15WIDESPREAD FATIGUE DAMAGE.

The development of widespread fatigue damage (WFD) in airplane structure is a concern for older airplanes.

Two types of multiple damages are known. The first type is the **multiple site damage (MSD)** (fig.5.1), which is characterized by the simultaneous presence of fatigue cracks in the same structural element. The second type is the **multiple element damage (MED)**, which is characterized by the simultaneous presence of fatigue cracks in similar adjacent structural elements. Both, MSD and MED, are a source of **widespread fatigue damage WFD** which is reached when the MSD or MED cracks are of sufficient size and density that the structure will not longer meet its damage tolerance requirement.

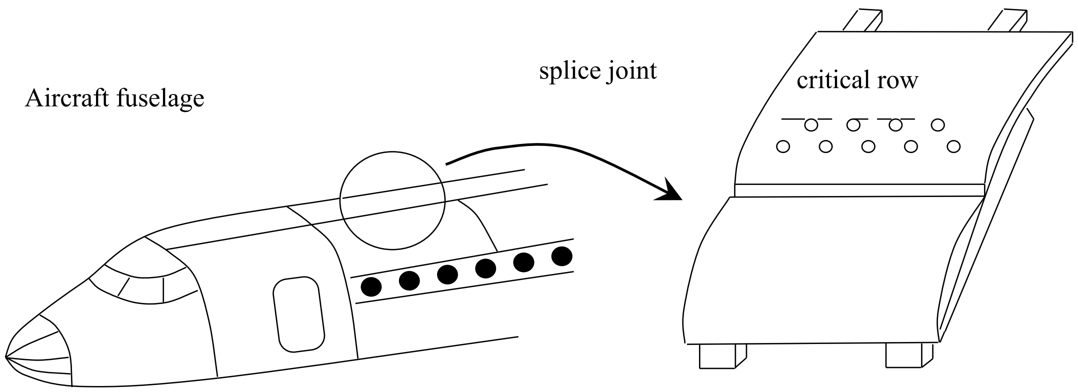


Fig.5.1.Schematical representation of MSD in an aircraft fuselage.

The effect of MSD is shown in fig.5.2. The left hand diagram describes the effect of MSD on a single lead crack used to establish the inspection program. In the presence of MSD adjacent to the lead crack the critical crack or the residual strength, respectively, are reduced drastically. The right hand diagram shows the reduction of the crack growth period due to the reduction of the critical crack length.

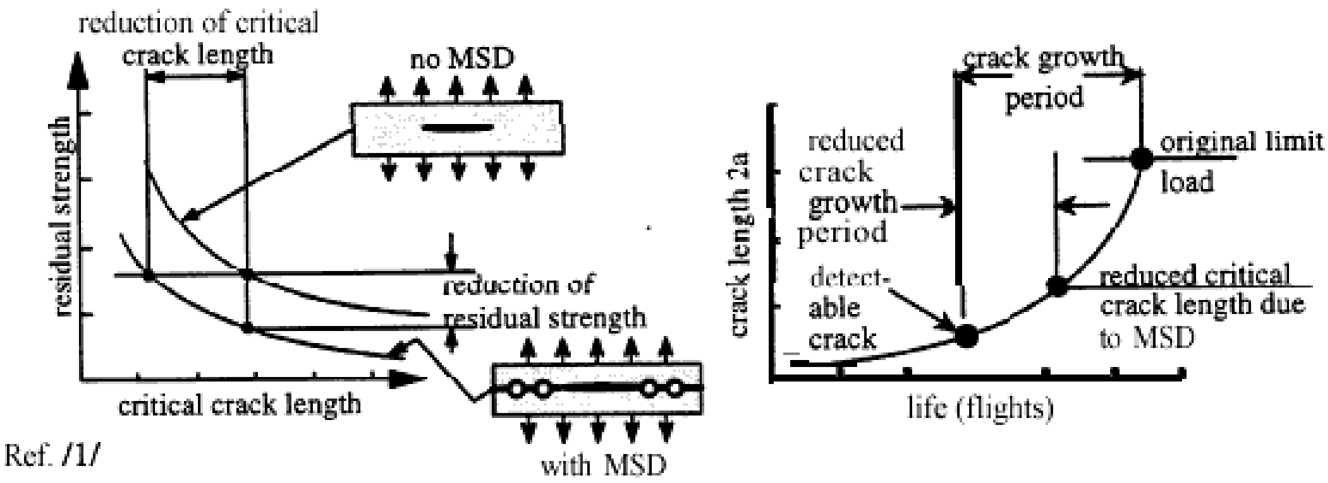


Fig.5.2. The effect of MSD on a crack.

Example 1. Boeing has made investigations about the effect of MSD on the residual strength of a lead crack. The residual strength load of a 14 inch (356 mm) long lead crack is reduced in the presence of adjacent MSD cracks of 0.05 inch (1.27 mm) by 30 percent. This demonstrates the dramatic effect even of small MSD cracks which are uninspectable by state of the art techniques.

Example 2. This skin splice at an aft pressure bulkhead is one area of airplane structure determined by the FAA to be susceptible to WFD (fig.5.3).

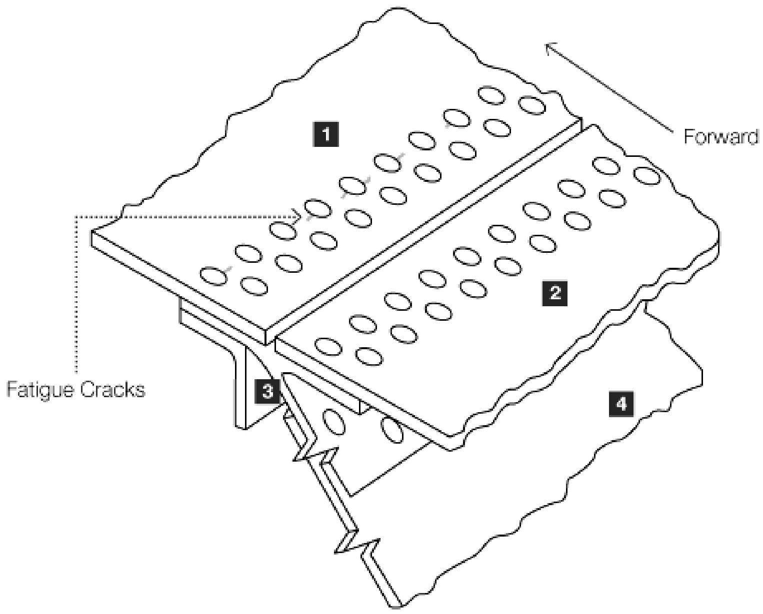


Fig.5.3. Skin attachment to the aft pressure bulkhead: 1- pressurized fuselage skin; 2 - unpressurized fuselage skin; 3 - “Y” - Tee chord; 4 – aft pressure bulkhead

Example 3. This example illustrated by figs. 5.4-5.6 deals with mentioned above Aloha Airline Flight 243.

The aircraft was fabricated in 1969 and had been in service for almost nineteen years. It had experienced 89,600 flight cycles before the accident. The single lap joint of the fuselage panel structures was manufactured by cold-bond process using scrim cloth and rivets. It was known that the cold-bonded joints have not enough durability in thermal and humid cycle condition. As a matter of course, fastener joints received heavy corrosion damage during 19-years operations. Under the thermal and humidity cycle conditions due to operation, the fuselage structure was subjected to Wide-spread Fatigue Damage (WFD), including Multiple-Site Damage (MSD). Moreover, the operator has not conducted the periodical inspection and maintenance of the structure required by Regulations even under such deteriorated condition. As a result, the operator overlooked cracks that were long enough to be found visually by passengers.

Detail analysis has revealed following failure sequence:

1. Bond-line and sealant had degraded at skin splices – Trapped moisture/moisture entry.
2. Corrosion developed in skin splice - stressing the skin around rivets.
3. Cracking initiated as stress corrosion cracking.
4. Pressurization caused cracks to grown.
5. Improper maintenance and surveillance.
6. Many cracks grew large and linked with adjacent cracks.
7. Total crack size was too large for tear straps to arrest.
8. Catastrophic decompression failure.

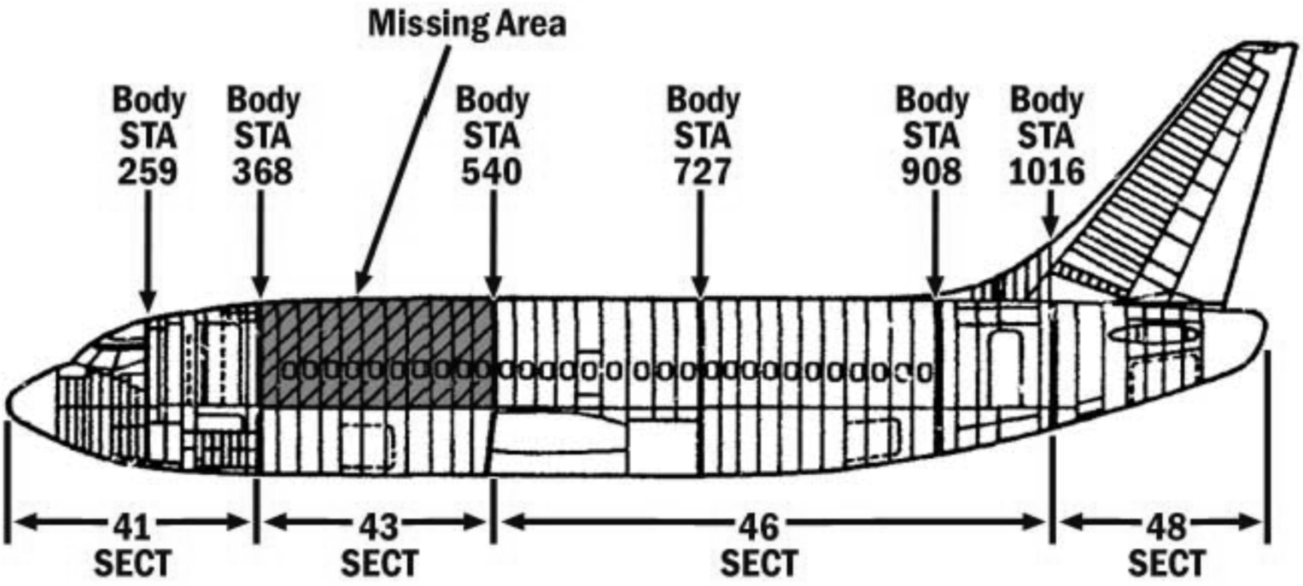
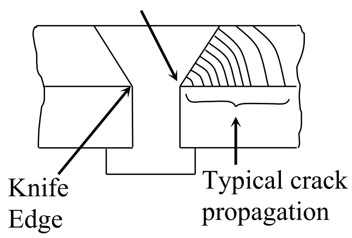
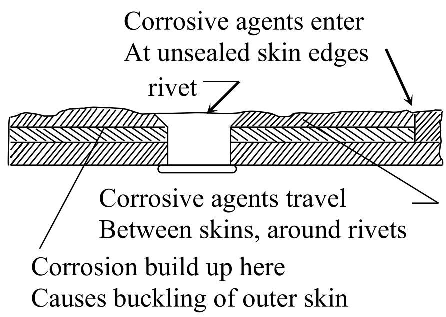


Fig.5.4. Schematics of Damage Cause to Aloha Airline Flight 243



a)



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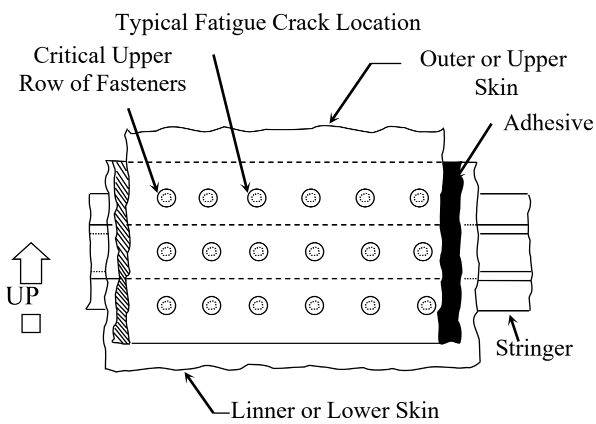

c)

Fig.5.5. Failure of riveted structure: a) corrosion in riveted joint; b) nucleation of the crack at the “"knifeknife”"edges of holes; c)) failure initiation in the critical upper row of fasteners

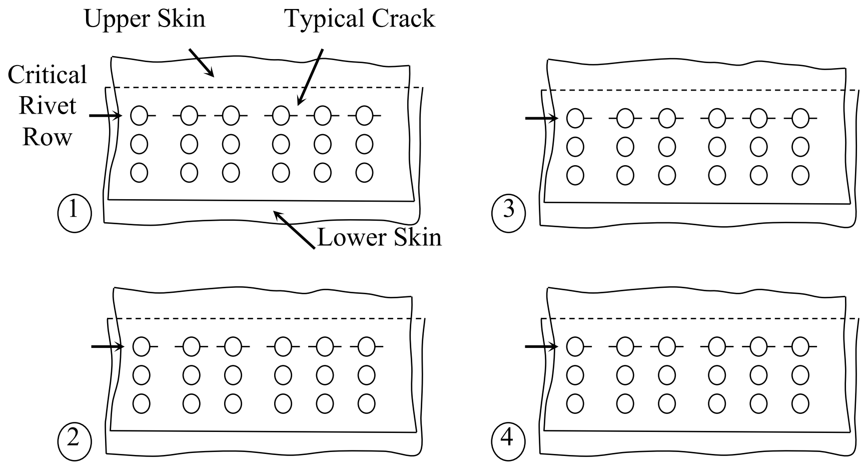

Fig.5.6. Stages of MSD evolution in Aloha's fuselage skin

Fourteen areas are identified as potentially susceptible to WFD:

Fuselage: Longitudinal skin joints, frames and tear straps (MSD, MED); circumferential joints and stringers (MSD, MED); fuselage frames (MED); aft pressure dome outer ring and dome web splices (MSD, MED); other pressure bulkhead attachment to skin-web attachment to stiffener and pressure decks (MSD, MED); stringer to frame attachment (MED); window surround structure (MSD, MED); over wing fuselage attachments (MED); latches and hinges of nonplug doors (MSD, MED); skin at runout of large doubler (MSD).

Wing and empennage: Skin at runout of large doubler (MSD); chordwise splices (MSD, MED); rib to skin attachments (MSD, MED); stringer runout at tank end ribs (MED, MSD).

Residual structural strength *R* is the most important parameter of the multi-site fatigue damage. It is, obviously, the random function of time and depends on many random variables:

1) quantity k of emerging cracks in n potential sources of fatigue damage;

2) size of cracks L_i ($i = 1, \ldots, k$) and their distribution on the sources;

3) the degree of influence of cracks on the stressed state in the sources of fatigue damage;

4) the degree of reciprocal effect of cracks to the rate of their increase.

As a result residual structural strength with operating time N (duration parameter for load of construction) is the random function of many variables $R(N, L_i, k, n, ...)$.

If R_{adm} – is the permissible residual strength on the conditions of airworthiness, then equation $R(N^*, L_i, k, n, ...) = R_{adm}$, determines the random maximum operating time N^*, by reaching it will make the construction inefficient.

Analyzing the equation, it is easy to see that the residual strength is the implicit function of operating time. This means that its level directly depends on the dimensions of crack, their quantity, mutual arrangement and etc. In this situation the task for determining N^* can be divided into two independent tasks:

1) the definition of residual strength as a certain determined function of quantity k, dimensions of crack L_i and of their mutual arrangement;

2) the determination of the random configuration of multi-site fatigue damage depending on operating time N.

Thus, the task of determining the maximum operating time before the reaching the lower permissible boundary of residual strength consists of determined and random component. The requirement of the first task is to use methods of mechanics of destruction. Here primary attention is paid to the second task.

The determination of the random configuration of multi-site fatigue damage is to offer the following stages:

1) determination with the given time N of the distribution of damages between the separate sources $pi(N)$;

2) determination of the standard probable configurations of multi-site fatigue damage;

3) determination of the residual strength Rk for each standard configuration with the given time.