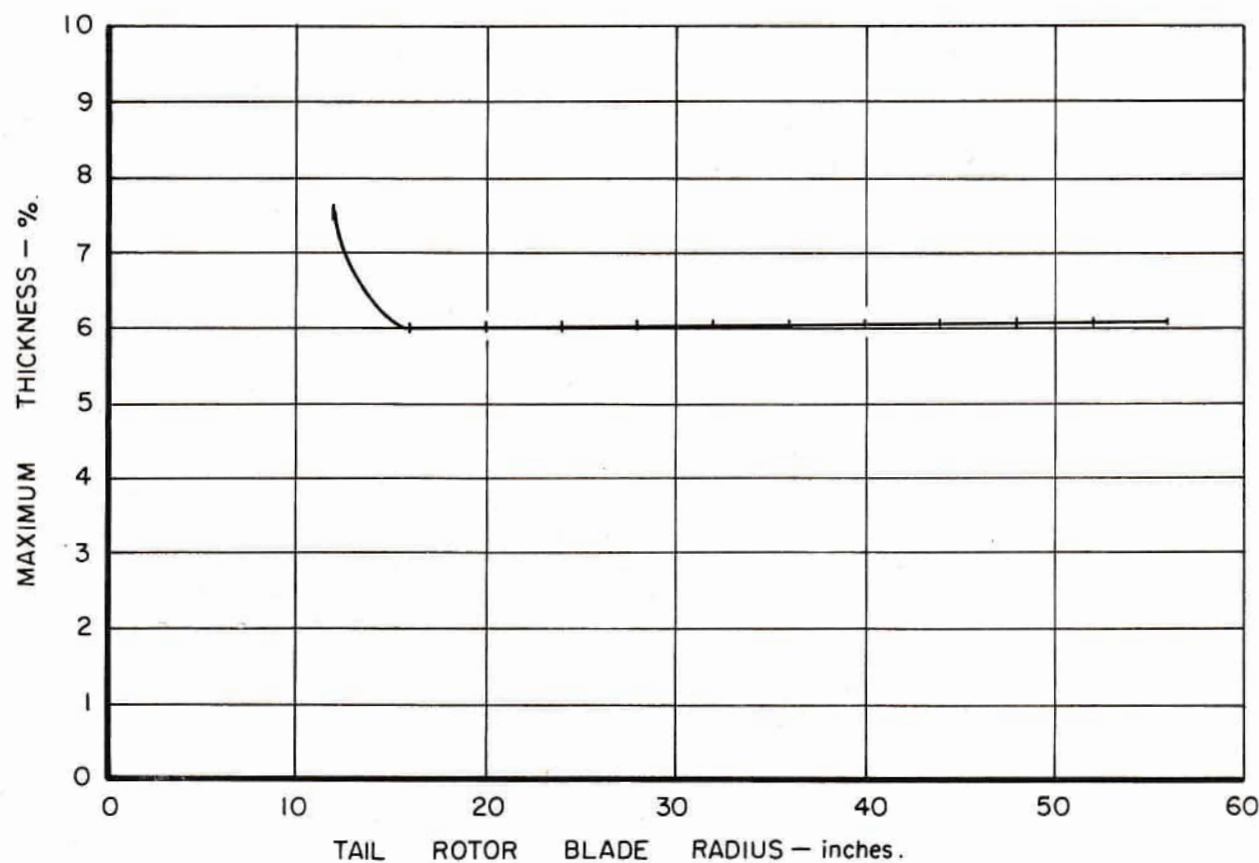
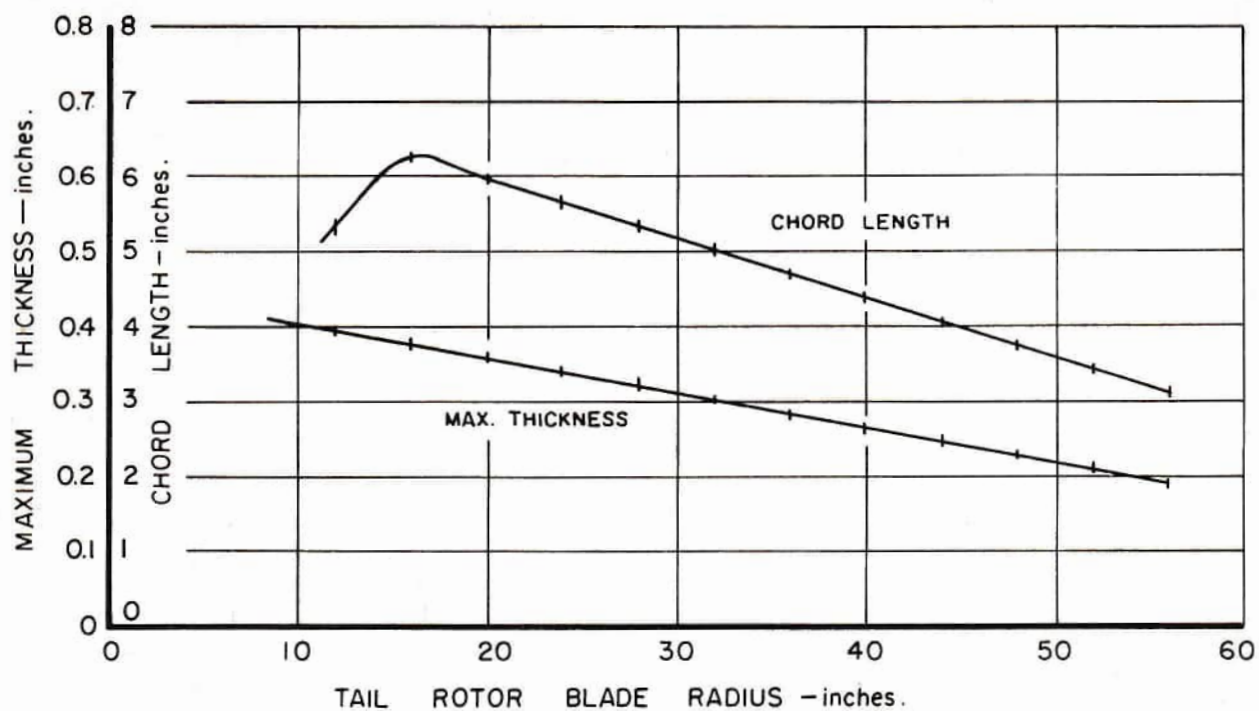
CHORD LENGTH AND THICKNESS OF MAIN ROTOR BLADES



TAIL ROTOR BLADE.



VARIATION OF LINEAR VELOCITY AND RADIAL ACCELERATION ALONG THE TAIL ROTOR BLADE AT VARIOUS R.P.M.



CHORD LENGTH AND THICKNESS OF TAIL ROTOR BLADE

APPENDIX B

EFFECT OF ICING AND DE-ICING ON AIRCRAFT HANDLING
FROM PILOT'S VIEWPOINT

(An abstract from the pilot's handling report by Major R. I. Walton, R. A.)

B. 1. 0 GENERAL

B. 1. 1 Flight during the tests was, of necessity, almost entirely by means of visual references. While results may show that there was little control problem under these conditions, unusual vibration and control movement could present a distraction to the pilot which would increase the already present difficulties of flight under I. F. R. conditions.

B. 2. 0 EFFECT OF ICE ACCRETION ON CONTROL

B. 2. 1 Flight with ice on the main and tail rotor blades had little effect on the handling of the aircraft, except control of r. p. m., provided shedding did not occur. There was a slight stiffening in the collective and cyclic pitch controls which was more noticeable at the lower ambient temperatures. This may have been due partly to the temperature and partly to the ice accretion, and was more evident, particularly in the UP direction, on the collective lever rather than the cyclic stick.

B. 2. 2 All main and tail rotor controls remained effective in spite of ice accretion, and on no occasion during the tests was the aircraft forced to descend other than to avoid continuous blind hovering.

B. 2. 3 At no time during the tests was ice accretion or shedding such that control of the aircraft was difficult except in two cases:

On several occasions early in the tests, the throttle control had to be opened against its stop in order to maintain r. p. m. On these occasions it was not possible to obtain more than 43 in. Hg of the maximum permissible inlet manifold pressure of 46 in. Hg. This condition occurred when the wind was high (20 to 30 m. p. h.), and the collective lever was relatively low. Thus the pressure was probably limited by the throttle/pitch linkage through the boost control unit. The fact that the aircraft was not forced down was probably due to self-shedding. Without intentional or self-shedding, it would probably not be possible to maintain r. p. m. for other than quite short periods in some icing conditions.

After a flight in simulated freezing rain, the aircraft was flown back to the hangar. On increasing forward speed to about 20 knots, there was a marked decrease in lateral stability. Speed had to be reduced quickly, whereupon the

tendency disappeared. No reason for this was found. There was a considerable amount of ice on the aircraft, which had not been de-iced, and the windscreens (including side panels) were, except for the area of the electric de-icer, well iced. Visibility was thus very restricted and some sort of vertigo may have been a factor in the incident. The pilot was not fatigued, as only 20 minutes' flying in the freezing rain had been done that day. There was little wind and no turbulence. The incident may indicate that icing conditions can exist which can present a problem with increased forward speed.

B. 2. 4 The build-up of ice on the main rotor blades tended to cause a drop in r. p. m. but little change in height. Control corrections, other than those to counteract turbulent conditions, were thus made mainly with the throttle. No significant progressive increase in collective pitch was necessary to correct for ice accretion.

B. 3. 0 SHEDDING (MAIN ROTOR)

B. 3. 1 During intentional shedding of ice from the main rotor, little effect was normally noticed on the controls other than the necessity to reduce the throttle setting to avoid an increase in r. p. m. When the optimum de-icing cycle had been determined, throttle movement was reduced to a comfortable minimum. When large amounts of ice were allowed to build up before shedding, large and fairly rapid throttle movement on shedding was necessary. A slight airframe shudder was sometimes felt during, and for short periods after, shedding. This was probably due to the fact that ice shed earlier or more extensively from one blade than from the others. Often the small pieces of ice could be seen flying off the rotor.

B. 3. 2 At higher ambient temperatures, self-shedding took place. This was not always symmetrical on all three blades. During asymmetric self-shedding there was, at times, slight feedback to the cyclic stick accompanied by moderate shaking of the aircraft similar to that normally attributable to uneven dampers. The oscillation appeared to be mainly lateral and died away as the ice reformed. The frequency, as estimated by the observer, appeared to be about one per two main rotor revolutions.

B. 3. 3 Insufficient flights were made under suitable conditions to assess the effect of intentional asymmetric or symmetric zone shedding. However, experience with partial asymmetric self-shedding indicates that if one blade remains fully iced while the others are completely shed, severe vibration and control feedback will probably occur.

B. 3. 4 A slight tendency to ground resonance was noticed when landing with asymmetric ice.

B. 4. 0 SHEDDING (TAIL ROTOR)

B. 4. 1 During many of the tests, the positioning of the aircraft had to be such

that the tail rotor was outside the icing cloud. When the tail rotor was in the cloud, however, it picked up ice which was self-shedding at the medium and higher ambient temperatures. Self-shedding was usually asymmetric to some extent, and this was thought to be the cause of some airframe vibration. There was no feedback to the tail rotor pedals, however.

B. 4. 2 On one occasion, at a very low ambient temperature, a large amount of ice had formed on the tail rotor, but no self-shedding had taken place. The aircraft stood in the sun for some time with the rotor stopped while the ice was inspected. On restarting the rotor, severe airframe vibration occurred which necessitated the immediate stopping of the rotor. The cause was found to be total self-shedding of one blade only. The ice had probably been loosened by the sun. If self-shedding of this magnitude occurred on one blade in flight, the aircraft would have to land at once.

B. 5. 0 VIBRATION

It was not possible to say with any certainty what was the cause of the airframe vibrations which were sometimes experienced. Most of the vibrations were similar to those often experienced during hovering in clear air at critical wind speeds and heights above the ground. It was felt that most vibrations were, at least partially, of this nature and not entirely due to ice. The severe turbulence experienced on the test site was probably also a contributory factor in making the vibrations intermittent, and thus liable to confusion with shedding cycles.

B. 6. 0 C. F. DROOP STOPS

The C. F. droop stops did not fail to operate during the tests, but it was felt that they were inclined to be sluggish at the lower ambient temperatures. Cases occurred when they would not come out by the time the maximum r. p. m. (130 r. p. m.) allowed with the stops in was reached, and the cyclic stick had to be used to encourage them. It was difficult to say whether these effects were due to stiffness at the low temperature, ice on the arms or weights of the stops, or reduced main rotor coning angle due to ice on the blades.

B. 7. 0 WINDSCREEN ANTI-ICING

B. 7. 1 The electric windscreen anti-icer was successful in clearing the pilot's windscreen and keeping it clear even under conditions of freezing rain. Clearance, however, took an appreciable time. The position of the de-icer was not satisfactory as the pilot had to lower his head to see out the port side of the windscreen. It was felt that the top line of the de-icer should have been horizontal so that it could be used as a flight reference.

B. 7. 2 The fluid anti-icers on the windscreen wipers were also successful in keeping the windscreens clear of ice, but not so effective in removing thick ice

which had already formed. The distribution of fluid was wasteful, being concentrated on one part of the wiper blades. The fluid ran down onto the lower front perspex where it evaporated, thus preventing clear vision through that window.

B. 8.0 FLIGHT IN THE CLOUD

B. 8.1 Trimming

Before the first morning and afternoon cloud flights of the day, the aircraft was hovered at 50 feet outside the cloud and the trimmers were adjusted to minimize the possibility of flying into the rig when temporarily blinded by the cloud.

B. 8.2 Blind Flying

The state of the art of instrument flying in helicopters, except possibly with the aid of a special auto-pilot, was such that all flights had to be made with visual references for the pilot. Blind flying instruments were not used at all, the pilot's attention being fully engaged in watching the rotor tachometer, inlet manifold pressure gauge, and in cycling the windows for visual references of position and attitude. Under certain conditions, with practice, it was found possible by "freezing onto the controls" to remain completely blind for periods of say 4 to 5 seconds, after which one of the windows usually had a visual reference. If no visual reference appeared after that time, the cloud was left as rapidly as possible and in a direction consistent with not striking the rig or any of the other obstacles near the site. The intention was to fly with the rotor in the cloud but with the cockpit outside it, although this was rarely possible for any length of time.

B. 8.3 Visual References

Visual references were used through both door windows in addition to the front windscreens and bottom perspex. References on the sides could be confusing if the wind changed, if the aircraft was turned on the spot, or if the references were a long way away. Things which were obstacles in one wind direction could thus become useful references in another wind direction. The best references were the mast itself, viewed through the front windscreens, and the control hut and guy rope anchor points, seen through the bottom perspex (Fig. B-1). If the outermost anchor point was visible through the bottom perspex, it could be safely assumed that the rotor, though close, was not going to touch the rig unless the wind direction had changed during the flight. When the rig had not been rotated with the wind - and this was not always possible in fluctuating winds - the forward end of the lattice could constitute a hazard to the main rotor. On one occasion the guy ropes were anchored to points downwind of the rig, and while they made good references, they were a hazard to the main rotor. The references visible through the bottom perspex were more often used when the wind speed was low and the front windscreens were more frequently in cloud. Without the bottom perspex, flying would have been very much more difficult. The coils of the power cable, being

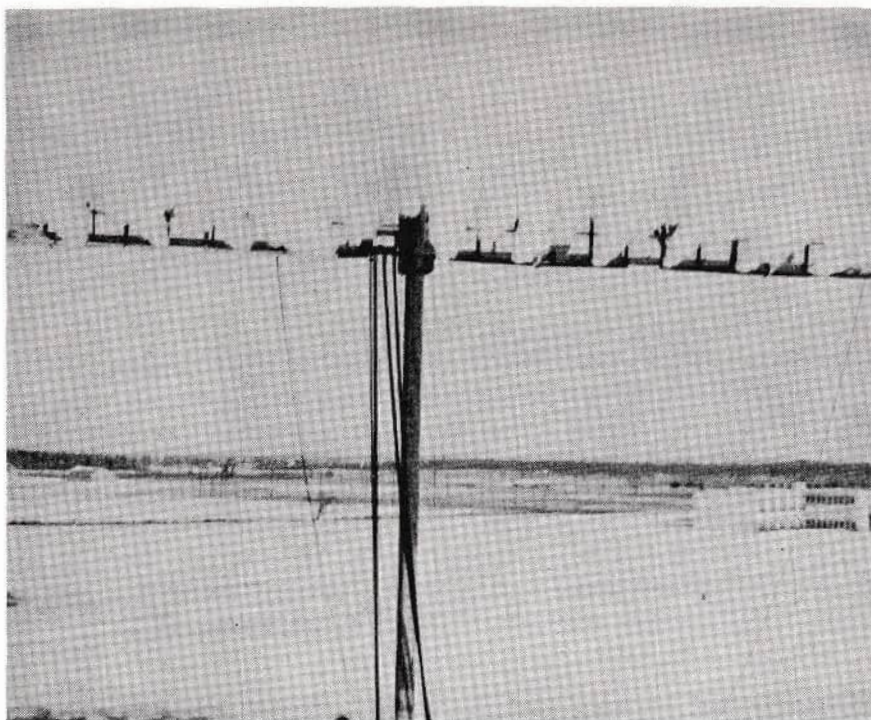
black against the snowy ground, also provided a useful method of orientation. It was sometimes necessary to make a turn on the spot in order to place a reference in a more convenient window.

Visibility and ground surface condition were large factors in rapid orientation after periods of fully blind flying. The best conditions were found when the sky was blue and the ground free from blowing snow and ice, both conditions forming good contrast with the cloud. If the ground was covered with snow, it was best when rolled, as the lines of the rolling were helpful. The sun on clear days was blinding when low and behind the rig. It was then better to break cloud in the shadow of the cloud if the sun was not too low for a shadow to form.

There was a tendency to prefer references visible through the port rather than the starboard window. Blowing snow did not normally affect flying in the cloud, but was difficult for landings. On one particular occasion, when there was a thin layer of snow crystals on the ground, little wind, and a grey sky with intermittent light snow, the cloud was pulled over the cockpit. A descent was made together with a rotation in anticipation of sighting a coil of power cable through the port side of the bottom perspex. The aircraft did not break cloud, however, as unknown to the pilot a cloud of loose snow was formed on entering the ground cushion. The aircraft struck the ground with the pilot still unable to see any visual references. Fortunately no damage resulted, but this type of weather condition was thereafter considered unsuitable for the tests.

The Windscreens

Except during the freezing rain tests very little windscreen icing occurred. This was probably due to the fact that the cockpit was only in the cloud for short periods. The bottom perspex usually remained quite clear. Any icing was in the form of small crystals sticking to the glass. This occurred on the door windows as well as on the front windscreens, but only once was the quantity sufficient to impair visibility significantly. The electric anti-icer was able to maintain a clear area even in the freezing rain.



(a) PILOT'S VIEW OF RIG WITH CORRECT WIND SPEED



(b) GENERAL VIEW FROM THE AIR OF HUT INSTALLATION

PILOT'S VIEW FROM AIRCRAFT DURING ICING FLIGHT

APPENDIX C

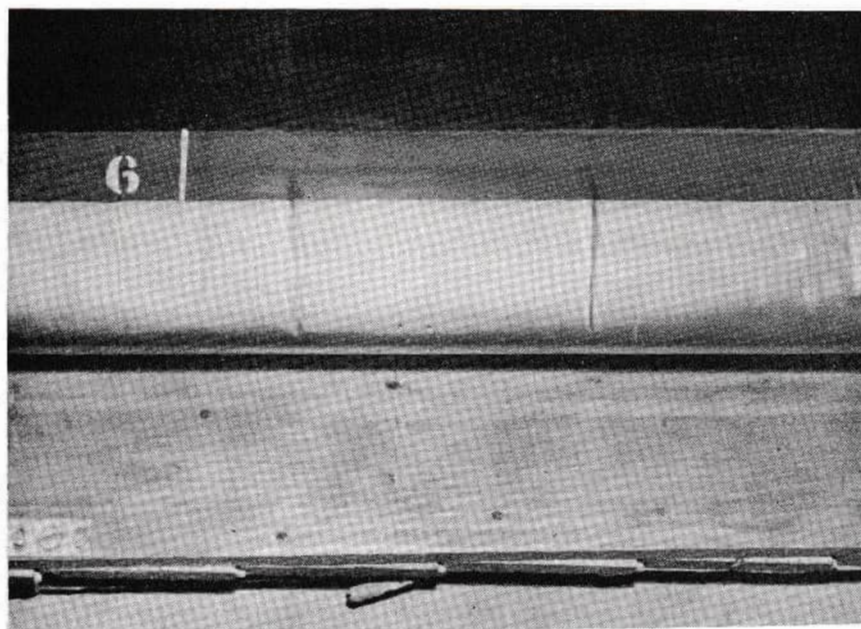
DE-ICER PAD FAILURE

The creases (Fig. C1(a)) which developed in the stainless steel erosion shield after installation of the protected blades on the aircraft were the first indication of pad deterioration. Blade flapping and the droop which occurs after stopping the rotor caused cracks to develop along these creases (Fig. C1(b), C2(a)). Cracks also developed in the nichrome strips of the heater element (Fig. C2(b)), producing open circuits. In one instance flexing of the blade while the power was switched on caused a broken strip to make contact and produce arcing. This burned away the insulation and produced a conductive film which, together with the outer sheath, sustained the short and burned the wooden veneer under the pad at that point (Fig. C3).

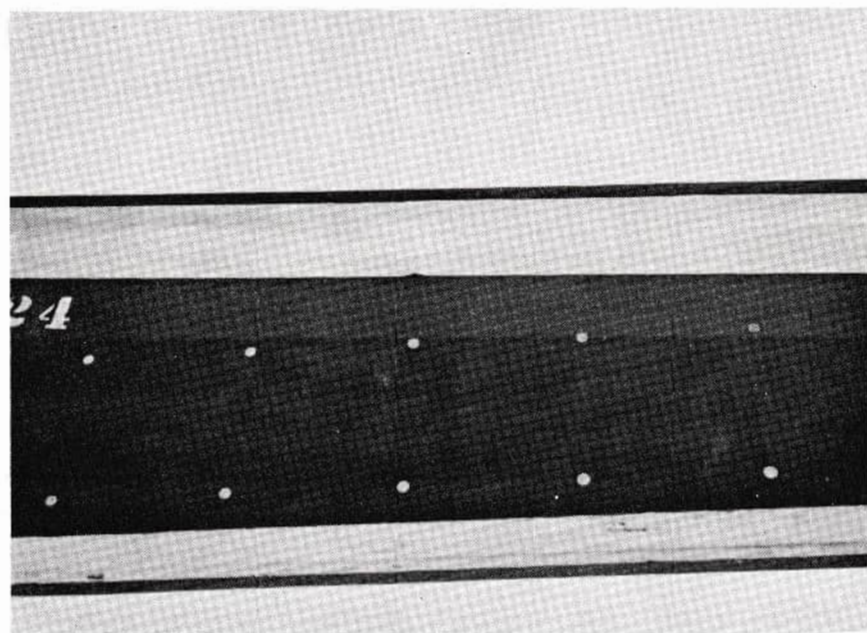
The majority of the creases developed where the angular deformation was greatest. Two of the blade elements failed at about Station 250, the first after 8 hours, 20 minutes, the second after 9 hours, 40 minutes. Surprisingly, the third blade did not develop creases in this region and a suitable explanation cannot be given. It remained serviceable throughout the test programme.

To prevent further cracks from developing in the outer shield a repair scheme was tried in which the metal around a crease was removed and a neoprene patch cemented over the area (Fig. C4(a)). This was not successful as further cracks developed. Removal of the metal erosion shield also caused local delamination between the insulation and the element.

In the case of a broken heater strip the insulation was removed locally and a nichrome strip spot-welded over the gap. A neoprene patch was then cemented over the repair. Figure C4(b) shows such a repair. This repair failed after a further 12 hours flying.

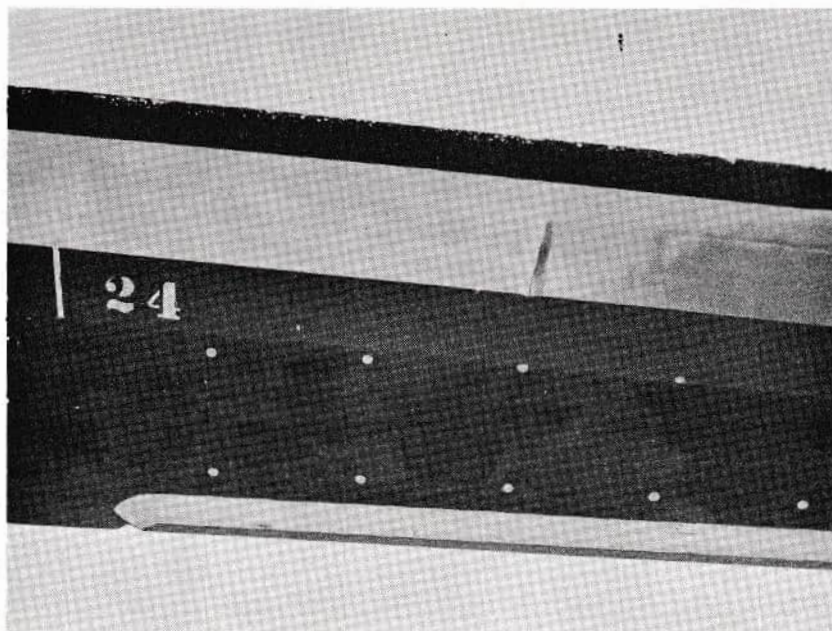


(a) CREASES WHICH DEVELOPED IN STAINLESS STEEL COVER

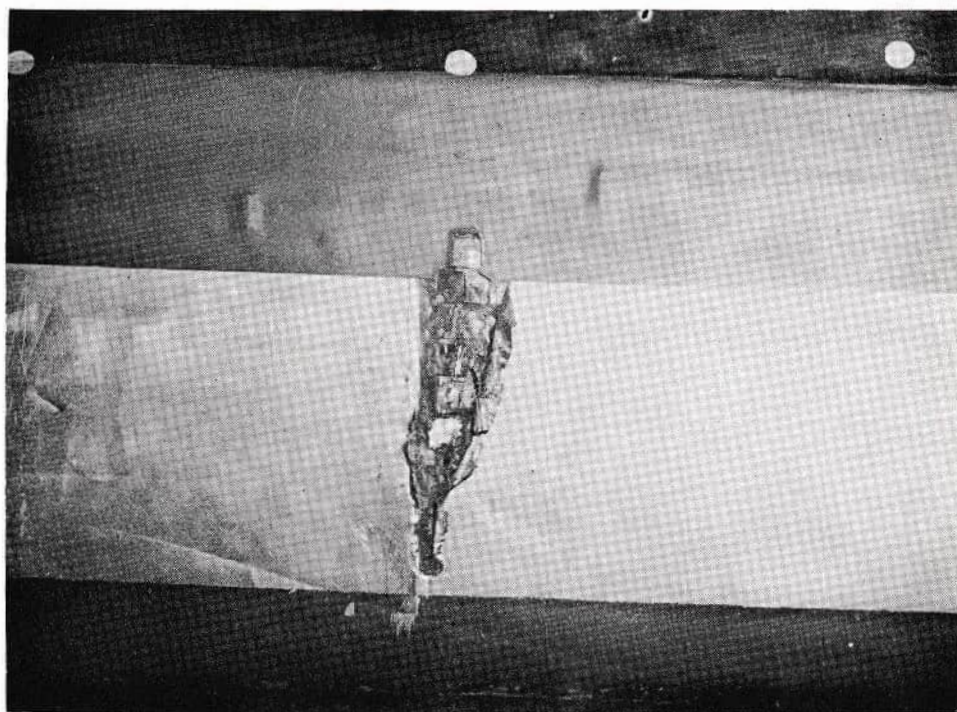


(b) CRACKING AND LIFTING OF STAINLESS STEEL COVER
DUE TO BLADE FLEXING

DE-ICER PAD DETERIORATION

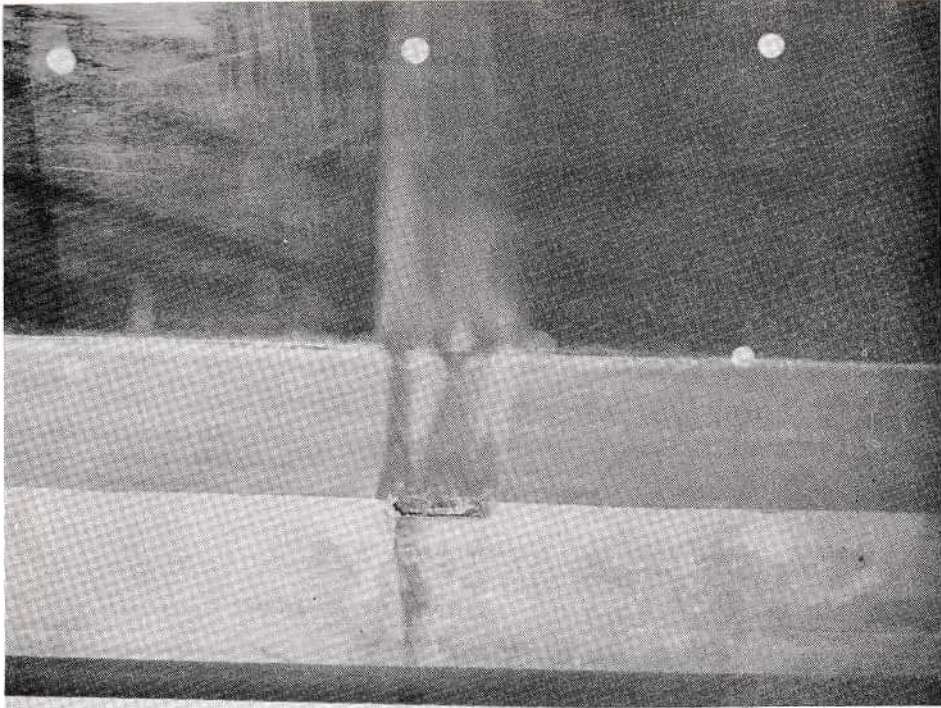


(a) SHOWING HOW CRACKS DEVELOPED ALONG CREASES

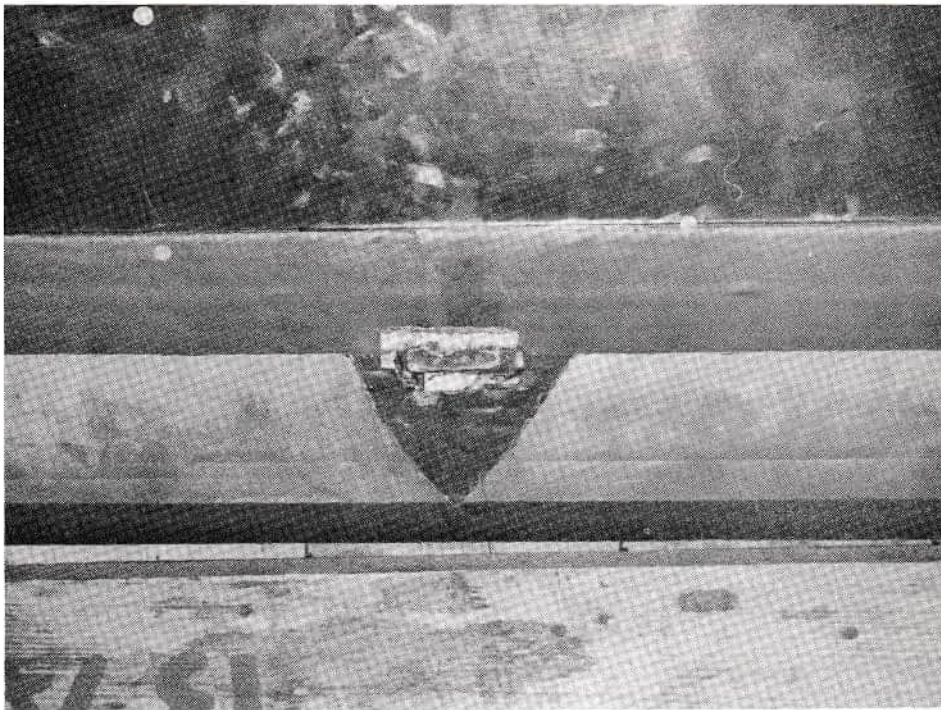


(b) CRACKS IN NICHROME HEATER ELEMENT

DE-ICER PAD FAILURE

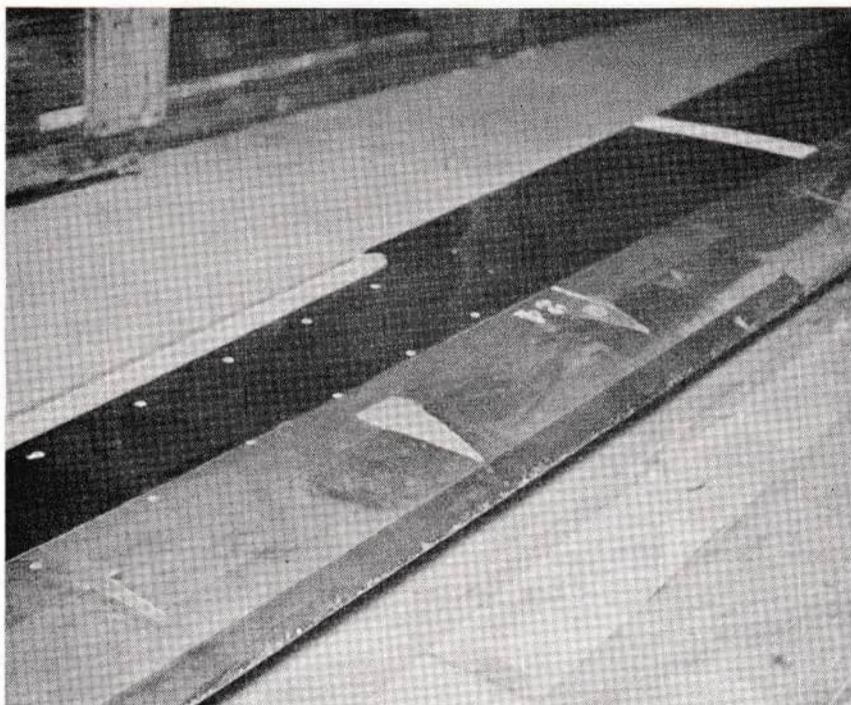


(a)

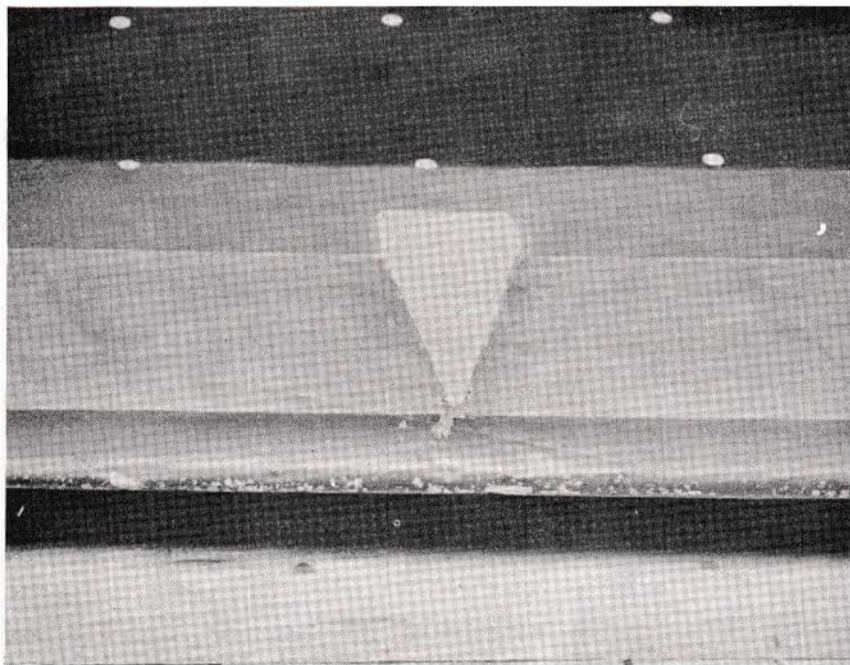


(b)

DAMAGE TO WOODEN BLADE DUE TO SHORT CIRCUIT



(a) REPAIR SCHEME FOR REMOVAL OF CREASES



(b) REPAIR OF A BROKEN HEATER ELEMENT

(NOTE IMPACT DAMAGE DUE TO ICE THROWN FROM TAIL
ROTOR INTO PATH OF MAIN ROTOR)

REPAIRS TO MAIN ROTOR DE-ICER PAD

<p>NAE LR-221 National Aeronautical Establishment, Canada.</p> <p>HELICOPTER ICING AND DE-ICING FLIGHT TRIALS ON A BRISTOL SYCAMORE TYPE 171, MK. 3 J. M. H. Heines, D. L. Bailey and J. R. Stallabrass. May 1958. 28 p. + 6 tabs. + 44 figs. (Lab. Rept. LR-221)</p> <p>A Sycamore helicopter fitted with an electro-thermal de-icing system was tested under different simulated conditions of icing severity over a wide range of temperatures. The effect of icing on handling and performance was assessed and power requirement for clean shedding was determined.</p> <p>The de-icer pads had a low fatigue life due to the flexibility of the main rotor blades. Flexing caused creasing of the erosion shield and cracking of the nichrome heater elements.</p>	<p style="text-align: center;"><u>CONFIDENTIAL</u></p> <ol style="list-style-type: none"> I. Icing, Rotor 2. Icing - Prevention 3. Helicopters (Bristol Sycamore 171) <ol style="list-style-type: none"> I. Heines, J. M. H. II. Bailey, D. L. III. Stallabrass, J. R. IV. NAE LR-221 	<p>NAE LR-221 National Aeronautical Establishment, Canada.</p> <p>HELICOPTER ICING AND DE-ICING FLIGHT TRIALS ON A BRISTOL SYCAMORE TYPE 171, MK. 3 J. M. H. Heines, D. L. Bailey and J. R. Stallabrass. May 1958. 28 p. + 6 tabs. + 44 figs. (Lab. Rept. LR-221)</p> <p>A Sycamore helicopter fitted with an electro-thermal de-icing system was tested under different simulated conditions of icing severity over a wide range of temperatures. The effect of icing on handling and performance was assessed and power requirement for clean shedding was determined.</p> <p>The de-icer pads had a low fatigue life due to the flexibility of the main rotor blades. Flexing caused creasing of the erosion shield and cracking of the nichrome heater elements.</p>	<p style="text-align: center;"><u>CONFIDENTIAL</u></p> <ol style="list-style-type: none"> 1. Icing, Rotor 2. Icing - Prevention 3. Helicopters (Bristol Sycamore 171) <ol style="list-style-type: none"> I. Heines, J. M. H. II. Bailey, D. L. III. Stallabrass, J. R. IV. NAE LR-221
<p>NAE LR-221 National Aeronautical Establishment, Canada.</p> <p>HELICOPTER ICING AND DE-ICING FLIGHT TRIALS ON A BRISTOL SYCAMORE TYPE 171, MK. 3 J. M. H. Heines, D. L. Bailey and J. R. Stallabrass. May 1958. 28 p. + 6 tabs. + 44 figs. (Lab. Rept. LR-221)</p> <p>A Sycamore helicopter fitted with an electro-thermal de-icing system was tested under different simulated conditions of icing severity over a wide range of temperatures. The effect of icing on handling and performance was assessed and power requirement for clean shedding was determined.</p> <p>The de-icer pads had a low fatigue life due to the flexibility of the main rotor blades. Flexing caused creasing of the erosion shield and cracking of the nichrome heater elements.</p>	<p style="text-align: center;"><u>CONFIDENTIAL</u></p> <ol style="list-style-type: none"> 1. Icing, Rotor 2. Icing - Prevention 3. Helicopters (Bristol Sycamore 171) <ol style="list-style-type: none"> I. Heines, J. M. H. II. Bailey, D. L. III. Stallabrass, J. R. IV. NAE LR-221 	<p>NAE LR-221 National Aeronautical Establishment, Canada.</p> <p>HELICOPTER ICING AND DE-ICING FLIGHT TRIALS ON A BRISTOL SYCAMORE TYPE 171, MK. 3 J. M. H. Heines, D. L. Bailey and J. R. Stallabrass. May 1958. 28 p. + 6 tabs. + 44 figs. (Lab. Rept. LR-221)</p> <p>A Sycamore helicopter fitted with an electro-thermal de-icing system was tested under different simulated conditions of icing severity over a wide range of temperatures. The effect of icing on handling and performance was assessed and power requirement for clean shedding was determined.</p> <p>The de-icer pads had a low fatigue life due to the flexibility of the main rotor blades. Flexing caused creasing of the erosion shield and cracking of the nichrome heater elements.</p>	<p style="text-align: center;"><u>CONFIDENTIAL</u></p> <ol style="list-style-type: none"> 1. Icing, Rotor 2. Icing - Prevention 3. Helicopters (Bristol Sycamore 171) <ol style="list-style-type: none"> I. Heines, J. M. H. II. Bailey, D. L. III. Stallabrass, J. R. IV. NAE LR-221