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HELICOPTER ICING
A PROBLEM TO BE DEFINED

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1. Nearly every paper on helicopter icing starts with the same series of statements. Icing affects the engines by icing intakes, which then block or cause ice to be injected to damage the engine. The ice affects the rotor by increasing drag to the point of the limit of engine and gearbox power and to render the rotor incapable of maintaining auto-rotation in a powered off descent. The flight envelope is seriously reduced and, lastly, ice affects weight and center of gravity. Sometimes secondary intakes and aerials and the transparency of windscreens are affected.

2. The fact that after more than 10 years of intensive effort only windscreen problems can be struck off the list shows that there is something seriously wrong with the approach to the problem of helicopter icing. To a representative of the Military, who are asked to pay the bill for much of the Research and Development work, this is a serious situation. I suggest that it is the result of not really defining the problem of icing before proposing a solution.

The Rotor

3. Let us consider the helicopter rotor. Proposed solutions to rotor icing are numerous: cyclic heating of the leading edge, de-icing fluid, induced vibration, pastes and the use of flexible substrate to induce shedding (Reference 1). All these have their attractions and disadvantages but they are all the suggestions of mechanical, electrical or chemical engineers. Nowhere do we see a specification, which has been set out by the aerodynamicist or the rotor designers, as to the amount of degradation that the rotor will tolerate.

4. This is surprising. I am attracted to the visualisation of the advance of rotor design whereby the major and minor axes of a graph display the degrees of freedom of aero-dynamics and structural elements. The advances are made by pushing back the boundary at various point towards the complete understanding of the mechanics of the rotor system. The whole point of

this advance of course is to enable the rotor to be designed to greater efficiency. This by definition means less redundancy. Again, by definition then, new rotors in their pure form will become less and less tolerant to degradation, unless they are specially designed for the purpose.

5. These dangers have, by coincidence, been recognised in some work which has recently been done by the Royal Aircraft Establishment in UK (Reference 2). This shows how performance of the rotor of the Wessex (S58 type) is degraded when the blades are roughened. In the test a 25 mm wide tape was stuck to the leading edge of the blade, covered with particles of less than 0.3 mm diameter grit. The tape was placed on the outer 1.5 metres of the rotor blade span. The effect of this degradation was that the speed at which critical control loads occurred was reduced from 117 to 72 kts. This work was merely aimed at investigating the effects of erosion. The task of simulating the effect of large growths of ice, which we can predict to be up to, say, 25 mm thick, has not been seriously addressed. The need for work in this area has now been recognised in UK but, short of letting experimental flight test crews continue to fly around with unknown quantities of ice on their rotors, no actual research has been done. New rotor sections now being proposed promise advances in both structural and aero-dynamic performance but until we know how these respond to a degradation of their section it will be impossible to judge whether the work should be pursued.

6. An understanding of this degraded performance is also needed if a protection system is to be designed and proven. This is highlighted by the fundmental concept of electrically de-iced rotor systems. All these systems depend on building up ice on the surface of the blade. The surface of the blade is then heated, this breaks the bond and the ice sheds. As I have said work has not yet been done to establish just how much ice can be built up tolerated but, further than this, the stated principle of these systems is that un-iced surfaces are not heated because, if they are, run-back ice is bound to occur. But all current systems, because they are all controlled either on a strict time cycle or very crude measuremet of ice build, take no account of the non-homogeneity of cloud through which the helicopter is passing. Heating of un-iced surfaces is therefore bound to occur. No work has been done to estimate the tolerance of the rotor to this run-back ice and no method is even available to measure the extent of the problem in flight.

7. During the work on unprotected rotors we in UK (Reference 3) have seen rates of torque increase of 100% a minute. This rate will saturate any ice system so far specified. This has often been borne out by the results of systems which have so far been tested in the natural environment. The design engineers seem always to respond to a failure of their de-icing system to cope with a condition encountered on a test flight by proposing a change in heating time in the de-ice cycle or the heating intensity but, even the most cursory study will show that their systems will not protect aircraft from the occasional high torque rise being experienced. The risk of this happening and the consequences need to be quantified.

The Weather

8. Let us move a stage further in to the realms of the unknown. To the understanding of the weather conditions. Now, weather forecasting is an inexact science but where low level icing is concerned the situation is serious. If we suppose that we cannot use our existing rotor systems to allow routine operations through ice then we need to be able to avoid the conditions by forecast or detection or, at the least, to be able to estimate the level of risk if an aircraft is permitted to operate without full protection.

9. We are not able to do this. Extensive experience on icing trials has shown that conventional forecast methods do not form even a basis for the short or long term planning of icing encounters. By analogy the forecast cannot be considered to be a reliable tool for avoiding icing in routine operations. We are then presented with a problem of avoiding the condition. The radar scientists have said that droplet size of an icing cloud makes it unsuitable for short range detection, while the current atmospheric sampling devices do not detect the right characteristics quickly enought to allow avoiding action to be taken in a time-scale acceptable to a civilian air traffic control organisation.

10. The estimation of risk is fundamendtal to the whole current dilemma of certifying authorities. Because of the lack of knowledge of the type and frequency of icing conditions, coupled with an inability to predict the effect of these conditions on rotor performance, there is at present no way of quantifying the risk of an incident or accident being

suffered by a helicopter performing routine operations. Without this information certification is relegated to guesswork, when we have come to expect it to have a scientific base.

The Engine

11. The situation of engines is somewhat better in that at least the mechanism of the icing problem is better understood. The stand taken by the USA that helicopter engines should in future have an integral Foreign Object Filter and be tolerant to the ingestion of solid objects, is a step in the right direction. I have not seen what tests are to be carried out to ensure that these filters will not generate their own ice and snow problems.

12. The systematic study of the intakes filters and the conditions downstream of them is not yet possible because there is no test cell in the world which will simulate the whole range of mixtures from ice, snow crystals and free water. As well as these effects there is the need to reproduce slow and rapid changes of temperature around zero degrees centigrade so that the run-back refreezing and internal shedding characterisitcs can be studied.

Certification Problems

13. Reviewing this catalogue of unknown factors, it may seem that the scene is one of unmitigated gloom. This is not quite true because at least is is possible to write down a reasonable list of actions which have to be taken before we will be able to give a helicopter clearance to fly in continuous icing. I think that the UK is now approaching the point of having a fair idea of what needs to be done.

14. The point, which should be obvious to the internationalists, is that there is a real danger that national organisations will embark on particular programmes which will overlap in some areas while leaving some others uncovered. From a scientific point of view this is unfortunate. From the practical point of view it will be disastrous.

15. A trend can already be discerned where project managers have been commissioned - or taken upon themselves the commission - of providing a release for the clearance of a particular helicopter to fly in icing. The programme is laid out - usually to show a 3-year timescale - and the activity sets off with a confident step. The prototype hardware for blade and engine

protection is produced and a trial is arranged. It is only after this point that the problems begin. This is when the trial is complete, the test results have to be analysed and recommendations have to be made. All the unknowns come together and the engineer is presented with a great dilemma: should a clearance be given, with a risk that a helicopter will suffer a serious incident or accident when it needs an untested condition or, should the whole project be put into the "Too Difficult" category and cancelled. Engineers are loath to recommend this latter course because it gets their subject the reputation of being a failure. In these days of financial constraints this is an unwise move. The result is usually a certification which is not really usable but which is given with a promise that one more year's testing will provide the unlimited release required. In this way projects can dribble on, keeping engineers employed but doomed to failure for lack of a scientific base.

16. I do not accuse anyone of dishonesty. There is a genuine desire to solve the problem. Maybe there is a realization that the sort of scientific effort needed to obtain a release, to the confidence levels normally associated with aircraft certification, is outside the budget of an individual helicopter project. The best must be made of the resources available, the argument goes.

17. The danger is that pressure from programme management can wear down the engineer until clearances are given on insufficient evidence. It is worth pointing out that, conventionally we talk of risk levels of 10^{-5} or 10^{-6} in certification work. Experience of 20 individual flights in good icing is typical of a whole season's testing. When the number of variables which have to be covered in flight and meteorological conditions are considered it can be seen that a reasonable statistical base is almost impossible to achieve.

18. Problems will inevitably occur where there is an attempt to carry certifications across national boundaries. In my experience, while certifying authorties are sometimes prepared to compromise standards in the cause of national projects (where they are also in charge of the operating procedures of the customer) there is a positive reluctance to lower the standards when underwriting foreign certifications.

Problems to be Addressed

19. These then are the problems as I see them: the technical problems of defining just what the rotor and engines will tolerate, the meteorological problem of defining what low altitude ice and snow really is, the international problem of defining what risk levels are to be accepted, the international problem of laying down what evidence is needed to satisfy certifying authorities and, lastly, the international problem of providng the scientific and engineering data to allow rational analysis of test results.

20. It is the latter programme which is the most pressing because without a scientific base the other work is of little use. Indeed it can be said that action in the absence of good scientific tools and knowledge is positively harmful because it will lead to programme failures, which will reinforce the already bad reputation that helicopter icing has amongst scientists, engineers and financiers. These days, if a programme is to survive scrutiny, there has to be a clearly defined need to the programme has to be soundly based. On an international scale I feel that, on both counts, helicopter icing is a subject which is least able to tolerate close scrutiny. The problem has yet to be defined.

Reference 1 J H Sewell. Ice shedding from surfaces by vibration induced flexing. Royal Aircraft Establishment Technical Report 75051.

Reference 2 P Brotherhood, D W Brown. Flight measurements of the effect of simulated leading edge erosion on helicopter blade stall, tortional loads and performance. Royal Aircraft Establishment Technical Report 66039.

Reference 3 J Bradley, H B Lake. The problems of certifying helicopters for flight in icing conditions. Presentation to the Royal Aeronautical Seciety, London, 26 November 1975.