MR SHAPIRO Thank you, Mr Shippey, for a most interesting Paper I am sure this will give us much ground for a good discussion I shall now call upon Mr H E LE SUEUR to deliver his Paper on Airworthiness of Helicopters and Lives Mr Le Sueur has, since June, 1949, been a Design Surveyor at the Air Registration Board and was engaged in investigating the airworthiness of rotary wing aircraft, the S 51, Bristol 171, the Firth project, the Hiller and Bell helicopters From 1947 to 1948 he was Assistant Lecturer at the Medway Technical College, Gillingham Prior to 1947 he was in the Stress Office of Short Brothers

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Airworthiness of Helicopters and Lives

By H E LE SUEUR, A F R Ae S

When asked if I would contribute to this afternoon's discussion I wondered what there was that I could say in such a field as Standards of *Maintenance Coming from the Design side of this vast organism the* Aircraft World and having had very little to do with the maintenance of aircraft, let alone helicopters, in what way could I contribute when there were so many other far more knowledgeable, capable and experienced people and, in any case, when were the Design side concerned about maintenance of anything, their heads always in the clouds, hovering at Mach numbers of one or above with a safety factor of 1 5 ?

However, I wanted to say something, but then how could I say it ? Having read and re-read the proposed title of the discussion, I eventually came to the conclusion that there was a possibility that those engineers requiring helicopter licences should know how such things as " what an Airworthiness Authority is likely to consider to be a safe scrap life " are obtained

I would therefore crave your indulgence whilst I try to formulate a procedure which, in my opinion, might satisfy some fictitious Airworthiness Authority—I will not say the A R B , for although this discussion is being led by that body, of which I myself am an employee, I must say that the opinions given here are my own and not necessarily those of the A R B

The Conversation The problem then is this the Helicopter Designer or Engineer, with the aid of his staff, has produced a helicopter He has proved that it flies, hovers and does everything that he wanted it to do In fact, it is an experimental success However, the powers that have sponsored his design now look for some return for their financing of the project It is therefore necessary to sell the product or, at least, others of similar design Everybody should buy it It will revolutionise the whole of transport, both public and private BUT the Airworthiness Authority say " STOP, you dan't throw lumps of metal around the sky, slung under whirling pieces of machinery—it's not safe !"

The designer says " It is safe and, to prove it, I am prepared to fly the machine "

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The Airworthiness Authority spokesman then says "So what! That does not prove anything, but merely demonstrates your insanity already suspected since your conception of such a lethal machine."

The designer says "But it's like any other aircraft except that it's safer because it can actually take-off and land with little or no forward speed. In fact, if it overshoots it can fly backwards, and I am quite prepared to demonstrate it to you and prove all my figures."

"Good," says the Airworthiness Authority spokesman, "but you know there must be a lot of vibration and fluctuating stresses up in that there windmill on top. And what's the material being used in its construction? Anyway if it's a material with a fatigue limit, can you prove that you never exceed this limit and, if it is aluminium, well anybody knows that aluminium is suspectible in fatigue."

The designer must then scratch his head and say "Humph, will strain gauging be acceptable?"

"Maybe," says the spokesman, "Anyway we will have to agree to a schedule of tests and we won't guarantee that we will be satisfied even then." And with that he will depart to think up some excruciating tests that can be levelled at this airbeating monstrosity.

The Thoughts. The following are some that he has thought out.

(*a*) *The Tests*

It will be required to demonstrate that, over the whole extended engine and rotor speed range, no resonance occurs in any of the shafting and transmission; there shall be no undue vibration anywhere in the cockpit, passenger cabin or of any part of the rotorcraft where vibration is likely to cause discomfort to passengers or crew and damage to freight; and no flutter of any part of the lifting, stabilising or control surfaces and rotors shall take place. The engine and rotor speeds shall be extended beyond their normal operational ranges by an agreed amount. The above tests are to be done on the ground and over the full flight speed range, forwards, backwards and sideways in the air. The operational speed ranges will be reduced below that demonstrated by an agreed amount.

During this general vibration and resonance testing it will be as well to fit some exploratory method of strain gauging in order to assess the order of the stresses in those parts of the structure, transmission and rotor system, including controls, where it is considered that high stresses or strains are likely to occur.

As mentioned, this strain gauging should be of an exploratory nature and it will be necessary to investigate more thoroughly the critical parts of the rotorcraft under the operational conditions where it is found that stresses or strains are likely to be criteria.

(*b*) *The Cases*

The ground and flight conditions which should be explored are as follows:

Ground tests should be made to include the starting up of engines and rapid acceleration during clutch engagement (if applicable) and over the full speed range up to maximum demonstrated engine and rotor speeds and the movement of the flying controls over the full practical range.

It shall be demonstrated that no undue stresses or deflections occur when moving along the ground over surfaces of a maximum roughness to be defined both under its own power and when being towed Any specified ground locks may be engaged during these tests to avoid any undue damage

In flight the rotorcraft, particularly the rotors and that part of the flying controls in the vicinity of the rotors, shall be strain gauged over the full speed range, forwards, backwards and sideways, and up to the maximum altitude All the usual helicopter manoeuvres shall be explored, *e g*, turns, pull ups, hovering, etc The strain gauging should cover simulated engine failure, auto-rotation if the rotorcraft is single engined or if such a manoeuvre is scheduled as a normal flight procedure in a multi-engined craft, and change from auto-rotation to power on The investigation should cover all possible forms of take-offs and landings up to the prescribed maximum take-off and landing speeds

Checks should be made in the vicinity of any likely rotorcraft induced rough flying conditions, *e g*, steep descent from hovering, maximum forward speed with stalling of retreating blades, high altitude flying in warm atmospheres

(*c*) *The Analysis*

What one does with all these strain gauge results depends on the type of construction of the part tested

(i) *Metal Spars*

If the part is made of a material for which a maximum stress-frequency fatigue (or S-N) curve can be obtained, it is suggested that the following procedure be adopted When the material has a fatigue limit, then so long as the measured alternating stresses are lower than this fatigue limit associated with the appropriate steady stress and there is reason to believe that there are no stress concentrations, such a part need not be lifed

Where stress concentrations do occur, for example bolted joints or a change in section, then it is suggested that such parts or the critical joint should be tested for fatigue under loads similar to the most critical found during the strain gauge investigation Alternatively, a maximum stress-frequency curve should be determined for the joint

If the material of the part or the joint has no fatigue limit or if the measured stresses exceed the fatigue limit of the material or joint, then it will be necessary to assess the length of time that the rotorcraft is likely to be involved in the manoeuvres, which give rise to the critical stresses during, say, 100 hours of normal operational conditions This will, of course, depend upon the type of operation for which the helicopter is to be used For example, if the critical stresses occur during the flare out just prior to landing, then a rotorcraft used for crew training or crop spraying would spend more of its flying life in these critical conditions than a similar machine engaged on long-range haulage Having obtained an assessment of the time involved in such a manoeuvre, the frequency of the critical stresses during the manoeuvre, and having obtained from the S-N curve the number of cycles that the material can withstand the critical stresses occuring during the manoeuvres, it will be possible to assess the safe scrap life by invoking the Cumulative Damage principle It would probably be best to show this by means of an example

A helicopter rotor blade is found to undergo critical oscillatory stresses during the flare out prior to landing and, throughout the whole of the remainder of the flight regime, no critical stresses are found. It is found that the manoeuvre lasts for approximately 20 seconds (I must apologise for the long time but it is an example) and the frequency of the oscillatory stresses is 1 × rotor speed, which is 300 r.p.m. The number of reversals that the part can withstand the critical stress is 2×10^5. Then the number of times that the rotorcraft can enter the manoeuvre without failing is

$$\frac{2 \times 10^5 \times 60}{20 \times 300} = 2{,}000$$

It would be necessary to put a safety factor on this, unless the stresses already have been factored above those measured, as 20 per cent increase in stress may mean a life factor of as much as 5 or even more. In this case, the number of safe operations would be 400. If the length of one average operation is 1 hour, then the safe life of the blade would be 400 hours, whereas if one operation lasts for 3 hours, the safe life would be 1,200 hours.

It is suggested that the above procedure would apply to metal forgings and extrusions where critical stresses occur along the axis of the grain.

(ii) *Wooden Spars and Others*

If the part is made of material for which no S-N curve can be obtained, it will be necessary to test the part by loading a specimen or specimens repeatedly until failure under the cases which give rise to the measured critical strains, or until it can be agreed that a safe scrap life can be estimated on the basis of information from such previous testing.

The loads which give rise to these critical stresses may be obtained by loading the actual part used in the strain gauge investigation until the strain gauges give similar readings to those found in this investigation. Whether this is possible or not has yet to be proved.

(iii) *Alternatives*

A combination of the two above methods may be agreed upon and it is possible that one further alternative is that someone should fly a rotorcraft under operating conditions and the approved scrap lives of suspect parts on certificated rotorcraft should be a fixed factor below the lives of similar parts fitted to this one rotorcraft. It is hoped that such a procedure should not be necessary even if it is only for the sake of the test crew, unless flight conditions can be simulated on the ground in a safe place such as a pit or tower suitably protecting the outside world and the crew. Any flying time that has accrued on rotorcraft of similar design can be taken into account for Certificate of Airworthiness purposes.

Where critical stresses arise in occasional unnecessary manoeuvres, *e.g.*, running over rough ground, then it may be possible to ban such a manoeuvre by suitable wording of the C. of A. If in an emergency it is necessary to enter a condition where critical stresses arise, it would be the responsibility of the licensed aircraft engineer to see that this was drawn to the attention of the constructor and Airworthiness Authority so that agreement could be reached on the effect of the emergency condition on the safe life of the part This will need a new form of legislation and conception of minimum damage It may be necessary to include a list of manoeuvres or emergency conditions in the Service and Instruction Manuals which must be reported by the pilot whenever they occur

(*d*) *Other Parts*

Those parts of the rotorcraft for which the vibratory stresses cannot be obtained and where failure would not cause catastrophic collapse of the rotorcraft, should have a safe scrap life based on vigilant inspection carried out during type and endurance testing of the rotorcraft These, of course, can be increased or waived by agreement

Conclusions

Operating conditions, wear and corrosion may influence the scrap life of a part and these effects will need to be considered in the assessments of the safe scrap life

There are certain aspects of design which may have to be considered in the assessment One in particular, which must concern some present is the effect of elevated temperatures on the fatigue properties of the material used , *e g* , when the rotor blades are used to conduct hot compressed air for the purpose of jet propulsion at the blade tips and these ducts are part of the main structure of the blade, and similarly when it is considered expedient to anti-ice a blade by a thermal method, either gaseous or electrical, and the heat is likely to be transferred to the main structure In the latter case the time that the anti-icing system is in use is significant

No mention has been made of the effect of gusts on rotor lives and, in case anybody is wondering whether this phenomenon affects the lives of rotors, the same as it affects the lives of spars on fixed-wing aircraft, it should be noticed that, with a flapping hinge, the effect of a gust is to increase the coning angle with little increase of stresses and the frequency of gusts is much lower than the cyclic stresses which occur once per revolution, that is, in the order of 20,000 per hour In the case of non-flapping blades, the stresses due to gusts will be slightly higher, but, owing to their much lower frequency, it is considered that they are not contributory to the fatigue of the blades

It is to be hoped that the above will help the licensed engineer to appreciate that scrap lives are not just pulled out of a hat or thought up at the whim of some gremlin lurking in one of the cupboards in Brettenham House

Apologies I would apologise for any possible cribbing that I may have done from other people's work, and, if anyone should think that such is the case, will they please rejoice that at least one more person has bothered to apply their information If any disagree, will they please bring their arguments to the attention of the existing Airworthiness Authority and, if within the subject of this discussion, then let them raise their points when given an opportunity by our Chairman

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Mr Shapiro Thank you Mr Le Sueur