

GENERAL PRINCIPLES OF DESIGN IN RELATION TO FATIGUE

INTRODUCTION

This Item outlines some general principles and procedures that are relevant to the design of aircraft components subjected to fatigue loading. The matter is presented under the following headings.

1. Fatigue loads,
2. Allowable stresses,
3. Detail design, and
4. Effects of manufacturing procedures.

The order in which items are dealt with does not necessarily indicate their relative importance. More detailed guidance on many of the aspects covered may be located by reference to the Engineering Sciences Data Index.

1. FATIGUE LOADS

The first essential of satisfactory design in relation to fatigue is a correct evaluation of the loading conditions, remembering that almost all aircraft components are liable to be subjected to fatigue loading and that the conditions of loading are often complex, subjecting the part to fatigue stresses that are significant under more than one combination of amplitude and frequency of occurrence.

Fatigue loads vary with type of aircraft. Although particularly important in relation to civil aircraft they must also be considered in the design of military aircraft. They are influenced by operating conditions, for example, atmospheric gusts whose frequency decreases with increase in altitude, and by the ground to air cycle, the importance of which is liable to be underestimated.

Fatigue loads that merit systematic assessment in design may conveniently be classified as those that occur infrequently, and those that occur many times per flight. The most important loads are listed below.

Loads that Occur Infrequently (Once or Twice per Flight)

- Steady wing lift and rotor loads
- Tail unit balance loads
- High-lift-device and airbrake loads
- Steady aerodynamic loads on fuselage
- Engine thrust and reverse loads
- Cabin pressure loads
- Undercarriage loads resulting from retraction, extension and landing impact
- Catapult and arrestor loads
- Thermal loads arising from supersonic flight
- Steady ground loads.

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Loads that Occur Many Times per Flight

Wing and rotor loads	}	due to gusts, manoeuvres, fuel usage and changes in trim
Tail loads		
Fin loads		
Fuselage loads		
Flap and flap attachment loads		
Control-surface and control-surface attachment loads		
Helicopter rotor fluctuating loads and rotor-induced loads		
Speed-control, and airbrake loads		
Control-surface hinge loads resulting from vibration		
Undercarriage oscillating loads, due to drag, roughness and use of brakes and steering		
Hydraulic-system loads		
Air-system loads		
Fuel-system loads		
Flying-control system loads.		

Loads resulting from:

- Buffeting
- Pressure fluctuations due to slipstream, jet efflux and boundary-layer turbulence, for example, acoustic effects
- Propeller and engine vibrations
- Tail-plane and fin vibrations during engine run-up.

Loads due to use of armament.

2. ALLOWABLE STRESSES

For preliminary design purposes fatigue loading spectra for aerodynamic loads are estimated from available information. Subsequently and as soon as possible these should be verified and corrected from flight-record data.

The number of cycles of stress that a part will withstand without failure increases as the range of stress decreases and for some materials an infinitely long life may be expected, provided that the range of stress is sufficiently low. In most cases, owing to the need to economise in weight, structures are designed for a finite life.

Variation from the estimated average stress spectrum and the corresponding mean life to failure (estimated or from test), arising from both inherent scatter and estimation errors, and progressive deterioration in service are allowed for by an overall 'life factor'. The magnitude of this factor, generally between 2 and 10, depends on the type of construction, the methods of load and life estimation (for example, whether test or calculation), the degree of monitoring of loads in service, *et cetera*. The value used in a particular instance is specified by, or agreed with, the appropriate airworthiness authority.

In certain cases, where the fatigue endurance required is relatively great (for example, greater than 10^7 cycles), it may be preferable to apply a factor to stress rather than life, for example, in the design of helicopter transmission and rotor components.

An increase in the tensile mean stress reduces the alternating stress that would produce failure at a given life.

The effects of stress concentration and fretting on fatigue life need to be considered. Comparison of test results obtained on plain test pieces with those obtained on joints and a complete structure shows the considerable magnitude of these effects.

The safe fatigue life of a part can be highly dependent on the rate of crack growth. By the time a fatigue crack of recognisable size (0.010 in (0.25 mm) without magnification and 0.003 in (0.075 mm) with magnification) is detectable, a considerable proportion of the life of the part (variously stated as 30 to 80 per cent) has been consumed. Consequently consideration of crack propagation rates and fracture toughness is important.

In order to establish the permissible design stress and the size of member required, the fatigue loading data must be combined with relevant fatigue test data, and in the absence of precise information the following Cumulative Damage Rule may be used to estimate the life when the part operates under a spectrum of loading. The rule may be stated as

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} \text{ et cetera} = 1 \text{ at failure,}$$

where n_1 is the applied number of cycles at a given stress level and N_1 is the number of cycles required to cause failure at that stress level, and so on for n_2 , N_2 et cetera. It should be remembered that the stresses discussed include the mean stress.

Permissible design stresses should not be established by calculation alone, particularly when complex loading cycles are involved. Fatigue tests should be run at an early stage to confirm predictions.

3. DETAIL DESIGN

Under static load the ductility of most materials partially reduces the effect of local stress concentration. However, under fatigue conditions local stresses are important and careful detail design that will minimise stress concentration is therefore vital. It also follows that the permissible design stress can vary widely, depending upon the particular detail design features.

This section therefore lists a number of points of detail design that are of importance in reducing stress concentration.

Design parts to be as symmetrical as possible with respect to the principal loading path. When appreciable lack of symmetry is unavoidable, pay particular attention to the consequent local bending actions, and make the necessary reinforcements.

Avoid abrupt changes in cross-section and provide generous fillets at the intersections of all integral structural elements. If stepped tapers are employed, for example, in joint splices, use generous radii in the steps.

Avoid all sharp corners and edges, and radius the edges of holes. Spot facing should be done with a radiused tool and counter-sinking must not penetrate through the member and thereby produce a feather edge.

Avoid joggles in highly stressed tension – compression members such as stringers.