# A Case Study on Fatigue Failure in Air Crafts

**GnanaTejesh M[1], Chilamakuri Bhavesh[1], Harikrishna Reddy L[1], Revanasiddappa M[2]**

[1]Department of Mechanical Engineering PES Institute of Technology-Bangalore South Campus, Karnataka-560100, India [1]e-mail:gnanat_m@yahoo.com

[2]Department of Engineering Chemistry PES Institute of Technology-Bangalore South Campus, Karnataka-560100, India
[3]email:revum75@gmail.com

**Abstract:** ***Fatigue is a failure whereby cracking occurs under the influence of repeated or cyclic stress, which are normally substalially below the nominal yield strength of the material. In general, Fatigue failures occur when a component or structure is no longer able to withstand the stress imposed on it during operation .Commonly failures are associated in aircrafts with stress concentrations which mainly occur due to design errors, corrosion, variation in micro structure of the material, etc. Fatigue failure was first discovered in the railroad industry. This industry presented some of the first situations where extensive reputation of mechanical loading of metal parts caused failures. As sources of vibration and of dynamic loading of materials have increased, fatigue failures have become increasingly important in Engineering. Failure of an aircraft structural component can have catastrophic consequences, with resultant loss of life and of aircraft .Perhaps nowhere is the prevention of failure by fatigue more important than in the aircraft industry. The main objectives of this paper is to illustrate the failure occurred in aircraft due to fatigue and to suggest in what manner the failure can be minimized relevant to Engineering.***

**Keywords:** fatigue; aircraft; railroad; stress

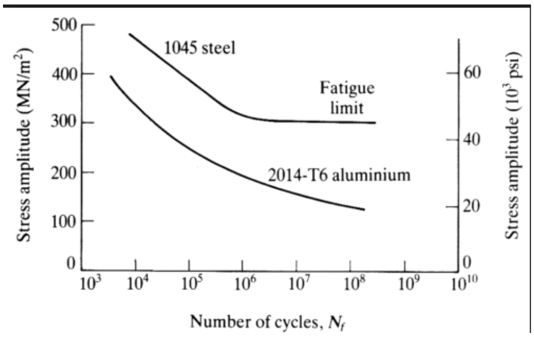
## 1. Introduction

Fatigue is a special type of failure in which fracture of a material occurs not because of an instantaneous load that is applied using a crack to grow. Rather it is because a repetitive or fluctuating stresses are applied for a period of time, in which the crack gradually propagates until it reaches the limiting or critical stress. Fatigue failure may take place even before the yield point is reached. For an instance, the yield strength of mild steel is 220Mn $m^{-2}$, but it will tend to fail at any earlier level of stress value (i.e. at a stress of 155 MN $m^{-2}$), if it is subjected to a very huge number of stress reversals.

Commonly shafts, connecting rods, air craft wings and leaf springs are some of the structural examples of the machine components that are subjected to billions of cycles of alternate compression and tensile stress during its period of work. Majority of failures of such components in service are due to fatigue fracture.

**S-N curve**

The fatigue behavior of any material can be best understood by conducting a fatigue test and analyzing the results from the test. For example when a test was conducted for Steel of 0.45% C and Aluminum alloy and the corresponding number of stressing is noted down. A graph of stress vs number of cycles to fail is plotted as shown in the below diagram.




This is also called as S-N curve or fatigue life curve .this serves a useful way to analyze or visualize the time to failure for a specific material under a particular stress .From the graph we can understand that for any material ,the stress to cause failure decreases as the number of cycles increases or in other word ,the fatigue strength decreases as the number of cycles is increased up to certain limit and then at a certain limiting stress the fatigue limit remains constant with increased number of cycles (endurance limit) ,in the case of steel or the fatigue limit may decrease continuously as the number of cycles increases, as in the case of aluminum.

**Fatigue Failure**

Fatigue failures can widely be classified into two types. They are failure due to fracture and failure without fractures. Each of these categories can be further classified based upon whether they are caused by mechanical, chemical or thermal influences. Mechanical failures are further classified based upon the nature of forces, whether they are by repetitive or monotonic loads.

As air craft components are generally subjected to undulating stresses irrespective of the mechanism of crack initiation, ultimately fail by fatigue failure. Despite the fact that most engineers and designers are aware of fatigue, and that a vast amount of experimental data has been generated on the fatigue properties of various metallic and non-metallic materials, fatigue failures of engineering components are still common. Majority of services failures in air craft components occurs by fatigue and it amounts to about 60% of the failures. Some of the factors influencing the fatigue life of the components in service, which are as follows. Complex stress cycles, engineering design, material of construction etc. From the previous records, we can estimate that we can estimate the frequency of failure mechanism. Which is as shown below in the table, so we can say that the incidence of fatigue failure dominates the distribution in aircraft.

| Failure Mode | Engineering Components (%) | Aircraft Components (%) |
|---|---|---|
| Corrosion | 29 | 16 |
| Fatigue | 25 | 55 |
| Over load | 11 | 14 |
| Wear/abrasion/erosion | 03 | 06 |
| High temperature corrosion | 07 | 02 |
| Creep | 03 | - |
| Corrosion fatigue | 06 | 07 |
| Brittle fracture | 16 | - |

Failure of a component due to fatigue usually undergo three stages, they are

- Nucleation of crack - this is due to brittle particles, stress raisers such as flaws, holes etc.
- Propagation of crack – when the crack propagates, the load carrying capacity in the region of crack decreases, due to which the area left fails to support the load.
- Fatigue fracture – when critical crack length is reached by the crack, the material that has not been affected by the crack is no longer strong enough to withstand the applied stress, and hence permanent failure occurs.

## 2. Factors Promoting Fatigue Failure

Failures generally occur when the structure is not able to sustain the load imposed on it during its service. The factors that initiate and propagate a crack thereby causing a material to fail are as follows

**1) Corrosion**

Corrosion can be defined as the degradation of a material due to its reaction with the environment. Degradation implies decrease in physical properties of the material. This can be a weakening of the material due to a loss of cross-sectional area, it can be the shattering of a metal due to hydrogen embrittlement, or it can be the cracking of a polymer due to sunlight exposure. Corrosion plays a very vital role for the fatigue fracture to take place. There are many different types of corrosion, each of which can be classified by the cause of the metal's chemical deterioration.

**2) Pitting Corrosion**

Pitting results when a small hole, or cavity, forms in the component, usually as a result of de-passivation of a small area. This area becomes anodic, while part of the remaining metal becomes cathodic, producing a localized galvanic reaction. The deterioration of this small area penetrates the metal and can lead to failure. This form of corrosion is often difficult to detect due to the fact that it is usually relatively small and may be covered and hidden by corrosion-produced compounds.

**3) Galvanic corrosion**

Occurs when two different metals are located together in a corrosive electrolyte. This type of corrosion mainly occur due to material selection and poor design. A galvanic couple forms between the two metals, where one metal becomes the anode and the other the cathode. The anode, or sacrificial metal, corrodes and deteriorates faster than it would alone, while the cathode deteriorates more slowly than it would otherwise.

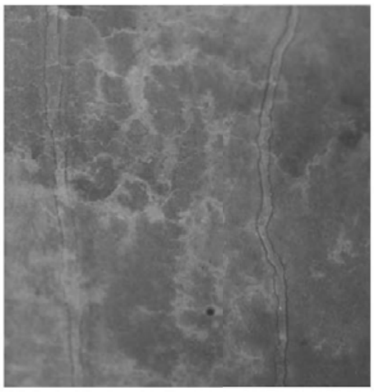


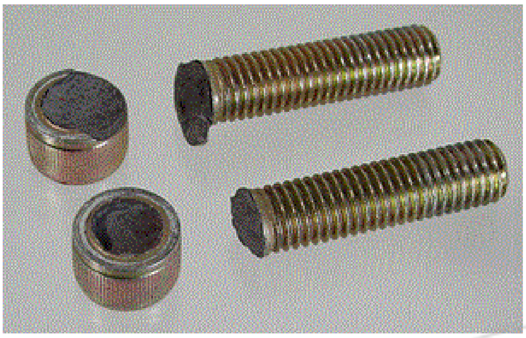
FIGURE 6.30 Double-pane window completely "frosted" due to a broken seal and subsequent corrosion of the glass material.

**4) Crevice corrosion**

This type of corrosion is often associated with a stagnant micro-environment, like those found under gaskets and washers and clamps. Acidic conditions or a depletion of oxygen in a crevice can lead to crevice corrosion. Crevices can be formed at joints between two materials, e.g. threaded or welded structures, contact of a metal with a nonmetallic material, or a deposit of debris on the metal surface.

### 5) Hydrogen embrittlement

Embrittlement is a phenomenon that causes loss of ductility in a material, thus making it brittle. The brittleness is due to introduction and subsequent diffusion of hydrogen into the component. This basically occurs during forming and finishing operations. For aircraft components, the common source of hydrogen embrittlement is hydrogen absorption during manufacturing processes such as electroplating etc.



### 6) Stress corrosion

Stress-corrosion cracking refers to cracking caused by the simultaneous presence of tensile stress and a specific corrosive medium. During stress-corrosion cracking, the metal or alloy is virtually not attacked over most of its surface, while fine cracks progress through it. This cracking phenomenon has serious consequences since it can occur at stresses within the range of typical design stress.

### 7) Design errors

Design features like grooves, keyways, holes; sharp corners etc. act as stress riser and fatigue crack initiation site. Therefore these features should be carefully designed to minimize the crack initiation. Most of the air craft's fail due to poor design techniques followed by the engineers. Due to poor designs, the crack gets initiated and the stress concentration magnifies the stresses at the crack tip. As a result the cracks will grow much more quickly causing the component to fail far before its yield strength.

### 8) Defects in Micro structure

Temperature of the material affects the behavior of the component when subjected to uneven loads. Many materials, which are ductile at high temperatures, become brittle at low temperatures. This tends to change in micro structure and continuous changes from ductile to brittle composition will lose its strength and hence fail.

The ductile failure occurs when a material has been exposed to an applied load at a relatively slow rate to the breaking point of the material. Whereas on rapid application of load, brittle fracture takes place.

## 3. Examples of fatigue failure

Till now we have seen the causes for the fatigue and how it fails. Now we have some of the examples as where and why the failure takes place.

### 1) Landing Gear Failure

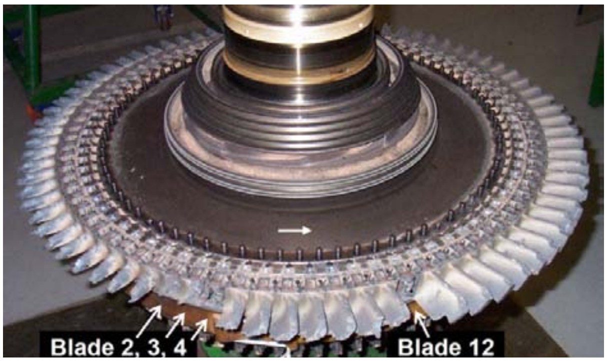
Landing gear is the undercarriage containing wheels equipped with shock absorbers supporting the aircraft when it is not flying. i.e. when the flight is landing or taking off. During landing and takeoff of air craft, the loads fall on the landing gear and hence they are made with strong materials. But these components fail when they are worn out before their allowable service limits. The Incident shown below has occurred in Cessna L19 Bird Dog aircraft that had suffered the failure of an axle in the landing gear when it landed on rough terrain.

### 2) Journal Bearing failure

Fatigue failure in journal bearings usually involves multiple cracking of the liner material and often spalling and subsequent disintegration. To evaluate separately such characteristics as fatigue resistance and wear resistance is difficult. Moreover, some essential requirements of a good liner material—such as wear resistance, resistance to seizure, low coefficient of friction, and corrosion resistance - are sometimes incompatible with high resistance to fatigue under the rolling load stresses in a bearing. The fig. shown below depicts how the bearing cage has failed.

### 3) Failure due to Turbine Blades

Wear, Thermal stress, and material damage produce an impact on high-cycle fatigue failures in aircraft engines. The load on turbine blades of aircraft engines comprises of an axial load. The axial load is the centrifugal force combined with the tensile and compressive loads, caused by the vibrations of the blades themselves. When these vibrations exceed the threshold frequency the crack propagates and hence fails. The failure can be seen in the picture below.




## 4. Fatigue Protection Methods

Fatigue fracture is the common cause for an air craft failure. Here are some of the preventions which can be taken into account to improve the fatigue life of the materials. They are as described below.

**1) Stress Concentration**
Is one of the most important factors to be taken care off. The stress on any component should be given uniformly. If not uniformly at least with slight variation the load distribution can be made. But make sure that the load distribution will not exceed the threshold or limiting stress value. Up to certain extent, stress concentration should be reduced in the initial stages of design of components. For example, components like grooves, keyways, holes, etc. act as crack initiators. Hence these should be taken care as they have sharp edges. Fatigue life of shafts can be improved by providing with a round fillet at the point where there is a change in dimension.

**2) Surface Conditions**
Cracks formation generally starts from the surface of the material. So the surface of the component should be made smooth so that stress risers are minimized and crack doesn't initiate at less load levels. Case hardening can be done to increase the surface hardness and smooth. Polishing and galvanizing are also some of the methods to increase the fatigue life of the components.

**3) Corrosion**
Chemical attack or corrosion on a component reduces the fatigue life. As it enhances the crack propagation. Here are some of the important aspects one should take care off so that corrosion can be minimized to some extent.

- Selecting materials with high fracture toughness and slow crack growth.
- Using metals that are not dissimilar. Sing higher alloys for increased resistance.
- By adding protective coatings to the material.
- By keeping the working environment frequency away from the natural frequency of the structure.
- Choosing metals having low coefficient of expansion for mating parts.

**4) Residual Stresses**
Compressive residual stresses oppose the tensile load and hence decrease the cyclic load amplitude. Therefore few machining process such as cold working, carburizing, shot peening etc. are good for the component because they induce compressive surface residual stress ,as a result the fatigue life is increased.

## 5. Conclusion

Fatigue cracking is the most common cause of structural failure in aircraft. Case study of fatigue failures in aircraft gives us the basic knowledge of different types of fatigue failures in aircraft and steps to prevent them. This helps us to analyze and observe where the basic fatigue failures can occur in aircraft and how it helps us in improving the safety of aircraft and prevention of fatigue failures in aircraft.

## References

[1] https://en.wikipedia.org/wiki/Stress_corrosion_cracking
[2] Material science and engineering, V Raghavan, PHI.
[3] https://en.wikipedia.org/wiki/Hydrogen_embrittlement
[4] http://www.corrosionclinic.com/types_of_corrosion/pitting_corrosion.htm
[5] http://www.preservationscience.com/materials/metals/PGC.html
[6] Corrosion Engineering Principles and Practice by- pierrer.roberge
[7] FATIGUE OF AIRCRAFT STRUCTURES by- Horace J. Grover, Battelle Memorial Institute.
[8] http://www.efunda.com/formulae/solid_mechanics/fatigue/fatigue_reduction.cfm