speed Also noteworthy is its performance when flying sideways In this case the induced power is much reduced (curve 'K') whereas the parasitic power of the fuselage is very much increased (curve 'L') The total power required in this condition of flight is shown by curve 'M' This indicates that the tandem can also be made to fly at very little power although at much lower speed than that of the main/tail rotor configuration

The question arises now which are the respective domains of these two-rotor configurations? To draw a definite line of demarcation is very difficult Small changes in any of the operative parameters can cause considerable movement of this line It is, however, fairly obvious that at 20,000 lb all-up weight (and more) the tandem rotor configuration offers considerable advantages

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Discussion

The **Chairman** said that Mr HAFNER had given an extremely interesting and frank account of the development of the Bristol Type 173 and the problems that had reared themselves He was glad to hear the good news about the latest flights They must have been very encouraging on the eve of his lecture

Prof H B Squire (*Member—Imperial College of Science and Technology*) said he was not sure whether he had correctly understood Mr HAFNER's comments on the Fig No 6 Was the explanation for the variation of yaw control the differential torque between the two rotors? If so, from what did that differential torque arise?

Mr Hafner said that a number of factors were involved First, there was the difference in induced flow The rear rotor was subject to greater induced flow than the front one Consequently the two rotors required different power and as they ran at the same speed this was expressed by a difference in torque which gave a moment in yaw

The second factor was that the rotor discs of the Type 173 happened to be differentially inclined Therefore in forward flight, the rear rotor, which was more inclined forward than the front one consumed more power, so producing a net yawing moment

The third factor was connected with blade flapping With increasing forward speed every rotor showed increasing longitudinal flapping but there was generally also a lateral flapping component This latter component produced a side force in Type 171 As the rear rotor in Type 173 was a mirror image of the front one the lateral flapping was in the opposite direction This feature produced a yawing moment

Prof Squire asked whether the three factors were of comparable importance and whether they all contributed significant magnitudes

Mr Hafner replied that there was no general answer to this question The moment due to the induced flow was always in evidence and was significant The other two factors depended on details of design

Prof Squire understood Mr HAFNER to say that the longitudinal control was a combination of fore and aft tilt of the thrust vectors and of the collective pitch variation between the two rotors Was it correct that except at very low speeds the effect of the forward tilt of the two rotors was unimportant in control ?

Mr Hafner said there was at all times a longitudinal moment as well as longitudinal force control The latter was insignificant at high speeds because the general drag was large compared with this little control force which could not alter the speed very much In hovering, however, this control force was most important as it was available without delay Pitching of the helicopter by means of differential collective pitch alone, in order to obtain a longitudinal force was sluggish, as it involved aircraft inertia

Prof Squire assumed that as far as the aircraft was flying, and ignoring the control very close to the ground at very low speeds, the control was a differential pitch control

Mr Hafner said that in forward flight the differential collective pitch control was the most important element in fore and aft control One could in forward flight do without the longitudinal force but certainly not without the moment control

Prof Squire asked whether the pilot could fly without any great difficulty in a region where the maximum adverse slope was, say, 20 feet per second ? If the helicopter was behaving like an aeroplane it was unstable but at very low speeds one was uncertain whether one was justified in talking about trim curves in relation to stability

Mr Hafner indicated a position on the slide which was unstable and another which was markedly stable

Prof Squire asked whether the instability in the region indicated was noticeably objectionable to the pilot

Mr Hafner said that Mr HOSEGOOD would perhaps answer that question

Mr C T D Hosegood (*Founder Member—Bristol Aeroplane Do Ltd*), asked whether Mr SQUIRE was referring to speeds from 30 knots upwards He said he did not believe that going through this speed range into forward flight would present any real difficulties, but that passing back through it when slowing up to hover, might under certain conditions, be rather unpleasant

Mr J Wotton (*Member—Hunting Percival Aircraft Ltd*), asked whether Mr HAFNER could explain why the anticipated reduction in vibration in forward flight with the use of stub wings was absent in Type 173 It was generally thought that the unloading of the rotor would immediately result in a decrease in vibration Did Mr HAFNER suggest that this was because Type 173 had not yet been pushed to its limit in forward speed, and would he expect an improvement higher in the speed range ?

Mr Hafner replied that the vibration problem was most complex Firstly, excitation of the fuselage come about in two ways—through the rotor hub and through the rotor slip stream By adding stub wings, one increased the surface exposed to the fluctuating slip stream This may increase excitation On the other hand—and this was a most important point—it did appear from the latest experience that the most critical factor in fuselage vibration was resonance The wings could also act as air dampers He did not think it was possible to give a general answer

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Mr R L Lickley (*Fairey Aviation Co, Ltd*), said with regard to testing for ground resonance that he was inclined to agree with Mr HAFNER that ropes, cables and so on did no good and might hide the results But did he think impedance testing was a sufficient guarantee that troubles would not occur later ? If so, how did he think he could deal with trouble if it did come ? This was perhaps an unfair question, but Mr HAFNER had begun by saying he wanted to get rid of the ropes and cables which most people thought of using as a restraint He himself was not certain that they might not be a restraint in the final condition when the amplitudes became very large compared with the strain in the cables giving the restraint

Mr Hafner said it was true that cables were a restraint, but they did not necessarily restrain the sort of thing one wanted to restrain He had seen a severe case of ground resonance which was restrained by cables, and the helicopter was completely wrecked The parts to which the cables were attached were still there, but that was all ! This was a case when the cables did not save the helicopter They might save it in some cases, but it was dangerous to assume that they would always do so

Moreover, there was the unpleasant thought of having successfully gone through a tie-down procedure, one had to worry when first operating without the cables

He had great respect for the phenomenon of ground resonance, and he did not for one moment suggest that they knew enough about it, one was here at the fringe of knowledge Impedance testing was by no means the cure for all ailments but it was at least a scientific and rational approach to the problem

Coleman's theory was no doubt right, but it was an over simplification of the practical case Impedance testing was supplying exactly the part which could not be dealt with mathematically

The combination of these two processes covered the ground satisfactorily It seemed to him a reasonable way of dealing with the problem

Mr Lickley asked what was the weight penalty in going to four blades to cut down vibration

Mr Hafner said that the two additional blades weighed a little over 200 lb But as the all-up weight of the aircraft was going up, more blade area was badly needed anyway There were two ways of achieving this—deeper chord blades or more blades They thought they were killing two birds with one stone by fitting more blades

Mr Lickley thanked Mr HAFNER for a most interesting hour-and-a-half and said that everyone must be grateful to him for giving so much of this valuable experience

Wing Commander R A C Brie (*Founder Member—B E A Helicopter Experimental Unit*), asked what effect, if any, the down-wash from the rear rotor on to the rear large-span fixed wing had on the aircraft

Secondly, curves were normally double Dutch to him, but on this occasion he thought he understood the implications That was to say, there was an undesirable divergence at one particular point fore and aft and in yaw This happened to occur around 35 or 40 knots In the types of helicopter one envisaged taking into city centres, flying under all weather conditions, this happened to be in what was felt to be the critical speed range on the approach under instruments conditions Could one take it that with the tandem type of helicopter the auto-pilot might perhaps be a compulsory instrument ?

Thirdly, Mr HAFNER was forthright in his comments as to the pros and cons of this or that configuration Like most things in life, it all depended on which side of the fence one was sitting He himself believed he was sitting centrally when he asked if Mr HAFNER would say at what particular point in the load capacity of these aircraft the tandem showed to advantage He noticed that the word ' large ' had been used Did that mean 30, 40 or 50 passengers ?

Mr Hafner said with regard to the down-wash on the rear wing that in hovering the fixed wings in the compound helicopter were stalled They had been afraid to find discontinuity in trim at the speed when the stalling of the wing would set in, but none was experienced

Wing Commander Brie said his question was directed to hovering flight in still air

Mr Hafner said in hovering flight there was a downward force on the fixed wing

Wing Commander Brie said it seemed to him that in these circumstances the aircraft was trying to do what was theoretically supposed to be impossible in a human being—to lift oneself by one's own braces What he wanted to know was not the lift from the wing but what, if any, was the effect of the down-wash from the main rotor on the fixed wing on the aircraft as a whole Was there any extra vibration, for instance ?

Mr Hafner said there was no buffeting There was no unpleasant vibration nor any serious difficulty at all

Regarding performance it had not been possible as yet to make a full range of tests The results available were only approximate They indicated that there was a negligible difference in hovering Perhaps a little more power was required to hover with the stub wing, but in forward flight the power required was much less

At present, they were engaged on roles which did not involve the use of stub wings but were concentrating on the pure helicopter In due course, however, the stub wings would be considered again

The negative slope of the line (fore and aft control) was important It was a difficulty, particularly in slowing down No doubt auto-pilots would overcome this they would certainly have to deal with all these problems Perhaps it was not advisable to stay at the critical speed What did Mr Hosegood think ?

Mr Hosegood said he did not quite get the question

Wing Commander Brie said that under instrument conditions the normal speed of approach would probably be about 40 knots Did that mean the pilot's difficulties would be added to because the negative slope happened to be at that critical speed ?

Mr Hosegood said he did not think the pilot would be as unhappy as the curve might suggest, particularly if he was able to hold a steady speed If it was necessary to vary the speed a lot around 30 knots his task would be rather more difficult

Mr Hafner said there was an analogy with the collective pitch control The pilots had become quite used to its unstable behaviour and did not mind it

Regarding the comparison of the two configurations, he sincerely hoped he was neither on one nor the other side of the fence His company built both ,kinds of helicopter The comparison was based on various scale-laws There was the structural argument and also the coning angle argument for rotor blades The coning angle argument said that with increasing rotor size, rotor weight became progressively uneconomic The structural argument was the 2 4 lb per sq ft blade area With conventional designs, one could show that the structural argument intersected the coning angle argument at a rotor size of 30 to 40 feet rotor diameter Below 30 ft diameter the structural argument applies Here there was no difference between single and tandem rotor helicopters With small rotors the gearbox argument also was unimportant

Wing Commander Brie asked whether Mr Hafner was suggesting that the tandem would be preferable for any size above a ten-seater

Mr Hafner Yes, about this size

Wing Commander Brie said he stressed the matter because there were obviously others besides himself who did not share that opinion

Mr Hafner said he would suggest that the size of Type 173 and anything upwards favoured the tandem configuration

Mr T L Ciastula (*Member—Saunders-Roe Limited*), referring to ground resonance, stated that the impedance tests in ground resonance were essential, but the fundamental point still remained whether full-scale testing of ground resonance should still be done They have done such full-scale tests on the Skeeter helicopter at Saunders-Roe

Regarding the usefulness of snubbing arrangements for full-scale testing, he said that it was possible to design such a snubbing system and they have used it on their investigations quite successfully It was necessary to have satisfactory instrumentation, so that curves and records of what was happening to the machine could be taken

It was true that if one went too near to actual instability range and snubbing was applied too late, some damage to the blades could occur Snubbing arrangements at Saunders-Roe were applied on many occasions and, only once, when applied too late, was some damage done to the blades

It was still his view that theoretical analysis by Coleman's method, supported by impedance tests, did not provide a 100% answer, mainly due to the complicated behaviour of oleo legs in a helicopter

Referring to the curves of control displacements ,he asked whether Mr Hafner could tell them what happened to control forces in the same conditions, and whether in the 4-bladed Type 173, he had to use power assistance or power operation That was a very important point since the manual control of a helicopter is a very delicately balanced system

Mr Hafner said there was no doubt a limit to the size of helicopter beyond which one could not go with simple control but had to have power control The present 4-blader was flying as a normal manually operated aircraft without even irreversibility in the control system The aircraft could be flown comfortably without power assistance right up to 110 knots

He did not think the argument for or against power control was connected so much with the rotor configuration as with the design of the rotor hub With tie-rod suspension—(the blades were held by means of flexible tie-rods to the hub)—much friction was saved That made it possible to fly such a heavy aircraft as Type 173 at high speeds without power assistance With ordinary ball or thrust bearings this would be impossible

Mr F H Pollicutt (*Hunting Percival Aircraft Ltd*), referring to comparison between the main-tail rotor system and the tandem system, said he believed if Mr Hafner had been born into the other camp, he could have put up an equally good argument on the other side But he had left out two considerations One could possibly be deduced from the rest of the paper, on the question of vibration levels in the two configurations Perhaps he would say whether he thought the main-tail rotor system would show a better vibration level than the twin system

The author had not mentioned at all the old bogy of cost Again, he himself believed it was essentially cheaper to have one of anything than two It paid both in first cost and in maintenance It was cheaper to maintain one, even if it was bigger, than two

He looked forward to the very early publication of Mr Hafner's paper It was rather a large meal to digest at once, and everyone would like to read it at leisure

The Chairman said he thought the paper would be published in May

Mr Hafner said he had made a comparison between two types of two-rotor helicopter configuration, the 171 and the 173 He had not brought the true single-rotor helicopter into the picture at all He agreed that with the genuine single-rotor helicopter there was considerable simplification

With shaft-driven motors there were at least two rotors He had shown in his comparison of the engineering elements that every element in the 171 helicopter was also found in the 173 and vice versa

Vibration was a very important matter, and he had heard it said so many times that tandem rotors had higher vibrations than the main-tail rotor configuration One heard it from other people, and also the 3-bladed Type 173 had a higher vibration level than the Sycamore At that time there was an inclination to believe that some penalty had to be paid with the tandem After the modification to four blades, he could give an assurance, that tandems cluld be made at least as smooth as " single " rotor helicopters

Mr G H Tidbury (*Member—Saunders-Roe Limited*), said the lecture had taken him back a few years to the days when the Air Horse was being developed Unfortunately, it had had to be dropped or postponed His mind was teeming with similarities in the problems encountered

Was there any rolling effect on the Type 173 when the yawing control was applied? He believed it was announced at the time of Mr Shapiro's lecture on the Air Horse that a similar control to that used on the type 173 had been tried, and there was an unfavourable rolling moment This moment was removed by applying the lateral cyclic to the front rotor only, when a quite smooth control was obtained

On the basis of Mr HAFNER'S lecture, he thought it might be a good idea to return to three rotors, because there was no bump in the fore and aft control position curve at 40 knots Was there some effect that was not realised at the time that was favourable to three rotors from the control point of view? Was it that the down-wash over the rear rotors was not sufficiently powerful to give control instability above 40 knots? Or was the real answer that we did not go fast enough? At the time it was not possible to go very fast, because there was a large once per rev vibration that deteriorated with speed The problem was not investigated thoroughly owing to more pressing work and, in any case, Mr HAFNER and his team of vibration experts were not available! He himself felt sure the vibration could have been sorted out had there been time, and more valuable lessons could have been learned from the three rotor configuration

Mr Hafner thought vibration could be sorted out But this was already difficult with two rotors, and he could imagine the problems that would arise in solving this for three rotors

The question of instability at the critical speed range of the three-rotor configuration was very interesting He had forgotten the geometry of the Air Horse Was the single rotor forward of aft?

Mr Tidbury said there was one in front, and the front was always more heavily loaded than either of the others

Mr Hafner said that would appear to give a more advantageous picture, because as the front rotor had a smaller span than the two rear ones, one caught not only the down-wash of the front rotor but partly also the up-wash This might explain the difference between the two configurations

Mr Squire said that some wind tunnel tests at the R A E on three rotor helicopters had shown that, with the single rotor forward and the pair of rotors behind, the mean down-wash over the rear rotors was very small

The Chairman said that in comparing configurations there was always a tendency to ignore the difference between the basic design methods which might be employed in two different firms One tended to assume the same constructional and design methods in both cases For example, if one took the type of trimmer used in the 171, then the penalty for the same kind of trimmer on a large single main rotor helicopter was 310 lbs This was, however, a totally unacceptable way of dealing with the C G problem There were other ways, *e g*, by the use of offset hinges which might well be fitted for other reasons Possibly in the same way, the blade weight might not be quite so unfavourable as Mr HAFNER suggested

Whilst he was supposed to be an impartial Chairman, he was encouraged to hear that fixed wings underneath the rotor showed no deleterious effects and that Mr HAFNER was pleased with the smoothness of his Type 173, it was the smoothest he had flown in Perhaps one day he would like to try the Fairey Jet Gyrodyne which was smooth too!

A vote of thanks to Mr HAFNER, proposed by the CHAIRMAN, was carried by acclamation