

9.1 Required Analysis

All repairs made to cracked structure, and all structure and structural changes made to in-service aircraft require some form of damage tolerance analysis. The degree of intensity of each analysis, however, depends on the consequences of failure in the repaired or modified structure if cracks are present. For example, the extent of the analysis of a repair to replace a compressively loaded fuselage member that is removed for corrosion damage would be minimal, while a force-wide modification to the tension-loaded, primary-load-path, lower wing skin structure of a fighter aircraft would require an in-depth evaluation of expected fatigue crack growth behavior.

The best categorization of what requires an in-depth damage tolerance analysis can be directly taken from the JSSG-2006 specification applicable to new structure. This specification requires that all safety-of-flight critical structure be designed using a damage tolerance analysis. This analysis ensures that cracks potentially present in this type of structure will not cause loss of the aircraft during flight for some predetermined period of in-service operation. The above suggests the first guideline for structural repairs and modifications, i.e., all structural repairs and modifications to safety-of-flight critical structure, must be subjected to in-depth damage tolerance analyses to ensure that the structure is not degraded as a result of the repair (or modification) below a level considered satisfactory for the subsequent in-service operational period contemplated.

A question arises relative to the definition of what constitutes safety-of-flight critical structure and their locations within the airframe. Based on the information required by MIL-HDBK-1530 for the support of force management operations, a critical parts list is prepared by the airframe contractor and appended to the Force Structural Maintenance (FSM) plan supplied to the Air Force. It is suggested then that clear definitions for safety-of-flight critical structure be provided with each aircraft's FSM plan along with the appendix that lists and illustrates safety-of-flight critical structure. If the manufacturer can conceive of potential problems associated with the repair or modification of special designed (or manufactured) safety-of-flight critical structure, then the manufacturer should identify such problems in the FSM plan with reference to additional details in the T.O.-3 repair manual.

The intensity of the analysis also varies as a function of the extensiveness of the change of the force. If the repair or modification can be incorporated into any given aircraft or will be applied to all aircraft in the force, than a more careful analysis of the impact of a crack potentially existing in the structure should be conducted. For one-of-a-kind repairs applied to an airframe in order to return the aircraft to a depot for more extensive repair, the type of damage tolerance analysis would be primarily of a residual strength type, without much consideration being given to variable amplitude fatigue loading.

There are two basic elements in damage tolerance analysis: a residual strength analysis and a sub-critical crack growth analysis. In the residual strength analysis, one develops a relationship between load carrying capability and crack length. In the sub-critical crack growth analysis, one determines a relationship between time-in-service and length for a given type of operation.

In a damage tolerance analysis, one obtains an estimate of the structural life to grow the initial crack damage in the structure to critical size. The residual strength analysis determines the critical crack size required to fail the structure; the sub-critical crack growth analysis is used to obtain the life estimate. One could also determine the decay in residual strength as the crack

extends under service loading by coupling the residual strength analysis with the sub-critical crack growth analysis. The first part of [Figure 9.1.1](#) illustrates the relationship between residual strength and crack length, and the second describes the relationship between crack length and time-in-service. The third part of the figure couples the information in the first two parts to obtain the relationship between the decay in residual strength and time-in-service.

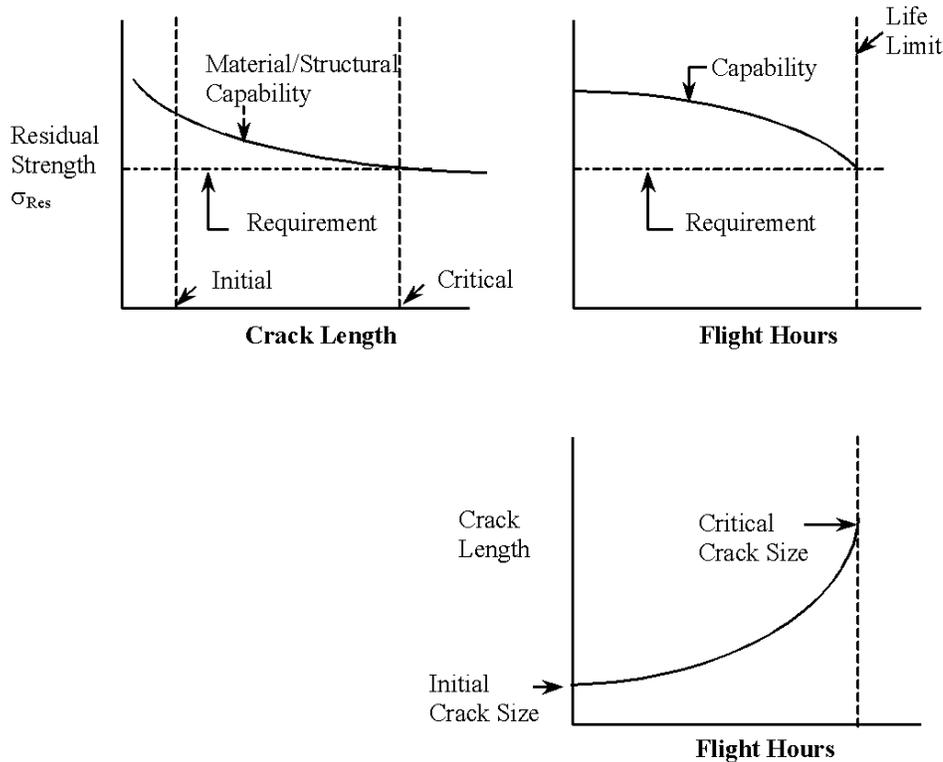


Figure 9.1.1. Relationship Between Residual Strength, Crack and Time-in-Service

As described in previous sections, the analyst needs the following structural/material information to conduct a damage tolerance analysis:

- Definition of quality – to obtain the initial crack length (a_0) for the sub-critical crack growth analysis.
- Definition of operational loading and environmental conditions – to establish the residual strength requirement and to grow the crack in the sub-critical crack growth analysis.
- Definition of the structural parameter that relates loading, global geometry, as well as crack size and geometry to crack tip conditions – this parameter makes it possible to relate laboratory behavior to in-service hardware.
- Definition of material properties that characterize resistance to fracture and to sub-critical crack growth – to provide the basis for estimating fracture level and the rate of crack growth in the structure.

- A damage summation model – to integrate the effects of variable amplitude loading and time dependant behavior in the sub-critical crack growth analysis.
- A fracture model – to provide the criteria for estimating the critical crack length.

For a safety-of-flight critical structural component, detailed analysis and understanding is required for the above structural/material information. Such detailed analysis is described in earlier sections. This section has been prepared to highlight what might be accomplished with both limited information and structural analysis capability. The method of approach in this section is to illustrate how approximate methods can reduce the complexity of a residual strength analysis or full-scale cycle-by-cycle sub-critical crack growth rate analysis. The approximate methods facilitate parameter studies that isolate those features of the structure, its material, the usage, the environment, or method of inspection, which control the level of damage tolerance associated with the structure, in an unrepaired or repaired condition.

The remainder of this section is organized to present (a) some general observations about usage characteristics for crack growth life estimates, (b) a detailed analysis of three transport wing stress histories and the effects of stress scaling, (c) fatigue life sensitivity analysis for stress effects, (d) fatigue life sensitivity for analysis for hole repair, (e) fatigue life sensitivity analysis for blend-out repairs, (f) a residual strength parametric analysis to establish limits for return to depot, (g) a detailed residual strength analysis of a cockpit longeron repair, and (h) a detailed residual strength analysis of a wing skin repair.