Preface

The materials used in manufacturing the aerospace, aircraft, automobile, and nuclear parts have inherent flaws that may grow under fluctuating load environments during the operational phase of the structural hardware. The design philosophy, material selection, analysis approach, testing, quality control, inspection, and manufacturing are key elements that can contribute to failure prevention and assure a trouble-free structure. To have a robust structure, it must be designed to withstand the environmental load throughout its service life, even when the structure has pre-existing flaws or when a part of the structure has already failed. If the design philosophy of the structure is based on the fail-safe requirements, or multiple load path design, partial failure of a structural component due to crack propagation is localized and safely contained or arrested. For that reason, proper inspection technique must be scheduled for reusable parts to detect the amount and rate of crack growth, and the possible need for repairing or replacement of the part. An example of a fail-safe-designed structure with crack-arrest feature, common to all aircraft structural parts, is the skin-stiffened design configuration. However, in other cases, the design philosophy has safe-life or single load path feature, where analysts must demonstrate that parts have adequate life during their service operation and the possibility of catastrophic failure is remote. For example, all pressurized vessels that have single load path feature are classified as high-risk parts. During their service operation, these tanks may develop cracks, which will grow gradually in a stable manner. To avoid catastrophic failure, a thorough nondestructive inspection, a proof test prior to service usage, and a comprehensive fracture mechanics analysis (i.e., safe-life analysis) are requested by the customer.

To demonstrate that structural failure of single load path component does not occur and that the part has adequate life during its entire operation, a comprehensive fatigue and fracture mechanics analysis using linear elastic fracture mechanics must be performed. In conducting safe-life analysis, full fracture mechanics data for the material must be available. These data are generated based on the ASTM testing standards. Because fracture toughness is thickness dependent and structures have components that have different sizes and thicknesses, numerous fracture toughness tests must be conducted to include the plane strain, plane stress, and the mixed-mode conditions. In addition to fracture toughness values, the fatigue crack growth rate data must also be available to analysts in order to conduct a meaningful safe-life analysis. These tests are costly and time consuming, and the cost and time of testing will increase substantially when scatter in fracture allowable, as the result of material variation, need to be considered. Therefore, any method that can reduce the number of tests will be useful to the industry to avoid unnecessary costs when fracture allowables are needed as an input to the life-assessment analysis.

The safe-life analysis of high-risk components will demonstrate the ability or tolerance of parts at the presence of existing crack under the load-varying environment. For this reason the fracture mechanics analysis in many cases is called "damage tolerance" analysis. In reality, the total life of structural components is the sum of crack initiation cycles and crack propagation. In aircraft industry, the number of cycles to crack initiation must be accounted for when assessing the total life of the part. Figure 1 shows the process of creating a crack growth/residual strength analysis with emphasis on the comparison (feedback) of analysis with practice. That is, crack growth analysis should be checked against results obtained from the field experience through the interval inspection. Airlines already implemented this approach through their Reliability Centered Maintenance program to adjust their interval inspection period of the entire fleet. As indicated in the figure, the total life analysis is incomplete without having fatigue and fracture allowables through testing.

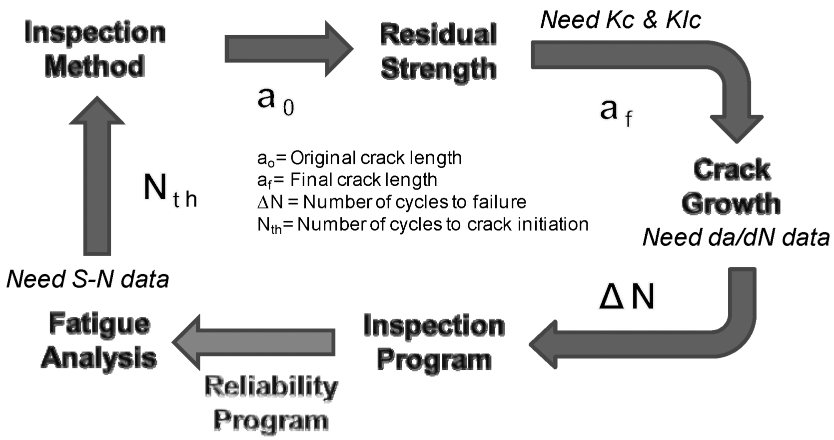

Fig. 1 Comparison (feedback) of analysis with practice. Analysis is incomplete without fatigue and fracture data

Because the induced stresses in aircraft components must be kept in the elastic range, the high cycle fatigue data generated through the stress to life (*S–N*) can be useful in the fatigue assessment analysis (also called durability analysis). These data are stress ratio (*R*) dependent and require considerable time and cost to generate the full range of the *S–N* curve. Any analytical technique that can be used to generate the *S–N* data without conducting the traditional laboratory coupon tests will be helpful to the aircraft and aerospace industry to avoid tests.

The sole purpose of this book is to provide the structural engineers with the present and near-future approaches to the virtual testing techniques, where fatigue and fracture mechanics data can be generated rapidly with minimum amount of tests. As mentioned before, fatigue and fracture allowables are needed as an input to the damage tolerance and durability assessment of fracture critical parts. In many instances, analysts do not have fatigue fracture mechanics values and the budget is not adequate to generate data through testing approach. In other instances, the time does not allow to conduct tests, because of deadlines that designers must meet and laid down by the customers. Therefore, the virtual testing is the right tool to have when both the budget and time do not allow engineers to conduct tests for durability and damage tolerance analysis. The virtual testing technique for generating fatigue and fracture allowables will be presented in this book through two unique techniques. The first approach will use the conventional continuum mechanics approach, which will allow engineers to generate the *S–N;* fracture toughness, *Kc;* and fatigue crack growth rate data (da/dN versus ΔK) through analytical approach. The second method of generating these data is based on the fundamental laws of physics (i.e., the ab initio), where material will be assessed from the bottom-up approach. Both approaches to the virtual testing will be presented in this book. The latter utilizes the multiscale modeling and simulation technique to predict the material properties. For this reason the author chooses to use "Virtual Testing and Predictive Modeling" as the title of this book.

Chapters 1, 2, 3, 4, 5, and 6 of this book will be dedicated to virtual testing using the continuum mechanics approach. Both metallic and composite materials will be addressed with numerous examples related to the aerospace and aircraft parts. Chapters 7, 8, 9, 10, and 11 will discuss the multiscale modeling and simulation technique. Both quantum mechanics and molecular dynamics approaches will be used to conduct the predictive modeling analysis.

Because of outstanding mechanical properties of nanoparticles, there is a strong future demand for their application in aerospace and aircraft structural parts. These particles when combined with polymer matrix will enhance the mechanical properties of polymer, which is an important factor in reducing the weight of the structural parts in modern airplanes. The implementation of multiscale modeling and simulation at the interface region between nanoparticles and matrix is challenging and proper chemistry between nanoparticles and polymer is needed to provide a good bond at the interface region. To make nanoparticles more easily dispersible in polymer, it is necessary to physically or chemically attach certain molecules, or functional groups, to their smooth sidewalls without significantly changing the nanoparticle's desirable properties. This process is called functionalization. The production of robust composite materials that can allow the transfer of load without causing localized damage requires strong covalent chemical bonding between the filler particles and the polymer matrix that can be achieved through the functionalization process. Chapter 12 will address the most recent approach to the functionalization technique that can be useful to bond dissimilar material with achieving adequate interface strength.

Finally, Chapter 13 will be allocated to the verification technique using the state-of-the art approach to verify the interface region between nanoparticles and the matrix by applying the transmitted electron microscope (TEM) and atomic force microscope (AFM). The experimental flexibility of these techniques will provide insights into the fundamental structure and deformation processes of nanoscales materials. The *in situ* measurement of interface region while material under stress will be discussed.

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