enthusiastic mail handler at one of the stops reached into the mail compartment and threw the bags out over his shoulder One of these bags was thrown so high that it was struck by the rotor Examination of the blade revealed a smooth impression ¼ inch deep in the blade leading edge from the mail bag bronze lock—readable in the steel abrasion strip were the letters " U S Mail " transferred from the lock This blade was repaired but one of less rugged structure might have been extensively damaged

The independent commercial helicopter operator frequently cannot afford to maintain sufficient quantities of spare blades We maintain a supply of blades which we loan to the operator while we are overhauling his damaged blades so that he can continue with his commercial endeavours We encourage these operators to write in to us for advice on repairs and our engineering opinion on conditions he may have observed This is equally beneficial to the manufacturer and the owner—he gets the service free and we maintain contact with the blades as they accumulate service time and of course, we learn a great deal about the blades in this manner

We contract with the Government to maintain their blades on an annual term arrangement—the blades are shipped in from all over the country and from foreign bases for rehabilitation After completion, the blades are tracked and balanced and returned to Government stores We prefer to do this type of work by means of a licence agreement with the helicopter manufacturer so that we have a mutual interest in the project We, however, are fully responsible for the quality and service and frequently relieve the helicopter manufacturer of all responsibility for satisfactory service of his blades

We find valuable information by visiting the military operating bases and are usually in a position to reassure the maintenance crews about service problems Our engineers are encouraged to visit these bases which, of course, reflects in improved future blade designs by exposing the engineering staff to the maintenance problem first hand

Discussion

The CHAIRMAN said Mr PRICE had covered very extensive ground and had raised many interesting and some controversial points in describing the manufacturing methods which Parsons had used so successfully in the past and were contemplating in the newer metal blade field

Mr T L Ciastula (*Member*) (*Saunders-Roe Ltd*), opened the discussion and congratulated Mr PRICE on the very important lecture which he had given It had shown that the design of rotor blades, particularly of metal blades, was not a simple business but involved a great deal of research and development Designers in this country could not speak from great experience because they had not built metal blades in large quantities Consequently, Mr PRICE'S description of the methods employed in America was extremely valuable , he had given data which was not available at this stage in this country

Saunders-Roe were also doing work for the Ministry of Supply in the design of metal blades for transmission driven helicopters, but their conception was totally different from that outlined by the lecturers It was, of course, a bonded blade, for they believed that the riveted blade was " out " , but, it would be interesting to do some fatigue tests for blades with only spanwise riveting and not chordwise The fundamental principle of the blade on which they were working was to reduce the blade to a number of simple spanwise elements, done by the same manufacturing process—in this case by machining, and then bond it in one bonding operation

The lecturer had severely criticised the method of stress simulation on the rotor blade whirl tower and it would be interesting to hear the case histories which had led to this criticism Why did the lecturer think that this method was a failure ? Everyone knew that stress simulation on the rotor test tower was difficult, but it could be done, particularly if somewhat higher torsional stress in the blade were accepted It might be essential to test the blade as a whole For instance, he would be afraid to take a number of separately bonded blade specimens, test them, and draw conclusions from these tests about the properties of the complete blade, which has been bonded in one operation Thermal expansion effects, etc , required that any such specimens should rather be obtained from a complete blade

Unfortunately, in this country they were far less likely to have a number of blades on which to work with a new design than were their colleagues in America Operators in this country never talked in terms of hundreds

Whatever test was carried out on a bonded joint, it seemed essential to develop some means whereby every single blade could be tested at its bonded joint Mr Ciastula had attempted to solve this problem on the Company's bonded blade , they had been in touch with people dealing with ultra-sonic flow detecting equipment and had inspected all the bonded joints with them on a complete blade Afterwards the blade was cut into a large number of specimens and half of each specimen was visually inspected, the other half being tested for shear strength of bonding In this manner, a complete spanwise plot of the shear strength of bonding was obtained in parallel with the qualitative indication of ultra-sonic equipment So far, this method of approach had not produced sufficiently consistent results, but this was no criticism of the firms which had co-operated in the work, for he was sure that they would finally solve the problem How was it tackled in the Parsons Corporation ?

Turning to the question of repairs, he said he had little experience of it because he never dealt with sufficient quantities, but he understood that the fundamental principle was that helicopter blades should be amenable to repair by the Services This seemed a doubtful proposition in view of balancing accuracies required for any blade, and he wondered how it was tackled in America

Mr Price (*in reply*), agreed that it would be a good idea to do more testing of riveted structures, particularly with single direction riveting He believed in whirl tower testing—this may not have been made clear in the Paper—but thought it essential that the test should simulate flight conditions In the United States, after a blade had given about 200 hours service on the tower they did not bother to test it any longer, yet blades had failed with as much as 500 hours flight service This was clearly because the whirl tower was not exactly simulating the flight load , the machine was being flown in a manner different from that expected and loads were being generated which had not been reproduced on the tower The tower must exactly simulate flight loads

Turning to the bonding of samples, as compared with production parts, he said they were trying to ensure that they had precise control of the test and the bonding operation so that it could be duplicated in production The samples were made from full-length spars , a full-length piece was made and a sample cut from it

He had not made it clear that in one type of blade to which he had referred, the main structural element, the steel spar, had no adhesive joints , it was brazed as a single piece structure, inspectable by X-ray The Company felt that the primary structure was readily inspectable

Referring to the inspection of adhesive joints, he said that a number of processes were being developed The Company were not yet using any in production, but he was sure that some would soon be available

The United States Air Force had civilian organisations on contract maintaining its aircraft The organisations bid for such work and carried out the repair work at field service level Major repairs could be carried out either at a base set up by the Government—it could be either a Navy or an Air Force base—or at the manufacturer's Parsons had at various times held Air Force and Navy contracts for 12 months periods If a blade were returned for major repairs, it was rehabilitated and rebalanced and then shipped back to the Forces

Mr J S Shapiro (*Founder Member*) (*Consulting Engineer*), said he wished to make comments which he hoped would bring blushing colours to the lecturer's cheeks The work which the Parsons Corporation had done and which had been described in the lecture was very important, and the most important slide of all was that showing the 10,000th blade This slide had perhaps not been sufficiently emphasised It was, in fact, this difference between the approach of the designer and the technician to the manufacture of a product and that of the production engineer which was the most valuable contribution of the Paper

It was sometimes difficult for a technician, who had for years been fighting problems as they arose and who was surrounded with difficulties, to give an unqualified "Yes" to the question which was in the minds of much less technical but more practical questioners This was an extremely important question on which the future of the industry was based

If they believed in helicopters, they did so because they thought a rotating wing could be made as safe as a fixed wing That was the basis on which they worked, and that was the question to be answered Whilst this belief was based on a few samples, there was a missing link and they could not reply "Yes" to the question without qualification

But they had now seen the 10,000th blade They had seen the manner in which the manipulation of probabilities had been made to work, producing an established article so that it could now be said that at least one element of the rotating wing had been proved to be as safe as the fixed wing

To some extent he disagreed with the lecturer's view that the blade was not a very difficult component It was difficult, *not* because it was highly loaded but because it had to fulfil in its design two entirely different requirements—the requirement of lifting and the requirement of control It was this combination which created a component which did not exist in any other branch of aeronautics They could not escape this fact in any type of design it was a component which must, by its very nature, join together in a perfectly safe and certain way three of four forms into which the material had been cast—sheet, tubular and some form of machined solid root by which the whole thing was held to the hub

It was this novelty in the type of component which had created the designer's difficulty and it was this unfamiliar combination of elements which had to be proved Nothing could have proved it so much as the 10,000th blade They should congratulate and perhaps envy their friends across the Atlantic for the opportunity to prove in practice something which had been a belief—well-founded and logical—but still only a belief

Years ago he had wondered whether they could make to work the philosophy of safety which had been gradually evolved in the design of flying machines and, particularly, of helicopters—the philosophy which could be expressed in a paradoxical way "The right thing to do is to make all parts of a machine equally unsafe" Now it had been made to work From now on they could say with complete confidence that the question was no longer, "Why should we have rotating wings ?" but was "Why should we not have rotating wings ?" If anybody questioned their endeavours and tried to introduce all manners of inferior substitutes for the rotating wing, because it seemed so difficult to attain, that was the answer which could be given, based on the Paper , for it had been proved that the blades of rotating wings were as safe as fixed wings It was necessary to draw attention to this fact so that they might feel more confident of their future endeavours

The lecturer had shown them a metal blade based on sheet metal and brazing Could it be concluded that this blade was thought to be superior to all other approaches in design which had been tried and rejected or was that too far-reaching a conclusion ?

Dealing with another part of the blade profile, was it possible to conclude that the honeycomb trailing edge section had been found not so good in production and service as that section finally chosen by the Corporation ?

Mr Stulen (*in reply*), dealt with the question whether many other blade designs had been rejected before the spar was selected In a study fashion some were certainly rejected but not through physical manufacture , the Corporation had certainly not built every type of metal blade and rejected all others in favour of the pressed rolled steel section They had experimented with various types of metal blades and had rejected spot welds The rolled construction had been chosen primarily because of its economy , these spars were rolled at the rate of 80 ft per minute The shear web was rolled off The two were combined in a fixture Actual brazing did not require more than 10 minutes per spar

This was a very economical construction and it was chosen because at that stage of development they had felt the need to grasp some process which was readily available throughout the country They did not want to wait for the Government to build a large extrusion press facility in their plant or to try to get into some large press which was already in use for other aircraft components They wanted a manufacturing method which was readily available, and rolling mills were available in many shops all over the United States Furthermore, this was a quick and inexpensive way to tool for a spar

The direct answer to the question was that they had not rejected a lot of other designs, for there were many very applicable methods of manufacture which are being considered

The honeycomb section was difficult in production and it was difficult to handle and contour accurately, but methods of dealing with it were being developed The best method was by the use of band sawing the honeycomb blocks purchased from the manufacturers , these were bonded into the aft structure The aft structure development in their minds at the moment was pointing toward the use of fibre glass reinforced plastics, primarily because of the lack of notch sensitivity and associated fatigue problems and the ease of repairability and of dealing with relatively small quantities from the standpoint of tooling Wood tooling could be used, whereas metal component tools involved more expense The Corporation had not finally settled on any one construction It might be entirely wrong in its belief in the fibre glass aft section, but at the moment that approach looked promising

Dr H Roberts (*Founder Member*) (*Fairey Aviation Co Ltd*), said they had heard a lot about the activities of the Parsons Corporation and he was tempted to ask what would certainly be the 64 dollar question why could such an organisation exist in America when there was no comparable organisation in this country ? It was an interesting commercial question and it was important, for when they were dealing with such large numbers as 10,000 blades, there was some possibility of mass producing a type and developing particular techniques, whereas if they were dealing with 30 aeroplanes, or even fewer, it might not be worthwhile to develop any technique on the scale necessary

Secondly, what range of sizes had been used in the blades so far produced ? Size raised another question with a very large blade, did the techniques still hold good or were they then facing a new set of problems, which meant throwing the techniques out of the window and starting again ?

Thirdly, on large rotor blades, there was the obvious problem of what to do at the inner end The blades shown in the slides seemed to go right up to the root Had Parsons found this the best way of making blades or the most convenient way ? Possibly it was the latter rather than the former

Fourthly, the blades shown were based on direct drive transmission What was the position with hot gas blades ? Could bonding be used or were they brought back to rivets, which had been mentioned rather disparagingly by Mr Ciastula Dr Roberts himself was not sure that rivets along the chord represented the best solution , he thought there was more to be said for rivets spanwise, particularly if the rib spacing was close

Fifthly, the lecturer had tended to skate over the question of aerodynamics It was easy to say that they did not affect the work, but was that being honest ? They were faced with this problem if they produced the ideal blade from the manufacturing standpoint its flexibility might be such that good aerodynamics of the blade could not be maintained They might achieve optimum design with a very thin section which crumpled or went into waves under load The question could not be rejected as easily as that Had the Corporation considered various shapes of blade both in plan view and in blade section with a view to getting good performance ?

Finally, much had been heard about the very extensive and interesting testing techniques being used by the Corporation. One aeroplane company in this country believed that testing was far more important than analysis. Dr Roberts had never shared that view. He felt that analysis could not be rejected in favour of extensive testing, although there might well be a temptation to reject it. Did the Corporation go to very great lengths to work out resonance, vibration and structural characteristics or did they rely entirely on testing?

Mr Stulen (in reply), said they did an extensive amount of analysis. In fact, they had pioneered in the industry the use of International Business machines for high speed computation in analysis of rotor blade structures. They were solving such problems as blade flutter, frequency problems, aerodynamics, bending moment problems and other blade problems by analysis every day. While analysis work was very important, testing was necessary in order to ensure that the analysis was right. Analyses were at present not sufficiently reliable; but they were being improved every day and brought into closer agreement with testing. The day would come when they could slacken off with testing and rely more on paper analyses.

They were concerned with the aerodynamics of the profile in as far as it was smooth and would retain shape in flight, but at the moment they were not seeking especially clever aerofoil shapes to give results not previously experienced. They were not combining the best twist and the best shapes to get the last 2 per cent. of performance out of the blades in all cases. They would take that last 2 per cent. if they could get it, of course, but they looked at the manufacturing problem first and if they had to compromise they did so in favour of getting a blade in production rather than one on the drawing board. The engineering team had some shapes which were said to be very efficient aerodynamically, but they were not in production as yet.

Turning to the question of hot gas blades and rivets, he said that riveting was a plausible answer and should not have been rejected as speedily as it had been in the United States. Its rejection was a long history, starting in the spot weld failure to which Mr Price had referred. Everybody at once said, "Rivets are terrible." As a consequence they had ever since been using oatmeal, chewing gum and all sorts of bonding and doing the best they could with it. Now that more was known about loads, stresses, and fatigue, they should be able to put rivets in blades and make them safe, but it was difficult to overcome the feeling about rivets, which was that they reduced strength fatiguewise beyond a point where they could be reckoned with. People should realise that rivets might well be better than having joints come apart! There was, however, a trend to put in some safety rivets; wherever they could they put in safety bolts and rivets.

Fortunately, bonding methods were becoming more reliable, as was shown from developments in this country. The significant fact was that adhesives were being developed which would accept 500°F.; they were in the laboratory stage and would be available and reliable in probably 5 to 10 years' time. Adhesives should not be by-passed just because of hot gas blade requirements, because hot gas adhesives would be produced. In the interim they could use something like rivets.

The Corporation's present techniques were being adapted to a blade of 29 ins. chord, or 82 ft. diameter. There were some modifications to the aft section. Channel designs were not adaptable to large sizes. Consequently, they had gone to a full depth honeycomb aft section.

He had not understood the question about blades going right to the root. They carried their typical structure to the retention and tried to grab hold of that in a most reliable manner. It was a designer's choice; he had the hub and the blade and had to mate them in some fashion. Some of the methods chosen had been shown. There were probably better retention schemes, some of which the Corporation had on the drawing board. It had been the designer's choice to adopt the methods shown.

Mr Price (in reply), thought the question about commercial existence was important. The problems were the same in America as in this country; a small company was started which was not related to any primary manufacturer and tried to take away from the primary company the part which it most wanted to work on All people who built machines had favourite ways of making rotor blades

The Corporation entered the business during the war, in 1942, when no one was producing blades in what for those days were large quantities, and it had been gradually growing ever since, but he was sure that it existed only because it performed a service

On occasions the Corporation had been given the task of designing and building rotor blades while the Helicopter Company spent its time on such things as the air frame and gear box, but it was difficult to get people to agree to that, for the rotor was a very important part of the helicopter and if it failed the whole machine failed

At present, many new designs were coming forward with alternate rotor blades, where the customer—in this case the Government—presumably felt that there were advantages in having more than one rotor design from the start Several new machines had alternate blades, one made by the manufacturer of the machine and one fabricated by the Blade Company This provided competition, which was a good thing, and it gave the machine a better chance of getting through its trials, because there were two sources of supply and two kinds of blade

Secondly, the Corporation was proud of the service which it gave The engineering group was small compared with that of larger organizations, but as soon as they landed a job they tried to get the blade finished They tooled up quickly and thus got their "foot in the door" They were in production while the larger firm was still making up its mind The Corporation had not the benefit of Government facilities, such as were given to large plants It was a small privately owned organisation supplying its own facilities from its profits in the production of blades

Mr R G Austin (*Member*) (*Auster Aircraft Limited*), thanked Mr Price for an interesting lecture On blades where they were not passing hot gas along the spar they still preferred to use brazing rather than adhesives Could he be given the reason for that? Was it purely a question of inspection or had they found that at the moment adhesives were not reliable?

If he had read the lecture and the S-N curves correctly, it appeared that Mr Price suggested an operating stress of 14,000 lbs per sq in as a reasonable maximum which should not be exceeded in helicopter blade design Presumably this was based on a fluctuating stress of plus or minus 14,000 lbs per sq in But apart from fluctuating stress, in a helicopter blade there was also a mean tensile load, and obviously the fluctuating stress to give the infinite fatigue life desired would vary with the mean tensile stress If he was right in thinking that the S-N curves suggested plus or minus 14,000 lbs per sq in, then with a high mean tensile load that fluctuating stress would have to fall somewhat

This was imposing a very heavy weight penalty on an aircraft The blade weight went up approximately as an exponential function of the mass/strength ratio of the material If they halved the operating stress they were doubling the mass/strength ratio and putting up the blade weight as an exponential of the power of that ratio It meant they would have an aircraft composed of blade weight and no pay load!

He had seen the results of some work done on steel fatigue before the war This was done in the United States by Bullen and seemed to show that if they operated high grade steel at a maximum stress of no more than 50 per cent of the ultimate tensile strength they achieved infinite fatigue life Mr Austin suggested that a more reasonable stress level would be to have a mean tensile stress in the blade—using a material of say about 100,000 lbs per sq in ultimate—of about 25,000 lbs per sq in, which was desirable for the stability of the blade structure, and to have a fluctuating stress of about plus or minus 20,000 lbs per sq in

Without a fairly high mean tensile stress they were almost bound to run into compression buckling troubles especially on the trailing edge, even assuming that the material was of lower E than the main structure He would like the lecturer's comments on these points

Mr Stulen (in reply), said the data should be obtained by testing the actual part as it exists , that was the part for which they wanted the endurance figure, because that was the part which would fly

They were not suggesting lowering the standards of rotor blades by accepting the statistical analysis that one in 10,000 blades could fail at that level In fact, they were trying to improve the standards of rotor blades by recognising the existence of this scatter and by recognising that someone would fly a blade at the wrong end of the scatter Scatter could go a long way and it was important to ensure that it was covered That was the reason for using the statistical analysis and the one-in-ten thousand level, not accounting for improvement of the odds by other contingencies, such as damage to blades before flight

That was why the figure for the one-in-ten thousand probability seemed so low , it accounted for the scatter The average endurance for this spar was 28,000 and 1 out of 2 could fail if subjected to stresses above this value

The effects of mean stress were dealt with by the Goodman diagram method, Goodman being an Englishman who had developed a means of handling the effect of mean stress

The choice of brazing in this instance was simply for manufacturing reasons A more reliable, more accurate section was obtained by this method than by the D-spar tube section

Mr Pollicutt (*Hunting Percival Aircraft Ltd*), said that in view of Parsons' considerable experience Mr PRICE had delivered the lecture with considerable restraint and modesty His two quotations tempted Mr Pollicutt to offer a quotation which summed up the present mental state and expectation of life of a designer—either a fixed wing designer or a helicopter designer

"The trials that beset us,
The troubles we endure,
The manifold temptations,
That death alone can cure"

He had some questions to ask arising out of Parsons' experience over 10 years of very high manufacturing output Had they encountered many fatigue failures in operation ? If they had, had they been catastrophic or had there been some warning, such as the growth of cracks ?

How had blades developed in that ten years ? If they were today designing a blade for conditions similar to those 10 years ago, would they be able to reduce the weight very much ? Had they achieved increased life or decreased cost ? How had the 10 years gone and did they see, in the next decade, the likelihood of a further reduction in cost or increase in life ?

Mr Price (in reply), said they had not had the number of failures which people might have expected, and this was largely because most of their flight experience had been with wood rotor blades There had been some failures, none catastrophic but one very nearly catastrophic In that case the blade had accumulated over 500 hours of service—blades of that design had probably a total of 20,000—30,000 hours of service—when there was a failure with a machine doing a special type of flying It was a wood fatigue failure, and it occurred at the place in the blade with the lowest stress margin

In the flight which was being performed the stresses were higher than they had expected by a considerable margin—which brought them back to the question of whirl testing to a certain load anticipated in a blade, only to find that someone took the blade 1,000 miles away, did something unexpected with it and broke it It made them wary of saying that they had met the problem of loads liable to occur in any blade

On this occasion the pilot was trying to do the same thing continually and accumulated the extra load It might never happen again He lost a portion of the blade, but he was only three or four feet off the ground and the aircraft sat down with no damage whatever This was a perfect test, for there was failure of the blade but it could be inspected afterwards Usually it would have meant complete loss of the aircraft and tourists running away with all the evidence

If they were designing a blade today, compared with 10 years ago, it would last longer, they would be more certain of having done a good job and it would probably be cheaper He did not think it would be lighter or prettier Some beautiful rotor blades were built 20—30 years ago which were not being developed today because polishing cost a great deal

Mr Stulen (in reply), said the blade made today would be more serviceable The name tags would not fall off, the paint would not crack and the tips would not open up—all the little serviceable items would be of better quality Those were advances which had been made, in addition to the entry into the metal field Production techniques and costs had also been substantially improved

Mr D J Moore (*Member*) (*Hunting Percival Aircraft Ltd*), asked a question on control of weight and C G Assuming that they manufactured the blades from standard sheet with standard tolerances on it, did they get control by designing to the heaviest possible weight and then putting in a lot of lead to make up or did they make the blades in a series of different weights and use selective assembly ?

Mr Stulen (in reply), said the majority of production had been in matching sets Three blades were matched so that they were as nearly alike as possible Their weight would be alike within that group, but it might be an entirely different weight from that of a different group of blades which was matched and carried through the production line

One of the reasons for going into metal or all-weather blades was that this development was allowing Parsons and others in the United States to match blades to a master, so that every blade could be built to the same weight It might be necessary to pick three groups of masters, building some blades to one master and some to another In one design they thought they had pegged what the extremes would be , they were building blades and hoping to match all blades to these extremes.

He wished to correct an impression which might have been created by the slide of the 10,000th blade and the talk of one-in-ten thousand failing There was no connection between the two ! He was sure the 10,001st would be as good as the others !

Metal blades also had a weight problem A few thousandth variation in the gauge of the sheet of metal, in the length of the blade could mean 10—20 lbs difference in weight, particularly if the metal were in the aft edge of the blade From the production standpoint, therefore, metal blades were not everything to be desired , wood could give variations but so could metal

The **Chairman** said it was not often that he regretted that they were to have dinner at the Dorchester but he regretted it on this occasion for the discussion was just getting going, and yet because of the dinner, he must bring it to a close People in this country were facing up to the problem of blade manufacture on a bigger scale than hitherto and he was sure that they had many questions yet to ask the lecturer and his colleague

He sincerely congratulated Mr Price and Mr Stulen for the excellent and modest lecture which they had given They had gone to a great deal of trouble to assemble material which was meaty and which would repay more detailed study later As Mr Pollicutt had pointed out, they had been very modest and some significant points might have been overlooked had they not been emphasised in the discussion The questions asked after the lecture had illustrated the deep thought which it had evoked

They all joined in wishing the authors well and in thanking them very much indeed for their excellent paper that evening

The vote of thanks to the lecturers was carried by acclamation