EIGHTH EUROPEAN ROTORCRAFT FORUM

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WIND TUNNEL STUDY OF ICING AND DE-ICING ON OSCILLATING ROTOR BLADES

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SUMMARY

Icing and de-icing tests were carried out on a length of a helicopter rotor, in an icing test facility belonging to the Centre d'Essais des Propulseurs (CEPr) at Saclay. The models were oscillated to simulate the cyclic variation in the angle of attack.

The effect of the oscillation on the extent of the impingement area is analysed for several flow velocities. The effect of the velocity, the static temperature, the oscillation, the diameter of the droplets and the liquid water content (LWC) on the resulting shape on the ice is explained.

The representativity of this type of test for icing and de-icing is then discussed. The effectiveness of various de-icing cycles, tested in flight, are confirmed in the wind tunnel.

RESUME

Des essais de givrage et de dégivrage sur un tronçon de pale d'hélicoptère ont été réalisés dans une soufflerie de givrage du CEPr (Saclay). Les maquettes étaient animées d'un mouvement oscillatoire simulant la variation cyclique d'incidence.

L'effet de l'oscillation sur l'étendue de la zone de captation est analysé pour diverses vitesses de l'écoulement. L'influence de la vitesse, de la température statique, de l'oscillation, du diamètre des gouttes et de la teneur en eau liquide sur la forme du givre obtenu est exposée.

La représentativité de ce type d'essai, en ce qui concerne le givrage et le dégivrage, est discutée. L'efficacité de divers cycles de dégivrage, essayés en vol, est retrouvée en soufflerie.

INTRODUCTION

Helicopters today are expected to fly more and more missions of more and more varied types. Manufacturers are attempting to design rotorcraft capable of all-weather flight, and under freezing conditions in particular.

As the experience of fixed-wing aircraft manufacturers in this field is only partially applicable to helicopters, the development and certification of protection systems requires much testing. These tests are mainly carried out on full-scale mock-ups, which makes the tests very long and very costly. The possibility of developing systems in wind tunnels was inspired by this need to reduce costs ; however, experimenting on complete rotor assemblies in a wind tunnel poses a great many technical problems (such as the need to work on a reduced scale) and leads to test costs which are still quite high.

A technique was proposed to maintain the scale of the system to be qualified, while also allowing a major reduction in the cost of the tests. This technique consists of testing a full-scale section of the blade, with the blade oscillating in the same way as the rotating helicopter rotor varies its angle of attack. The initial results from the icing tests (blade not de-iced) and de-icing tests are then explained.

1. TEST PROCEDURE

The tests were run on the R2 icing test facility of the Saclay CEPr. The test stand characteristics are :

- diameter of test duct	550 to 1150 mm
- simulated altitute	from 0 to 9000 m
- maximum speed	from M = 0.4 at ground level to M = 1 at altitudes over 4000 m
- temperature	from - 40°C to room temperature
- diameter of droplets	from 15 μm to 30 μm

A length of blade from the main rotor of the SA330 Puma helicopter, built by Aérospatiale, was used. This sample length was taken from the untapered section (SA 1312) of the blade, with a chord length of 600 m. It is equipped with a Paulstra de-icer.

The set-up shown in figure 1 includes a hydraulic actuator to vary the angle of attack around a mean angle i_o, which can be between 0° and 10°, to attain a moving angle of attack i_1 as great as 6°.

The shape of the ice formation is measured after a rather long icing interval. To compare the forms resulting from the various tests run with different parameters, the duration of the test was determined so that the mass of water passing through a unit section normal to the airflow would be the same each time.

In analysing the test results, a distinction was made between the part of the wetted surface where less than 3 mm of ice was deposited and the growth surface on the leading edge of the blade, where the greatest amount of ice accumulates (see Fig. 2).

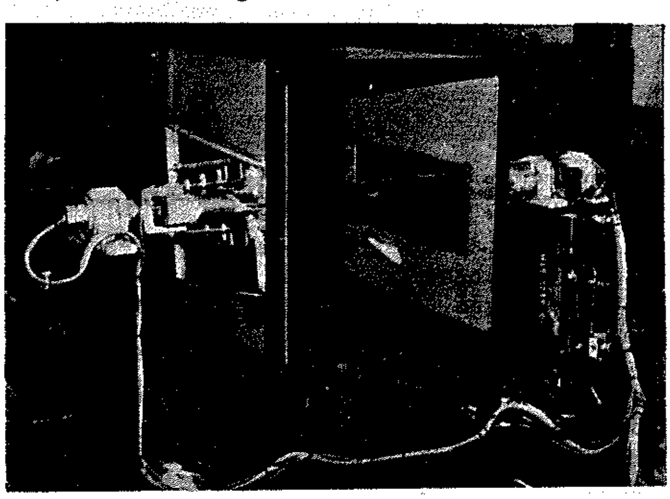


Fig. 1 — Photo of test set-up.

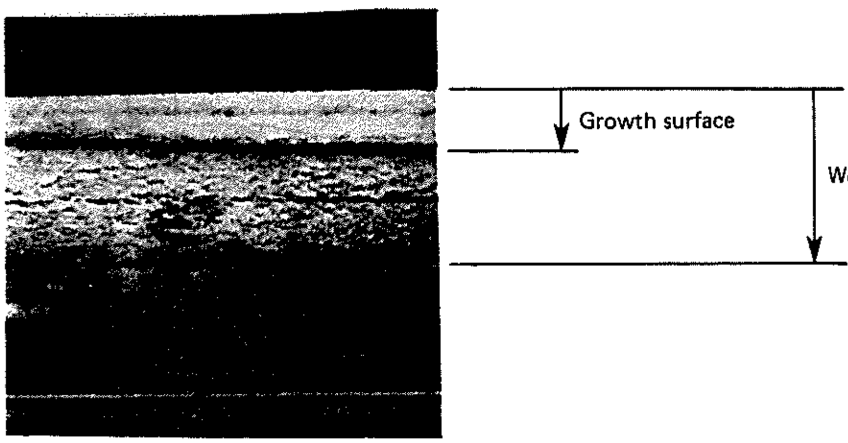
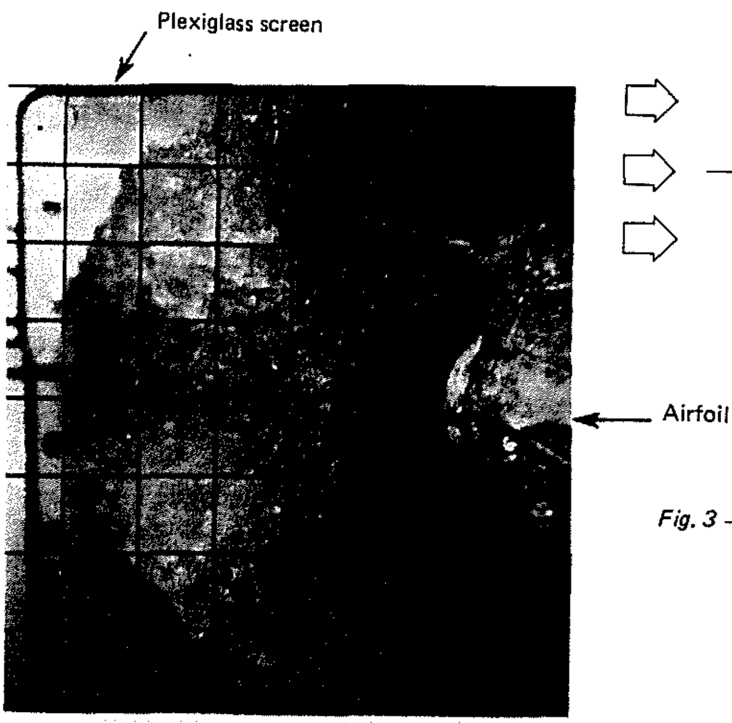


Fig. 2 — Definition of wetted surface and growth surface.

The extent of the wetted area was determined by lines drawn on the blade section, starting at the leading edge.

The geometry of the ice formation was measured by photographing the section through a grid pattern printed on a plexiglass screen (see Fig. 3).



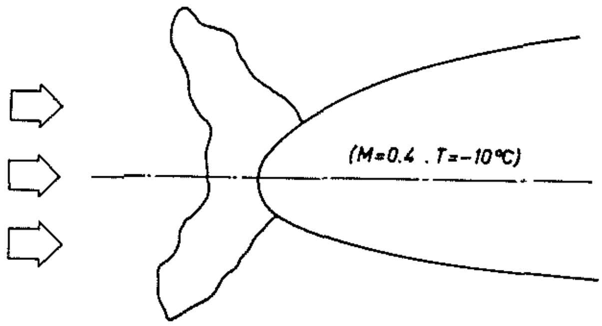


Fig. 3 – Procedure for measuring the ice geometry.

2. REPRESENTATIVITY OF THE IMPINGEMENT TESTS

The shapes obtained at the CEPr on an oscillating section were compared with those obtained from a scale model of the rotor used in the S1MA wind tunnel at Modane (see Fig. 4), where a molded plaster model was used to study the geometry of the ice.

The test conditions comply with conventional rules of similitude (see reference 1). The speed indicated for the rotor is the maximum speed (advancing blade).

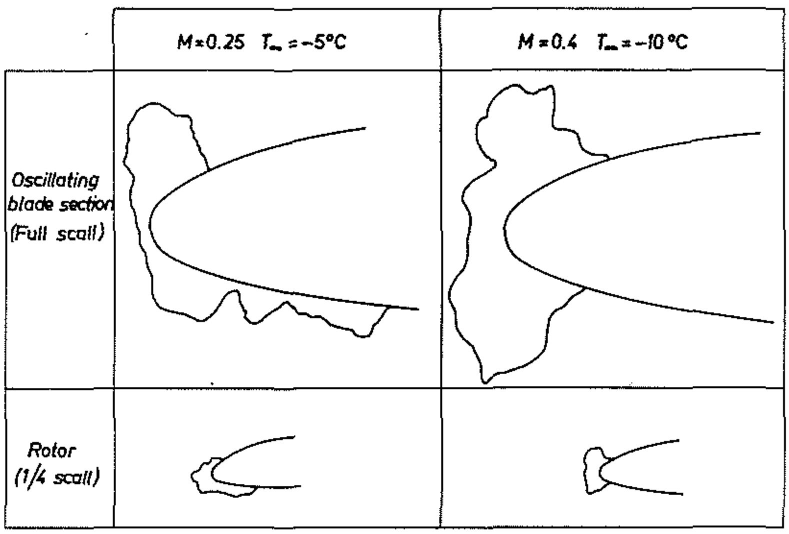


Fig. 4 – Comparison between shapes of ice forming on a rotating rotor and on an oscillating blade.

The comparison shows that the appearance shape are very similar in the two cases. It therefore seems that the centrifugal forces do not have a decisive influence on the shape of the ice deposit, and that the growth of ice on an oscillating section therefore provide a rather close simulation of those obtained on a rotor.

3. STUDY OF PARAMETERS INFLUENCING THE SHAPE OF THE ICE

3.1 Wetted surface

The effect of the oscillation, at various velocities, on the extent of the wetted surface was studied with droplets of a constant 20 µm diameter.

Figure 5 shows the algebraic sign convention for the angle of attack.

The angle of attack of the section is $i = i_0 + i_1 \sin \omega t$. The maximal angle of attack is $i_0 + i_1$ for the lower surface and $i_0 - i_1$ for the upper surface.

Figure 6 shows the extent of the wetted area as a function of the maximum angle of attack for Mach 0.25.

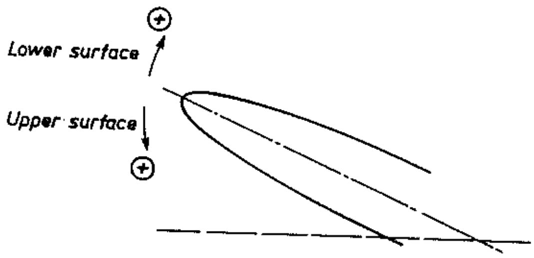


Fig. 5 — Definition of angles of attack for the lower surface and upper surface.

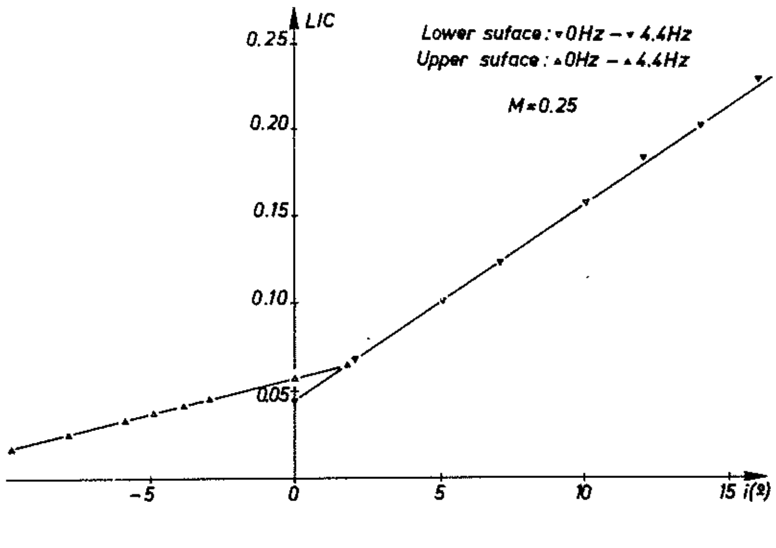


Fig. 6 a) — Extent of the wetted surface as a function of maximum angle of attack.

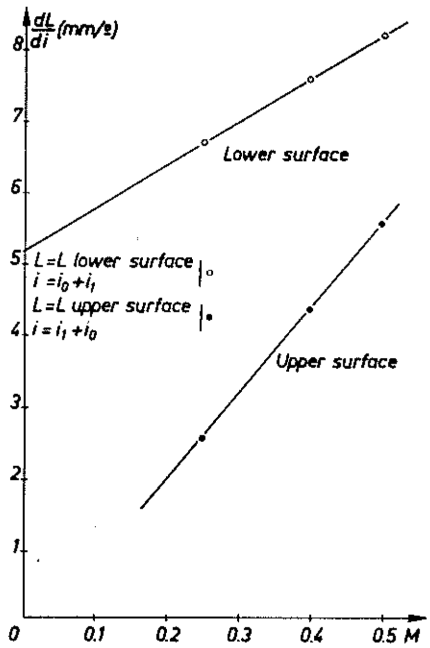


Fig. 6 b) — Variation in wetted area at maximum angle of attack, as a function of speed.

The following observations can be made :

- The extent of the wetted surface varies linearly with the maximum angle of attack of the section (following the sign convention given above), for each velocity.

- The results obtained with an oscillation of 4.4 Hz perfectly match those obtained without oscillation (zero frequency).

We can conclude from this second observation that the wetted area can be determined by means of relatively simple computation codes, since the oscillation does not seem to induce any perturbations.

3.2 Effect of velocity on the ice growth

The velocity of the airflow has a decisive effect on the shape of the ice. The stagnation temperature increases with the velocity, and this reduces the proportion of water that freezes in the stagnation area. This in turn increases the runoff, which gives rise to a horn-shaped ice growth which becomes more flared as it becomes more pronounced (see figure 7).

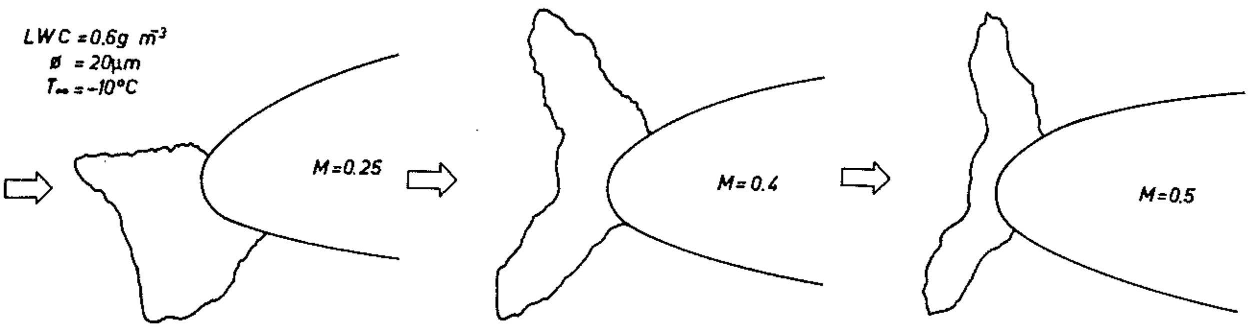


Fig. 7 – Effect of velocity on the geometry of the ice growth.

3.3 Effect of static temperature and liquid water content on the shape of the ice

Figure 8 shows the similar effect that an increase in static temperature and liquid water content have (the test duration for water content increase, was reduced so that the masses of the ice would be comparable). In both cases, the horn shape is much less pronounced and the ice growth is bulkier, extending farther behind the leading edge.

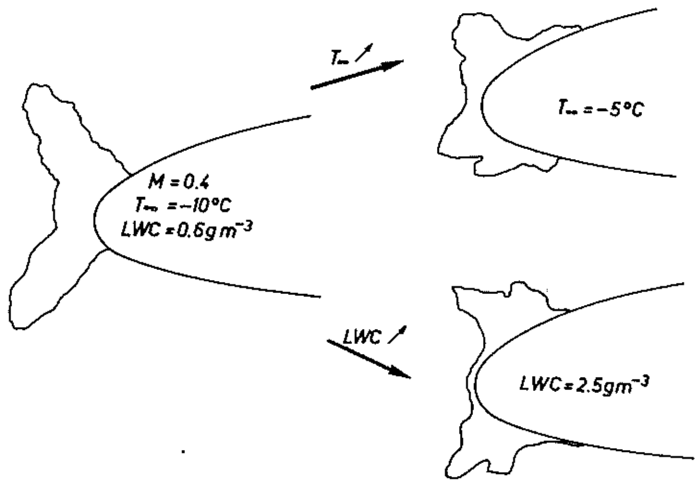


Fig. 8 – Effect of static temperature and liquid water content.

3.4 Effect of droplet diameter on the ice geometry

The larger the droplets, the less they are deflected and the greater the mass of water impinging on the test body. This results in a less pronounced horn shape and a growth extending farther behind the leading edge (see Fig. 9).

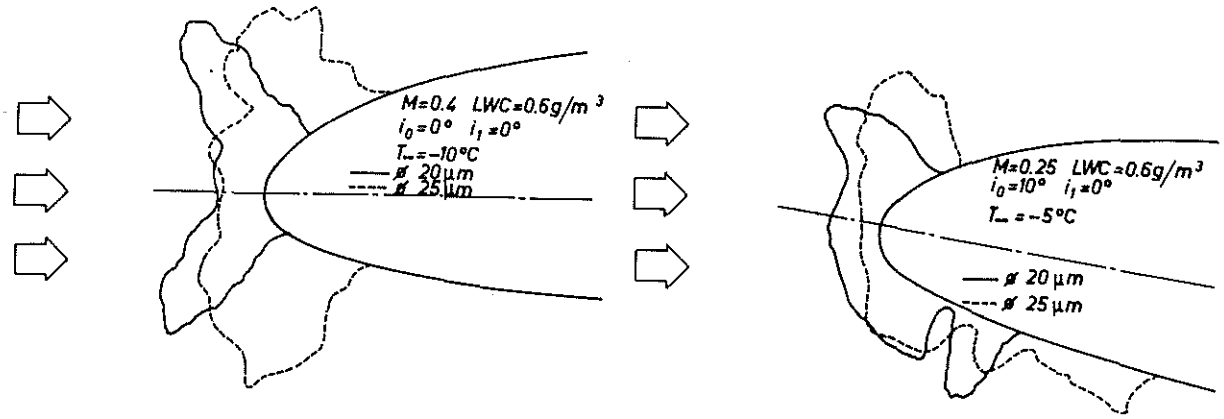


Fig. 9 – Effect of droplet diameter on the ice geometry.

3.5 Effect of the amplitude of the oscillations

When the ice forms at leading edge, the amplitude of the oscillations has practically not effect on the ice geometry. This is because the block of ice intercepts the droplets and protects the area behind the leading edge, without affecting the local thermodynamic conditions. This means that the distribution of the ice is the same in all cases (see Fig. 10).

On the other hand, if the icing conditions are such that the leading edge remains more or less clear (such as when the static temperature and the rate of airflow are high) the ice grows farther away from the leading edge as the amplitude of the oscillations increases (see Fig. 11).

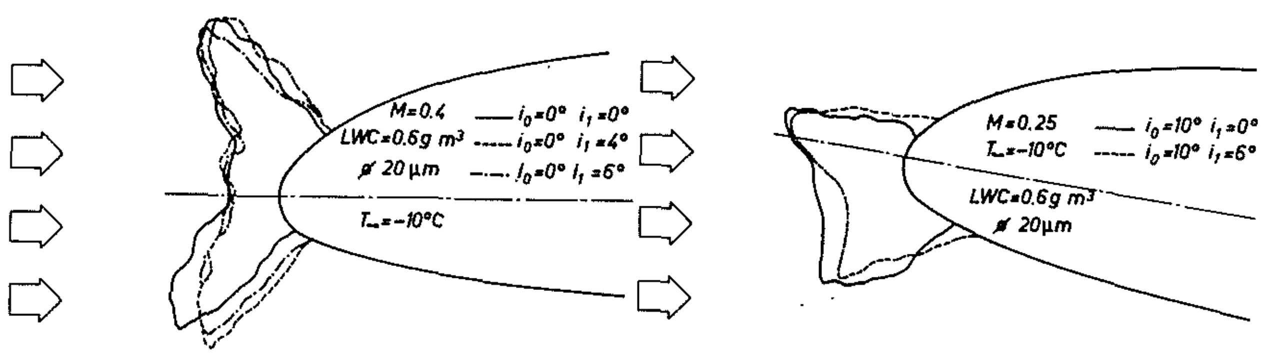


Fig. 10 – Effect of the amplitude of the oscillations.

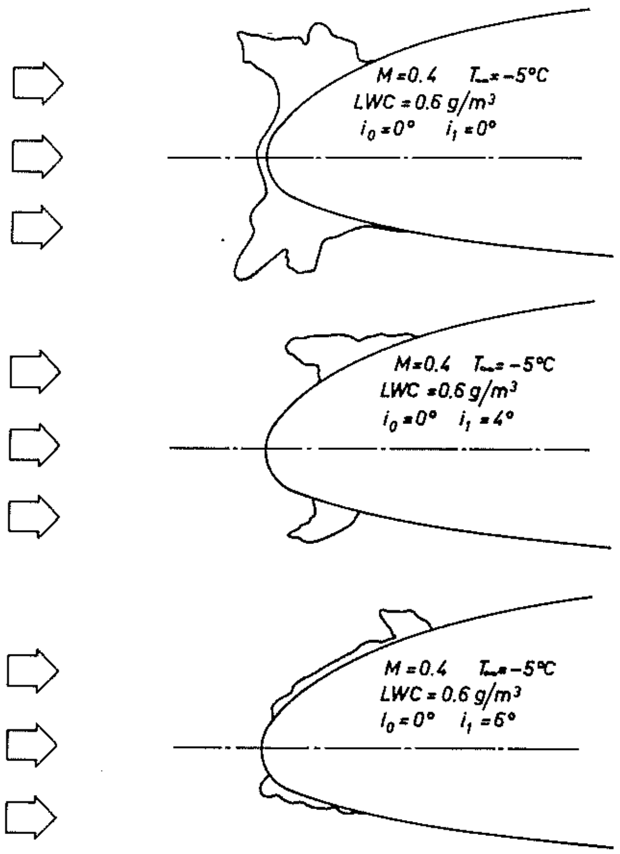


Fig. 11 — Effect of the amplitude of the oscillations.

3.6. Conclusions

The parameters modifying the ice geometry are the same as those affecting the thermodynamic balance at the blade surface, allowing more or less water to run off locally. These parameters are mainly the static temperature and the rate of airflow. If these two factors modify the equilibrium, they nonetheless do not act in the same way. The rate of airflow affects the balance at the stagnation point but the liquid portion solidifies relatively fast and this explains the horn shape. If the static temperature is higher the liquid portion solidifies more uniformly over the leading edge of the test body.

The effect of increasing the water content and, to a lesser extent, the diameter of the droplets, is similar to the effect of the temperature.

The oscillation has a major effect on the ice geometry when the ice formation is reduced in the stagnation area (high stagnation temperature). Otherwise, it has little, even negligible effect.

4. REPRESENTATIVITY OF THE DE-ICING TESTS

Flight tests carried out on the Puma (SA330) showed that the de-icer heating sequence needed modification when the static temperature was less than - 10°C. Below this temperature, the heating strip on the leading edge has to be supplied twice during heating cycle ("severe" cycle) to maintain acceptable flight conditions (see reference 2).

This need to modify the cycle at temperature below - 10°C was confirmed during the tests on the test blade, whether oscillating or not. Figure 12 shows that the skin temperature measured at the leading edge is negative, during half the cycle if a "normal" cycle is used, while it always remains positive if a "severe" cycle is used.

The tests show that the same quantitative results are obtained as in flight, and that the use of a length of blade is representative of a rotor, as far as de-icing itself is concerned. The ice is lifted off only when a sufficient film of water is set up between the ice and the blade structure. Producing this film of water is a purely thermal process which does not depend on the stress applied to the ice.

On the other hand, a difference appears if the test is prolonged. During de-icing, the melted ice water runs along the blade contour and solidifies beyond the protected zone. This refreezing has not been observed in flight.

Figure 13 shows clearly that if the leading edge is cleaned off during a heating cycle, the melted ice water is completely unaffected by the heating cycle and runs back to form ice on the trailing edge.

The tests nonetheless allowed various de-icing cycles to be tested.

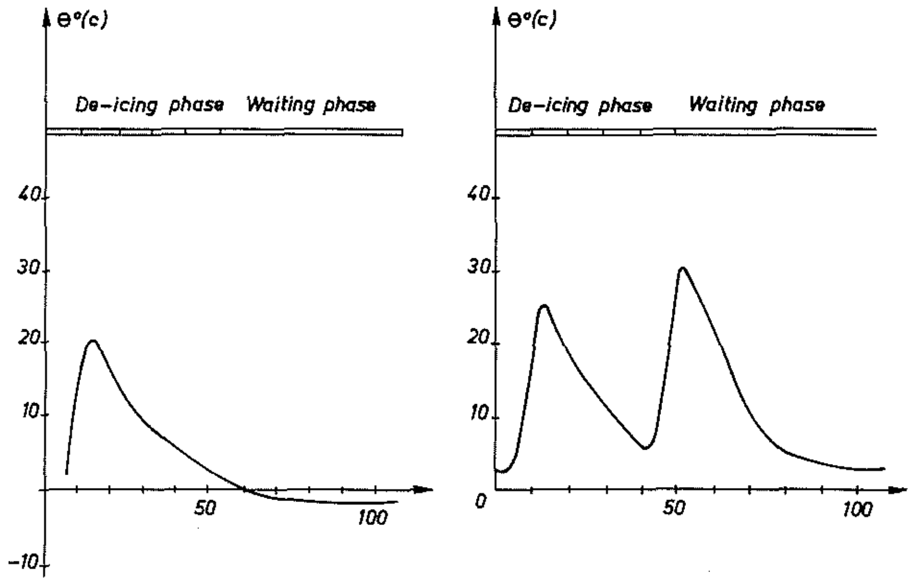


Fig. 12 – Skin temperature variations at the leading edge during a de-icing cycle.

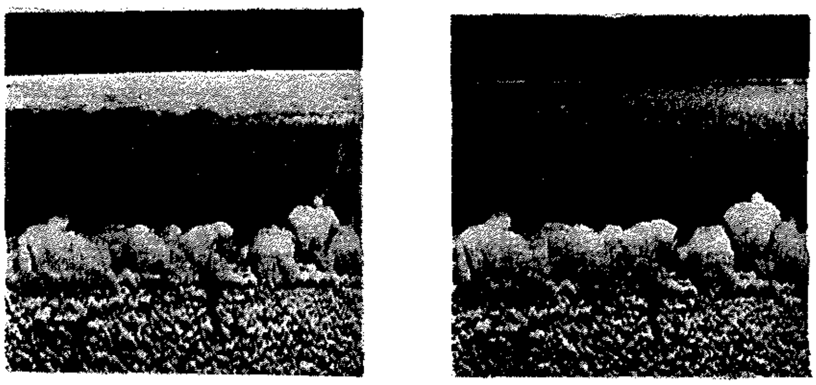


Fig. 13 – View of the contour at the beginning and end of the de-icing cycle (de-icer operating for 10 min.).

CONCLUSION

The tests carried out at the CEPr in Saclay showed that an oscillating length of blade satisfactorily represented a rotor insofar as the impingement and geometry of the ice were concerned.

The oscillating movement has an effect on the extent of the impingement, but very little on the resulting shape of the ice formation or on the de-icing process. In particular, this test technique provided a low-cost means of studying the influence of various physical parameters on the shape of the ice. As far as de-icing is concerned, the effectiveness of the flight-tested cycles is not consistently demonstrated on the oscillating blade section. However, a re-freezing phenomenon appeared downstream of the protected zone, and this had not been observed during flight tests. This must be due to the absence of centrifugal forces, vibrations or cyclic distortions of the blade. The presence of this phenomenon does not annul the validity of the tests, as the effectiveness of the de-icing can nonetheless be studied ; but it does limit the duration of the tests and the number of heating cycles.

Additional research is needed to improve the quality of this type of simulation while maintaining its advantages : flexibility, low cost and simple instrumentation.

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[2] J.C. Lecoutre - Protection systems against icing on the Puma - Symposium on Helicopter icing, NATO Army Armaments Groups Panel X, London, November 1978.