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Discussion

The CHAIRMAN said they had heard a fascinating discourse on a very difficult problem and they were greatly indebted to Professor RICHARDS for preparing this comprehensive paper on a subject which was very timely to all helicopter firms and was of particular value to his own, the Fairey Aviation Company

Mr F B Greatrex (*Rolls-Royce Ltd*), said that he had thought there would be no noise problems with helicopters when he had heard that helicopters had been operating into and out of Norwich at 3 0 a m for a whole winter without any trouble Perhaps that was because the buildings nearby were offices and nobody was sleeping in the neighbourhood

Although he knew little about the helicopter field, he believed that the paper would be a classic reference for some time

In the curve showing the sound level at which serious interruption occurred, he had been surprised to see that the curve rose continuously right down to the lowest frequencies Although this curve followed a typical background noise down to about 300 cycles, he would have thought that at the lowest frequency it was about 20 decibels above a typical background It might be that a loud low-frequency noise was not considered to be a serious interruption, and he would be interested to hear comments on that

He was not qualified to speak on rotor noises, but a point discovered on propellors was that reducing the disc loading as a rule reduced the noise Could anything be done in that respect on helicopters ?

He knew a little more about jets—particularly continuous jets, not pulse jets First he wanted to pour a little cold water on Professor RICHARDS' hot jets, for he thought the Author wrong to emphasise so much the part which combustion and turbulence played in the noise of a hot jet In fact, the evidence given did not prove the point at all The noise level of his hot jet was about 8 decibels greater than that of the cold jet at the same thrust, as measured by the pressure at which the air was delivered A jet of given area fed at a given pressure would in general always have the same thrust, whatever its temperature , but if it were a hot jet it would have a lower mass flow and higher velocity—and, since jet noise increased to the eighth power, or even higher, of the velocity, the hot jet would be noisier An increase of 200°C in temperature—he did not know what the actual temperature figures were—would easily account for all the increase in noise mentioned by Professor Richards

The classic experiment of Lassiter and Hubbard, which the Author quoted, could be explained in another way The double bend in the pipe might well have introduced a very bad velocity distribution, so that the velocity of the jet coming out of the pipe was about double what it would have been with a uniform distribution That was all that was needed to account for the difference in noise There was other evidence to support the view that turbulence did not contribute greatly to jet noise, and it was that the noise increase obtained with reheat on a jet engine was only as much as would be expected from the increased jet velocity—no more

Mr GREATREX said he was interested in the effect of rotation on the noise of tip jets It had been taken for granted for a long time that noise was a function of the relative velocity between jet and air to the eighth power , but it had never been conclusively proved, as it had been by the simple test shown

Of the very wide range of silencing devices tested, the cross-tail seemed to be very effective The 12 per cent thrust loss was due, he was sure, to the too-sudden change in shape , but the thrust loss was probably due not so much to a change in effective area as to the reduction in velocity caused by pressure losses in the pipe He was sure that this could be eliminated by more careful design But this only meant that the noise reduction was probably not as great as 9 decibels If it were assumed that all the 12 per cent thrust loss occurred because of reduction in velocity, this meant a 6 per cent reduction in velocity, which, on the eighth power law, meant 2 decibels noise reduction Of the 9 decibels reduction, therefore, 7 decibels appeared to be a genuine reduction in noise

The cross-tail was not unlike the corrugated type of nozzle which had been tested at Rolls-Royce, and it seemed probable that a nozzle with about four corrugations—or perhaps six as an optimum—was about the right number to produce an appreciable attenuation There were a large number of corrugations on the corrugated nozzle illustrated—perhaps 50 or so—and he would not have expected that to be so effective, since the frequency at which the attenuation occurred was very selective and depended directly on the number of corrugations A reduction of as much as 12 decibels had been achieved with the corrugated nozzle without any effect on the thrust, and he was sure that this could be done with pressure jets, too

He was sure that the silencing part of Professor Richards' annular jet device would be effective, but he was sorry that the Author had not measured its thrust, because thrust loss might be the nigger in the woodpile If a body were placed in the high velocity part of a jet, a lot of thrust would be lost The results ought, therefore, to be accepted with caution until the thrust had been measured Nevertheless, he echoed Professor Richards' cautious conclusion that tip jet noise was probably not insurmountable

Professor Richards said he had heard about the Norwich operations and had realised that they apparently contravened the conclusions of the paper However, there was a great danger in hoping for the best on the basis of a single set of experiences, and stressed that no noise measurements were available in this case

He said that events might well prove him to be pessimistic, but there were two approaches to the problem—the approach of what noise interfered with people and the statistical approach, illustrated in the United States by the number of people who had actually taken legal action It might be that people in this country were more apt to take things lying down When he first spoke to Dr BOLT about the figures he suggested that they had been put forward in fun, but Dr Bolt had assured him that a large number of cases had been analysed in formulating the figures For each Norwich, Dr Bolt had put forward ten South Banks To assume that all would be all right because there had been no trouble at Norwich was very unwise In addition, people were often kept happy by the novelty of the first operations If he were to be responsible for carrying out helicopter operations, and if he felt that injunctions would be taken out against him, he would not feel happy if he had no information available to show that the noise level was not bad

On tip jets, Mr GREATREX had rightly pointed out that it would not be expected that the hot jet and the cold jet would have the same velocity for the same thrust All Professor Richards had tried to say was that there might be a gain here It was hard to believe that it was not just turbulence, because the double bends were a long way up in the pipe , it was not as if they were immediately before the nozzle It was true that these experiments must be regarded with caution, but the evidence must be accepted until there was evidence to the contrary on engines with much larger orders of turbulence than those occurring in the jet engine

Mr Greatrex asked what larger orders of turbulence the Author had in mind than those of reheat pipes

Professor Richards said he would have thought that the pattern was fairly uniform compared with that in a very elementary pressure jet The relative fuel consumption indicated this

Mr Greatrex said his firm would be flattered by that comment

Professor Richards dealt next with the Fairey Tests Dr HISLOP had raised a point with him when the paper was first submitted The tests had been carried out over a whole series of air-fuel ratios and thay had indicated that the ratio did nct appear to be a perameter of major importance It seemed that if you took a constant output, a constant thrust, you could vary the air-fuel ratio through quite wide limits and get roughly the same noise level These two pieces of information coming together had made him feel that there might be a point in connecting the noise with turbulence, but he had toned this down to saying, " There may be a gain " Personally, he thought there was a gain to be made in this direction, but the evidence clearly needed to be analysed in greater detail

He agreed that the silencer device with tiny flutes, the first tried, did not give much gain, even at the highest frequencies at which the measurements were taken, but the cross-tail, which was a development of the Southampton ideas and which was to quite an extent similar to the Rolls-Royce arrangement, certainly gave a good reduction The lost thrust could probably be recaptured with careful design There was perhaps a certain amount of noise increase due to non-uniformity There must be a higher velocity in one spot if there were a lower velocity in another spot, to get the mass flow the same so that any change aimed at making the flow more uniform would give a noise reduction

Mr Greatrex asked why the mass flow should be the same

Professor Richards replied that the same amount of air was being used in each comparison, the results being compared on a basis of a constant internal pressure and mass flow, the air-fuel ratio being modified to make this possible

Dealing with the measurement of thrust in his idea of a peripheral pressure jet, he said that he was not convinced at all that the drag needed to be very high The jet had turned in such a way that it did not blow along the cone, but slightly away from it There were perfectly good flow conditions, as measured by streamers, but again, judging by the streamers apparently the velocity was not very high along the cone The thrust would be measured but experience on blowing over the upper surfaces of wings suggested that the drag increase need not be great

Mr G H Vokes (*Assistant Chief Designer*, *Vokes Ltd*), said that the paper gave a very good general line on a very difficult subject It would be accepted for some time as one of the standard works of reference on the subject

His main interest at present—although it might not be in the future—was in the silencing of the engine exhaust of piston-engined helicopters His firm had been responsible for the silencer fitted in the tests on the South Bank The general reduction in noise from that silencer was about 10 decibels overall, which did not line up exactly with the figures obtained at the works, where over 20 decibels reduction was obtained The inference was that the silence of the exhaust had been brought down below that of the rotor

The paper suggested at one point—unless he had misunderstood it—that the National Physical Laboratory tests had indicated that a 20 decibel reduction through exhaust silencing made an overall difference of about 10 decibels Perhaps Professor RICHARDS would add a few words on that subject

On the general question of the addition of two noises of different form, such as rotor noise and engine exhaust noise, the generally accepted principle was that in considering two noises of equal value and subtracting one completely, you reduced the decibels by three But did that always give the exact subjective effect on a listener ? The engine exhaust noise differed from that of the rotor in that it was more predominately of one frequency It sometimes happened that a single concentrated frequency could obtrude more over the general background noise than could the more random noise produced by the rotor Admittedly, the latter had a certain peak frequency, but possibly it was not quite such a sharp peak Might it not be worthwhile therefore, to reduce the noise peak at engine firing frequency rather more than the 10 decibels immediately suggested by their results ?

Dealing with the tests on the S 55 he said that Westland's would confirm that the performance of the machine was not noticeably affected in any way, which indicated that useful exhaust silencing could be obtained with a suitably designed silencer, with very little effect on either power or payload That had been one of the main worries in both helicopter and fixed wing aircraft work in the past

He hoped that in the future he would be able to take some interest in some of the other problems mentioned Professor Richards had spoken of resonance in the tail pipe of some jet units Could this be reduced by a suitable acoustic design of the unit ?

Professor Richards had brought out the question of scale effect, but this was found not only in the small jet It was found in practically every line of country which they had investigated , on the small scale results could be good, but on the large scale they were not necessarily so Silencers were a case in point, as change of size could influence not only frequency characteristics but acoustic impedance and directional effects which were more difficult to assess Hence, although model tests were essential in most aircraft research, when dealing with acoustics, full scale work was especially desirable

Professor Richards said that 20 decibels was the figure deduced by Fleming following measurements made at Bristol Owing to the lack of time available for these tests, Fleming had been unable to make a direct comparison with the helicopter in the worst position He had, therefore, analysed all the measurements made and had then extrapolated effectively turning the helicopter round so that the exhaust was in the worst position As a result, Fleming said, "We will get the noise down by 20 decibels in the very worst position of the helicopter if we get rid of the exhaust noise altogether On that helicopter, of course, it would have been necessary to fit a silencer which would give a 20 decibel reduction

But the point which he had made referred to the Westland helicopter Here a silencer which had regularly indicated a 20 decibel reduction on test, except in a tiny frequency range, had quite regularly indicated only a 10 decibel overall reduction over a large representative number of positions in the air The only possible conclusion was that there was another noise of very much the same spectrum shape which was preventing the 20 decibel reduction It was difficult to see any other explanation With the Bristol helicopter, on the other hand, it appeared at first sight that a 20 decibel silencer would be needed

Dealing with the subjective effect of the propeller, aerodynamic and exhaust noises, there was something to be said for tuning the exhaust rather more to peak frequencies, but in some measurements taken with narrow band analysis in the United States it seemed that the peaks of the exhaust noise were no narrower than the peaks of the rotor noise Clearly measurements only gave a very rough guide to the acceptability or otherwise of noise A great amount of work was going on in the field of subjective effects but he could not discuss this now

Scale effects were always found in aeroplane design The answer was that if they understood the fundamental physics of the subject, the scale effect could be accounted for but people working on silencers usually used empirical methods, and they were bound to get into trouble as soon as they went from one condition to another

Mr A Stepan (*Member—Fairey Aviation Co Ltd*), thanked the Author for his concentrated summary of the problems involved in noise suppression and especially for the moral support he had given in the present rather hopeless outlook by not only describing the existing situation but giving a number of useful hints and suggestions

Mr Stepan had experienced tremendous scale effect, a silencing device which gave certain results on the small scale gave quite different results in a bigger unit But he welcomed Professor Richards' encouragement not to take the test results and their disappointment too seriously but to repeat them There were a number of hidden and unknown problems which meant that tests carried out on the same basis did not give the same results This applied to a number of silencers which had been shown in the slides Some devices had proved successful but when tried again had no effect

The only device which seemed to corroborate other work, especially that of Rolls-Royce, was the cross-tail device, which gave promising results There was 12 per cent thrust loss, but the results of all the designs shown in the slides rectified on the same mass flow If for some reason there was the same pressure in the combustion chamber but less mass flow, due to a change in the effective orifice, the noise level measurements were corrected with the normal mass flow assuming an increase of noise intensity proportional to the mass flow

It was true that a part of the silencing effect was due to the lower outlet pressure, which showed itself in the decrease in thrust He agreed that a better aerodynamic design would rectify this

Another question was that of the hot and cold air jet and the influence of turbulence on jet noise The slide which showed the difference between the noise of the cold air jet and that of the hot air jet gave the position at 22 and 90 deg He had looked up his records and found that in the 45 deg position, in the higher pressure ranges, up to 30—35 lbs gauge pressure inside the chamber, there was a reduction of up to 14—15 decibels It was this reduction which first gave him the idea of the turbulence effect, because even taking the difference in outlet speed between the hot and cold air jet into account there was still a difference which could not be accounted for by the normal application of the law of noise reduction proportional to the eighth power of speed He had, therefore, felt that the change of turbulence in the jet due to burning might make some difference

The test which he had carried out had made him feel that although it might be impossible to change the overall noise level, of a jet at constant pressure ratio giving a certain thrust and, therefore, a certain mass flow, the composition of the noise itself might make a difference, and if one succeeded in changing the burning in such a way as to mix the noise and change the noise spectrum and the frequency spectrum so as to shift to the higher frequency—there might be an improvement

Work with two jets of the same thrust, pressure, and overall noise level was carried out, one with a burning pattern giving mere high frequency noise, the other producing the more low frequency noise The latter, with a turbulence due to burning, with much bigger amplitudes and very rough burning, was more unpleasant to listen to in the distance than was the jet working at a higher frequency This suggested a way of changing the noise effects without changing the overall noise of the burning jet

One of the most interesting features of the paper had been the annular jet exit, and it would be interesting to test this type of silencing device on a burning jet Its arrangement, with very high fuel-air mixtures and very high temperatures might present difficulties, but it was a welcome suggestion which should be tried, even if it increased the overall diameter of the jet at the exit or lengthened it

Professor Richards thanked Mr STEPAN for his comments and for the information which he had supplied and which made up part of the paper The peripheral jet suggestion was only one step in a certain direction, and the eventual direction which he thought to be sensible was that of a long thin two-dimensional jet blowing at an angle downwards from the trailing edge If the jets were turned down at an angle it would give augmentation of lift particularly at lower speeds A system could be produced which would have many advantages, not only from the noise point of view but from the helicopter performance point of view Professor RICHARDS had thought a lot about this and would like to discuss it with designers The effect of the change would be to give more lift on the rearward-going blades with lower velocity and, therefore, much more uniform lift in travelling forward It might even be possible to get rid of the cyclic pitch and collective pitch by varying the mass flow, but that was looking a long way ahead

There were so many parameters tied up with combustion noise that it would be foolish to talk too much about the exact cause of the noise The answer was that more tests should be carried out, and it might well be that they could be carried out on the model-size suitably by simply putting turbulence into the model jets

This had been done on one occasion at the University of Southampton They thought that if they could swirl the jet they might get a quicker mixing rate, and they put into the mixing chamber a swirling system and made the air swirl around But they set the blades at too wide an angle and they had quite large turbulence coming away from the blades This gave rise to a very high noise level indeed, and they attributed the increase to the fact that they had put an initial turbulence into the stream It might be that there was a separation of flow due to the angle of the blades, but it seemed that the fact they they had put turbulence in caused the noise level to rise More work should be done on this

Mr Stepan's point about raising the frequency was a good one A ground muffler had been designed at Southampton on that basis The purpose was to modify the jet from a circular one to one consisting of a long thin almost two dimensional type There might be more noise in the very high frequency range Those who had been near to a Viscount and then a little distance away across the aerodrome would know how much the high frequencies were attenuated partly by viscous action A report on this approach to the noise suppression problems would be issued shortly

Mr R H Whitby (*Member—British European Airways*), said he would add to the chorus of thanks to the Author for his happy knack of making what had become a specialised subject sound very simple—probably deceptively simple Particularly interesting had been the slide showing two curves of acceptable noise level and rotor noise plotted against frequency He had been much closer to helicopters than 200 feet several times with rotors still turning but with the engine throttled back and also after autorotational descent, and he found it difficult to believe that the noise from the rotor was disturbing That, of course, was merely one individual's subjective reaction

If that reaction were correct, then one of those two curves must be wrong Either the curve of acceptable noise was at fault, possibly because of the manner in which it was derived—people in the United States might be more inclined to go to law than people in this country—or the method of derivation of the curve for the rotor noise, which he understood was a difference method, was not correct Could Professor RICHARDS give more information on that ? In any case, he supported the view that more work should be done on the question of rotor noise, because Professor Richards had presented a *prima facie* case that it was serious

On the same slide was a curve of pressure jet noise Could this be defined a little more closely ? He had heard both the S N C A S O Djinn and Ariel , one was tip burning and made an appalling noise and the other just pushed the air out under pressure and made not at all a bad noise at 200 feet Accepting his own subjective reaction, the difference would be a demonstration of the V^8 law, for the jet speeds were different, as was the turbulence due to burning

The whole of the S 55 noise reduction was on the port side of the aircraft, which was the side of the exhaust He believed that there was no significant reduction on the starboard side, or, putting it another way, in an unsilenced aircraft the side away from the exhaust was about 10 decibels quieter than the exhaust side

Professor Richards suggested that on engine shut-down the rotor r p m fell off, which would result in the 100 f p s reduction of which he had spoken and consequent reduction in noise

Mr Shapiro said there was no fall-off at all

Professor Richards accepted this and said that he could not offer an explanation for Mr Whitby's experience Rotor noise consisted, however, of several components It could be that the component due to lift was the dominating one Thus the noise might depend more on the lift of the blades and not directly the power This raised a danger in using the extrapolation figures given in the paper based on airscrew experience The rules put forward there were based on the assumption that the noise from the various components (*e g* , vortex noise, lift noise, thickness noise), were of the same order The figures given in the paper were measurements The difference method had been used because Dr Fleming had made the measurements on the electric motor, with the rotor only, when the position was incorrect and he had had to extrapolate But Dr Fleming did not usually put forward figures unless he was certain of them and there was little reason to doubt his figures on rotor noise There was also the case of the Westland aeroplane, which showed the same sort of sound pressure levels when the exhaust was well silenced

The noise of the pressure jet shown in the slide for comparative purposes was the noise of the unit tested at Fairey's corrected to the distance of 200 feet It was an experimental curve corrected to 200 feet in order to compare it with the criterion

It was a little difficult to explain Mr Whitby's subjective effects, but these effects differed with different people and at different distances That was one of the points which worried him, and the measurements given were the best which could be done Furthermore, there were favourable and unfavourable noises For instance, at Hatfield they loved to hear the Comet make a noise A psychological factor was involved , nobody could fully explain this, but much work was being done in the United States, Canada and this country on the relationship between measurements and subjective effects

He had not appreciated that the noise reduction on the side away from the exhaust was zero on the Westland S 55 helicopter This meant that the noise from the exhaust was at a much lower level, which justified the suggestion that a smaller silencer would be satisfactory

The Chairman said he was somewhat baffled by the Author's reports of the high rotor noise A thought which crossed his mind was that if one could have a rotor operating, engine off and on at the same collective pitch setting one ought to get a more accurate measure of the noise due to the rotor alone Generally speaking, one heard the rotor noise only in autorotation when the collective pitch angle was very low Possibly the only way to check the rotor contribution at high pitch settings was to take a Bristol 171 with its very high inertia rotor and during a hold off close to the ground, with the collective pitch being steadily increased, take some noise observations as the r p m decreased It should thus be possible to build up a true comparison on a rotor at the same r p m , same collective pitch setting, and with the engine both off and on At present, however, it seemed that there must be something wrong with American standards of rotor noise

Mr Greatrex drew attention to the noise made by the Viscount as the propeller " bites " after " revving " up the engine There was a noticeable increase in noise as the pitch increased

The Chairman referred to the case of the Gyrodyne with the tip jet system as illustrated by the author On a later design this unit had been changed and very different results had been achieved In the past the system was rather crude as emphasis had initially been placed on getting the thrust, but in later developments radial combustion was being tried with the products of combustion being turned through 90 to provide thrust There was evidence that the noise was quite different —if anything, it was lower—but it was still rather early to be sure Replying to Professor Richards, he said that possibly there was less turbulence in the latter design The pressure jet was originally designed and made as a device to give acceptable thrust and fuel consumption, but it was rather crude and the next phase was to clean up the process and bring the noise level down

Mr G M Lilley (*College of Aeronautics, Cranfield*), said he had found the paper very interesting He was surprised, however, to find that Professor Richards had not made more of the noise from rotors at very high tip speeds Much was heard about the possibility of supersonic rotor speeds in the future for helicopters and convertiplanes, but it seemed from what the Author had said that these would be ruled out by their noise With regard to pressure jets or jets in general, it was the noise at a particular distance from the jet and not at a number of jet diameters which was of main concern It was clear, therefore, that a number of very small diameter jets providing a given total thrust was preferable to one large diameter jet unit He would like Professor Richards' comments on this statement

Professor Richards had, from his analysis of full scale test results, put the damper on the so-called 'Cranfield teeth,' which Mr Lilley and his colleagues had introduced They had not coined the name, which in many ways was an unfortunate choice, but this phrase had probably set a precedent for jet noise reduction devices invented by other Universities and Establishments

He said that the toothed nozzle was introduced at an early stage of the experiments on jet noise and was among the first devices to give extreme promise on a model scale It was now well known that the penalty to be paid was in loss of thrust However, they demonstrated clearly that noise reduction could be obtained by a reduction in the mean velocity gradient across the jet, an increase in the rate of jet spread, by an alteration in the intensity and scale of the turbulence in the jet mixing region, and by the formation of a corrugated type jet boundary These characteristics associated with the toothed nozzle had, he felt, paved the way to the newer types of jet noise suppressor particularly those developed by Mr GREATREX at Rolls-Royce

Professor Richards said that inventions had already emanated from Southampton It was only fair to Dr Powell and to Southampton University to point out that he was the first to use the corrugated jet pipe Some of the explanations then put forward were not strictly correct, but that was where the first experiments on those lines were carried out Now the devices were being fitted to aeroplanes developed by Rolls-Royce, while the Fairey cross-tails and other devices had come from this work

The use of a number of small jets was extremely sensible and was a good way of tackling the problem , his only reason for not thinking it feasible was that he did not think the helicopter people would "play"

He was not sufficiently a helicopter man to know what was taking place in the minds of helicopter people, but the thought of supersonic tip speeds for helicopters filled him with horror He was quite sure that such systems would be unacceptable from the noise point of view A battle had taken place in this country regarding supersonic propellers , and they had been disregarded on account of the noise they made, for the supersonic propeller could be noisier than the reheat jet

Mr J Wotton (*Member—Hunting Percival Aircraft Ltd*), referred to the statement, which had later been borne out by Mr Vokes, that the silencer on the S 55 incurred a weight penalty of only 25 lbs Mr Vokes had said that there had been no appreciable loss in performance If this were a case of getting something for nothing, Mr Wotton was surprised, for he had heard that there was a loss of about one passenger seat on the helicopter

He supported Mr Whitby's comments on the relative noise level of rotors compared with that of engines Speaking, again, subjectively, he found no unpleasant noise from the rotor as such, apart, perhaps, from the cyclic effect—the whack of the blade on the air as it went round He was surprised to be told by the paper that the lower frequencies were less troublesome He found that, with the S 52 or the 171, the rotor running up at 100 r p m was unpleasant, but as the speed rose he was not worried by the aerodynamic noise until the point was reached at which the tip speed approached the compressibility range There was a marked difference between the S 51 which had a maximum tip speed of about 550, and the 171 Bristol Sycamore, which had a maximum of over 700

He was allergic to whistling noises and the 171 whistled most unpleasantly just before taking off at low pitch It seemed to fade, however, as the pitch increased and the machine took off In this connection the time was approaching when more and more helicopters would be turbine-powered, and he had expected Professor Richards to make some reference to noises other than exhaust noises The high-pitched whine which came back through the intake of any jet engine was most unpleasant when compared with the exhaust noise, and he wondered whether anything could be done about it

Reference had been made to the characteristics of the rotor in terms of disc loading and tip speed Disc loading was likely to go up, especially with large helicopters There were aerodynamic advantages in using high disc loading during hovering and low forward speeds, and the possibility was opened up of considerable advantages on hovering, landing or take-off The free turbine would also come to the fore in helicopter work, and would enable the use of a greater degree of slip in the final turbine system than was useful in fixed wing aircraft There might be some advantage in relation to noise problem in lowering the tip speed during hovering by

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making use of the increased torque available with the free turbine slipping at full r p m With the tip jet there would be a loss in performance beyond a certain reduction in tip speed

Presumably Professor Richards obtained his information from Hunting Percivals as estimates of the noise level of the low pressure gas drive The anticipated low order compared well with other forms of drive and the initial running of the rotor confirmed this It had not yet run at full power but so far was surprisingly quiet Characteristics of this form of drive were high mass flow and low jet exit velocity making for a quieter rotor than could be obtained with other forms of tip drive

Professor Richards said he was very pleased to hear that the exhaust unit was very quiet He had always thought it would be and was pleased to learn that that was the case The figures he had given were in fact estimates given to him by Hunting Percival's

Dealing with the suggested loss of a passenger seat through the use of a silencer, he said that experience indicated that a 25 lb loss was not an optimistic estimate, at any rate for the eventual development of a silencer He did not know the estimate for the weight of a passenger, but with his baggage it would be about 170 lbs , and he could not believe that it was impossible to make a silencer for less weight than that

Mr Wotton commented that he was thinking in terms of loss of performance

Professor Richards said there might well be a loss of performance People had said that there was no loss, but it would be surprising if there were no loss of performance in forward flight It need not be very large, however

Mr Vokes said that the pilots responsible for flying the machine had insisted that, if anything the performance of the machine seemed to be slightly improved He would not answer that ! All he could say was that the back pressure of the silencer was a matter of 2-in of water—and the rest was all conjecture He would like to deal further with that point in a written contribution

Professor Richards said that came into the same category as scale effect If they understood basically what was happening, they would find that there must be a drag He could see no reason for the performance being better , it had certainly not been better on any aeroplane he knew which had been fitted with a silencer

He dealt next with the question of the high-pitched noise and the silencing of the turbine and suggested that the position need not be as bad as was thought In one figure in the paper (Fig 21) he had shown the engine noise compared with the tip jet noise, and one could see how far the tip jet noise had to be reduced to bring it into line with the engine noise of a propeller turbine But, there would be propeller and impeller noise on any unit such as the Gyrodyne Impeller noise had been quite large on some aeroplanes The only way to do something about that was to silence the intake in some way Impeller noise was in fact not very large on modern jet engines, though it might be a problem on a centrifugal compresser type He did not think it need be a major problem

Turning to the problem of whistle, he said it was usually due to some break-away of flow or to a periodic passing of blades close to each other A speed of 700 f p s was approaching a Mach number of 0 7 which was rather high Possibly shock waves were forming, with a break-away of the flow giving a pulsating flow of a certain frequency

Mr B H Arkell (*Founder Member*), said Professor Richards had proposed a design for a two dimensional jet along the length of the blade as a means of reducing the noise level of a jet driven rotor Had he any information regarding the noise level of the new Marquardt ram jet booster for helicopters which was very similar to his suggested design ? How did the noise level of that unit compare with the noise level of an orthodox ram jet of similar thrust ?

Professor Richards said he had not come across any ram jet information which had relevance to helicopters There was some noise measurement on ram jets for other purposes, but he knew of no information available on the two-dimensional ram jet Obviously the two-dimensional type would be quieter, but it would still be pretty noisy, simply because it was a ram jet with a high efflux velocity Nobody knew exactly how noisy it would be It was certainly a step in the right direction with ram jets

The Chairman said they were most grateful to Professor RICHARDS for his paper this evening It was the last meeting of the Session and the Association were fortunate in having him to give such a strong finish to the Session On behalf of the meeting, he thanked Professor Richards for his paper and for providing such a wonderful fund of thoughts and ideas for the reduction of helicopter noise, which must somehow be achieved

The vote of thanks to Professor Richards was carried by acclamation

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WRITTEN CONTRIBUTION RECEIVED FROM MR G H VOKES

As my contribution to the verbal discussion came early in the proceedings, I was unable to comment on references to silencing of piston engine exhausts by later speakers , if I may, therefore, I would like to add a few remarks for the record

It is generally assumed (sometimes rather conveniently, I believe) that piston engine exhaust silencing for aircraft generally, is impracticable on economic grounds, through loss of performance from (*a*) deadweight of silencing system , (*b*) " drag " of external components and (*c*) reduction of engine power In the case of a helicopter, it is my impression that (*b*) is of less relative importance, owing to the poorer aerodynamic form and slower speed of the machine, whereas (*a*) and (*c*) can be even greater limiting factors than with fixed wing aircraft

If, for the moment then, we confine ourselves to (*a*) and (*c*)—*i e* , deadweight and power reduction, I think it can be reasonably shown that the penalty need not be serious and, in theory, there is no logical reason why performance should suffer

Referring firstly to weight, experience on helicopters, so far, is limited The first silencer which I designed for the Westland S 55, was made by my Company last year, to overall dimensions specified by the Aircraft Company No time was available for experimentation, and it was gratifying to record that performance on test conformed closely with that predicted on the basis of analogous electrical theory, with average sound attenuation of some 20 db for negligible back pressure (under 2 inches water gauge on test) However, weight was relatively high at 60 lbs for the silencer, plus some 27 lbs for ancillary piping, supports, etc

If and when use of titanium alloy becomes economic, it is reasonable to suppose that silencer weight could be reduced to 25 lbs by careful design to requirements

Now for engine performance loss The assumption is usually made that silencing *must* reduce engine power I submit that this is not necessarily the case, and would offer the following points to suggest that in certain circumstances, performance might even be improved

(1) Cooling effect from exposed surfaces, resulting in lower discharge velocity, and so reduction in " velocity head loss " of the exhaust gases

(2) Discharge characteristics can be improved over those obtainable from a conventional exhaust pipe

(3) The introduction of a tuned system to give an extractor effect on a near-constant speed engine, would seem feasible

(4) I think it is true that dependent upon exhaust valve timing and " overlap," the presence of a fairly high velocity column of gas in a relatively long pipe, can have a beneficial effect on scavenging

All the above presuppose that the silencer itself has pressure loss characteristics simulating those of a plain exhaust pipe of similar diameter, a condition, I think, we can now claim to have proved possible, both in theory and practice

Returning finally to the question of aerodynamic drag of external equipment, it must be admitted that the only answer to this one (if serious) is reduction in size and improvement in shape I feel certain that these objections can be largely overcome by co-operation between aircraft designer and acoustic engineer, if the performance loss justifies this action