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Publisher's version / Version de l'éditeur:

<https://doi.org/10.4224/40004027>

Aeronautical Report (National Research Council Canada. National Aeronautical Establishment); no. LR-356, 1962-10

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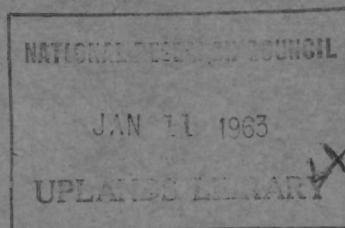
LR - 356

ICING FLIGHT TESTS OF A
FLUID ROTOR BLADE ICE PROTECTION SYSTEM
ON A WESTLAND WESSEX HELICOPTER

BY

G. A. GIBBARD

DIVISION OF MECHANICAL ENGINEERING



OTTAWA

OCTOBER 1962

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19613

NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

Low Temperature Laboratory

Pages - Preface - 3
Text - 11
App. - 2
Tables - 1
Figures - 10

LIMITED

Report: LR-356
Date: October 1962
Lab. Order: 14329A
File: CM4-A3-R26

For: Ministry of Aviation, Aeroplane & Armament Experimental
Establishment, Boscombe Down, Salisbury, Wilts, England.

Reference: Letter to Mr. J. J. Samolewicz dated 21 December 1960, on
file CM4-A3-R26.

Subject: ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE
PROTECTION SYSTEM ON A WESTLAND WESSEX
HELICOPTER.

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SUMMARY

A Westland Wessex helicopter equipped with a fluid ice protection system for the main and tail rotor blades was flight tested in an artificial icing cloud. The tests indicated that icing protection will be required on this helicopter at temperatures less than -5°C , because of the effects of uncontrolled shedding of large chunks of ice from the rotor blades. The installed fluid anti-icing system was not able to prevent ice from forming because of poor distribution of fluid over the leading edge of the rotor blades.

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ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A WESTLAND WESSEX HELICOPTER

1.0 INTRODUCTION

During November and December, 1961, and January, 1962, a Westland Wessex Mk. 1 helicopter, equipped with a fluid rotor blade ice protection system, was flight tested at the National Research Council's Helicopter Spray Rig. Another Wessex, equipped with an electro-thermal de-icing system, had been tested in the same rig the previous winter (Ref. 1), and it had been found that icing protection would be required on this helicopter because of the effects of uncontrolled shedding of ice from the rotor blades. The electro-thermal system had operated adequately, but it was complicated, expensive and heavy. The development of the fluid system was made in an effort to overcome these objections.

The trials were made on behalf of the British Ministry of Aviation who supplied the aircraft, pilot, and maintenance and test personnel. Westland Aircraft Ltd. also provided an observer for the icing tests, while N. R. C. personnel were responsible for the operation of the spray rig and the over-all supervision of the icing trials.

The test programme was based on the method stated in Reference 2. The meteorological test conditions laid down by this test instruction conformed with the continuous maximum icing standard outlined in the British Civil Airworthiness Requirements. Using these specifications, tests were made to determine the fluid flow requirements for icing prevention on the rotor blades and a number of different fluids were used to determine their relative merits. This report presents the results of these tests.

2.0 PURPOSE

- (i) To determine the feasibility of using a fluid ice protection system on the Westland Wessex helicopter by investigating the effectiveness of the system in keeping thick ice accretions from building up on the rotor blades under various icing conditions.
- (ii) To determine the minimum anti-icing fluid flow rate required to prevent thick ice from accreting on the rotor blades in order to determine the weight penalty of the fluid required.
- (iii) To investigate the possibility of using the fluid system for de-icing.
- (iv) To investigate a number of different anti-icing fluids in order to determine their relative effectiveness.

3.0 TEST EQUIPMENT

3.1 Aircraft

The aircraft used was a Westland Wessex H.A.S. Mk. 1 helicopter (Fig. 1) powered by a Napier Gazelle (Mk. 160) free turbine engine. The maximum all-up weight of the helicopter was 12,600 lb.

The 4-bladed main rotor was 56 ft. in diameter with a constant blade chord of 16.4 in. and a NACA 0012 aerofoil section. The 4-bladed tail rotor was 9.33 ft. in diameter and had a 7.35-in. chord and a NACA 0012 aerofoil section.

For the icing tests, the main rotor speed was held at 220 r.p.m. with a corresponding speed of 2250 r.p.m. for the tail rotor.

3.2 Ice Protection System

In a fluid ice protection system a freezing point depressant fluid is distributed over the leading edge of a helicopter rotor blade to form a non-freezing mixture with impinging supercooled water droplets. In the system tested the fluid was pumped from a 5-gal. tank through flow meters to the main and tail rotors. The main rotor fluid was fed through a rotary seal at the base of the rotor shaft and pumped up through the centre of the hollow shaft into a small reservoir on top of the rotor hub. From this reservoir the fluid was fed by gravity and centrifugal force through flexible tubes to the supply channels in the rotor blades, which in turn supplied the dispersing grooves along the leading edge of the blades (Fig. 2). Needle valves were provided in the supply lines for precise control of the fluid flows. The two dispersing grooves along the leading edge of the main rotor blades were divided in three sections as shown in Figure 2, with the fluid being fed into these grooves from the supply channels at the inboard ends of each of the sections, i.e. at 8, 53 and 82 percent radius. To simplify the construction of the experimental blades the fluid was fed from the supply channels to the dispersing grooves through small external transfer ducts protruding from the leading edge, as can be seen in Figure 2. The tail rotor fluid was pumped through needle valves to a fluid slipring on the rotor hub from where it was fed directly to the two dispersing grooves along the leading edges of the blades (Fig. 3). The indicators for the flow meters and a fluid level indicator in the tank were located in the cockpit of the helicopter. This system is described more fully in Reference 3.

For fluid distribution to the external blade surfaces two rows of holes were drilled through the stainless steel abrasion covers into the two dispersing grooves. The holes were 0.033 in. in diameter and, on the main rotor blades, the holes in each row were on 1.25-in. centres on the two inboard sections and 1.00-in. centres on the outer section. The two rows of holes were staggered one to the other. The location of the rows of holes relative to the centre line of the blade is shown in Figures 2 and 3. The distance between the two rows was about 0.5 in. On the tail rotor blades the holes were on 0.75-in. centres and the two rows of holes were not staggered.

The weight penalty of the modifications necessary to introduce the fluid system was about 25 lb. exclusive of the weight of the fluid.

3.3 Fluids

For these tests five different freezing point depressant fluids were used. The details of each of these fluids are given below.

<u>Fluid</u>	<u>Description</u>
A	90% (vol.) SDAG No. 1-G Denatured Alcohol plus 10% Ethylene Glycol, DTD 979
B	TKS Aircraft de-icing fluid R328
C	TKS Aircraft de-icing fluid H-63A
D	90% (vol.) SDAG No. 1-G Denatured Alcohol plus 10% Glycerine, c.p.
E	Aeroshell Compound 7, DTD 406A

The actual compositions of these fluids are as follows.

<u>Components</u>	<u>Fluid A</u> % vol.	<u>Fluid B</u> % vol.	<u>Fluid C</u> % vol.	<u>Fluid D</u> % vol.	<u>Fluid E</u> % vol.
Methanol	5	2	2	9	-
Ethanol	75	8	10	78	5
Ethylene Glycol	10	75	35	-	85
Glycerol	-	-	13	9.5	-
Water	10	15	40	3.5	10
<u>Specific Gravity</u>	0.82	1.04	1.04	0.84	1.09

The compositions of Fluids A, B and C were found by an analysis made by the Fuels and Lubricants Laboratory of the National Research Council (see Appendix A), and the compositions of D and E were determined from the specifications of the ingredient fluids. The viscosities of each of these fluids are shown in Figure 4.

3.4 Spray Rig

The spray rig described in Reference 4 and shown in Figure 1 was used to produce the icing cloud. Instrumentation at the test site measured windspeed, temperature and icing cloud parameters.

4.0 TEST PROCEDURE

The tests were performed in accordance with the method outlined in Section 5 of Reference 2, with modifications being made as found necessary. Wherever possible icing severity conditions used conformed with the continuous maximum rating specified by the British Civil Airworthiness Requirements which is as follows.

<u>Air Temperature</u> °C	<u>Liquid Water Content</u> gm./m ³
0	0.8
-10	0.6
-20	0.3
-30	0.2

Icing conditions were usually simulated by hovering the helicopter in the artificial cloud about 100 ft. downwind from the spray rig. On low windspeed days, however, it was necessary to do ground runs because the cloud was drawn down over the cockpit and seriously obscured the pilot's visibility. Most of the runs were made to assess the performance of the icing protection system, but a few preliminary tests were made with no fluid flow to check the amount and extent of ice impingement on the blades.

A few flights were made to determine the feasibility of using the fluid system for de-icing. On these runs an appreciable thickness of ice was first allowed to build up on the blades by flying in the cloud for a few minutes with no ice protection. The fluid was then turned on to determine whether it would shed the ice. On most runs the de-icing was performed in clear air out of the cloud after an accretion run or, in one case, after an unsuccessful anti-icing run. On one run, de-icing was performed while the helicopter remained in the cloud.

On anti-icing runs the fluid was usually turned on before the helicopter entered the cloud. Both continuous and cyclic flow anti-icing were tried and in each case various flow rates were used to determine the minimum amount of fluid required to prevent ice from building up on the blades. For cyclic anti-icing the fluid was

manually cycled on and off every 30 seconds during the run to determine whether the residual fluid on the blades would prevent severe icing on the off times. All anti-icing runs were short in duration (about 5 min.) because of the limited capacity of the fluid tank.

Various fluids were used during the trials and, in order to ensure that there was no contamination of one fluid with another, the system was thoroughly flushed with alcohol before any new fluid was used. During the tests the temperature of the fluid in the tank was measured after every run.

5.0 RESULTS AND DISCUSSION

5.1 General

A total of 30 test flights was made on the fluid ice protection system between 28 Nov., 1961 and 4 Jan., 1962. The tests were made over a range of temperatures from -3.3°C to -21.7°C and liquid water contents from 0.15 to 0.55 gm./m³. The droplet size for all runs in the artificial cloud was held constant at about 30 microns (median volume diameter). The results of all the tests are shown in chronological order in Table I.

5.2 Ice Accretions

The few ice accretion runs were made to determine the areas of major ice build-up in relation to the placement of the holes. In general, these runs showed that the top row of holes was too far back from the leading edge, as, on all occasions, these holes on the inner two sections were either just barely covered or were completely clear of ice. On the outer section, the holes of both the top and bottom rows were not covered, as the ice accretion built up entirely on the leading edge between the two rows. The bottom row of holes on the inner two sections was generally well covered by the ice accretion. These results indicated that with the hole pattern used any fluid ejected through the top row would likely be wasted and that no icing protection at all would be afforded from 80 percent radius to the tip. In an attempt to remedy some of the difficulty, a second row of holes was drilled into the top groove of one blade from 30 to 50 percent radius, but because of the construction of the blade it was possible to make this row only 0.1 in. closer to the leading edge. Although this new row of holes was better covered by the ice, subsequent fluid anti-icing tests proved that it had little effect on the distribution of the fluid to the critical parts of the blade over the leading edge.

Because the helicopter used for these trials (Registration No. XM331) was very much smoother in vibrations than the aircraft used for the icing tests the previous year, the tendency to self-shed ice from the rotors was much less. As a result quite heavy ice accretions built up on the rotor blades out to 60-percent radius, even at fairly high temperatures. This indicated that there would be a danger of damage from large chunks of ice being thrown from the blades, even at

temperatures up to about -5°C , and further emphasized the need for a de-icing system for this aircraft. The helicopter used for the previous year's tests (Registration No. XM837) had been rough enough that at temperatures above about -10°C most of the ice shed from the blades before it had built to any appreciable thickness. Subsequent modifications to all production aircraft (including XM331) have very greatly reduced the vibrations in this type of helicopter.

5.3 Tests of Fluid Ice Protection System

With a fluid ice protection system, complete shedding of the ice from the rotor blades is never achieved, as there are always large amounts of light residual ice anchored on the areas of light fluid coverage on the blades, particularly between the rows of holes. Because of this residual ice, the criterion for successful operation of the system cannot be taken to be the relative cleanliness of the blades at the end of a run, as is used for tests on electro-thermal rotor blade de-icing systems. Since the major effect of icing on the Wessex helicopter is the damage that can be caused by chunks of ice thrown from one rotor striking another rotor or the fuselage, this fluid system was judged to have operated successfully only if it prevented any thick accretions of ice from building up anywhere on the rotor blades.

5.3.1 De-Icing Tests

In general, de-icing was not successful on the few runs it was tried. This same result has been found on other fluid ice protection systems. Once the ice had formed a solid bond to the blades, the fluid could not spread out over the surface and had little effect in removing the ice. At best the fluid melted a small hole through the ice on the areas of thin ice accretion, but many of the holes remained blocked at the end of a run. On runs N28-2 and D15-2 with fluid A, and run D29-1 with fluid E, practically no shedding of ice occurred at all using moderate flow rates and various fluid-on times up to 3 min. For examples, see Figure 5. On run D19-1 with fluid B, there was some slight shedding of the ice, but this was partly due to the self-shedding caused by the high temperature (-5.4°C). On run D15-4 with a high flow rate of fluid A, the ice was mostly shed, but this ice had been picked up during run D15-3, a continuous anti-icing run, and had likely been partially loosened on the blades.

These results indicate that the fluid system on this helicopter will require a very sensitive ice detector in order that the fluid can be turned on before any large amounts of ice have accreted on the rotor blades. In fact, it would be advisable for the pilot to turn the system on before entering any cloud formations that could contain supercooled water droplets. Otherwise the ice would be able to form a strong bond to the dry blades and thick accretions could build up.

5.3.2 Anti-Icing Flights

5.3.2.1 Continuous Flow

Runs were made under various icing conditions with each of the fluids to determine the continuous fluid flow that would be required to prevent the formation of

hazardous ice on the blades. With fluid A, slight success was achieved at higher temperatures only, as parts of some of the blades were kept ice-free. However, none of the blades were ever completely cleaned of ice, as large patches remained unshed at the end of the runs (runs N30-2, N30-3 and D14-1). At lower temperatures with fluid A, icing was not prevented on any part of the blade. On run D15-3, with the same low fluid flow as used on the higher temperature runs, and on run D15-5 with a very high fluid flow, only the inner 2 or 3 ft. of the blades and a few small patches received sufficient fluid to prevent icing. On most of the rest of the blades the ice covered completely the bottom row of fluid ejection holes, and eventually prevented the fluid from flowing. Examples of the anti-icing performance with fluid A can be seen in Figure 5.

The tests of fluid E and the one run with fluid C produced only slightly better results with continuous fluid flows (Fig. 6). At high temperatures parts of the blades were kept clear of ice, but considerable ice had built up on the blades at the end of the run. At lower temperatures the protection afforded by fluid E became even less, and large sections of the blades were covered with ice even with maximum flow rates, which, with the more viscous fluids C and E, were only about 24 gal./hr. compared with about 45 gal./hr. for fluid A.

The only runs on which acceptable clearing was obtained were with fluids B and D at moderate temperatures (Fig. 7). On runs D15-6 and D19-3 with maximum flow rates of 25 gal./hr. of fluid B, the blades were completely clear of heavy ice at -5.2°C (run D19-3), and only one thick patch of ice about 6 ft. long remained on one blade at -13.5°C (run D15-6). At about -12°C with fluid D at 24 gal./hr. the centre sections of the blades remained iced, but at 30 gal./hr. the blades were kept fairly clean (runs D22-3 and D22-2 respectively). At lower temperatures ($<-19^{\circ}\text{C}$), however, fluid B (run J4-4) completely failed to prevent icing on the main rotors, and with fluid D (runs J4-2 and J4-3) only the inner halves of the blades were anti-iced, in all cases with maximum fluid flows (Fig. 8).

Because of the poor fluid coverage on the leading edge of the blades resulting from the incorrect placement of the fluid ejection holes, the anti-icing performance was very erratic. Consequently, it was difficult to obtain an estimate of the rate of fluid flow that would be required to protect this helicopter in icing conditions. However, there was an indication that if the fluid distribution were improved the maximum flow rate required for the main rotors would be about 35 gal./hr. of either fluid B or D for protection in moderate icing conditions down to about -20°C . This would be a flow of about 0.006 gal./min./ft. of blade, which was about the same as required by previously tested fluid de-icing systems (Ref. 5). With the installed 5-gal. tank the system would then have a duration of only about 8 min., indicating that a much larger tank would be required. The weight penalty of the fluid alone for this system would be about 400 lb. or 330 lb. for each hour of icing protection using fluids B and D respectively. These figures include fluid required for the tail rotor blades, assuming the same flow per foot as the main rotor blades. In addition, the modifications to the helicopter needed to introduce the fluid system would be the 25 lb. of the system tested plus the added weight of a much larger tank

to accommodate the fluid required. The minimum weight of the system for one hour's protection would then be about 400 lb. In comparison, the previously tested electrical de-icing system which gave continuous protection weighed about 270 lb.

5.3.2.2 Cyclic Fluid Flow

In an attempt to extend the duration of the fluid system the feasibility of cyclic anti-icing was investigated. In this technique the fluid is turned completely off for short periods during a run but, because of the residual fluid on the blade, only small amounts of ice form before the fluid is again turned on. The mushy ice that does accrete during these off times has very low adhesion to the blades and is easily thrown off by centrifugal force. This differs from a de-icing system in that, with this method, ice is never allowed to form a solid bond to the blades nor build up to any appreciable thickness on them.

An anti-icing cycle of 30 sec. on, 30 sec. off, which had been successfully used on another fluid system (Ref. 5), was tried with the best fluids, B and D. Because of the poor fluid coverage on the leading edge, the ice was able to form a solid bond to the blades during these runs and little success was achieved. Only on one run (D19-2) at -5.2°C , with maximum flow rate of fluid B, was any appreciable clearing of the blades effected. At lower temperatures (runs D15-7 and D22-1) the ice was not prevented from building on most of the blades with either fluid (Fig. 9).

Assuming that the fluid distribution on the Wessex blades could be very greatly improved and, as a result, cyclic anti-icing could be used, the weight penalty for about one hour's protection would still be about 200 lb. These results indicate that for other than very limited protection the fluid system would not be feasible for this helicopter. For the long duration protection required for the anti-submarine role of the Wessex, it will likely be necessary to use the electro-thermal de-icing system.

5.3.3 Tail Rotor

The fluid system on the tail rotor blades was tested during only 3 runs. Because of the large size of the helicopter the tail rotor was only occasionally in the icing cloud and picked up little ice, and consequently the system was completely disconnected for most of the runs. On a few runs some light ice was accreted and was partially self-shed from the blades (Fig. 10). On two of the runs on which the fluid system was tested (N28-2 and D15-2), very high flow rates were used and the blades were kept mostly clear of ice. On the third run (D15-3) the flow rate was reduced to 3 gal./hr. and all but the inboard foot of the blades was kept clear of heavy ice (Fig. 10). From this brief testing, it was impossible to assess the efficiency of the tail rotor system. However, it could be seen that the hole pattern on these blades was also too far aft to obtain good coverage over the leading edge. Even on the runs with the very high flow rate there was light ice anchored on the leading edge. Also on the runs where there was no flow to the tail rotor, most of the ice picked up was on the leading edge well forward of the rows of holes.

5.3.4 Fluids

The system was designed to use a mixture of 90 percent denatured ethyl alcohol and 10 percent glycerine (fluid D), but, in addition, it was intended to test the other fluids in order to compare their suitability. However, shortly before the trials the aircraft manufacturer stated that fluid D would be corrosive because of the glycerine content, and as a result fluid A was substituted as the main fluid. It was not until later in the tests that permission was obtained to do some testing of fluid D. The trials were begun with fluid A and, in general, very poor results were achieved. Little clearing of ice resulted, and there was no trace of residual fluid on the blade at the end of a run, although there was a dense cloud of vapour visible coming from the blades during the run. In addition, it was found when filtering that a sludge was forming in this fluid. Analysis of this sludge (see Appendix A) showed that it was ethanalamine phosphate, an inhibitor used in the ethylene glycol. This substance was insoluble in alcohol, and hence precipitated when the components of fluid A were mixed. An early malfunction of one of the flow meters was likely caused by this sludge. This incident illustrated that care must be taken in choosing inhibitors for this application. However, fluid A's anti-icing performance had previously ruled it out as a likely fluid to be used in this system.

Fluid E gave slightly better results than fluid A, but its performance was still poor. In addition, because of its high viscosity at low temperatures, the maximum flow rate of the pumping system was about half what it had been with fluid A. This fluid left a sticky film adhering to the blade surfaces, but did not appear to melt the ice or prevent it from freezing solidly to the leading edge of the blades. Fluid C was tested on only one run and its shedding efficiency appeared to be about the same as fluid E.

Fluids B and D gave the best results with the anti-icing system. Both gave good protection at high temperatures, but became less effective as the temperature decreased. At temperatures around -20°C neither fluid was effective, with fluid B giving no clearance and fluid D only partial clearance. Both of these fluids left a residue on the blades, but fluid D with its high alcohol content appeared to have a better ice melting characteristic at lower temperatures. Fluid D was much less viscous than fluid B and it was possible to get higher flow rates at low temperatures to improve the anti-icing. Because it also has a lower specific gravity than fluid B, it appears that of the five tested fluid D would be the best for a rotor blade anti-icing system. This fluid apparently has the drawback that an inhibitor would be required for corrosion resistance. However, no corrosion was noticed on extensive tests with this fluid on other helicopter anti-icing systems, and hence it is felt that this is a minor problem. Also the glycerine in this mixture has a tendency to settle out in long storage, and thorough mixing would be required before using.

To summarize, these tests have shown that the ideal fluid for an anti-icing system should have the following properties:

1. Good freezing point depressant
2. Good ice melting ability

3. Low volatility
4. Low surface tension
5. Low viscosity
6. Low specific gravity
7. Stable on storage
8. Low corrosivity

The temperature of the fluid was measured after each run and, because it was never allowed to cold soak in the aircraft for very long after leaving the warm hangar, the fluid was always quite warm. In practice, the fluid would be close to ambient temperature, particularly just after take-off in cold weather, before it could receive any warming from the aircraft. This would mean that maximum pump flow rates would be lower and probably the anti-icing properties of the fluid would be worse than during these anti-icing tests.

6.0 CONCLUSIONS

The production Wessex helicopter will require a rotor blade icing protection system for flights in icing conditions at temperatures less than about -5°C to prevent damage from thick ice accretions being shed from a rotor blade and striking another part of the aircraft.

The installed anti-icing system was not adequate to protect the Wessex helicopter in icing conditions because of the poor fluid distribution on the rotor blades.

Except for short duration protection a fluid anti-icing system would not be practicable on the Wessex helicopter because of the large amount of fluid required; viz. over 300 lb./hr. for a continuous flow system. Cyclic flow anti-icing was not successful on these tests; but, even if this technique could be used, the weight penalty of the system would still be too great to make it feasible.

The fluid ice protection system will likely not be suitable for de-icing ice accretions that have formed a solid bond to the blades.

A sensitive ice detector will be required to turn on the fluid anti-icing system as soon as possible after entering icing conditions.

Of the fluids tested, the best one for a rotor blade anti-icing system was found to be a mixture of denatured ethyl alcohol and glycerine in a 9:1 ratio (by volume).

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TABLE I
RESULTS OF FLUID TESTS

Run No.	Ambient Temp. °C	L.W.C. gm./m ³	Time in Icing min.	M/R Ice Thickness in. @ radius	Type of Fluid	M/R Flow Rate gal./hr.	Fluid Temp. °C	Type of Run	Remarks
H28-1	-4.7	0.15	5	1/16 @ 20%	-	-	-	Accretion only	Ice self-shed to 53%, top row holes just covered, T/R clean.
N28-2	-4.5	0.15	10	-	A	33	13	Accretion and de-icing	Fluid on for 30 sec. - no shedding. T/R flow 13 gal./hr. - clean.
N30-1	-5.6	0.50	5	1/8 @ 40%	-	-	16	Accretion only	Top row of holes not covered by ice.
N30-2	-5.1	0.50	5	-	A	29	10	Continuous anti-ice	One blade not shed. Other blades not shed 53%-65% - patchy elsewhere.
N30-3	-3.3	0.50	5	-	A	29	29	Continuous anti-ice	One blade shed to 50% - others to 25%-35%, holes in ice, T/R clean.
D14-1	-5.1	0.25	5	9/64 @ 30%	A	30	7	Continuous anti-ice	Heavy ice left to 40%-45%, light ice to 70%, holes in ice, T/R clean.
D14-2	-4.0	0.25	5	1/8 @ 30%	-	-	7	Accretion only	Ice self-shed to 53% - top row of holes just in ice.
D15-1	-19.0	0.25	5	11/64 @ 50%	-	-	11	Accretion only	Ice accretion to tips - holes in outer section not covered by ice.
D15-2	-18.3	-	-	-	A	23	7	De-icing of D15-1	Fluid on for 2 min. - no shedding. T/R flow 15 gal./hr. Light ice left.
D15-3	-16.6	0.20	5	3/16 @ 60%	A	29	6.5	Continuous anti-icing	Heavy ice to tips. T/R flow 3 gal./hr. - mostly clean.
D15-4	-16.2	-	-	-	A	44*	6.5	De-icing of D15-3	Fluid on for 2 min., ice mostly shed - light patches left.
D15-5	-16.1	0.20	5	9/64 @ 52%	A	46*	5.5	Continuous anti-icing	Heavy ice 25% to tips. Light T/R ice.
D15-6	-13.5	0.30	6	3/16 @ 55%	B	25*	7	Continuous anti-icing	One blade heavy ice - 55%-78%. Rest of blades - light ice or patches.
D15-7	-14.2	0.25	10	-	B	24.5*	14	30 sec. off-on cycle	Three blades heavily iced, other blade mostly clean. T/R clean.
D19-1	-5.4	0.45	5	1/8 @ 33%	B	25*	7	Accretion, then de-icing	Fluid on for 1 min. - ice shed 35%-40%, mainly self-shedding.
D19-2	-5.2	0.25	10	-	B	25*	10	30 sec. off-on cycle	One blade heavily iced to 53% - other blades light ice to 53% or clean.
D19-3	-5.2	0.25	7½	-	B	25*	13	Continuous anti-ice	Blades mostly clean - small patches of light ice left.
D21-1	-9.7	0.45	7	5/16 @ 40%	-	-	14	Accretion only	Ice to 82%, top row of holes out of ice.
D22-1	-12.7	0.50	10	1/2 @ 30%	D	33	7	30 sec. off-on cycle	Heavy ice to about 50% all blades, patches outboard. Light T/R ice.
D22-2	-12.3	0.50	5	3/32 @ 60%	D	30	7	Continuous anti-icing	Blades mostly clear - light patches. Heavy patch 60%-65% on one blade.
D22-3	-12.1	0.50	7	1/8 @ 55%	D	24	1.5	Continuous anti-icing	Heavy ice on centre sections all blades.
D22-4	-12.0	0.50	5	-	E	24*	12	Continuous anti-icing	Heavy ice to 30%-35%, thin ice and patches to 85%, light T/R ice.
D29-1	-8.1	0.40	5	3/16 @ 50%	E	25*	10.5	Accretion and de-icing in cloud	2 min. off, 3 min. fluid on - heavy ice to 65%.
D29-2	-8.1	0.40	7	-	E	25*	12	Continuous anti-icing	Ice on all blades anchored on leading edge.
D30-1	-15.3	0.55	6	17/32 @ 55%	E	25*	15.5	Continuous anti-icing	Heavy ice to 55% all blades - light ice outboard, T/R clean.
D30-2	-13.3	0.50	8½	-	C	34*	14.5	Continuous anti-icing	Light ice on all blades.
J4-1	-21.7	0.30	5	9/64 @ 60%	D	36	8	Continuous anti-icing	No clearing - heavy ice to tips, ice on T/R.
J4-2	-21.3	0.30	5	3/16 @ 80%	D	40*	7	Continuous anti-icing	Inner 2 sections mostly clear, tip section - no clearing. Ice on T/R.
J4-3	-21.0	0.30	4	5/32 @ 60%	D	40*	4	Continuous anti-icing	Inner section clear, outer two sections iced-to tips. Ice on T/R.
J4-4	-19.8	0.40	5	1/4 @ 55%	B	26*	10	Continuous anti-icing	No clearing - heavy ice to tips. Ice on T/R.

M/R - main rotor

T/R - tail rotor

* - maximum flow obtainable

APPENDIX A

NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

Fuels and Lubricants Laboratory

LIMITED

Report: MPT-2702

Date: 15 December 1961

Lab. Order: 14367A

File: M2-12-3

For: Low Temperature Laboratory, N. R. C., Ottawa, Ontario.

Reference: Memorandum dated December 7, 1961 from Mr. J. J. Samolewicz.

Subject: EXAMINATION OF THREE DE-ICING FLUIDS AND MATERIAL SEPARATED FROM ONE OF THE FLUIDS.

Submitted by: J. W. Broughton
Section Head

Author: L. Gardner

Approved by: D. C. MacPhail
Director

Identification of Samples

<u>NRC Sample Number</u>	<u>Description</u>
NRL 20448	Anti-icing fluid, 90% SDAG 1-G + 10% Ethylene Glycol, DTD 979
NRL 20449	Material separated from NRL 20448
NRL 20450	T. K. S. Aircraft de-icing fluid No. R328
NRL 20451	T. K. S. Aircraft de-icing fluid No. H-63A

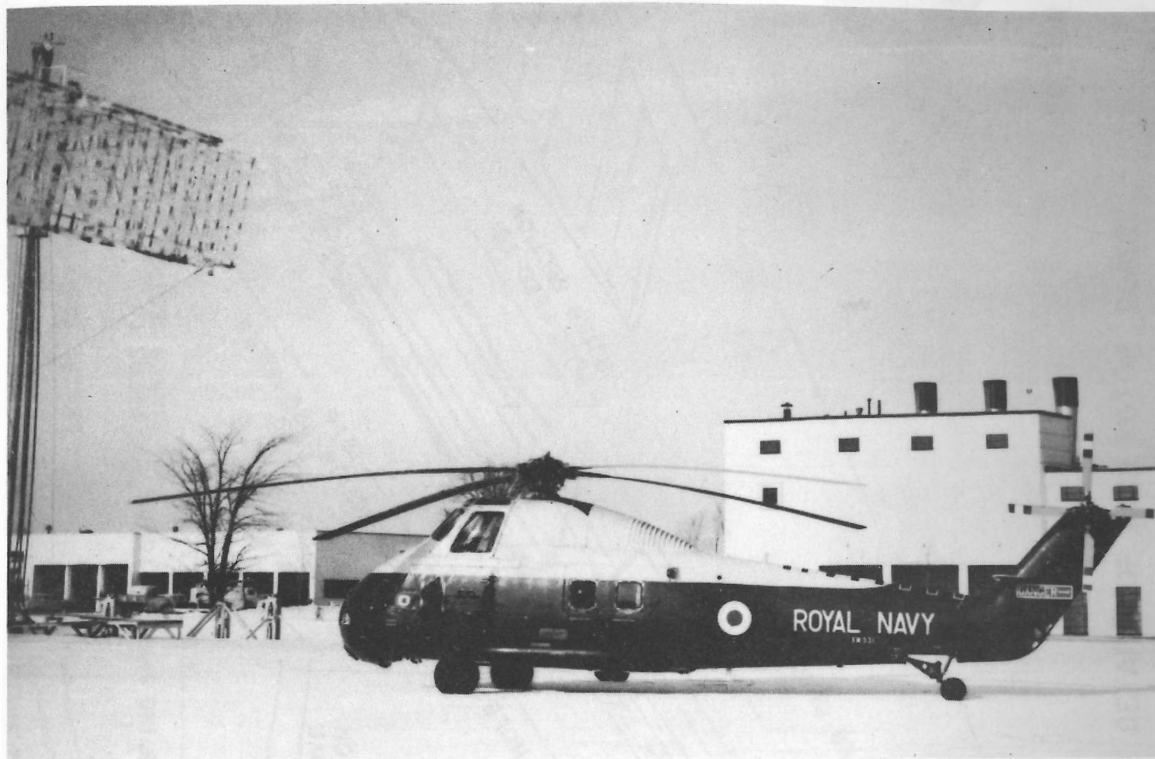
Results:

1. Analysis of three fluids: NRL 20448, 20450, 20451

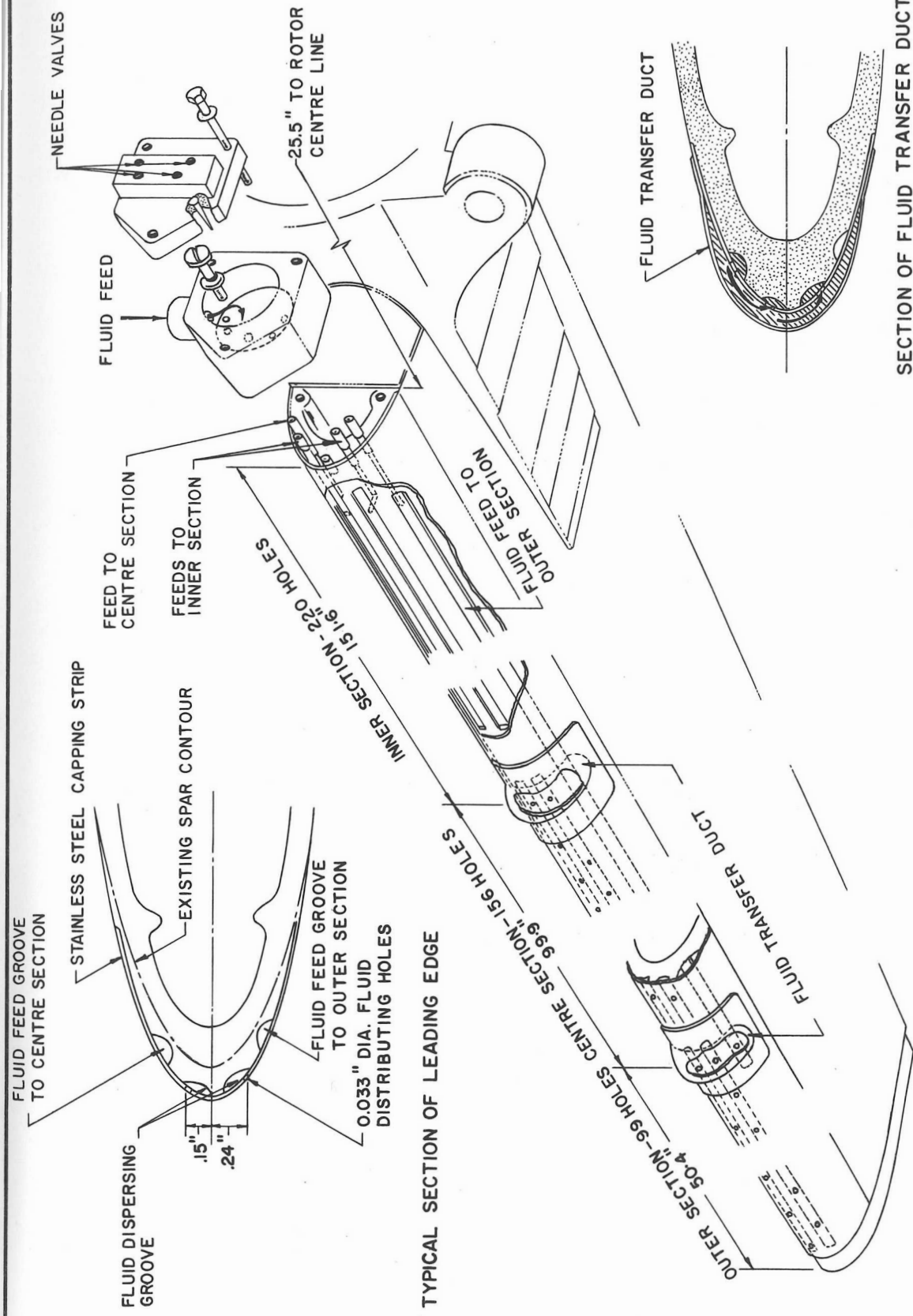
<u>Components</u>	<u>NRL 20448</u> <u>% vol.</u>	<u>NRL 20450</u> <u>% vol.</u>	<u>NRL 20451</u> <u>% vol.</u>
Methanol	5	2	2
Ethanol	75	8	10
Ethylene Glycol	10	75	35
Glycerol	-	-	13
Water	10	15	40

2. Analysis of material (NRL 20449) removed from NRL 20448

This material was identified as ethanolamine phosphate; this material is used as an inhibitor in certain anti-freeze solutions, e.g. CGSB Specification 3-GP-850, Coolant, Aero-Engine and may possibly have been included in sample NRL 20448 for this purpose. 3-GP-850 type coolants are glycol-base and ethanolamine phosphate is soluble in ethylene glycol; however, it is not readily soluble in alcoholic solutions such as NRL 20448. On the basis of this limited solubility it would therefore appear that ethanolamine phosphate should not be recommended for use in alcohol-base solutions.



THE TEST HELICOPTER AT THE SPRAY RIG



DETAILS OF MAIN ROTOR BLADE

(FROM REFERENCE 3)

SECTION OF FLUID TRANSFER DUCT

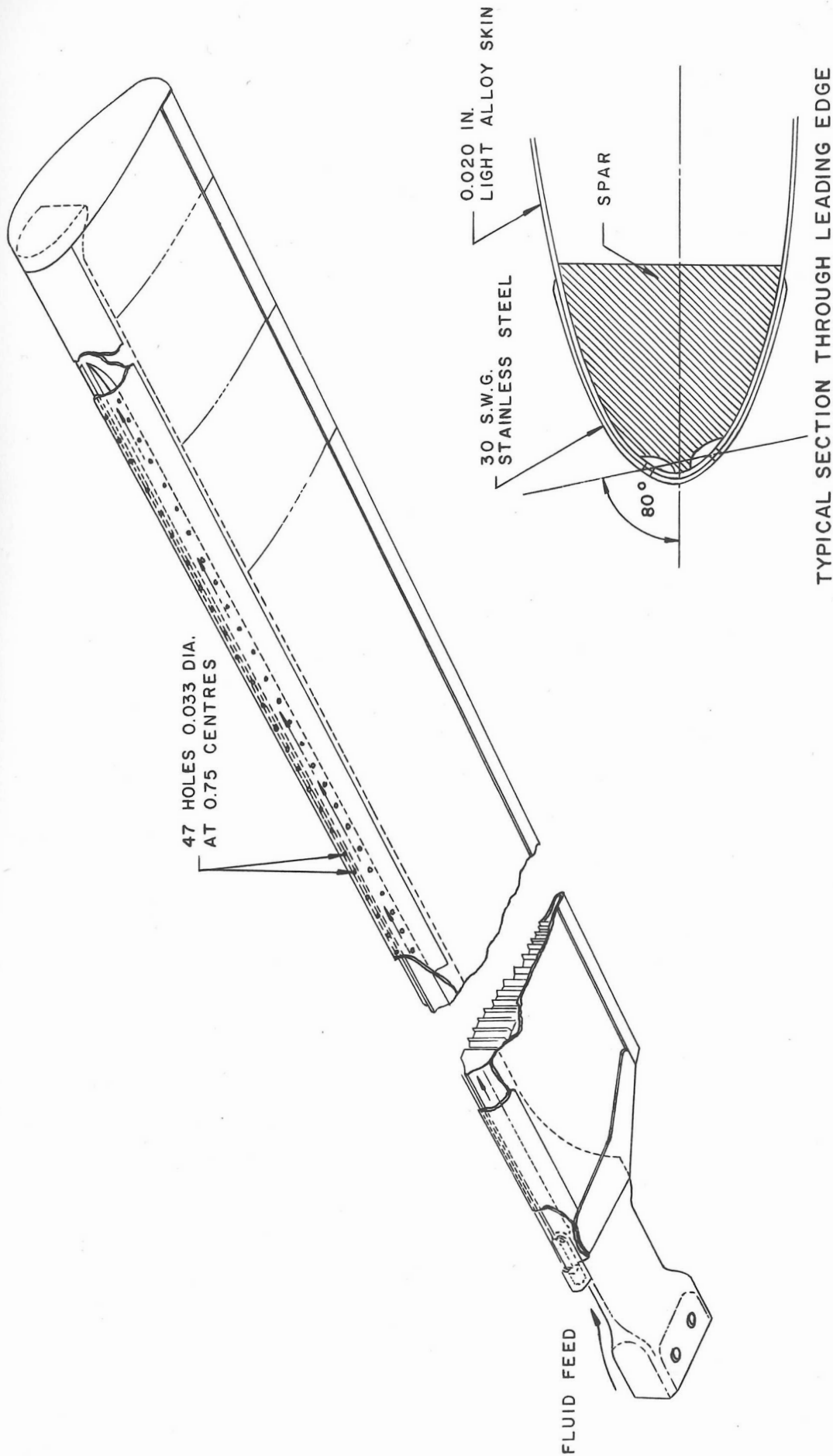
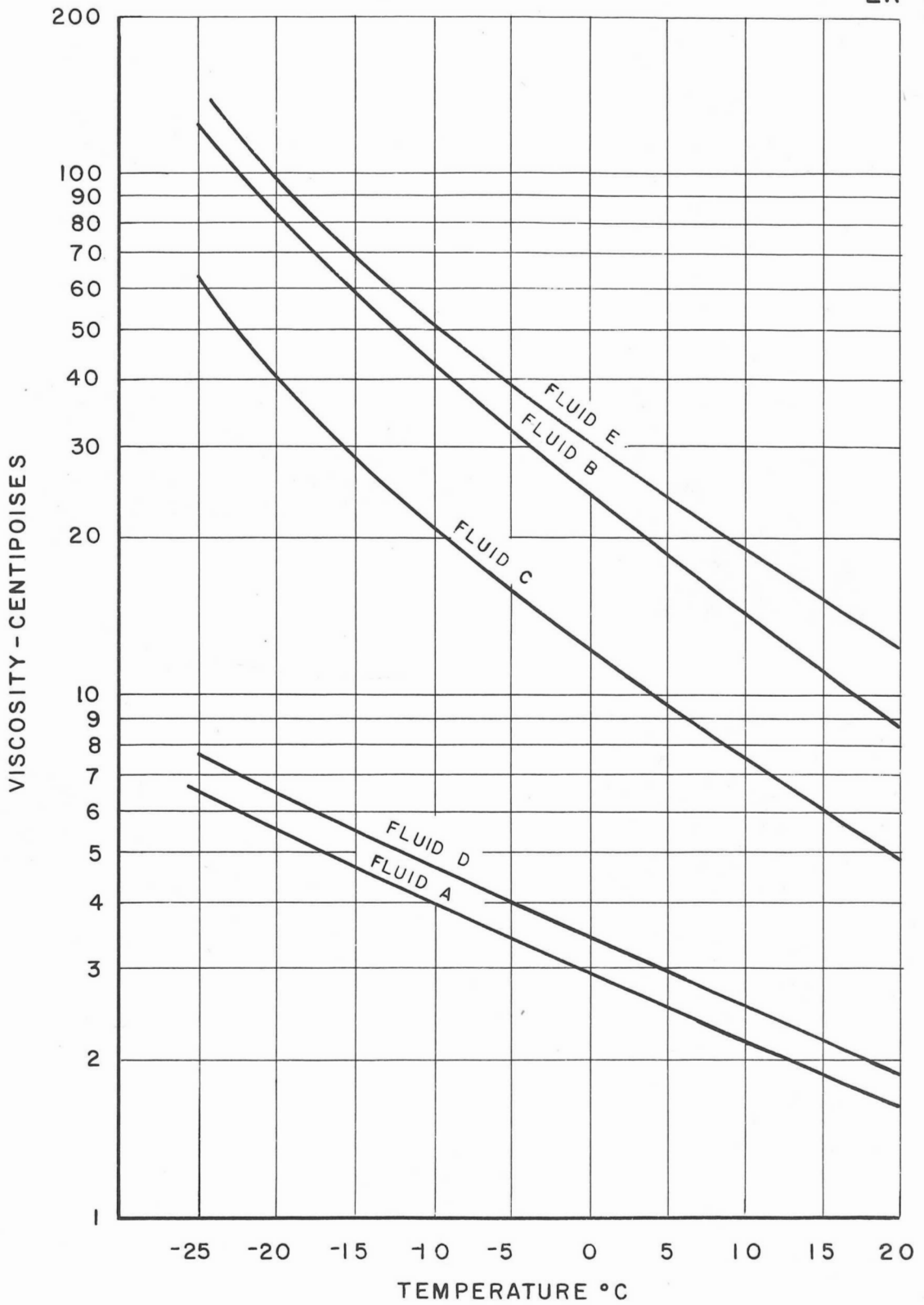


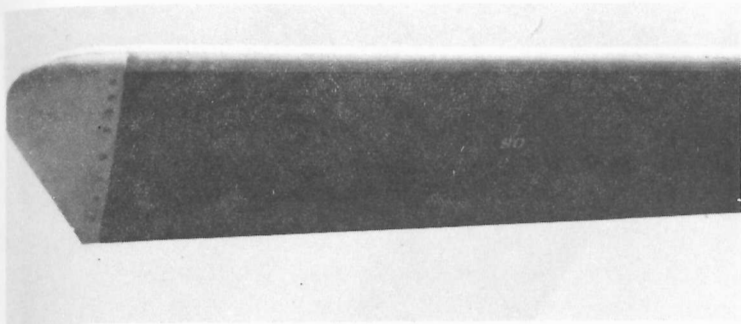
FIG. 3
LR-356

DETAILS OF TAIL ROTOR BLADE

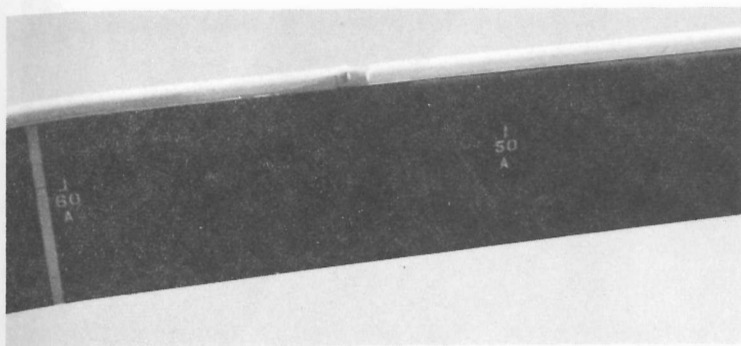
(FROM REFERENCE 3)



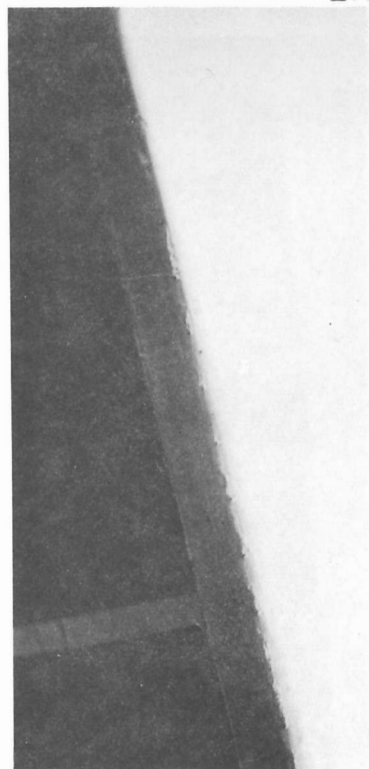
DYNAMIC VISCOSITY OF FIVE ANTI-ICING FLUIDS



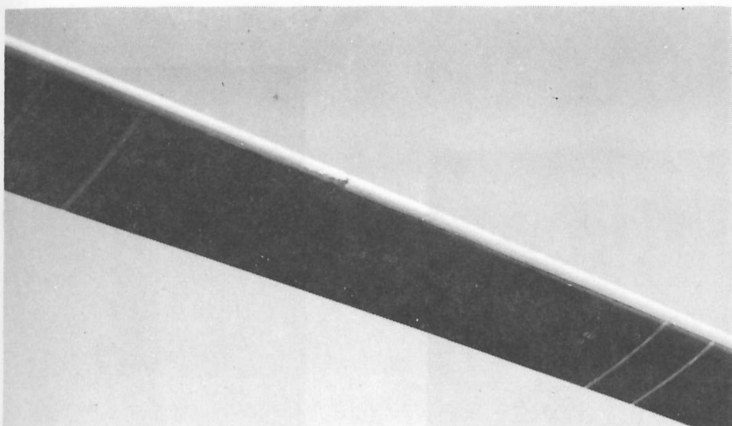
RUN D 15-2, DE - ICING



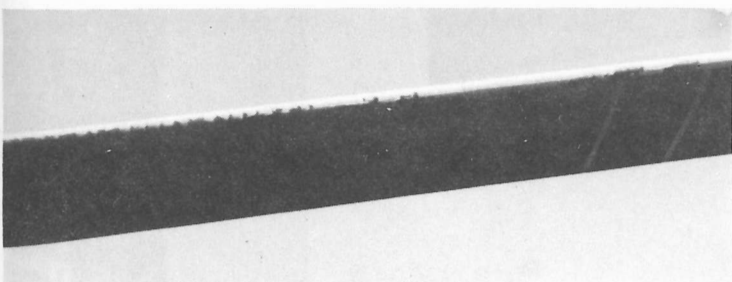
RUN D 15-2, DE-ICING



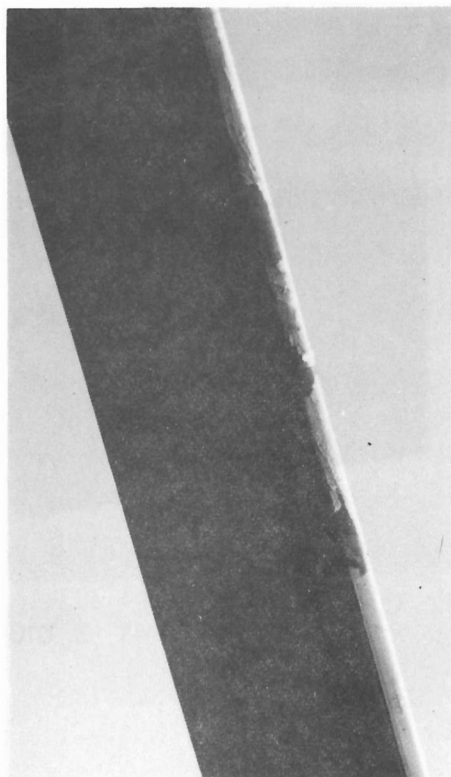
RUN N 30-3, ANTI-ICING



RUN D 15-3

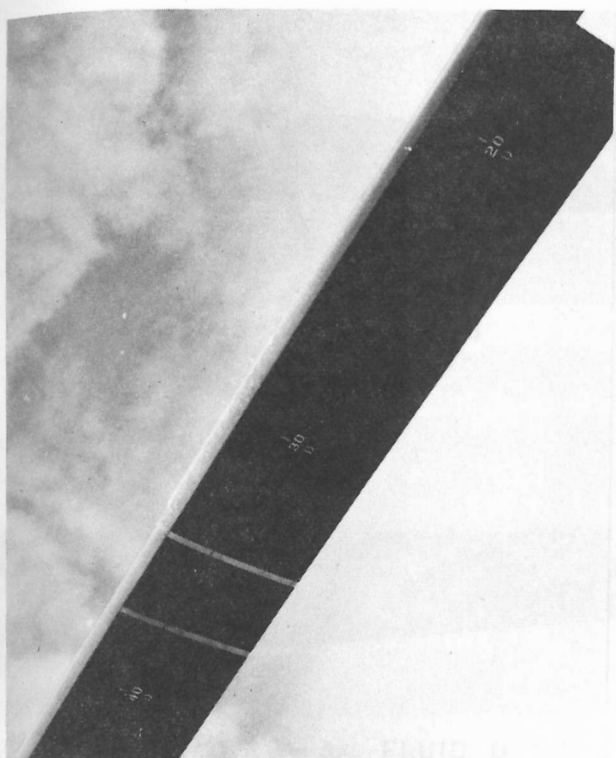


RUN D 15-5

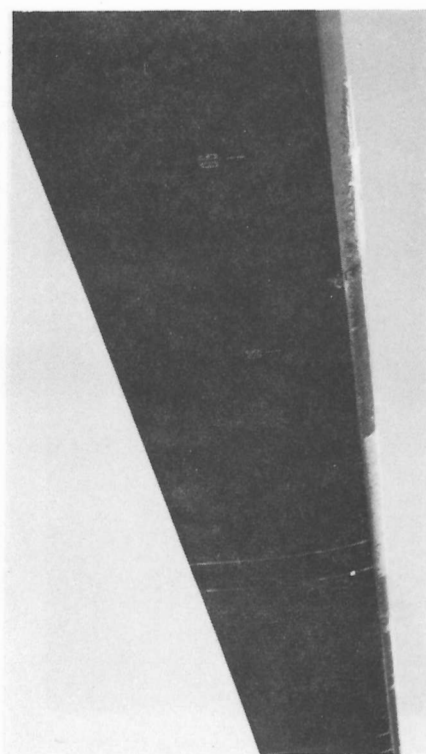


RUN D 15-3

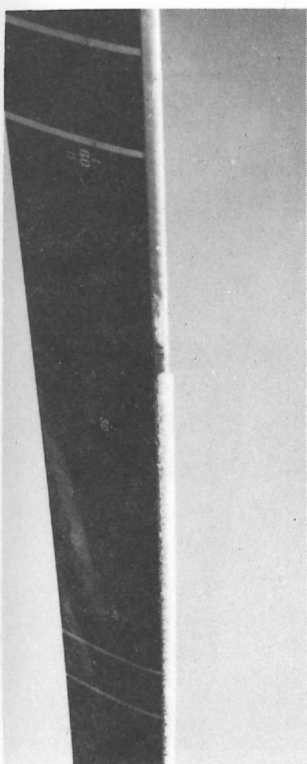
MAIN ROTOR BLADE DE-ICING AND ANTI-ICING WITH FLUID A



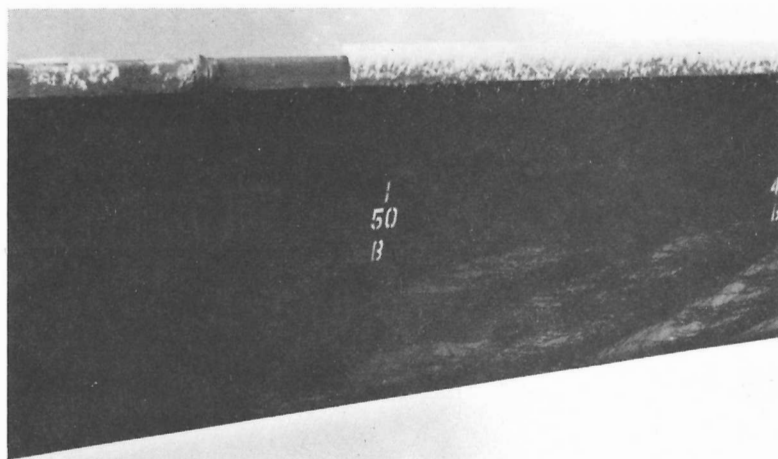
RUN D22-4, FLUID E, T=-12.0°C



RUN D30-2, FLUID C,
T= -13.3°C

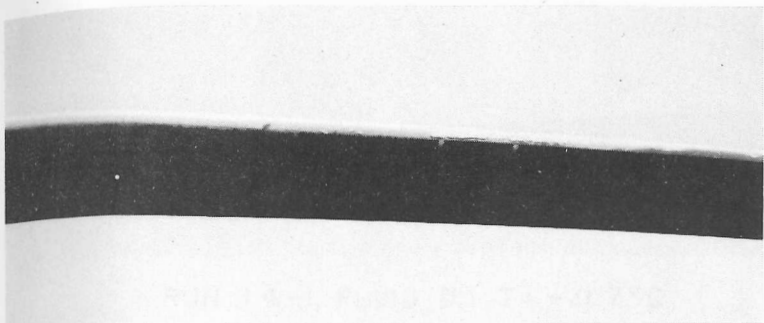


RUN D 30-1, FLUID E,
T=-15.3°C

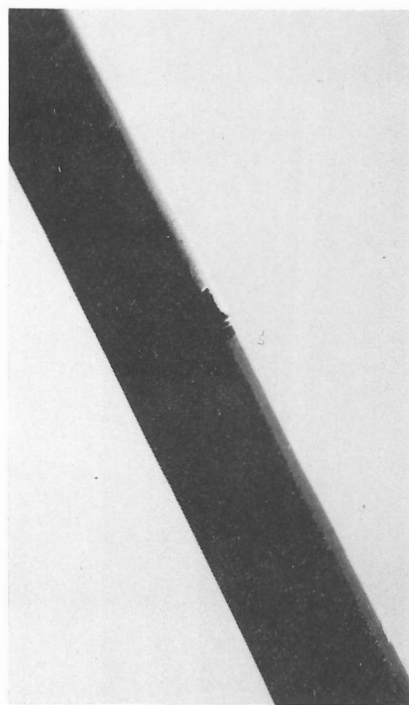


RUN D30 -1, FLUID E, T=-15.3°C

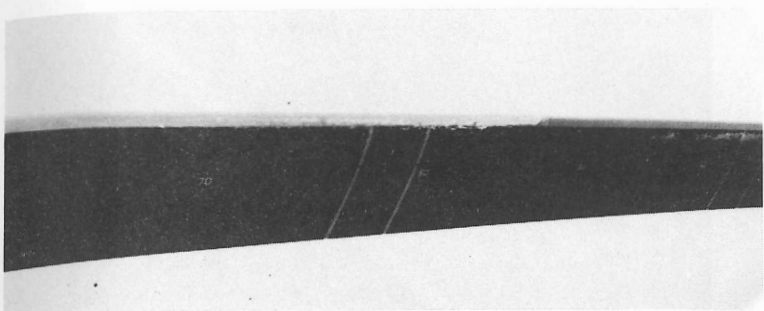
ANTI-ICING RESULTS WITH FLUIDS C AND E



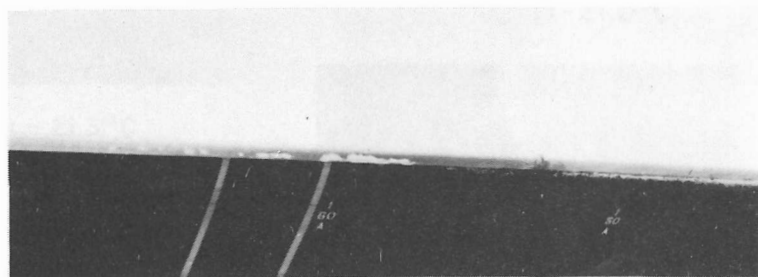
RUN D15-6, FLUID B



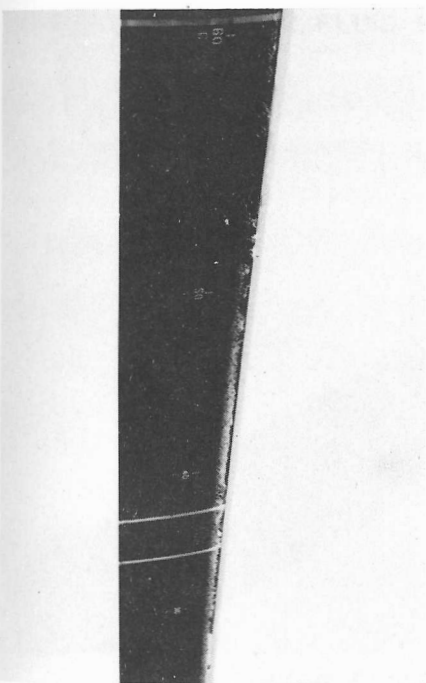
RUN D15-6, FLUID B



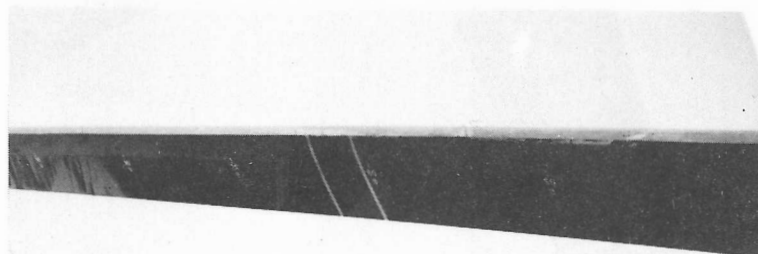
RUN D 22-3, FLUID D



RUN D 22-2, FLUID D

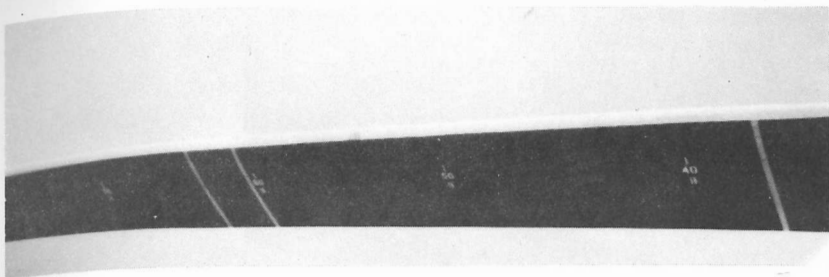


RUN D 22-3, FLUID D

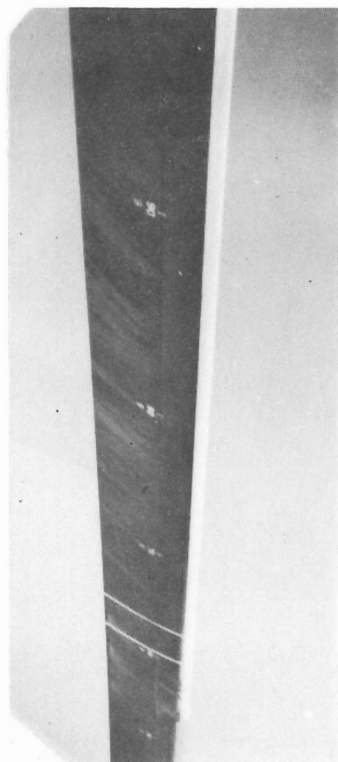


RUN D 22-2, FLUID D

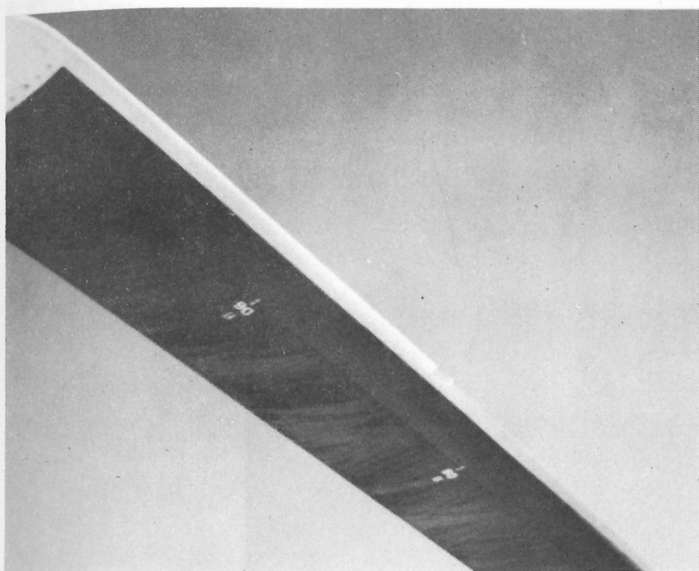
SUCCESSFUL ANTI-ICING RUNS - FLUIDS B AND D



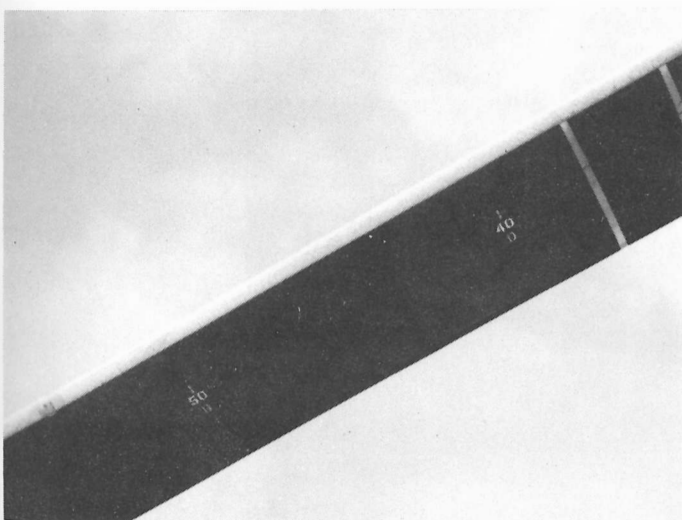
RUN J 4-1, FLUID D, $T = -21.7^{\circ}\text{C}$



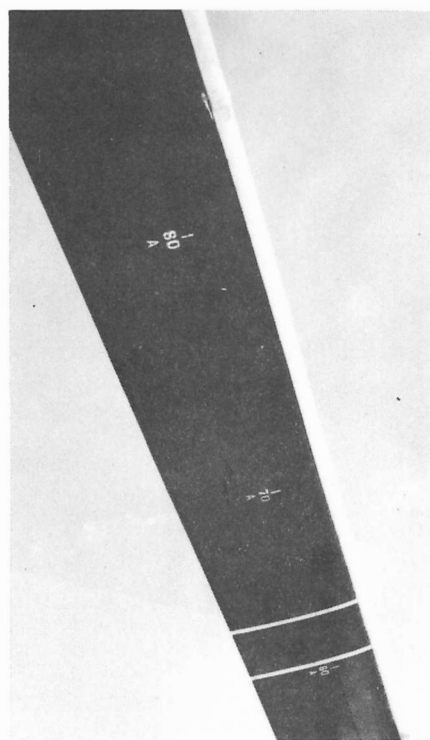
RUN J 4-3, FLUID D,
 $T = -21.0^{\circ}\text{C}$



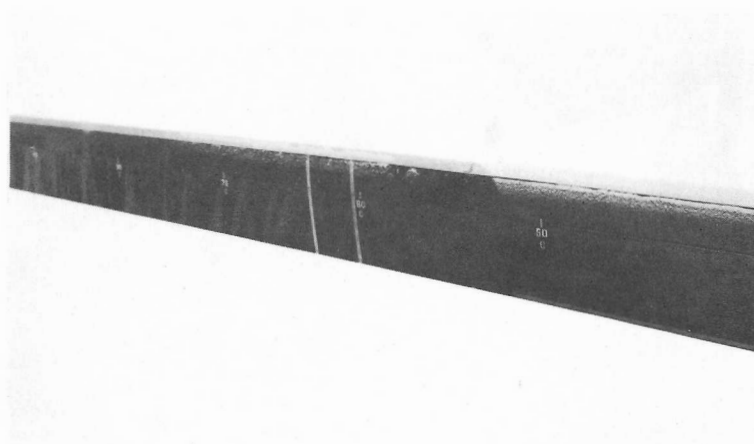
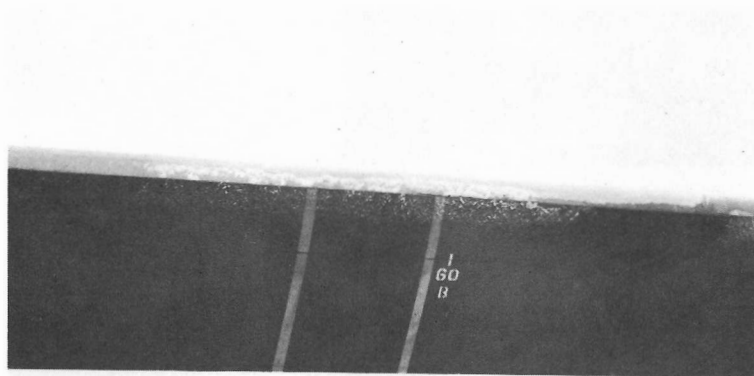
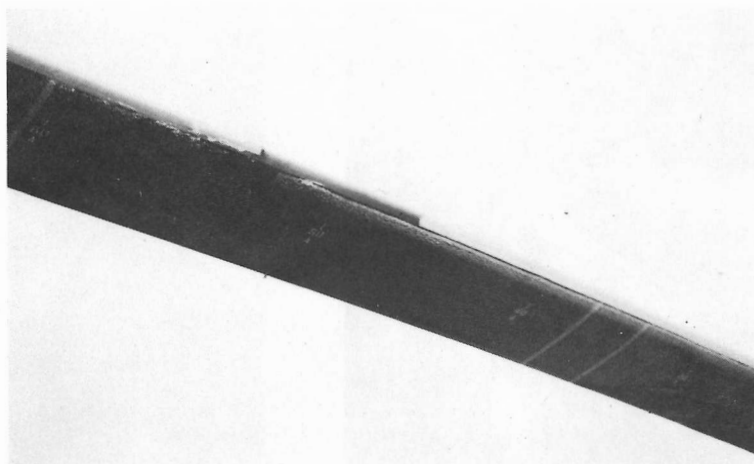
RUN J 4-2, FLUID D, $T = -21.3^{\circ}\text{C}$

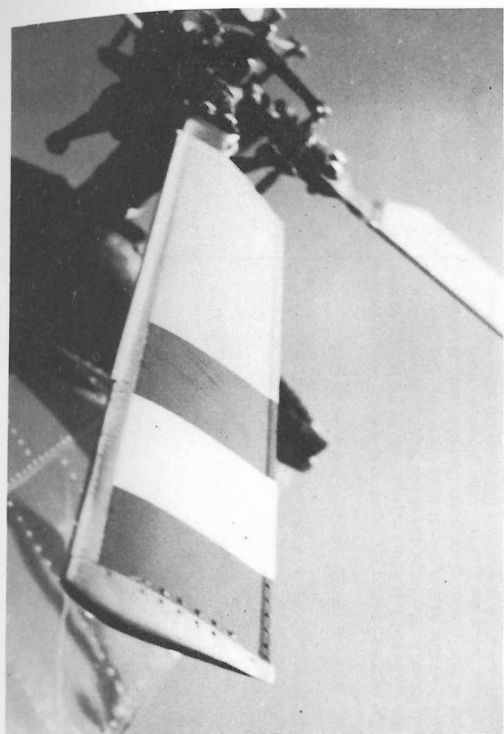


RUN J 4-4, FLUID B, $T = -19.8^{\circ}\text{C}$

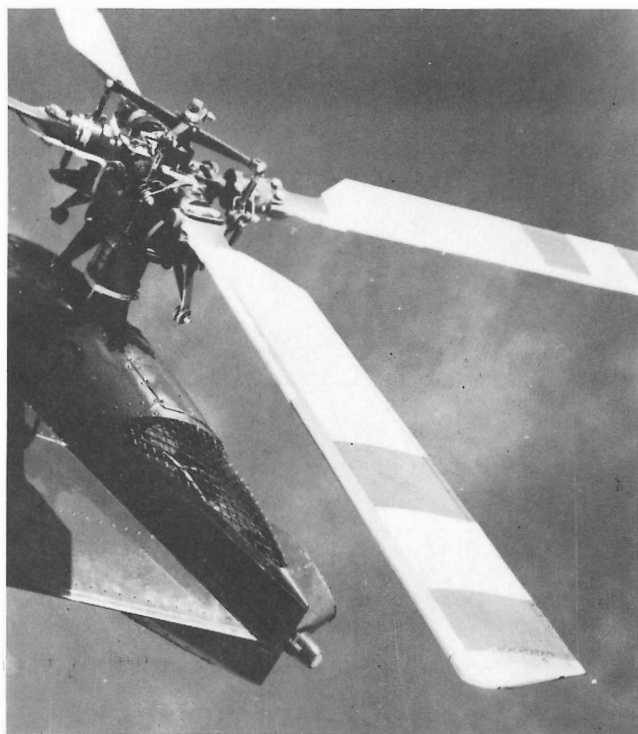


RUN J 4-4, FLUID B,
 $T = -19.8^{\circ}\text{C}$

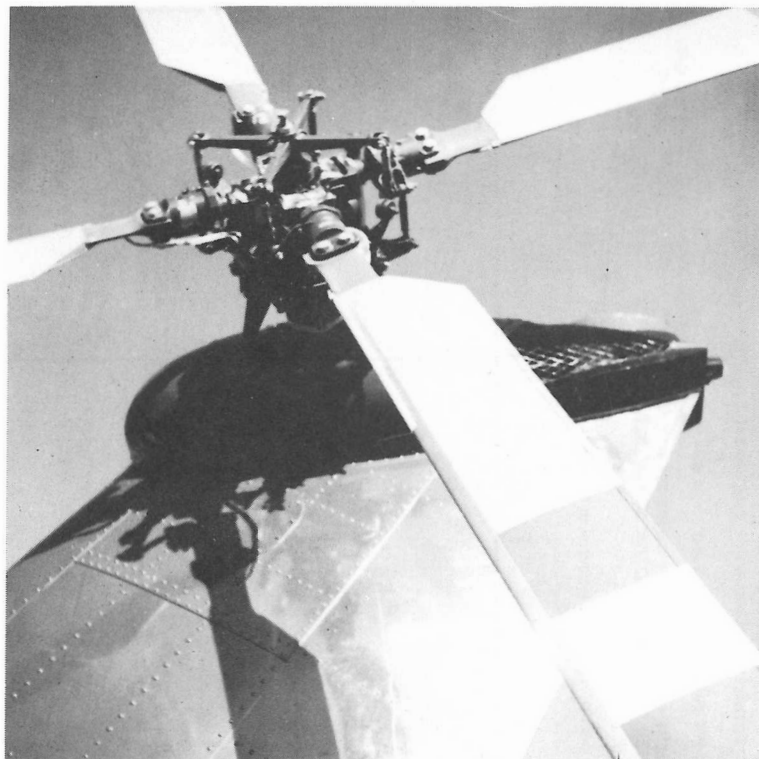




RUN D 15-1, T=-19.0°C, SELF-SHEDDING



RUN D 22-4, T=-12.0°C, SELF-SHEDDING



RUN D 15-3, T=-16.6°C, ANTI-ICING

TAIL ROTOR SELF-SHEDDING AND ANTI-ICING

<p>NRC LR-356 National Research Council, Canada, Division of Mechanical Engineering.</p> <p>ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A WESTLAND WESSEX HELICOPTER. G.A. Gibbard, October 1962. 16 pp. + 1 tab. + 10 figs.</p> <p>A Westland Wessex helicopter equipped with a fluid ice protection system for the main and tail rotor blades was flight tested in an artificial icing cloud. The tests indicated that icing protection will be required on this helicopter at temperatures less than -5°C, because of the effects of uncontrolled shedding of large chunks of ice from the rotor blades. The installed fluid anti-icing system was not able to prevent ice from forming because of poor distribution of fluid over the leading edge of the rotor blades.</p>	<p style="text-align: center;"><u>LIMITED</u></p> <ol style="list-style-type: none"> 1. Rotor blades - Icing 2. De-icing systems - Testing 3. Helicopters (Westland Wessex) <ol style="list-style-type: none"> I. Gibbard, G. A. II. NRC LR-356 	<p style="text-align: center;"><u>LIMITED</u></p> <p>NRC LR-356 National Research Council, Canada, Division of Mechanical Engineering.</p> <p>ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A WESTLAND WESSEX HELICOPTER. G.A. Gibbard, October 1962. 16 pp. + 1 tab. + 10 figs.</p> <p>A Westland Wessex helicopter equipped with a fluid ice protection system for the main and tail rotor blades was flight tested in an artificial icing cloud. The tests indicated that icing protection will be required on this helicopter at temperatures less than -5°C, because of the effects of uncontrolled shedding of large chunks of ice from the rotor blades. The installed fluid anti-icing system was not able to prevent ice from forming because of poor distribution of fluid over the leading edge of the rotor blades.</p>	<ol style="list-style-type: none"> 1. Rotor blades - Icing 2. De-icing systems - Testing 3. Helicopters (Westland Wessex) <ol style="list-style-type: none"> I. Gibbard, G.A. II. NRC LR-356
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