1.3 Summary of Damage Tolerance Design Guidelines

USAF damage tolerance design guidelines are specified in Joint Service Specification Guide JSSG-2006 [1998]. The guidelines apply to all safety of flight structure, i.e., structure whose failure could cause direct loss of the aircraft, or whose failure, if it remained undetected, could result in the loss of aircraft. The guidelines stipulate that damage is assumed to exist in each element of new structure in a conservative fashion i.e., critical orientation with respect to stress field and in a region of highest stress. The structure must successfully contain the growth of the initial assumed damage for a specified period of service, and must maintain a minimum level of residual static strength both during and at the end of this period.

1.3.1 Summary of Guidelines

The damage tolerance design guidelines are illustrated in Figure 1.3.1 in a diagrammatic form. Since residual static strength generally decreases with increased damage size, the residual strength and growth guidelines are coupled through the maximum allowable damage size, i.e. the damage size growth limit established by the minimum-required residual strength load. The safe growth period (period of unrepaired service usage) is coupled to either the design life requirement for the air vehicle or to the scheduled in-service inspection intervals. While the specific guidelines of JSSG-2006 may seem more complex than described in Figure 1.3.1, all essential elements are as illustrated. The remainder of Section 1.3 will describe these individual elements.

A structure can be qualified under one of two categories of defined damage, either Slow Crack Growth or Fail Safe. In the Slow Crack Growth category, structures are designed such that initial damage will grow at a stable, slow rate under service environment and not achieve a size large enough to cause rapid unstable propagation. In the Fail Safe category, structures are designed such that propagating damage is safely contained after failing a major load path by load shift to adjacent intact elements or by other damage arrestment features.

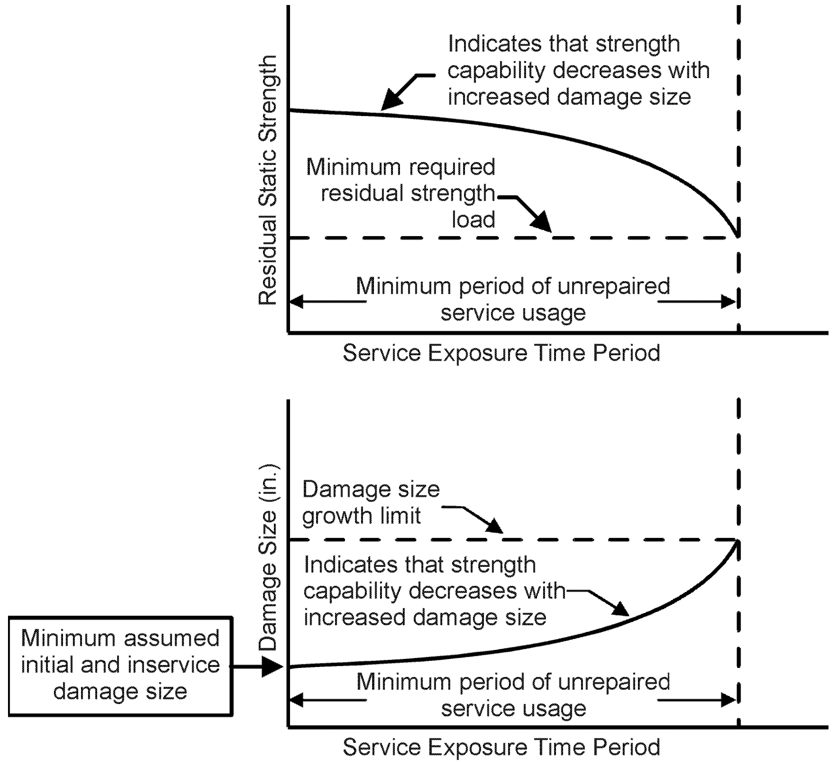


Figure 1.3.1. Residual Strength and Damage Growth Guidelines

In Slow Crack Growth qualified structure, damage tolerance (and thus safety) is assured only by the maintenance of a slow rate of growth of damage, a residual strength capacity and the assurance that sub-critical damage will either be detected at the depot or will not reach unstable dimensions within several design life times.

In Fail Safe qualified structure, damage tolerance (and thus safety) is assured by the allowance of partial structural failure, the ability to detect this failure prior to total loss of the structure, the ability to operate safely with the partial failure prior to inspection, and the maintenance of specified static residual strength through this period. Section 1.3.2 discusses the design categories.

Each structure must qualify within one of the designated categories of in-service inspectability (referred to as "The Degree of Inspectability" in JSSG-2006), including the option to designate Slow Crack Growth qualified structure as "in-service non-inspectable." The various degrees of inspectability refer to methods, equipment, and other techniques for conducting in-service inspections as well as accessibility and the location of the inspection (i.e., field or depot). These degrees of inspectability are discussed in Section 1.3.3.

The selection of the most appropriate damage tolerance category under which to qualify the structure is the choice of the designer/analyst. The choice of degree of in-service inspectability is somewhat limited, however, to those described in JSSG-2006. The inspection guidelines have been developed based upon past and present experiences and are felt to be reasonable estimates of future practice.

The intent of the guideline is to provide for at-least design limit load residual strength capability for all intact structure, i.e., for sub-critical damage sizes in slow crack growth structure and damage sizes less than a failed load path in fail safe qualified designs. This requirement allows for full limit load design capability and thus unrestricted aircraft usage. The imposition of the requirement constrains structure qualified as Slow Crack Growth to either depot level inspectable or in-service non-inspectable.

As described in Section 1.3.2, fail safe structure must meet both the intact structure and remaining structure guidelines. Slow crack growth structure will meet either the depot level inspectable or the non-inspectable structure guidelines. For each structure, evaluation of the following parameters is required:

- Design Category
- Degree of In-Service Inspectability
- Inspection Intervals
- Initial Damage, In-Service Damage and Continuing Damage Assumptions
- Minimum Required Residual Strength
- Damage Size Growth Limits
- Period of Unrepaired Service Usage
- Remaining Structure Damage Sizes

Each of these are described in the following sections, and Section 1.3.7 shows several examples.

1.3.2 Design Category

As specified in JSSG-2006 paragraph 3.12, all safety of flight structure must be categorized as either Slow Crack Growth or Fail Safe.

Slow Crack Growth structure consists of those design concepts where flaws or defects are not allowed to attain the critical size required for unstable rapid crack propagation. Safety is assured through slow crack growth for specified periods of usage depending upon the degree of inspectability. The strength of slow crack growth structure with sub-critical damage present shall not be degraded below a specified limit for the period of unrepaired service usage.

Fail Safe structure is designed and fabricated such that unstable rapid propagation will be stopped within a continuous area of the structure prior to complete failure. Safety is assured through slow crack growth of the remaining structure and detection of the damage at subsequent inspections. Strength of the remaining undamaged structure will not be degraded below a specified level for the period of unrepaired service usage.

In the development of the guidelines, it was recognized that multiple load path and crack arrest type structure have inherent potential for tolerating damage by virtue of geometric design features. On the other hand, it is not always possible to avoid primary structure with only one major load path, and therefore some provisions are necessary to ensure that these situations can be designed to be damage tolerant. It is the intent of the guidelines to encourage the exploration of the potentials for damage tolerance in each type of structure. Single load path or monolithic structures must rely on the slow rate of growth of damage for safety and thus, the design stress level and material selection become the controlling factors.

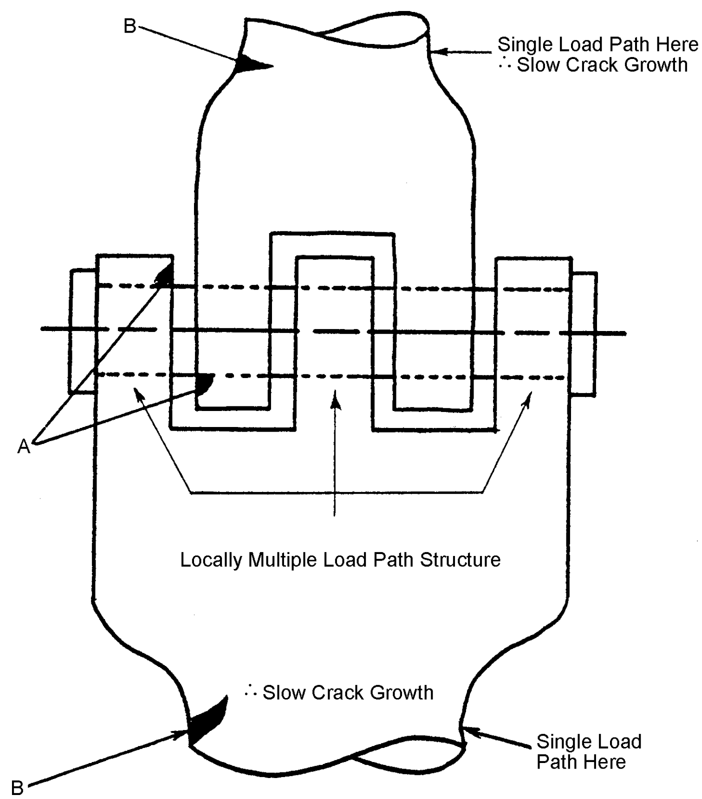
Single load path "monolithic" structures must be qualified as Slow Crack Growth. However, the guidelines allow flexibility for qualification of multiple load path cases. The decision may be made to qualify multiple load path structure as Slow Crack Growth, instead of Fail Safe, if sufficient performance and life cycle costs advantages are identified to offset the burdens of the inspectability levels for Fail Safe structure. Therefore, the method of construction may not agree with the design category selected, i.e. all multiple load path structure is not Fail Safe. When deciding on the design category option, the most important factor to consider is that once a design category is chosen, the structure must meet all the guidelines in the guidelines that cover that category.

The mere fact that a structure has alternate load paths (local redundancy) in some locations does not necessarily qualify it as Fail Safe. Examples are helpful in illustrating this point. Examples 1.3.1 and 1.3.2 illustrate the fact that a structure is often locally redundant (usually good design practice), but in an overall sense may have some restriction such that one is not able to take advantage of the localized redundancy in order to qualify the structure as Fail Safe.

Considerable judgment is required for the selection of potential initial damage locations for the assessment of damage growth patterns and the selection of major load paths. The qualification as Fail Safe is thus a complex procedure entailing judgment and analysis. Because of this, the choice is often made to qualify the design as Slow Crack Growth regardless of the type of construction. As stated in JSSG-2006 A3.12.2.3 Requirement Lessons Learned "There are currently no aircraft in the Air Force inventory which have been qualified as fail-safe crack arrest structure under Air Force criteria".

EXAMPLE 1.3.1 <u>Identifying Non-Redundant Structure – Lug Example of Slow Crack Growth Structure</u>

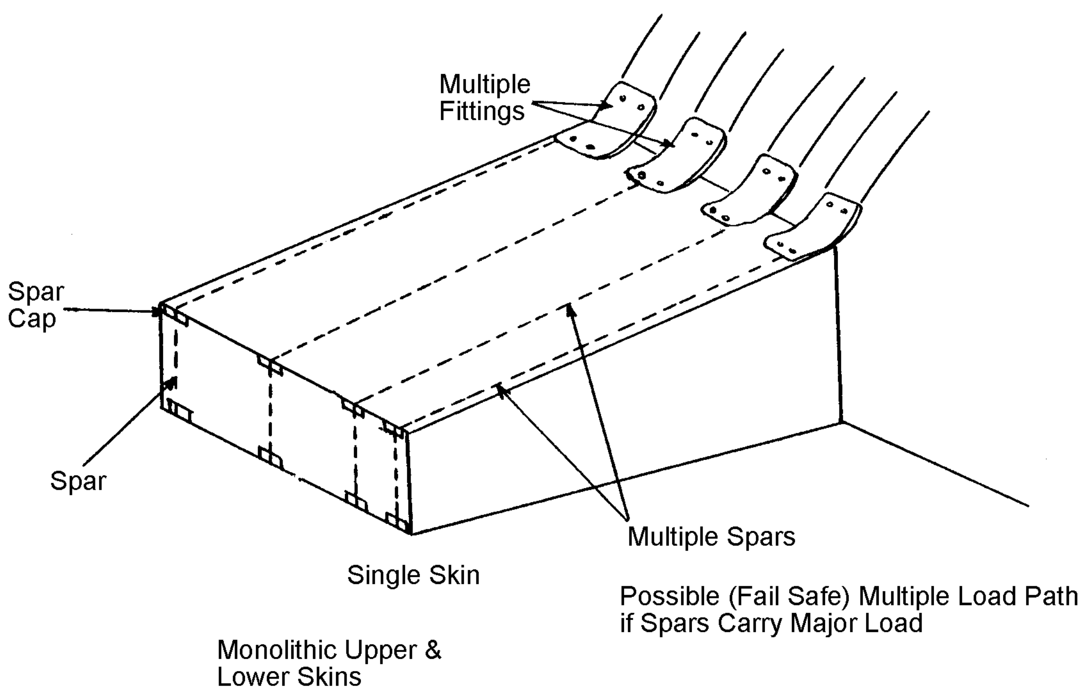
The lug fitting illustrated here has multiple lug ends at the pinned connection. Failure or partial failure of one of the lugs (A) would allow the load to be redistributed to the remaining sound structure. Localized redundancy is often beneficial, and in this case is good design practice. However, the fitting cannot be qualified as Fail Safe Multiple Load Path structure since the occurrence and growth of damage at a typical location (B) would render the structure inoperative. The only means of protecting the safety of this structural element would be to qualify it as Slow Crack Growth.



EXAMPLE 1.3.2 <u>Choice Options for Redundant Structure – Wing Box Example</u>

As shown here, a wing box is attached to the fuselage carry through structure by multiple fittings. The upper and lower skin is one piece for manufacturing and cost reduction. The substructure consists of multiple spars spaced to attach to the individual attachment fittings. A case could be made to qualify this structure as Fail Safe Multiple Load Path. Depending upon the amount of bending carried by the spars, it would be possible to design the structure such that damage in the skin would be arrested at a spar prior to becoming critical. The design might also tolerate failure of one spar cap and a portion of the skin, prior to catastrophic failure. The attachment system could be designed to satisfy Fail Safe guidelines with one fitting failed.

On the other hand, if the skin was the major bending member with a design stress of sufficient magnitude to result in a relatively short critical crack length, then the skin and spar structure could only be qualified as Slow Crack Growth structure.



1.3.3 Inspection Categories and Inspection Intervals

For each individual aircraft system, the Air Force is obligated to specify the planned major depot and base level inspection intervals to be used in the design of the aircraft. Typically, these intervals will be approximately 1/4 of the design service life. The types and extent of inspection (i.e., equipment, accessibility, necessity for part removal, etc.) required at each of these major inspections is dependent upon the specific aircraft design and modifications resulting from development and full-scale tests or service experience. The Air Force wants its contractors to design a damage tolerant structure that will minimize the need for extensive non-destructive depot or base level inspections. Primary emphasis should therefore be placed on obtaining designs for which significant damage sizes can readily be found by visual inspection. However, where periodic inspections are required to satisfy the damage tolerance guidelines, the contractor must recognize that the USAF will probably conduct the inspections. The in-service damage sizes associated with the inspection categories of JSSG-2006 paragraph 3.12 reflect the estimated capability of the Air Force to find damage.

Guidelines for degree of inspectability are contained in JSSG-2006 paragraph 6.1.15. The degree of inspectability of safety of flight structure is established in accordance with the following definitions:

- In-flight evident inspectable - If the nature and extent of damage occurring in flight will result directly in characteristics which make the flight crew immediately and unmistakably aware that significant damage has occurred and that the mission should not be continued.
- Ground evident inspectable - If the nature and extent of damage will be readily and unmistakably obvious to ground personnel without specifically inspecting the structure for damage.
- Walkaround inspectable - If the nature and extent of damage is unlikely to be overlooked by personnel conducting a visual inspection of the structure. This inspection normally shall be a visual look at the exterior of the structure from ground level without removal of access panels or doors without special inspection aids.
- Special visual inspectable - If the nature and extent of damage is unlikely to be overlooked by personnel conducting a detailed visual inspection of the aircraft for the purpose of finding damaged structure. The procedures may include removal of access panels and doors, and may permit simple visual aids such as mirrors and magnifying glasses. Removal of paint, sealant, etc. and use of NDI techniques such as penetrant, X-ray, etc., are not part of a special visual inspection.
- Depot or base level inspectable - If the nature and extent of damage will be detected utilizing one or more selected nondestructive inspection procedures. The inspection procedures may include NDI techniques such as penetrant, X-ray, ultrasonic, etc. Accessibility considerations may include removal of those components designed for removal.
- In-service non-inspectable structure - If either damage size or accessibility preclude detection during one or more of the above inspections.

The specified frequency of inspections for each of the inspectability levels is indicated in Table 1.3.1 and is based on estimates of typical inspection intervals. As previously mentioned, the typical depot or base level frequency is once every one quarter of the design lifetime but may be otherwise specified in the appropriate contractual document. Special visual inspection requires Air Force approval before being considered as a design constraint but, if approved, shall not be required more frequently than once per year. The justification for this restriction is cost and maintenance schedule guidelines.

Table 1.3.1. Summary of In-Service Inspections from JSSG-2006 Appendix Table X

Degree of Inspectability	Typical Inspection Interval
In-Flight evident inspectable	One flight*
Ground evident inspectable	One day (two flights)*
Walk-around inspectable	Ten flights*
Special visual inspectable	One year
Depot or base level inspection	¼ Design service lifetime
In-Service non-inspectable structure	One design service lifetime

* Most damaging mission

The design of some aircraft components for intermediate special visual inspections, typically once per year, may be advantageous from a performance or cost standpoint and may be used by the contractor in satisfying the guidelines. Normally, special visual inspections will not be specified by the Air Force in the design and development stage but may be dictated, subsequent to design, by the results of testing or service experience.

The assumed Air Force depot or base level inspection capabilities depend on the type of inspection performed. In special cases where potential benefits justify it, the contractor may recommend to the Air Force that specific components be removed from the aircraft and inspected during scheduled depot or base level inspections. If approval is given, the recommendations may be incorporated during design. In these cases, the assumed initial damage sizes subsequent to the inspection shall be the same as those in the original design providing the same inspection procedures are used and certified inspection personnel perform the inspection.

Conventional NDI procedures such as X-ray, penetrant, magnetic particle, ultrasonic, and eddy current are generally available for depot or base level inspections. Such inspection procedures will be performed as dictated by the specific aircraft design inspection guidelines, or as modified because of subsequent tests and service experience. In establishing the design inspection guidelines, the contractor should attempt to minimize the need for such NDI, and should not plan on nor design for general fastener pulling inspections.

1.3.4 Initial Damage Assumptions

To insure that the airframe will have adequate residual strength capability throughout its service life, initial flaws are assumed to exist in the structure. The airframe should have adequate residual strength in the presence of flaws for specified periods of service usage. These flaws are assumed to exist initially in the structure as a result of material and structure manufacturing and processing.

JSSG-2006 paragraph A3.12.1 assumes that any fastener hole in the structure can be marginal and can have an initial damage equivalent to a 0.005 inch radius corner flaw. Thus, the guidelines requires assuming that this flaw exists at each fastener hole within the structure at the time of manufacture. Since the 0.005 inch size is based on limited data, the contractor may provide data representing his own manufacturing quality and negotiate with the Air Force for a smaller size of the apparent initial flaw to represent marginal hole quality.

The most critical location for the initial flaw should be determined by reviewing all elements of the structure and considering features such as edges, fillets, holes, and other high stressed areas.

1.3.4.1 Intact Structure Primary Damage Assumption

The basic premise in arriving at the initial damage sizes is the assumption that the as-fabricated structure contains flaws of a size just smaller than the maximum undetectable flaw size found with the NDI procedures used on the production line. These flaw size shapes which are intended to be covered by the initial flaw size assumptions include radial tears, drilling burrs, and rifle marks at fastener holes as well as forging defects, welding defects, heat treatment cracks, forming cracks, and machining damage at locations other than fastener holes.

Table 1.3.2 and Figure 1.3.2 summarize the initial damage assumptions as specified in JSSG-2006 paragraph A3.12.1 and Table XXX. For slow crack growth and fail safe primary element structure, the assumed initial flaw at holes and cutouts is a 0.05 inch through the thickness flaw at one side of the hole if the material thickness is equal to or less than 0.05 inch. For thicker materials (> 0.05 inch), the assumed initial flaw is a 0.05 inch radius corner flaw.

At locations other than holes, the assumed initial flaw is a semi-circular surface flaw with a length of 0.25 inch and depth of 0.125 inch, or, for material thickness less than 0.125 inch, a through thickness flaw of 0.25 inch length.

These assumptions - relative to the size, shape and location - were based on a review of existing NDI data. The crack length values given in Figure 1.3.2 and Table 1.3.2 were selected as most appropriate for the types of cracks considered and for the two design categories.

Table 1.3.2. Initial Flaw Assumptions for Metallic Structure, JSSG-2006 Appendix Table XXX

Category	Critical Detail	Initial Flaw Assumption*
Slow crack growth and Fail Safe primary element	Hole, Cutouts, etc.	For $t \leq 0.05$", 0.05" through thickness flaw For $t > 0.05$", 0.05" radial corner flaw
	Other	For $t \leq 0.125$", 0.25" through thickness flaw For $t > 0.125$", 0.125" deep x 0.25" long surface flaw
	Welds, embedded defects	TBD

* - Flaw is oriented in the most critical direction

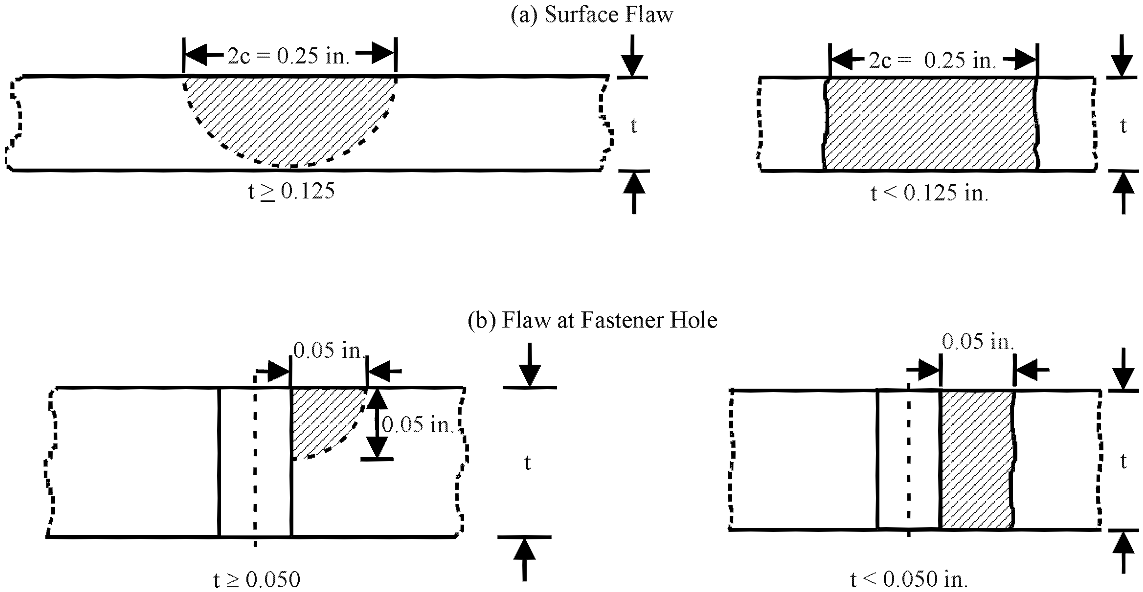


Figure 1.3.2. Summary of Initial-Flaw Assumption for Intact Structure

The Slow Crack Growth initial damage sizes are based on NDI probability of detection (POD) data (90 percent probability of detection with 95 percent confidence). The 0.050 inch crack size for holes and cutouts is based on POD data obtained in the lab using eddy current inspection with fastener removed. The surface flaw size, 0.250 inch long by 0.125 inch deep, was obtained from Air Force sponsored inspection reliability programs where several techniques were used including ultrasonic, dye penetrant and magnetic particle. In these programs, most techniques were found to be sensitive to both surface length and flaw depth and thus the NDI capability must be judged in terms of the flaw shape rather than simply surface length or crack depth.

1.3.4.2 Continuing Damage

In applying JSSG-2006 paragraph 3.12 to a built-up structure, it is noted that cyclic growth behavior of primary damage may be influenced by the geometry of the structure or the arrangement of the elements. In order to provide an orderly and progressive path for the crack that eventually causes the structure to fail, the continuing damage assumptions were incorporated. There are three cases where the continuing damage assumptions are made in order to keep the crack moving; these cases are described with examples.

Figure 1.3.3 describes a skin-stringer construction where equivalent initial (primary) damage is assumed to exist in both elements of the hole marked A. According to JSSG-2006 paragraph A3.12.1, all other holes are secondary cracking sites (marked B) and contain the small imperfections equivalent to the 0.005 inch radius corner flaw. As the primary damage progresses in both the skin and stringer, eventually the radial crack in the stringer will extend to the edge of the stringer, shown in Figure 1.3.3 - cracking sequence (ii). At this time, a new crack, equivalent to the 0.005 inch radial crack flaw plus the growth prior to the primary element failure, is assumed to exist on the diametrically opposite side of the failed hole, as shown in Figure 1.3.3 - cracking sequence (iii). This continues the growth process until the complete stringer fails, shown in Figure 1.3.3 - cracking sequence (iv).

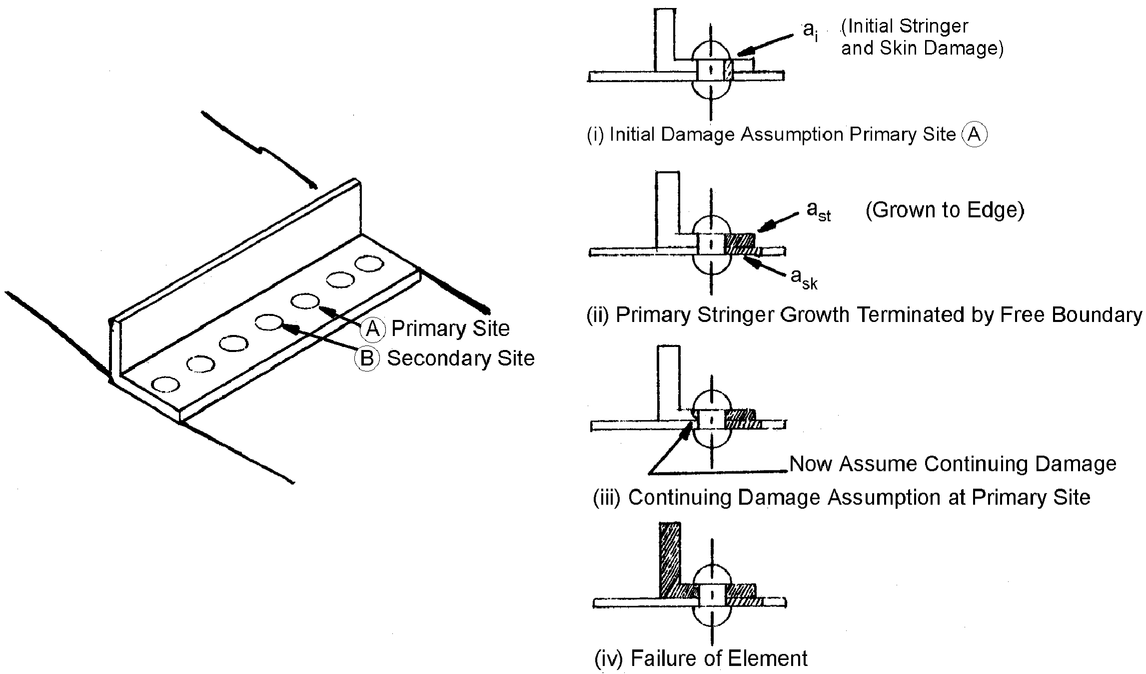


Figure 1.3.3. Example of Continuing Damage Growth Terminated at Free Edge and Terminated by Failure of Member

Under the condition that the primary damage terminates due to a member or element failure, such as the stringer illustrated in Figure 1.3.3, the designer is required to assume that continuing damage is present. The continuing damage is assumed to be present at the most critical location in the remaining element or structure. The continuing damage is either a corner crack that starts from an initial small imperfection of 0.005 inch or a surface flaw with length of 0.02 inch and depth of 0.01 inch, plus the amount of growth which occurs prior to element failure.

Figure 1.3.4 illustrates several choices for potential critical locations where continuing damage might be assumed subsequent to the failure of the stringers. Secondary Site 1 is assumed to be an adjacent hole, and the crack growth is in the skin and opposite in direction to the primary skin crack. Such a situation would eventually result in a stepwise shift in the crack growth path. Most logically, this type of damage could be assumed to exist at the primary damage site in the skin on the diametrically opposite side of the hole once the stiffener fails. Secondary Site 2 is located in the skin and would provide a path for link-up with the primary crack. Secondary Site 3 is located in a parallel stringer-skin hole and would also allow for possible link-up with the primary crack.

The type of continuing damage assumption that the designer must make when the assumed primary damage enters into and terminates at a fastener hole is described in Figure 1.3.5. The continuing damage in this case is a crack on the opposite side of the hole entered by the primary crack. The continuing damage crack is taken as the crack that has grown from an initial small imperfection of a 0.005 inch radial corner crack through the time period that it takes the primary damage to terminate at the hole.

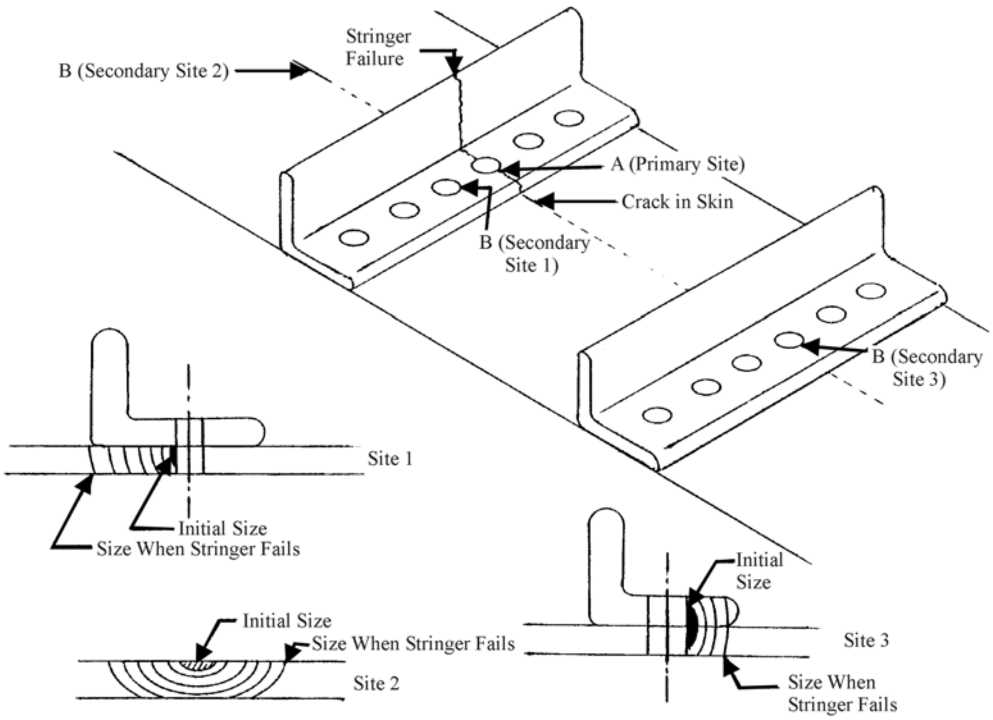


Figure 1.3.4. Example of Continuing Damage Types and Locations Assumed When Primary Damage Terminates Due to Element Failure

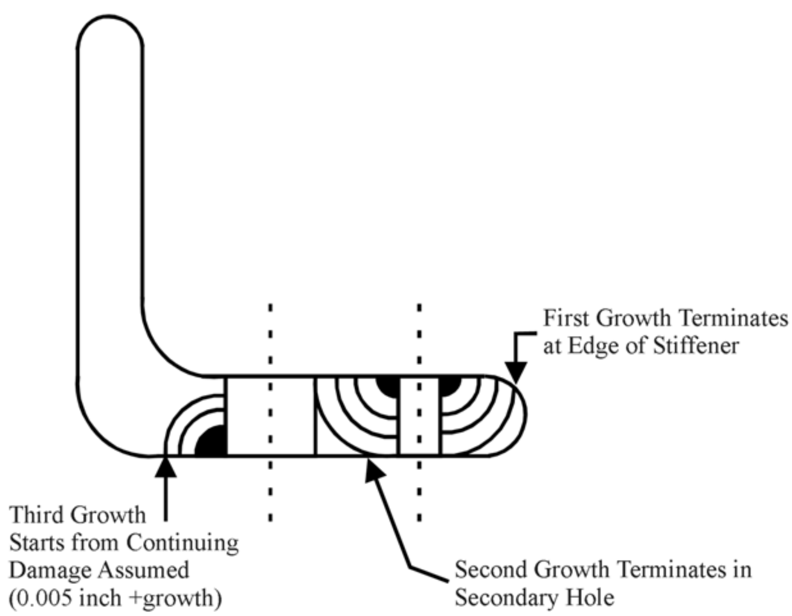


Figure 1.3.5. Continuing Crack Assumed at Opposite Side of Hole When Primary Crack Terminates at a Hole

1.3.4.3 Fastener Policy

In practice, the growth of flaws from fastener holes can be retarded by the use of interference fit fasteners, special hole preparation such as cold work, and to some degree, by joint assembly procedures like friction due to joint clamp-up. Because these procedures delay flaw growth, the slow crack growth lives (or intervals) can be significantly longer than those obtained from structure containing conventional low torque clearance fasteners

Experience has shown that to achieve the beneficial effects of these techniques consistently, exceptionally high quality process control is required during manufacture. However, this is not always obtained. As a result, it is thought unwise to consider all interference or hole preparation systems effective in retarding crack growth.

As stated in JSSG-2006 paragraph A3.12.1.g, to maximize safety of flight and to minimize the impact of manufacturing errors, the damage tolerance guidelines should be met without considering the beneficial effects of specific joint design and assembly procedures such as interference fit fasteners, cold expanded holes, and joint clamp-up.

Exceptions to this policy can be considered. The limits of the beneficial effects used in design should be no more than derived from assuming a 0.005 inch corner flaw as initial damage in an as-manufactured, non-expanded hole containing a neat fit fastener in a non-clamp-up joint.

1.3.4.4 In-Service Inspection Damage Assumptions

The basic rationale used to write assumed sizes following an in-service inspection is essentially the same as for the case of intact structure. Once it is established that reliance on in-service inspection is required to ensure safety, the damage size assumed to exist after an in-service inspection is that associated with the appropriate level of NDI capability, as opposed to that associated with initial manufacturing inspection capability. In special cases where specific part removal at the depot is economically warranted, the contractor may recommend that this action be taken. In this case, the assumed damage subsequent to part removal and inspection may be smaller than that associated with in-service inspection capabilities. It may in fact be the same as in the original design, providing the same inspection procedures as used in production are used and certified inspection personnel perform the inspection.

Figure 1.3.6 and Table 1.3.3 summarize the in-service post inspection damage sizes as a function of conditions and thickness, from JSSG-2006 Table XXXII. With fasteners installed and sufficient accessibility to the location, the maximum undetectable damage size is 0.25 inch of uncovered length at fastener holes. Depending upon part thickness, this damage may be a through or part-through flaw. The flaw size was established based on limited available inspection reliability data where the inspection was performed on the assembled aircraft as opposed to the part level inspection performed during production fabrication. These assumptions are considered to be applicable for penetrant, magnetic particle, and ultrasonics. Because of lack of sensitivity, X-ray is not considered appropriate for detecting tight fatigue cracks and thus is not applicable to these flaw size assumptions.

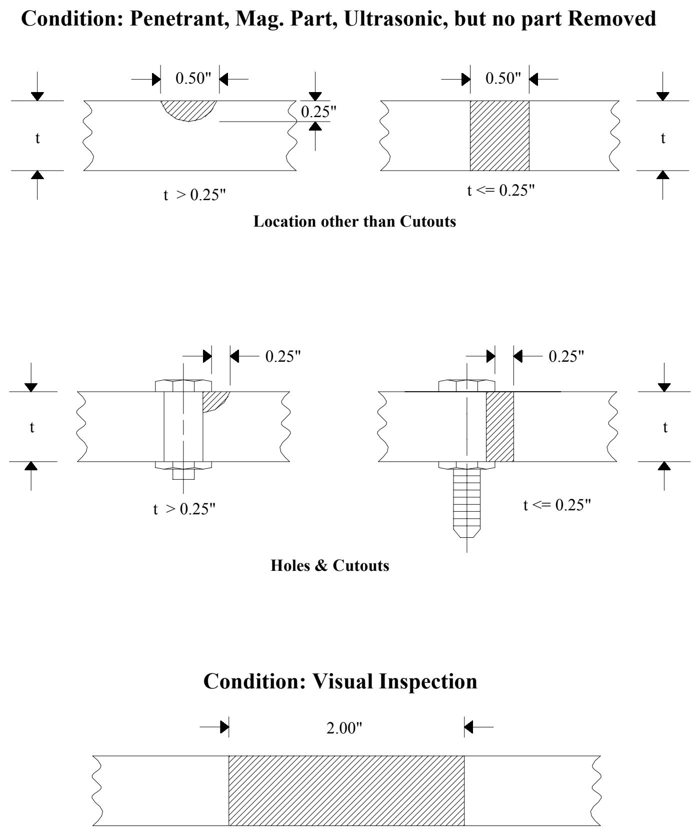


Figure 1.3.6. Summary of Initial-Flaw Sizes for Structure Qualified as In-Service-Inspectable

Table 1.3.3. In-Service Inspection Initial Flaw Assumptions

Accessibility	Inspection Method	Initial Flaw Assumption
Off-aircraft or on-aircraft with fastener removal	Same as initial	Same as initial
On-aircraft without fastener removal	Penetrant, magnetic particle, ultrasonic, eddy current	For $t \leq 0.25$”, 0.25” through thickness flaw at holes; For $t \leq 0.25$”, 0.50” through thickness flaw at other locations; For $t > 0.25$”, 0.25” radial corner flaw at holes; For $t > 0.25$”, 0.25” deep x 0.50” long surface flaw at other locations
On-aircraft with restricted accessibility	Visual	For slow crack growth, non-inspectable For fail-safe structure, primary load path failed

At locations other than holes or cutouts, a flaw size of surface length 0.50 inch is assumed to be representative of depot level capability. Where visual inspection is performed on the assembled aircraft, the minimum assumed damage is an open through the thickness crack having an uncovered length of 2 inches. This value was established based on visual inspection reliability data derived from inspection of large transport type aircraft during fatigue testing and subsequent teardown inspection, shown in Figure 1.3.7.

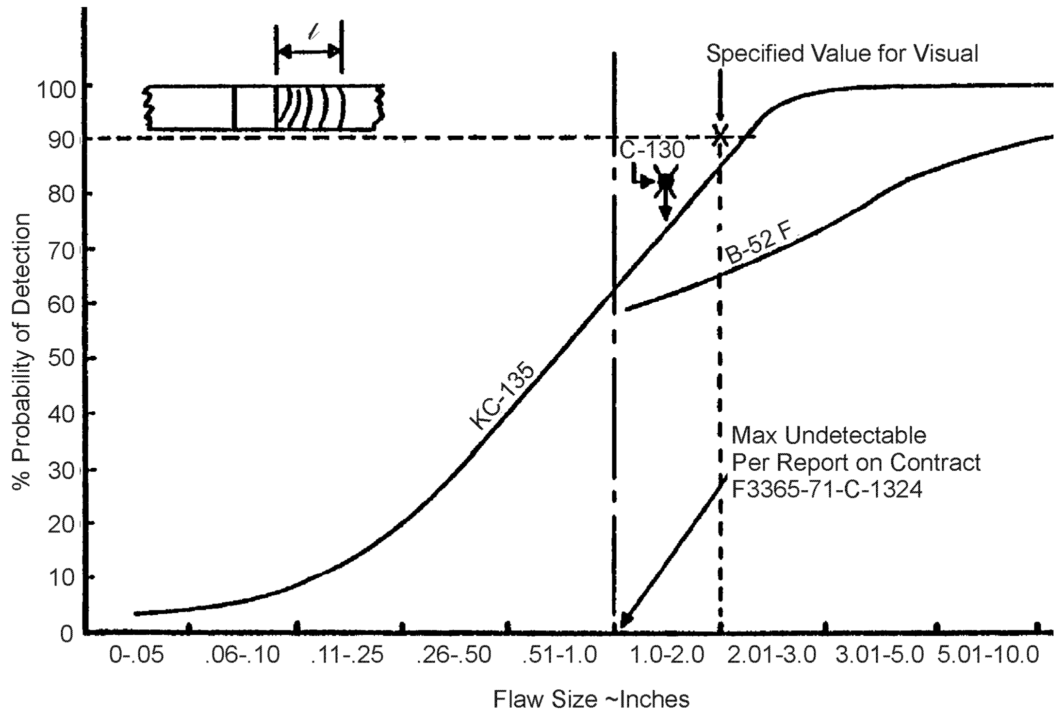


Figure 1.3.7. Development of Minimum NDI Detection for Visual Inspection

1.3.4.5 Demonstration of Initial Flaw Sizes Smaller Than Those Specified

The choice of smaller initial damage must be justified either through an NDI demonstration or a proof test. The NDI demonstration program is described in JSSG-2006 paragraph 4.12.1.a. The program must be formulated by the contractor and approved by the Air Force and must verify that, for the particular set of production and inspection conditions, flaws will be detected to the 90% probability level with 95% confidence.

Where no other means of NDI is available or where it is cost effective, the proof test can be an effective means of screening structure for flaws. Proof testing generally has been successful for the more brittle materials which exhibit plane strain fracture behavior (e.g. high strength steels) and for small structural components. The application of proof testing to complete airframe structure in the USAF has been somewhat limited. The notable exception has been the cold proof tests (-40° F) of the F-111 aircraft to clear the D6AC steel wing carry-through and appendage components for flight usage.

In general, proof testing has only been used on major airframe components as a last resort to allow operation (usually restricted) until extensive modifications are made to the structure (e.g. wing reskin modification of the B-52D). In deriving estimates of the initial flaw size associated with the proof test conditions, approved upper-bound fracture toughness values shall be used for the materials under proof test conditions. Section 3 also presents more information on the proof test concept.

1.3.5 Residual Strength Guidelines

The residual strength capability is defined as the amount of static strength available at any time during the service exposure period considering that damage is initially present and grows as a function of service exposure time. The strength degrades with increased damage size, as shown in Figure 1.3.8. The intent of JSSG-2006 paragraph 3.12.2 is to provide residual strength capability for intact structure of at least design limit load at all times throughout the service life of the structure. The requirement to maintain limit load capability is considered necessary to allow unrestricted operational usage.

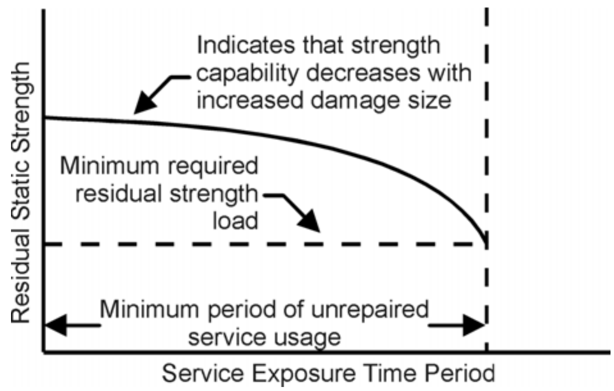


Figure 1.3.8. Residual Strength Diagram

The residual strength guidelines are specified in terms of the minimum internal member load P_{xx} that must be sustained. The magnitude of P_{xx} depends upon the service exposure time of the structure between inspections and the overall degree of inspectability. The load P_{xx} is intended to represent the maximum load that the aircraft might encounter during the time interval between inspections.

The required P_{xx} is at least design limit load for all intact structure whether the structure is being qualified as Slow Crack Growth or Fail Safe. The required P_{xx} is also at least design limit load when the only planned safety inspections are at the depot (i.e., the depot or base-level inspection category).

In addition, all Fail Safe Structure must be designed to be at least depot level inspectable, and P_{xx} over this inspection interval must be at least limit load. This restriction is obvious since the only means to protect the safety is not to allow damage growth to degrade the strength of the structure to less than design limit load. Where partial failure is allowed and subsequent detection of failed load path is required, the limit load requirement on intact structure has two benefits. First, it is the only way that the operational force can be maintained with unrestricted capability; and second, when coupled with the intact structure damage growth guidelines, it provides assurance that, under normal situations, early nuisance cracking will not occur as a result of lower stress.

1.3.5.1 Fail-Safe Structure at Time of Load Path Failure

For Fail Safe Structure, there is a requirement that the remaining structure at the time of a single load path failure must be capable of withstanding a minimum load P_{yy}. This load P_{yy} is at least the load that causes the load path failure, plus an additional increment to account for the dynamic conditions of the breaking member. While most data and analyses indicate that the dynamic magnification factor associated with the member failure is probably very small, the current guidance in JSSG-2006 requires that a 1.15 dynamic factor be applied to the redistributed incremental load unless another value is determined by test or analysis. For non-metallic structure, the dynamic factor should be verified by testing. Figure 1.3.9 illustrates the change in residual strength guidelines as a result of a load path failure.

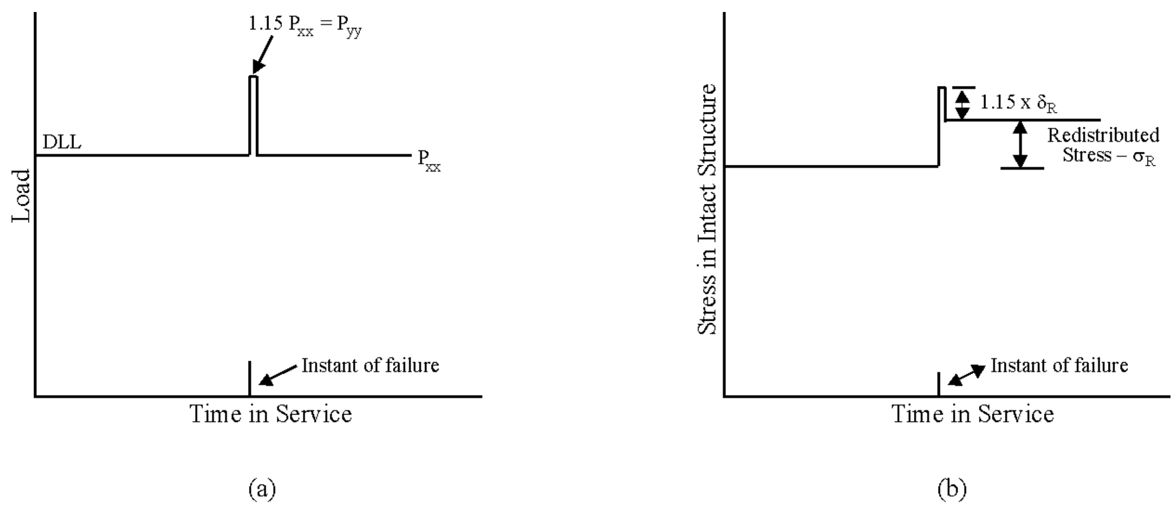


Figure 1.3.9. Schematic Residual Strength Guidelines for Fail Safe Structure

1.3.5.2 Determining the Residual Strength Load for Remaining Structure

The magnitude of the required residual strength load depends upon the exposure time in service because the longer the exposure time, the greater the probability of encountering a high load. Accordingly, the value of required P_{xx} load increases with an increase in the inspection interval or period of unrepaired service usage (allowable crack growth period). For the short service exposure times between inspections for the In-Flight Evident, Ground Evident and Walk Around Visual categories, the probability of encountering limit load conditions is low and thus the required P_{xx} may be significantly below design limit load. For the longer exposure times between depot or base level inspections, the probability of encountering limit load is much higher, and therefore for Depot Level and Non-Inspectable categories, the minimum required P_{xx} must be at least limit load, but P_{xx} need not be greater than 1.2 times the maximum load in one lifetime.

The value of P_{xx} is established from load spectra data derived from a mission analysis of the particular aircraft considering average usage within each mission segment. Unless otherwise stated, MIL-A-8866 is the basic source of load factor data for the various classes of aircraft. Since safe operation depends upon the residual strength capability and since any individual aircraft may encounter loads in excess of the average expected during the particular exposure time, the P_{xx} load required is larger than the average derived value.

One way to determine the level of P_{xx} required is to hypothetically increase the service exposure time for the aircraft between inspections by a factor of *M*. This is the method used in JSSG-2006. The values of *M* are specified in JSSG-2006 Table X, and summarized in Table 1.3.4. For example, under the ground-evident level inspectability category, the P_{xx} load is the maximum load expected to occur once in 100 flights (*M* x inspection interval = one flight x 100).

Table 1.3.4. Inspection Interval Magnification Factors from JSSG-2006 Table X

P_{xx}	Degree of Inspectability	Typical Inspection Interval	Magnification Factor M
P_{FE}	In-Flight Evident	One Flight	100
P_{GE}	Ground Evident	One Flight	100
P_{WV}	Walk-Around Visual	Ten Flights	100
P_{SV}	Special Visual	One Year	50
P_{DM}	Depot or Base Level	¼ Lifetime	20
P_{LT}	Non-Inspectable	One Lifetime	20

* P_{xx} = Minimum average interval member load that will occur once in *M* times the inspection interval. Where P_{DM} or P_{LT} is determined to be less than the design limit load, the design limit load shall be the required residual strength load level. P_{xx} need not be greater than 1.2 times the maximum load in one lifetime if greater than design limit load.

The basis for the specified *M* values is somewhat arbitrary although it is felt that the loads derived by this method are not unreasonably conservative. The basis for *M* = 100 is exceedance data for transport type aircraft, where it has been observed that shifting exceedances by approximately two decades (i.e., *M* = 100) magnifies the value of load factor (or stress) by approximately 1.5 (Figure 1.3.10). It was recognized that for fighter data, exceedances approaching or exceeding design limit values are probable but that extrapolation of the basic exceedances curve very far beyond limit load factor (n_z) is often meaningless and unwarranted due to physical limitations of the vehicle and crew. Furthermore, in most cases actual service data is somewhat sparse for this region of the curve. Therefore, (1) an upper limit was required on P_{xx} for fighter aircraft and (2) the value of *M* should be less for longer inspection intervals in order that unreasonable factors would not be imposed should the actual derived P_{xx} be less than the specified upper limit. The values of *M* equal to 20 and 50 are arbitrary but probably not unreasonable. Where the derived P_{xx} is larger that that associated with the design limit conditions, P_{xx} can be taken as 1.2 times the maximum load expected to occur in one design lifetime.

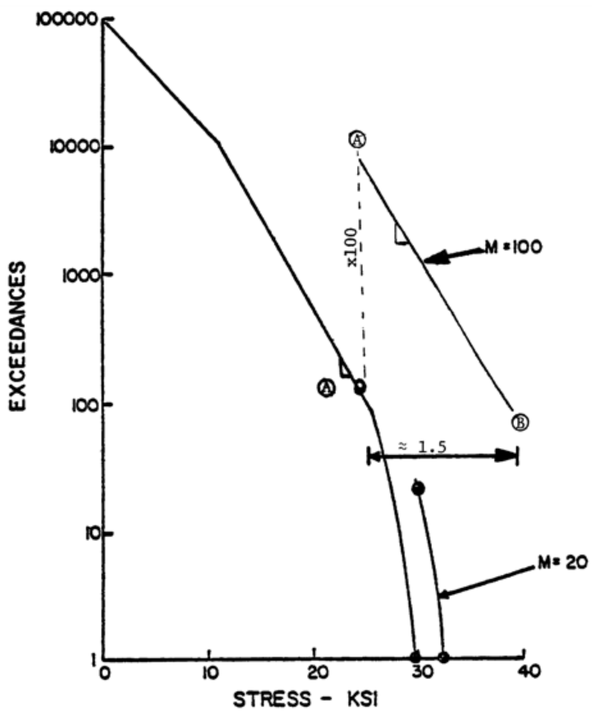
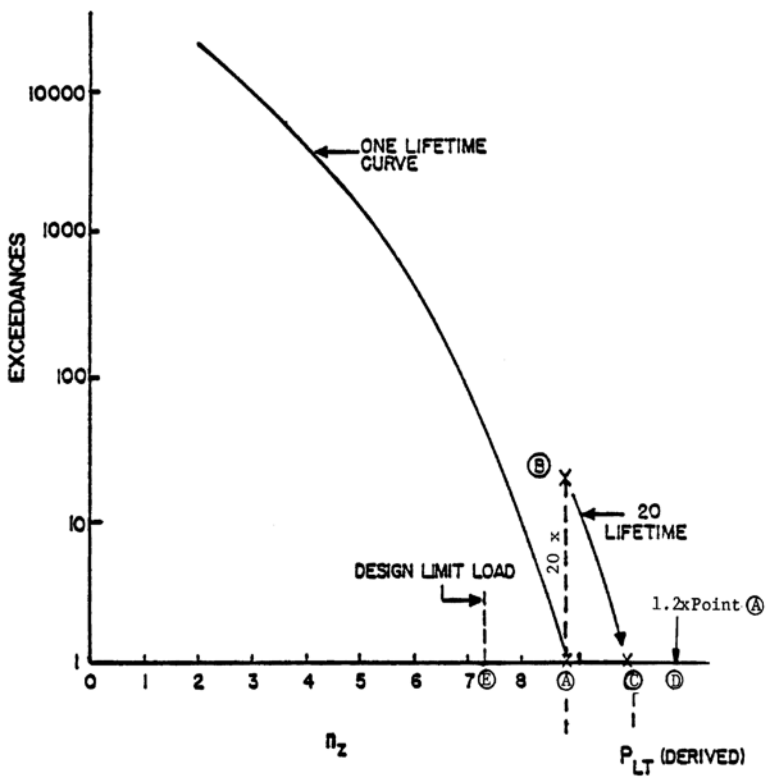


Figure 1.3.10. Illustration of Procedure to Derive *M* Factor to Apply to Exceedance Curve

EXAMPLE 1.3.3 Derivation of P_{xx} From Exceedance Data for Non-Inspectable Structure

The procedure for obtaining P_{xx} is illustrated using the exceedance plot shown here. This figure presents the average exceedance data for one design lifetime. The point A represents the maximum load expected in one lifetime; this is shown to be larger than the limit load (Point E). For the core of a non-inspectable structure, the twenty lifetime (M_x inspection interval) exceedance curve is obtained by shifting the exceedance curve from point A to point B and extrapolating to point C. The twenty lifetime exceedance curve yields P_{xx} (derived) at C. The required load P_{xx} then is either the value derived at C or 1.2 × (load at point A) i.e., the load at point D, whichever is smaller. In this case, P_{xx} (= P_{LT}) is the load at point C.



1.3.6 Required Periods Of Safe Damage Growth

All safety of flight structure are required to maintain the required residual strength in the presence of damage for a specified period of unrepaired service usage. During the period of safe damage growth, the initial damage, which is presumed to exist in the structure, will not grow to a critical size and cause failure of the structure.

The required period of safe damage growth is a function of design category (either slow crack growth or fail safe) and the degree of inspectability as defined in Section 1.3.3. In order to cover various uncertainties associated with crack growth during service usage that may not be adequately accounted for in the analyses or laboratory test, the structure must withstand a period of service usage longer than the planned inspection interval. The periods of unrepaired service usage for the inspectability categories is given in JSSG-2006 Table XXXIII and repeated in Table 1.3.5.

Table 1.3.5. Minimum Periods of Unrepaired Service Usage for In-Service Inspectable Structures

Degree of Inspectability	P_{xx}	Minimum Period of Unrepaired Service Usage
In-Flight Evident	P_{FE}	Return to base
Ground Evident	P_{GE}	Two flights of most damaging design mission
Walk-Around Visual	P_{WV}	5 × Inspection interval (= 5×10 flights)
Special Visual	P_{SV}	2 × Inspection interval (= 2× one year)
Depot or Base Level	P_{DM}	2 × Inspection interval (= 2× ¼ lifetimes)

1.3.6.1 Slow Crack Growth Structure

For slow crack growth structure, the required period of unrepaired service usage is two service usage lifetimes. A factor of two is applied to cover various uncertainties associated with crack growth during service usage, such variability in material properties, manufacturing quality and inspection reliability.

1.3.6.2 Fail Safe Multiple Load Path Structure

Fail safe structure must be able to withstand a specified period of service usage after a primary load path failure. The period of unrepaired service usage depends upon the type and frequency of inspection for the structure.

An initial inspection interval is established to insure detection of any premature primary element failure. The initial inspection interval is dependent on the particular geometry and degree of inspectability, as given in Table 1.3.5. The initial inspection interval should not be greater than one half of the time to primary load path failure from the specified initial flaw for primary elements plus one half of remaining time to failure of adjacent structure from its flaw size at the time of primary element failure. These initial flaw sizes are specified in Section 1.3.4.

Subsequent inspection intervals are also based on the degree of inspectability of the primary element as given in JSSG-2006 Table XXXIV and repeated in Table 1.3.6.

1.3.6.3 Fail Safe Crack Arrest Structures

Fail safe crack arrest structure must be able to withstand a specified period of service usage after a primary load path failure. The period of unrepaired service usage depends upon the inspectability level for the structure. The degrees of inspectability for fail safe crack arrest structure are the same as for fail safe multiple load path structures.

The initial inspection intervals are given in Table 1.3.5, and subsequent inspection intervals are given in Table 1.3.6.

Table 1.3.6. Subsequent In-Service Inspection Intervals for Fail-Safe Structures

Primary Element Degree of Inspectability	P_{xx}	Subsequent Inspection Intervals
In-Flight Evident	P_{FE}	Each flight of most damaging design mission
Ground Evident	P_{GE}	Two flights of most damaging design mission
Walk-Around Visual	P_{WV}	Ten flights of most damaging design mission
Special Visual	P_{SV}	One year
Depot or Base Level	P_{DM}	One half of the remaining time to failure of the adjacent structure from the flaw size specified for adjacent load paths at the time of primary element failure; or, if the adjacent structure is inspected, one half of the remaining time to failure of the adjacent structure from in-service inspection flaw size for the adjacent structure as specified. In either case, the primary element is assumed to be failed.

1.3.7 Illustrative Example Of Guidelines

These examples are based on the lower wing structure shown in Figure 1.3.11. The structure is comprised of multiple skin and stringer elements. The skin panels 1−5 are considered the major load paths. At each spanwise splice, a major splicing stringer is located and the construction is such that the load paths are independent, i.e., no common manufacturing tie exists between the skin panels.

The design service life is assumed to be 40,000 hours for these examples.

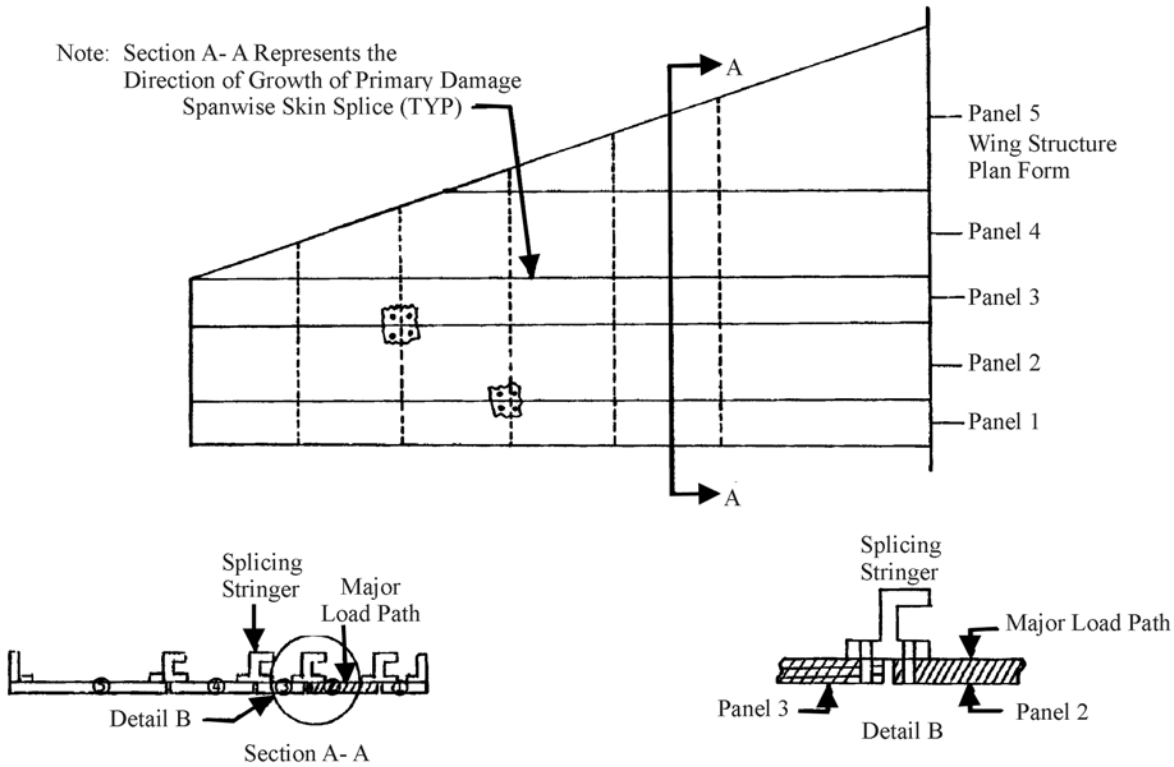


Figure 1.3.11. Structural Example of Lower Wing Skin

1.3.7.1 Slow Crack Growth Structure

The choice of structural design concept for this example is Slow Crack Growth Structure. The steps required to satisfy this requirement are outlined in the following sections. Panel ② is chosen to be the critical load path for purposes of illustration

1.3.7.1.1 Initial Flaw Sizes Assumed to Result from Manufacturing

The assumed flaws for the slow crack growth type structure are described in Section 1.3.4. Thus, an 0.050 inch corner flaw is assumed to exist at the critical fastener hole joining panel ② and the splicing stringer, as shown in Figure 1.3.12. For this example, it is assumed that a common drilling operation was employed to prepare the hole with the primary damage, and therefore the same size crack is assumed in both elements. Also, as explained in Section 1.3.4, initial flaws equivalent in stress-intensity factor level to an 0.005 inch radius corner flaw shall be assumed to exist in each hole of each element in the structure, such as shown in Figure 1.3.12.

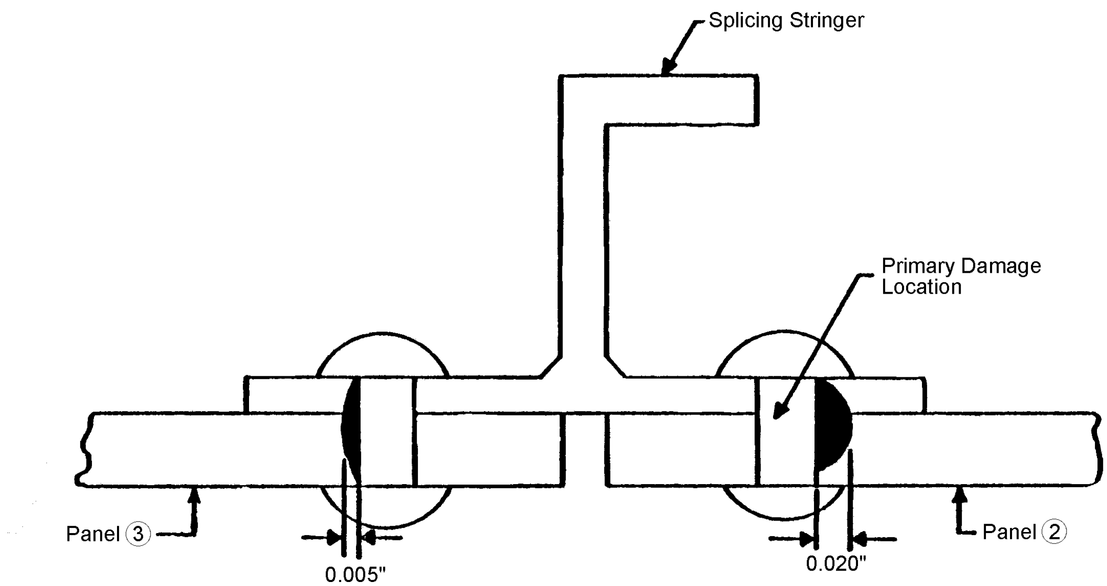


Figure 1.3.12. Illustration of Initial Flaws for Structure Qualified as Fail-Safe Multiple Load Path

1.3.7.1.2 Choice of Inspection Category

There are only two inspection categories that are available to the designer for Slow Crack Growth Structure: in-service non-inspectable and depot level inspectable. The choice of inspection category directly impacts the guidelines for residual strength and for damage growth limits. For purposes of this discussion, both categories are presented.

1.3.7.1.3 In-Service Non-Inspectable Category

For this example case, no special in-service and no depot level inspections will be required to protect the integrity of the lower wing structure shown in Figure 1.3.11. The implication is that no inspections are desired; however, there are cases in which the flaw size at failure is so small that such a flaw might easily be overlooked during an inspection. Thus, the in-service non-inspectable category covers those cases where inspections are neither desirable nor practical.

Residual Strength Load, P_{xx}

From Table 1.3.4, the required level of residual strength P_{xx} for non-inspectable structure is P_{LT}. This is the maximum load that could occur in one lifetime. Example 1.3.3 describes the method for establishing this load level.

Analysis Guidelines

The slow crack growth and residual strength guidelines for this category are illustrated in Figure 1.3.13. This figure specifically shows that the initial manufacturing damage is restricted from growing to critical size and causing failure of the structure due to the application of P_{LT} in two (2) design service lifetimes. Note that the damage limit is the ultimate failure of the wing. Engineering judgement may dictate that a more reasonable limit and, perhaps, an easier situation to adhere to, would be to establish the limit at some intermediate point, such as the failure of the primary load path panel ②. This might be accomplished in design at very little expense to overall weight.

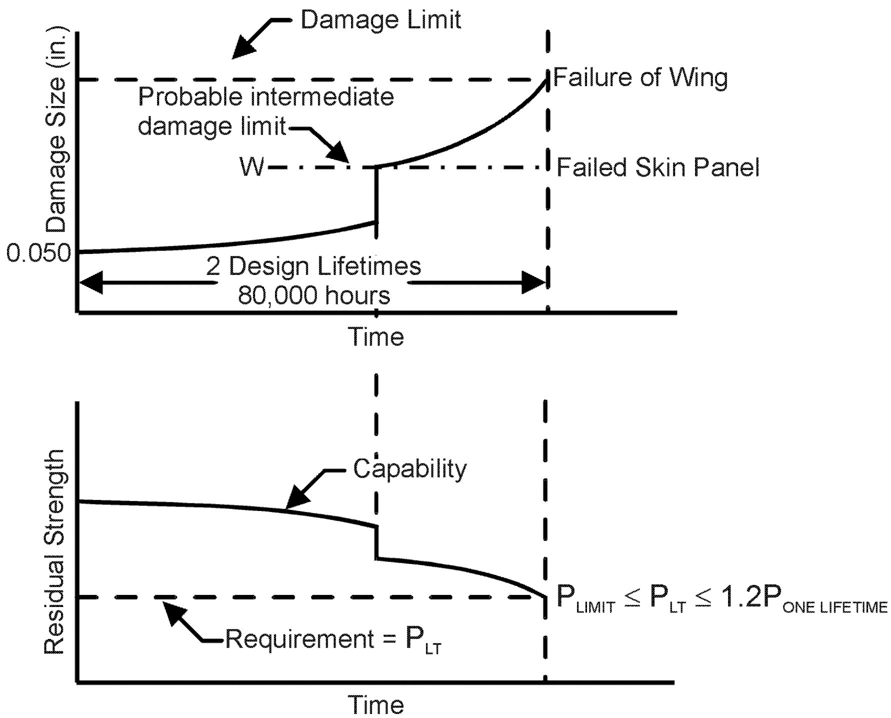


Figure 1.3.13. Illustration of Damage-Growth and Residual-Strength Guidelines for Example Problem Qualified as Slow Crack Growth Non-Inspectable

1.3.7.1.4 Depot Level Inspectable Category

For this example case, the damage which is presumed to exist in the structure after completion of the depot or base level inspection is given in Table 1.3.3.

In-Service Flaw Assumptions Following Inspection

The capability of inspection in the field is generally less than at the depot. The sizes of damage assumed to exist following inspection are specified in Table 1.3.2. For this example, assume that penetrant or ultrasonics will be used at the depot both exterior and interior to the lower surface. If this type of inspection is conducted, the damage likely to be found will be much smaller than the failed skin panel. From Table 1.3.3, the minimum damage size to be assumed at the hole is a through crack of 0.25 inch uncovered length. The locations of the 0.25 inch flaw in both the skin and the splicing stringer should be selected on the basis of inspectability but should be the location most critical to subsequent growth. Assume for purposes of illustration, that the damage is as indicated in Figure 1.3.14. The 0.005 inch flaw away from the primary damage site represents the initial manufacturing type damage as explained in Section 1.3.4.

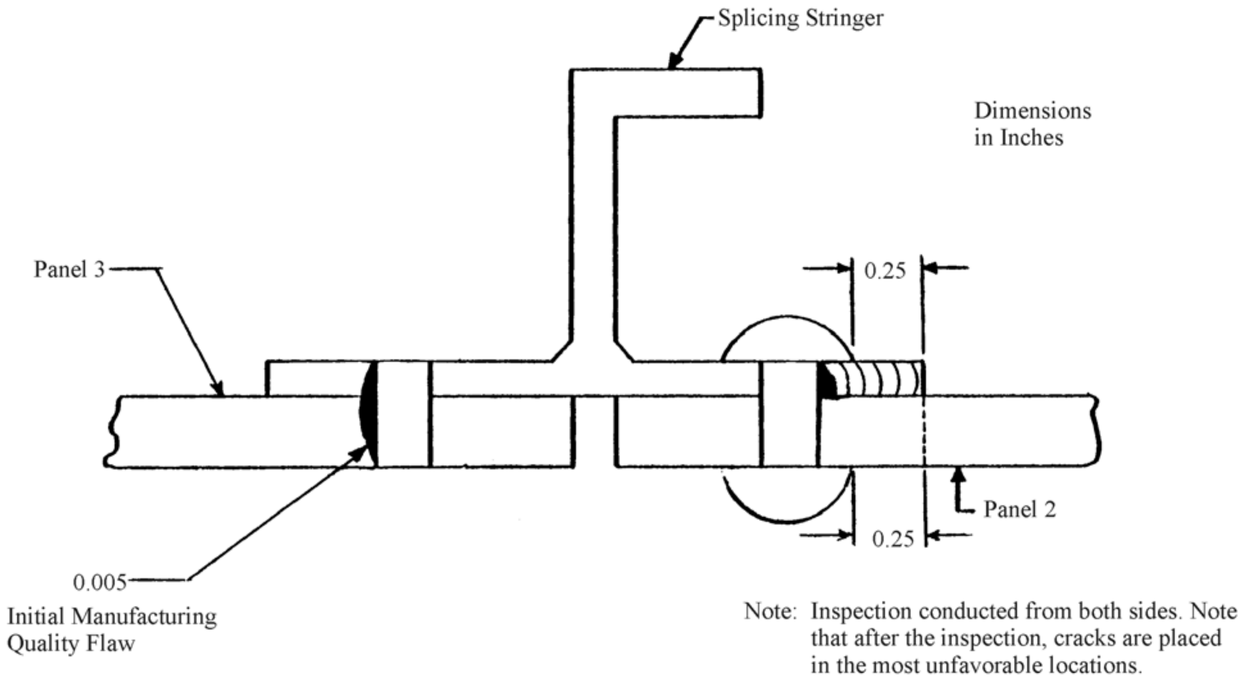


Figure 1.3.14. Illustration of Primary Damage Following a Depot-Level Penetrant or Ultrasonic Inspection

Residual Strength Load, P_{xx}

The required level of residual strength P_{xx} for the depot or base level inspection category is P_{DM}, as shown in Table 1.3.4. This is the maximum load that would occur in the planned ¼ lifetime (10,000 hour) inspection interval. The method for establishing this particular load level follows the method outlined in Example 1.3.3 where the one life time exceedance curve is multiplied by a factor of 5 rather than 20.

Analysis Guidelines

Figure 1.3.15 illustrates the slow crack growth and residual strength guidelines for this category, as established by JSSG-2006 paragraph A3.12.2. This figure specifically shows that the post-inspection damage is restricted from growing a crack to critical size and thereby causing failure of the structure due to the application of P_{DM} in two times the inspection interval (½ lifetime, 20,000 flight hours).

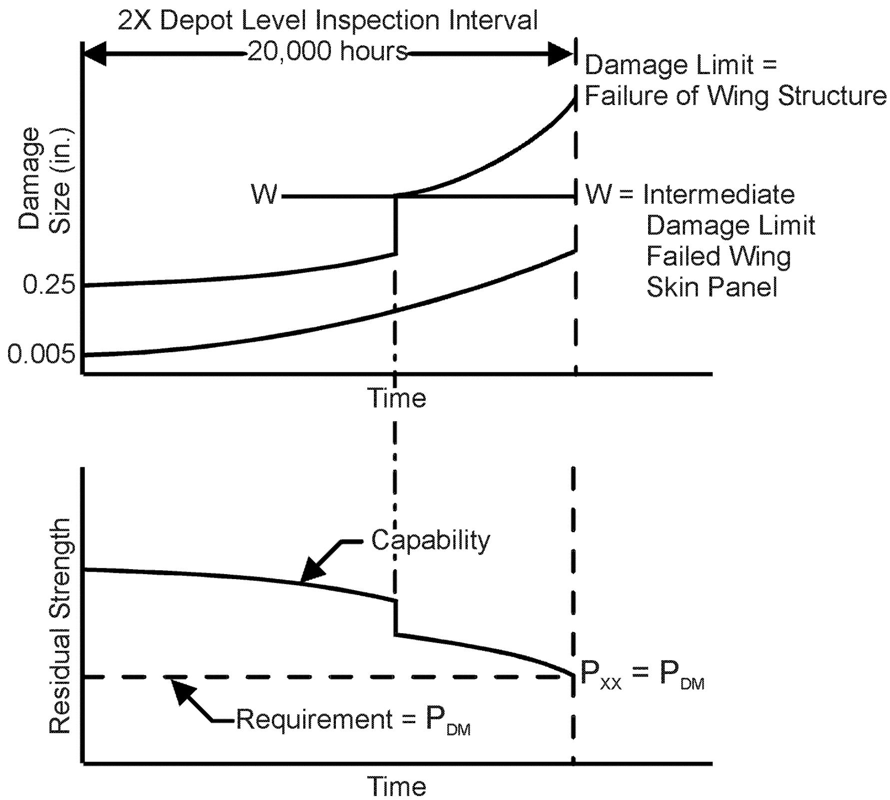


Figure 1.3.15. Illustration of Damage-Growth and Residual Strength Guidelines for Example Problem Qualified as Depot-Level-Inspectable

1.3.7.2 <u>Fail Safe Structure</u>

This example of fail safe structure is based on the lower wing structure shown in Figure 1.3.11. The structure is assumed to be a Fail Safe Multiple Load Path Structure and the steps required to satisfy this requirement will be outlined. The structure will be designed to be Fail Safe by virtue of being able to sustain the failure of one major load path or skin panel and still maintain the residual strength and remaining structural guidelines. For illustration purposes, panel ② was chosen as the critical load path. Although the loss of panel ② is critical from a remaining structure point of view, every panel must be designed to meet the intact guidelines.

1.3.7.2.1 In-Service Inspection Consideration

Since the design is intended to satisfy the Fail Safe Multiple Load Path category, an in-service inspection plan is required. It is assumed that the lower surface will be periodically inspected in the field by a walk-around-visual-type examination, generally unaided. The frequency of these inspections is approximately every ten flights. In addition, the structure will undergo a depot level inspection at approximately ¼ design lifetime intervals of every 10,000 hours. During manufacture, inspections by conventional methods will be conducted and a fracture control program will be instituted.

1.3.7.2.2 Initial Flaw Considerations

Flaws assumed to result from manufacturing and/or material conditions are specified in JSSG-2006 paragraph A3.12.2 for Fail Safe Structure. The primary damage at a fastener hole (Figure

1.3.16) is an 0.05 inch corner flaw. Since the drilling operation is common to the skin and splicing stringer, the 0.05 inch flaw must be assumed in both members. Panel ② is considered for this example because it was previously chosen to be the critical load path. Note that only one primary damage site is assumed for each load path (e.g. along the path of expected damage, along a wing section). Also, it is not necessary to consider the interaction of flaws from adjacent primary sites. Each analysis of primary damage is conducted independently. At each hole other than the assumed primary site, an 0.005 inch radius corner flaw is assumed to represent average or typical manufacturing quality. The effect of interactions between the 0.005 inch flaws and the primary flaws must be considered when conducting the analysis.

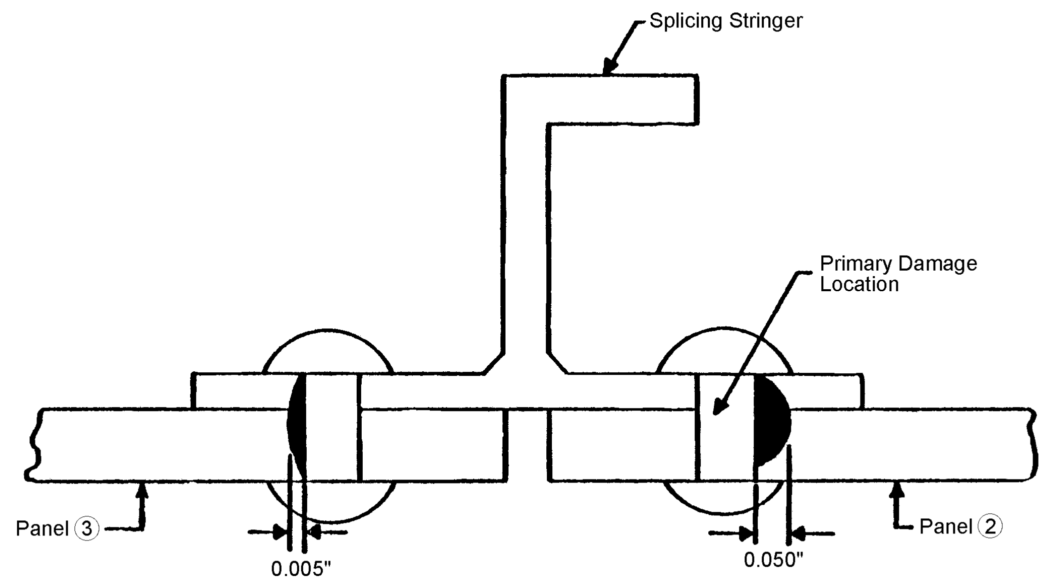


Figure 1.3.16. Initial-Flaw Assumptions for Example Case Qualified as Fail Safe

1.3.7.2.3 In-Service Flaw Assumptions Following Inspection

The capability of inspection in the field is generally less than at the depot. The sizes of damage assumed to exist following inspection are specified in JSSG-2006 paragraph A3.12.1. For this example, assume that penetrant or ultrasonics will be used at the depot both exterior and interior to the lower surface. If this type of inspection is conducted, the damage likely to be found will be much smaller than the failed skin panel. From JSSG-2006 Table XXXII the minimum damage size to be assumed is a through crack of 0.25 inch uncovered length. The locations of the 0.25 inch length both in the skin and in the splicing stringer should be selected on the basis of inspectability but should be the location most critical to subsequent growth. Assume for purposes of illustration, that the damage is as indicated in Figure 1.3.17. The 0.005 inch flaw away from the primary damage site represents the initial manufacturing type damage as specified in JSSG-2006 paragraph A3.12.1.

1.3.7.2.4 Adjacent Structure Damage Following the Failure of the Major Load Path

Figure 1.3.18 illustrates the condition of the structure following the complete failure of the primary load path (skin panel ②) represented by the cross hatched area. The condition of the remaining structure is as specified in JSSG-2006 paragraph A3.12.1c(2) since this is an example of independent structure. Each fastener hole in the structure is assumed to contain the 0.005 inch typical manufacturing hole quality flaw. The Δa_2 increment is the growth of these typical flaws from the time of manufacture until the point at which the load path is assumed to have failed. The increment Δa_2 will be discussed later.

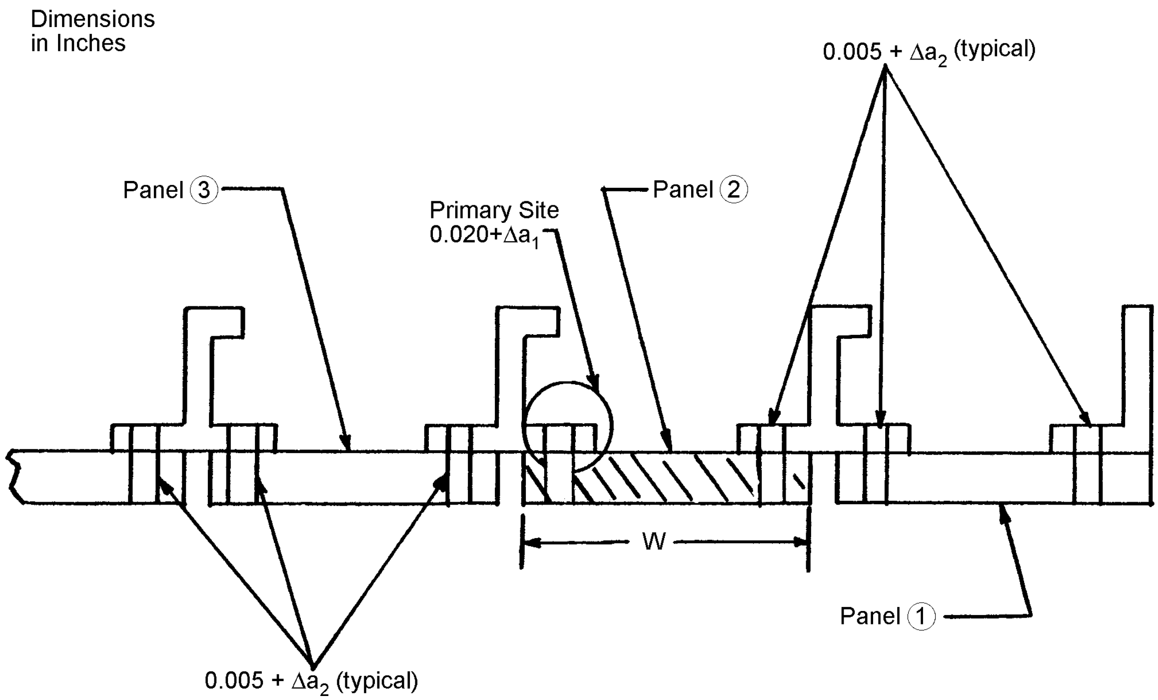


Figure 1.3.17. Illustration of Primary Damage Assumptions Following the Failure of Major Load Path (Panel 2)

1.3.7.2.5 Analysis of Intact Structure–Residual Strength Guidelines and Damage Growth Limits

The specific set of guidelines for intact structure depends upon the capability of the depot level inspection. Since this example has assumed the situation where the normal inspection can detect less than a failed load path, this case will be examined first.

The intact requirement is that the in-service damage, assumed to be present following the depot level inspection (Figure 1.3.17), shall not grow and cause failure of the major load path (panel ②) before the next opportunity to discover the damage, i.e., the next inspection.

Since this is merely a one-time design requirement, not specifically intended for safety, it is not necessary to account for prior service at the time at which the requirement was imposed. Thus, the structure is considered as "new" and no incremental growth Δa due to prior service is computed. Figure 1.3.18 illustrates schematically the residual strength and growth guidelines that must be met for the intact structure.

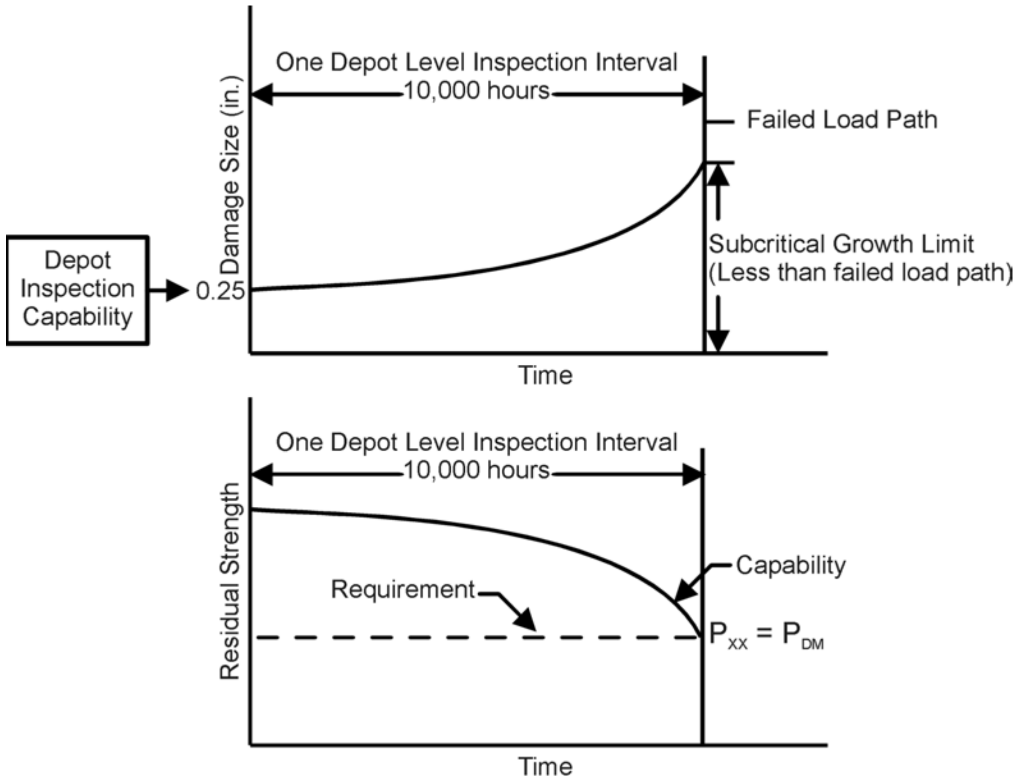


Figure 1.3.18. Illustration of Damage-Growth Limits and Residual-Strength for Intact Structure Following Depot or Base-Level Inspection for Less-Than-Failed Load Path

1.3.7.2.6 Analysis of Intact Structure (Alternate Requirement)

If the depot level inspection is incapable of finding damage less than a failed load path, then the requirement for intact structure is given in JSSG-2006 paragraph A3.12.1c. This states that initial manufacturing damage shall not grow to the size required to cause load path failure due to the application of P_{LT} in one design lifetime. The initial damage assumption for this case is illustrated in Figure 1.3.16. The schematic of the growth and residual strength guidelines are illustrated in Figure 1.3.19.

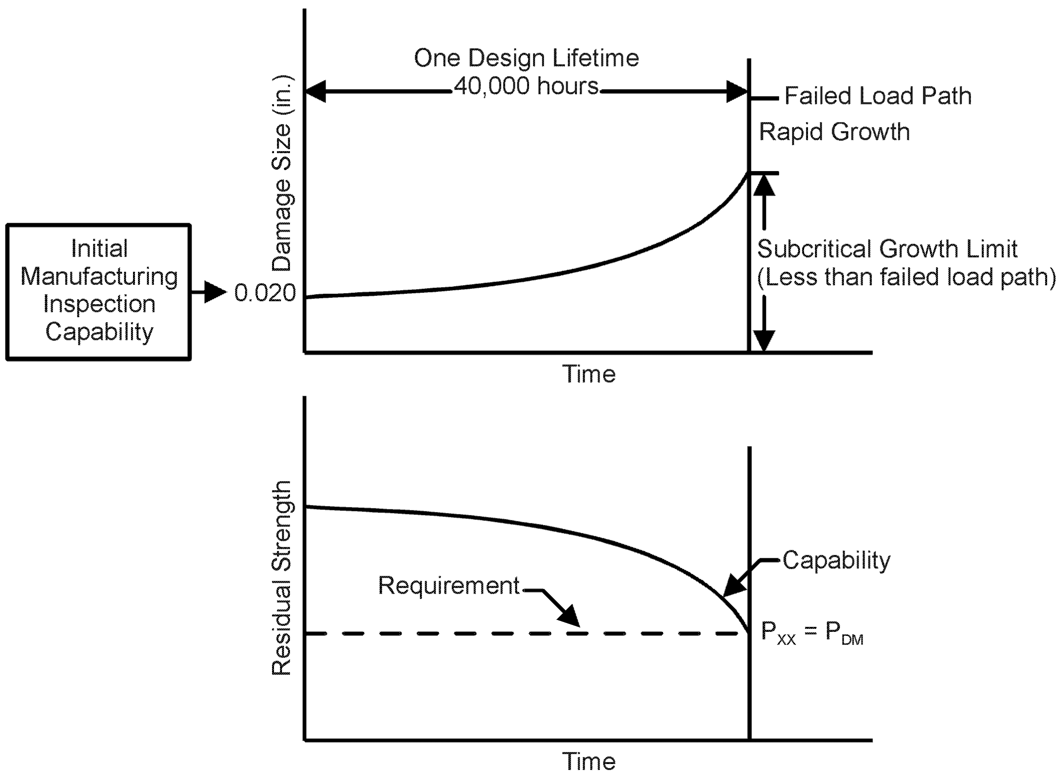


Figure 1.3.19. Illustration of Damage-Growth Limits and Residual Strength; Intact Structure for When Depot Inspection Cannot Detect Less-Than-Failed Load Path

1.3.7.2.7 Discussion of Intact Structure Analysis

Although the structure in the example was assumed to be depot level inspectable for less than a failed load path, the intact structure requirement associated with this set of conditions might have been more difficult to meet than would be the case if the structure were not inspectable for less than a failed load path. In the latter case, it would be satisfactory for the designer to qualify the structure under the alternate requirement described in Section 1.3.7.2.6. As is often the case, the designer may choose to qualify the structure in the easiest (analysis) manner.

1.3.7.2.8 Analysis of Remaining Structure Subsequent to Load Path Failure

The fail safe characteristics of this structure, i.e., the ability to fail panel ② and fly safely until the failed panel is detected, depends upon the residual strength capability at the time of and subsequent to load path failure and the capability of and frequency of in-service inspections. The remaining structure guidelines are specified in JSSG-2006 paragraph A3.12.2.2.

As stated earlier, the fail safety will be supported by walk-around-visual inspections for damage sizes on the order of a failed load path. Generally, the walk-around-visual inspection can be aided by detectable signs such as fuel leakage. At any rate, the minimum inspection capability for this example will be considered to be a failed load path.

The damage as illustrated in Figure 1.3.17 shall not grow to a size such as to cause loss of the wing due to the application of P_{VW} in 5 times the inspection interval (10 flights), i.e. in 50 flights. This is illustrated in Figure 1.3.20. The load $P_{xx} = P_{yy}$ will generally be less than the design limit condition and P_{yy} (as discussed in Section 2.5) will always be equal to or greater than that associated with the design limit condition.

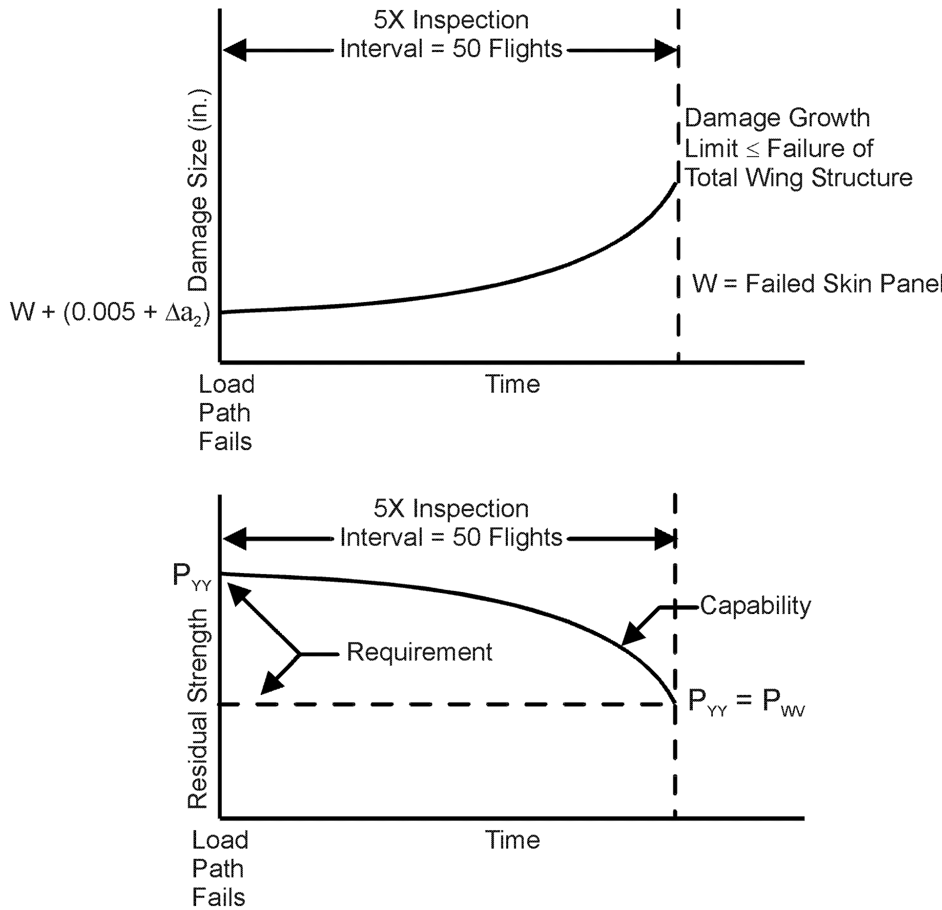


Figure 1.3.20. Illustration of Damage-Growth Limits and Strength Guidelines; Remaining Structure Subsequent to Load-Path Failure

1.3.7.2.9 Derivation of Residual Strength Load

In the analysis of the intact structure, the critical damage limit is failure of the skin panel ②. The mode of failure was slow growth of either depot level inspection type damage or initial manufacturing damage (Figure 1.3.18 and 1.3.19, respectively). In each case, the damage is assumed to grow in a stable manner until the critical damage size in the skin panel is reached. The critical damage size for this case would be that size at $P_{xx} = P_{DM}$ or $P_{xx} = P_{LT}$ where P_{xx} is bounded by

$$P_{limit} \leq P_{xx} \leq 1.2 P_{one\ lifetime}$$

For a balance fail safe design, the remaining structure must be capable of withstanding the effects of the major load path failing, including the redistribution of load to adjacent members at the time of load path failure. This is the basis for the requirement that the remaining structure must support the P_{yy} residual strength load. The load P_{yy} is dependent upon the design allowable for the first panel (Panel ② in this case).

Assume for example that the P_{xx} allowable for first panel failure is exactly P_{limit}. The remaining structure must be capable of supporting P_{limit} with adjacent panels carrying the increment or that portion originally carried by panel ② at P_{limit}. This is illustrated in Figure 1.3.21 where the amount of load in panel ② at the limit design condition, i.e. P_2 is redistributed after it is multiplied by 1.15 to account for dynamic effects (ΔP_1+ΔP_2+ ΔP_3+ ΔP_4+ ΔP_5). The total redistribution increment then is

$$1.15P_2 = \left(\Delta P_1 + \Delta P_3 + \Delta P_4 + \Delta P_5\right)$$

The residual strength capability of the remaining structure is then checked against this condition; the P_{yy} requirement for panel ③ is $P^3_{yy} = P^3_{yy} + \Delta P_3$.

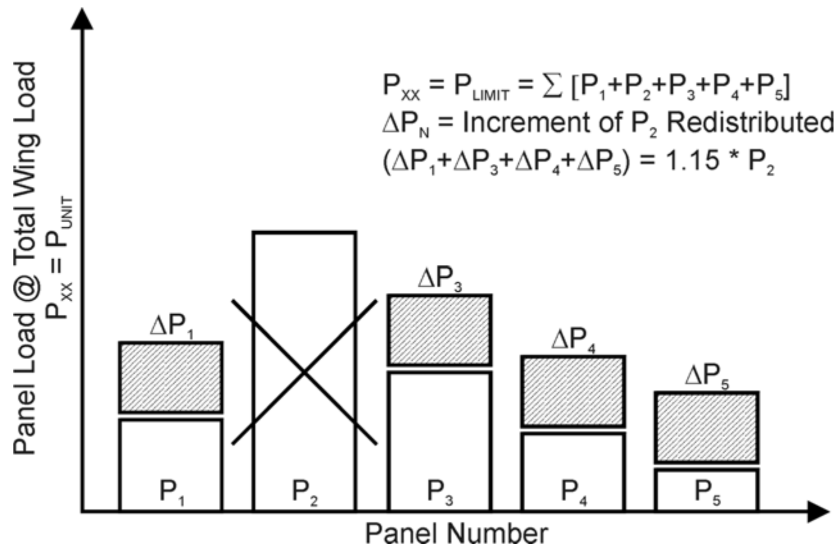


Figure 1.3.21. Illustration of Redistributed Panel Load P_2 to Adjacent Structure

1.3.7.2.10 Incremental Damage Growth Δa

The remaining structure analysis of damage growth and residual strength considers damage in the adjacent structure at the time of load path failure which has grown an amount Δa from the time of manufacture (Figure 1.3.19). Since the structure must met the single design lifetime requirement, it becomes necessary to establish at what point during the lifetime the failure of the load path is assumed to take place so that the proper amount of growth Δa can be computed to represent growth during this time segment.

Figure 1.3.22 illustrates the growth of the 0.005 inch manufacturing type damage from time zero for one design lifetime. In this example, the walk-around-visual inspection is used to detect the failure of the major load path and the inspection interval is 10 flights. JSSG-2006 Table XXXIII requires a factor of 5 on this interval and thus the damage growth life requirement is 50 flights. Therefore, the maximum amount of Δa and the condition to be met would be growth for one design lifetime minus 50 flights.

For any other in-service inspection interval the amount Δa would be computed in a similar manner. For example, if the walk-around-visual inspection was not conducted and fail safety was dependent upon discovery of damage at the scheduled 10,000 hour depot level inspection, then the increment of growth Δa would be one design lifetime minus 2x 10,000 hours, as in Figure 1.3.23.

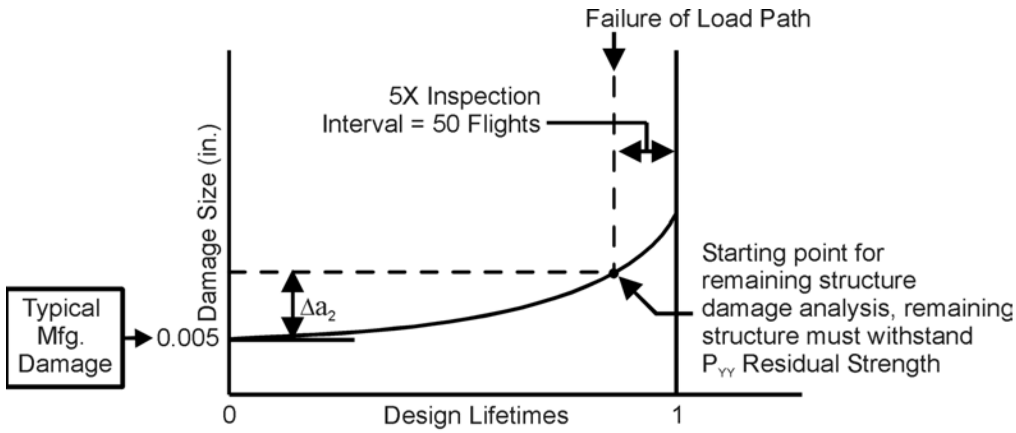


Figure 1.3.22. Development of Increment of Growth Δa_2 for Walk-Around-Visual Inspectable Damage

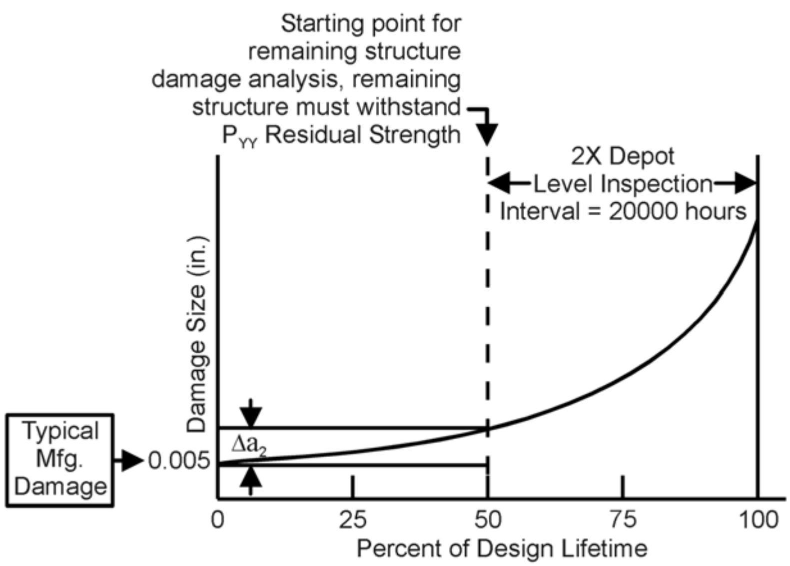


Figure 1.3.23. Development of Increment of Growth Δa_2 for Depot-Level-Inspectable Damage

1.3.7.2.11 Alternative-Analysis of Remaining Structure Subsequent to Load Path Failure

As indicated in 1.3.7.2.10, the designer may choose to depend upon the depot level inspection instead of the walk-around visual. This would be a satisfactory alternative and for this situation the assumption would be made that the major load path failed between depot level inspections and that the aircraft would be designed to operate safely with the failed load path until the next depot inspection. Figure 1.3.24 illustrates this case.

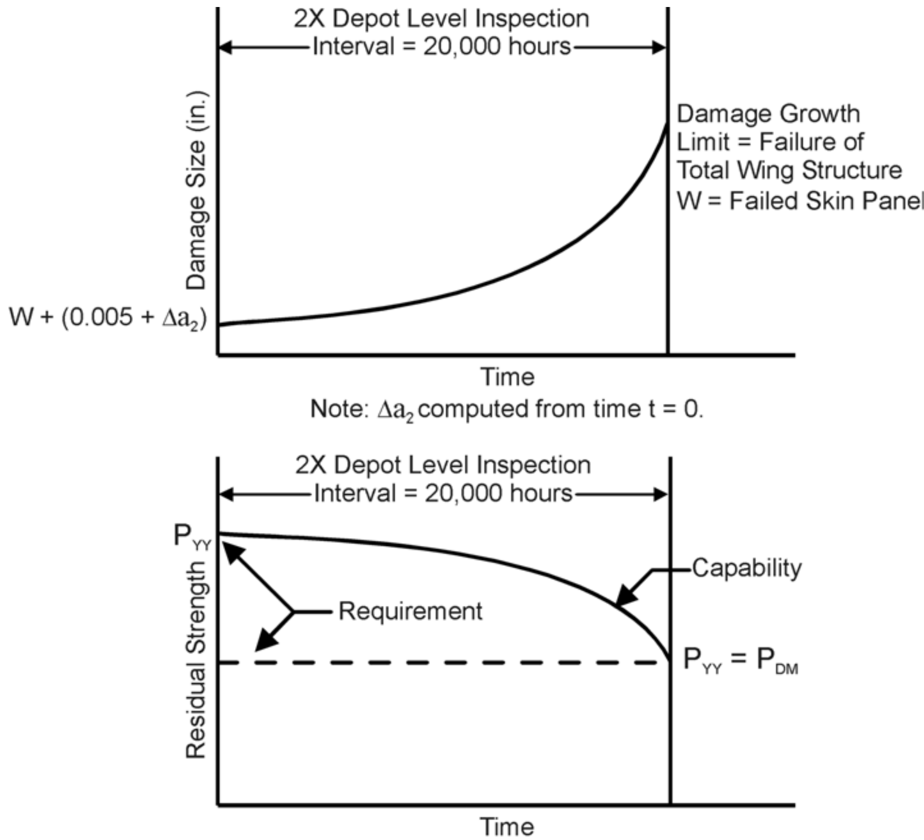


Figure 1.3.24. Illustration of Damage Growth and Residual-Strength Guidelines for Remaining Structure-Depot-Level-Inspectable

1.3.7.2.12 Summary and Comments

This example has illustrated the steps required to qualify the structure under the category of Fail Safe Multiple Load Path Structure. For this category, an intact structure requirement (prior to load path failure), a residual strength requirement at the time of load path failure, and a remaining structure damage growth and residual strength requirement had to be met.

The requirement to qualify the structure generally requires a complex set of analyses, and in the early design stage may be impractical. The design could be made to satisfy Slow Crack Growth Structure guidelines, either non-inspectable or depot level inspectable, while still maintaining some level of fail safety, but not necessarily meeting the guidelines specifically. This approach would generally be satisfactory and usually requires a lesser amount of analysis, particularly for computing residual strength and the growth increment.