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NATIONAL RESEARCH COUNCIL OF CANADA

AERONAUTICAL REPORT

LR - 382

DE - ICING FLIGHT TESTS
OF A BOEING - VERTOL 107 - II HELICOPTER
PART 2 - 1962/63 TESTS

BY

G. A. GIBBARD AND R. D. PRICE

DIVISION OF MECHANICAL ENGINEERING

OTTAWA

JUNE 1963

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REPORT

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Low Temperature Laboratory

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Subject: DE-ICING FLIGHT TESTS OF A BOEING-VERTOL 107-II HELICOPTER. PART 2 - 1962/63 TESTS.

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SUMMARY

Icing flight tests were performed in an artificial cloud on a Boeing-Vertol 107-II helicopter equipped with an electro-thermal ice protection system for the rotor blades and for the engine inlets. The results showed that the rotor blade de-icing system gave adequate ice protection, but that further development work was required on the engine inlets.

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1.0 INTRODUCTION

During December 1962 and January 1963, a Boeing-Vertol 107-II helicopter equipped with an electro-thermal ice protection system for the rotor blades and for the engine inlets was tested by the Vertol Division of the Boeing Company in simulated icing conditions in the National Research Council's helicopter spray rig. The aircraft, pilot, and maintenance and test personnel were provided by Vertol, while N.R.C. personnel were responsible for the operation of the spray rig and the over-all supervision of the icing trials. The trials were conducted under the sponsorship of the R.C.A.F. who also supplied hangar and office facilities, ground equipment and operating personnel.

This was a continuation of the tests which were performed on this type of helicopter during the 1961-62 icing season and described in References 1 and 2. The previous tests had been hampered because of several malfunctions and only a limited amount of testing had been done on the ice protection systems. The rotor blade de-icing system was extensively modified and performance tested prior to returning for trials at the spray rig this year.

2.0 PURPOSE

2.1 To determine the optimum element-on time necessary to achieve satisfactory blade de-icing at ambient temperatures between 0°C and -30°C. If satisfactory de-icing at the lower temperature could not be achieved, then it was necessary to determine the minimum temperature at which the system would function satisfactorily.

2.2 To assess the operation of the ice detection system and to integrate it with the de-icing system to obtain automatic protection; the degree of protection provided was to be assessed during a prolonged flight.

2.3 To assess the engine and windshield anti-icing systems.

2.4 To evaluate aircraft handling and power requirements with rotor blade ice accretion.

3.0 TEST EQUIPMENT

3.1 General

The aircraft used was a Boeing-Vertol 107-II (Registration No. N6679D), a large tandem rotor helicopter (Fig. 1) powered by two General Electric CT58-110 gas turbine engines rated at 1250 h.p. each. The gross weight of the helicopter was 18,450 lb.

Each of the 3-bladed rotors of the helicopter was 50 ft. in diameter. The blades had a constant chord of 18 in. and a constant NACA 0012 aerofoil section.

For the hovering tests at the spray rig the rotor speed was kept constant at 264 r.p.m.

3.2 Rotor Blade De-Icing System

3.2.1 Heater Elements

Two types of heater element installation on the rotor blades were tested; woven wire in plastic, and Spraymat. The heated area of both of these was made up of six spanwise strips, each about 235 in. long and 1.05 in. wide. The spanwise coverage of all elements was from the root-end box ($5\frac{1}{2}$ ft. radius) to the blade tip (not including the tip cap), and the chordwise coverage was from 12 percent chord (2 in.) on the upper surface to 25 percent chord (4 in.) on the lower surface (see Fig. 2).

The wire type heater elements, which were made by Goodyear Tire and Rubber Co. and called by the trade name "Iceguards" were made of nichrome wire woven in glass cloth at a density of 48 wires per inch. The individual 1-in. wide heater circuits were made up of two $\frac{1}{2}$-in. passes joined together at the blade tip so that all electrical connections to the mats were made at the root end. The typical maximum gap between the passes of an element and between the six different elements on a blade was 0.055 in. Fibreglass cloth and plastic resins were used for the insulation layers between the blade and the heater element and between the elements and the abrasion shield. The layout and dimensions of the Iceguards are shown in Figure 2.

The construction of the Spraymat heater elements, which were manufactured by the Sierracin Corporation, is also shown in Figure 2. In this type of mat the heater element is a sprayed Kumanel metal and the insulation layers are glass cloth and epoxy resin. The six 1.05-in. wide heater circuits were joined together at the tip and the common return buss-bar ran along the top of the blade just aft of the heater elements. The typical gap between heater elements was 0.050 in.

All areas of all elements were designed for a power density of 23 watts/in^2 with an input of 180 volts, but higher power densities could be safely achieved using higher input voltages. The leading edge portions of the heater elements on all blades were protected by stainless steel abrasion shields. Weatherproof molded harnesses and plugs were used for all electrical connections on the blades.

Polyethylene and Teflon-impregnated fibreglass cloth tapes were used on the rotor blades on a few runs to investigate their ice shedding capabilities. These tapes were applied on top of the stainless steel abrasion strips of the blades from about 40 to 60 percent radius.

Blade stations and identifying numbers were marked on the lower surface of each of the rotor blades for easy identification and for clarity in the test photographs. The blade stations were at 10 percent radius intervals and the serial number was marked on the inboard end of each blade. The following rotor blades were used during the tests:

	Blade Serial No.	Type of Heater Element
Front Rotor		
	A-1-135	Iceguard
	A-1-128	Spraymat
	A-1-129	Spraymat
Aft Rotor		
	A-2-121	Iceguard
	A-2-119	Spraymat
	A-2-131	Spraymat

3.2.2 Power Supply and Control

The electrical power for the de-icing system was supplied by the aircraft's stand-by 20 KVA, 208V, 400-cycle, 3-phase generator. The power was fed from the generator and voltage regulator to the master controller mounted on a test panel in the helicopter cockpit. The power lines were protected by magnetic differential circuit breakers. The controller received a signal, either from an ice detector or from a manually-operated switch, and by means of an ambient temperature sensor it regulated the power-on time and switching of the blade heater circuits. The power was fed from the controller to each of the rotors through slipring assemblies mounted at the lower end of the shafts and then up to the 3-pole, 6-position, rotary stepping solenoid distributor switch mounted on top of the rotor hub.

Each of the heaters in the three blades of a rotor was connected to one phase of the electrical system in a delta circuit. In the normal shedding sequence the heaters in the blades of the forward rotor were first energized in order, starting from the leading edge (see Fig. 2 for order of shedding), and then the power was switched to the aft rotor and its heaters were energized in the same order.

3.2.3 Ice Detector

An ice detector employing a beta radiation source manufactured by the

United Control Corporation (Ref. 3) was fitted in the oil cooler air inlet on the aft pylon where there was some induced air flow over the probe.

3.2.4 Weight of De-Icing System

The approximate weights of the components of the de-icing system were as follows:

Weight of heater elements (including wiring harness)
- approx. 10 lb. per blade

(About half of this weight was compensated for by removing balance weights from the blade.)

Weight of Control System including ice detector, controller, temperature sensor, transfer unit, sliprings, distributor, wiring and hardware
- 25 lb.

The total weight penalty of the de-icing system less generator and voltage regulator was therefore about 55 lb. Since the generator and voltage regulator used were the normal stand-by system of the aircraft, their weight of about 75 lb. is not included in the total weight penalty of the de-icing system.

3.3 Engine Inlet Anti-Icing

The areas around the leading edges of the engine inlets were anti-iced by means of thermostatically-controlled woven-wire electro-thermal heaters with the temperature of the surface being kept at 230° F. The power dissipation of the heater graded from 15 watts/in^2 at the leading edge to about 4 watts/in^2 at the trailing edge of the heater, both inside and out. The total power required was about 4700 watts and was drawn from the aircraft's main generator.

On each of the engines the starter cover, inlet guide vanes and top frame struts were heated by compressor bleed air. The bottom frame strut was heated by hot lubricating oil. Conically-shaped foreign-object damage prevention screens were used on each of the engine inlets on a few of the early flights.

3.4 Windshield Anti-Icing

The front panels of the windshield were protected by thermostatically controlled, electric film-type anti-icers. This was also supplemented by a hot air defrost system using cabin heater air.

3.5 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 the necessary icing and meteorological parameters.

3.6 Instrumentation

The helicopter was instrumented with a 50-channel oscillograph to record all voltage and current readings from the de-icing system, ice detector signals and vibration pick-ups mounted in various positions on the aircraft. Additional instrumentation was incorporated to give an indication of turbine inlet temperature, engine gas temperature, fuel flow, engine inlet temperature and torque, thereby enabling an accurate assessment of engine power changes due to icing. Also, pressure probes were fitted in each engine and were connected to altimeters in the cockpit. These instruments indicated air flow pressures at the engine inlet to give an indication of any blockage of the inlet screens.

Contact was maintained between the aircraft and the ground by means of VHF radio.

4.0 TEST PROCEDURE

The tests were performed in accordance with the method outlined in Reference 5 with modifications being made where found necessary.

Wherever possible, the icing severity conditions used conformed with the most severe continuous maximum rating specified in Part 4b of the F.A.A.'s Civil Air Regulations, which is as follows:

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

Because of the large size of the helicopter, it was not possible to immerse both of the rotors in the cloud simultaneously. On very low windspeed days the helicopter was hovered at an angle to the cloud about 100 ft. from the spray rig with just the aft rotor in the icing cloud. Visibility from the cockpit was then unaffected by the cloud being drawn down through the rotor. At higher windspeeds (> 15 m.p.h.) it was possible to hover the helicopter facing straight into the rig. In this case the cloud was drawn down through the back of the forward rotor disc and through most of the aft rotor disc. For all icing flights the helicopter was kept at a low gross weight of about 14,500 lb.

The first few tests were made to determine the maximum duration in the icing cloud with the engine inlet screens fitted. The aircraft was hovered in the cloud while an observer monitored the value of the engine inlet air pressures indicated on the two altimeters connected to the individual pressure probes. With 14,500 lb. gross weight and out-of-ground-effect, the altimeters normally indicated about 1500 ft. If during the icing runs the height indication increased, it was indicative of screen blockage. The flights were abandoned when the altimeter readings increased to 6000 ft., which meant that the engine inlet screens were seriously blocked by ice formations and engine performance would be affected.

After the screen tests, a few runs were made to determine the rate of icing on the rotor blades. The aircraft was hovered in the cloud for a short time, then landed and shut down for inspection and ice thickness measurements. Attempts were then made to shed this ice from the blades by hovering in clear air and running a de-icing cycle.

Most of the flights were made to test the de-icing system. On these, the helicopter was first hovered in the cloud long enough to accrete about 3/16 in. of ice on the blades. The helicopter was then flown out of the cloud and hovered in clear air and a de-icing cycle at some preset "on time" was initiated. After de-icing, the aircraft was landed and the rotors stopped so that the extent of shedding could be inspected. If complete shedding had not been accomplished, the blades were manually cleaned, and (if the control system was operating satisfactorily) the run was repeated at longer on times until a complete shedding point was found. Conversely, if the first cycle resulted in complete shedding, the run was repeated at shorter on times until shedding was incomplete. This method gives a number of good and bad shedding points such that when plotted, the mean line between them compensates for inconsistencies in shedding energy caused by variations in accretion thickness and represents the optimum operating conditions.

De-icing was usually performed in clear air rather than in the cloud. This presented the more severe case, since the ice temperature under clear air conditions would have been close to ambient, whereas in the cloud it would have been nearer to 0°C and dependent to a large extent on the value of the liquid water content; thus this variable was removed from the shedding performance. It is desirable to design for this condition of clear air shedding to cope with the case of shedding after emerging from an icing encounter. When de-icing in the cloud, this method also eliminates any confusion that may be caused by ice rebuilding on areas of the blades where it was shed early in the de-icing cycle.

Once the power-on times for the particular temperatures had been established, extended flights, during which repetitive icing and de-icing were performed, were made to determine the effects of de-icing while in the cloud.

The engine inlet anti-icing systems were operated continuously on most runs in the icing cloud, and many of the runs were made specifically to test the inlet systems. A few runs were made with one or other of the systems off, to determine the amounts of ice that would be picked up.

5.0 RESULTS

5.1 General

Between 10 December, 1962, and 31 January, 1963, 66 test flights were made at the spray rig with a total duration of 8.5 hr. in the icing cloud. The rotor blade de-icing system was tested on 37 of these runs while on the remainder the engine inlet systems were tested and the rate of ice accretion on various parts of the helicopter was determined. One forward flight was made after an accretion run to determine the handling characteristics with iced rotor blades.

The tests were conducted over a range of temperatures from -24.3°C to -2.1°C, but the rotor blade de-icing runs were made between -21.9°C and -7.7°C. The liquid water contents used ranged from 0.12 to 0.7 gm./m.^{3} Except for one run where freezing rain was simulated, the droplet size was kept at about 30 microns (median volume diameter).

The test conditions for all runs along with the results of the de-icing flights are shown in Table I.

5.2 Icing Flights

5.2.1 Rotor Blades

Rotor blade ice thickness measurements were made after most accretion runs and on de-icing runs whenever ice was left on the blades. The thickness of ice on the aft rotor blades along with the blade radius (in percent) where it was measured is shown in Table I. The maximum chordwise coverage of the icing on the rotor blade was about 1 in. on the top (measured along the chord) and 3½ in. on the bottom surface of the blade.

With the instrumentation used on the engines this year, it was possible to obtain an indication of the amount of additional power required to hover because of the ice building on the rotor blades. It was found that up to 438 extra horsepower was required to hover during many of the accretion runs. Some of the values of the power increases required are shown in the remarks column of Table I.

On the one forward flight in which speed runs in level flight, turns and autorotations were made with ice on the rotor blades, the aircraft's handling characteristics were found to be satisfactory.

5.2.2 Fuselage Icing

Some small scale components of the helicopter such as screens and grilles picked up icing (Fig. 3) and a heavy frosting of a large portion of the fuselage was noticed on long duration flights, but no detrimental effects of this icing were experienced. One possibly serious effect that was encountered was the freezing over of the ends of some of the engine drain pipes (see Fig. 4). The pipes were being blocked partly from direct icing on their tip and partly from the freezing of the water dripping from the pipes. A few modifications were tried to overcome this problem but no positive solution was found.

5.3 Engine Inlet Anti-Icing

As had been the case the previous year, the electro-thermal anti-icers on the leading edge lips of the engine inlets prevented icing on the heated area, but water was running back to form into thick ice accretions on the unheated areas behind, both inside and outside the inlet tunnel. Examples of this icing can be seen in Figure 5. This runback was appreciably greater when the anti-icing system was operated in snow or blowing snow conditions because of the melting of the solid crystals and the resulting water running back into the inlet. On two occasions damage was caused to the inlet guide vanes and to the first stage rotor blades, probably by fragments of this runback ice breaking off and being ingested into the engine. On run 185-1 several guide vanes and rotor blades were bent on both engines and on run 190-4 one inlet guide vane was bent. Figure 5b shows some of the ice remaining in the inlet after run 185-1. In all cases it was possible to inspect and repair the damage without having to remove the engines from the aircraft.

Direct impingement icing was building up directly on an area in the bottom of the duct as well as at the discontinuities between the inlet fairing and the expansion ring, and between the expansion ring and the engine.

A number of modifications were made to try to overcome the inlet icing problem. Supplementary heaters were applied around the outside of the expansion ring and other portions of the inlet tunnel, and the temperature control on the existing heaters was altered to allow the leading edge surface of the heater to run at 290° F instead of 230° F. Neither of these changes resulted in appreciable improvements. An anti-icing paste, Carbowax 1500, was also tried in the inlet, but provided only short duration protection.

The foreign object damage prevention screens which were used on the engine inlets on the first few runs in the icing cloud very quickly iced over and blocked the airflow enough to affect the operation of the engine. A few tests were also made in clear air, high humidity conditions at temperatures around freezing. No icing of the screens resulted in this case. After run 155-2 the screens were removed and all further icing runs were made with the inlet uncovered.

The anti-icing system on the inlet guide vanes and struts successfully prevented icing, provided that reasonably high engine speeds were maintained. However, on one run (run 166-2) when one of the engines was operated at low ground-idle speed (52 percent torque) heavy icing of the inlet guide vanes resulted. This can be seen in Figure 5a. This ice was about 1/2 in. thick.

Serious starter cover icing occurred on most runs on which compressor bleed air was used. On the original set of covers and on some of the subsequently modified configurations where there was still insufficient airflow, the ice built in a fairly uniform area on the nose and on an area on the top of the covers (Fig. 6). On some configurations at warmer temperatures the nose was kept clear, but thick runback ice built up on the areas behind. Figure 6 shows examples of the ice that was accreted on the starter covers. In Figure 6a, the icing that would build up on the unheated cover is shown. Notice the chunk of ice that has broken off and is lying in the bottom of the duct. In Figures 6b and 6c, with the original covers, the nose has been kept clean, but ice has built up in the areas behind. In Figures 6d and 6e, with modified covers, the ice has built on all but a small area near the centre of the nose. The only modifications that prevented thick ice accretions from building on the covers was the one in which externally ducted combustion-chamber-cooling bleed air was used in the covers. Examples of this can be seen in the photographs of Figure 5. Even with this method small amounts of slushy ice and water were noticed dripping off the covers at the end of some runs.

5.4 Rotor Blade De-Icing System

The shedding results from the de-icing tests are shown in Table I. The results for both rotors are shown, although in general the aft rotor blades were better positioned in the cloud, and hence they picked up greater amounts of ice than the forward blades. Shedding results from runs on which the ice thickness on the forward blades was obviously too thin to shed have been omitted. The extent of shedding shown in Table I was from the tip to the blade radius shown. There was generally little difference in the extents of shedding of the Spraymat blades on the same rotor, and hence their average shedding extent was used.

On some of the early runs trouble was experienced with the on time control of the de-icing system, when there was a considerable variation in on time from one section of the heating elements to the next. The on times for these runs quoted in Table I have been marked with an asterisk to indicate that they are nominal values only, and the shedding results from these runs have not been used in determining the shedding efficiency of the heater elements.

The shedding results along with the actual power densities (watts/in^2) and specific energies (joules/in^2) used on each run are shown in Table II. The results are also shown plotted in Figures 7, 8, 9 and 10 in the form Specific Energy (power density X on time) vs. Temperature for each of the two types of heater elements tested on each of the rotors. Different symbols were used to denote the extent to which shedding occurred. Shedding was considered successful if ice was removed to 25 percent (75 in.) radius, although the heater element extended as far inboard as about 21.5 percent radius. Shedding between 25 and 35 percent radius was considered marginal, and outboard of 35 percent it was unsatisfactory. The power density varied slightly from run to run as can be seen in Table II, but generally the output of the heaters on the aft blades was about 26.5 watts/in^2 and on the front blades 27.0 watts/in^2. Assuming these power densities and averaging the results from the front and aft rotors, the curves were replotted in Figure 11 in the form On Time vs. Temperature for a direct comparison of the shedding efficiency of the two types of heater elements.

On many of the single cycle de-icing runs the ice was not shed cleanly off all portions of the inner half of the rotor blades. Light runback icing was produced on some runs, and at lower temperatures the ice over the dividing strips between the heater elements was left anchored to the blade. Also on some of the runs the ice shed to the inboard end of the heater elements, but small patches of ice a few inches long were left anchored on the leading edge on the outboard sections of the blades. These patches were usually fairly light accretions anchored by particularly prominent cold strips in the heater element. Examples of the shedding performance of the heater elements are shown in Figures 12 and 13. On some of these photographs the cold strips holding the ice to the blades can be clearly seen.

At the end of the multiple cycle de-icing runs the ice had usually shed from the blades, but on some of them there were appreciably greater amounts of runback than had been built up on the single cycle de-icing runs. On run 185-1 in particular, where the on time was excessive by about 3 sec., fairly heavy runback was produced on all blades after 5 de-icing cycles (Fig. 12). On other runs where the on time was close to optimum the runback was lighter. No detrimental effects were produced by the runback ice.

On the three runs (177-1, -2, and -3) where polyethylene and Teflon tapes were applied on the rotor blades to investigate whether they would facilitate self-shedding, ice accretions up to 3/8 in. were built up on the tape without any shedding occurring. This was considered an excessive amount for this helicopter, and hence no further tests were made with the tapes.

5.5 Ice Detector

The signalling response of the ice detector during the tests is shown in Table III. The time to the first signal after entering the cloud is listed along with the average time between all of the signals of each run. The major problem experienced with the ice detector used during this season's testing was that it gave a large number of false signals. False signals are extraneous signals given immediately following a true icing signal, before there has been time for more ice to build up on the detector probe. For example on run 182-1 the fifth true icing signal was given after 9 1/4 min. in the cloud and 139 sec. after the previous icing indication. In the next 17 sec., 5 false signals were given. Near the end of the tests special circuitry was incorporated into the controller to ignore the false signals and to count an appropriate number of the true signals before initiating a de-icing cycle.

5.6 Windshield Anti-Icing

At the beginning of the tests the helicopter was fitted with an electrically heated windshield on the right-hand (pilot's) side and a standard windshield on the left-hand (co-pilot's) side. On one day when the helicopter was undergoing a ground run, the electric windshield and the hot defrost air were inadvertently selected 'on' at the same time and in a few minutes the windshield became overheated and was partially destroyed (see Fig. 14). The unserviceable right-hand windshield was then replaced by a standard windshield and a heated panel was fitted to the left-hand side. To avoid any further damage the hot air defroster was then not used while the windshield was being electrically heated. The windshield remained serviceable throughout the remainder of the test period.

The electric windshield anti-icer was tested on one run (run 202-2) in simulated freezing rain conditions. The panel was kept completely clear during the 45-min. run (Fig. 14). The anti-icer was also used successfully on the runs in the icing cloud, but only small amounts of frosting were picked up under those conditions because of the low forward speed and the low collection of the windshield surface.

The hot air defroster was also tested on run 202-2 and, used in conjunction with the windshield wiper, it maintained partial visibility through the window. However, it was not as effective as the electric anti-icer used on the other side (Fig. 14).

6.0 DISCUSSION

6.1 Icing Flights

6.1.1 Rotor Blades

Throughout the trials the duration of the icing flights was regulated so that about 3/16-in. thickness of ice was built at 50 percent radius on the rotor blades before de-icing was attempted. This was considered a sufficient thickness for the proper operation of the de-icing system but was not thick enough to produce impact damage when fragments of ice were thrown from the blades. With these accretions there was little vibration change, and no impact damage was sustained during the runs. There is still a possibility, however, that damage might be caused to the engines by the ingestion of this rotor blade ice. At the end of one run a fragment of this ice was found on top of the fuselage in front of the engine.

The increased power required to hover this helicopter with ice on the rotor blades indicated that even with its great power reserve there could be limitations to its load-carrying capacity, range and single engine performance when operating in icing conditions, particularly at higher altitudes. The extra power required on these tests was quite high despite the fact that there was not complete coverage of all rotor blades in the spray rig cloud. With uniform coverage on both rotors it could be expected that, for the same icing time, greater power increments would result. This demonstrated an important reason why the rotor blade de-icing system is desirable on this helicopter. With the de-icing system operating correctly, the maximum power increment should be only 100 to 150 h.p. before the ice is shed from the blades.

The tests this year again demonstrated that the heater elements were adequately protecting the areas of major ice impingement on the rotor blades. No runs were made with maximum all-up weight to determine the maximum chordwise extent of icing on the bottom surface of the blades with high angles of attack, but there should be adequate heater coverage to shed all impinging ice. With the longer duration runs performed this winter, fairly thick accretions built up on the blade spars inboard of the heated area. This can be seen in Figures 12 and 13. However, because of the large diameter of this section and the low airflow over it, its catch efficiency is low, and hence it is not expected that this ice could build to hazardous proportions except in extremely long icing encounters. It would be advisable, however, to remove thick accretions of this ice from the blade on shutdown at the end of a flight before the rotor blades were started up again. Otherwise there might be a possibility of this ice being partially loosened and shedding into the engines as the blades were accelerated.

The one forward flight made with ice on the rotor blades indicated that the aircraft's handling characteristics were satisfactory in level flight speed runs, turns and autorotations. However, the ice accretion was fairly light on this run, and further tests would be necessary to completely evaluate these points.

6.1.2 Secondary Icing Effects

With the longer duration flights made on this winter's tests a better assessment was made of the effects of icing of screens, antennae and fuselage. Some of the screens and grilles picked up icing but there was not sufficient blockage of cooling air to cause any overheating of any components at the ambient operating temperatures of the tests. The icing of other appendages and the frosting of the fuselage caused no difficulties other than the minor problem of the obscuring of visibility through some of the cabin windows.

The icing of the engine drain pipes was serious because it could have prevented excess fuel from draining from the engine at the end of a flight which could have resulted in a fire when the engine was started up again. The modifications of cutting the pipes off flush with the aircraft skin and putting baffles over the ends of the pipes (Fig. 4) prevented most of the icing from direct impingement of cloud droplets, but water dripping from the pipes still froze and, in time, partly blocked the pipe.

6.2 Engine Inlet Anti-Icing

The engine and engine inlet anti-icing systems are still not adequate and this remains the major problem existing with the helicopter's icing protection capability. The electro-thermal anti-icing of the inlet lips produced considerable runback ice on the unheated areas behind and the shedding of the resulting ice was a serious hazard to the engines. The damage that was caused to inlet guide vanes and first stage rotors did not necessitate the changing of the engines, but the aircraft had to be towed back to the hangar and extensive inspection and repair work had to be done before the helicopter was serviceable again. It is possible that much greater damage could have been caused if the run had been continued longer than the 20 min. There can be no doubt that this icing is an unacceptable hazard to the engine. The only time it was reduced to an acceptable level was when low liquid water contents were used and when the ambient temperature was fairly high (above -10° C).

None of the modifications made to try to overcome the runback problem in the inlets proved completely successful. The supplementary heaters were applied to the inside section of the ducting to prevent the runback from the inlet lip anti-icers and the directly impinging droplets from freezing and to feed it into the engine as liquid water. However, the heaters were applied around the outside of the expansion ring and there was not sufficient heat to maintain the inner surfaces above freezing. A heater applied to the areas of the inner surface where it is needed would be able to eliminate more efficiently the icing. The raising of the nominal operating temperature of the inlet lip fairing anti-icers from 230° F to 290° F did not appreciably reduce the amount of runback produced.

The starter cover icing problem was apparently the result of the insufficient flow of air of suitable temperature to the area where it was needed. Most of the various modifications made to the covers were to improve the distribution of the air over the inside areas of the cover but they were of little effect. The use of the combustion-chamber-cooling bleed air was reasonably effective for anti-icing, but too expensive on power drain from the engines. The high performance T-58 engines can tolerate only small amounts of bleed air and apparently there is not enough available to keep the starter covers free of ice. The only solution to this problem appears to be to use electrical heater elements on the covers.

The icing of the inlet guide vanes when the engine was run at low idle speed brought to light the fact that this engine had passed its icing qualification trials at low engine speeds by periodically surging the engines to obtain enough hot air flow to the struts and guide vanes to shed off the ice accretions before they became too thick. It should therefore be emphasized that the engines of this helicopter should not be run at low power settings any longer than necessary in suspected icing conditions.

6.3 Rotor Blade De-Icing System

Of the two types of heater elements tested on the rotor blades the Spraymat elements were identical with those tested the previous year, while the Iceguards were an improved version of the plastic insulated elements previously tested. Throughout the tests the Iceguard elements consistently gave the cleanest shedding of ice, clearing about 10 to 15 percent more blade span than the Spraymat elements or, stated more significantly, the Iceguard elements required one or two seconds less "on time" for clean shedding than the Spraymat elements. This was shown in Figures 7 to 11. In Figure 13 comparisons between the shedding of the two types of elements on runs 190-4 and 183-1 are shown. In both cases the on time was adequate to shed the Iceguard blades cleanly, but ice remained on the Spraymat blades. The effectiveness of both types of heater was affected at low temperatures by cold strips between the passes of the elements over the inner half of the blades. These cold strips were apparently more prominent in holding the ice onto the blades on the Spraymat elements.

Despite the cold strips, both types of heater element were found to be adequate to protect the helicopter at temperatures down to about -20° C with the power densities used. At this temperature about 20 sec. on time was required. Individual element on times longer than this would likely not be feasible because of the very long time that would be required for the complete de-icing cycle. However, meteorological statistics show that about 98 percent of all the icing conditions that a helicopter is likely to meet will be at temperatures above -20° C. Even at temperatures lower than this the result of the on times being too short would mean that ice would not be shed cleanly on the inner sections of the blades, and some runback would be produced. However, the outer portions of the blades, the most critical areas for drag and thrown ice considerations, would likely be kept clear each shedding cycle. Only on long duration flights at these conditions might there be a danger of large fragments of ice being shed from the inner part of the blade and causing damage by being ingested into an engine.

Although there was little difference in the extents of shedding of the heater elements of the same type on this year's tests, the on times required to shed the Spraymat blades were considerably different from those of the previous year. Despite the fact that slightly higher power densities were used this year (26.5 to 27 watts/in^2 as compared with about 25 watts/in^2 last year) and thicker ice accretions were allowed to build up before shedding, element-on times of up to 3 or 4 sec. longer were required on this year's tests. This can be seen in Figure 11. The Iceguard elements were of different construction each year, and therefore their results cannot be compared. The reason for the apparent discrepancy in the Spraymat results may be a fault in the instrumentation on either year's testing, or perhaps a non-uniformity from blade to blade of the manufacturing of the heater elements. If the latter is true there will be a need for a more rigid form of quality control testing to ensure reasonably matched sets of blades. If the blades are widely different in their shedding efficiency, the on time will have to be set up for the least efficient blade and the resulting excessive on time on the other blades will produce runback on long duration runs. This could also be the case if mixed sets of Spraymat- and Iceguard-equipped blades were used because of their different shedding properties. Runback icing was noticed on extended runs on which the on times were excessive (Fig. 12).

There were no electrical or mechanical breakdowns of the heater elements on the blades or of their abrasion covers as had been the case the previous year. The weatherproof coverings over the electrical connections to the blades prevented any electrical short circuits from moisture on corrosion. Daily megger checks revealed that the insulation value of some of the blades had decreased after a full day's testing, but the value was not dangerously low, and it returned to normal by the next morning. This partial breakdown of the insulation was found to be caused by poor fitting seals on some of the weatherproof plugs allowing small amounts of moisture into the connectors, a problem that can easily be remedied. The abrasion covers remained securely bonded to the blades throughout the tests and were suitably applied so as not to cut into the heater elements.

The regulation of the power supply and the protection of the circuits were also improved this year. On last year's tests there was a considerable variation in the power supplied to the blades from run to run and sometimes just from one element of the shedding cycle to the next. This year there was only a slight variation recorded over the complete set of de-icing runs. The magnetic differential circuit breakers in the power lines should adequately protect the rotor blades by preventing the maintaining of any prolonged short circuits as had been the case the year before when two rotor blades were damaged. On a few of the early runs the circuit breakers were tripping after only one section of the de-icing cycle, and consequently the de-icing results for these runs were lost. This was found to be caused by a faulty voltage regulator and the problem was remedied with its replacement.

Only a few malfunctions occurred with the components of the de-icing system control circuits. Most of the faults found in the system the year before had been eliminated, but the temperature sensing power-on control still gave trouble. The main problem was with the location of the ambient temperature probe near the outlet from the cabin heater. The result was that the on time varied considerably from one section of the de-icing sequence to the next. This difficulty was overcome for most of the tests by using a manually set decade box to replace the temperature sensor for controlling the on times. The relocation of the probe to obtain an accurate ambient temperature reading should solve this problem in the future.

6.4 Ice Detector

It was difficult to correlate the rate of signalling of the ice detector with the rate of ice build-up on the rotor blades because of the number of false signals and the sometimes different cloud coverage of the blades and the location of the probe. In general, for the spray rig tests about 3 or 4 true icing signals from the ice detector corresponded to the optimum thickness of ice on the rotor blades. However, the number required could be changed by better cloud coverage of the helicopter and by icing at higher forward speeds.

The false signals were apparently the result of there being insufficient heat-on time on the probe to melt all the ice, and not enough airflow over it to blow the water and loosened ice away. The water and ice were refreezing to the probe as soon as the heat was turned off, and hence another signal was immediately given. A modification to the probe heater or the re-location of the probe in an area of higher airflow will be needed to overcome this problem.

6.5 Windshield

The electrical heaters in the windshield, without the addition of heated defrost air, supplied sufficient heat to maintain clear vision for the pilot in icing or freezing rain conditions. However, when defrost air was used alone, insufficient heat was supplied to keep the windshield as clear as with the electrical heaters alone.

Care must be exercised to ensure that the electrical heaters and the defrost air are not used simultaneously on the windshield when the aircraft is stationary. Otherwise delamination of the electro-conductive layers and cracking of the outer glass could occur (see Fig. 14).

7.0 CONCLUSIONS

The icing flight trials of the Boeing-Vertol 107-II confirmed that this helicopter will require a protection system to prevent the accretion of large amounts of ice on the rotor blades. The thick accretions cause large increases in the power required to hover, and, if thrown from the blades, may damage other blades or the engines.

The rotor blade de-icing system was adequate to protect the aircraft against icing at temperatures down to -20° C. However, a few minor problems, notably the element-on time controller, still require some attention.

Of the two types of heater elements used on the rotor blades, the Goodyear Iceguards and Sierracin Spraymats, the former were more effective, and over the complete temperature range required less energy to shed.

The engine inlet anti-icing systems were not adequate to prevent ice from building up in the inlets and becoming a hazard to the engines. Thus, the icing of the inlets and not the rotor blades remains the major problem limiting the operation of the helicopter in icing conditions. The electro-thermal heaters in the cowling lips produced large amounts of runback ice around the inlet and the hot air protection of the starter covers was inadequate.

The anti-icing of the struts and inlet guide vanes was satisfactory except at low power settings.

The engine inlet screens, intended for prevention of foreign object damage, iced up rapidly and could not be used in icing conditions.

The windshield anti-icing systems both operated satisfactorily, but the electrically heated window was more effective than the hot air defroster system. The possibility of operation of both systems simultaneously when the aircraft is on the ground should be excluded because it may result in damage to the windshield.

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TABLE II

ROTOR BLADE DE-ICING DATA

[illegible]	Temp. °C	On Time sec.	Aft Rotor Blades				Front Rotor Blades			
			Power Density w./in.^{2}	Specific Energy j./in.^{2}	Shedding		Power Density w./in.^{2}	Specific Energy j./in.^{2}	Shedding	
					Spraymat	Iceguard			Spraymat	Iceguard
[illegible]	-18.2	8.5	26.0	221	U	U	26.6	226	U	G
[illegible]	-10.6	5.1	26.3	134	U	U	26.9	137	U	U
[illegible]	-10.9	4.1	26.6	109	U	U	27.2	111	U	U
[illegible]	- 8.8	6.7	27.2	183	M	G	27.8	187		
[illegible]	- 8.5	5.5	26.7	147	G	G	27.2	150		
[illegible]	- 9.2	7.3	26.4	193	G	G	27.0	197		
[illegible]	- 8.1	8.5	27.7	236	G	G	28.3	241	G	G
[illegible]	-11.7	3.5	(26.5)	(93)	U	U	(27.1)	(95)	U	U
[illegible]	- 8.8	6.0	(26.5)	(159)	G	G	(27.1)	(163)	G	G
[illegible]	-18.1	12.6	26.3	330	M	G	26.9	337	U	G
[illegible]	-17.2	14.4	26.5	382	M	G	27.1	390	U	G
[illegible]	-14.0	12.5	27.6	344	G	G	28.2	351	G	G
[illegible]	-13.3	10.0	26.4	263	U	M	27.0	269	M	G
[illegible]	-12.9	12.0	(26.5)	(318)	G	G	(27.1)	(325)	G	G
[illegible]	-13.0	12.5	(26.5)	(331)	G	G	(27.1)	(338)	G	G
[illegible]	-16.0	17.1	26.3	448	G	G	26.9	457	G	G
[illegible]	-16.0	15.1	26.5	398	G	G	27.1	406	G	G
[illegible]	-16.0	12.4	26.5	329	G	G	27.1	336		
[illegible]	-13.2	10.2	26.4	271	G	G	27.0	277		
[illegible]	-20.9	15.2	27.4	418	U	U	28.0	426	U	U
[illegible]	-19.5	18.4	27.4	503	U	G	28.0	514	G	G
[illegible]	-16.6	10.2	26.6	271	M	G	27.2	277	G	G
[illegible]	-16.0	8.2	(26.5)	(217)	U	U	(27.1)	(222)	U	U
[illegible]	-16.2	12.4	26.7	330	G	G	27.3	337	G	G
[illegible]	-19.6	20.6	(26.5)	(545)	M	G	(27.1)	(556)	U	G
[illegible]	-18.8	14.2	26.0	370	U	U	26.6	376		
[illegible]	-10.1	7.5	(26.5)	(198)	G	G	(27.1)	(202)	G	G
[illegible]	-21.9	22.7	26.1	592	M	G	26.7	605	M	G

( ) - Estimated values
G - Good shedding
M - Marginal shedding
U - Unsatisfactory shedding

SUMMARY OF RESULTS

Run No.	Temp. °C	L.W.C. gm./m³	Time In Icing min.	Ice Thickness		On Time sec.	Extent of Shedding				Engine Inlet Remarks	Rotor Blade Remarks
							Spraymat		Iceguard			
				in.	sts.		Front	Aft	Front	Aft		
155-1	- 2.1	0.35	5	.02	40						Screens iced 50%.	Self shed to 40%.
155-2	- 2.3	0.25	4.5	.02	35						Screens iced heavily.	Self shed to 35%.
156-2	-16.0	0.35	2	1/8	60						Screens removed. S.C. & runback ice.	Accretion run. Icing to rotor tips.
156-3	-16.0	0.32	2	1/8	60						S.C. & runback ice.	De-ice system failed - 1 pulse only.
157-2	-10.5	0.60	2	1/16	60						S.C. & runback ice.	Accretion run only.
159-2	-15.4	0.25	2	1/8	50						S.C. & runback ice.	Accretion run only.
159-3	-15.6											De-icing of run 159-2. De-ice system failed. 1 pulse only.
159-4	-15.6					7.5*	30	30	22	22		2nd de-ice attempt. Ground run.
160-1	-15.6	0.15	2								S.C. icing.	Accretion run only. De-ice system failed.
165-2	-18.2	0.2	3			8.5	75	75	20	55	Light icing.	Light runback - cold strips.
166-2	-24.3	0.2	4	3/16	60						Heavy S.C. icing - No. 2 engine. Heavy I.G.V. icing - No. 1 engine - low power.	Accretion run only.
168-2	-11.0	0.12	4	9/64	60						S.C. & runback ice.	Accretion run - rear rotor only
168-3	-11.0					5.0*		40		40		De-ice of run 168-2.
168-4	-10.6	0.4	4	3/16	40	5.1	50	50	60	35	S.C. & runback ice.	Accretion & de-ice. 94 h.p. increase.
171-2	-10.9	0.35	5	3/32	50	4.1	80	60	75	40	-	Accretion & de-ice. 71 h.p. increase.
171-3	- 8.8	0.3	5	9/64	50	6.7	40	33	22	22	S.C. icing.	Light runback. 35 h.p. increase.
171-4	- 8.5	0.35	5			5.5		20		20	-	Poor coverage.
177-1	-11.9	0.25	3	3/16	50						Combustion bleed air used on starter covers. Clean light runback ice.	Accretion run - tape tests - no shedding. 115 h.p. increase.
177-2	-12.5	0.25	3	3/8	60						-	Accretion run - tape tests - no shedding.
177-3	-11.3	0.25	6	7/16	60						Drain icing.	Accretion run - tape tests - no shedding. 438 h.p. increase.
177-4	- 9.2	0.5	3	3/16	60	7.3		22P		22P	Light runback.	Accretion & de-ice. 236 h.p. increase.
178-1	- 8.6	0.5	3	1/8	60						Light runback.	Accretion run only - poor coverage.
178-2	- 8.1	0.5	3			8.5	22P	22	22	22	-	Accretion & de-ice. 66 h.p. increase.
178-3	- 7.7	0.5	6			5.0*	22	22	22	22	Runback ice.	Accretion & de-ice - 2 cycles.
178-4	- 8.2	0.5	15			5.0*	22P	22	22	22	Runback ice inside & outside.	Extended run - runback to 60%.
181-1	-12.5	0.55	3½			6.0*	22	22	22	22	Light runback ice.	Accretion & de-ice - cold strips.
181-2	-11.7	0.55	3½	3/16	60	3.5	60	70	60	67	Light runback ice.	Accretion & de-ice. 141 h.p. increase.
181-3	-10.6	0.55	7			7.5*	25	22	22	22	Heavy runback outside inlet.	Two de-icing cycles - light runback. 106 h.p. increase.
181-4	- 9.6	0.55	7			3.0*	25	30	27	22	Heavy runback outside inlet.	Two de-icing cycles.
182-1	- 8.8	0.25	27			6.0	20	20	20	20	Runback ice.	Three de-icing cycles. Light runback. 158 h.p. increase.
183-1	-18.1	0.36	5	3/16	50	12.6	45	27	22	22	Runback ice outside inlet.	Cold strips anchoring ice. 306 h.p. increase.
183-2	-17.2	0.36	5	3/16	40	14.4	55	35	22P	25	Runback ice outside inlet.	Cold strips anchoring ice.
184-1	-14.0	0.5	4			12.5	22P	25P	22P	22	Light runback.	Cold strips anchoring ice.
184-2	-15.3	0.3	8	1/4	50	10.0	30P	45	22P	34	Fuel drain iced.	Cold strips anchoring ice.
184-3	-12.9	0.25	32			12.0	22P	25	22	22P	Runback outside inlet. Severe drain icing.	Multiple cycle de-icing run.
185-1	-13.0	0.5	20			12.5	22	22P	22	22P	Heavy runback inside & outside. Damage to several IGV's & rotors - both engines.	Extended run. Heavy runback on blades. 236 h.p. increase.
188-1	-16.0	0.4	6			17.1	22	22	22	22	Runback ice - modified S.C. icing.	Accretion & de-ice.
188-2	-16.0	0.45	5			15.1	25	25P	22	22	Runback ice.	Accretion & de-ice.
189-2	-15.0	0.45	4			12.4		22		22	Clean.	Accretion & de-ice.
190-1	-17.2	0.7	4			10.2		22		22	Runback icing.	Accretion & de-ice. 212 h.p. increase.
190-2	-20.9	0.3	5	1/8	50	15.2	40	70	40	40	Runback icing.	Accretion & de-ice. 74 h.p. increase.
190-3	-15.5	0.32	4			18.4	22	40	22	25	Runback icing.	Accretion & de-ice. 212 h.p. increase.
190-4	-16.6	0.3	4			10.2	25	35	22	22	Runback icing. [illegible]	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	22P	22	22	22	Runback ice inside & outside.	Extended run - runback to [illegible]
181-1	[illegible]	0.55	3½			6.0*	22	22	22	22	Light runback ice.	Accretion & de-ice - cold strips
181-2	-11.7	0.55	3½	3/16	60	3.5	60	70	50	67	Light runback ice.	Accretion & de-ice. 141 h.p. increase.
181-3	-10.6	0.55	7			7.5*	25	22	22	22	Heavy runback outside inlet.	Two de-icing cycles - light runback. 406 h.p. increase.
181-4	- 9.6	0.55	7			3.0*	25	30	27	22	Heavy runback outside inlet.	Two de-icing cycles.
182-1	- 8.8	0.25	27			6.0	20	20	20	20	Runback ice.	Three de-icing cycles. Light runback. 158 h.p. increase
183-1	-18.1	0.36	5	3/16	50	12.6	45	27	22	22	Runback ice outside inlet.	Cold strips anchoring ice. 300 h.p. increase.
183-2	-17.2	0.36	5	3/16	40	14.4	55	35	22P	25	Runback ice outside inlet.	Cold strips anchoring ice.
184-1	-14.0	0.5	4			12.5	22P	25P	22P	22	Light runback.	Cold strips anchoring ice.
184-2	-13.3	0.3	8	1/4	50	10.0	30P	45	22P	34	Fuel drain iced.	Cold strips anchoring ice.
184-3	-12.9	0.25	32			12.5	22P	25	22	22P	Runback outside inlet. Severe drain icing.	Multiple cycle de-icing run.
185-1	-13.0	0.5	20			12.5	22	22P	22	22P	Heavy runback inside & outside. Damage to several IGV's & rotors - both engines.	Extended run. Heavy runback on blades. 236 h.p. increase.
188-1	-16.0	0.4	6			17.1	22	22	22	22	Runback ice - modified S.C. icing.	Accretion & de-ice.
188-2	-16.0	0.45	5			15.1	25	25P	22	22	Runback ice.	Accretion & de-ice.
188-3	-16.0	0.45	4			12.4		22		22	Clean.	Accretion & de-ice.
189-1	-13.2	0.7	4			10.2		22		22	Runback icing.	Accretion & de-ice. 212 h.p. increase.
190-2	-20.9	0.3	5	1/8	50	15.2	40	70	40	40	Runback icing.	Accretion & de-ice. 74 h.p. increase.
190-3	-19.5	0.32	4			18.4	22	40	22	25	Runback icing.	Accretion & de-ice. 212 h.p. increase.
190-4	-16.6	0.3	4			10.2	25	35	22	22	Runback icing. Damaged IGV.	Light runback. 188 h.p. increase.
191-1	-16.0	0.22	10	3/16	50	8.0	60	50	38	38	Runback & internal ice	Accretion & de-ice. 193 h.p. increase.
191-2	-16.2	0.22	10			12.4	22	22	22	22	Runback icing.	Accretion & de-ice. 217 h.p. increase.
192-1	-20.4	0.15	10	5/16	50						Clean.	Accretion run only on ground.
192-2	-19.6					20	50	28	25	25	-	De-ice of run 192-1.
192-3	-18.8	0.15	9	1/4	50	14.2		50	.	36	Clean.	Accretion & de-ice.
195-1	-19.1	0.3	5								S.C. & runback ice.	Accretion run only - for engines.
195-2	-19.2	0.3	10								S.C. & runback ice.	Accretion run only - for engines.
195-3	-19.0	0.3	5								S.C. & runback ice.	Accretion run only - for engines.
195-4	-18.7	0.35	5								Icing in inlet & S.C. ice.	Accretion run only - for engines.
196-1	-16.0	0.45	4								Heavy runback & S.C. ice.	Accretion run only - for engines.
196-2	-15.0	0.45	4								Heavy runback & S.C. ice.	Accretion run only - for engines.
197-1	-18.1	0.18	8			17.5	- not assessed -				Light icing.	Accretion & automatic de-ice.
197-2	-16.9	0.22	12			17.5	- not assessed -				Light icing.	Accretion & automatic de-ice.
199-1	-10.1	0.24	31			7.5	22	22	22	22	Clean.	3 cycles in cloud. 165 h.p. increase.
200-1	-10.2	0.55	3								S.C. & runback ice.	Accretion run only. 123 h.p. increase.
200-2	- 9.7	0.6	10			7	- not assessed -				S.C. & runback ice.	Accretion & 2 de-ice cycles.
200-3	- 9.8	0.5	8			7	- not assessed -				Light S.C. ice.	Accretion & 2 de-ice cycles.
200-4	- 9.6	0.24	43								Clean.	Accretion run - poor coverage.
201-1	- 9.6	0.6	16			6	- not assessed -				Runback ice.	Poor coverage - 1 de-ice cycle at 4 min.
201-2	-10.0	0.6	6	1/4	60						Clean.	Accretion run - poor coverage.
201-3	-10.5	0.6	3								Clean.	Accretion & forward flight.
202-1	-21.9	0.26	3½			22.7	25P	25P	22P	22P	Light S.C. & runback ice.	Accretion & de-ice.
202-2	-20.0	Freezing rain	45								No coverage.	Windshields tested.

* Nominal value only.

P Patches of ice left on blade.

S.C. Starter cover.

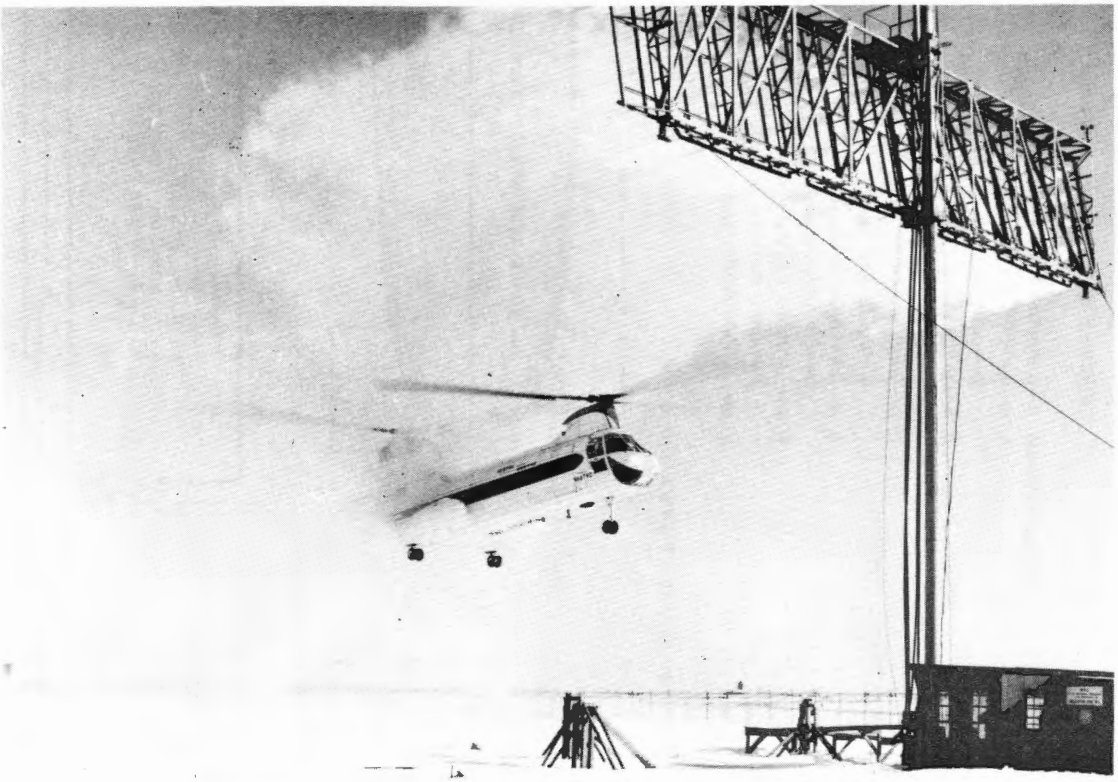
I.G.V. Inlet guide vane.

TABLE III

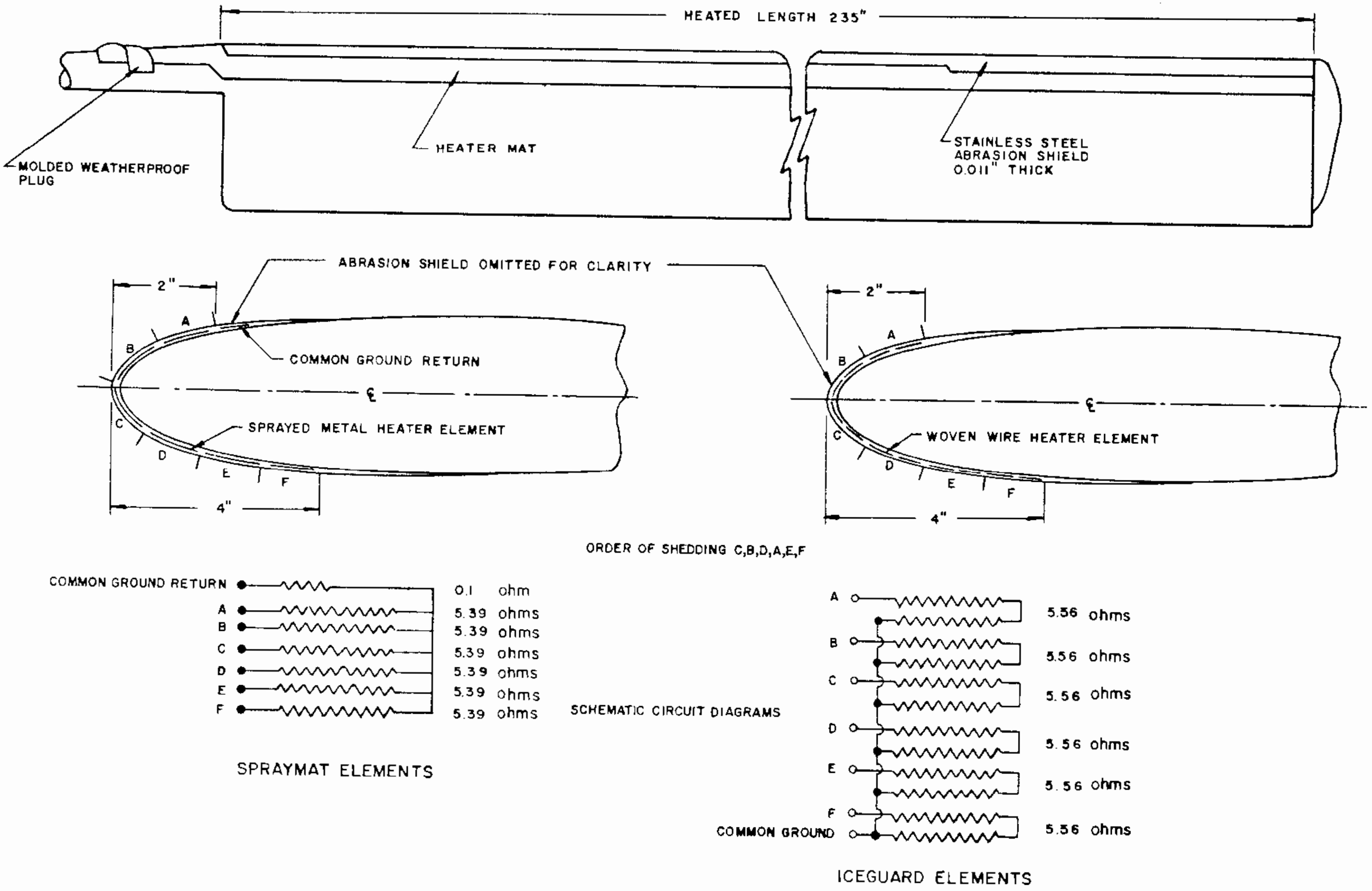
ICE DETECTOR RESULTS

Run No.	No. of Signals	Time to First Signal (sec.)	Rate of Signalling (sec./sig.)	No. of False Signals	Remarks
155-1	2	288	159	1	
155-2	2	106	127	1	
156-2	2	131	82	1	All signals after leaving cloud.
159-2	2	51	60	3	
166-2	3	121	64	5	
171-3	1	217	217	-	
171-4	1	155	155	1	
177-1	1	126	126	1	
177-2	1	128	128	2	
177-3	4	112	144	3	1 signal after leaving cloud.
177-4	1	140	140	1	
178-1	1	167	167	1	
178-2	2	37	59	2	
178-3	3	80	152	3	
178-4	9	68	82	5	
181-1	2	106	77	1	
181-3	3	86	104	5	
181-4	2	133	145	3	
182-1	13	58	104	17	
183-1	1	44	44	4	
183-2	5	80	84	8	3 signals after leaving cloud.
184-1	4	85	53	2	
184-2	1	134	134	4	
184-3	6	153	263	18	
185-1	8	98	147	18	
188-1	3	65	83	9	
188-2	1	138	138	1	
188-3	2	112	94	4	
189-1	3	76	120	6	
190-2	3	71	89	6	1 signal out of cloud.
190-3	3	24	89	6	
190-4	2	84	100	3	
191-1	4	36	121	10	
191-2	7	68	73	16	
192-1	2	316	153	10	
195-1	2	58	117	11	
195-2	5	62	120	17	
195-3	3	24	59	4	
195-4	2	64	82	4	
196-1	2	87	104	7	
196-2	1	85	85	6	
197-1	2	202	195	3	
197-2	6	13	92	3	
199-1	10	133	154	16	
200-1	2	168	97	2	1 signal out of cloud.
200-2	3	101	83	1	
200-3	2	93	130	-	
201-1	4	347	198	8	
201-2	1	215	215	1	

FIG. I
LR-382



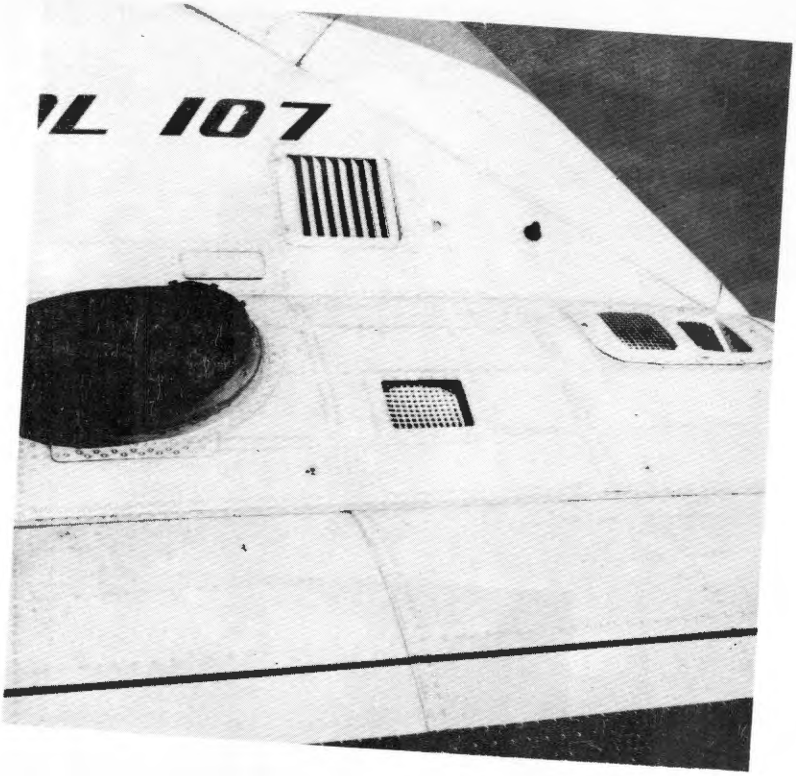
THE VERTOL 107-II HELICOPTER AT THE SPRAY RIG



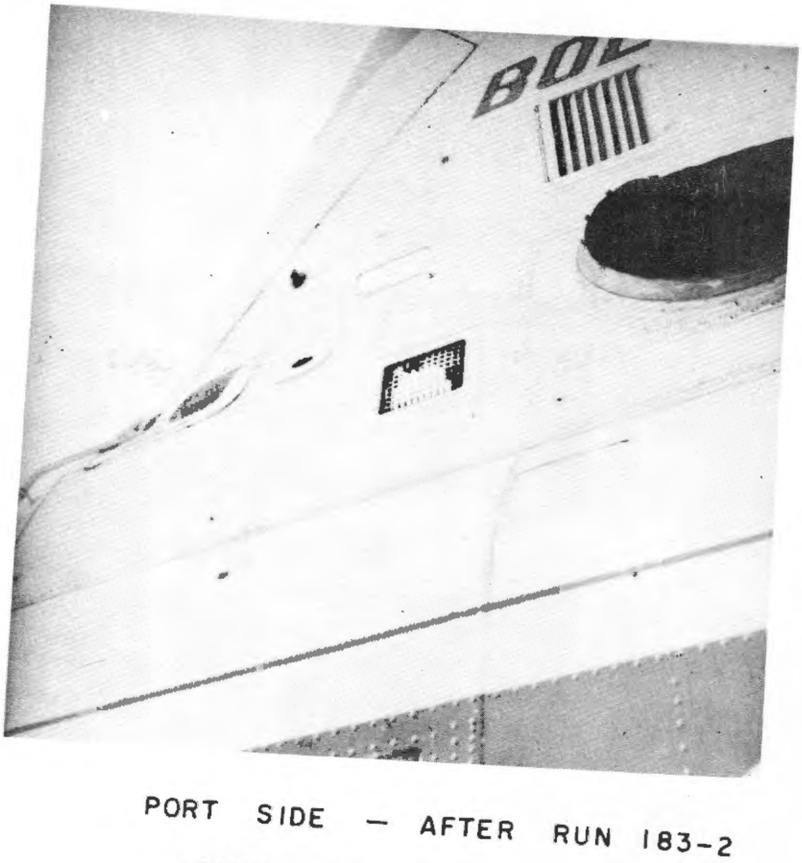
ROTOR BLADE HEATER ELEMENTS

FIG. 2
LR-382

FIG. 3
LR-382



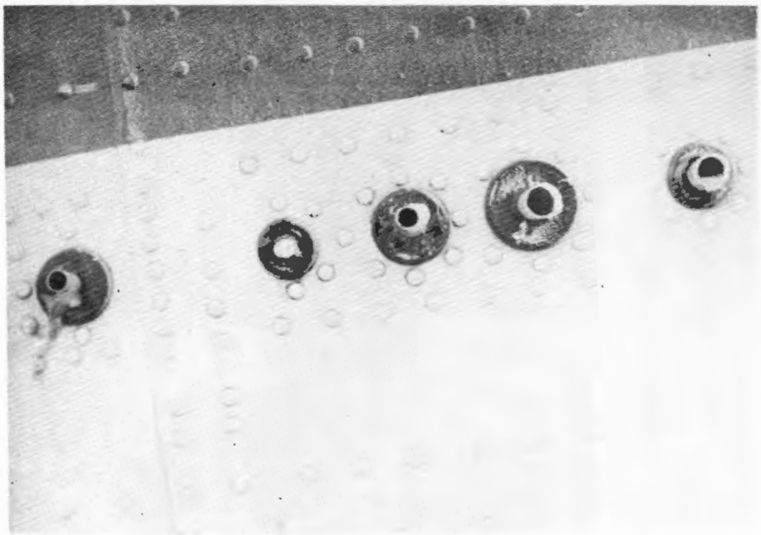
STARBOARD SIDE — AFTER RUN 166-2



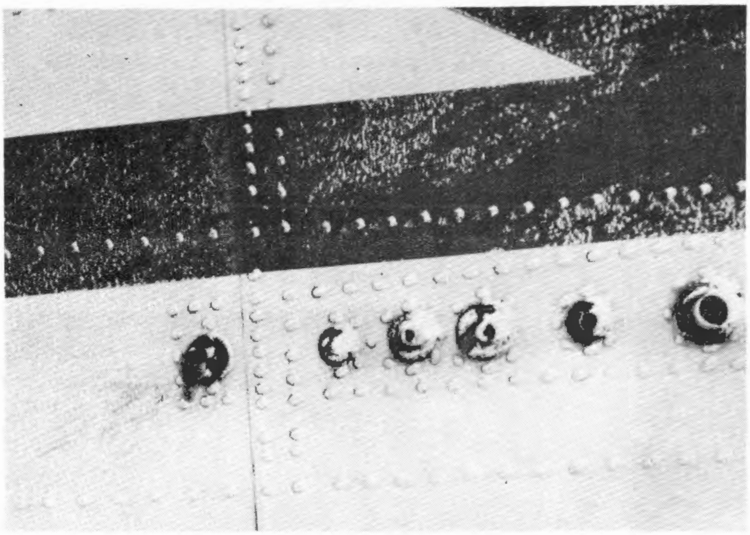
PORT SIDE — AFTER RUN 183-2

ICING OF SCREENS

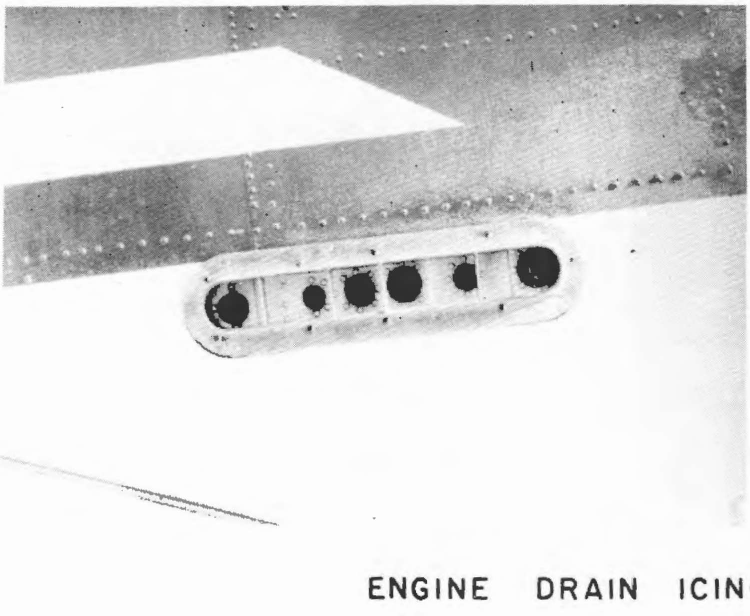
FIG. 4
LR-382



AFTER RUN 177-3



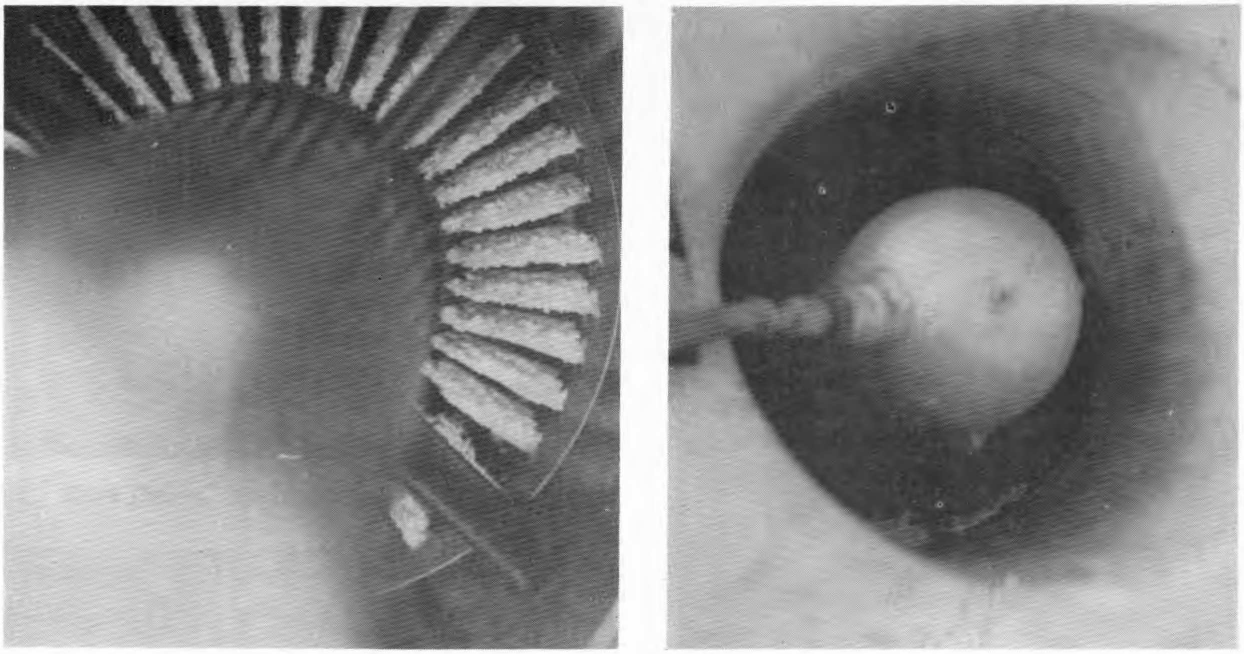
AFTER RUN 184-3



AFTER RUN 190-2
WITH BAFFLE
INSTALLED

ENGINE DRAIN ICING

FIG. 5
LR-38



(a) I.G.V. ICING, RUN 166-2

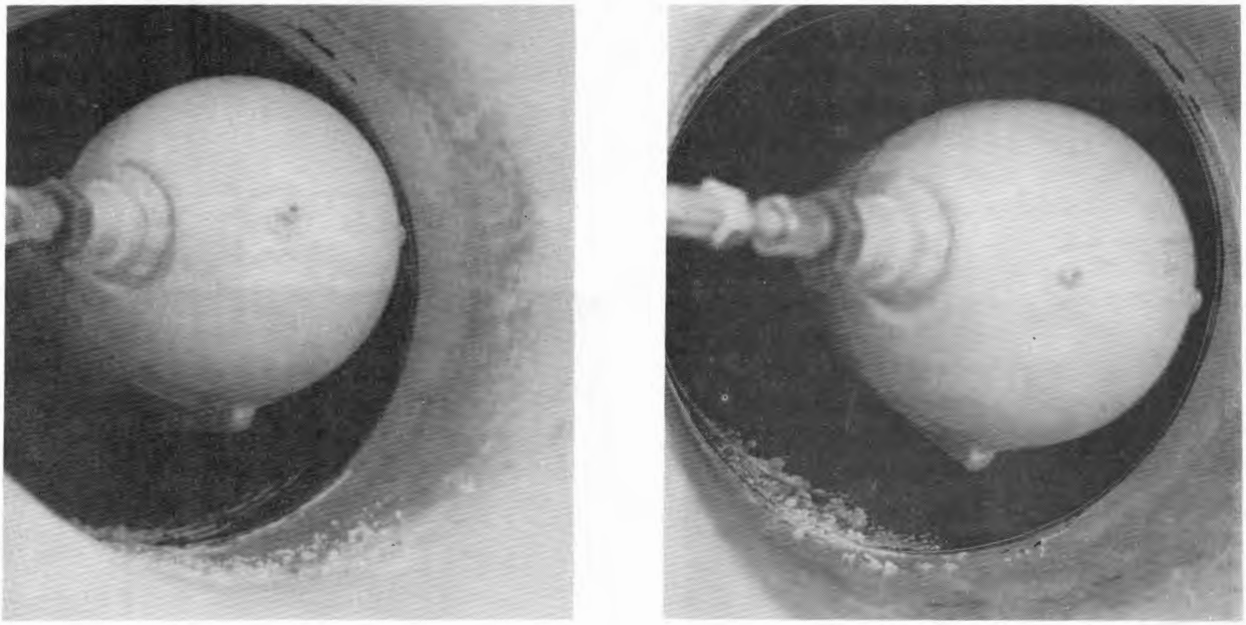
T= − 24.3°C, L.W.C= 0.2 gm./m³.,4 min.

52% torque

(b) RUN 185-1

T= −13.0°C, L.W.C. = 0.5gm./m³.

20 min.



(c) RUN 190-3

T= − 19.5°C, L.W.C.= 0.32 gm./m³

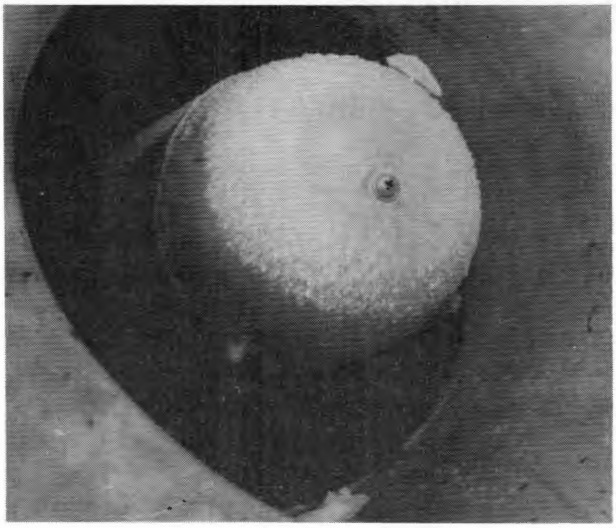
4 min.

(d) RUN 192-1

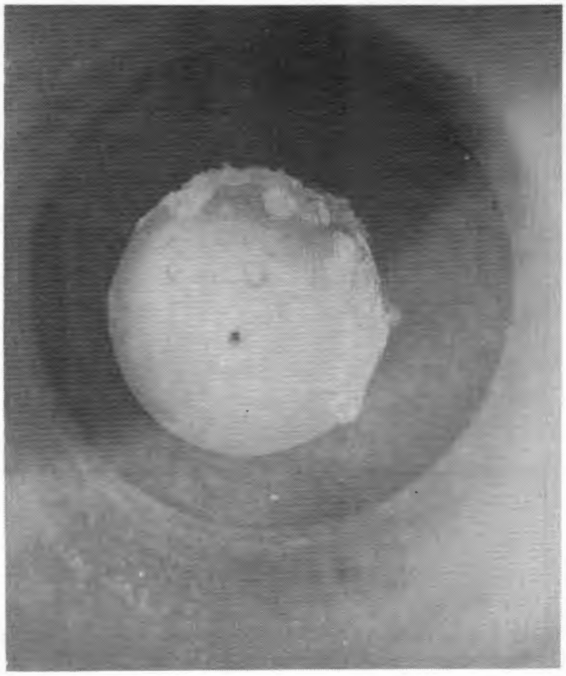
T= −20.4°C, L.W.C = 0.15 gm./m³.

10 min.

ENGINE INLET ICING

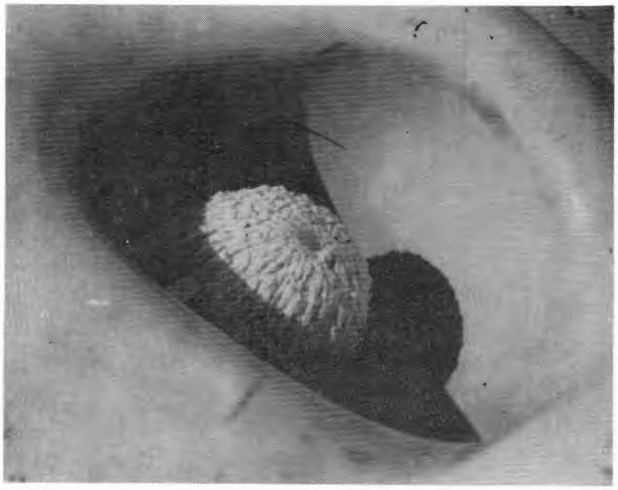


(a) RUN 195-4 ANTI-ICING SYSTEM OFF



(b) RUN 159-2

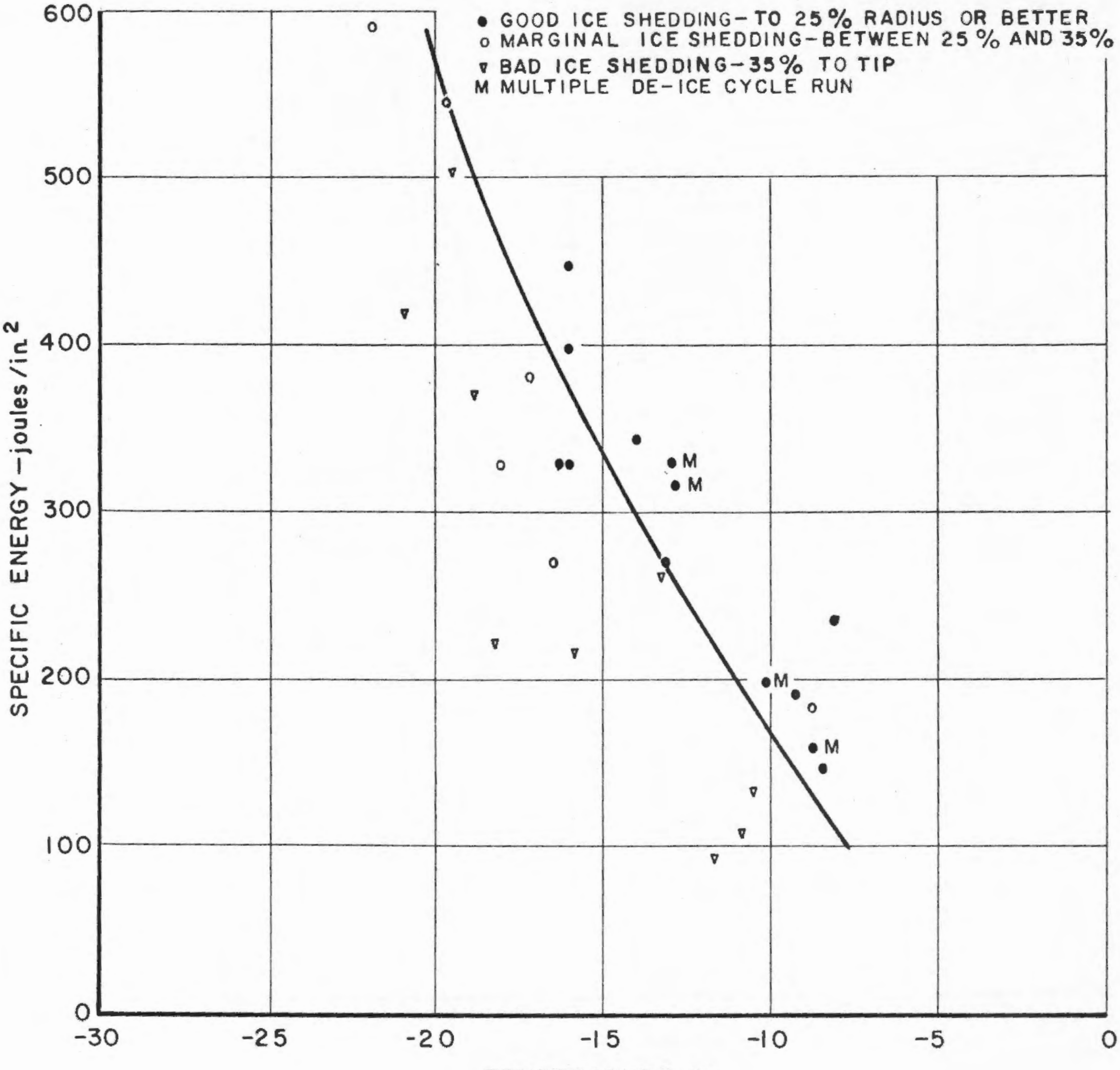
(c) RUN 160-1



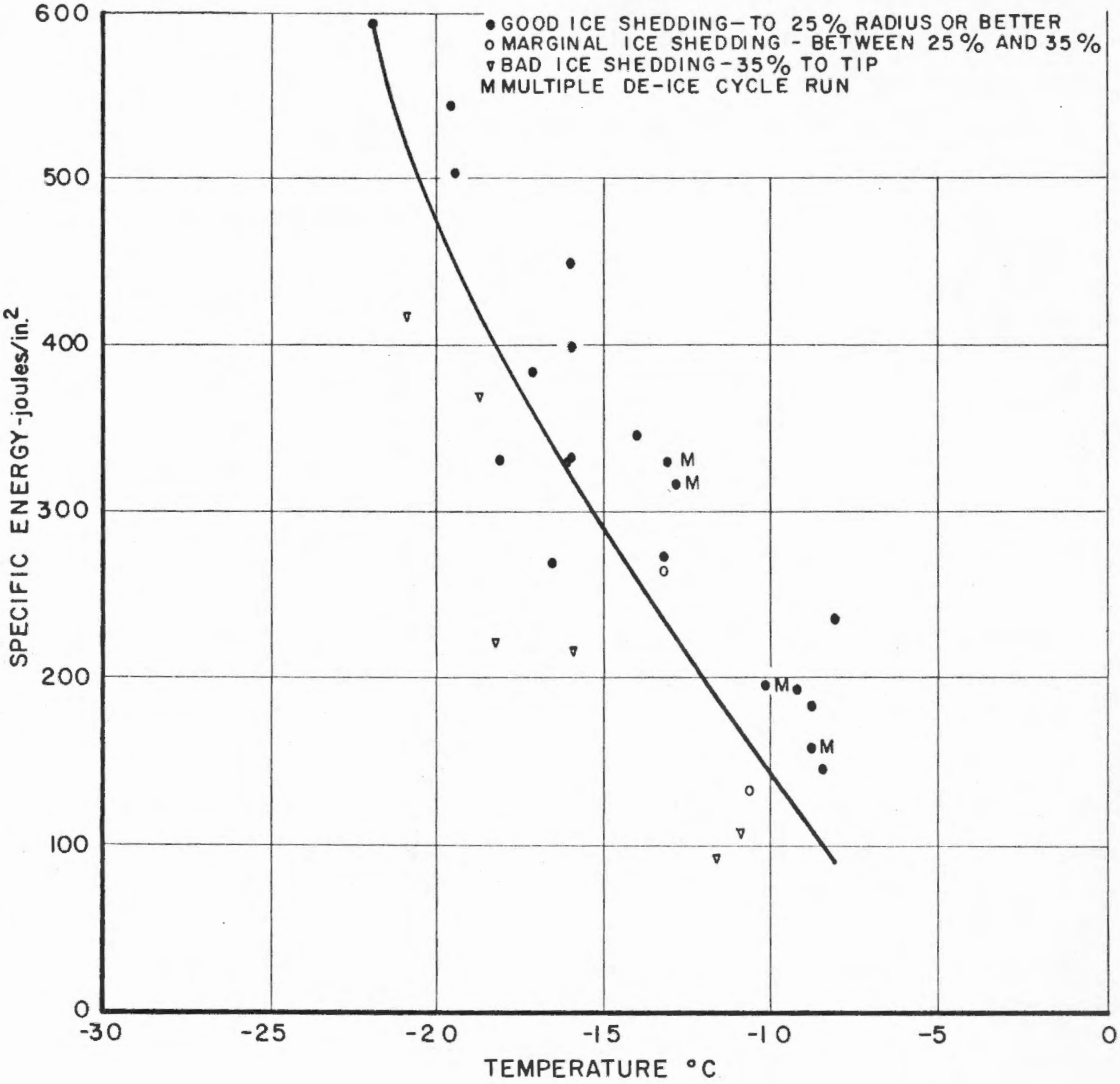
(d) RUN 166-2

(e) RUN 171-3

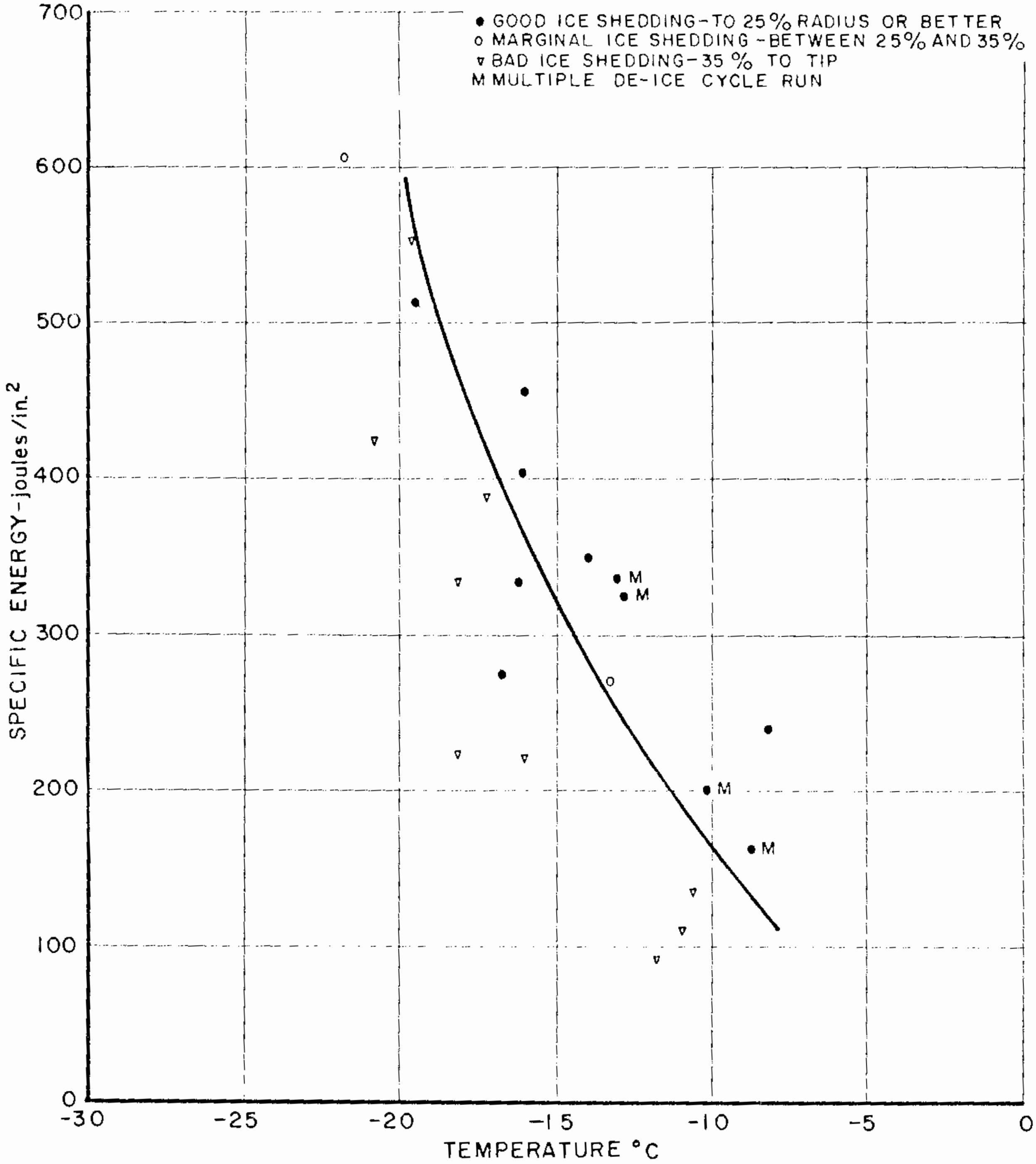
ICING ON STARTER COVERS



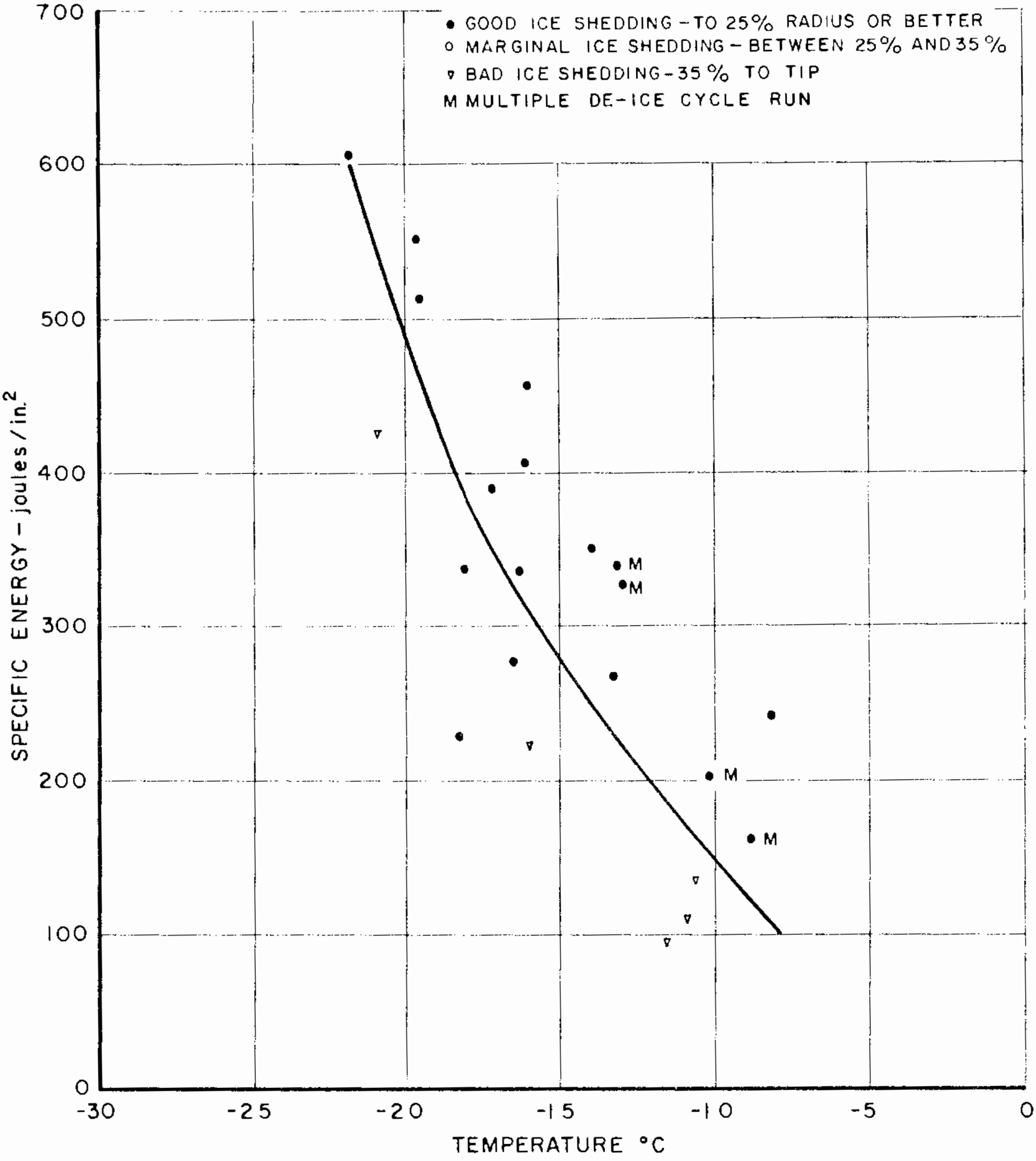
ENERGY REQUIRED TO SHED SPRAYMAT ELEMENTS - AFT BLADES



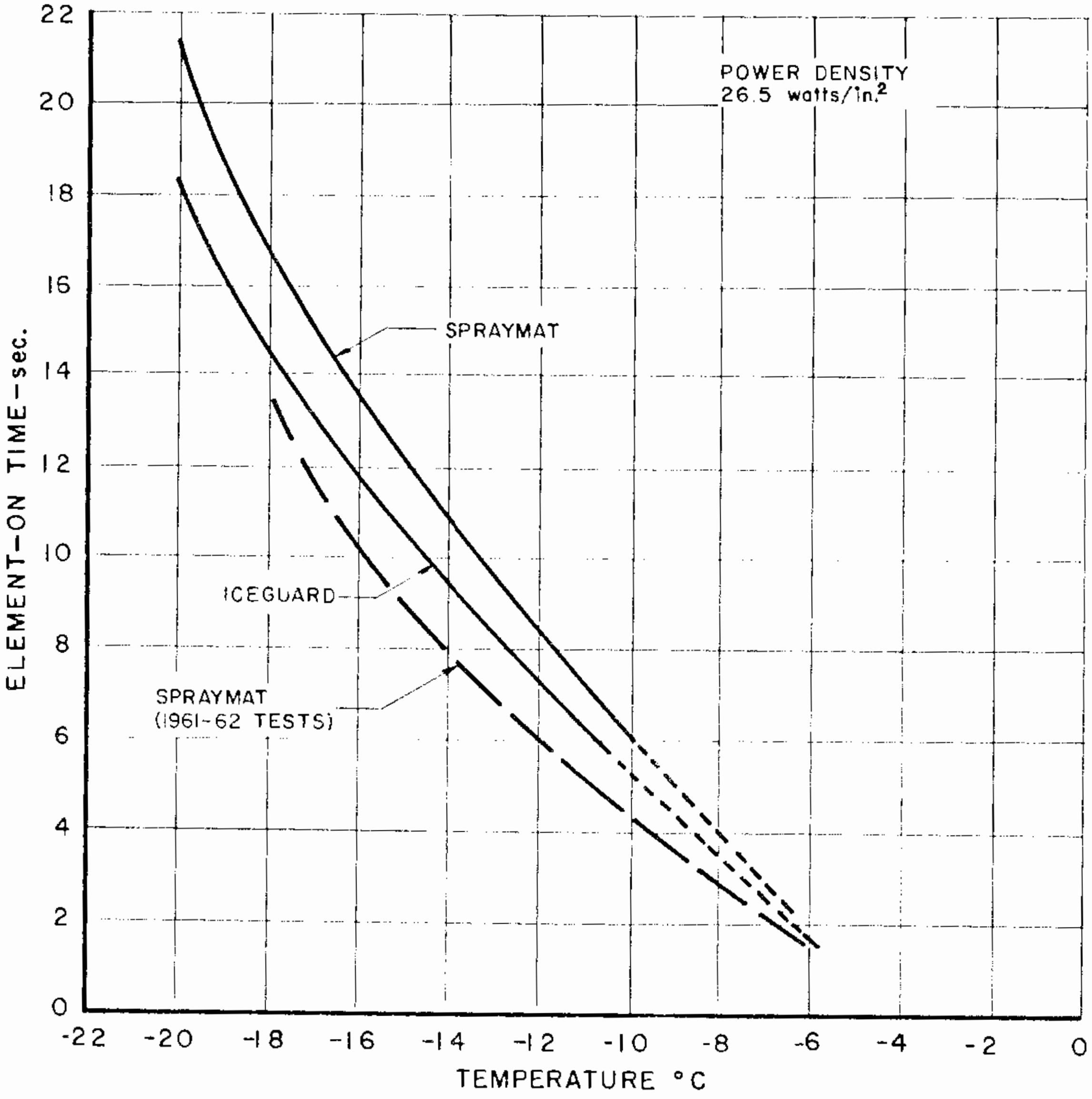
ENERGY REQUIRED TO SHED ICEGUARD ELEMENT – AFT BLADE



ENERGY REQUIRED TO SHED SPRAYMAT ELEMENTS - FORWARD BLADES



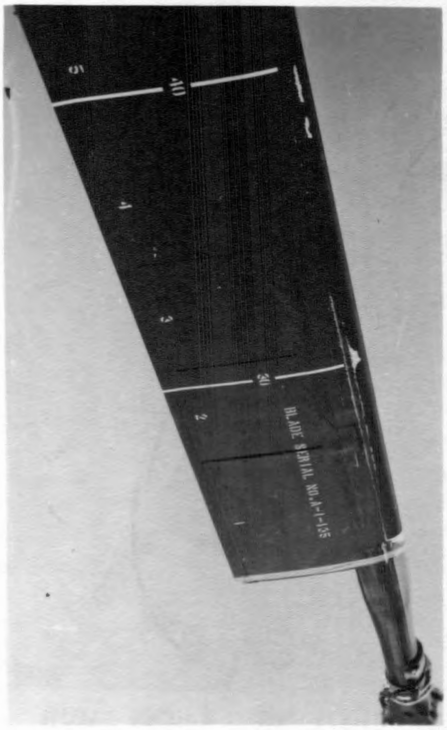
ENERGY REQUIRED TO SHED ICEGUARD ELEMENT — FORWARD BLADE



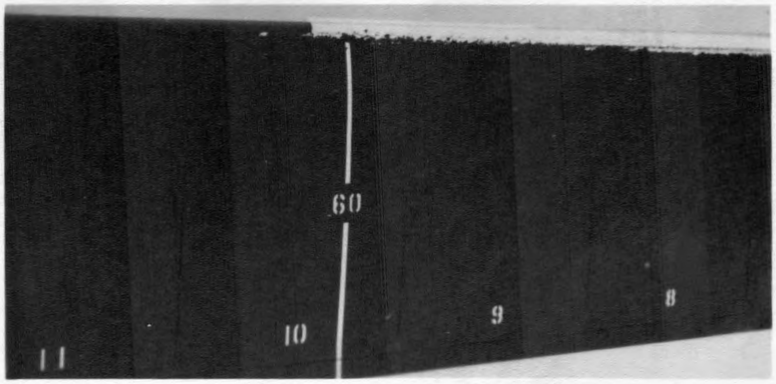
COMPARISON OF ON TIMES REQUIRED

FOR TWO TYPES OF HEATER ELEMENTS

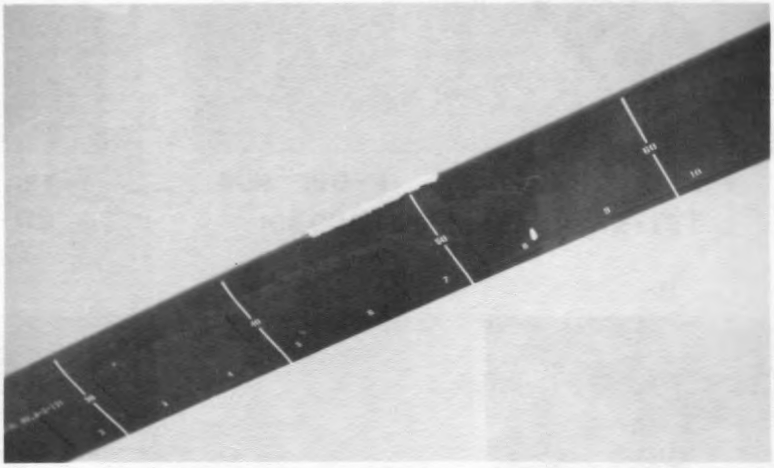
FIG. 12
LR-382



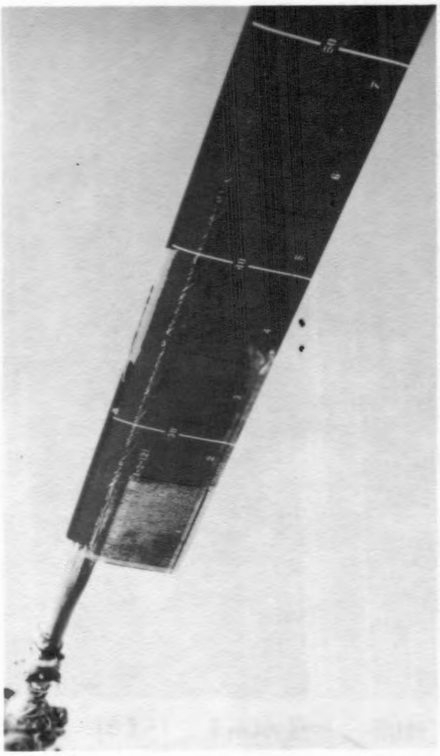
RUN 181-1 FRONT ICEGUAR BLADE



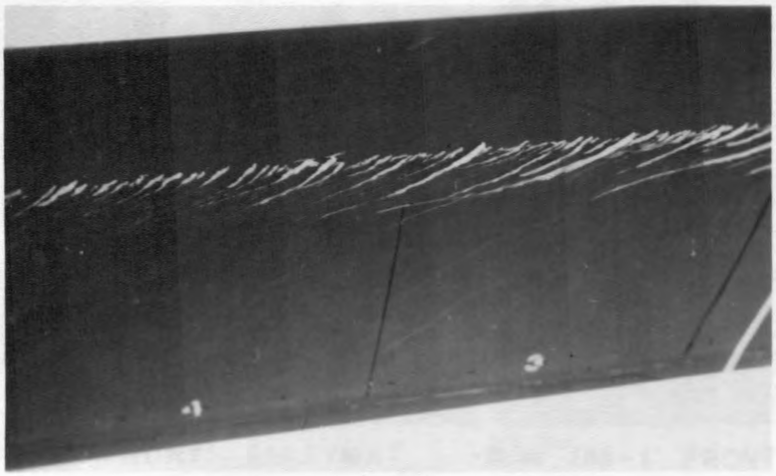
RUN 181-2 INCOMPLETE SHEDDING FRONT SPRAYMAT BLADE



RUN 184-1 PATCH OF ICE ON AFT SPRAYMAT BLADE



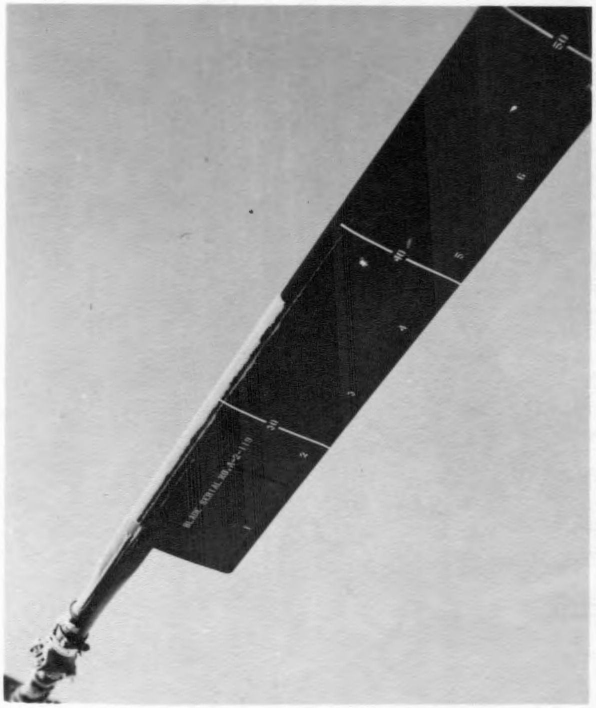
RUN 185-1 PATCH OF ICE ON AFT ICEGUARD BLADE



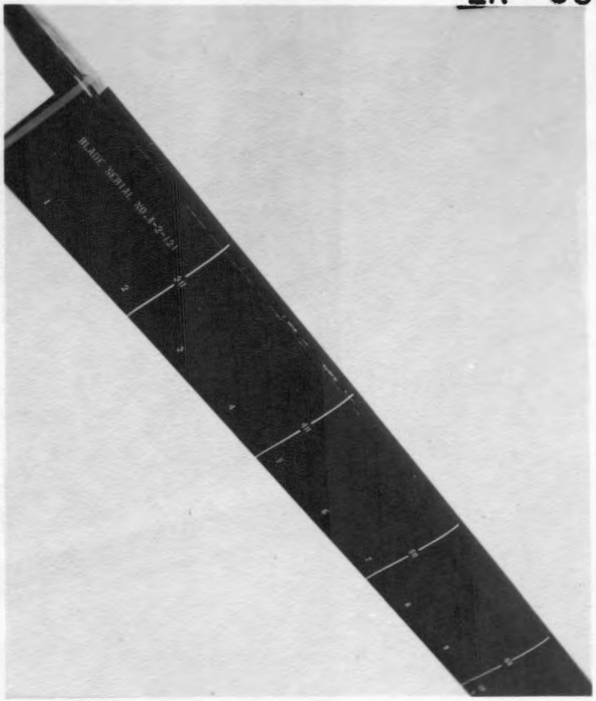
RUN 185-1 RUNBACK ICE

EXAMPLES OF SHEDDING FROM ROTOR BLADES

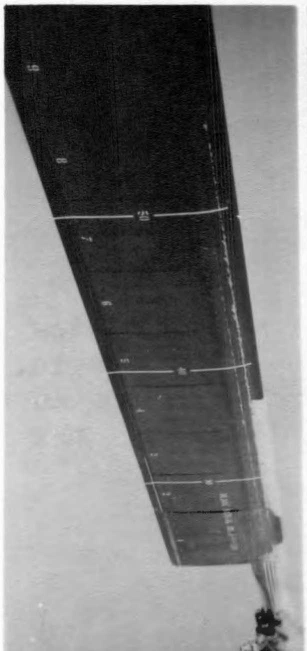
FIG. 13
LR-382



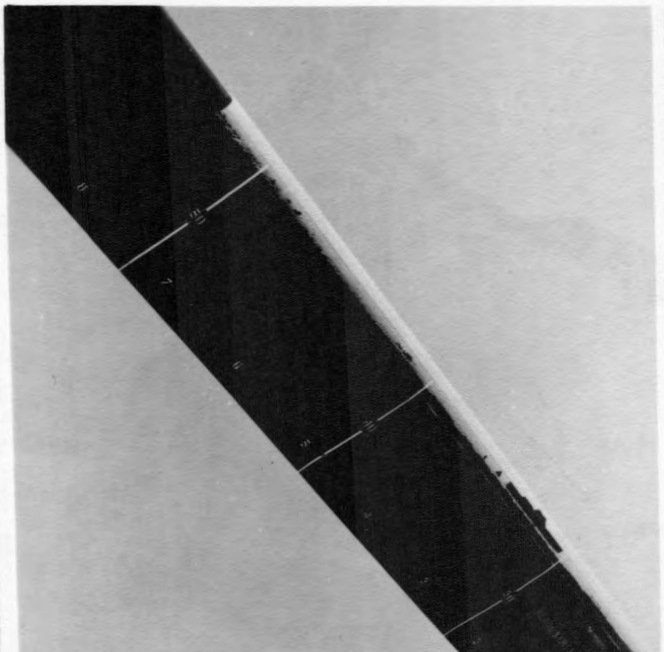
RUN 190-4 DE-ICING OF AFT SPRAYMAT BLADE A-2-119



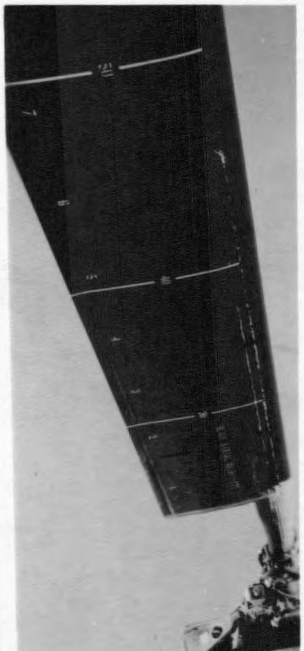
RUN 190-4 DE-ICING OF AFT ICEGUARD BLADE A-2-121



RUN 183-1 FRONT SPRAYMAT BLADE A-1-128



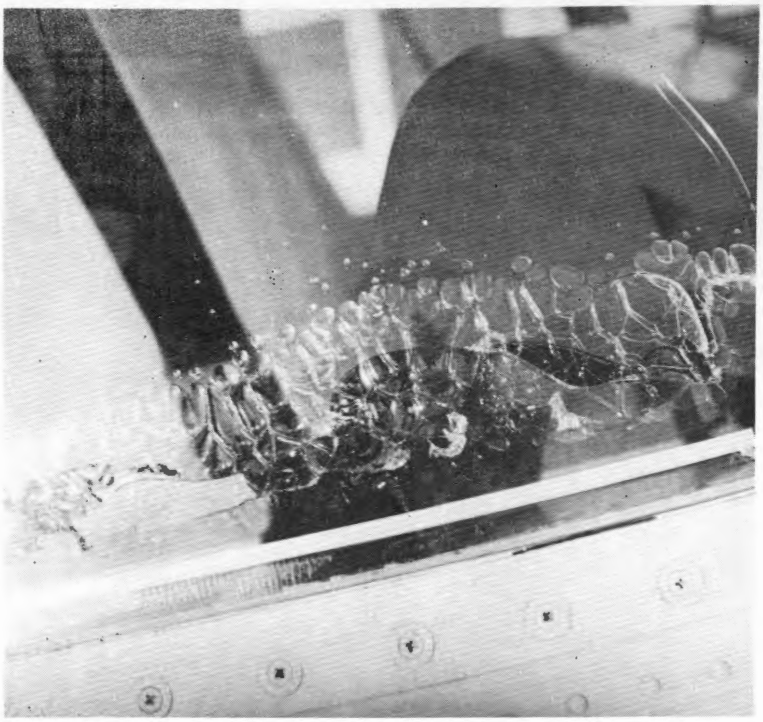
RUN 183-1 FRONT SPRAYMAT BLADE A-1-129



RUN 183-1 FRONT ICEGUARD BLADE A-1-135

COMPARISONS BETWEEN THE SHEDDING OF ICE FROM SPRAYMAT AND ICEGUARD HEATER ELEMENTS

FIG. 14
LR-382



CRACKING OF WINDSHIELD FROM OVERHEATING

HOT-AIR DEFROSTER ON STARBOARD SIDE

ELECTRICAL ANTI-ICER ON PORT SIDE

RUN 202-2 WINDSHIELD ANTI-ICING IN FREEZING RAIN

WINDSHIELD ANTI-ICING