4.1 Introduction

The basic concept in damage tolerance design is to ensure the safety of the structure throughout the expected service life. To provide the required safety, a structure must be designed to withstand service loads even when cracks are present or when part of the structure has already failed; i.e., the structure has to be damage tolerant. The overriding philosophy is to maintain a minimum required residual strength so that catastrophic failure of the structure is prevented.

Figure 4.1.1 identifies the major sequence of events that ultimately define the residual strength requirements. As can be noted from the figure, once a safety-of-flight-critical element is identified, either its structural configuration or its degree of inspectability will establish the allowable structural design concept and the inspection level categories. Every safety-of-flight-critical element must be qualified in at least one design concept category and in one inspection category. Each allowable combination of design concept and inspection category is coupled in JSSG-2006 to a residual strength requirement, a service life requirement, and a requirement to assume a level of initial damage.

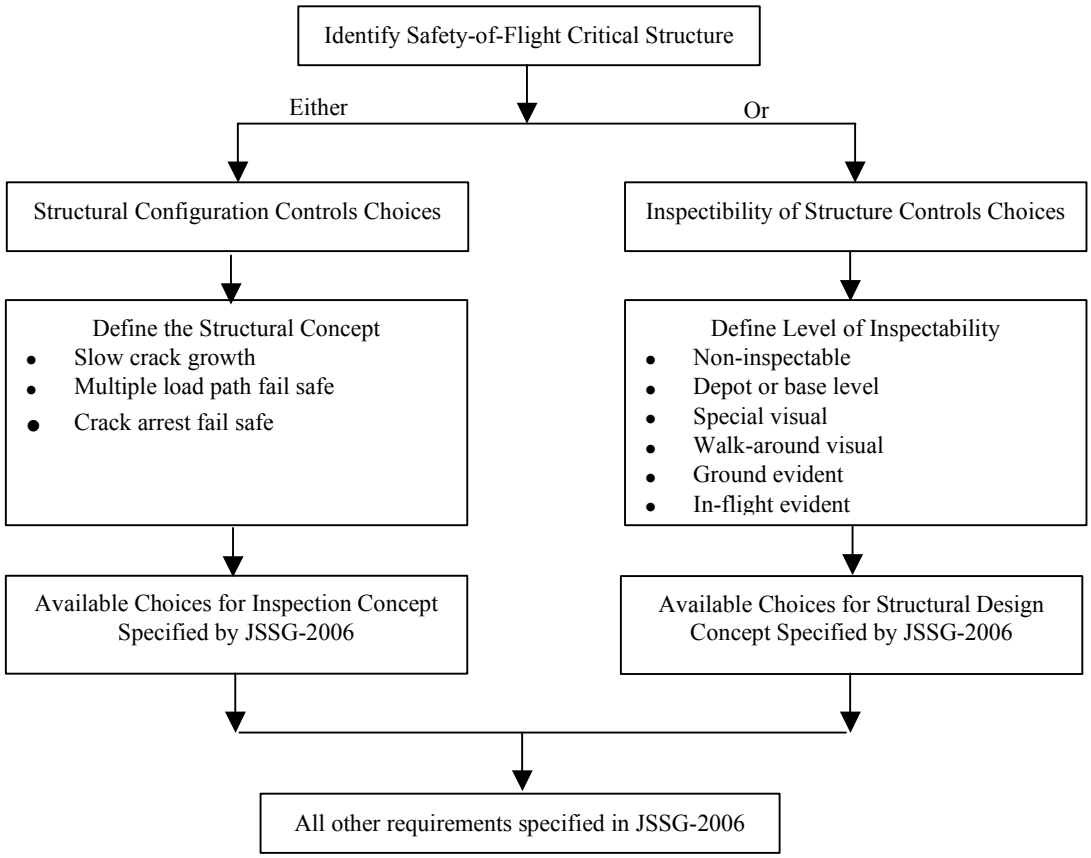

Figure 4.1.1. The Structural Configuration or Degree of Inspectability Controls the Subsequent Choices of Design Concept and Inspection Level

Figure 4.1.2 illustrates the residual strength and the service life interval requirements as well as a residual strength capability curve. The residual strength capability curve defines the level of

load that the structure can withstand without failing in the presence of a growing crack. To account for the change in residual strength capacity as a function of time, it is necessary to determine the crack size as a function of time. The crack-growth-life curve and its various properties are shown schematically in Figure 4.1.3. Shown are the various technology and specification requirements needed to define the crack growth curve which, in turn, establishes the life limit.

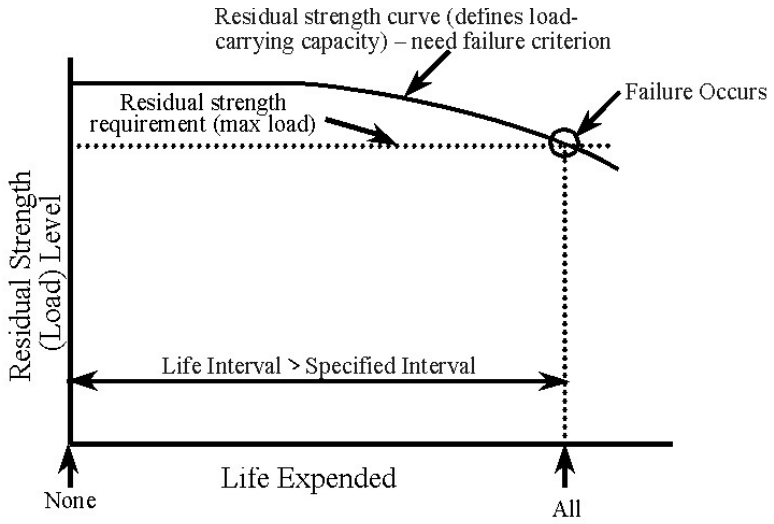

Figure 4.1.2. Relationship Between the Life Expended and Residual Strength Capability Showing a Monotonic Decrease in Load Carrying Capacity Due to Damage

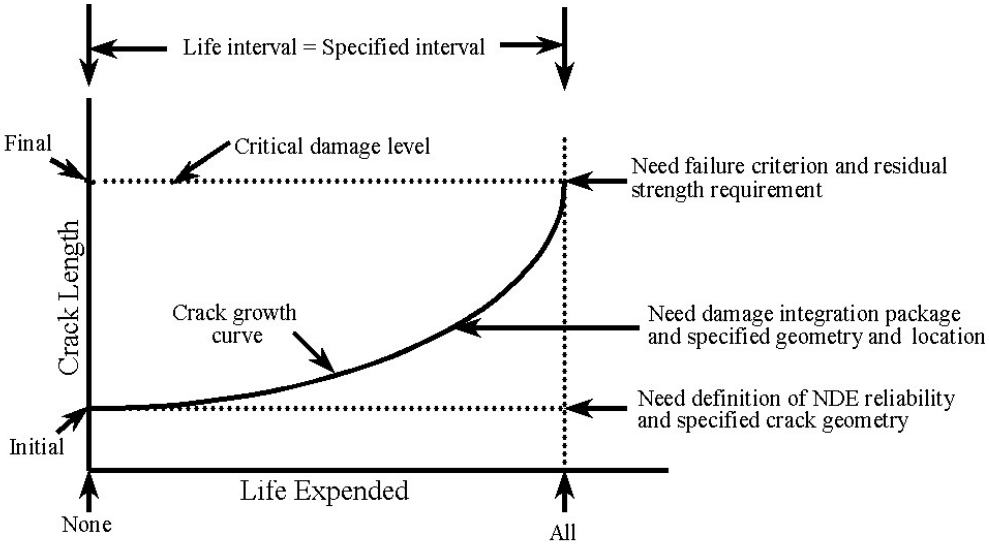

Figure 4.1.3. Relationship Between Crack Length and Life Expended Showing a Monotonic Increase in Crack Length Up Until Failure

As can be seen from Figure 4.1.2, when the residual strength of the structure falls below the maximum stress in the service load history, failure can be expected. To avoid such a failure, a thorough understanding of the problem is essential. Significant advances have been made in recent years in procedures for analyzing damaged structures. Assessments now consider residual strength, damage growth, interactive multiple damage sites and quantitative structural maintenance and in-service evaluations.

The application of existing fracture mechanics solution techniques has yielded effective methods for analyzing the residual strength of the cracked structure. The necessary theories and methods for determining the residual strength capability of cracked structures are presented in this section. Prior to presenting this information in the following sections, a few remarks are made about the residual strength requirements for the two damage tolerant design categories: slow crack growth structure and fail-safe structure.

4.1.1 Slow Crack Growth Structure

In a slow crack growth structure, the damage tolerance must be assured by the maintenance of a slow rate of crack growth, a residual strength capacity, and the assurance that subcritical damage will either be detected at the depot or will not reach unstable dimensions within the design lifetime of the structure. The residual strength curve for a structure which is inspected periodically is schematically shown in Figure 4.1.4. As a result of the inspections, the initially assumed cracks do not grow to a critical size and the structure is restored to its original load carrying capability when an inspection capability equal to that of the manufacturer's is employed.

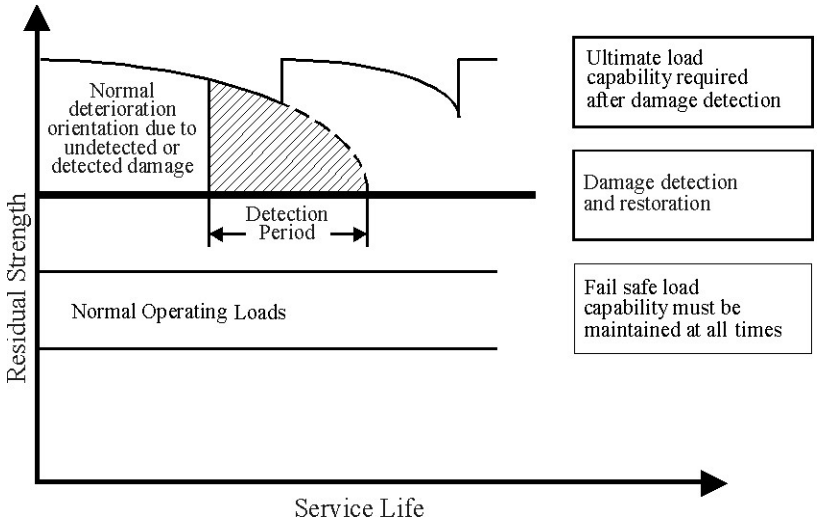

Figure 4.1.4. Strength Criteria for Periodically Inspected Damage Tolerant Structure

Single-load-path "monolithic" structure must be qualified in this category; the residual strength estimation procedure for this type of structure is fairly straightforward. Built-up (multiple-load-path) structure can be qualified either in this category or in the fail-safe category.

4.1.2 Fail-Safe Structure

The residual strength requirement of a fail-safe structure is to assure damage tolerance following a partial failure of the structure. Damage tolerance is maintained through detection of this failure prior to total loss of the structure and sufficient residual strength capability for operating safely within the partial failure prior to inspection. The fail-safe structure is typically a built-up structure with multiple load paths or crack arrest features in its design. In the event of failure of a structural member, its load must be transferred to and withstood by the remainder of the structure, which also contains crack damage, without causing the loss of whole structure. The residual strength of the built-up structure must be determined under such critical circumstances so that the fail-safe design requirements are met.

The analysis of residual strength capability for built-up structure requires the estimation of the critical stress level at which the partial failure occurs, as well as an understanding of the capability of the total structure to withstand this partial failure at and subsequent to the time of failure. The required load associated with the time subsequent to failure is based on the inspection category and, the partially-failed structure must be able to maintain this load until the time of inspection.