6.2 Damage Development And Progression

Fatigue-crack-growth prediction is complicated by the assumptions that have to be made for the progression of damage through the structure (continuing damage and remaining structure damage). These damage assumptions are specified in JSSG-2006 Table XXX and will not be repeated here. This section will discuss interpretation of these requirements through a series of three examples of increasing complexity. The examples pertain to a Slow Crack Growth component, a Multiple Load Path Dependent, Fail Safe structure, and a Crack Arrest, Fail Safe structure, in this order. They are illustrations of the analysis procedure. No general rules can be given.

6.2.1 Slow Crack Growth Structure

The first example is a heavy-section spar cap (Figure 6.2.1a). The spar cap will be treated as Slow Crack Growth structure. The initial flaw has to be assumed at the most critical location. Assume that this is location A (Figure 6.2.1a). Due to assembly drilling the skin is assumed to be flawed also. If there is load transfer from the cracked spar cap to the skin, it should be taken into consideration. The damage development for the spar cap is shown schematically in Figure 6.2.1b, the change of the stress-intensity factor is shown schematically in Figure 6.2.1c.

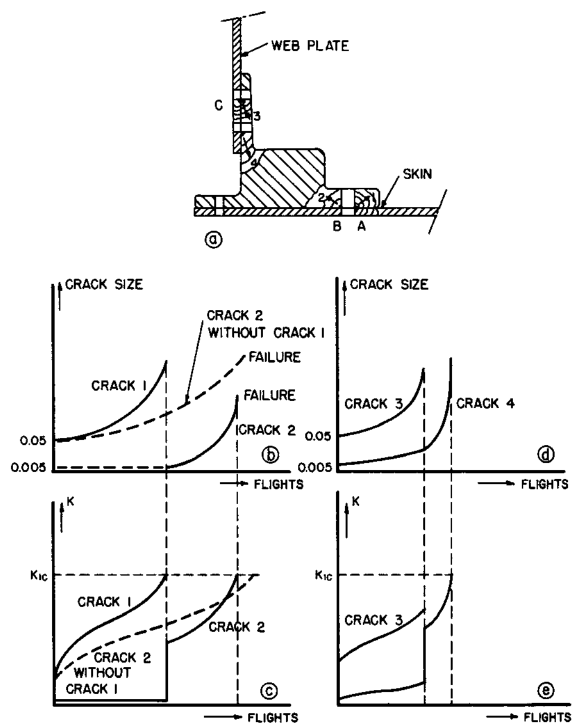

Figure 6.2.1. Damage Development in Slow Crack Growth Structure

Crack 1 starts as a 0.05 inch crack. It grows until the remaining ligament fails at $K = K_{Ic}$. The continuing damage is a 0.005 inch flaw at the other side of the hole (point B). Its prior growth need not be considered, since the primary damage terminated by ligament failure (JSSG-2006 paragraph A3.12.1e). Hence, it may be assumed to have been stationary thus far.

At ligament failure, crack 2 is suddenly introduced and the stress-intensity factor is determined by the total damage size, consisting of the failed ligament, the hole, and a 0.005 inch crack. This damage grows to failure by the growth of crack 2.

Now consider the case that B is the critical location (Figure 6.2.1a). In that case, crack 1 would be absent (ligament intact), but crack 2 would start at 0.05 inch (dashed lines in Figure 6.2.1b,c). Due to the absence of crack 1 it will grow slower.

Now assume that C is the most critical location. This case is depicted in Figure 6.2.1d, e. Crack 3 will start as a 0.05 inch crack, and terminates in the next hole. Continuing damage is a 0.005-inch crack at the other side of the hole, plus its prior growth, Δa, must be assumed (JSSG-2006 paragraph A3.12.1e). Contrary to the previous case, the 0.005 inch crack was growing previously. Its independent growth, Δa, has to be calculated. Due to this previous growth there is an increase of K. When crack 3 terminated in the next hole the stress-intensity factor of crack 4 jumps, because crack 3 and 4 together now constitute the total damage. Therefore, the growth of crack 4 will be much faster than before.

6.2.2 Multiple Load Path, Fail Safe Structure

The second example is academic, but illustrative. It is a multiple load path dependent beam consisting of members A, B, C (Figure 6.2.2a). Assume that crack 1 is the critical crack. (If the critical location was at the other side of the hole, damage development would be similar as in Figure 6.2.2). Due to assembly drilling the two members, A and B should both be assumed flawed. The damage development is shown in Figure 6.2.2b, c.

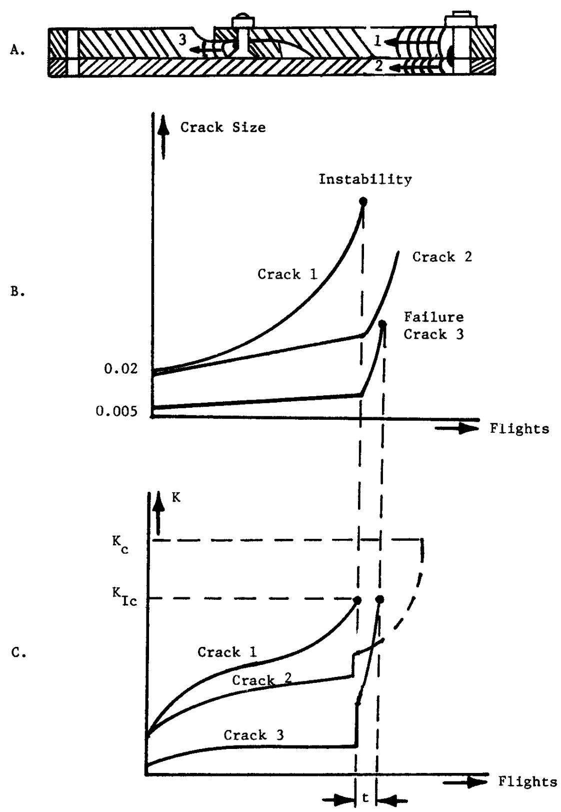

Figure 6.2.2. Damage Development in Multiple Load Path, Fail Safe Structure

Cracks 1 and 2 both start as 0.05 inch flaws. Crack 1 is assumed to grow faster, and when $K = K_{Ic}$ rapid crack propagation (instability) will occur at which point member A is assumed failed. Remaining structure damage has to be assumed in the adjacent member (crack in member C). It is a 0.005 inch crack plus its prior growth, Δa.

Due to member failure the stress-intensity factors of all cracks will show a jump. Therefore, cracks 2 and 3 will grow much faster than before: Final failure will occur when the stress-intensity factor (K) of crack 3 reaches K_{Ic}, or when K of crack 2 reaches K_c, whichever occurs first. (It is assumed that plane stress prevails in the thin member B). The period between failure of member A and final failure (indicated by t in Figure 6.2.2c) has to be adequate for one of the options of remaining structure damage inspection. Otherwise, the structure would not qualify as Multiple Load Path, Fail Safe structure.

6.2.3 Crack Arrest, Fail Safe Structure

The last example is Crack Arrest Fail Safe structure consisting of a skin with tear straps, as shown in Figure 6.2.3a. Due to assembly drilling, skin, tear strap and shear clip are assumed to have 0.02 inch corner flaws, giving rise to cracks 1, 2, and 3. Damage development is shown in Figure 6.2.3b. Stress-intensity factor (K) development is shown in Figure 6.2.3c. Corresponding points on the flights axes are indicated by A, B, C, and D.

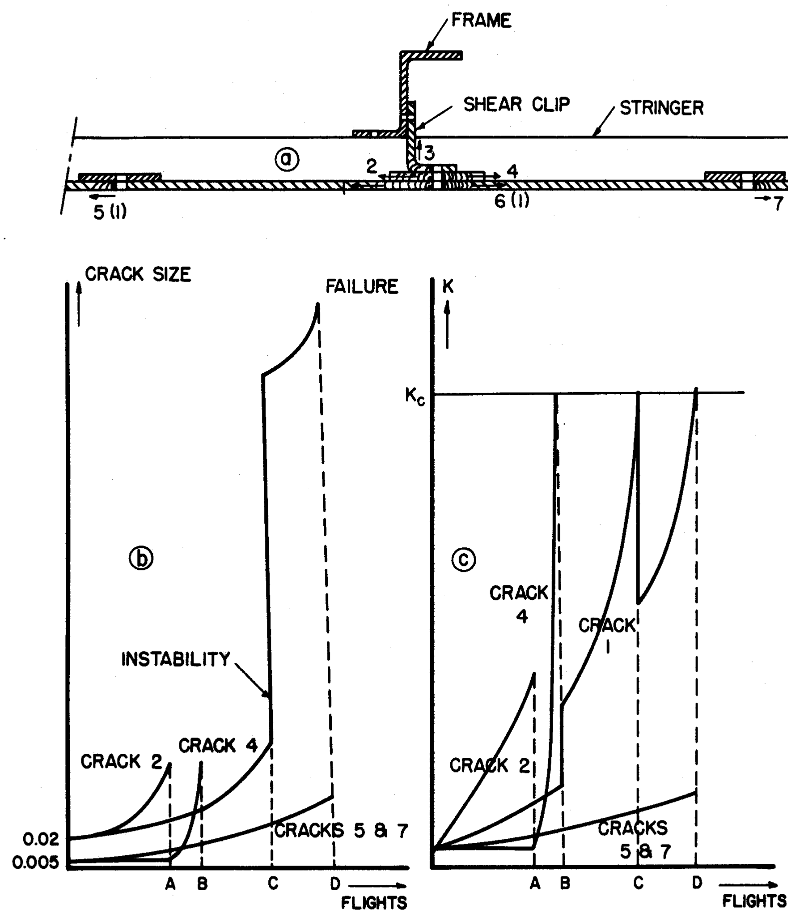

Figure 6.2.3. Damage Development in Crack Arrest Fail Safe Structure

First consider cracks 2 and 4 in the tear strap. When crack 2 terminates due to ligament failure, the continuing damage is a 0.005 inch crack 4 without prior growth. From point A onwards, growth of crack 4 will be rapid until the tear strap fails.

The independent previous growth of crack 1 was slow. However, upon tear strap failure there will be load transfer from the cracked tear strap to the skin. Consequently, there will be a sudden increase of the stress-intensity factor of the skin crack resulting in accelerated growth. When K of the skin crack reaches K_c, instability (rapid crack growth) will occur, and the crack will run to the left tear strap. Due to load transfer from the skin to the tear strap, K will drop (point C), and the instable crack will be arrested at the tear strap.

Subsequent damage development is strongly dependent upon remaining structure damage assumptions (which may be mutually agreed upon by the USAF and the contractor). In this particular example, the most logical damage would be a 0.005 inch crack at both 5 and 6 (only prior growth of 5 should be considered). At the moment of instability of crack 1, the shear clip will most likely be failed, because it was cracked already. Hence, there will be little load transfer to the frame. Therefore, it is most likely that crack 6 becomes unstable immediately in conjunction with crack 1, so that the skin crack would be from the left to the right tear strap. This case would be as in JSSG-2006 paragraph A3.12.1d. (A two-bay crack with the central strap failed). It is questionable whether also the frame should be assumed cracked. Upon failure of the shear clip, continuing damage requirements would strictly apply to the frame, at the next fastener hole (away from the primary damage source). The complexity of these assumptions is obvious.

Further growth of the skin crack (with continuing cracks 5 and 7) will take place until K_c is reached again. The period CD would have to be adequate, otherwise the structure would not qualify as Crack Arrest Fail Safe structure.