Chapter 8 – FRETTING CORROSION AND FATIGUE

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8.1 INTRODUCTION

Virtually all mechanical joints of fixed wing aircraft, rotary wing aircraft, engine and propulsion systems, gearbox and other electrical and mechanical components of aircraft are susceptible to the occurrence of fretting fatigue. The complexities of fatigue design, either safe-life or damage tolerant or HOLSIP (Holistic Structural Integrity Processes), are enough to challenge the most talented technical personnel. Add to that the occurrence of fretting and truly complex phenomena occur that require a fully comprehensive structural integrity design policy.

Fretting fatigue was originally discovered in the early part of the 20th century. Since that time a great deal of work has been done to understand the mysteries of fretting fatigue. As well, engineers have devoted a significant effort to studying fretting fatigue to be able to cope with the potentially deleterious effects it may have on the life of engineering components.

Fretting is a phenomenon that involves both environmental effects (corrosion in metals) and wear. Thus, it is a complex phenomenon. Figure 8-1 shows some of the parameters involved in fretting fatigue. When it acts with cyclic loading on engineering components the result frequently is to either shorten the fatigue life or to lower the fatigue design allowable.

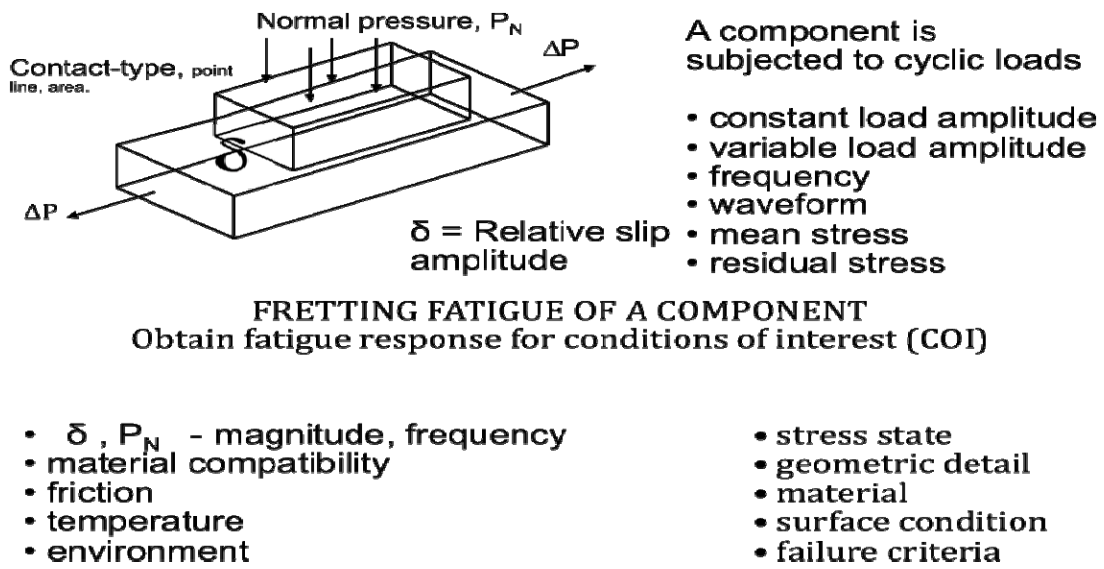

Figure 8-1: A Depiction of the Large Number of Parameters that may be Involved in Fretting Fatigue (the view shown in the upper left depicts single sided contact but many contacts are double sided) – from Hoeppner, 1991.

Historically three approaches have been employed in fretting fatigue studies as shown in Figure 8-2 below. One approach is to perform fretting fatigue testing by simulating the contact or fastening conditions.

The fretting fatigue test results thus generated are used to determine the fretting fatigue life reduction factor K_{ff}. Although this approach has been to introduce a fretting fatigue life reduction factor into the fatigue design process this is not always a satisfactory procedure. A second approach is to develop the fatigue structural allowables by testing the mechanical joints and including fretting considerations in these tests including the alleviation or prevention schemes. Another approach is to use a fretting protection and control plan to focus on potentially blocking the occurrence of fretting or to prevent the propagation of cracks from fretting damage areas. This approach simulates fretting damage that will assist in developing greater understanding of the basic mechanisms of fretting which in turn will lead to the development of standardized fretting fatigue test methods. In addition, this approach will help to find some preventive systems to alleviate fretting fatigue problems on structural components. This mechanistic approach also will be useful to develop inspection systems. Some investigators are coupling damage tolerance concepts to fretting studies to assist in more accurate tracking of damage as well as setting more realistic inspection intervals. Therefore, one of the needs for improved fretting fatigue resistance is the development of adequate experimental procedures to simulate fretting fatigue phenomena.

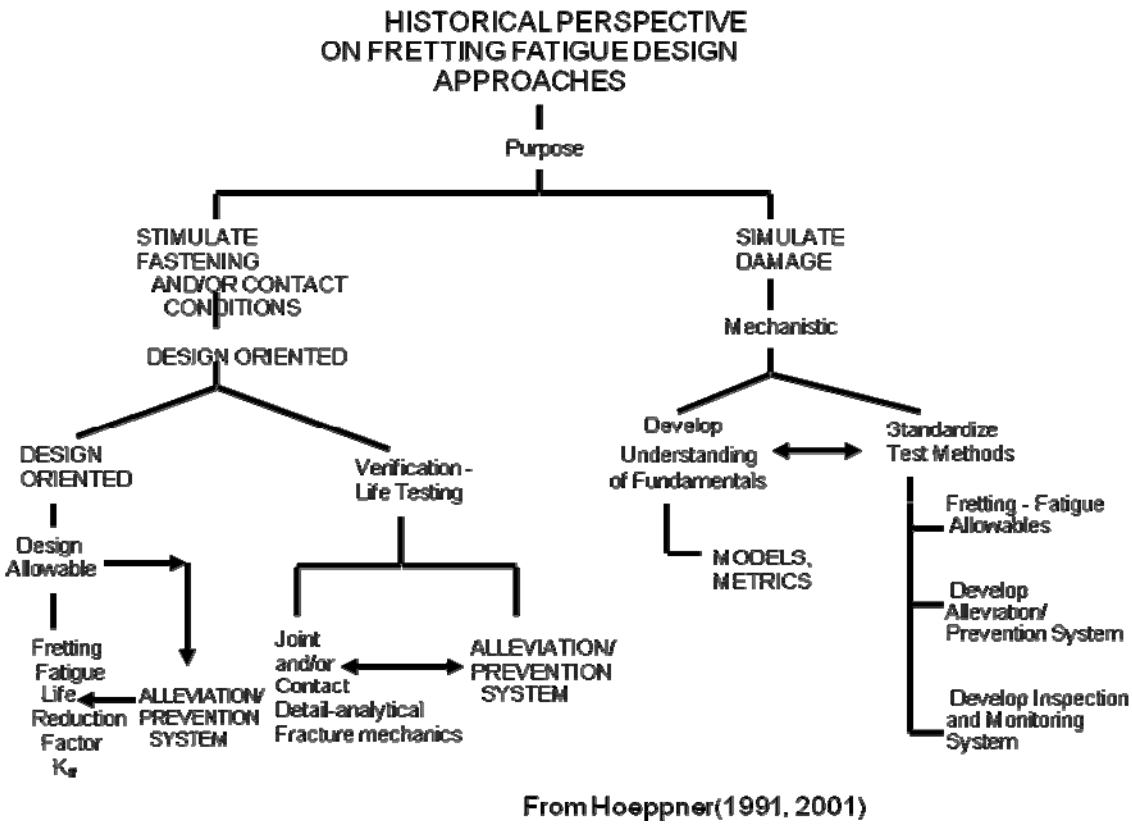

Figure 8-2: Historical Perspective of Approaches to Fretting Fatigue Design Studies.

8.2 MECHANISMS OF FRETTING

Fretting is believed to rupture the protective oxide films of the metal alloys that are in contact although the influence of oxide film is brief in the subsequent degradation mechanism of fretting. Therefore, it is commonly believed that the first stage of fretting is adhesive contact of the asperities on contact surfaces [1]. Microscopic plastic deformation of the contacting asperities in relative motion may result in the nucleation of cracks. In addition, metal transfer may occur from one surface to another depending on the hardness and the relative displacement of the contacting surfaces. The production of fretting debris and the

oxidation of the fresh surface may result in the build-up of oxides on the contacting surfaces. These may result in the formation of pits on the contacting surfaces. These damages may very well accelerate the nucleation of cracks. Depending on the contact stress state the nucleated cracks may result in early propagation in a rapid manner. Contact stresses are high enough to significantly influence crack propagation. The cracks may propagate at various rates and angles. Subsequent final propagation of cracks may depend on the bulk stress alone rather than on the contact stress. As the crack grows into the material, a depth is reached beyond which the contact stresses have little or no influence and the applied cyclic stresses play a dominant role. Therefore, the fretting process can be divided into four stages viz. nucleation of cracks, early propagation of cracks by contact stress state, final propagation of cracks by bulk stress and instability resulting in the decreased fatigue life. The aforementioned fretting process is dependent on many different variables such as material microstructure, stress state, environment, relative slip amplitude, and contact pressure.

The theories related to nucleation of fretting fatigue cracks are usually based on the adhesive contact of the asperities as well as the cracks that form sub-surface. Displacements that are “small” on a macroscopic scale are very large when acting on asperities. Relative movement of adhesively bonded asperities results in plastic or near-plastic strains around asperities. The importance of the formation of oxides may be based on their affect on adhesive contacts. Oxides usually prevent direct metal contact and reduce coefficient of friction by rolling. However, under certain conditions, such as the presence of discontinuities and/or sliding motion, cracks could nucleate sub-surface.

Dependent upon nucleation and contact stress state it has been observed that after a specific time, fretting contact no longer affects the fatigue life. This implies that nucleation occurs very early. In addition, it should be noted that fatigue life reduction occurs only after a specific amount of fretting damage and the nucleated crack must be large enough to propagate under bulk stress alone [2].

8.3 FRETTING FATIGUE IN AIRCRAFT JOINTS

Fretting fatigue has been observed as a potential degradation mechanism in aircraft structural components [3]. Many cracks have been found to originate at fasteners and on faying surfaces. Cracks may form due to fretting mechanisms from one or more rivet holes leading to the concept of multiple-site damage. Evidence supports that elimination of fretting with adhesives greatly increases fatigue life [4]. Also, it has been observed that cracks appear in lugs much sooner if fretting is present. In addition, failures observed originating at areas of fretting damage often occur away from fastener holes. Figure 8-3 shows a schematic of the design methods proposed in the past by Hoeppner [4],[5] to minimize the effect of fretting fatigue in aircraft joints. In addition, the methods to alleviate fretting fatigue challenge in aerospace components are provided in the next section.

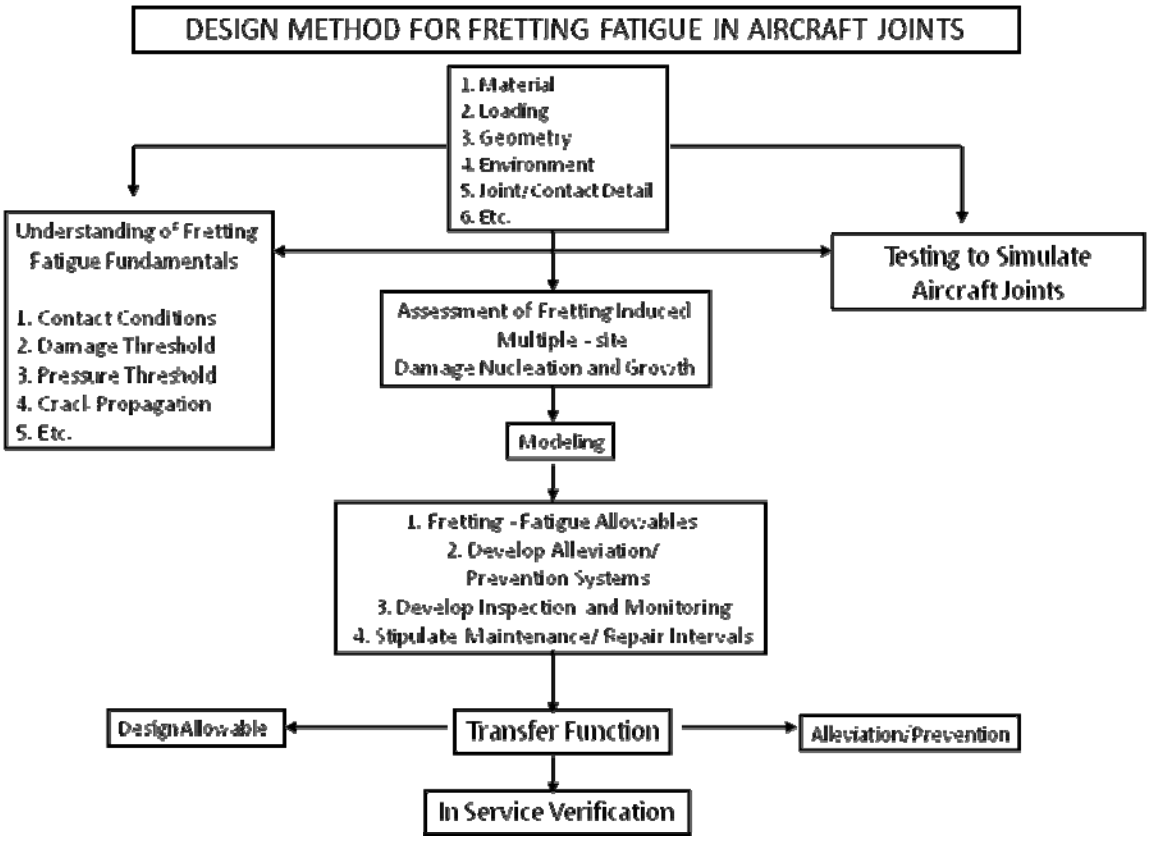

Figure 8-3: An Illustration of an Approach that has been Used to Design for Fretting Fatigue Resistant Aircraft Joints (4, 5).

8.4 REDUCTION OR PREVENTION METHODS

The following are some methods that can be employed to reduce the problem of fretting fatigue in aircraft joints [5]. It is important that a surface integrity engineering plan be developed to assure the integrity desired for fretting fatigue resistance. The items listed below will all fall within a typical surface integrity engineering plan.

I – Design

a) Prevent all relative motion of the surfaces.

b) Prevent the surfaces from contacting.

c) Surface roughness changes that may involve either an increase or decrease in roughness depending on the conditions of interest.

d) Surface hardness changes that may involve either an increase or decrease in hardness.

The most common approach appears to be to increase the hardness of the component whose life is being affected.

II – Mechanical Methods

a) Shot peening.

b) Vapour blasting.

c) Bead blasting.

d) Surface rolling.

e) Dimpling of the surface.

These methods include processes that cold work the surface to increase hardness and introduce residual surface compressive stresses.

III – Coatings

a) Hard metal coatings.

b) Soft metal coatings.

c) Polymer coatings.

There are multiple purposes to coatings. One is that they provide a separation of surfaces that are in contact. Another is that the coating may become sacrificial to the fretting fatigue loading such as in some shims or bushings. Coatings can be hard or soft depending on the overall purpose that is desired which varies with design application. On occasion the coating will be selected to provide a lower sliding frictional behavior. This usually involves extensive trial and error evaluation.

IV – Lubricants

a) Solid lubricants.

b) Greases.

c) Oils.

In the case of lubricants they too have purposes that vary with the design application. In some cases they provide hydrodynamic lubrication and thus provide a film between the surfaces that actually maintains separation. In addition, even if hydrodynamic lubrication is not attained the lubricant may provide separation and a concomitant reduction in contact force which decreases the propensity for fretting. Lubricants also provide for significant reductions in dynamic or sliding friction which also has been noted to reduce fretting thereby reducing fretting fatigue life reduction. Some lubricants also assist in fretting debris removal which is important to aiding the reduction of fretting induced surface damage. In some cases it has been noted that a temperature reduction occurs by the use of lubricants thereby decreasing the fretting surface damage as well. Each case of lubrication provides it unique challenge and to date no general design rules have emerged that are reliable for all fretting fatigue cases.

V – Surface Treatments

a) Anodization.

b) Ion implants.

c) Sulphidization.

d) Phosphatization.

Surface treatments, similar to the discussions under III and IV above, can have varying beneficial effects based on the same general principals. They have the added potential benefit of providing, in some cases, compressive surface residual stresses that also can significantly enhance fretting fatigue resistance.

VI – Influence of Substances Used in Aircraft Joints

a) Faying Surface Sealants:

- ADHESIVE types can significantly increase fretting fatigue life.

- FLEXIBLE sealants can decrease fretting fatigue life.
- Increasing sealant thickness decreases fretting fatigue life.

b) Adhesives:

- Can significantly improve fatigue life even if fretting does not occur.
- Curing an adhesive, then assembling the joint can decrease fatigue life due to decreased friction.

c) Penetrants:

- Usually reduce fatigue life but can have no affect or increase life.
- Penetrants applied after joint assembly can easily enter joints depending upon the type of faying surface sealant.

VII – Palliatives Tested in Aircraft Joints

a) Cold working can significantly improve joint fatigue life.

b) Solid lubricants escape from the joint or are wiped away.

c) Teflon usually decreases fatigue life due to load transfer to fastener shanks.

8.5 SUMMARY

In summary, adhesion based mechanisms of fretting fatigue appear to be most common and fretting contact significantly increases stress at and near the surface.

It should be noted that palliative effectiveness is extremely **CASE SPECIFIC** as noted in the above discussions and only methods which induce surface residual compressive stresses consistently increase fretting fatigue life. Moreover, evidence shows that fretting fatigue is a pervasive mode of failure with riveted aircraft joints and many contact related joints in gas turbine engines and helicopter applications. Furthermore, methods which reduce fretting in aircraft joints often do not increase the fatigue life as a reduction in coefficient of friction requires more load to be taken by the fastener shank in the case of mechanical fasteners. It is desirable that in time more specific design guidelines be established. Regrettably no extensive **long-term** studies of the phenomenon of fretting fatigue have been undertaken in any NATO or other country in which the efforts have been focused in fretting fatigue. There have been studies in some laboratories around the world where the focus has been on the general phenomenon of fretting fatigue. Many studies from these laboratories are reported in the general bibliography provided after the references. Those interested in the progress on this important subject should go to the entire series of publications of the International Symposia on Fretting Fatigue. Undoubtedly future meetings of that body will provide much continuing insight into fretting fatigue. Finally it is important to note that Japan assembled the first group of fretting fatigue workers to produce a fretting fatigue test standard. This too is mentioned in the general bibliography. In recent months the ASTM has produced a draft fretting fatigue standard that is currently being voted on by the ASTM E9 membership. Hopefully these recent developments will bode well for the future production of much more understanding of the fretting fatigue phenomenon, much more reliable data to allow comparison of fretting fatigue data between various laboratories, and effective design guidelines for the anticipation, elimination of and control of fretting fatigue of aircraft structures.

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