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AERONAUTICAL REPORT

LR - 317

ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A BELL HU - 1 HELICOPTER

BY

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DIVISION OF MECHANICAL ENGINEERING

OTTAWA

OCTOBER 1961

NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

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ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A BELL HU-1 HELICOPTER

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SUMMARY

Flight tests were performed in an artificial icing cloud on a Bell HU-1 helicopter equipped with a fluid icing protection system for the main and tail rotor blades. Icing protection is required for this helicopter because vibrations are caused by the asymmetric self-shedding of rotor blade ice accretions. The results indicated that the anti-icing system will be adequate to protect the helicopter for limited duration flights in moderate icing conditions.

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ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A BELL HU-1 HELICOPTER

1.0 INTRODUCTION

Previous testing (Ref. 1) indicated that the Bell HU-1 helicopter will require some form of rotor blade icing protection before it can safely fly in icing conditions. The major effect of icing on this helicopter was that severe vibrations were caused by the asymmetric self-shedding of ice from the rotor blades. In the winter of 1959-60 an electro-thermal and a fluid rotor blade ice protection system were tested on this helicopter (Ref. 2) and it was found that, because of poor fluid coverage of the main rotor blades, modifications and further testing of the fluid system would be necessary.

In the summer of 1960 a set of modified 15-in. chord blades was fabricated and numerous flow tests made to check the fluid distribution. The uniform coverage obtained on these blades proved that the correct method of locating the fluid ejection holes had been found, and so a set of 21-in. chord blades, the blades intended for the production HU-1B helicopter, was made to undergo further icing tests. However, because of an unfortunate manufacturing difficulty, some of the holes of these blades were blocked and hence there were some areas of marginal fluid coverage. As a result, the 15-in. chord blades had to be used for the bulk of the icing tests to determine if the fluid system would be feasible for this helicopter. A few runs were made with the 21-in. blades, but the fluid coverage was not adequate to protect the helicopter from vibration.

This report presents the results of this last series of rotor blade icing trials performed in January 1961, in the National Research Council's helicopter spray rig, and also the results of tests on two ice detectors performed in conjunction with the rotor blade tests.

2.0 PURPOSE

2.1 To determine the feasibility of using a fluid ice protection system for the rotor blades of the Bell HU-1 helicopter by investigating the effectiveness of the system in keeping the aircraft free of vibration when flying under various icing conditions.

2.2 To determine the minimum anti-icing fluid flow rate required to prevent ice from accreting on the rotor blades.

2.3 To investigate the possibility of using the fluid system for de-icing.

2.4 To test two icing detector systems mounted on the helicopter.

3.0 TEST EQUIPMENT

3.1 Aircraft

The XH-40 (HU-1) helicopter (Fig. 1), used as a test vehicle for the rotor blade anti-icing tests, was powered by the Lycoming T-53 free-turbine engine, with SHP (min.) ratings of 860 military and 710 normal. The 2-bladed main rotor was 44 ft. in diameter and had a constant NACA 0015 aerofoil section. Both 15-in. and 21-in. (the HU-1B blade) chord blades were used in these tests. The 2-bladed tail rotor was 100.8 in. in diameter and had a chord of 8.41 in. and an NACA 0015 aerofoil section. At an engine speed of 6400 r.p.m. the main rotor speed was 314 r.p.m. and the tail rotor 1604 r.p.m.

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. Figure 2 shows the configuration of the Bell system tested. Fluid was pumped from the reservoir through control valves and pressure gauges to the main and tail rotor slinger rings mounted on the rotor hubs. A solenoid valve was provided in the main rotor circuit so that fluid-on and fluid-off times could be closely controlled. From the slinger ring, fluid was distributed to each of the main rotor blades through three flexible tubes connected to the three supply channels machined along the rear face of the nose block of the blade. Fluid was fed from these supply channels to the two distribution grooves along the blade leading edge at three locations, 22, 39 and 55 percent radius, as shown in Figure 3. The two distribution channels in each of the tail rotor blades were fed directly from the slinger rings through flexible tubes.

For fluid distribution to the external blade surfaces two rows of holes were drilled through the stainless steel abrasion covers into the two distribution grooves. The placement of the holes on the leading edge of the main rotor blades was determined by a careful study of the location of stagnation points on all regimes of flight (Ref. 3), in order to ensure fluid coverage of both top and bottom of the blade. Leakage of fluid from one groove to the other, which could cause one side of the blade to be starved for fluid, was prevented by a rubber strip seal between the two grooves. The holes were 0.035 in. in diameter on approximately 1-3/16-in. centres and the two rows of holes were staggered and 0.30 in. apart. On the tail rotor blades the two rows of holes were located symmetrically on either side of the centre chord line 0.14 in. apart.

The fluid used in this system was a mixture (by volume) of 90 percent denatured ethyl alcohol and 10 percent glycerine.

The total installed weight of the system including 11 U.S. gallons of fluid was about 145 lb.

A more complete description of this fluid ice protection system is given in Reference 1. The system used for these tests was essentially the same as described in that report except for modifications made to the location of the holes on the main rotor blades to improve fluid coverage.

3.3 Ice Detectors

The Bell ice detector system consisted of two orifice-type detector probes built into the main rotor blades and connected to a pressure switch mounted on the rotor hub. A small detector plate with several dynamic pressure holes was located over a small plenum chamber in the leading edge of each main rotor blade at about 55 percent radius (see Fig. 4). The static pressure port for the chamber was located on the underside of the blade directly chordwise from the detector plate in an ice-free location. The pressure from the plenum chambers was ducted through tubes inside the blades to the diaphragm-type pressure switch on the rotor hub. These ice detectors were built into a special set of rotor blades having fluid icing protection only out to the ice detectors. No special de-icing was provided for the detector plates.

The operation of the pressure switch shown in Figure 5 was as follows: In normal non-icing operation the spring force and the positive pressure from the dynamic holes acting on the lower surface of the diaphragm held a micro-switch connected to the centre of the diaphragm in an open-circuited position. However, when the dynamic pressure holes on the leading edge of the blades were iced over, the pressure below the diaphragm became negative because of the centrifugal pumping through the static ports. The resulting downward movement of the diaphragm tripped the micro-switch and an icing signal was given. Normally this signal would be relayed from the micro-switch to the cockpit through a simple slipring assembly, but for the experimental system tested a small radio transmitter mounted on top of the pressure switch was used to send the signal to a receiver in the helicopter cabin.

A few tests were also made on an experimental icing detector employing a beta particle source manufactured by the United Control Corporation. The detector probe was mounted in the engine inlet cowling and the controller was located in the helicopter cabin.

3.4 Spray Rig

The spray rig used to produce an artificial icing cloud for these tests is described in Reference 4 and shown in Figure 1. Instrumentation at the test site measured wind-speed, temperature and humidity.

4.0 TEST PROCEDURE

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, thereby seriously obscuring 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 icing protection. The fluid was then turned on to determine if it would shed the ice without causing vibrations. Normally this de-icing was performed in the cloud, but on one flight the helicopter was flown away from the spray rig so that de-icing could be attempted at forward speed.

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 in order to determine the minimum amount of fluid required to prevent vibrations under a range of icing conditions. For cyclic anti-icing the fluid was cycled on and off during the run, with all the on and off times being 1 min. or less. On occasion when the cyclic anti-icing method was not sufficient to prevent vibrations from building up, the fluid was switched to continuous flow in order to reduce the vibration level.

Two flights were made in a natural freezing drizzle at forward speeds from 20 to 40 knots. On run 6-10 the helicopter was flown for 15 min. without any fluid flowing to the blades, to check the rate of ice accretion. On run 6-11 the fluid was turned on to clear the ice from the previous run and to anti-ice the blade for a further 15 min. However, the freezing drizzle turned to light snow after a few minutes of the flight and little icing was encountered on this run.

For most of the tests on the ice detectors the helicopter was flown in the cloud only long enough to obtain one ice detector signal and then immediately landed for inspection of the ice. A few extended runs during which several icing signals were given were made on the United Control detector, but longer runs could not be made on the Bell System because the detector plates could not be de-iced. The sensitivity of both detectors was changed several times during the tests in order to obtain the quickest possible response to icing conditions. The Bell detector system was modified by varying the size and number of the dynamic pressure holes, changing the stiffness of the pressure switch diaphragm and spring, and by decreasing the volume of the pressure switch chamber.

5.0 RESULTS AND DISCUSSION

5.1 General

A total of 30 test flights was made on the fluid icing protection system, the first 11 with the 21-in. chord blades and the remainder with the 15-in. chord blades. These tests were made over a range of temperatures from -9.5°C to -21.1°C and liquid water contents from 0.25 to 0.8 gm./m^3. The droplet size for all runs, except those in natural freezing drizzle, was held constant at about 30 microns (median volume diameter).

Twenty tests were made on the ice detectors with the United Control detector being tested only on the last nine. The range of temperatures for these tests was from -20.8°C to -13.5°C and liquid water contents ranged from 0.2 to 0.5 gm./m^3.

The results of all the tests performed on the two sets of fluid anti-icing rotor blades are shown in chronological order in Table I, and the ice detector results are shown in Table II.

5.2 Icing Accretion Runs

On the few accretion runs, it was verified that ice was readily built up on the main and tail rotor blades and vibrations were produced when self-shedding of this ice occurred. On long duration flights in the cloud, ice was also picked up on unprotected areas of the helicopter such as the engine intake screen, stabilizer bar and bob-weights and the tail boom. None of this secondary icing caused any adverse effects on the operation of the aircraft. Examples of ice accretions on various parts of the helicopter are shown in Figure 6.

5.3 21-in. Chord Blade Tests (Runs 4-1 to 6-11)

The tests on the set of 21-in. chord blades indicated that the fluid coverage on the bottom surface of the blades was inadequate for successful operation. It was known from previous flow tests that there were areas of poor fluid distribution from about 90 in. to 145 in. radius on one blade and from 115 in. to 155 in. and 190 in. to 220 in. radius on the other. These were the areas of general ice anchorage on all runs with these blades (Fig. 7). On most anti-icing runs vibrations were produced from the asymmetric shedding of this ice after less than 10 min. duration. All anti-icing with these blades was done during ground runs, except the one flight test in freezing drizzle, run 6-11. The icing was very light on this run and the blades had shed cleanly on landing.

Because the 21-in. chord blades were not adequate to protect the helicopter in icing, the 15-in. chord blades, which were known to have good fluid coverage, were installed for the remainder of the tests.

5.4 15-in. Chord Blade Tests

A number of de-icing and anti-icing runs were made using the 15-in. chord blades. There were no large areas of ice anchorage on these blades as there had been with the other set. Complete shedding of ice from the rotor blades was never achieved, however. There were always large amounts of light residual ice at the end of a flight (Fig. 8, 9 and 10) anchored on the leading edge of the blade between the two rows of holes. Because this ice always remained on the blades the criterion for successful operation of the system could not 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. Instead, the effectiveness of the fluid anti-icing system was judged by its ability to prevent vibrations from uneven shedding of ice from the rotor blades.

The definitions of vibration level used for these tests are as follows:

light - barely noticeable vibrations

medium - more noticeable vibrations but still within the comfort level

heavy - vibrations exceeding the comfort level.

These levels were determined by the pilot.

5.4.1 De-Icing Flights

In general, de-icing was not successful on the few flights in which it was tried. On runs 12-16 and 12-19 heavy vibrations resulted when the fluid was turned on to shed the ice. On runs 10-14 and 13-20 fairly large areas of ice were unshed at the end of the run and if further de-icing cycles had been made it is possible that they could have shed unevenly and caused vibrations. Examples of ice remaining on the blades after de-icing runs can be seen in Figure 8. The only run on which the blades were shed fairly cleanly without causing vibrations was 20-28 when the helicopter left the cloud after 4 min. and then de-iced at forward speed. The fluid-on time for this run was much greater than for the other de-icing runs.

These results indicate that a fluid system for this helicopter will require a sensitive ice detector in order that the fluid can be turned on before any large amounts of ice have accreted on the rotor blade. Otherwise bad vibrations from uneven shedding could result.

5.4.2 Anti-Icing Flights

5.4.2.1 Continuous Fluid Flow

Runs were made under various icing conditions to determine the rate of continuous fluid flow required to keep the rotor blades anti-iced. Runs 16-22 and 16-23 were short duration runs (2 or 3 min.) on which anti-icing was successfully achieved using constant high flow rates of 0.04 and 0.05 qt./min. ft. respectively. Only light residual ice remained on the blades at the end of these runs (Fig. 9a, b). On run 12-17 at a liquid water content of 0.5 gm./m^3 and ambient temperature of -16.7°C, the blades were anti-iced for 17½ min. without any vibrations being produced using a constant fluid flow of 0.045 qt./min. ft. These runs certainly proved the feasibility of anti-icing, although the fluid flow was too high to be economical.

Run 18-24 was made to determine the minimum continuous flow rate required to anti-ice the blades at conditions of low temperature (-19.5°C) and a liquid water content of 0.25 gm./m^3. Starting with 0.05 qt./min. ft. the fluid flow was reduced slightly every 5 min. until it was found that main rotor vibrations were still being prevented with a fluid flow of 0.02 qt./min. ft. (Fig. 9c). Fluid distribution tests had previously shown that this was about the minimum fluid flow that could be used while still maintaining good fluid coverage over the full length of the blades. On run 9-13 a similar procedure to that of run 18-24 was followed but at conditions of higher liquid water content (0.45 gm./m^3). The fluid flow was slowly reduced until it was found that vibrations started to be produced at flows of about 0.03 qt/min. ft.

On run 20-30 the flight was started using a low fluid flow (0.022 qt./min. ft.) at 0.5 gm./m^3 liquid water content. After 3½ min. the vibration level started to build up and it was necessary to increase the fluid flow for a few minutes to eliminate the vibrations. The flow was then reduced again to about 0.025 qt./min. ft., but after a further three minutes the fluid flow again had to be increased because of vibrations.

These tests indicate that for continuous flow anti-icing of the rotor blades at all ambient temperatures down to -20°C (-4°F), a fluid flow rate of 0.03 U.S. qt./min. ft. will be required. Since a lower flow rate could be used at higher temperatures and with light icing conditions, fluid could be conserved by using a two-speed pumping system with flow rates of about 0.03 and 0.02 U.S. qt./min. ft. The low flow would then be used for normal light icing conditions and the boosted flow rate would be available for conditions where the 0.02 U.S. qt./min. ft. flow could not cope with the icing, and vibrations were being produced. With its 11-gal. capacity this would then give the anti-icing system a duration of about 55 min. on the low flow rate and 38 min. on high.

5.4.2.2 Cyclic Fluid Flow

In order 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.

On runs 10-15 and 12-18 a one-minute on, one-minute off flow cycle was used at liquid water contents of 0.3 and 0.45 gm./m.^{3} respectively. In both cases high flow rates were used and the blades were first thoroughly wetted by leaving the fluid on continuously for 4 min. before initiating the cyclic flow. On both runs light vibrations were produced even with the very high flow rates used. These flow rates were too high to make the 1-min. on-off cycle worthwhile.

On run 18-25 a 30-sec. on-off cycle was tried after an initial 3-min. fluid-on period using 0.028 qt./min. ft. at 0.25 gm./m.^{3} liquid water content. The flight was successfully continued for a total of 27½ min. with light to medium vibrations being noticed only for a few seconds at the beginning of each on cycle. At the start of run 18-26 the 30-sec. on-off cycle was again found to work satisfactorily with 0.25 gm./m.^{3} liquid water content and a flow rate of 0.026 qt./min. ft., so a 45-sec. off, 30-sec. on cycle was tried. After about 3 min. of this method, medium vibrations built up and it was necessary to switch to continuous flow to reduce them. Later in the run the 30-sec. on-off cycle was tried again on two occasions, but both times the vibration level increased after about 3 min. and high continuous flow had to be used to eliminate the unbalances. The pilot doubted that he could have flown on instruments under the vibration conditions experienced in this run. On run 18-27 the 30-sec. on-off cycle was used throughout the run at the same flow rate as on run 18-26 and at higher liquid water content. Only light vibrations were produced for the 9-min. duration of the run, and very light patches of ice remained on the blade at the end of the run. Examples of residual ice on the blades after cyclic anti-icing runs can be seen in Figure 10.

From the above-described runs it is evident that the longest time the fluid can be turned off during a cyclic anti-icing run is about 30 sec. With longer times than this the residual fluid on the blade is depleted and the ice begins to adhere to points of poor fluid coverage, particularly between the row of holes. Once these points of anchorage for the ice are established on the blades it is very difficult to eliminate them and prevent the ice from building up enough to cause vibrations when the chunks of ice shed.

The cyclic anti-icing tests have indicated that the most economical configuration for a fluid icing protection system for this helicopter is to use a flow rate of about 0.030 qt./min. ft. with a two-position control switch such that in the normal position the flow is cycled 30 sec. on, 30 sec. off and in the second or boosted position the fluid is flowed continuously at the same flow rate. The continuous flow would be used for heavy icing conditions and to combat any increases in vibration that might occur during a cyclic de-icing flight. This system would have a duration of about 75 min. on cyclic flow and 38 min. on continuous for the 11-gal. (U.S.) capacity.

Run 20-29 illustrated how this system would be operated under quite heavy icing conditions (0.5 gm./m^3 at -20°C). Although the blades were coated with fluid before entering icing conditions, vibrations gradually built up using the 30-sec. on-off cycle and it was necessary on two occasions during the 25-min. run to switch the fluid to continuous flow for a short while and then to return to cyclic flow when vibrations had subsided to a safe level.

5.5 Tail Rotor

The anti-icing tail rotor blades were known from past tests to work very well and no particular attention was paid to their performance during these tests. Normally some arbitrary flow was set up for the tail rotor and left constant throughout a run. On one occasion during a run the fluid flow to the tail rotor was accidentally turned off for a few seconds and medium vibrations resulted. However, these were quickly eliminated when the fluid flow was resumed. Other than on this one occasion, no difficulties were encountered from tail rotor icing on any of the tests.

5.6 Ice Detector Systems

The tests on the Bell ice detector indicated that this system can give fairly rapid indication of icing at low temperatures. After many modifications, the best hole pattern on the detector plate was found to be the following: four 0.025 dia. holes in the top row, six 0.035 dia. holes in the middle row, and five 0.025 dia. holes in the bottom row. In this final configuration and with other changes in the pressure switch, the detector was signalling with an ice thickness of between 1/64 in. and 1/32 in. on the blades at the detector plate. It was necessary for the holes to be only about half blocked for a signal to be given. No tests were made on this detector system at temperatures above -13.5°C, however, and it is likely that its performance would be affected by the wet mushroom-shaped accretions experienced at higher temperatures. It was also found that false signals were given under some conditions of flight out of icing conditions. Further testing will be necessary to investigate the effects of these two items before any final conclusions can be drawn about the suitability of this detector system.

The United Control detector, mounted in the engine inlet also gave fairly rapid indication of icing condition on the few runs it was tested, but, in general, it was not as sensitive as the Bell system. This detector had the added feature that it was de-iced by means of an electric heater after each signal, and as a result it gave a series of signals as long as the helicopter remained in the icing conditions. The frequency of these signals was then an indication of the rate of icing. However, the heater apparently burned out near the end of the tests and no further extended runs could be made. The principle of this detector appears very good with the only drawback being the manufacturing difficulty of providing it with a reliable heater.

6.0 CONCLUSIONS

The fluid anti-icing system tested on the Bell HU-1 helicopter was adequate to prevent vibrations for limited duration runs in moderate icing conditions with a fluid flow of about 0.03 U.S. qt./min. ft.

The fluid system was not satisfactory for de-icing as vibrations were produced owing to the asymmetric shedding of ice from the rotor blades when the fluid was turned on.

On the tests of the 21-in. chord blades vibrations were produced from ice building up on isolated areas of the blade receiving little fluid. This shows that a fluid rotor blade anti-icing system requires precise location of the fluid ejection holes to ensure that all areas of the blade receive adequate fluid coverage.

A sensitive ice detection system would be recommended for use with the fluid system to ensure that the fluid is turned on as soon as possible after icing is encountered in order that no appreciable ice thickness can build on the rotor blades and cause vibrations from asymmetric shedding

The Bell ice detector system operated adequately for the limited range of conditions experienced during the tests. However, more testing will be necessary to investigate the effects of higher temperature icing and of flight condition that might cause false signalling.

The United Contral ice detector appears to be good in principle but requires the addition of a reliable heater.

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Table I

RESULTS OF FLUID ANTI-ICING RUNS

Run No.	Elapsed Time min.	Time in Icing min.	Ambient Temp. °C	L.W.C. gm./m^3	Ice Thickness in.	M/R Flow Rate qt./min. ft.	Type of Run	Remarks
4-1	-	2	-10.7	0.5	11/64 @ 9'	off	Accretion only	
4-2	-	3½	-11.0	0.5	9/32 @ 9'	off	Accretion only	T/R ice 9/64 at 2' radius
5-3	-	2	-18.9	0.5	9/64 @ 13'	off	Accretion only	
5-4	5	-	-18.1	-		.043	De-icing of run 5-3	Poor fluid coverage - patchy shedding on M/R - T/R clean
5-5	-	10	-17.6	0.5		.043	Anti-icing	Ground run - patchy M/R shedding - T/R clean
5-6	0		-16.5	0.5		off	Accretion, then de-icing	Start ground run - de-icing in cloud after 2 min.
	2					.043		Fluid on
	6½	6½	-16.2			.043		End of run - patchy M/R shedding - T/R clean
5-7	-	7	-13.0	0.5		.030	Anti-icing	Ground run - patchy M/R shedding - T/R clean
5-8	-	10	-12.6	0.5		.035	Anti-icing	Ground run - patchy M/R shedding - slight M/R vibration
5-9	-	8	-11.8	0.3		.035	Anti-icing	Ground run - patchy M/R shedding - slight M/R vibration
6-10	-	15	- 9.5	-	3/32 @ 10'	off	Accretion only	Forward flight (20-30K) in natural freezing drizzle
6-11	-	17	- 9.5	-		.024	Anti-icing	As run 6-10 - M/R blades mostly clean - T/R clean
9-12	-	3	-12.6	0.45	9/32 @ 10'	off	Accretion only	Slight M/R vibrations on landing - T/R ice 3/16 at 3' radius
9-13	0		-12.7	0.45		.040		Start run out of cloud with ice from run 9-12
	2					.040	Anti-icing	Enter icing cloud
	4					.035		Fluid flow reduced
	11					off		Fluid inadvertently off - slight vibrations
	12½					.035		Fluid on again
	14					.030		Fluid flow reduced
	18					.040		Slight vibration, fluid flow increased
	25	23	-12.9					End of run - residual ice on M/R leading edge to 18' radius
10-14	0		-15.6	0.5		off	Accretion, then de-icing	Start run - de-icing in cloud after 4 min.
	4					.041		
	7	7	-15.4			.041		End of run - no shedding to 13' radius, patchy shedding to tip - light T/R ice
10-15	0		-15.2	0.3		.040	Anti-icing	Start run with residual ice from run 10-14
	4					.040	Cyclic Anti-icing	Start 1 min. fluid off, 1 min. on cycle - to end of run
	12	12	-15.0		7/64 @ 5'	.040		End of run - residual M/R ice to 20' radius - light T/R ice left
12-16	0		-17.7	0.6		off	Accretion, then de-icing	Start run - de-icing in cloud after 6 min.
	6					.043		Heavy lateral M/R vibration
	11½	11½	-17.3		7/8 @ 10'	.043		End of run - no shedding to 11' radius - patchy shedding to tip - T/R clean
12-17	-	17½	-16.7	0.5		.045	Anti-icing	Residual M/R ice to tips - light T/R ice
12-18	0		-16.3	0.45		.060	Anti-icing	Start run
	4					.060	Cyclic anti-icing	Start 1 min. fluid off, 1 min. on cycle - light vibrations
	20					off		Fluid off
	21½	21½	-16.2			off		End of run - residual M/R ice to tips - T/R ice fairly thick
12-19	0		-14.0	0.5		off	Accretion, then de-icing	Start run, de-icing in cloud after 4 min.
	4					.061		Fluid on - heavy vibrations
	9¼	9¼	-13.8		1/2 @ 12'	off		End of run - patchy M/R shedding - T/R clean
13-20	0		-13.3	0.5		off	Accretion, then de-icing	Start run - de-icing in cloud after 3 min.
	3					.059		Fluid on
	6¼	6¼	-13.3		15/64 @ 9'	off		End of run - patchy shedding - residual ice to 19' radius
13-21	-	1½	-12.7	0.8		.057	Anti-icing	Run terminated prematurely because of rig failure
16-22	-	3	-16.2	0.5	7/64 @ 10'	.040	Anti-icing	Around run - residual ice to 21' - no shedding to 9' radius - T/R mostly clean
16-23	0		-14.6			.050		Start run - fluid on - out of cloud
	1			0.5		.050	Anti-icing	Enter cloud
	3¼	2¼	-14.6		5/64 @ 9'	off		End of run - slight vibrations - residual M/R ice to 20' - light T/R ice
18-24	0		-19.7	0.25		off	Accretion	Start run, 2 min. accretion - then fluid on
	2					.050	Anti-icing	Fluid on
	7					.045		Fluid flow reduced
	12					.032		Fluid flow reduced - T/R vibration for few secs. when fluid inadvertently turned off
	17					.025		Fluid flow reduced
	22					.020		Fluid flow reduced - no vibrations
	25	25	-19.3			off		End of run - light residual ice to tips - T/R clean
18-25	0		-18.9	0.25		.028	Anti-icing	Start run in cloud
	3					.028	Cyclic anti-icing	Start 30 sec. off-on cycle
								Light to medium M/R vibrations at start of each on-time
	27½	27½	-18.5			off		End of run - residual ice on M/R to tips - T/R clean
18-26	0		-17.0	0.25		.026	Cyclic and continuous anti-icing	Start run in cloud
	3					.026		Start 30 sec. off - 30 sec. on cycle
	7					.026		Start 45 sec. off - 30 sec. on cycle
	10					.026		Medium M/R vibration - switch to continuous flow
	12½					.026		Vibration level reduced - return to 30 sec. off-on cycle
	15½					.026		Med. Vibrations - to continuous flow
	17½					.040		Still increasing vibrations - flow increased
	19					.026		Vibrations reduced - return to 30 sec. off-on cycle at low fluid flow
	22					.045		Vibration increasing - to high continuous flow
	24					.025		Light vibration - flow continuous
	35	35	-16.6			off		End of run - residual ice to tips of M/R - T/R clean
18-27	-	9	-16.4	0.4		.026	Cyclic anti-icing	30 sec. off-on cycle - light vibrations - residual M/R ice - T/R clean
20-28	0		-21.1	0.5		off	Accretion	Start run
	4					.035	De-icing	Leave cloud for forward flight de-icing
	13	4	-20.6			off		End of run - residual M/R ice to 21' - T/R clean
20-29	0		-20.6	0.5		.029	Cyclic and continuous anti-icing	Start run - fluid on, out of cloud - 30 sec. off-on cycle
	4					.029		Enter cloud
	13					.029		Med. M/R vibrations - fluid on - continuous for 15 sec. - vibration subsided
	19					.029		Heavy M/R vibration - fluid on - continuous
	20					.029		Vibrations subsided - return to cyclic flow
								Light to medium vibrations for rest of flight
	29	25	-19.8			off		End of run - residual ice to tips of M/R - light T/R ice
20-30	0		-18.4	0.5		.022	Anti-icing	Start run
	3½					.040		Vibrations increasing - flow increased
	6½					.024		Vibrations subsided - flow decreased
	10					.042		Vibrations increasing - flow increased
	10½					.025		Vibrations subsided - flow decreased for rest of flight
	15	15	-18.0			off		End of run - heavy residual ice to tips of M/R - light T/R ice

M/R = main rotor

T/R = tail rotor

Table II
LR -317

TABLE II

ICE DETECTOR RESULTS

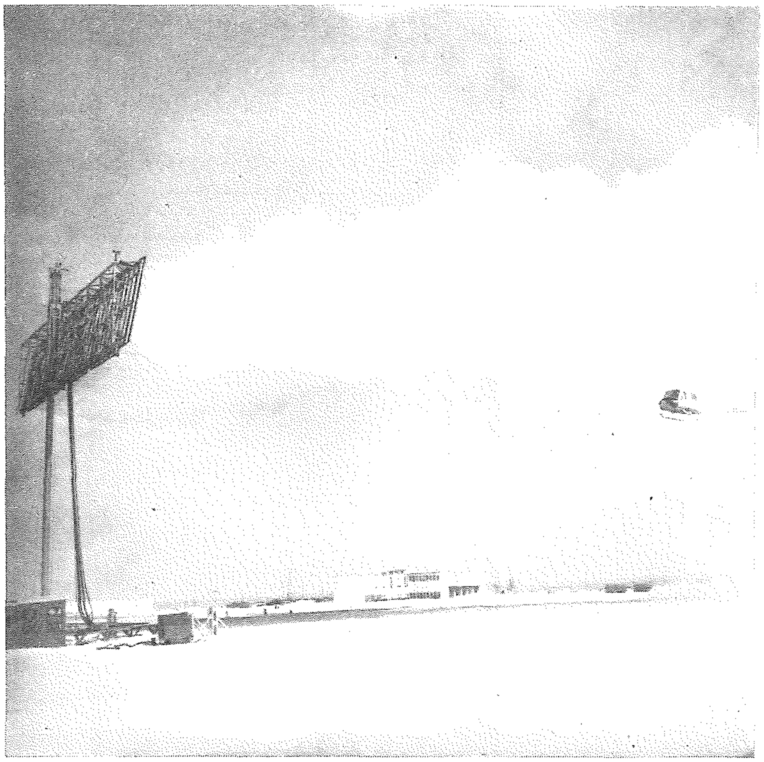
Bell Ice Detector

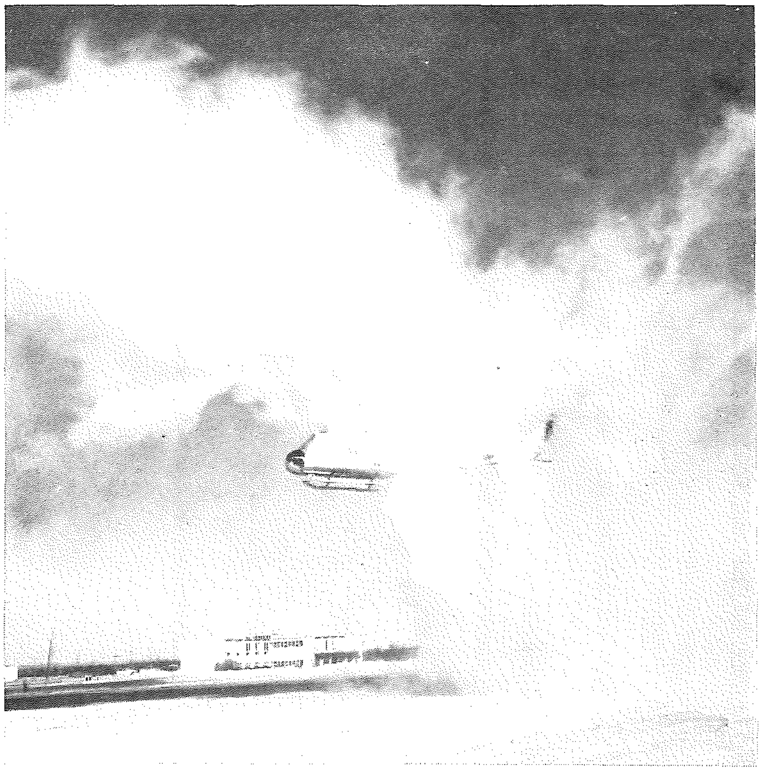
Run No.	Temp. °C	L.W.C. gm./m.^{3}	Ice Thickness At I/D in.	Time To Signal sec.	Remarks
25-31	-19.3	0.25	.094	130	Original configuration - 27 holes in 3 rows
25-32	-18.6	0.25	.102	150	27 holes in 3 rows
25-33	-18.3	0.25	.086	110	Number of holes reduced to 19 in 2 rows
26-34	-20.8	0.30	.063	90	19 holes in 2 rows
26-35	-20.0	0.5	.078	110	27 holes in 3 rows again
26-36	-19.0	0.5	.070	70	Number of holes reduced to 15 in 3 rows
26-37	-18.2	0.5	-	50	15 holes in 3 rows
27-38	-18.4	0.3	.023	54	15 holes in 3 rows - hole dia. reduced to 0.025 in.
27-39	-17.7	0.3	.016	44	15 holes in 3 rows
27-40	-16.0	0.5	.039	50	15 holes in 3 rows
27-41	-15.4	0.5	-	43	15 holes in 3 rows
30-42	-20.6	0.25	-	15	15 holes - spring and diaphragm changed
30-43	-18.2	0.25	-	11	15 holes in 3 rows
30-44	-17.7	0.3	-	-	No signal - transmitter inoperative
30-45	-14.4	0.3	-	37	15 holes in 3 rows
30-46	-14.0	0.3	-	40	15 holes in 3 rows
30-47	-13.5	0.4	-	35	15 holes in 3 rows
31-48	-17.8	0.25	-	74	15 holes in 3 rows
31-49	-16.3	0.5	-	39	15 holes in 3 rows
31-50	-15.2	0.2	-	28	15 holes - volume of pressure switch reduced

United Control Ice Detector

Run No.	Temp. °C	L.W.C. gm./m.^{3}	Number of Signals	Time to 1st Signal sec.	Signal Rate sec./signal	Remarks
30-42	-20.6	0.25	1	105	-	
30-43	-18.2	0.25	2	135	85	
30-44	-17.7	0.3	4	54	99	Controller adjusted
30-45	-14.4	0.3	4	96	55	
30-46	-14.0	0.3	5	60	60	
30-47	-13.5	0.4	4	25	60	Controller adjusted
31-48	-17.8	0.25	4	61	57	
31-49	-16.3	0.5	1	64	-	Heater inoperative
31-50	-15.2	0.2	1	50	-	Heater inoperative

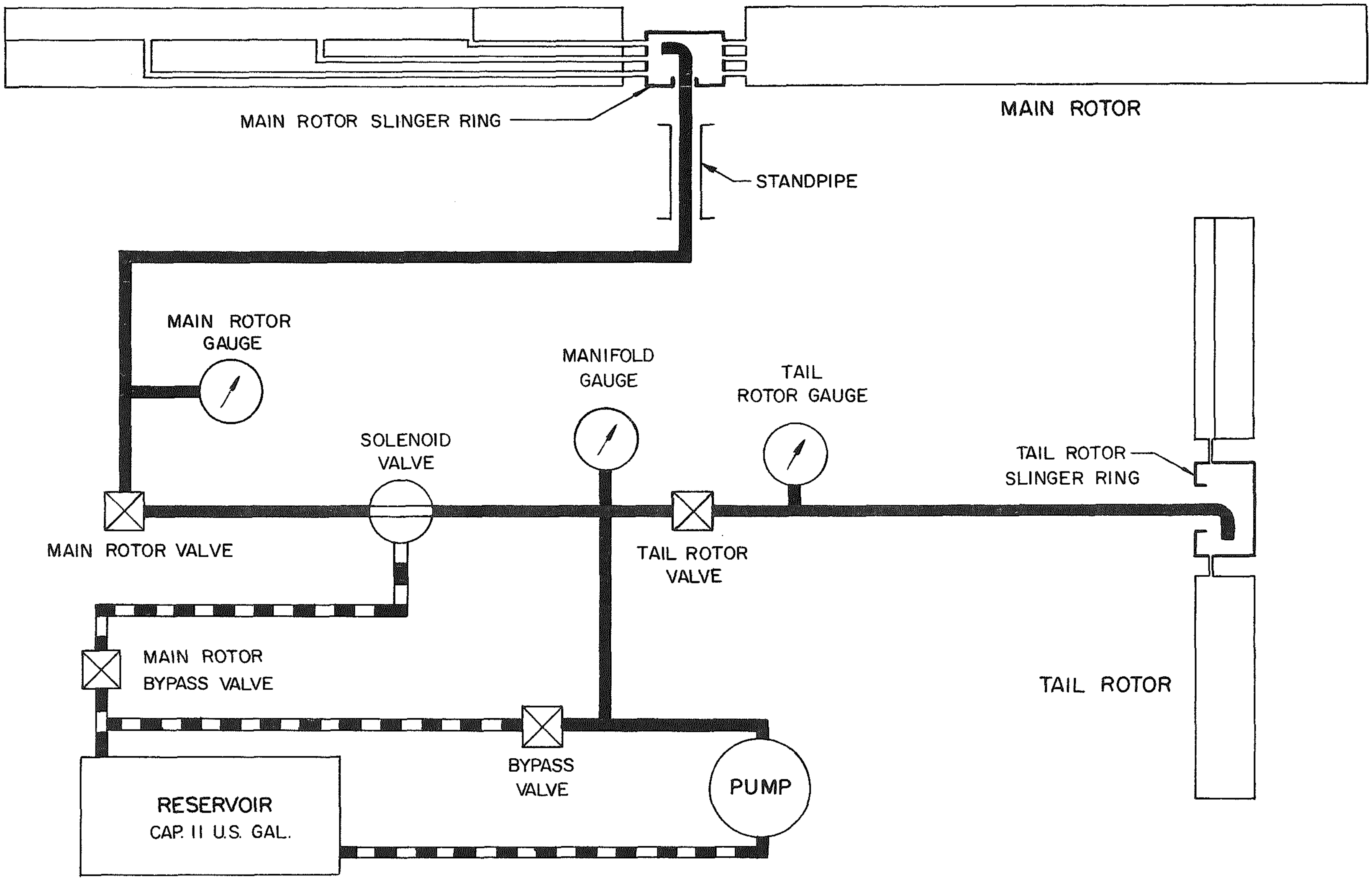
FIG. 1
LR-317



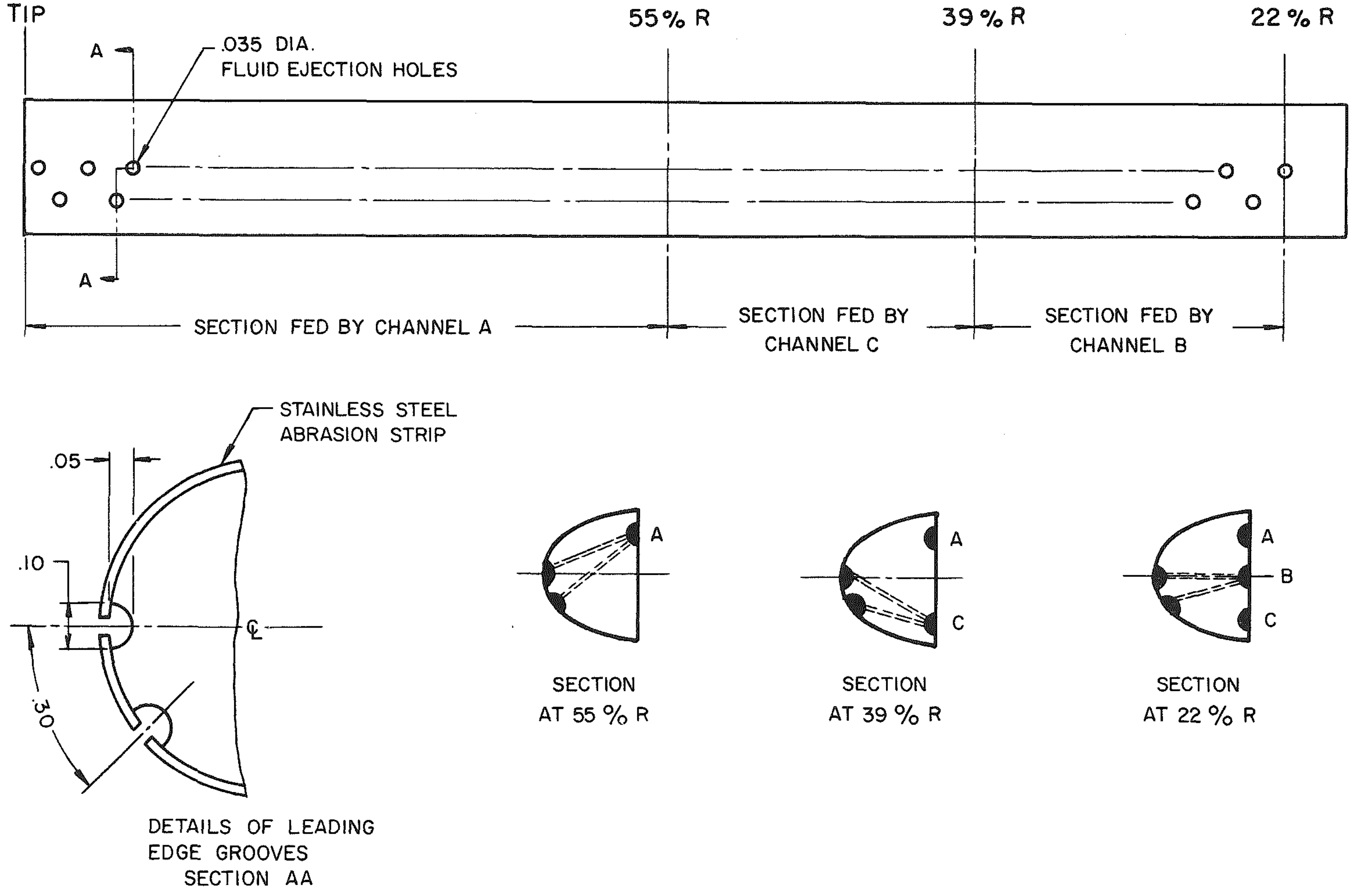


THE TEST HELICOPTER IN THE SPRAY RIG

FIG. 2
LR-317



SCHEMATIC OF FLUID ICE - PROTECTION SYSTEM.
(From Reference 2)



DETAILS OF LEADING EDGE GROOVES SECTION AA

SECTION AT 55 % R

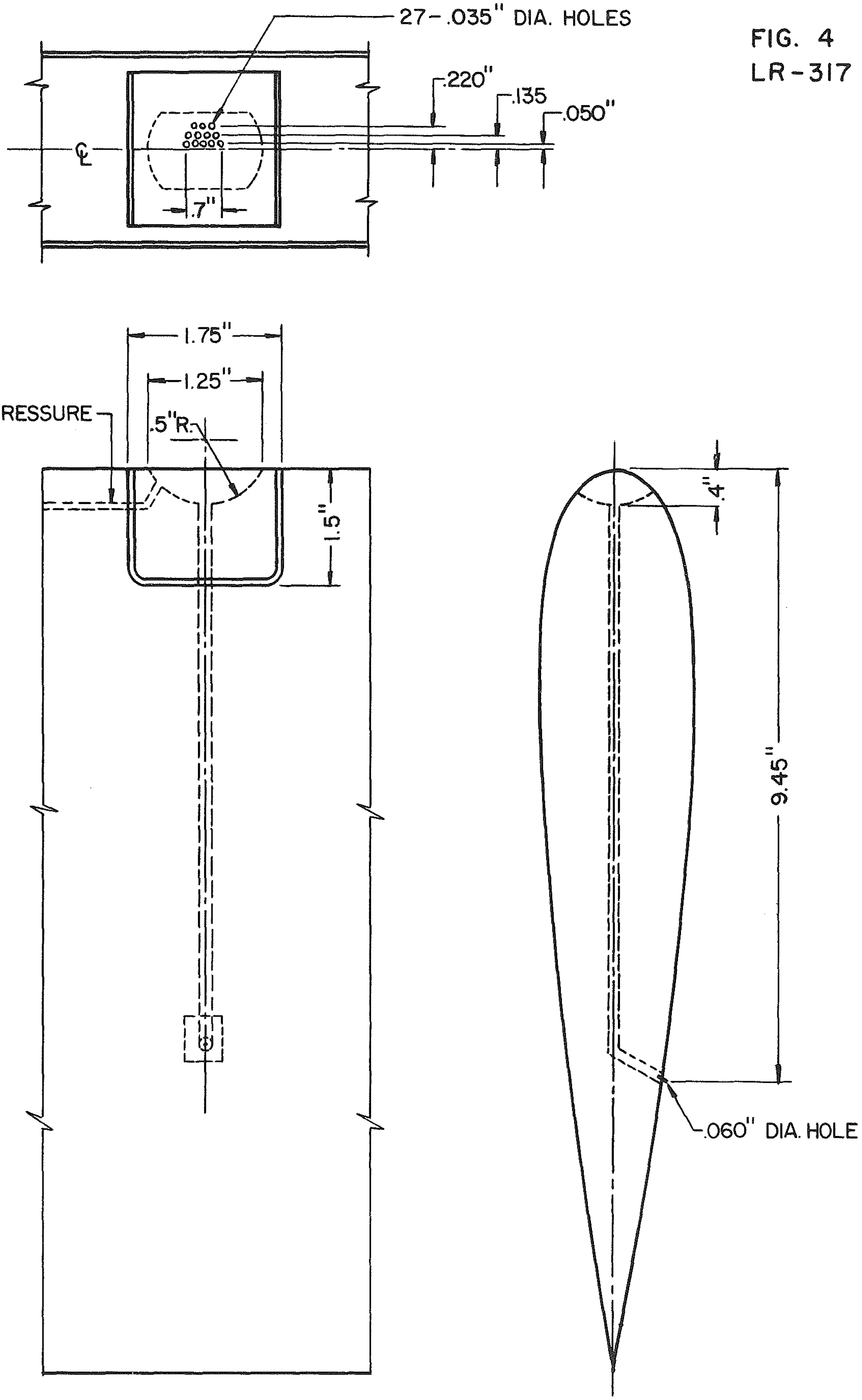
SECTION AT 39 % R

SECTION AT 22 % R

DETAILS OF FLUID ICE - PROTECTED MAIN ROTOR BLADE.

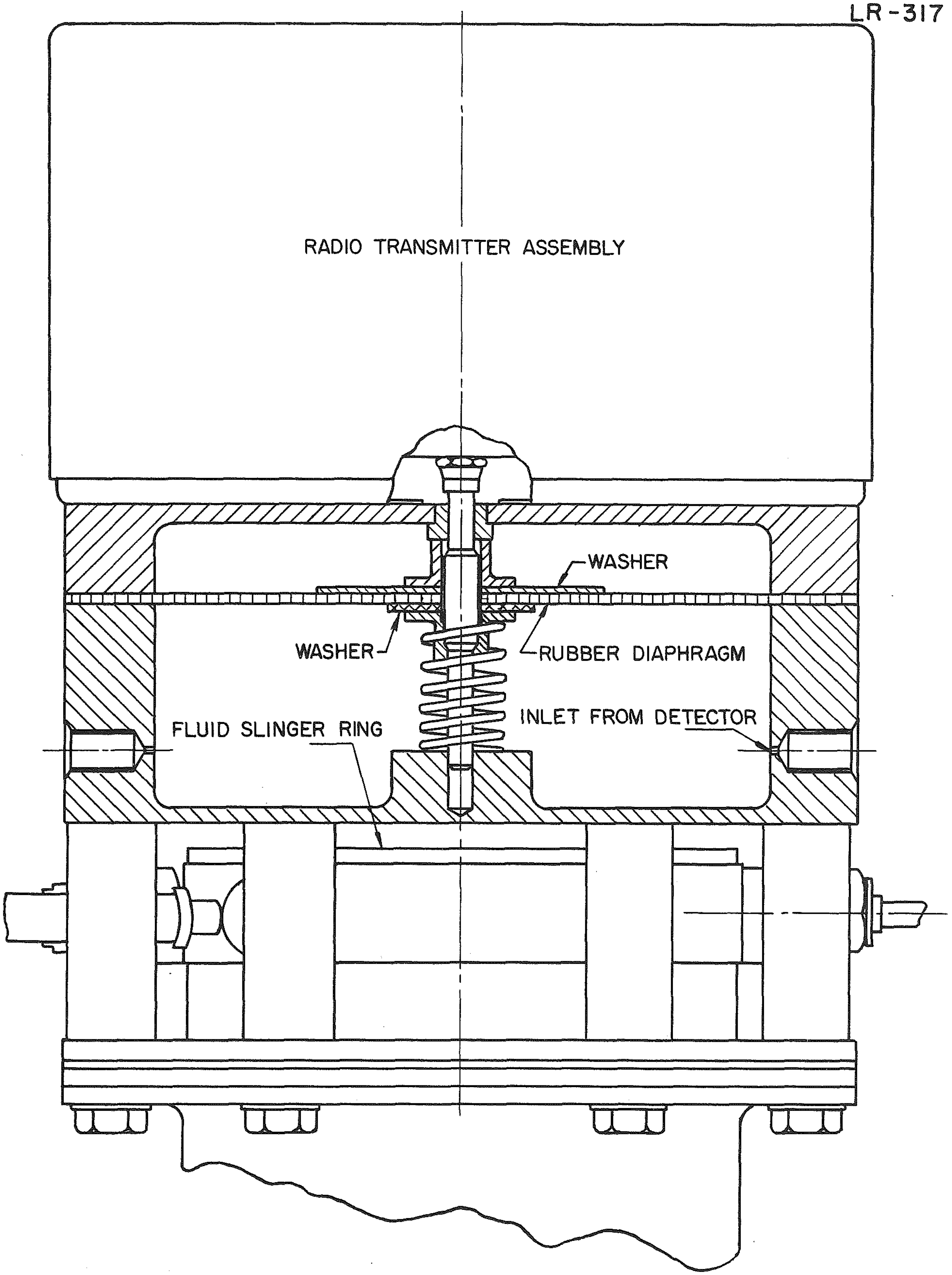
FIG. 3
LR-317

FIG. 4
LR-317

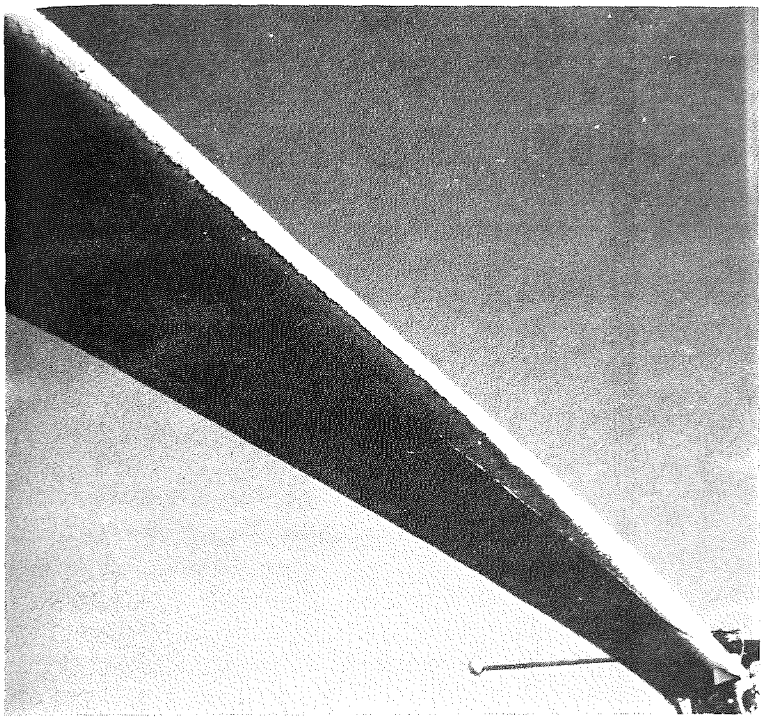


ICE DETECTOR IN MAIN ROTOR BLADE.

FIG. 5
LR-317

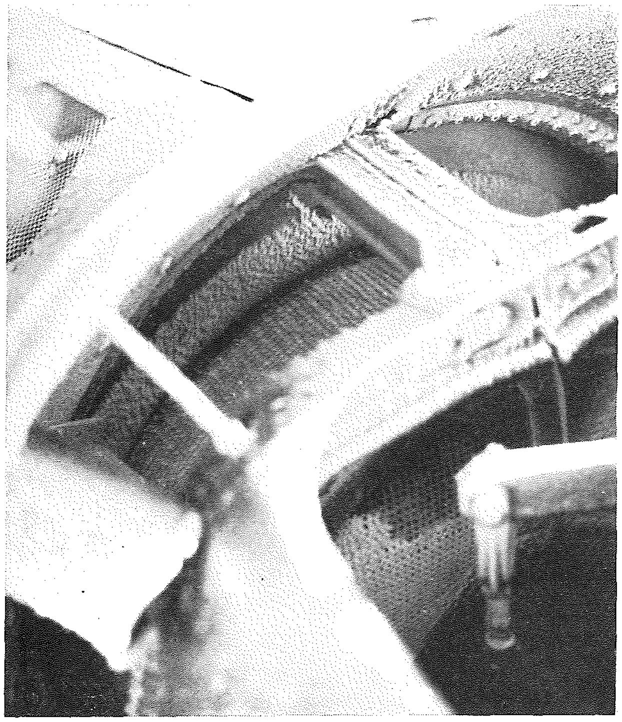


ICE DETECTOR PRESSURE SWITCH.

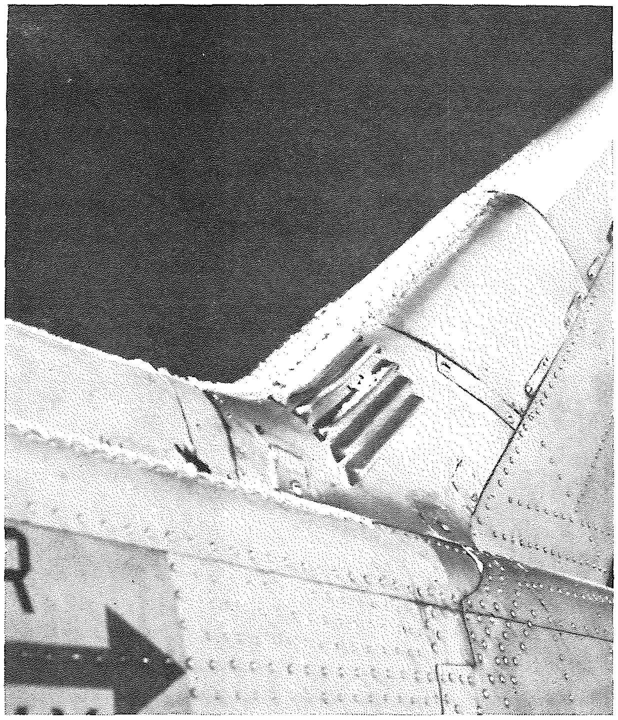


ROTOR BLADE ICING
RUN 9-12

STABILIZER BAR AND
BOB-WEIGHT ICING
RUNS 12-16 AND 12-17



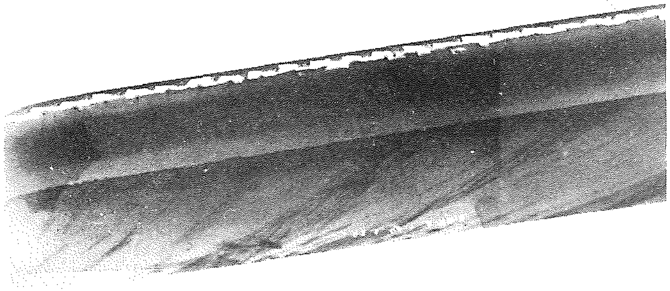
ENGINE INLET SCREEN ICING
RUNS 12-16 TO 12-18



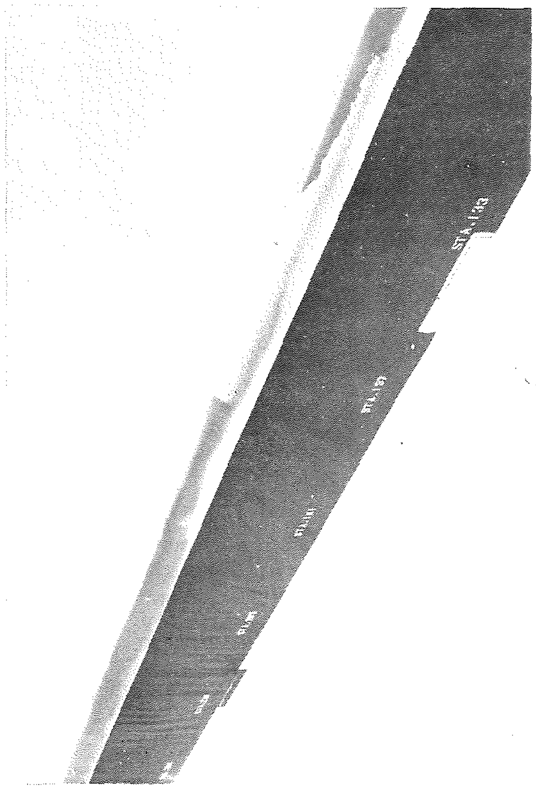
TAIL BOOM ICING
RUNS 18-24 TO 18-26

ICE ACCRETIONS ON HELICOPTER

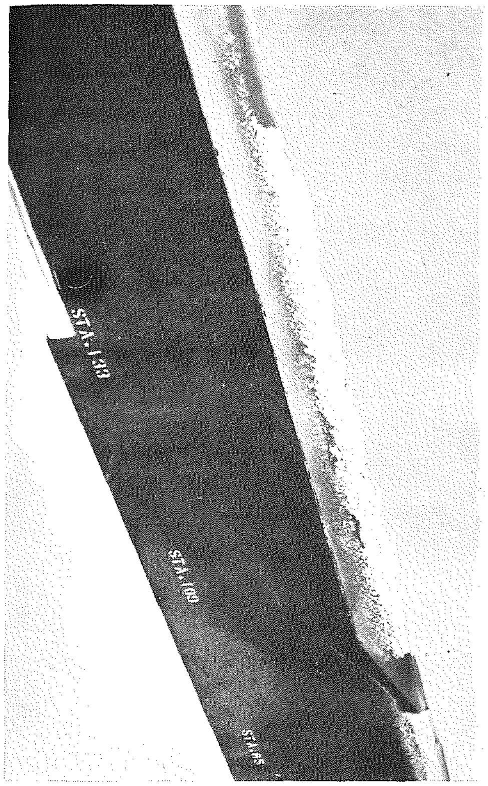
FIG. 7
LR-317



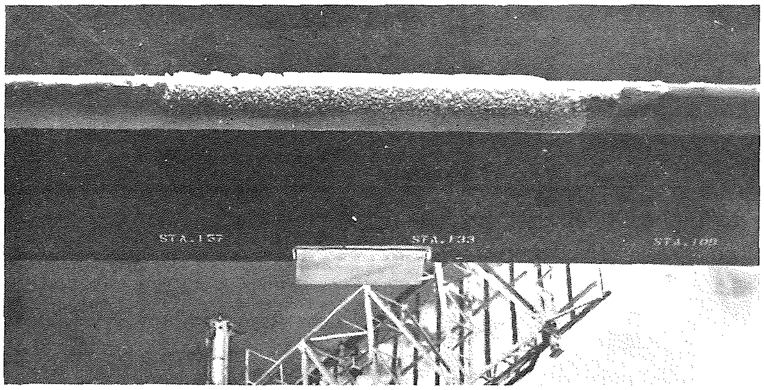
RUN 5-4



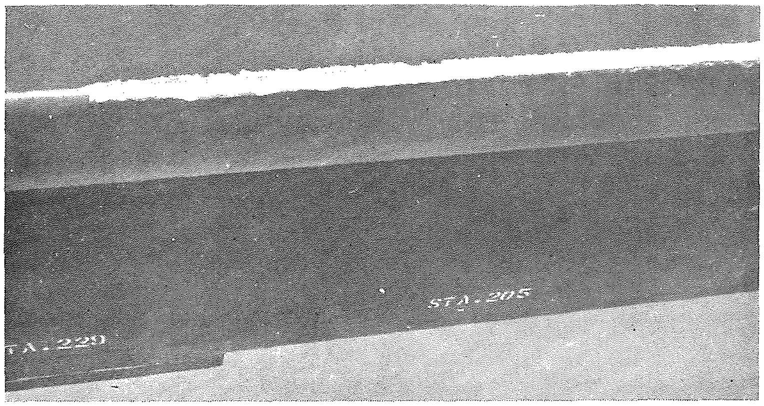
RUN 5-5



RUN 5-6



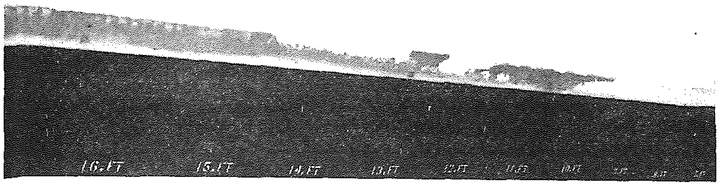
RUN 5-6



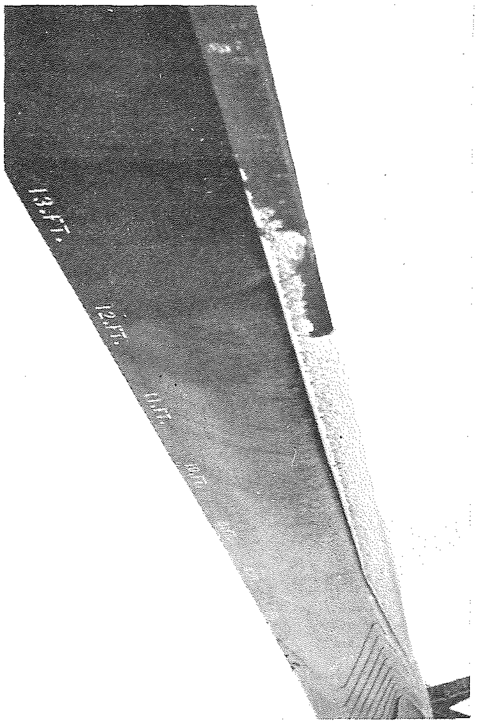
RUN 5-7

EFFECTS OF POOR FLUID COVERAGE—21-IN. CHORD BLADES

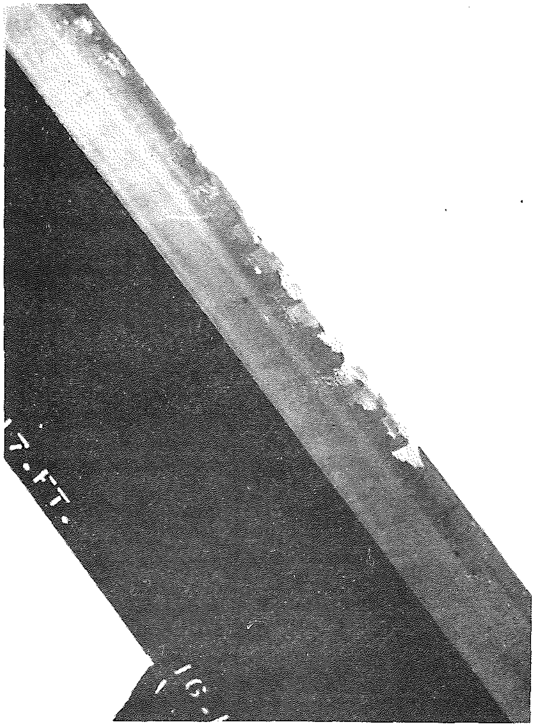
FIG. 8
LR-317



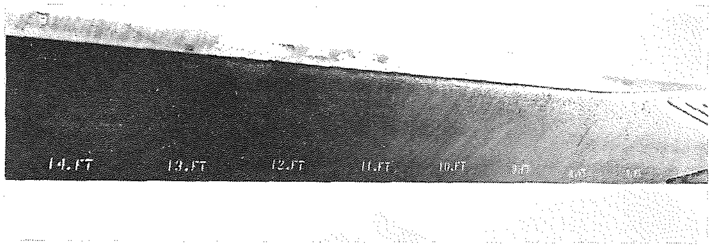
RUN 10-14



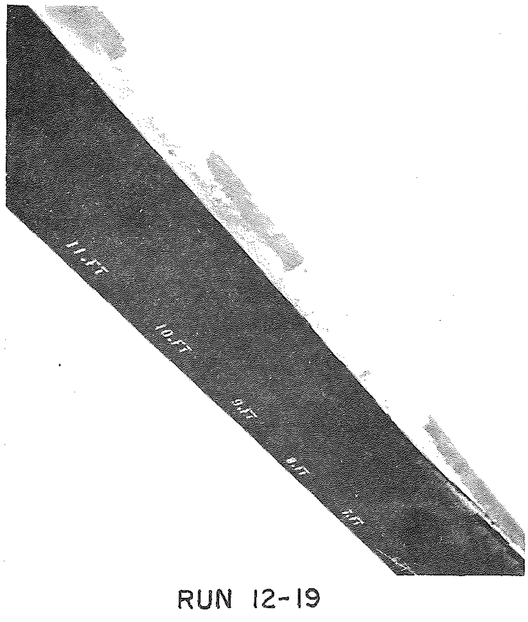
RUN 12-16



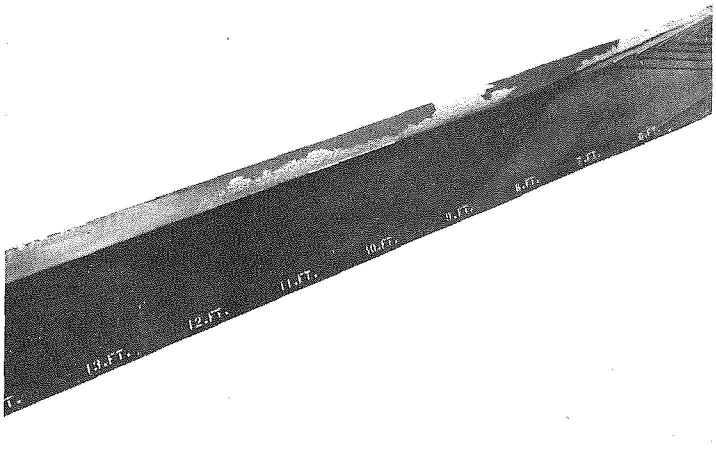
RUN 12-16



RUN 12-16



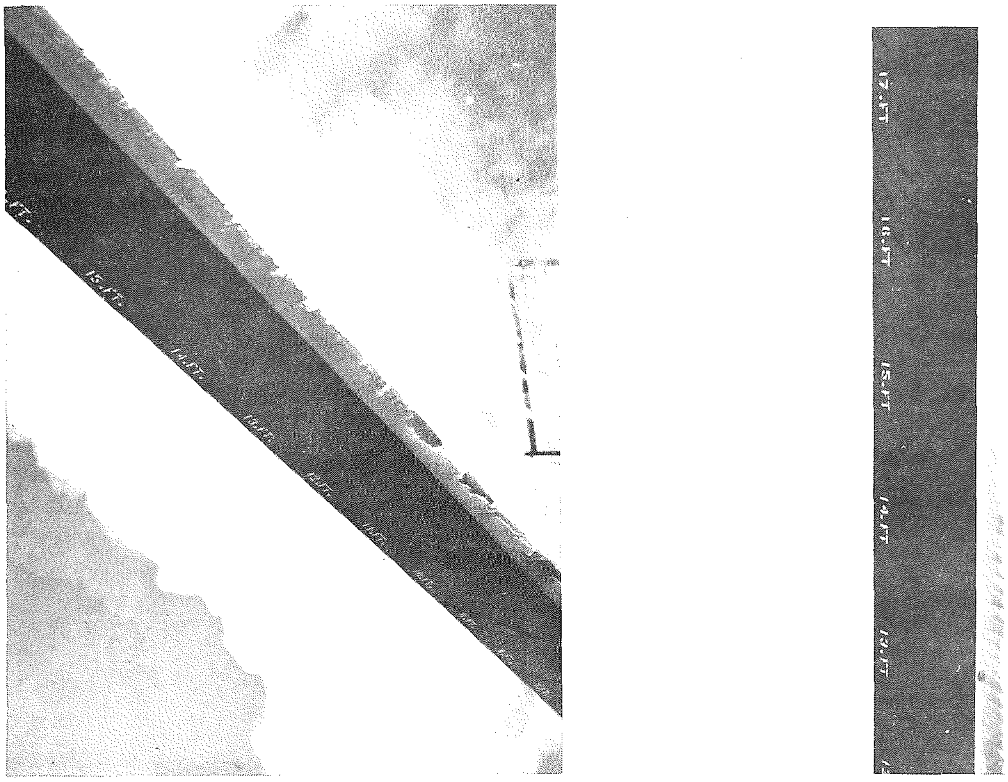
RUN 12-19



RUN 13-20

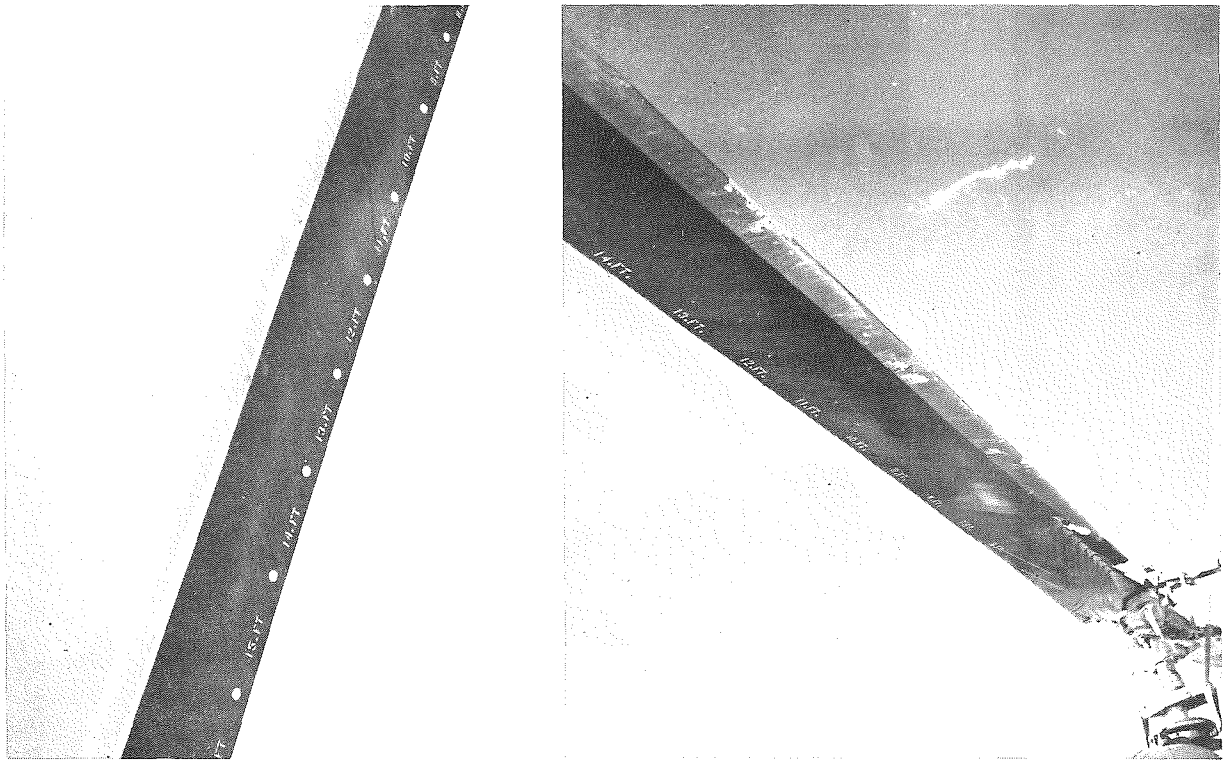
EXAMPLES OF FLUID DE-ICING PERFORMANCE

FIG. 9
LR-317



(a) RUN 16-22

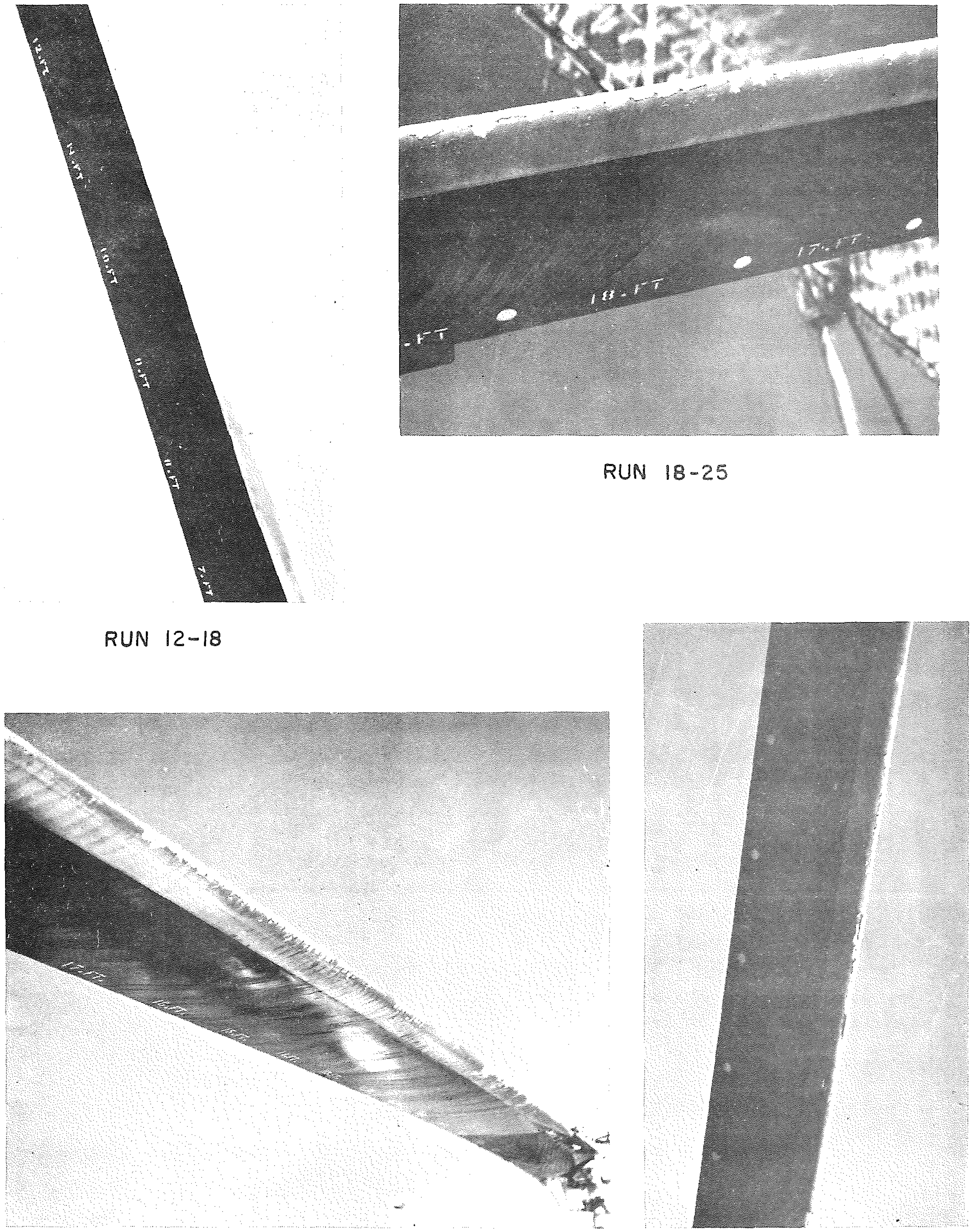
(b) RUN 16-23



(c) RUN 18-24 EXTENDED ANTI-ICING RUN

RESIDUAL ICE ON BLADES AFTER SUCCESSFUL ANTI-ICING RUN

FIG. 10
LR-317



RUN 12-18

RUN 18-25

RUN 18-26

RUN 18-27

CYCLIC ANTI-ICING RUNS

NRC LR-317
National Research Council, Canada. Division of
Mechanical Engineering.

ICING FLIGHT TESTS OF A FLUID ROTOR BLADE ICE PROTECTION SYSTEM ON A BELL HU-1 HELICOPTER.
G.A. Gibbard. October 1961. 17 pp. + 10 figs.

Flight tests were performed in an artificial icing cloud on a Bell HU-1 helicopter equipped with a fluid icing protection system for the main and tail rotor blades. Icing protection is required for this helicopter because vibrations are caused by the asymmetric self-shedding of rotor blade ice accretions. The results indicated that the anti-icing system will be adequate to protect the helicopter for limited duration flights in moderate icing conditions.

LIMITED

1. Helicopter rotors - De-icing systems
2. Helicopters - Ice formation
3. De-icing systems - Test methods

I. Gibbard, G.A.
II. NRC LR-317

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