acceleration pick-ups are the resistance and the inductance types

A typical design of inductance pick-up now available has ranges from 1G up to about 15G For a range of $\pm$ 12G it has a natural frequency of about 180 c p s Thus, it can be used at least up to 150 c p s The problems of design are comparatively easy, and the pick-up can be made very small

Of the types of resistance pick-ups I would refer to the unbonded fine wire type, which contains a complete Wheatstone bridge made up of very fine wires, the wires themselves forming the spring of the accelerometer The vibration produces strain in the four arms of the resistance bridge, which gives an output from the accelerometer proportional to the applied acceleration The main advantage of this type of pick-up is that at these low frequencies, it possesses sufficient sensitivity for use directly with a low frequency vibration galvanometer and a camera, without the use of an amplifier There is thus the possibility of making a very simple instrument using the unbonded resistance accelerometer to cover the range of (say) 1-50 c p s , for helicopter work

Finally, I should mention briefly the electrical circuits used with vibration and acceleration pick-ups The electromagnetic generator vibration pick-up gives a voltage output proportional to velocity, whilst the bridge circuit associated with a resistance or inductance acceleration pick-up gives a voltage output proportional to acceleration For a signal proportional to amplitude, therefore, a vibration pick-up requires one stage of electrical integration and an accelerometer two stages An electrical integrating circuit may consist of a straightforward resistance-capacitance network or a negative feedback amplifier in which the feedback is controlled by a resistance-capacitance differentiating circuit In the former case there are phase and amplitude errors at the low frequency end, and in the latter case errors exist at both the high and low frequency ends The required accuracy at the two extreme frequencies is attained by suitable choice of the electrical time constants and the degree of feedback For a limited frequency range, say 1 to 50 c/s, this choice presents very little difficulty, and is in general far more practical than attempting, in the design of the vibration pick-up, to overcome the phase and amplitude errors at frequencies in the region of one c/s

Airworthiness in the Presence of Vibrations

By R H WARDE (Air Registration Board)

Introduction

Before dealing with the subject of airworthiness in the presence of vibrations, I would like to make it clear that all my remarks refer to civil type helicopters, for which a Certificate of Airworthiness is required

Turning now to the actual Requirements for the airworthiness of helicopters, the Air Registration Board, in December, 1949, made a provisional issue of Section G (Rotorcraft) of British Civil Airworthiness Requirements The following quotations indicate clearly their provisional nature

" This issue of Section G is to be regarded as provisional only, pending the accumulation of more knowledge on the behaviour of

Rotorcraft and the collection of statistical data to confirm the factors, etc , employed

A prototype rotorcraft shall be subjected to such laboratory, ground and flight tests as are necessary to establish whether a recommendation for a Certificate of Airworthiness can be made Until detailed requirements for such tests are prescribed, the Board will deal with any application on an *ad hoc* basis "

The Establishment of Airworthiness

When one realises that the helicopter, as a passenger carrying aircraft, is still in a very early stage of development, and it is appreciated that we are dealing with a complex application of the problem of fatigue of materials due to vibrations, I think we can all agree that we are faced with a very difficult task in our endeavours to establish airworthiness I think it is not an exaggeration to say that a helicopter incorporates a large number of parts, the failure of which will immediately result in a crash from which there is little chance of survival of the passengers Furthermore, these vital parts are, by the very nature of their duties, subject to vibratory stress and possible fatigue, which, as we all know, gives practically no warning of approach

Considerable progress has been made, with the valuable help of the British Constructors, towards the accumulation of data, and consideration is being given to the need for the issue, in the near future, of more detailed procedure In the meantime, a general policy has been followed for the testing, which, when satisfactorily undertaken, should demonstrate airworthiness of a prototype in the presence of vibrations It is wished to emphasise that, due to the complexity of the problems, no exact procedure can at present be laid down, as the sequence and details of the tests may have to vary due to the differences of individual helicopter design and the results of each test It is a case where close co-operation between all concerned is essential

In general, however, it is considered that airworthiness can be established and maintained by applying the principles of the well established test procedure and maintenance for engines and propellers for fixed wing aircraft It must be emphasised that all concerned with both the testing and maintenance of helicopters should follow the attitude or approach to the problem in the accepted practice for engines and propellers in contrast to that adopted by the constructors of fixed wing aircraft The standard of detail design and inspection of all moving parts of the helicopter must be of the highest possible order The tests, however, should be carried out and carefully considered Whilst the tests will, in a general way, establish airworthiness, it must be appreciated that the day-to-day safety of the helicopter is closely linked with careful inspection and maintenance, and the recognition that certain essential components may have a definite life, at the end of which they become scrap

Test Procedure for Prototype Helicopters

Assuming that a prototype helicopter has been designed and built to comply with the provisional Design Requirements, it is considered that a series of tests should be carried out in a carefully considered sequence This testing covers only the minimum that it is considered necessary to

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determine the airworthiness of a helicopter No reference will be made to the considerable development testing which, in most cases, will be necessary in the early stages of a new design

The following is an example of a typical sequence of tests

(1) Design development rig tests of components including preliminary fatigue tests of parts where the working stresses can be estimated by calculations

(2) Spin test of rotor system This test should, where possible, include the rotor hub complete with the rotor blades and pitch changing mechanism and should include an overspeed test with observations made to check for flutter

(3) Preliminary ground vibration stress measurements on the complete transmission system in an actual helicopter airframe with particular reference to torsional vibration and whirling of transmission shafting and the effect of starting and stopping rotation This test should include a preliminary investigation of the rotor blade vibratory stresses

(4) Approximately 50 hours running test of the complete rotorcraft to a schedule to be agreed This test should be done on the ground, which includes the case of the complete helicopter tethered close to, but not touching, the ground At the conclusion of the test a complete strip examination of all parts, and only when all concerned are satisfied with the condition of the parts, the tests continued in accordance with the following paragraphs

(5) Preliminary flight tests of the helicopter within a limited envelope of manoeuvres During this flying, vibratory strain gauging to be undertaken and checks made of control characteristics If the ground tests referred to previously have shown doubtful results by virtue of the condition of the parts or preliminary strain gauge tests, then new parts are to be used for this preliminary flying

(6) The following additional testing to be undertaken in a sequence to be determined according to the results obtained from the tests outlined in the preceding paragraphs —

(*a*) Extension of preliminary flying to obtain further data

(*b*) Further laboratory fatigue tests of components subject to vibratory stresses in the light of results so far obtained from the flight strain gauge tests

(*c*) Comprehensive flight strain gauge measurements under all manoeuvres

(*d*) Should the results of previous tests show the necessity, by reason of the results or the necessity for modification, the continuance of the ground running for an agreed period and further laboratory fatigue test of components

(*e*) Approximately 50 hours flight test to a schedule to be agreed At the conclusion of this test a complete strip examination of all parts

(*f*) Approximately 100 hours endurance flying during which handling suitability and performance tests may be undertaken At the conclusion of this test complete strip examination of all parts

Any reference to a total number of hours running in any of the tests described should be taken only as a guide to the general order of the length of the testing

The Maintenance of Airworthiness

As mentioned previously, it seems inevitable that many of the components of a helicopter subject to vibratory stresses, will have a life placed on them, after which they become scrap The tests described in this Paper should ensure a reasonable measure of reliability and establish a background on which to determine the life of these parts It is only by a rigid adherence to this principle, coupled with a very high standard of inspection at frequent intervals, that continued airworthiness can be ensured This subject presents some problems of considerable magnitude and cannot be dealt with in any detail at this time It may be, however, that for the immediate future the only way to ensure continued airworthiness for a passenger-carrying helicopter will be to gain experience while carrying freight This will entail limiting the operating hours in passenger service of any particular helicopter to some such figure as 85% of the maximum number of hours already achieved without trouble whilst carrying freight

Conclusions

Finally, we come to the main conclusions to be drawn from a study of the problem These are as follows

(1) The development of helicopters to a standard of airworthiness equivalent to that at present achieved for fixed wing aircraft, presents many difficulties, none of which are unsurmountable It may well be, however, that the vibrations in helicopters will prove to be the most difficult single problem for which a satisfactory solution has to be found

(2) The correct approach to the problem is to apply, with as much flexibility as possible, the well tried principles at present in use for engines and propellers of fixed wing aircraft

(3) The establishment of the airworthiness of a helicopter is no easy problem, but provided the correct equipment and personnel are available, the various difficulties can be overcome Any but the most conscientious approach to the problem is sure to fail

(4) The maintenance of a helicopter in an airworthy condition is a task requiring much care, and for the time being, until further experience is gained, the adherence to a procedure based on the limited experience available

(5) The procedure for establishing airworthiness of helicopters must remain provisional and subject to modification until sufficient operational experience has been obtained so that we can see more clearly the solution to the many problems The closest co-operation between all concerned is essential and discussions such as we are having to-day should prove to be of the utmost value

In conclusion, I wish to record my thanks to the Chief Executive of the Air Registration Board for permission to read this Paper