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AERONAUTICAL REPORT

LR - 308

ICING AND DE-ICING FLIGHT TESTS OF A KAMAN HU2K-1 HELICOPTER

BY

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DIVISION OF MECHANICAL ENGINEERING

OTTAWA

MAY 1961

NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

Low Temperature Laboratory

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Subject: ICING AND DE-ICING FLIGHT TESTS OF A KAMAN HU2K-1 HELICOPTER

Submitted by: J.J. Samolewicz
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Approved by: D.C. MacPhail
Director

SUMMARY

Flight tests were performed in an artificial icing cloud on a Kaman HU2K-1 helicopter equipped with a prototype electro-thermal rotor blade de-icing system. The results of the icing flights showed that icing protection will be required on this helicopter mainly because of icing in the engine inlet and the effects of uncontrolled shedding of ice from the rotor blades. During the runs on which it was tested, the installed main rotor blade de-icing system did not operate satisfactorily under all conditions, and the need for modifications to improve its performance was indicated.

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ICING AND DE-ICING FLIGHT TESTS OF A KAMAN HU2K-1 HELICOPTER

1.0 INTRODUCTION

During December, 1960, icing and de-icing trials of a Kaman HU2K-1 helicopter were performed at the National Research Council's helicopter spray rig. The aircraft was supplied by the U.S. Navy while Kaman Aircraft Corporation provided the pilot, maintenance and test personnel. N.R.C. personnel were responsible for the operation of the spray rig and the over-all supervision of the icing trials.

The helicopter was equipped with an electro-thermal de-icing system on the main and tail rotor blades and electrical windshield anti-icing.

Trials were made over a range of meteorological conditions to test the effect of icing on the handling and performance of the helicopter, and the de-icing system was tested to determine the energy requirements for clean shedding. The results of these tests are presented in this report.

As a consequence of the tests a number of recommendations were made and subsequently modifications to the de-icing system were made to improve its performance. The modified system was to have been retested in February 1961, but because of the unavailability of the aircraft at that time no further tests were performed during the 1960-61 icing season.

2.0 PURPOSE

2.1 To determine the effects of rotor blade icing on the performance and handling of the helicopter.

2.2 To assess the efficiency of the de-icing system installed on the main and tail rotor blades and on the servo-flaps.

2.3 To obtain information on the icing of the engine inlet components, including screen, plenum chamber, bellmouth and bullet nose.

2.4 To determine limits of impingement areas on the rotor blades and the effect of runback.

2.5 To assess the effects of icing on secondary components; fuselage, landing gear, control linkages, droop stops, etc.

2.6 To test the windshield anti-icing system.

3.0 TEST EQUIPMENT

3.1 Aircraft

The HU2K-1 helicopter (Fig. 1) is a high speed, all-weather utility helicopter, powered by a General Electric T58-GE-6 gas turbine engine. It has a retractable undercarriage and a four-bladed main rotor using the servo-flap control system. The maximum take-off weight is 9150 lb.

The main rotor is 44 ft. in diameter with a constant chord of 20.0 in. and a NACA 63_1012 aerofoil section. The flap has an 8.5-in chord and a NACA 63_3018 aerofoil section. The three-bladed tail rotor is 8 ft. in diameter and has a 9.3-in. blade chord and a NACA 63_1012 blade section.

For the icing tests the main rotor speed was held at 268 r.p.m. with a corresponding speed of 1510 r.p.m. for the tail rotor.

3.2 De-Icing Equipment

3.2.1 De-Icing Heater Mats

The heater mats on the main rotor blades and servo-flap and on the tail rotor blades were made up of a woven wire-in-glass cloth heater element embedded in Neoprene rubber. The mat was 0.045 in. thick and was covered by a 0.005-in. stainless steel abrasion shield.

The main rotor blade mats were divided into eight separate circuits in spanwise strips, each approximately 1 in. wide. Each individual strip was made up of four passes with all electrical connections being made at the root end. The gap between heating strips was 0.045 in.

The main rotor heater mats (Fig. 2) had a chordwise coverage of 15 percent on the upper surface and 23 percent on the lower surface. The spanwise coverage was from 24 percent (63.5 in. radius) to about ½ in. from the tip to allow for end bus-bar connections on the elements. The tip-cap was not protected.

The servo-flap and tail rotor heater mats were of single circuit construction. The coverage of the servo-flap was from 20 percent upper to 10 percent lower chord for the full span. The tail rotor blades were protected for 10 percent chord on both sides of the leading edge and from 37 percent radius to the tip. The tail rotor tip cap was not protected.

The main rotor elements were designed for normal operation at a uniform power density of 21 watts/sq. in. with an input voltage of 263 volts d.c. The tail rotor power density was 25 watts/sq. in.

In a de-icing cycle the same circuits in diametrically opposite main rotor blades were energized together in parallel. The shedding sequence was as follows (see Fig. 3): First, heater No. 1 in blades 1 and 3; second, heater No. 1 in blades 2 and 4; third, heater No. 2 in blades 1 and 3; fourth, heater No. 2 in blades 2 and 4 .... and so on for 16 cycles to de-ice the main rotor. Next the four flap elements were energized together in parallel, and lastly, on the 18th cycle, the three tail rotor mats were energized in series.

3.2.2 Power Supply

The electrical power for the de-icing system was supplied by a 10 KVA, 115/200V, a-c., 3-phase generator driven by the accessory transmission of the helicopter. The output of this generator was fed to a 6-transitron diode rectifier to produce 263 volts d.c. This d-c. power was then fed through a contacting relay and the main rotor sliprings to the 18-position stepping switch, mounted on the rotor hub. The tail rotor power was taken from the stepping switch back through two main rotor sliprings in parallel and out to the de-icing pads through the tail rotor sliprings.

The contacting relay was controlled by a timer that maintained a constant de-icing cycle time of about 2 min., made up of 18 individual circuit times of about 6 sec. each. For continuous de-icing, this then set the time between consecutive heatings of the same heater element at a constant 2 min. regardless of icing conditions, and thus eliminated the need for a rate-of-icing meter. An ambient temperature sensor automatically varied the power-on time for each circuit continuously from one to a maximum of about 5 sec. for the temperature range from 30°F to 0°F. The power-on and -off times were intermixed in the relationship illustrated in Figure 3 for a sample 2 sec. on time. Although this installed automatic control system was intended for production, it was possible to override the system and manually set up longer on times.

3.3 Windshield and Pitot Anti-Icing

The two forward vision windshields on the helicopter were fitted with electric film-type glass panels thermostatically controlled to maintain the temperature between 85°F and 100°F with either a high or low anti-icing capacity as selected by a pilot's control switch. Electrical anti-icing was also provided for the aircraft pitot probe.

3.4 Engine Inlet

The helicopter was equipped with an experimental single-entry engine inlet. Earlier models of this aircraft had a double inlet configuration drawing air from both sides of the fuselage. The fibre-glass laminate plenum chamber was shaped to accept air from the normal right side airframe inlet fairing of the helicopter (see Fig. 5). The entrance to the plenum was covered by a $\frac{1}{2}$-in. mesh screen for the tests. A blow-in door was provided in the front wall of the plenum chamber to supply air to the engine in the event of blockage of the screen. This door, which was normally held closed by a magnetic catch, was designed to open when the pressure in the plenum chamber dropped below a predetermined level. A light on the pilot's panel gave an indication when the door was open. Air through this blow-in door was drawn through the main transmission housing from a normally screened opening in the top of the aircraft.

The engine bullet nose, inlet guide vanes and top frame struts were heated by compressor bleed air and the bottom frame strut was heated by circulating lubricating oil. No portion of the engine inlet duct; plenum chamber or bellmouth was anti-iced.

3.5 Spray Rig

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

3.6 Miscellaneous

The aircraft was instrumented to measure engine power parameters, flight control positions and main and tail rotor vibrations as well as power-on indications from the de-icing system. These parameters were recorded on an oscillograph mounted in the helicopter cabin.

Contact was maintained between the aircraft and ground by means of an ARC-34 UHF radio in the test hut and the normal UHF radio in the aircraft.

4.0 TEST PROCEDURE

4.1 Icing Flights

A number of flights were made in the icing cloud to investigate the effects that icing would have on an unprotected helicopter. Particular attention was paid to the effects on performance and vibration and to the possibility of damage from ice thrown from the rotor blades, and also to the effects of icing in the experimental engine inlet.

On most flights the helicopter was hovered in the artificial icing cloud about 100 ft. downwind of the spray rig for a suitable length of time and then landed to record data on ice thickness and extent. On low windspeed days it was not possible to hover in the cloud because of poor visibility, and so ground runs were performed. One run was made on the ground in simulated freezing rain.

On two flights the helicopter was flown in the cloud to accrete ice on the rotors and then immediate forward flights were made to investigate any changes in performance caused by the ice.

4.2 De-Icing Flights

On a de-icing test, ice was allowed to build up on the rotors for a suitable time with de-icing power off. On the first 3 days of flight the helicopter was landed before de-icing to verify that a suitable ice thickness was being accreted. However, because damage was being caused to the tail rotor by ice thrown from the main rotor when starting up, all de-icing thereafter was performed immediately after the helicopter left the icing cloud and before landing.

When enough ice had been accreted on the rotor blade (as determined from inspection or from a previous accretion run) the helicopter was hovered in clear air and a de-icing cycle at some pre-set power-on time was initiated. After de-icing, the aircraft was landed and the rotor stopped so that the extent of icing could be inspected. If complete shedding had not been accomplished the blades were cleaned and 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 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.

A few extended flights during which repetitive icing and de-icing was performed were made to investigate the effects of continuous de-icing while in the cloud. On these runs ice was accreted for the first 2 or 3 min. and then the de-icing system was turned on and cycled continuously for the duration of the time in the cloud.

4.3 Windshield Anti-Icing

During the one run in freezing rain the windshield anti-icing system was tested at a windspeed of 15 m.p.h.

5.0 RESULTS

5.1 General

A total of 37 test flights was performed on 8 days between 8 December and 20 December, 1960. Of these, 22 flights were made to check the performance of the de-icing system and the remainder were used to determine the effects of icing on the operation of the aircraft.

The tests were conducted over a range of temperatures from -2.6°C to -18.9°C and liquid water contents from 0.2 to 0.7 gm./m^3. The droplet size was kept constant at about 30 microns (median volume diameter). The test conditions for each of the flights made are listed in chronological order in Tables I and II.

5.2 Icing Flights

5.2.1 Rotor Blades

Ice was accreted to the tips of the main rotor blades below about -12°C and to the tips of the tail rotor below about -18°C. An example of main rotor blade icing is shown in Figure 6. At temperatures higher than these, self-shedding occurred before the ice could build to any appreciable thickness on the outer portions of the blades. The maximum chordwise extent on the main rotor was 1 in. (5 percent chord) on the top and 3½ in. (17.5 percent chord) on the bottom surface (except on high temperature runs (see Fig. 13a) and in freezing rain (Fig. 10) where it was greater because of runback, particularly on the top surface). The maximum chordwise extent on the tail rotor was about 3/4 in.

Ice accretion on the servo-flaps was extremely light. Even on runs where the ice on the rotor blade just in front of the flap was greater than ½ in. thick, the maximum thickness on the flap was less than 1/32 in. Ice did build up on the flap control rod, however, After a total of about 10 min. in heavy icing (runs 8-1 to 8-4), heavy rime ice built up on the end of the rod, as can be seen in Figure 6. Had this ice built to a much greater thickness it could possibly have interfered with the movement of the rod.

Damage was caused by ice thrown from the rotor blades during many of the runs. Some bad and many small tail rotor dents were caused by ice thrown from the main rotor and a few dents were made in the main rotor from shed tail-rotor ice. Some of these dents were severe enough to necessitate the replacing of the blades. Figure 7 shows the tail rotor damage after run 3-1 and further dents in the same blade after run 4-3. Most of the bad dents were made in the first few days of testing when the rotors were started up with ice from a previous accretion run on the blades. The ice which had been partially loosened because of the flexing of the blades was thrown from the main rotor blade directly into the tail rotor while the coning angle of the main rotor was still low. At normal coning angles most of the ice would have been thrown right over the tail rotor disc. Only slight dents were made in the tail rotor blades after the de-icing procedure was changed.

Bad vibrations resulted from the asymmetric self-shedding of the tail rotor blades in ground runs 8-2, 8-3 and 8-4 when the de-icing blades were not installed. On run 8-4 the vibrations were particularly severe and the rotor was quickly stopped for fear of structural damage. Only slight vibrations caused by main rotor self-shedding were noticed during the tests. However, only short duration accretion runs were made (max. 15½ min.) except at very warm temperatures.

On the first forward flight run with ice on the blade (run 6-5) severe main rotor vibrations resulted at a speed of 50 knots. However, when the blades were cleaned and tracked and then the forward flight run repeated with about the same amount of ice on the rotor blades (run 6-6), there was no increase in vibrations up to a speed of 80 knots.

There was little noticeable power loss due to ice on the rotor blades on either the hovering or forward flight runs.

5.2.2 Engine Inlet Icing

It was found that the screen in the engine inlet iced very quickly and that only very light icing on the screen was necessary to cause the blow-in door to open. Examples of inlet screen icing sufficient to cause the blow-in door to open and of heavy screen icing are shown in Figure 8. The screen on the port through which air was drawn when the door was open also iced very quickly and was removed after the first day's testing. Although the blow-in door opening was large enough to supply sufficient air for engine operation through its operating range, it was usually necessary to terminate a run whenever the door did open because of the danger of grease or foreign matter being carried from around the transmission housing directly into the engine.

In an attempt to stop the blow-in door from opening so that longer icing runs could be made, the screen was removed after run 5-1. Ice then built up on the plenum chamber wall and on the bellmouth of the engine, and when hovering out of the cloud after run 5-4 a bump stall of the engine occurred. Upon inspection of the inlet after landing, it could be seen that a section of ice from the back plenum chamber wall and the bellmouth had shed and had apparently gone through the engine. However, inspection showed that this ice had caused no damage to the engine. The screen was re-installed after this flight and remained in for the duration of the tests, and no further engine trouble was encountered. With the screen in, only light rime ice built up in the plenum chamber and on the engine bellmouth.

The bullet nose anti-icing was not always very effective, and in some cases rime nodules or runback remained on the bullet nose after landing. The anti-icing system on the other engine components apparently operated successfully.

5.2.3 Icing of Controls and Airframe

The many exposed retentions and control linkages on the blade root and rotor hub of this helicopter iced very readily on all runs (Fig. 9). However, it was found that the rod bearings generally remained ice free, and the only difficulties experienced were with the droop stops and, on one occasion, with freezing of the pitch locks.

The droop stops failed to engage properly on several occasions. Only a light accretion of ice was sufficient to prevent the proper seating of the stops. Usually it was possible to make the droop stops engage by allowing them to strike the soft end of a broom for a few revolutions. Two anti-icing compounds, 'Icex' and 'Carbowax 600', were tried in an attempt to stop ice forming on the ends of the stops but they lasted for only one run before the stops were iced again.

Except for the freezing rain run the only other portion of the aircraft that picked up ice was the tail-rotor angle gear box screen (Fig. 9). After run 6-4 (over 21 min.) the top portion of the screen was iced but only about 1/3 of the total area was blocked. On the freezing rain run heavy glaze ice was picked up on the front fuselage and windscreens (Fig. 10) and on the landing gear.

5.3 De-Icing Flights

5.3.1 Main Rotor Blades

The de-icing data are shown in Table I. The extent of shedding was from the tip to the blade radius given. Slight variation in the extent of shedding was evident among the 4 blades. Since it was known that blades 1 and 3 were electrically more efficient than the other pair, a fact that was verified by their consistently better shedding, the shedding performance of these blades was used when plotting the results. These results are shown in Figure 11. Different symbols are used to denote the extent to which shedding occurred. Although the heater mats extended as far inboard as about 64 in., shedding was considered successful if ice was removed to 6 ft. (27.5 percent) or better. A straight line has been drawn through the points to indicate the approximate energy required for successful shedding at the 21 watts/sq. in. power density.

Various accretion times were used before de-icing was attempted. In general, the off times were kept short (< 5 min.) in order to limit the maximum thickness of ice that could self-shed and possibly damage the rotor blades.

The de-icing tests at low temperatures were greatly hampered by the fact that the maximum on time obtainable from the control system was found to be only 4.6 sec. As a result, very few good de-icing points were found. Only 3 runs (8-3, 8-5 and 8-6) were made with longer on times by disconnecting the timing control and cycling the system manually.

The actual extent of shedding was often difficult to determine because additional ice was shed from the rotors when they were decelerated on shutting down for inspection. Runs on which considerable shedding of this sort was noticed are marked with asterisks in Table I.

On most de-icing runs the ice shed cleanly only off the leading edge inboard of about 60 percent radius. On the top and bottom surface of the heater mats the ice over the dividing strips between the heated areas received insufficient heat to shed and remained on the blade, sometimes anchoring larger sections of ice. Examples of this can be seen in Figure 12. In Figure 12c particularly, the unmelted areas (dark) can be seen in the ice while the ice over the heater mats is melted (light areas) but anchored by cold areas on either side.

Ice was anchored on the unprotected tip cap and outer half inch of the main rotor on the low temperature de-icing runs (Fig. 12e). This ice apparently did not interfere with the shedding on the rest of the blade.

5.3.2 Servo-Flaps and Tail Rotor Blades

The servo-flaps de-iced cleanly except for a small area (approximately 2 in. long) at the flap rod end of the heated area. This ice was very light, however, and should cause no difficulties.

On the runs when the de-icing tail rotor blades were installed (runs 1-1 to 2-2 and 5-1 to 5-4) they all operated perfectly even with light ice accretions.

5.3.3 Extended Runs

On both extended runs 4-3 and 4-4 the maximum power-on time of 4.6 sec. was used, but it was not long enough for the particular temperatures (< -15°C). In both cases the ice continued to build up through the run and only a few patches of ice had shed from the main rotor blades at the end of the flight, some of which had been shed on landing. On run 4-3 slight damage was caused to the tail rotor by some of this shed ice. On both runs the ice on the blades had been partially melted over the heated areas but was anchored by the cold strips. Only very slight runback was produced on these runs.

On run 6-4 the 4.6-sec. on time was still marginal, although the temperature was higher (-11°C), but because the icing time was longer than on the previous extended runs, the ice was able to build up to such a thickness that it finally shed. In fact, before it shed the ice was building to a thickness sufficient to cause a noticeable power loss (approx. 100 h.p.). On landing it was evident that the ice had shed and had been rebuilt several times on the rotor blades during the run and that slightly more runback had resulted.

On run 7-6 the 4-sec. on time used was more than enough to shed the ice. The heated areas of the blades were clear after the run and fairly heavy runback had been produced (Fig. 13).

5.4 Windshield and Pitot Anti-Icing

The windshield anti-icing was tested only in the freezing rain (run 5-3). In normal icing flights, very little ice was picked up on the windscreens because of the low forward speed and the large scale of the fuselage. On the run when it was tested the protected windshield was kept clean while the unprotected side windows were heavily iced (Fig. 10).

The pitot anti-icing system kept the probe free of ice on all runs.

6.0 DISCUSSION

6.1 Icing Flights

6.1.1 Rotor Blades

Because of the large scale and engine power reserve of this helicopter the effects of rotor blade icing on the performance of the helicopter were slight. It would be expected that, even if longer accretion runs were made at lower temperatures, the power requirement would have increased more than it did but that self-shedding would have occurred before maximum power settings were reached.

The consequences of ice being self-shed from the rotors proved to be the critical problem of the operation of this helicopter in icing conditions. The extreme tail rotor vibrations experienced and the damage caused by the shedding ice hitting the rotor blades showed conclusively that a precisely controlled de-icing system will be required for any flight in icing conditions below about 20°F. Although the worst damage to the tail rotor did occur when ice was shed from the main rotor blades when starting up, this could happen in actual practice, and, moreover, some dents were produced from normal self-shedding and from induced shedding during the de-icing cycle. This fact, that the maximum thickness of ice allowed to build up on the blades will have to be closely controlled to prevent damage, accentuates the need for a sensitive ice detector and, ideally, a rate-of-icing meter for this helicopter.

The extent of ice accretion on the rotor blades encountered during the icing tests indicated that almost all the ice picked up will be on the area covered by the heater mats. In fact, ice was picked up only for about 1 in. on top of the blade, while the heated area extended for about 2½ in., indicating that one 1-in. wide section of the heating mat could be eliminated.

Icing of the servo flaps on this helicopter was much less a problem than had been expected. The Kaman H-43B, which had had difficulties from flap icing, has a similar sort of rotor blade but a smaller chord and different aerofoil section. Apparently because of these and other factors the flap on the HU2K-1 blade is better protected from icing and picks up only small accretions even in the heaviest icing conditions. The mushroom shaped build-up of ice on the flap rod could probably be eliminated by a simple redesign of the end of the flap rod if it were thought that it could cause any difficulties.

6.1.2 Engine Inlet Icing

The speed with which the engine inlet screen iced up enough to cause troubles indicates that further modifications and testing are required. Because this engine is so intolerant to particle ingestion it is unlikely that the screen can be greater than ½-in. mesh for normal operations. Therefore, some means of anti-icing the screen or retracting it in icing conditions will be necessary. Also a redesign of the plenum chamber is likely required to smooth out the airflow and stop ice from forming on the chamber walls. This will prevent chunks of ice from building up and shedding into the engine but there will then be the possibility of heavier icing in the engine itself. Therefore all the engine inlet components, possibly even the bellmouth, will have to be adequately anti-iced.

6.1.3 Icing of Controls and Airframe

No control difficulties were caused by the icing or asymmetric shedding of ice from retentions and linkages; however, the sticking of the droop stops and pitch locks will be a definite problem in operating this helicopter in icing conditions. The design of suitable covers to prevent the possibility of icing on the critical surfaces would be one possible solution to this problem. However, if the stops are at all prone to sticking from other causes it may be better to leave them uncovered so that positive visual inspection can be made on every shut-down and, if necessary, remedial action can be taken.

The results of the tests indicate that no difficulties are likely to arise from ice forming on the fuselage, landing gear or gear-box cooling air screens.

6.2 Performance of De-Icing System

6.2.1 Heater Mats

No mechanical or electrical difficulties were experienced with the de-icing heater mats during the tests (a total of approximately fifty heating cycles) other than a slight variation in shedding efficiency of the main rotor mats. However, creases formed in the thin stainless steel abrasion shield when the main rotor blades drooped and it is possible that, in time, fatigue cracks could result particularly from operations in cold temperatures. These creases can be seen in Figures 12b and 13a.

6.2.2 De-Icing Cycle

Some shortcomings existed with the method of having short off times intermixed with the heater on times and with the order of the shedding of the heated areas in alternate blade pairs as was shown in Figure 3. Both of these practices provided for fairly long times between the heating of certain adjacent heated areas and hence there was the possibility that after one heater had been energized, any runback or unshed ice from it would have had time to refreeze to the blade to help anchor the ice over the adjacent heated strip before it had been energized. This then helped to accentuate the effects of the cold strips.

A better system would be first to cycle through all the heated zones on one set of blades without any pauses (except for switching), then to energize the tail rotor, next to cycle similarly all the zones in the other pair of blades, then the four servo-flaps and then the tail rotor again, and finally to have one long off time to make up the total cycle time. This system is shown in Figure 4. For the 2-sec. on time example the maximum time between the heating of adjacent areas 1 and 3 on the same blade in this system is 4 sec., while it was 24 sec. for the other method. This system also allows for cycling of the tail rotor twice in a complete cycle and eliminates the unnecessary top aft strip of the main rotor blades.

6.2.3 Main Rotor Blades

The 21 watts/sq. in. power density of the main rotor blade heaters was not sufficient to overcome the cold areas of the heater mats to provide fast, clean shedding of ice from the blades. This could be seen from the considerable amount of ice anchorage on the cold areas during most of the tests. Also, for low temperature operation, it is apparent that much longer on times than those available from the timing system will be required unless the power density could be greatly increased. However, the maximum power density that can be used will be governed by the amount of power available and by the electrical limitations of the heater elements. For the most efficient operation of the system, it would probably be necessary to increase the power density to approximately 30 watts/sq. in. and to provide for on times up to about 12 sec. for de-icing down to about -20°C. These are average values of these parameters based on past tests on similarly constructed electro-thermal de-icing rotor blades (Ref. 2 and 3).

6.2.4 Servo-Flap and Tail Rotor Blades

The power densities and on times used on the servo-flaps and tail rotor blades were always adequate for clean shedding. In fact, because of the high centrifugal forces, the tail rotor blades would probably shed clean at a much lower power density than at the 25 watts/sq. in. used.

6.2.5 Extended Runs

The results of the extended runs indicate that slight runback is produced because of droplet impingement when de-icing in the cloud. Because there was little shedding on runs 4-3 and 4-4 there was no direct impingement of droplets on a heated area, and in fact the slight runback that was produced was probably from the melting of the ice anchored to the blade. When some shedding did occur as in run 6-4, there was slightly more runback and on run 7-6, when in fact an excessive on time was used for the temperature, quite heavy runback built up and could have been even greater on a very long run. This clearly indicates that control of the on time is necessary to prevent excessive runback.

6.3 Windshield Anti-Icing

The front windscreens were successfully anti-iced on the freezing rain run 5-3. However, this run was at low windspeed, 15 m.p.h., and high temperature, -3.4°C. At lower temperatures and higher windspeeds the heat dissipation from the windows would be considerably greater and hence no conclusions can be drawn regarding the effectiveness of the anti-icing system unless further tests are made.

7.0 CONCLUSIONS

7.1 Icing Performance

The critical problem of the operation of the HU2K-1 helicopter in icing conditions without an icing protection system is the effect of uncontrolled shedding of ice from the rotor blades. Bad vibrations, particularly from the tail rotor, can result from the asymmetric shedding of the ice and severe damage can be caused by the ice thrown from one rotor striking the other. For these reasons this helicopter should not operate in icing conditions below about -10°C without an adequate rotor blade de-icing system and, if possible, an ice detection system.

Because of the large scale and engine power reserve of the HU2K-1 helicopter, the effect of rotor blade icing on the flight performance of the aircraft was negligible.

The engine inlet components iced readily and modifications are needed to prevent the blockage of air by icing on the screens and the possibility of ice building up in the plenum chamber and shedding into the engine.

It can be expected that the operation of the droop stops will be affected in even very light icing conditions, and some protection might be required.

7.2 De-Icing Performance

The de-icing system on the main rotor blades did not work satisfactorily at the power density and on times used in these tests. Slight modifications to the system to increase these parameters and to rearrange the shedding sequence to keep the time between the heating of adjacent areas to a minimum is probably all that would be required to appreciably increase its efficiency.

The area of the blades protected by the heater mats was more than adequate to cover the extent of ice impingement. In fact impingement tests showed that the top aft strip could be deleted.

TABLE I

ROTOR BLADE ICING AND DE-ICING DATA

Run No.	Ambient Temp. °C	L.W.C. gm./m.^{3}	Time in Icing min.	Ice Thickness in. sta.	Power-on Time sec.	Specific Energy joules/in.^{2}	Extent of Shedding (ft.)				Remarks
							Blade 1	Blade 2	Blade 3	Blade 4	
1-1	-8.7	0.5	2½	7/64 @ 13'	-	-					Accretion only in light snow - no flap ice.
1-2-a	-8.5	0.4	2								Accretion in light snow.
-b	-8.4	-	-	-	2	42	14	14	14	14	De-icing - tail rotor shed clean
1-3	-8.5	0.25	3½	3/32 @ 14'	-	-					Accretion only in light snow - no flap ice.
1-4	-9.5	0.4	5½	13/64 @ 8'							Accretion only in light snow - T/R ice 1/16" at 2½'R
1-5	-9.8	0.2	9½	1/4 @ 8'							Accretion only, trace of flap ice, small dents in M/R, slight T/R vibration
1-6	-11.0	0.25	6	1/8 @ 6½'	4	84	5½*	6*	5½*	6½*	Accretion and immediate de-icing. T/R and flap shed clean.
2-1-a	-10.4	0.3	5	13/64 @ 9'							Accretion
-b	-9.5	-	-	-	4	84	6*	7*	6*	8	De-icing. T/R and flap shed clean.
2-2-a	-8.3	0.3	4	-							Accretion
-b	-7.4	-	-	-	4.6	97	5½	6	5½	5½	De-icing - dent in T/R.
3-1-a	-17.5	0.5	5½	11/32 @ 10'							Accretion - flap ice 1/64"
-b	-17.8	-	-	-	4.6	97	6½*	6*	6½*	6*	De-icing - bad dents in T/R; only L.E. ice shed to 14'
3-2-a	-15.6	0.3	2 1/3	9/64 @ 12'							Accretion
-b	-15.7	-	-	-	4.6	97	14 1/3	11	10½	14½	De-icing - flap clear.
4-1	-18.9	0.3	2½	13/64 @ 14'	4.6	97	13*	14*	14*	14½*	Accretion and immediate de-icing. Trace of ice on flap.
4-2	-18.3	0.25	4¼	3/16 @ 7'	4.6	97	5½*	6*	5½*	7*	Accretion and immediate de-icing.
4-3	-16.7	0.25	9	-	4.6	97	5½	16⅓'+6' to 10½'	13'+6' to 11'	6' to 10½'	3 min. accretion; then continuous de-icing in cloud - T/R dents
4-4	-15.0	0.25	12	-	4.6	97	5½	19'+5½' to 14'	16'+6½' to 14'	13'+6' to 10'	3 min. accretion; then continuous de-icing in cloud - last cycle out of cloud-flaps clean.
5-1	-4.4	0.5	3	5/64 @ 6'							Accretion only - M/R mostly self-shed - slight runback. No T/R or flap ice.
5-2	-4.0	0.5	4½	-							Accretion only - M/R mostly self-shed - slight runback. No T/R or flap ice.
5-3	-3.4	-	12	3/32 @ 8'							Accretion only in simulated freezing rain - runback on M/R. No T/R or flap ice - heavy fuselage ice.
5-4	-2.6	0.5	15	-							Accretion only. Heavy runback on blades.
6-1	-13.4	0.45	2¼	5/32 @ 10'							Accretion only. 1/64" on flap - small M/R dent.
6-2	-12.4	0.5	2¼	9/64 @ 8'	3.5	74	7*	8*	6½*	9½*	Accretion and immediate de-icing. M/R shed on L.E. only - slight runback
6-3	-11.6	0.5	2¼	9/64 @ 7½'	4.6	97	6*	6*	6*	7½*	Accretion and immediate de-icing
6-4	-11.0	0.5	21¼		4.6	97	6	6	5½	9	Accretion and continuous de-icing in cloud. Slight runback.
6-5	-9.5	0.5	6	3/32 @ 7'							Accretion and immediate forward flight - heavy M/R vibration at 50K.
6-6	-8.6	0.5	7¼	-							Accretion and immediate forward flight - no vibrations to 80K.
6-7	-7.5	0.5	15½	-							Accretion only - trace of flap ice.
7-1	-8.2	0.5	3	5/32 @ 10'							Accretion only - trace of flap ice.
7-2	-7.1	0.5	2	1/8 @ 10'	4	84	6*	16½	12*	16	Accretion and immediate de-icing.
7-3	-6.1	0.5	3	11/64 @ 8½'	3	63	14	14	14	14	Accretion and immediate de-icing. M/R had self-shed to 6' - 8' and light ice rebuilt before de-icing.
7-4	-4.8	0.5	4	17/64 @ 10'	4.6	97	10½	6	12	6	Accretion and immediate de-icing - L.E. section of blades 1 & 3 not operated - runback.
7-5	-4.0	0.5	3¼	-	4.6	97	6	6	6	6	Accretion and immediate de-icing.
7-6	-3.4	0.5	15½	-	4	84	6	6	6	6	Accretion and continuous de-icing in cloud - heavy runback to 12'.
8-1	-14.1	0.5	2	9/64 @ 12'							Accretion only - trace on flaps.
8-2	-13.4	0.7	2	5/16 @ 13'	4.6	97	5½*	17	5½*	18½	Accretion and immediate de-icing - bad T/R vibration. Trace on flap.
8-3	-11.9	0.5	2¾	9/32 @ 13'	6	126	7½	10	9	13	Accretion and immediate de-icing - T/R vibration - trace on flaps
8-4	-12.5	0.7	6½	35/64 @ 12'							Accretion only - extreme T/R vibration - T/R dents. 1/64" on flap.
8-5	-10.5	0.5	4¼	13/64 @ 10'	7	147	5½*	5½*	9	10	Accretion and immediate de-iding. Small T/R dent.
8-6	-9.7	0.5	3½		8	168	5½	5½	5½	5½	Accretion and immediate de-icing. Small T/R dent.

* Some ice shed when rotors stopped

M/R = main rotor
T/R = tail rotor
L.E. = leading edge

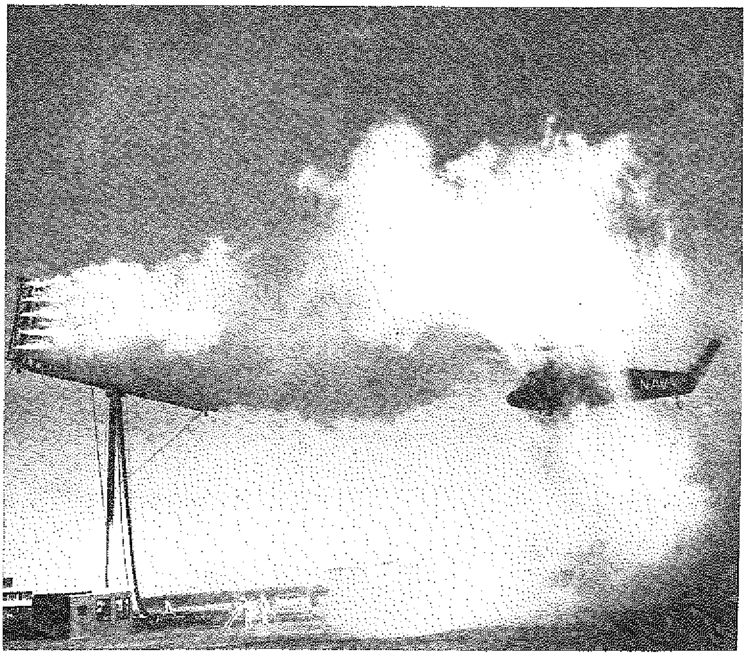
TABLE II

SUMMARY OF SECONDARY ICING EFFECTS

Run No.	Temp. °C	L.W.C. gm./m.^{3}	Time in icing min.	Engine Inlet Icing	Icing of Controls and Airframe
1-1	- 8.7	0.5	2½	3/32" on screen	light
1-2	- 8.5	0.4	2	light	light (3/32" on control rods)
1-3	- 8.5	0.25	3½	light	light
1-4	- 9.5	0.4	5½	light	medium-heavy (½" on control rods)
1-5	- 9.8	0.2	9½	light	medium-heavy - frost on windshield
1-6	-11.0	0.25	6	light	heavy (>½" on control rods)
2-1	-10.4	0.3	5	light	light
2-2	- 8.3	0.3	4	blow-in door opened, screen ice 3/16" wide, ¼" thick	light
3-1	-17.5	0.5	5½	blow-in door opened, nodules on bullet nose	light
3-2	-15.6	0.3	2 1/3	light	light
4-1	-18.9	0.3	2½	light	light
4-2	-18.3	0.25	4¼	light	light
4-3	-16.7	0.25	9	light	Droop stops not engaging.
4-4	-15.0	0.25	9	medium	Droop stops not engaging.
5-1	- 4.4	0.5	3	blow-in door opened, ice ¼" thick on screen	"Icex" on droop stops
5-2	- 4.0	0.5	4½	screen removed - ice in plenum chamber	"Icex" on droop stops - not engaging.
5-3	- 3.4	-	12	ice in P.C.	heavy glaze (>½" on control rods) - droop stops not engaging - heavy fuselage and side window ice - front windows clear. (windspeed - 15 m.p.h.)
5-4	- 2.6	0.5	15	P.C. ice through engine caused bump-stall	heavy (>½" on control rods)
6-1	-13.4	0.45	2¼	light frost - screen reinstalled	light - "carbowax 600" on droop stops
6-2	-12.4	0.5	2¼	light screen & P.C. ice, runback on bullet nose	medium - droop stops not engaging - "carbowax 600" on.
6-3	-11.6	0.5	2¼	light screen & P.C. ice, runback on bullet nose	
6-4	-11.0	0.5	21¼	blow-in door opened at 5 min. heavy screen ice - ½ closed, rime ice in P.C.	heavy (>½" on control rods) - angle gear box screen approx. 1/3 blocked.
6-5	- 9.5	0.5	6	blow-in door opened, ice in P.C.	heavy (½" on control rods) - control bearings free.
6-6	- 8.6	0.5	7¼	light	light - droop stops not engaging, mushroom ice on flap control rod.
6-7	- 7.5	0.5	15½	blow-in door opened, thick screen ice	heavy - bearings and rods iced.
7-1	- 8.2	0.5	3	light	
7-2	- 7.1	0.5	2	blow-in door opened	
7-3	- 6.1	0.5	3	light	droop stops not engaging.
7-4	- 4.8	0.5	4	blow-in door opened	droop stops not engaging.
7-5	- 4.0	0.5	3¼	mushroom ice on screen	droop stops not engaging.
7-6	- 3.4	0.5	15½	blow-in door opened, heavy screen ice	
8-1	-14.1	0.5	2	light	
8-2	-13.4	0.7	2	blow-in door opened	light
8-3	-11.9	0.5	2¾	light	droop stops not engaging.
8-4	-12.5	0.7	6½	heavy ice, blow-in door opened	pitch locks frozen
8-5	-10.5	0.5	4¼	light	droop stop not engaging.
8-6	- 9.7	0.5	3½	fairly thick P.C. ice build up	

P.C. = plenum chamber

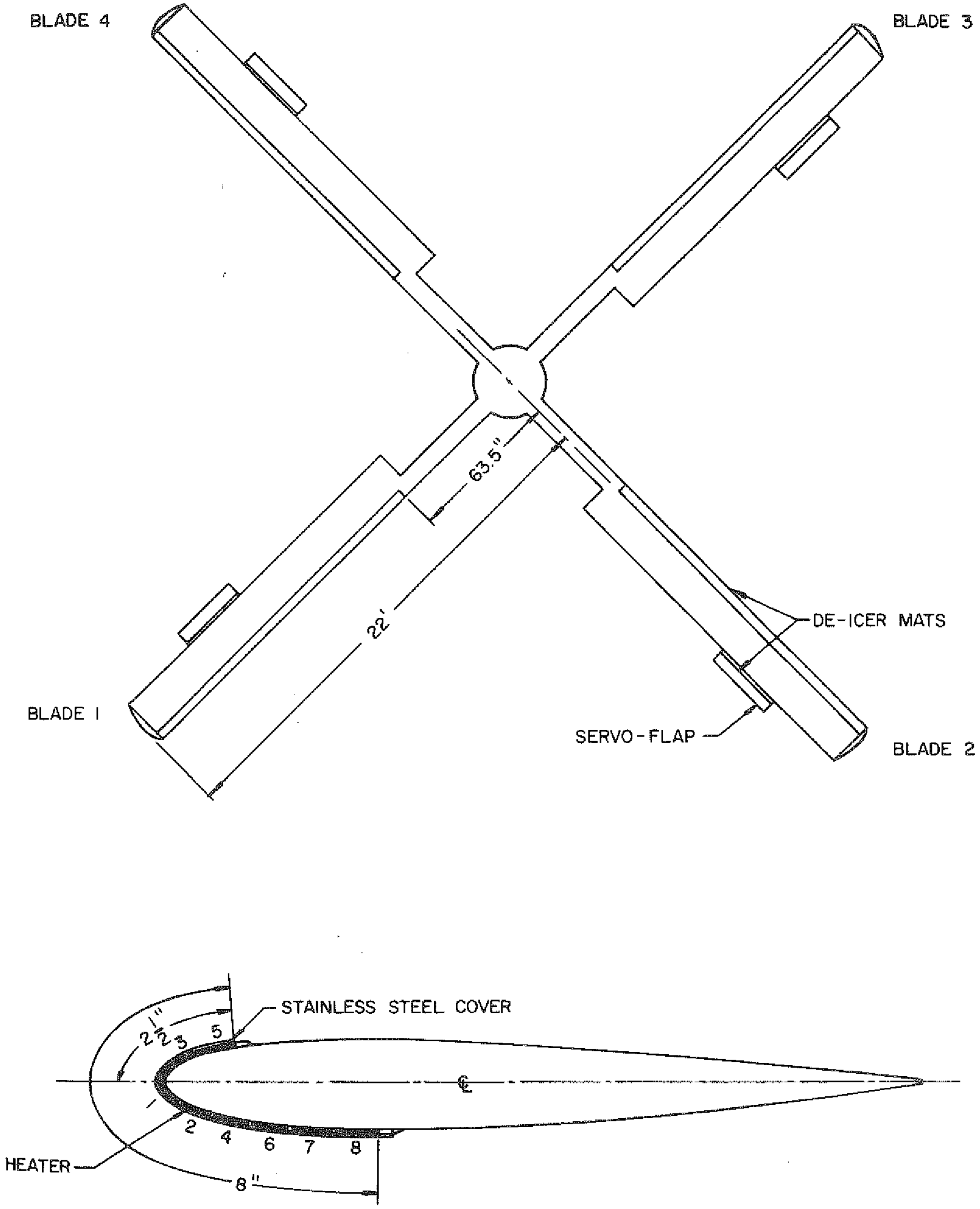
THE KAMAN HU2K-1 HELICOPTER



SPRAY RIG WITH HELICOPTER IN FLIGHT

THE TEST HELICOPTER

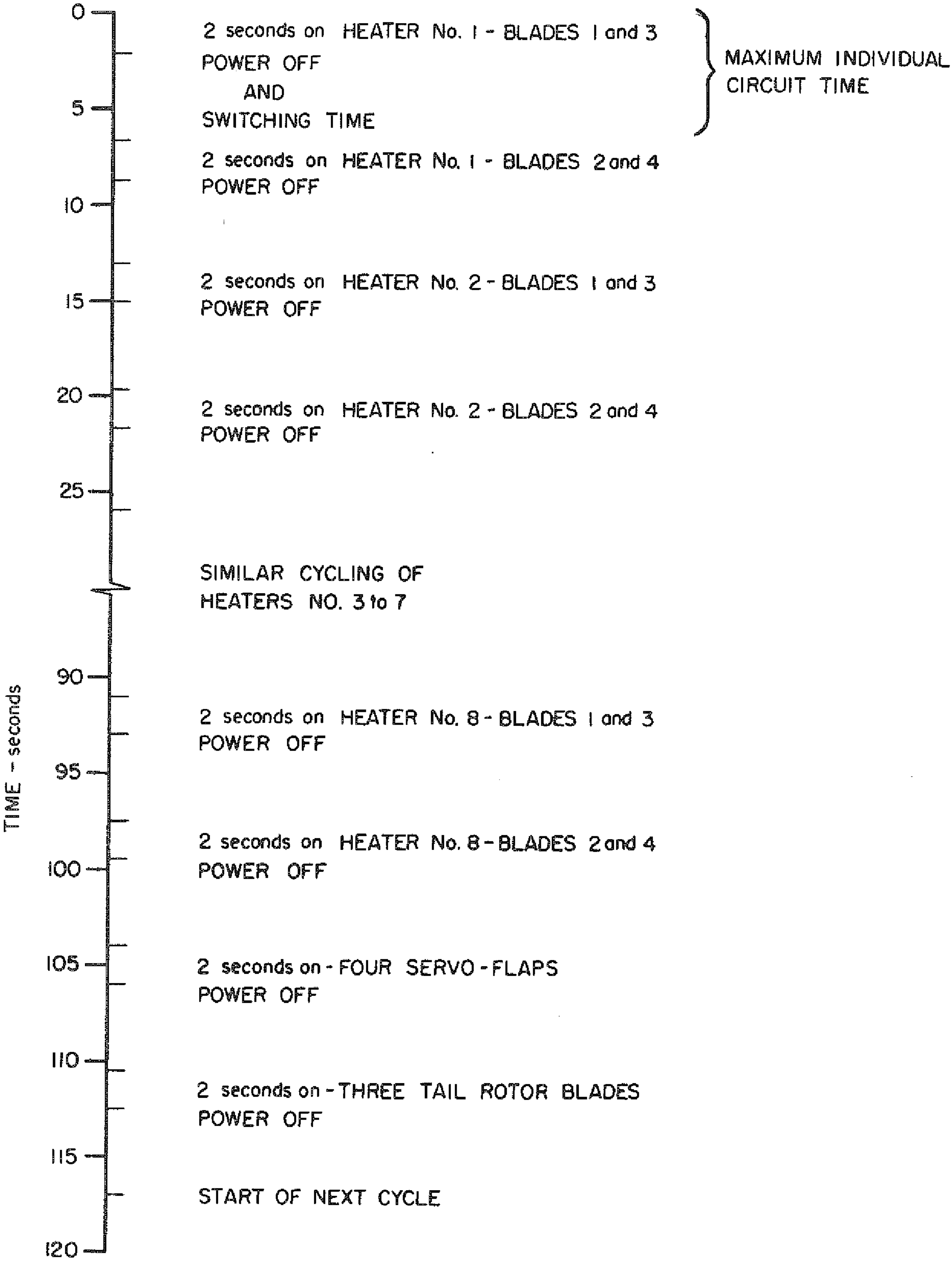
FIG. 2
LR-308



AREAS ARE NUMBERED
IN ORDER OF SHEDDING.

MAIN ROTOR WITH DE-ICER MATS INSTALLED.

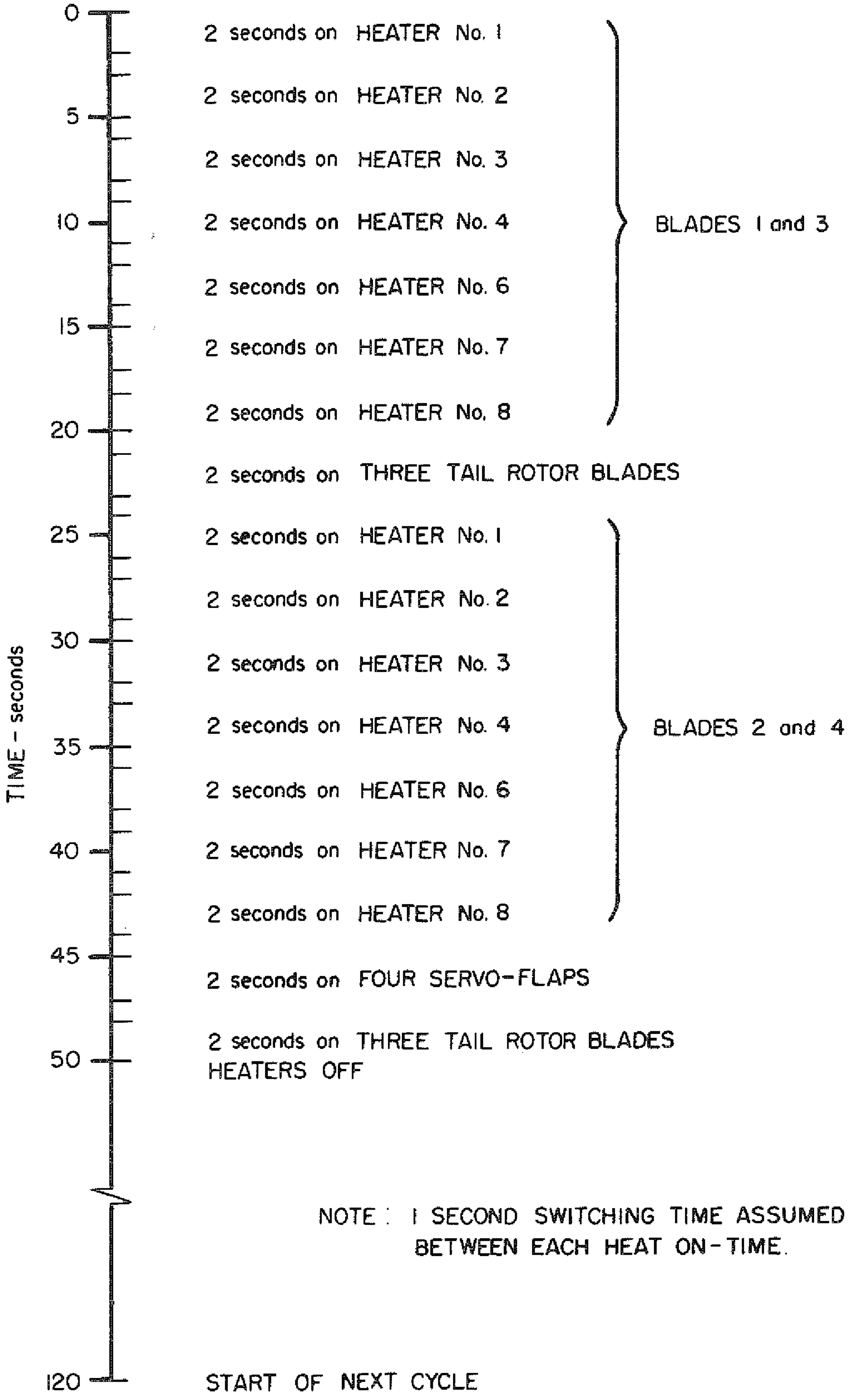
FIG. 3
LR-308



DE-ICING SHEDDING SEQUENCE USED DURING THE TESTS

Sample on - time - 2 seconds

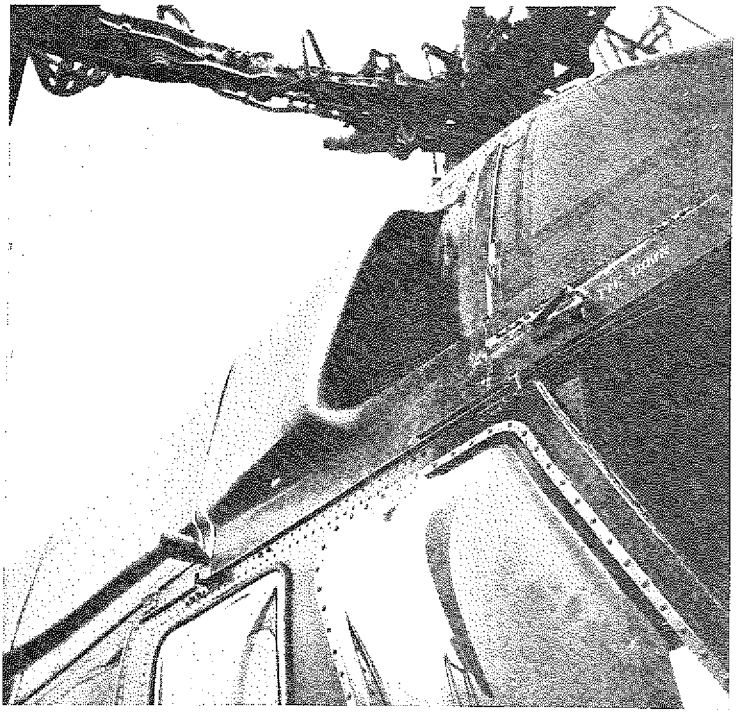
FIG. 4
LR-308



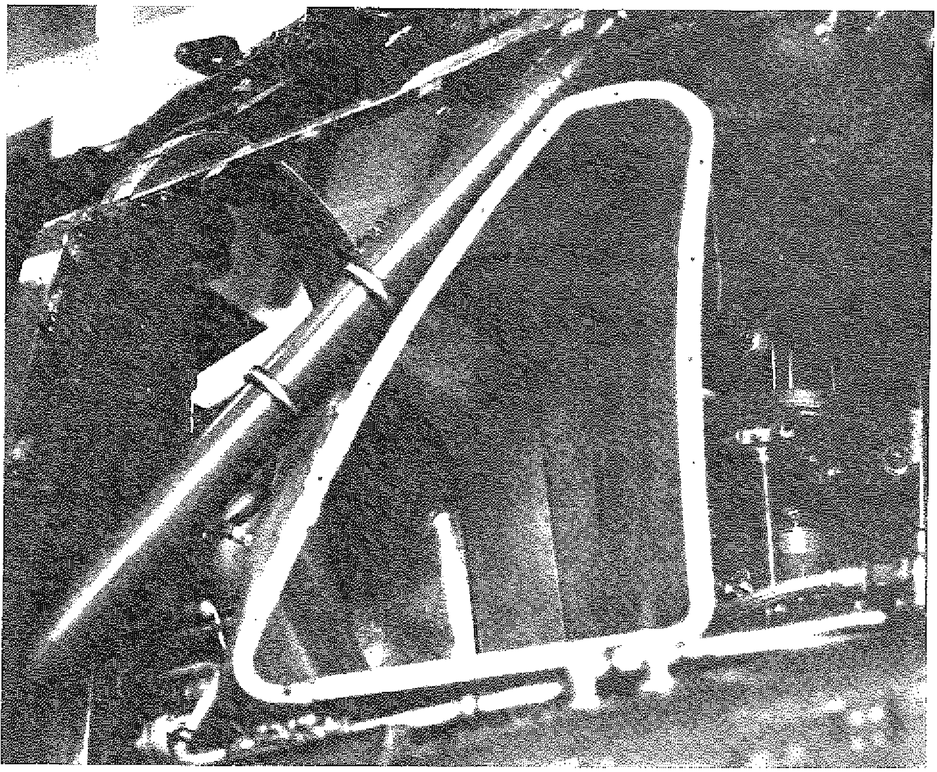
PROPOSED DE-ICING SHEDDING SEQUENCE

Sample on-time - 2 seconds

FIG. 5
LR-308



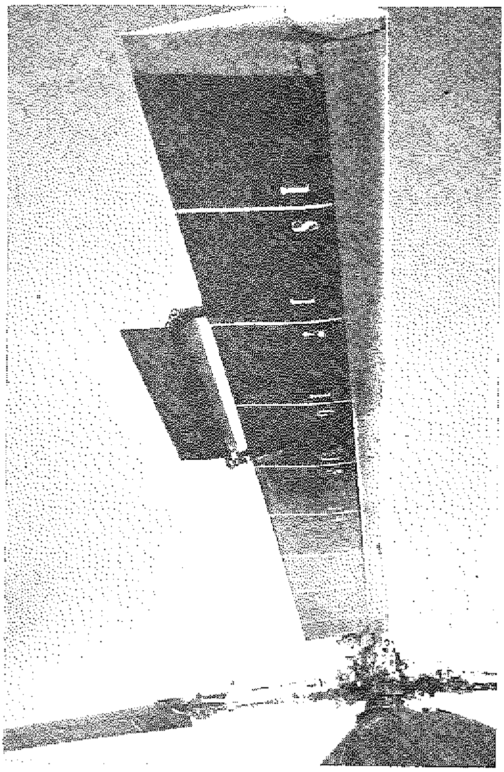
ENGINE INLET FAIRING

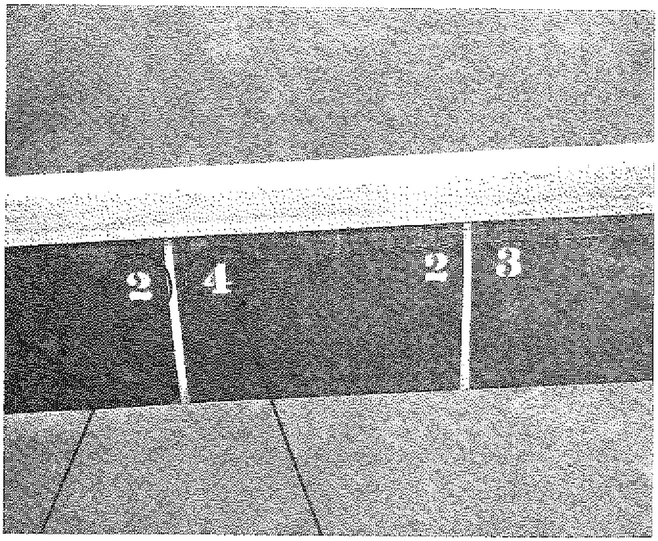


PLENUM CHAMBER WITH SCREEN AND FAIRING REMOVED

ENGINE INLET

FIG. 6
LR-308



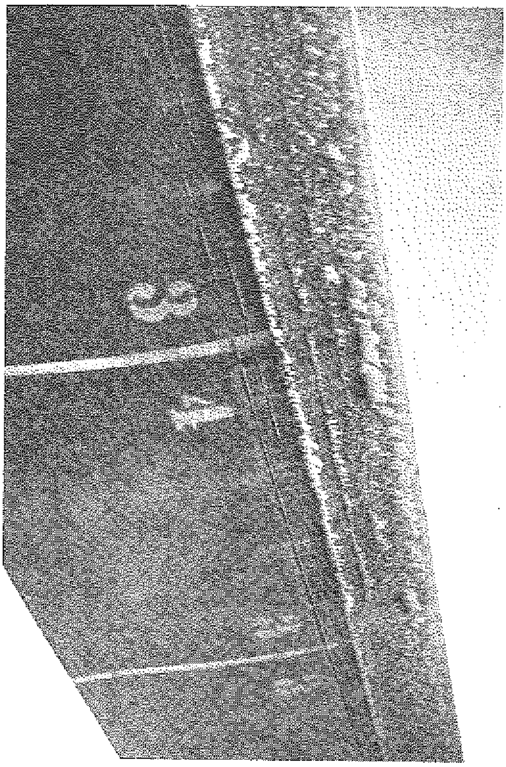


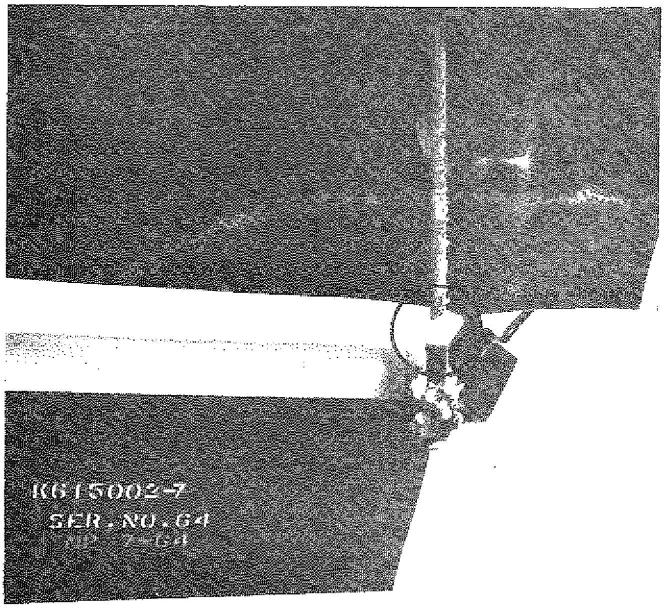
BLADE NUMBER
(BLADE NO. 4 NOT MARKED)

STATION NUMBER 'n'
WHERE BLADE RADIUS TO LINE = 2n + 4 ft.

RUN 8-4

TEMP. -12.5° C
L.W.C. $0.7\ \text{gm./m.}^3$
TIME IN ICING 6 1/2 min.



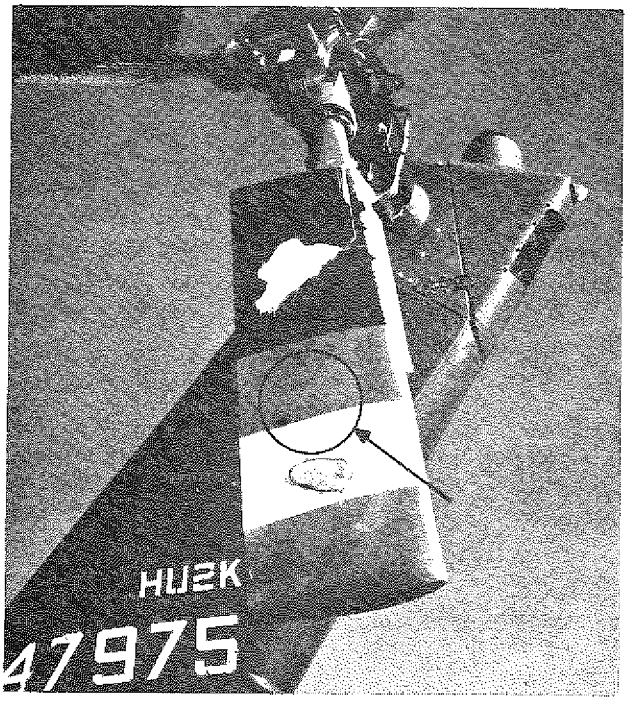


SERVO-FLAP ROD ICING

EXAMPLE OF HEAVY MAIN ROTOR ICING

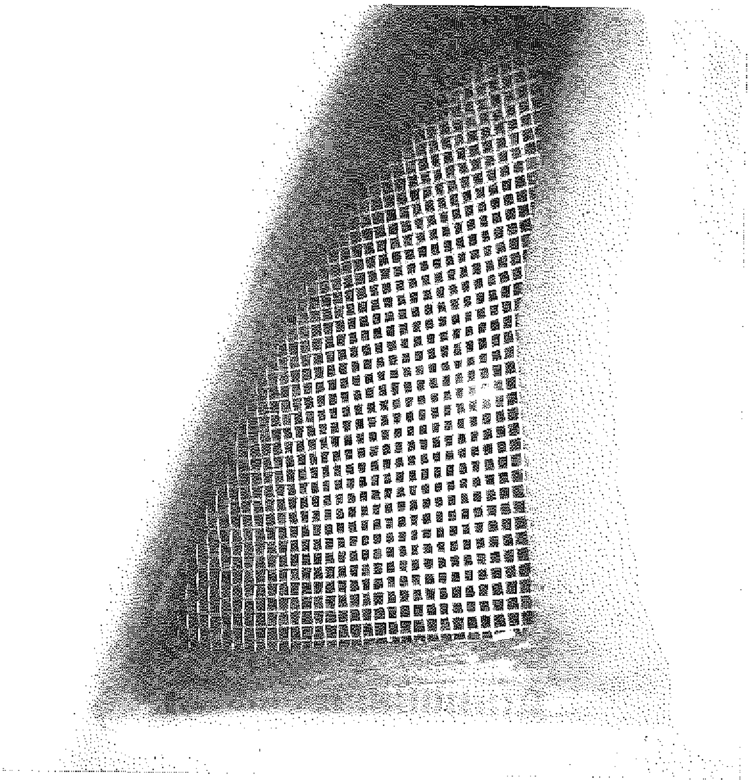
FIG. 7a, b
LR-308

(a) DENTS AFTER RUN 3-1



(b) ADDITIONAL DENTS AFTER RUN 4-3

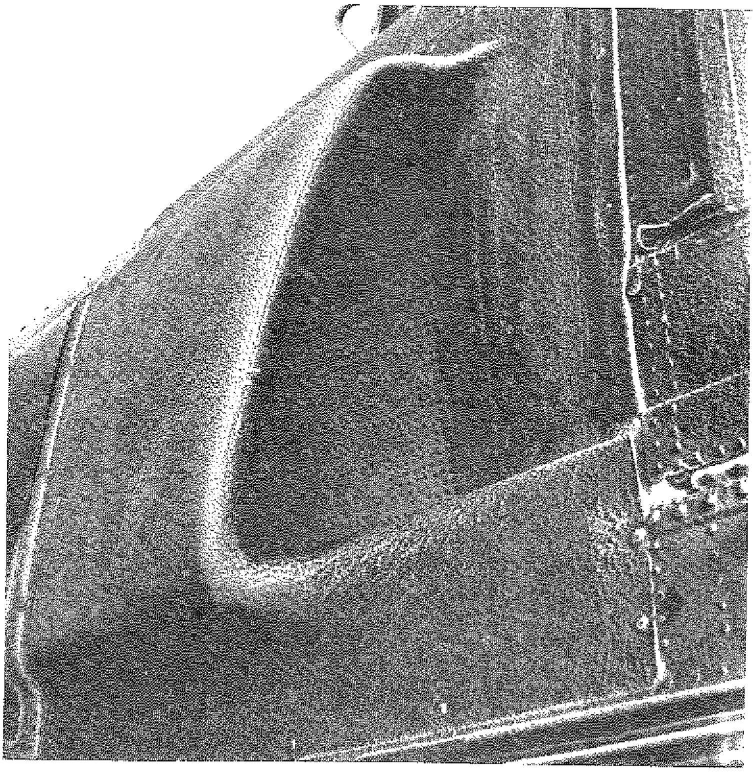
DENTS IN TAIL ROTOR



SCREEN ICE SUFFICIENT TO CAUSE BLOW-IN DOOR TO OPEN

RUN 7-2

TEMP. -7.1° C
L.W.C. 0.5 gm./m.^{3}
TIME IN ICING 2 min.



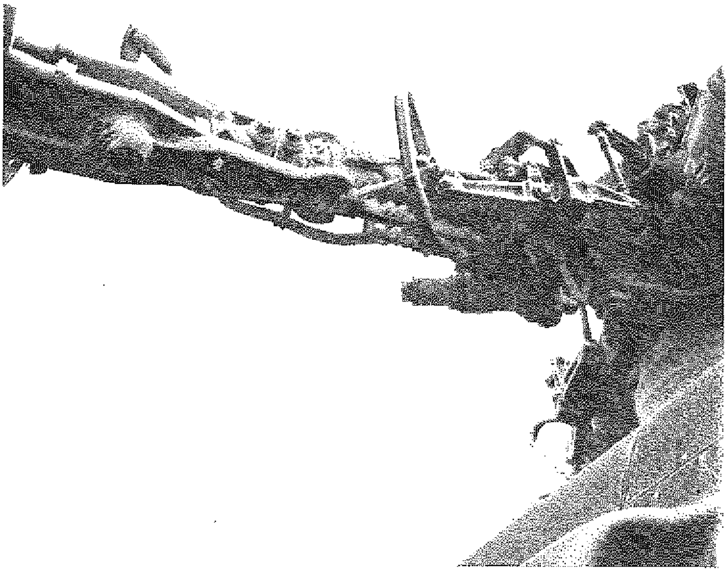
HEAVY SCREEN ICING

RUN 6-4

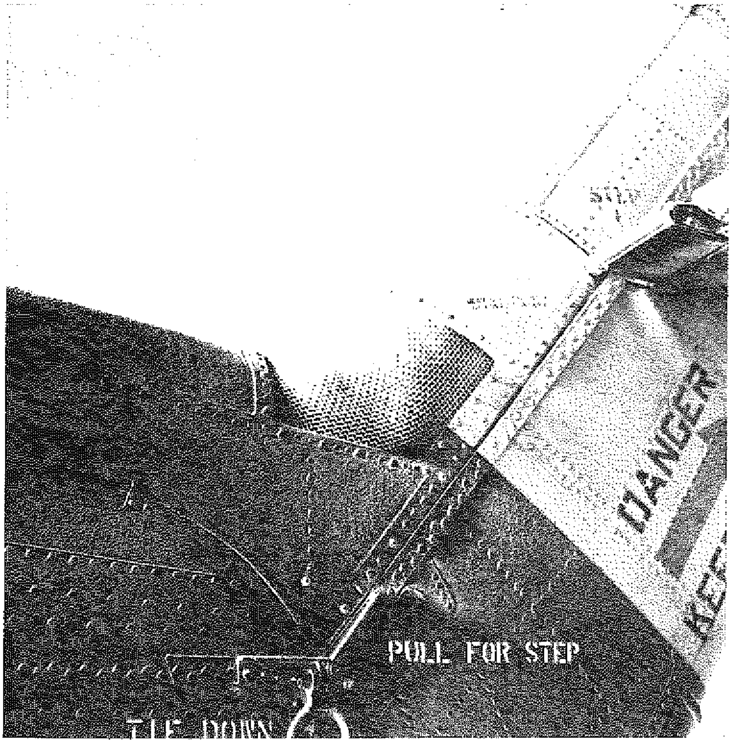
TEMP. -11.0° C
L.W.C. 0.5 gm./m.^{3}
TIME IN ICING 21 1/4 min.

ENGINE INLET SCREEN ICING

FIG. 9
LR – 308



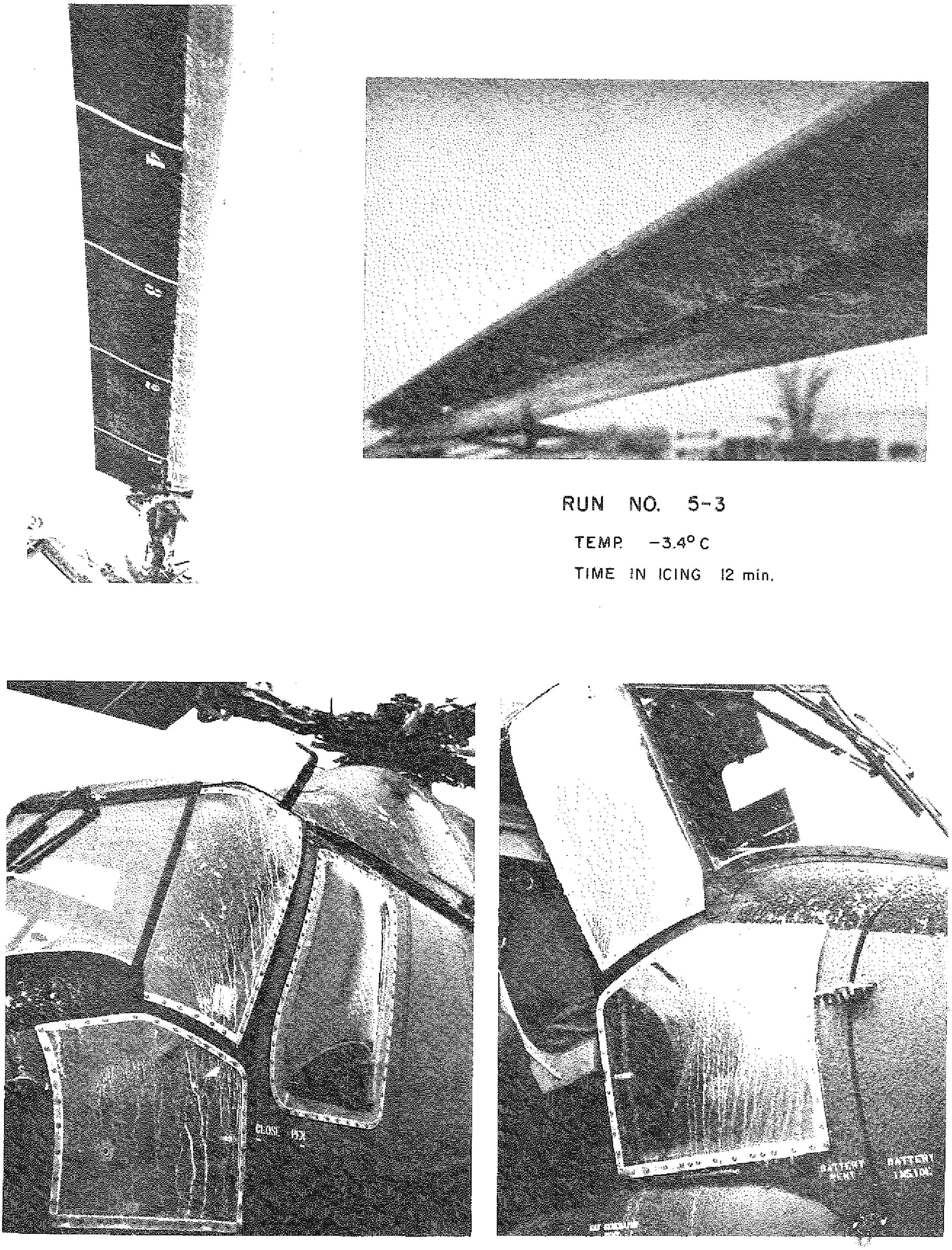
ICE ON MAIN ROTOR HUB



ICE ON ANGLE GEAR BOX SCREEN

SECONDARY ICING EFFECTS

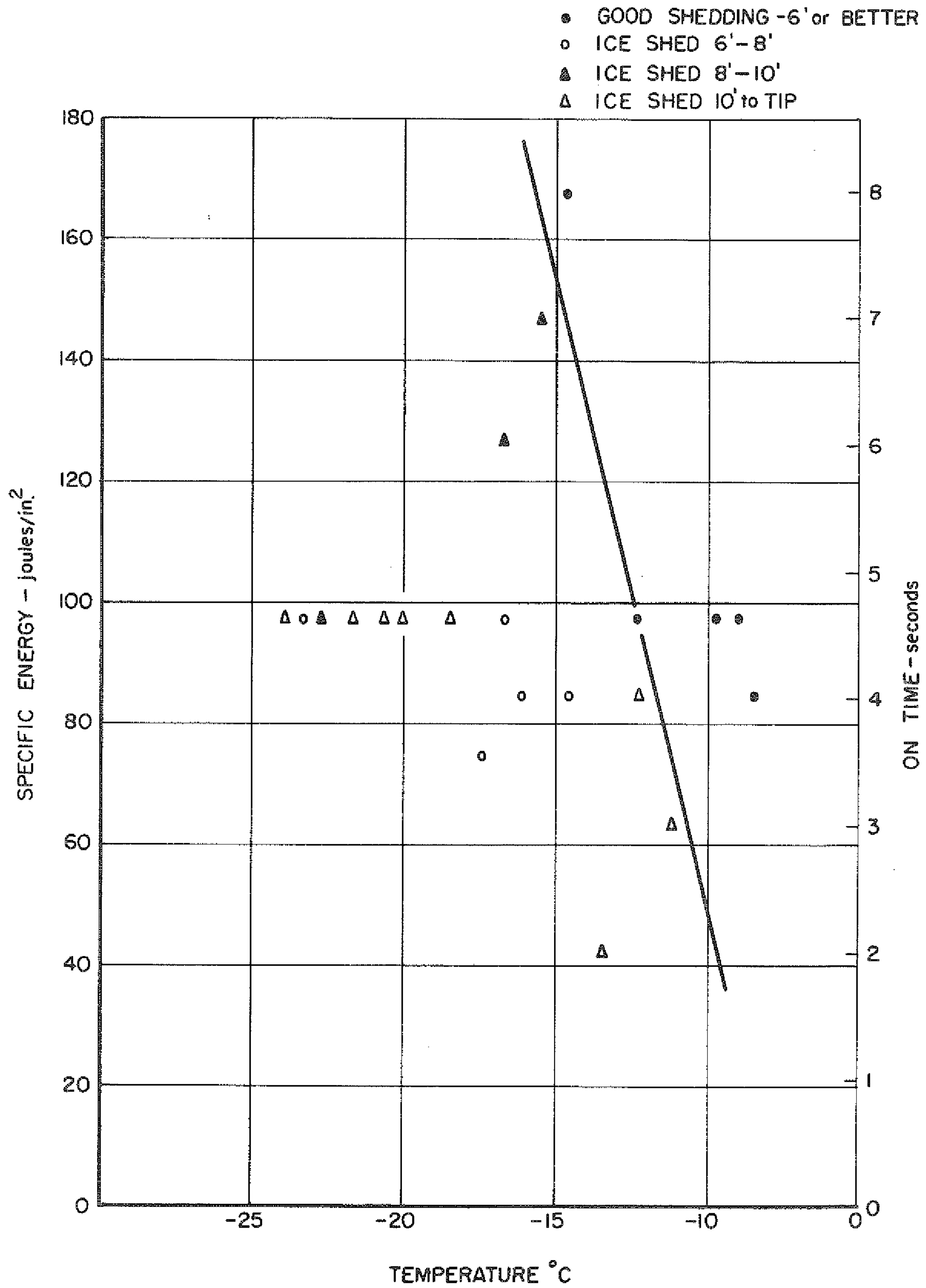
FIG. 10
LR-308



RUN NO. 5-3
TEMP. −3.4° C
TIME IN ICING 12 min.

ICE ACCRETION IN SIMULATED FREEZING RAIN

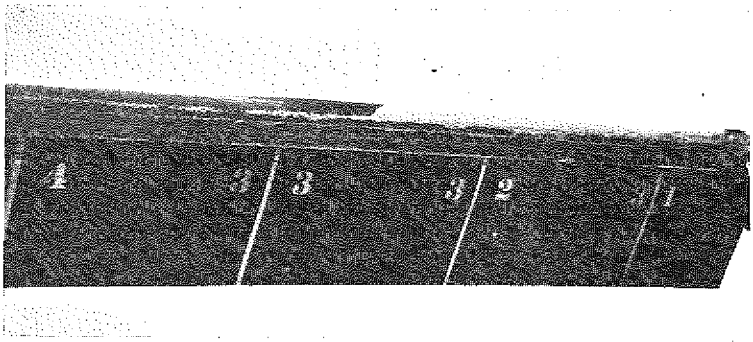
FIG. 11
LR-308



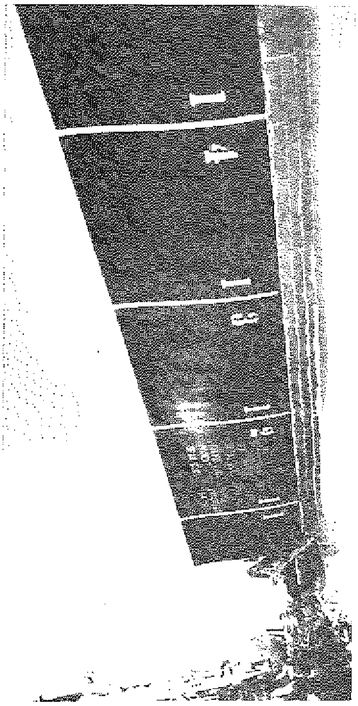
VARIATION OF SPECIFIC ENERGY REQUIRED TO SHED WITH TEMPERATURE

POWER DENSITY 21 watts/in.^{2}

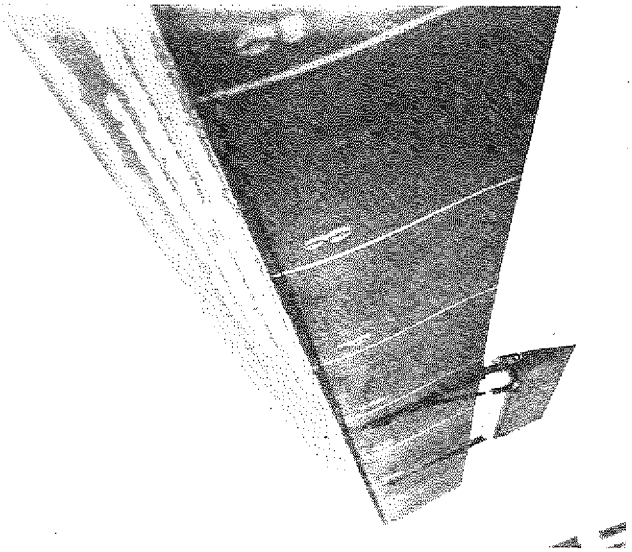
FIG. 12 a-e
LR - 308



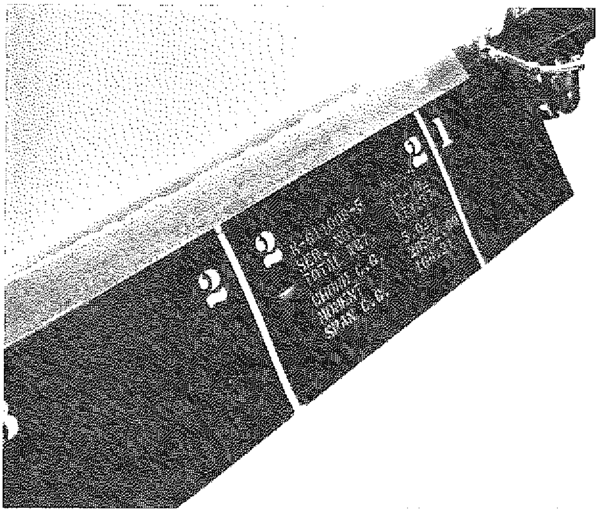
(a) RUN 8-3



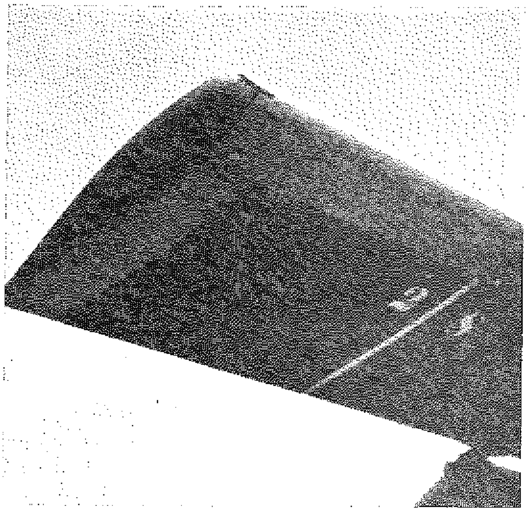
(b) RUN 8-3



(c) RUN 6-3



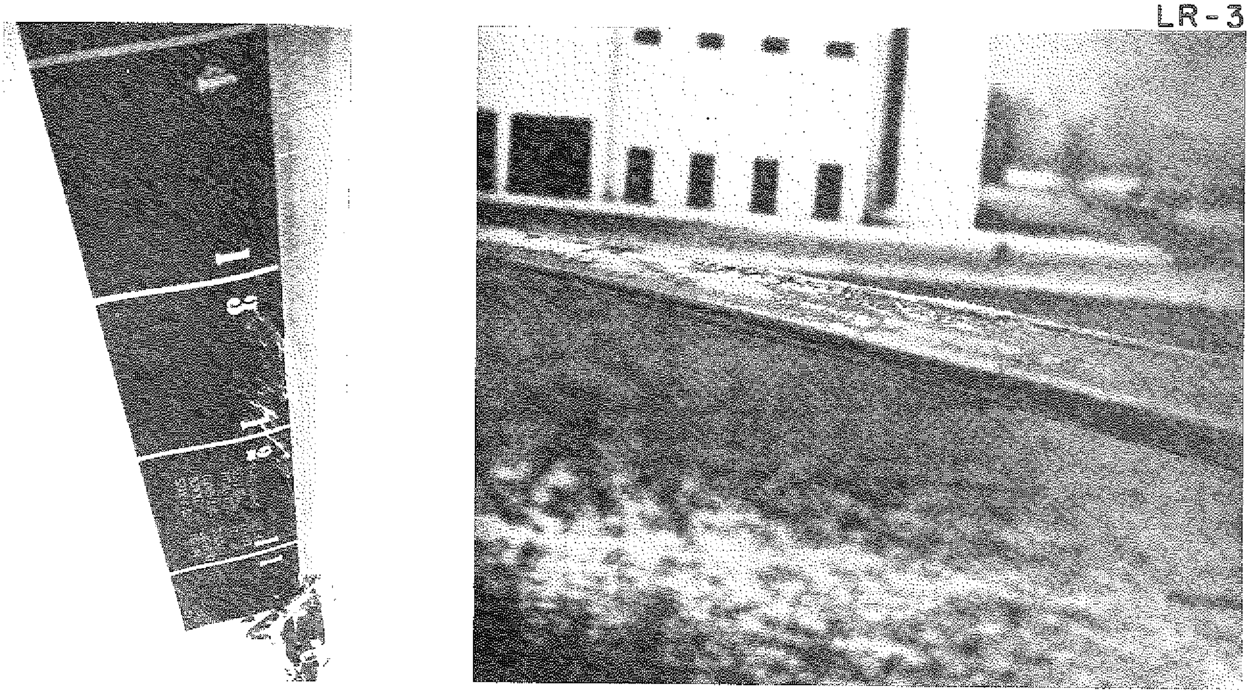
(d) RUN 4-2



(e) RUN 4-1 TIP CAP ICE

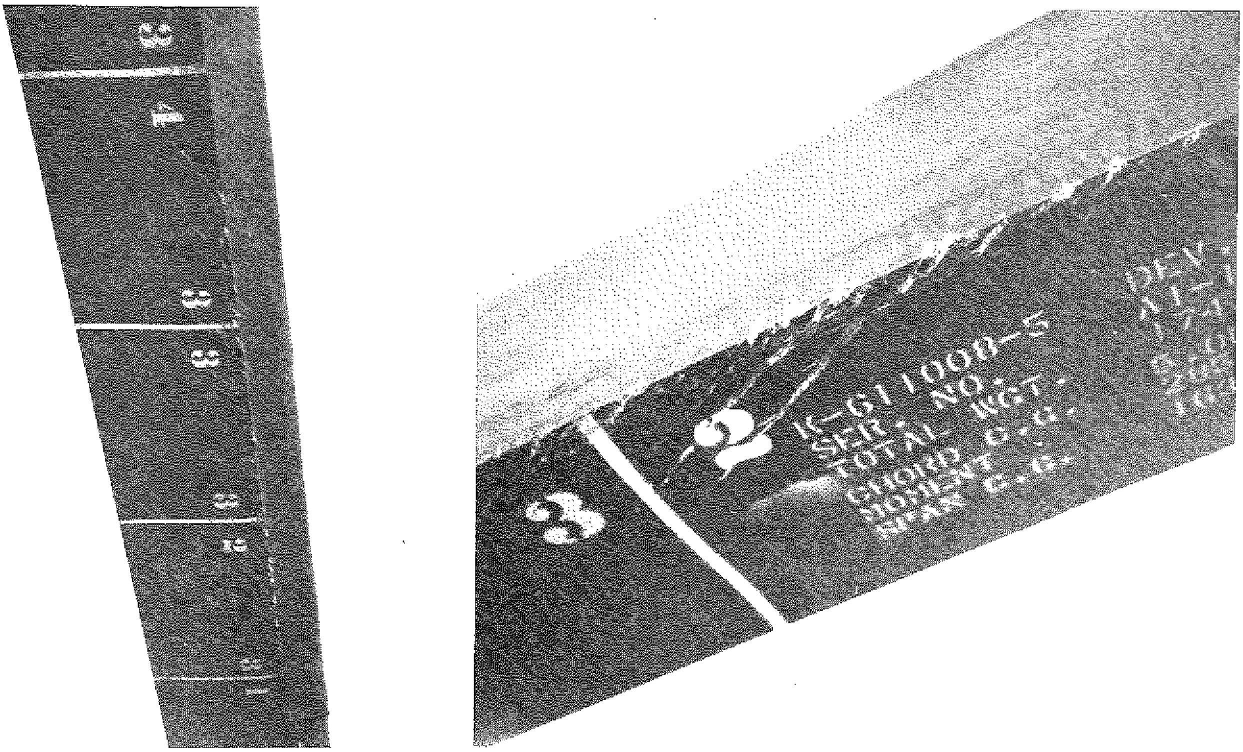
EXAMPLES OF MAIN ROTOR BLADE DE-ICING

FIG. 13a,b
LR-308



(a) RUN NO. 5-4 NATURAL RUNBACK

TEMP. −2.6° C L.W.C. 0.5 gm./m.^{3} TIME IN ICING 15 min.



(b) RUN NO. 7-6 RUNBACK FROM EXCESSIVE DE-ICING ON TIME

TEMP. −3.4°C L.W.C. −0.5 gm./m.^{3} POWER-ON TIME 4 sec.

RUNBACK ICE ON MAIN ROTOR BLADES

NRC LR-308
National Research Council, Canada. Division of Mechanical Engineering.

ICING AND DE-ICING FLIGHT TESTS OF A KAMAN HU2K-1 HELICOPTER.
G.A. Gibbard. May 1961. 22 pp. + 13 figs.

Flight tests were performed in an artificial icing cloud on a Kaman HU2K-1 helicopter equipped with a prototype electro-thermal rotor blade de-icing system. The results of the icing flights showed that icing protection will be required on this helicopter mainly because of icing in the engine inlet and the effects of uncontrolled shedding of ice from the rotor blades. During the runs on which it was tested, the installed main rotor blade de-icing system did not operate satisfactorily under all conditions, and the need for modifications to improve its performance was indicated.

LIMITED

1. Helicopters - Ice formation
2. De-icing systems

I. Gibbard, G.A.
II. NRC LR-308

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ICING AND DE-ICING FLIGHT TESTS OF A KAMAN HU2K-1 HELICOPTER.
G.A. Gibbard. May 1961. 22 pp. + 13 figs.

Flight tests were performed in an artificial icing cloud on a Kaman HU2K-1 helicopter equipped with a prototype electro-thermal rotor blade de-icing system. The results of the icing flights showed that icing protection will be required on this helicopter mainly because of icing in the engine inlet and the effects of uncontrolled shedding of ice from the rotor blades. During the runs on which it was tested, the installed main rotor blade de-icing system did not operate satisfactorily under all conditions, and the need for modifications to improve its performance was indicated.

LIMITED

1. Helicopters - Ice formation
2. De-icing systems

I. Gibbard, G.A.
II. NRC LR-308