Discussion

The **Chairman,** who congratulated Mr STALLABRASS on his excellent paper, said that the earliest experience of helicopter icing he could remember was on the Sikorsky R-4, early in 1944, just before it left Bridgeport on its first trans-Atlantic crossing to England A sudden loss in performance was quite a mystery at the time but eventually it became evident that the cause was carburettor icing The Author had not mentioned engine icing at all in his paper, presumably because it was not particularly a helicopter problem

Probably, that was also his reason for not referring to the possibility of icing in gas turbines It might, however, become a helicopter problem if and when these units were situated at the blade tips, as had been suggested and as one day might be the case

One wondered whether the shape of the secreted ice on the blade was merely random or whether there was an analogy to what happened at hypersonic speeds It was understood that meteorites, no matter what their shape might be initially, always became conical , they melted because of kinetic heating at such high speeds until their shape conformed with that of the Mach cone This could easily be simulated in a wind tunnel When ice, of any shape, was placed in a supersonic airstream, it melted away until it took the shape of a cone

What happened at subsonic speeds? With kinetic heating, there must be a Mach number effect, but was it relatively of little consequence? There might be other aerodynamic effects which could perhaps be simulated in a wind tunnel enclosed in an ice-box as the Author had described At Princeton University there was similar equipment with which Professor Nikolsky had conducted tests No doubt there was a periodic sweep-back effect as the blades went round the circle The Author had *mentioned cyclic de-icing, but perhaps cyclic icing had its own peculiar features*

Although some of these questions could be investigated with models, perhaps scale effect would be so important in regard to icing that model tests might be unreliable

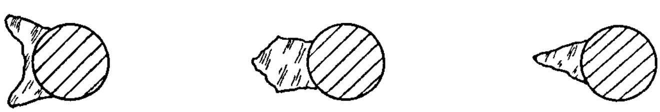
The **Author** replied that in regard to the shape of the icing, Mr Tom Dickey, formerly of the U S Navy Bureau of Aeronautics, had written a paper (see Ref 9) discussing the effect of various parameters on the shape of an ice accretion In general, that discussion applied to the shape of ice accretions on most bodies after a certain time The shape of the body determined the initial shape of the ice accretion, but there was an eventual final shape rather like the meteorite outcome

The primary variables were the temperature, the speed and the icing severity These three factors primarily determined the final shape that the ice accretion would take and whether, for example, it was of a mushroom, spearhead or knife-edge shape These terms were probably not familiar to anyone not connected with icing, so a brief discussion of them would probably be in order Consideration would be confined to the case of a cylinder

At higher temperatures not all the water would freeze where it impinged, but some of it would run back away from the stagnation area and freeze on either side producing the mushroom shape of formation In the extreme case no water might freeze at all on the leading edge, but might run back and freeze in ridges further back

At somewhat lower temperatures more of the water would freeze in its area of impingement, what water did flow back would produce a broadening of the accretion resulting in a spearhead shaped ice formation

At low temperatures all the water would freeze in its impingement area resulting in a knife-edge accretion



MUSHROOM SPEARHEAD KNIFE-EDGE

These three classifications (which are illustrated in the above sketch) may be defined by reference to the value of the freezing fraction The freezing fraction is *that fraction of the deposited water which freezes in its immediate impingement area,* and may be calculated from a knowledge of the heat transfer processes at the icing surface The mushroom formation occurs when the value of the freezing fraction lies between zero and a somewhat arbitrary " critical " value Spearhead icing occurs when the freezing fraction lies between its critical value and unity In both these regimes, since free water is present, the surface temperature is zero The third classification, knife-edge ice, is produced when the freezing fraction is unity, the ice surface temperature being at or below zero

It was therefore possible to predict, if the conditions were known, roughly the final shape the ice would take up

The **Chairman** Does that apply to the shape close to the stagnation point?

The **Author** The shapes illustrated apply only if we have no circulation Fig 5 shows how these basic shapes may be modified by circulation

The **Chairman** suggested that the symmetrical shape of the secreted ice was perhaps responsible for practically no change in the lift coefficient It was at one time thought that on the formation of ice, provision must be made for a change of blade angle to compensate for the change in lift coefficient, but it appeared from the paper that there was substantially no change This was probably due to the absence of flap effect at the leading edge with ice of symmetrical shape

The **Author** replied that it was probably due to the way in which the ice built up, but he could not state definitely

Mr D Rendel (*R A E*), said that he could not add much to what the Author had said about the way in which ice formed on aerodynamic surfaces The answer to the point about the ice forming cones and the heating effects of the aerodynamics was that the ice was much more sensitive to temperature than anything else Therefore, the air flow over the ice was not a critical factor In addition, the ice would normally take up a position on the aerofoil where it was stable aerodynamically and one would therefore expect it to have little effect on the aerodynamic coefficients , but since it swelled out, because it did not all freeze straightaway, it would obviously increase the drag due to the breaking down of the flow over the rear surfaces

Dr G S Hislop (*Fairey Aviation Co*) (*Member*), said that he had been associated with the design of an anti-icing system Obviously, one of the big criteria would be the weight and power involved, whichever system was adopted One of the earlier slides shown by the Author gave a significant variation from root to tip of the ice accretion Was there enough confidence in that result to make use of it in the design by varying the distribution of the heater pads accordingly?

In the aircraft in which Dr Hislop was particularly interested, it would appear from the details given by the Author that the order of power required was from 30 to 50 kW This was a lot of power but it was not far off some early estimates by Fairey Aviation Company , however, there was a great deal of difference between 30 and 50 kW The generator and cable sizes and weights would go up and the choice of the system would depend very much on the weight estimates Was it possible to save weight by exploiting this characteristic of varying the intensity of heat with blade radius

Speaking of the question of unsymmetric self-shedding, Dr Hislop said that when this conception first became known some years ago, he was frightened of it He imagined hunks of ice flying off and the helicopter beginning to shake even more than usual Was a small helicopter rotor likely to be more sensitive to asymmetric self-shedding of the kind normally experienced than a big diameter rotor?

Had the Author made an overall weight estimate and a power estimate for so equipping, say, a typical present-day helicopter of the S55 or the Bell type?

Mr Stallabrass replied that he had not himself made a detailed weight estimate but there were one or two instances that he could quote A study had been made

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of an electro-thermal de-icing installation for the Sikorsky S58 and the overall weight of the system was in the order of 125—130 lb , using a 20 kVA alternator This covered the complete system, including alternator, alternator controls and automatic controls for de-icing the main and the tail rotor

On the question of the small or large rotor blade, the " g " forces had a great deal to do with the relative susceptibility to self-shedding and, therefore, unbalance It would appear to be the case also that the smaller rotor was prone to greater asymmetry of self-shedding, although the reason was not known

Dr Hislop asked whether the variation in ice build-up could not be exploited

The **Author** replied that in a de-icing system the rate of icing was of little consequence as compared with an anti-icing system All that one tried to do was to melt the interface of the ice sufficiently to reduce the adhesion The weight of the ice would have some effect and, therefore, the thicker the ice, the more readily it would throw off , but the AUTHOR thought that a better approach would be to make use of the variation of " g " forces along the blade By reducing the power density at the tip and grading the power density along the blade having a higher power density at the root end the " g " forces could be used to remove the ice more efficiently

Dr Hislop asked whether that was an entirely practicable design approach at the moment or whether it was better to keep it uniform

The **Author** replied that with the N R C method, in which the span was split up into a number of segments, the power density could easily be varied In the strip method, however, it would not be quite as easy

Mr D L A Hand (*D Napier & Son Ltd*), referred to the Author's remarks stressing the importance of control systems in minimising run-back It was known from fixed wing experience that run-back ice formations could be quite serious The Author had referred to tests, in which it was known that temperatures well below 0°C were obtained Did he have any experience at temperatures in which there was a marginal condition, such that ice just formed? Usually there were large water concentrations at these temperatures and therefore the run-back problem was most serious

Did the Author consider that there was need for a secondary area in the system —*i e*, an aft area, not heated during the normal cycle, so that run-back ice could form on it and be shed subsequently, say after a few complete cycles?

There was a possibility with rotors, that due to centrifugal forces there would be large run-back formations outboard on the blades As with fixed wing, run-back would tend to move chordwise, but would also be thrown outwards so that quite large ridges could form towards the tips

The **Author** replied that run-back was, of course, more serious on a rotor blade because of the smaller scale than on a fixed-wing aircraft Experience showed that run-back had not been produced during shedding outboard of about 50 per cent of the span It was not possible to give an exact reason for this, but it appeared, therefore, as if it happily disposed to a large extent of the run-back problem

To a large extent, the run-back which had been observed was produced by the melting of the frosty secondary formation which was formed more on the inner part of the blade than towards the tips, where it was probably blown off either because of the higher speed or because of the higher kinetic temperatures at the tips In general however, the frosty formation contributed mostly to the run-back

At the marginal temperature conditions mentioned by Mr HAND, fortunately the kinetic temperature at the tip of the blade was sufficient to prevent any ice formation at the leading edge in this region Again, under these conditions, there had not been any experience of long diagonal streaks of run-back forming when there was no ice on the leading edge Although small amounts of run-back ice had formed at different places, it had never been observed to cause large ridges of ice

It did run back diagonally in long streaks at the inboard end of the blade, but, fortunately, it was not too serious aerodynamically in this region

Mr Rendel, who referred to the question of marginal conditions, said he was not clear what were the requirements to which the Author suggested that helicopters should be protected The question arose also from Dr Hislop's remarks For example, if protection was being provided only to reasonably high temperatures, it might be found that the choice between the various systems and the various means of protection was different from what was done at low temperatures

The helicopter was a vehicle which would have different encounters with ice from a fixed-wing aeroplane , they might not be so severe, but they might be of longer duration Furthermore, the helicopter was a vehicle which was obviously localised in its activities and it could, therefore, be protected for the particular geographical area in which it happened to be operating If the Author had any information about it, a word on the relative merits of short-term and long-term protection at different temperatures would be useful

In reply, the **Author** said that he was not in possession of too much information As yet, of course, helicopters had not been deliberately flown in icing conditions or in missions on which they had encountered icing conditions, so that statistically there was not yet enough information on which to lay down any requirements They might, however, be less severe than for the fixed-wing aircraft

In Canada—but probably not in Britain—icing might be expected at low altitudes down to —20 deg The liquid water content was probably no greater than about ½ grm per cu meter, so that design requirements would probably be less severe than in the fixed-wing case

In a number of instances, the operations of the helicopter might be localised, but, unfortunately, the Navy was not quite so stationary The Navy was perhaps the most worried of any of the Services, because it was operating over the briny instead of over dry land This meant that flights in icing by naval helicopters might have to be of longer duration with no chance of making an emergency landing

Captain J A Cameron (*British European Airways*) (*Founder Member*), who congratulated the Author on an excellent paper, said that B E A had had an experience of main rotor icing, probably the first in Europe, on two helicopters, six years ago The machines were flying in formation and were bound for Amsterdam Captain Crewdson was flying one, and he had flown the other

The experience was interesting , it happened not in cloud but around the outskirts of a heavy snow shower The helicopters were both forced to make landings, but being helicopters, they were able to effect these without damage The ice accretion on the main rotors of the machines made it impossible to hover before touch-down

It should not be thought that there is any great danger flying single-engine helicopters over land without any de-icing equipment Pilots have two things to watch when icing conditions prevail, and these are

(*a*) To fly in such a manner so that the machine is routed over terrain on to which a successful forced landing can be made Good pilots of single-engine helicopters always do this in any case, and

(*b*) By continuously moving all the controls to prevent their freezing up

The problem faced by the Navy was, of course, different Constantly flying over the sea, they stand a chance in winter of losing men and equipment because of the lack of any anti-or de-icing facilities

B E A were now doing a considerable amount of cloud flying in preparation for multi-engined equipment Because of this they were having the same problems as the Navy He said it was good to know that work was being done to overcome the problem

Mr Shapiro (*Consulting Engineer*) (*Founder Member*), remarked that the Author seemed to be very sure that the electro-thermal de-icing was the best method for helicopters On what grounds did he derive his certainty? It was surprising that no connection seemed to have been established with propeller de-icing, and it would be interesting to know why the conventional propeller de-icing had not been taken up One could think of a number of schemes, such as combined electro-chemical de-icing, with which much less energy might be required

The amount of energy required was staggering and its implications were perhaps not fully realised To have 130 lb on an S 58, the amount of power required probably meant an equivalent loss in payload In that case, something like 10 per cent of the payload would be accounted for by de-icing Although the conditions were not stated and probably there was a broad field for argument, nevertheless it was a rather large power and one should do everything possible to reduce it

Mr SHAPIRO was not at all sure that the Author had not been too dogmatic about the leading edge strip Again, he did not know where the information came from, but recently he had had occasion to study methods adopted for protection against cavitation, in which practically everything except the very hardest materials failed On the other hand, rubber afforded quite good protection Therefore, as in most attempted generalisations about erosion, one should be very careful not to generalise

It had been said that certain types of flexible leading edges might be as good as stainless steel It would therefore be useful to hear more about the two points of combined methods, or comparison with other methods, and the question of finishing the leading edge

Another question was whether the loss of efficiency due to icing for a certain time should not be accepted as being the lesser evil than a loss of 10 per cent of the payload because of a de-icing installation Had some sort of comparison ever been made?

The **Author** replied that his sureness about the electro-thermal method was based upon present-day developments Further developments in other fields might show that other methods were more satisfactory, but his own feeling concerning present developments was that the electro-thermal method was the most satisfactory

A paper had recently been given by three Authors of the Vertol Helicopter Company (see Ref 7) who had tested both a thermal hot air anti-icing system and an electrical de-icing system side by side at the Eglin Field and the Mount Washington test facilities Their conclusions were that the electrical system was to be preferred from the point of view both of operating efficiency and of weight The chemical method might have possibilities It had not yet been tested on a rotor blade and it would be interesting to see what results were achieved Certainly on the tail rotor, it might be quite good and it might work very well on the main rotor

When the Author and his colleagues had first sat down and thought about electro-thermal protection for rotor blades, they had thought of propellers and had come up with something which was regarded as a cross between propeller de-icing and wing de-icing Obviously, the area was so great that it had to be split up to be brought down to about the same size of area as on propellers Therefore, to say that the work done on propellers had not been taken into account was not strictly accurate It had been modified and wing de-icing methods mixed with it to come up with the ideas concerning rotor blade de-icing Propeller experience could, of course, be applied directly to the tail rotor without any modifications whatever

He agreed about the large power penalty which had to be paid, but if the operators insisted on operating in icing conditions they would probably have to accept the power penalty On short duration flights, the loss of efficiency due to the ice might be acceptable, but if long duration flights were to be made—as might happen in the case of the Navy, whose helicopters could be hovering for a considerable time over the water—it would not be acceptable He had already stressed the effect of thrown ice causing damage when allowed to build to a sufficient thickness that it was thrown off by centrifugal force

Referring to the erosion properties of materials, he agreed that neoprene rubber was probably one of the best erosion resistant materials in existence, but it had to be at least $\frac{3}{16}$ in in thickness If it was any thinner, there was not sufficient resilience in it for it to absorb the effect of the droplet impingement and it would then begin to split , and as soon as it started to do so, it would disintegrate rapidly

In large thicknesses, therefore, rubber was good, but when one was aiming at an efficient heater with as thin a layer of insulation over the heater as possible, this would ring the death knell of bare rubber This was the reason for turning to the next best material, stainless steel, with which to cover the heater pads

Mr A S Richardson (*D Napier & Son, Luton*), who spoke of the chemical de-icing of helicopter blades, said that at the 1957 Paris Salon he had seen two Russian helicopters with liquid slinger rings, both on the tail rotor and on the main rotor system After great difficulty, he had succeeded in tracking down somebody who appeared to know something about it The comment that he had managed to extract, after great difficulty in interpretation, was that although in principle this liquid system worked very well, due to the specialised nature of the distribution system along the leading edge—which in the case in question was porous metal with rubes running just behind it along the leading edge—there was trouble from sand and grit erosion In principle, over the sea, when the machine was not in erosive conditions it worked very well

It was interesting to see the Author's pictures showing that the extent of ice formation occurring on rotor blades varied according to temperature, and it would seem that when going up towards zero the limit of icing moved inwards, so that it was not necessary to de-ice the tip under certain temperature conditions Did the extent of icing that was encountered under certain temperature conditions tie up with the theoretical calculation which could be made on kinetic heat rise? *i e*, was that part of the blade in fact above zero according to theory? If so, one was intrigued by the possibility of, not a de-icing system, but of a continuous anti-icing system with a graded Watts loading running from the tip inwards as it should be possible to exactly supplement the kinetic heating according to the range of temperature required

A few quick sums might indicate that power requirements would be high On the other hand, however, there would be much to be said for the simplicity of the system There was a great deal of anti-black box feeling in the aircraft industry, and anything that could be done to get away from cyclic switches, and associated complications, would be desirable

The general line of thought concerning electrical distribution was in terms of cyclic switches mounted on top of the rotor head, as only three slip rings would appear to be necessary for a three-phase system On the other hand, some formidable engineering problems were involved Could the Author comment on this and also explain in a little more detail the cyclic timing control system embodied in his suggestion that it should be controlled by the temperature, and not by the time of shedding?

The **Author** replied that Mr RICHARDSON's remarks about the erosion properties of sintered stainless steel might be very true He did not know whether any erosion or abrasion tests had yet been done on sintered stainless steel, and it might well be that this would make the system inoperative or undesirable

Concerning a graded anti-icing system along the blade, it should be possible to get fairly close correlation between theoretical and actual heat balances along the blade The calculated spanwise extent of icing agreed fairly well with the actual observed extent When making an anti-icing system, however, one would have to decide whether a wet anti-icing system or an evaporative system was required

It was true that at higher icing temperatures, the surface temperature at the tip of the blade was at or above zero, and so no ice formed, but if just sufficient heat to prevent ice formation was applied further inboard, he was quite sure there would be considerable run-back There was little run-back towards the tip, largely because of sufficient blow-off due to the high speed, but further inboard this was not likely to be the case

In principle, it was a good thing to put the cyclic switch on the rotor head or, if it could be reduced small enough, to place it down inside the hollow rotor shaft There were, however, two ways of thinking about this One was that the cyclic switch on the rotor head would actually make and break the current as well as doing the cycling, in which case it would be a quite heavy and large arrangement The alternative was to have a light selector switch in the head and to have one main make and break contact down in the stationary part, so that the zone was actually selected when the main contactor was open This would mean that there might be a second or two between each section for switching time This method would save considerable weight, because there was no making and breaking of the load by the selector switch In either case, one would save the weight of all but a few slip rings and of carrying considerable numbers of wires up into the rotor head

In reply to Mr RICHARDSON'S last question, the AUTHOR said that normally what was done was to test the system and determine the time required to shed at different ambient temperatures with a given heat density There were objections to this where the generator or alternator was not used solely for de-icing purposes but might be used for other purposes within the aircraft itself There might then be considerable variations in the system voltage due to various loads in the aircraft

The voltage variation might completely swamp the temperature/time relation to such an extent that the pre-determined time was quite useless In this event, it was possible to put a sensing element on the element itself and by prior tests to determine the temperature to which the element had to rise to ensure shedding Therefore, it did not matter what the system voltage was As long as the blade reached a certain temperature at which it was known the ice would shed, everything was all right and the voltage could vary all it desired

Replying to the comment about " former " and " latter," the AUTHOR said he had been explaining that in a helicopter system, assuming that the alternator was used solely for de-icing, the control of time by ambient temperature seemed simpler to apply In fixed wing applications, however, the only method at present being used in an automatic system was the second one, *i e* , that of switching off the power when the element reached a certain predetermined temperature

Mr P J Sharp (*D Napier & Son, Luton*), said that he wished to take up the Author's remarks concerning spanwise versus chordwise element strips From the de-icing angle, the Author had said that the chordwise were preferable and he had painted a poor picture of the system employing spanwise strips Generally, on a large helicopter it was a compromise With chordwise strips there was considerable difficulty in leading the power to each strip On the Bell, rolled tapes were used but on larger aircraft wires would be necessary, the weight being considerable It was bound to be a compromise between what was best from an icing angle and what was most convenient from an engineering and weight point of view

Were the Author's remarks on the spanwise system made as a result of test observations ? Did he have much in the way of facts to back up the preference for the chordwise strips ?

In reply, **Mr Stallabrass** said, that to some extent his remarks were based on test observations He must, however, admit that there were no completely parallel cases of the two types of configuration to compare directly In the various pads tested, the construction of the spanwise elements was completely different to the construction of the chordwise elements and a direct comparison could not, therefore, be made It would be extremely useful to be able to compare the two systems directly with a similar type of construction for each

From test observations, it was noticed that the run-back with the chordwise areas —the National Research Council method—was distinctly less than with the strip elements

Mr Sharp asked whether that put the spanwise elements out of the question

The **Author** replied that he did not know, but it certainly did not rule them out for short duration He would not like to say what type of run-back, or how much run-back, there would be on flights of long duration When testing the Bristol Sycamore, it appeared that after the first one or two cycles, any run-back caused by the first heating cycle seemed to disappear subsequently This seemed peculiar, and it could not be explained When testing the H 13 helicopter for the Bell Company however, this was not the case It was one of those things that were rather inexplicable

Mr D L A Hand commented that if the objection to the spanwise strips was the run-back problem, there was a strong argument for applying the secondary area

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principle By heating the most aft spanwise strip less frequently than the remaining strips, say, every fourth cycle, the run-back ice formation would be controlled

The **Author** agreed It might be satisfactory on the lower surface, but he did not know what it might do to the aerodynamics of the upper surface if run-back was allowed to build up on the upper surface for four cycles

Mr Hand said that he assumed that run-back ice would not grow to any great extent on the upper surface

The **Author** pointed out that more weight was again being added by these additional zones This would contradict some of the comments made by Mr SHAPIRO When trying to save weight, it was necessary to reduce the coverage to the very minimum and not to add these extra secondary zones

Mr O Ballard (*D Napier & Son, Luton*), said that due to the necessary limitations of ground testing, all the tests were likely to be carried out in hovering flight, except for the small effect of wind velocity When a system so developed was taken into forward flight conditions, did the Author anticipate any problems or did he consider that the effect of forward velocity would be small when superimposed on an already fast-moving rotor?

The **Author** replied that he did not anticipate any problems in that regard There would, of course, be slightly different impingement patterns or ice coverage on the blades, but he did not think that these would be very much different It was the advancing blade which to a large extent determined the pattern of ice accretion on the blade It was generally towards the tips where one was most concerned about aerodynamic effects, and here the increased forward velocity would be a fairly minor addition As far as performance deterioration was concerned, this was most serious in hovering flight, so that in the hovering case the testing was being done at the most critical flight regime for a helicopter

Mr A Parkes (*Westland Aircraft Ltd*), said that the actual tip cap of the blade was in practice difficult to deal with Having taken the ice clearance right to the tip cap, was it necessary to deal with the tip cap itself?

He was puzzled by the Author's remarks about the ice detectors working at zero speed Presumably, what was meant was that the ice detector was to be carried on the airframe, but that did not seem to be the right place to carry it, because the airframe might or might not be subject to ice formation and no worry arose The worry arose because of the outer half of the blade, it was here that means of detecting were needed This was where the danger occurred

Reverting to the Navy and low flying, he asked whether any work had been done in conjunction with ice formation in the presence of salt water spray

The Author had shown a good picture of the Sikorsky helicopter with lots of ice on the rotor hub Would the placing of a screen round it form sufficient protection for the gear in the centre?

The **Author** replied that he hated the tip cap and liked to see a nice square-ended blade! Certainly at higher temperatures there was no need to bother about it At lower temperatures, however, if there was some ice on it, this would probably prevent ice from shedding from the blade adjacent to it It would act as a stop and prevent the ice from sliding off If the tip cap had to be retained in its present form, he did not know what could be done about it

Answering the remarks about the ice detector and placing it on the fuselage, he said that the purpose of the ice detector was to determine whether the machine was in an icing condition It did not matter whether ice was being accreted on the fuselage or not, as long as the detector revealed that the helicopter was in an icing condition as well as showing the severity of that condition, it could be used to control the blade de-icing

On the other hand, since it was the blades in which one was most interested, it would be convenient to have an instrument which showed the rate of build-up of ice on the blades However, mounting it on the whirling blades made things much more difficult

The AUTHOR said that he, too, would like to know whether anyone had investigated the problem of freezing sea spray, which was now confronting his colleagues in Canada

Regarding protection of the rotor hub, if a fairing was placed around it and was made airtight where the blade roots came through it by using a rubber sleeve or something of that nature so that no water droplets would impinge at all or enter the fairing, everything should be all right In addition, the hub would be cleaned up by putting a smooth fairing around it and there might be a reduction in the parasite drag at high speeds if pumping of the air was prevented—as suggested by putting a rubber sleeve to the blade root from the fairing

Mr J M Harrison (*Westland Aircraft Ltd*), said he wished to raise a point that seemed to him quite incomprehensible The Author had stated that he expected the maximum amount of trouble in hovering, and he had also stated earlier in his paper that the main effect of the ice accretion was to increase the profile drag without affecting the lift This was difficult to understand, because the Author had shown some fearsome looking photographs of sharp edge ice formations well out towards the tip which, one would have thought, would cause complete breakaway at high angles of attack and would therefore precipitate an early blade stall on the retreating side of the disc, which would reduce the cruising speed, causing civilian operators to complain bitterly

Could the Author elucidate why there was only a reduction in profile drag and no serious effects in the load distribution?

The **Author** replied that he had intended to say "normal angles of attack" He had, in fact, gone on to say that the ice reduced the maximum C_L value The paper pointed out that little loss of lift occurred at normal angles of attack but that the maximum C_L value was reduced There was, therefore, a great possibility of blade stall on a retreating blade, and to this extent he agreed with Mr HARRISON

Mr Harrison added that what constituted a normal angle of attack on a helicopter was fairly high on the retreating part of the disc

The **Author** admitted that since the tests had all been carried out at relatively low speed, the problem had not as yet presented itself in a practical way To investigate this, after getting some ice on the blades, it would be necessary to fly around at higher speeds and see what happened He would bear this in mind and try it next winter

Mr Norman Hill (*Redifon Limited*) (*Founder Member*), said he was surprised to hear the suggestion that chemicals be used as a de-icing method, for as a result of certain experimental work not so long ago he could assure those present that in his opinion the chemical method was "out" whether applied as paste, fluid, jam, putty or any other medium Fluid involved the use of all kinds of plumbing and porous metal sections built into the leading edge The porous metal caused design problems and erosion occurs Pipes were liable to fracture and unions to leak

In his opinion the electro-thermal method had advantages over any other system known today

Mr HILL preferred to speak of weight penalties rather than effects on payload He spoke of the weight penalty involved where the fluid system is used requiring a large electric motor to drive through gearing a large and complicated pump designed to cycle at different times and speeds to suit the fluid or conditions The pump and motor together could equal or exceed the weight of the generator installed in the aircraft

It was vitally necessary to solve the problems of all-weather flying before the helicopter could be of any use in the world, either commercially or militarily De-icing was the one outstanding problem, and it must be beaten if progress was to be made

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Mr D C Tanner (*T K S, Aircraft De-icing, Ltd*), said that he wished to clear up a few misconceptions concerning chemical de-icing It was interesting to hear the things which had been ascribed to it In the first place, the pump and motor together weighed 8 lb 1 oz Therefore, it could hardly be said to weigh as much as a generator It was true that a little simple plumbing was involved, but for the helicopter system one was working on a relatively simple system which was not likely to leak all over the place It was improbable that the quantity of fluid to be carried would make a terrible mess of the aeroplane

In the reference to the Russian helicopter it had been stated that it had porous metal Had it, in fact, been established that porous stainless steel was used on the Russian helicopter?

Mr Shapiro interpolated that he, too, had seen the helicopter in Paris It was not Russian, however, but Polish, and he thought that it had rubber leading edges both for the main and tail rotors

Mr Richardson said his impression was that it was a metal perforated leading edge and that he had taken some photographs of the distribution system

Referring to the work which had been done in the latest experiments on the chordwise cyclic area arrangement he asked whether the Author could foresee this becoming a reality as a piece of engineering From what he himself knew, most helicopter firms in the Western world at present had the intention of using a spanwise cyclic system This was certainly true in France, Britain, Canada and America and, probably, Germany

Did the Author feel that he had gone far enough with the chordwise system to put it forward as a serious engineering proposal, or did he think that the practical reasons that people could put forward for not using it—for example the difficulties of current distribution where one had 600 G—would mean that in practice it would not be used?

The **Author** replied that obviously, from a manufacturing viewpoint, simplicity was the overwhelming factor Therefore, speaking as a manufacturer, Mr Richardson would choose simplicity

The method which he was proposing as against the spanwise strips was put forward as an alternative, it would give the user something to think about It was always healthy to have an alternative or competition of ideas Possibly the performance increase of the chordwise system was fairly minor, but, on the other hand, were these constructional difficulties so very great? He was not convinced that they were

Mr Lennox (*B E A*), said that when de-icing was used for civil all-weather helicopters it would probably have to be duplicated in some way At least, the reliability of the system would need to be considered Perhaps it would be possible to have two systems which shared half of the load each, so that if one failed there would still be 50 per cent effectiveness

The **Author** replied that there were no duplicated systems, as far as he knew, on fixed-wing aircraft Certainly, some method of protection was needed against failure of an element on one blade, or failures of that sort, which might produce unbalance If the system failed, however, there would probably be enough time in hand at least to choose a landing site It was not such a pressing problem as with the fixed-wing aircraft

The **Chairman,** in closing the meeting, expressed the grateful thanks of members to Mr Stallabrass, not only for his instructive lecture, but for making the trans-Atlantic trip in order to be present tonight

The vote of thanks to Mr Stallabrass was accorded with acclamation, and the meeting then ended

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