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Substantiation of Safe Fatigue Life for Rotorcraft

By

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ROYAL AIRCRAFT ESTABLISHMENT

Substantiation of safe fatigue life for Rotorcraft

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W. A. P. Fisher, B.A., A.M.I.Mech.E.

SUMMARY

This paper gives a comprehensive system of development and testing to substantiate rotorcraft for fatigue.

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1 Introduction

The authorities responsible for checking that aircraft, both military and civil, are structurally safe are faced with the formulation of suitable requirements. When the requirements can be expressed specifically, e.g. by minimum proof and ultimate strength, their fulfilment is entirely objective. Either the required test figures are reached or they are not. Ideally, all testing requirements should be specific and a large part of structural research is done with the main purpose of crystallising requirements into specific tests for which interpretation of results is independent of personal judgment.

For fatigue strength it is more difficult to specify test conditions than it is for static strength and still more difficult to specify acceptable figures. These difficulties are greater for rotating wing than for fixed wing aircraft. The vibratory loads are induced by the rotorcraft itself; they may differ in rotorcraft of the same type according to the adjustment of the blades and the amount of wear; they vary greatly with forward speed and manoeuvres, and are sometimes excited in a very obscure manner. Wear and corrosion can be important factors affecting life. The stress induced in service may possibly be increased by elastic distortion, faulty adjustment, malfunctioning, or bearing defects. Testing may require power transmission by the component under test, involving possibly the design and construction of elaborate test rigs. The loading rate in such rigs may be slow, possibly about one-tenth of that generally used in fatigue testing machines, thus limiting the number of tests. At the same time, scatter in the fatigue strength of the components may be high. As yet, there is no absolute numerical standard of assessment.

The formulation of a rational scheme of specific requirements necessitates:-

(1) A testing philosophy defining main principles.

(2) A standardised testing procedure.

(3) Objective fatigue standards.

Experience to date is insufficient for complete attainment of these three objectives, and for a long time to come it will be necessary to rely on the judgment of engineers and fatigue specialists in the assessment of test results. But the writer believes that it is now possible to achieve (1), and to go a long way towards the achievement of (2) and (3). The present Note attempts to formulate the basic principles, to draft a standard development and testing procedure, and to lay down standards to be met. The procedure is an amplification of that already published in Section G of British Civil Airworthiness Requirements.

2 Definitions

In this Note, the following definitions apply:-

2.1 Fatigue Strength

"The alternating load corresponding to failure at a specified endurance shown by a conservative endurance curve obtained by fatigue testing at various alternating loads and representative mean load."

2.2 Endurance

2.21 Allowable Endurance

"Where full allowance has been made for scatter as well as roughness by factoring the alternating load, the allowable endurance is the geometric mean of the test endurances of a batch of specimens."

In some cases, however, (infrequent but high vibratory load and endurance less than, say, 500,000 cycles) it may be agreed to omit the scatter factor on the vibratory load and make allowance for scatter by reducing the allowable endurance by a factor depending on the number of specimens tested. Suitable endurance factors are given in Appendix I para.A3. These factors include an allowance for the difference in the number of cycles to produce a small crack and that necessary for failure.

2.3 Virtually Infinite Life

"A safe life of at least 10^9 cycles under the most severe operating conditions based on flight measurements covering the full range of conditions."

2.4 Substantiation for Virtually Infinite Life

"A component or assembly shall be deemed substantiated for virtually infinite life if tests show it to have an acceptable margin of fatigue strength over the measured vibratory loading." This does not apply to parts affected by fretting or corrosion (see para.2.31).

2.5 Indefinite Life

"Pending longer operational experience, a component may be assigned an unlimited fatigue life subject to reservations as to excessive vibration, wear, and surface condition. Its replacement would depend on the results of normal inspection."

This term is used for components which would have virtually infinite life except for the effects of wear, fretting etc. and is applied when insufficient operational experience is available to establish a definite retirement life.

2.6 Retirement Life (Permissible safe life)

"The retirement life of a component subjected in service to infrequent vibratory loading which exceeds the fatigue limit should be not greater than the flying time corresponding to the allowable endurance determined by rig tests." The allowable endurance as defined in para.2.21 is found by tests at factored loading.

3 Basic Principles

Three basic principles of fatigue substantiation for rotorcraft are:-

3.1 First Basic Principle: Designing for Virtually Infinite Life

"It is good practice to design parts, when possible, to give virtually infinite life." As already mentioned, however, there may be cases where this is not practicable and recourse must be had to retirement after a specified life.

A component may be designed for "virtually infinite life" under assumed mean and vibratory loads. By the application of generalised fatigue data, the fatigue strength of the component may be designed to be well in excess of the assumed loading. For steel parts free from attrition or corrosion, there is a real fatigue limit. The word 'virtually' is added in order to generalise for all practical purposes the term 'infinite life' to include aluminium alloy components which do not show a fatigue limit. For such parts, by extrapolation, the fatigue strength for 10^9 cycles may be taken as 1/1.35 that for 5 million cycles.

3.11 Components affected by corrosion (including fretting) or attrition in any form must be restricted to 'indefinite life' (see para. 2.5).

3.2 Second Basic Principle: Fatigue Substantiation

"All primary parts affected by vibratory stress must be shown to have an adequate safety margin of fatigue strength for a specified life and operational role."

In practice, only two distinct roles need be considered: military and civil.

Sufficient pre-flight fatigue testing should be done to show that production components have at least the fatigue strength to which they are designed.

Substantiation for a specified life requires measurement of the fluctuating loads or stresses in flight and the testing of a number of representative specimens which may involve a typical 'duty cycle'. Thus it would be somewhat premature to embark on a large rig testing programme until the flight loads have been determined; but sufficient fatigue testing machine capacity should be provided in good time to enable a preliminary evaluation to be made before the prototype is flown. Repetitive testing should never be regarded as time wasted, as the results will be of importance at a later stage.

3.3 Third Basic Principle: Factored Loading

Substantiation for virtually infinite life by fatigue testing necessitates factored loading, i.e. vibratory load(s) applied in the test should exceed the measured flight loads by a specified factor (see Appendix 1).

Fatigue testing at unfactored loads is unsatisfactory because the number of cycles to be sustained in service is very large; if the part does not fail after a large number of cycles the tests does not indicate whether there is a margin of safety or not. Factors on the vibratory load are necessary because of:-

(a) probable increase in roughness with wear and other variables,
(b) scatter in fatigue strength,
(c) the need to reduce to a minimum the time required for testing

These factors will be named respectively:-

(a) roughness factor,
(b) scatter factor,
(c) extrapolation factor.

4 Specific Principles and Procedure

The procedure of fatigue evaluation for rotorcraft will now be discussed.

Pre-flight work

4.1 Design assumptions and fatigue strength estimation

The fatigue strength of components should be estimated in the design stage. Throughout the design a consistent policy of "fatigue - proofing". i.e. minimising stress concentrations, should be followed. (See Ref.2)

The designing firm should make detailed fatigue strength estimates for all main parts subjected to fluctuating loads, specifically the following:-

Main rotor blades, including blade root attachments
Main rotor hub
Tail rotor blades and hub
Rotor head and blade articulation
Transmission shafting, couplings, gears, splines, etc.
Controls

Load fluctuations in these parts should be estimated from experience.

For parts such as rotor blades the estimate must necessarily be tentative.

In connection with the transmission, the engine manufacturer should be able to supply information on engine torque harmonics.

Where new forms of construction are used it will be necessary to establish their fatigue strength.

Rotorcraft depending on fixed wings for lift in forward flight require fatigue substantiation for the wing structure under the effect of gusts, which are known to be more frequent at moderate than at high altitudes. Accepted methods of life estimation for fixed-wing aircraft should be employed.

Tailplanes should be considered in relation to gusts and buffeting.

It would be advantageous to establish a central body to which rotorcraft fatigue estimates could be referred for comments and suggestions. Such a body would be able to accumulate and disseminate useful data, and at the same time help towards standardising design procedure with respect to fatigue.

4.11 Vibratory Loads

Whenever possible, parts should be designed to withstand indefinitely a specific vibratory loading estimated from experience or by calculation.

bending, torque, or shear, such as can be measured in flight by suitably arranging the strain gauges and calibrating them statically.

It is standard practice to estimate in advance the resonant frequencies of the transmission and rotor system to ensure that these frequencies are outside the operating range.

4.12 Code of Manufacturing Finish

A code of manufacturing finish should be prepared and strictly adhered to. The code should be in the form of an officially approved specification

More often than not, service fatigue failures have been associated with imperfect finish, e.g. badly cut fillets, badly finished threads, tool marks, or rough machining.

A joint committee might well arrange the preparation of an agreed code of standards.

4.13 Clearances Between Moving Parts

Sufficient clearances should be maintained to prevent serious cyclic loading from elastic deformation or bearing wear.

Experience has shown that adequate assembly clearances can be of vital importance, particularly in the rotor mechanism.

4.2 Development Fatigue Tests

Fatigue testing of components and assemblies should be made at an early stage in prototype construction so as to check the design, material and workmanship for fatigue

The object of this testing should be to substantiate the parts for fatigue under the assumed vibratory conditions, in the expectation that, where the measured vibratory loads are found to be greater in the prototype than estimated, means will be found for reducing them to a satisfactory level. Only when this is found to be impossible will further testing, of an ad hoc nature, be necessary for substantiation.

In development testing, both laboratory fatigue testing of components and running tests of assemblies should be made, as discussed below:-

4.21 Laboratory Testing

It is common experience that laboratory fatigue tests on structural elements or mechanisms will show where comparatively minor changes in design can produce a marked improvement in fatigue strength. Also, such tests will show which part in an assembly is most likely to fail in fatigue. One great advantage of rig testing over endurance running is that parts can be tested to failure without detriment to other components, and so definite fatigue strength figures can be determined.

Various degrees of alternating load should be applied to successive specimens so as to establish an endurance curve. Scatter due to manufacturing technique, e.g. in forging or welding, should be taken into consideration. Tests should be run to 5 million cycles or prior failure.

In the separate testing of components, it is sufficient, in most cases, to test the critical region of a component with respect to fatigue. Such regions are usually obvious. They cannot be tabulated completely in general form because of variations in design, but the following cases are given by way of example:-

Blades:	Root attachment. Any stress concentration in region of highest vibratory bending stress.
Hub Spider:	Flapping hinge lugs; threaded connections; fillets.
Shafts:	Welded connections; splines, keyways, couplings.
Rotors:	See para. 4.223
Gears and Controls:	See para. 4.221. 4.223

4.22 Assembly Testing

To reduce testing to a minimum it is preferable to test assemblies whenever possible, instead of isolated parts. For this purpose, main assemblies, such as gearboxes, shafts, rotors and controls can be tested as complete units.

4.221 Rotor Gearboxes

Fatigue of gear teeth is usually caused by the repeated loading which occurs once per revolution, and is not materially affected by the vibratory variations of this loading. Fatigue tests of gears should be based, therefore, on the continuous application of maximum torque and not on the torsional fluctuations. A suitable test load factor is applied to the mean plus vibratory torque transmitted to the rotor under full engine power conditions.

A testing arrangement whereby the power output from the test gearbox can be returned to the system through a 'slave' gearbox driven in reverse greatly reduces the power required from the external drive, which is normally by electric motor. The required torque can be introduced through a worm wheel and measured hydraulically. Tail rotor gears etc. can be similarly tested.

4.222 Shafting and Couplings

In contrast to gears, drive shafts and couplings are affected mainly by torsional fluctuations superimposed on a high mean torque. They are designed on such a basis, and the design should be substantiated by tests in fluctuating torsion based on the maximum expected vibratory loading.

4.223 Rotors

Although spin testing of complete rotors is necessary in any case, supplementary laboratory fatigue tests are considered essential for the hub, blades and other components. Simplified specimens representing the attachment lugs should always be tested. Experimental stress analysis, using the brittle lacquer technique, may be of value.

Attempts to induce vibratory blade bending on a test tower or on the tethered aircraft have been only partially successful, i.e. with respect to stresses near the blade root. The most satisfactory way of testing the mid portion of the blade (where vibratory bending stress is usually greatest) is by the rig testing of a number of representative specimens under combined steady tension and alternating bending.

A test rig successfully employed by the Piasecki Helicopter Corporation is described in Reference 3.

4.224 Controls

The best way of substantiating the controls is to measure the vibratory stresses in flight with a rotor deliberately chosen as being rougher in flight than would be normally allowed. Then the controls should be rig tested in the laboratory to the measured vibratory loading, factored for scatter only.

Development testing before flight may be carried out on selected control components if thought desirable.

4.225 Complete Transmission System

Useful data for limited approval can be obtained during the early ground testing of the rotorcraft (see para. 4.3). This testing may be combined with other testing, e.g. gearbox temperature observations.

Especially important is the investigation of transitory vibration accompanied by high fluctuating torsion. The investigation should therefore cover the effects of clutch engagement and of engine 'coughing'.

The vibrational behaviour of the engine and cooling fan may not be the same when mounted in the rotorcraft as in a test rig, even though in the same attitude, a further reason for thorough ground testing.

4.3 Ground Testing of Rotorcraft and Clearance for Flight

It is standard practice with prototype rotorcraft to complete a ground endurance test satisfactorily before clearance for flight handling trials. For testing procedure, see Appendix II. Strain-gauge equipment is applied to measure oscillatory stresses. Such a test, in addition to checking that the functioning of all parts and equipment is satisfactory, serves the purpose of demonstrating that there are no conditions of resonance, whirling or high stress.

Vibratory stresses in the transmission should be measured; also vibratory angular movements of engine block, etc. It is necessary to arrange for the recording of transmission torque fluctuations due to clutch engagement. The D. Eng. R.D. Specification for helicopter transmissions (No.2061) requires that the engagement of the clutch, whether automatic or self-controlled, shall be smooth and free from snatch. See also remarks on ground resonance tests, para. 4.31.

Detailed inspection before and after the test ensures that no parts have suffered undue wear or attrition.

Ground endurance running can be regarded as part of the fatigue testing programme, as it may sometimes indicate possibilities of fatigue trouble due to malfunctioning or vibration which would not be shown by testing the parts or assemblies individually; but fatigue substantiation, as distinct from clearance for flight trials, must be established separately by testing under factored alternating loads. From both the functional and the fatigue aspects it is reasonable to base clearance for 25 hours' flight testing of a prototype on 50 hours of satisfactory ground running followed by inspection. The ratio of $\frac{1}{2}$ is a precaution against scatter in endurance, applicable in the early stages only. For periods beyond 50 hours' ground running, a ratio of 1 hour's flight to 2 hours' ground running is not a complete safeguard against fatigue unless the cyclic loads have been suitably factored.

4.31 Ground Resonance Tests

Ground tests should include an investigation of ground resonance.

Any tendency to develop ground resonance should be eliminated and a report by the firm prepared in consultation with the test pilot should be required, giving particulars of all tests, modifications, precautions, or limitations in take-off or landing.

Measurement and evaluation of stresses in flight

4.4 Flight Load Measurements

When the prototype is cleared for a limited flight envelope, measurements should be made of the vibratory induced loads in flight.

The normal method of measurement is by means of strain-gauge recording equipment, transmitting signals through slip-rings where necessary. Strain gauges should be arranged so as to measure induced mean and vibratory loads in blades, hub, transmission, controls, etc. in such a manner that these loads can be accurately related to the rig loading on the ground.

Calibration for induced loads (e.g. blade bending moments, shaft torques, control rod tensile loads) should be made by static loading. Provision should also be made for spot calibration in flight for indicating local stress. The first flight stage is confined to a limited flight envelope. A preliminary fatigue assessment should then be made before flying is continued. The second stage involves a defined envelope of manoeuvres; and the final stage involves an increasing envelope, covering eventually the full declared flight envelope and a full schedule of manoeuvres.

In general, at least three separate records should be obtained for each flight condition to ensure as far as possible, that variations in flying technique and general conditions are covered.

The complete set of flight load data forms the basis for the substantiation for fatigue.

4.5 Substantiation for Fatigue (procedure)

The designing firm should be responsible for showing that there are acceptable fatigue safety factors on all primary components with respect to the comprehensive flight strain gauge load measurements.

4.51 Method of Substantiation

4.511 Substantiation for Virtually Infinite Life

Three different methods of substantiation are proposed:-

(a) If the fatigue strength of the component is already known the component may be considered subtantiated for virtually infinite life if the fatigue strength (expressed as alternating load for 5 million cycles) is at least 1.5 times the maximum sustained alternating load measured in flight (i.e. at critical manoeuvre or forward speed).

(b) An ad hoc test of the critical region of the component is made under suitably factored loads. For substantiation, the test must run to at least 5 million cycles without failure. Test load factors are given in Appendix 1 para. A.1.

(c) Subject to official agreement, well-established data for similar mechanisms or parts may be used as a standard. This procedure is not allowable unless quality control of materials and workmanship is subject to an agreed specification.

4.512 Substantiation for Finite Life (Retirement Life)

In general, the amplitude of vibratory load will vary with engine speed, forward speed of the aircraft, and pilot's action. Thus the load-frequency graph for a certain flying time, as in fixed-wing aircraft, will show a large number of small fluctuations, a less number of medium fluctuations, and a small number of high fluctuations. For some parts, even the latter may not be great enough to cause fatigue damage; for others, a comparison with the relevant endurance curve may show that the part will have a finite life.

In the latter case, the American practice has been to compute the life corresponding to the lowest test results and assign a definite allowable flying time or 'retirement life', after which the part must be replaced. In assigning this life a typical load-frequency graph or 'load spectrum' must first be obtained experimentally. The fractional damage occasioned by the different load levels in a given flying time is then calculated, and added up assuming the validity of the Miner Cumulative Damage Rule. A conservative 'retirement life' is then fixed by assigning a safe endurance factor to cover uncertainties. It may be, however, that vibratory loads high enough to occasion damage occur only during infrequent manoeuvres of short duration, so that the total safe flying hours are ample under normal operation.

The policy of fixing a safe retirement life is a costly one, which, because of the need for conservatism, may result in the retirement of parts long before it is really necessary. This is undesirable, especially in Service aircraft. Hence the importance of designing for virtually infinite life. Where this is not feasible, the policy advocated here is to determine, if possible, the endurance limit, so as to fix a "threshold of damaging vibratory loading". All vibrations above this level should be treated as if they were in fact equal to the maximum vibratory load. Alternatively, a rig may be arranged whereby a programme of mixed factored vibratory loads (duty cycle) is applied. More specific proposals will be found in Appendix I. para.A.3.

Substantiation can be allowed for a retirement life corresponding in the severest possible service to the allowable endurance. Thus, if the highest percentage of total flying time that the component is subjected to damaging vibratory loads be p and the frequency of these loads in flight be n cycles per second, the permissible 'life' in flying hours can be expressed as

$$\frac{100}{p} \times \frac{\text{Allowable endurance (cycles)}}{3,600\ n} \qquad (1)$$

the "allowable endurance" being as defined in para. 2.21. This estimate will be a conservative one to the extent that the test vibratory loads are more severe than the average damaging vibratory loads in service.

4.6 Fatigue in Relation to Type Approval Tests

The type approval test is a thorough functional endurance test of the complete rotorcraft and power plant. There should be reasonable grounds for confidence in the fatigue safety of the components before a type test is made, and the type test itself cannot establish fatigue life.

4.7 General Consideration

4.71 Inspection and Maintenance

New types under service trials should be examined at strip overhauls by specially trained personnel. Substantiation for fatigue, however done, cannot be valid unless rotorcraft in service are maintained in satisfactory mechanical condition. It is necessary not only to prevent excessive vibration due to wear, but to inspect thoroughly for surface markings such as could accelerate fatigue. Crack detection, normally carried out as a routine at periodic overhauls, can sometimes indicate incipient fatigue trouble. Attrition in any form, of which 'fretting corrosion' is an example, is highly undesirable. So too are score marks. In rotor heads, adequate clearances on re-assembly may be vital.

For Service use, the rotorcraft must stand up to Service conditions, and deterioration should be considered in fixing fatigue life, (e.g. 'indefinite life'). The Services require the maximum possible time between overhauls. Special requirements can be given in maintenance and servicing manuals.

4.72 Checking of Vibration

Pilots should be instructed to report unusual vibration of any sort, and a drill for ground checking of vibration should be laid down for each type of rotorcraft. Any abnormal vibration may be a warning of excessive vibratory stresses due to mal-adjustment or imperfect condition of the engine, transmission, or rotors. For example vibratory torques in the transmission during flight depend very much on engine condition. Any defect affecting the smoothness of power delivery, e.g. fouled sparking plugs, or uneven carburation, will increase the engine-excited torsional vibration. Imperfect tracking of rotors is a frequent source of vibration.

5 Comprehensive System of Development and Testing

The fatigue evaluation should be woven into the general development programme in accordance with the following scheme.

Prototype tests should be made in accordance with current British Civil Airworthiness Requirements[1]. The relevant paragraphs of the Recommendations Appendix to Chapter G7-1 of Reference 1 are quoted where applicable.

	Procedure	Ref. 1 Para. No.	Remarks
A	**Design Stage**		
	(1) Tests of new forms of construction. 'Fatigue Proofing' by design		
	(2) Preparation of fatigue estimates, code of manufacturing finish, and assembly clearances.		See paras. 3.1, 4.1
	(3) Consultation with advisory body on fatigue estimates.		
B	**Development Stage**		
	(4) Limited fatigue testing of components and assemblies in conjunction with functional rig tests. Spin test of complete rotor system to an agreed schedule.	2.11 2.12	See para. 4.2
	Prototype Testing (See Appendix II)		
	(5) Exploratory ground testing of the prototype rotorcraft, including ground resonance tests and vibration measurements to an agreed schedule.	2.13	See para. 4.3
	(6) Ground running test of complete rotorcraft (not less than 50 hours)	2.14	
	(7) Clearance for preliminary flight to assess control characteristics	2.15	
C	**Flight measurement Stage**		
	(8) Flight strain-gauge measurements in three stages:- (i) to a limited flight envelope, (ii) to a progressively increased envelope, (iii) comprehensive flight envelope up to maximum forward speed and including all manoeuvres.	2.17	See para. 4.4
D	**Fatigue Evaluation**		
	(9) Evaluation by firm of flight vibratory stresses		
	(10) Ad hoc rig tests if shown necessary by (9)	2.19	See para. 4.5
	(11) Fatigue Substantiation, including the assignment of retirement lives where necessary.		

Note: Additional testing, not covered in this Note, includes the following:- Type approval test - See British Civil Airworthiness Requirements (G7-2)

Performance trials.

6 Conclusions

The procedure suggested in para. 5 is governed by the three basic principles stated in para 3.

The pre-flight work (which should be sufficient to give confidence in the safety of the rotorcraft in a normal flight envelope for a reasonable period) begins in the design stage, when established 'fatigue proofing' principles are applied and, as far as possible, specific vibratory stresses allowed for.

As much pre-flight development fatigue testing as possible should be done, having regard to the proper balance between time schedules and safety.

Full substantiation for fatigue necessitates a reliable determination of the more damaging vibratory loads in flight, together with the fatigue testing of components and assemblies under suitably factored vibratory loads. Provisional factors are given in Appendix I, and procedures for substantiation are given under para 4.5. Special test rigs are necessary for the different assemblies or components.

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No.	Author	Title, etc.
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3	Earl T. Ireton Jr.	Simulated Service Testing of Rotor Blades. Amer. Helicopter Socy. Proc. Ninth Ann. Forum. May, 1953.
4	P. H. Frith	"Fatigue Tests on Rolled Alloy Steels made in Electric and Open-Hearth Furnaces" Iron & Steel Institute Report No. 50, p.127. October, 1954.

APPENDIX I

Ad Hoc Rig Testing (Para. 5 Stage (10))
(See Para. 3.3)

A.1 Test Load Factors

A.2 Duration of Tests

A.3 Test Load Factors for Finite Life Cases

A.1 Rig Test Load Factors for Ad Hoc Tests (applicable to alternating load only)

Substantiation for Virtually Infinite Life

Roughness factor* (to cover flight variables, increased vibratory load due to wear etc.)	1.2
Material and finish scatter factor**	1.2
Combined factor	1.4
Extrapolation factor*** (aluminium alloy parts, "virtually infinite life": extrapolation from 5×10^6 test cycles to 10^9 cycles)	1.35
Ditto from 50×10^6 cycles to 10^9 cycles	1.2

* The factor suggested is a tentative one. Experience shows that the increased roughness due to wear may give rise to increased vibratory loads in some components before the aircraft is due for overhaul. If the test is made with worn parts and the loads are occasioned mainly by wear, this factor may be omitted when applying the maximum vibratory loads measured in the worn parts in service.

** If 3 specimens are tested or if the test specimen is below minimum metallurgical acceptable standard this factor may be reduced to 1.1.

*** For alloy steels heat treated to above 60 tons/in.^{2} U.T.S. the endurance limit may not be reached at 5 million cycles. P. H. Frith[4] gives the following data:

60 T/in.^{2} U.T.S. endurance limit at 20×10^6 cycles
80 T/in.^{2} U.T.S. endurance limit at 40×10^6
110 T/in.^{2} U.T.S. endurance limit beyond 10^8 cycles.

Thus, high tensile steels require an extrapolation factor from 5×10^6 to 10^9 cycles, though a smaller one than that suggested for aluminium alloys. The value can be determined by reference to the Wohler endurance curve for the particular steel and heat treatment.

A.2 Duration of Test

When the testing frequency is sufficiently high, (e.g. rig tests of controls, simplified sections of rotor blades, transmission parts etc.) tests should be run if possible to 50 million cycles. Otherwise, tests for "virtually infinite life" should be run to at least 5 million cycles or prior failure. For "finite life" cases, tests should be run to failure.

A.3 Test Load Factors for Finite Life Cases

For finite life cases (see para. 2.6) the component should be tested to failure at unfactored mean load and vibratory load based on the most critical flight condition(s). If the aircraft on which the vibratory loads were measured is known to be exceptionally rough as regards the parts under consideration, the roughness factor may be reduced. But, if the aircraft is a random sample, of average roughness, a roughness factor of 1.2 should be applied. A scatter factor in accordance with para. A.1 should be applied to the alternating load.

In tests where it has been agreed to omit the scatter factor on the vibratory load (see para. 2.21) the allowable endurance is found by dividing the geometric mean* test endurance by a factor depending on the number of specimens, as indicated in the following table:

Number of specimens tested	1	3	6
Scatter factor on life	6	4	3

Depending on the difference in level between the maximum and the normal vibratory loads and on the relative duration per flight of the maximum load conditions, separate testing at factored normal continuous vibratory load may be necessary.

The calculation of retirement life is given by formula (1) in para. 4.5.12.

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*The 'geometric' mean is identical with that formerly termed the 'logarithmic mean'.

APPENDIX II

Sequence of Ground Testing Recommended by the Air Registration Board

(Extracted from B.C.A.R. Ch.G7-1. Issue 1. 1.1.54. Appendix Para.2)

Sequence

2.1 Whenever possible, the following general sequence should be adopted:-

2.11 Design development rig tests of components.

2.12 Spin test of complete rotor system to an agreed schedule.

2.13 Exploratory ground vibratory stress investigations on the complete rotorcraft, for the purpose of measuring torsional vibration and whirling of transmission shafting. Measurements to be made so far as practical over the full working range of speed and power, and during starting and stopping. The tests to include a preliminary investigation into the vibratory stresses in the rotor system.

2.14 Not less than 50 hours test of the complete rotorcraft on the ground to an agreed schedule. At the conclusion of the test a partial strip examination of all vital mechanical parts, excluding the engine, to determine whether they are in a safe condition to commence flight testing.

NOTE:- The Recommendations also cover flight testing. For details, the reader is referred to the original document.

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