7.5 Structural Hardware Tests

The structural hardware tests have two functions: to support the verification of the complete structural design, and to define those areas of the structure that need additional attention. These tests are scheduled so that there is sufficient time to incorporate structural changes into production aircraft. In fact, production go-ahead is predicated on completing at least one design lifetime of flight-by-flight loading in the full-scale durability test (see JSSG-2006 paragraph A.4.11.1.2.2.b). Structural hardware tests include joint tests, component tests, assembly tests, as well as full-scale structural tests.

Examples of variables that may be considered for the study of different design concepts, design details and structural materials are:

- fastener systems
- type of joints and joint detail
- forged versus machined or built-up structure
- production method
- reinforcement or tear strap shape, size, and spacing
- multiple or single load path
- materials or combination of materials
- effect of design stress level

The testing of one or more of these variables will not be specifically addressed. Rather, a discussion of the essential conditions for design development testing for damage tolerance is presented in general.

7.5.1 Test Conditions

Structural hardware testing can be a form of comparative testing during the development phase. That means that the test conditions do not always have to be an exact simulation of service conditions as long as the variables considered are tested the same way. However, it is strongly recommended that service conditions be approximated as closely as possible. How closely the test conditions have to resemble service conditions depends upon the predictability of the effect of a change in conditions.

The following guidelines are applicable to structural hardware testing for damage tolerance. First, the specimen should contain the design and manufacturing details that are the subject of the investigation. The load should be properly distributed at the point of interest. Second, if the purpose is to validate a piece of structure for damage tolerance, then load sharing, load interaction, and load transfer among different members should be simulated or otherwise accounted for. Type of loading (bending, tension) should be as in service, or be such that the stress distribution at the critical location is as in the actual structure. Special care should be taken that no undesired bending is introduced due to load eccentricities. This requires intelligent grip design. It may also require some special structure to distribute the loads properly from these areas into the specimen. Third, the nominal stress at the critical location should be as in service. Experiments should be performed on a flight-by-flight basis with landing loads included. A reasonable number of stress levels should be used. The stress sequence within a flight should be representative of service usage (see Section 5) or arranged in lo-hi-lo sequence. Block loading should not generally be applied.

7.5.2 Initial and Continuing Damage

In JSSG-2006 Tables XXX and XXXI, certain initial damage assumptions and continuing damage assumptions are prescribed. These assumptions form a basis for analysis but they cannot always be rigidly adhered to in damage-tolerance testing.

A 0.05 inch initial crack is assumed in slow-crack growth structure and in fail safe structures. If the specimens for design development testing are not provided with artificial defects, the cracks, once initiated, will grow through the sizes mentioned above. Crack-growth records would automatically cover the span of the requirements, provided the cracks can be detected. Otherwise the recorded crack-growth curve would have to be extrapolated backwards. If initial flaws are provided, it is recommended to make them the size assumed in the requirements or close to the size for analysis substantiation.

Continuing damage, from a testing standpoint, is more difficult to make as a result of the small initial sizes and the different growth requirements for different cases. Consider the example configuration shown in Figure 7.5.1 where A is the primary damage site, and B, C, D, & E are continuing damage sites. The four parts of the figure show (a) the initial damage assumed in the panel per JSSG-2006 paragraph 3.12.1 and Tables XXX and XXXI, (b) the initial damage and growth until the primary damage terminates at the edge, (c) the continuing damage that starts at B, the opposite side of the primary damage site which terminates in hole 2, and (d) the growth of continuing damage at C until termination at hole three. While the analysis can follow the assumptions required by JSSG-2006, it would be difficult (if not impossible) to manufacture the necessary continuing sizes either prior to test or after the primary damage (segment A) terminated at the edge. Therefore common practice is to put in the primary damage and continuing damage starter flaws as shown in Figure 7.5.1.a and let the specimen crack growth proceed without additional perturbations. Post test analysis of the crack growth data and fracture surface striation morphology will document this logic.

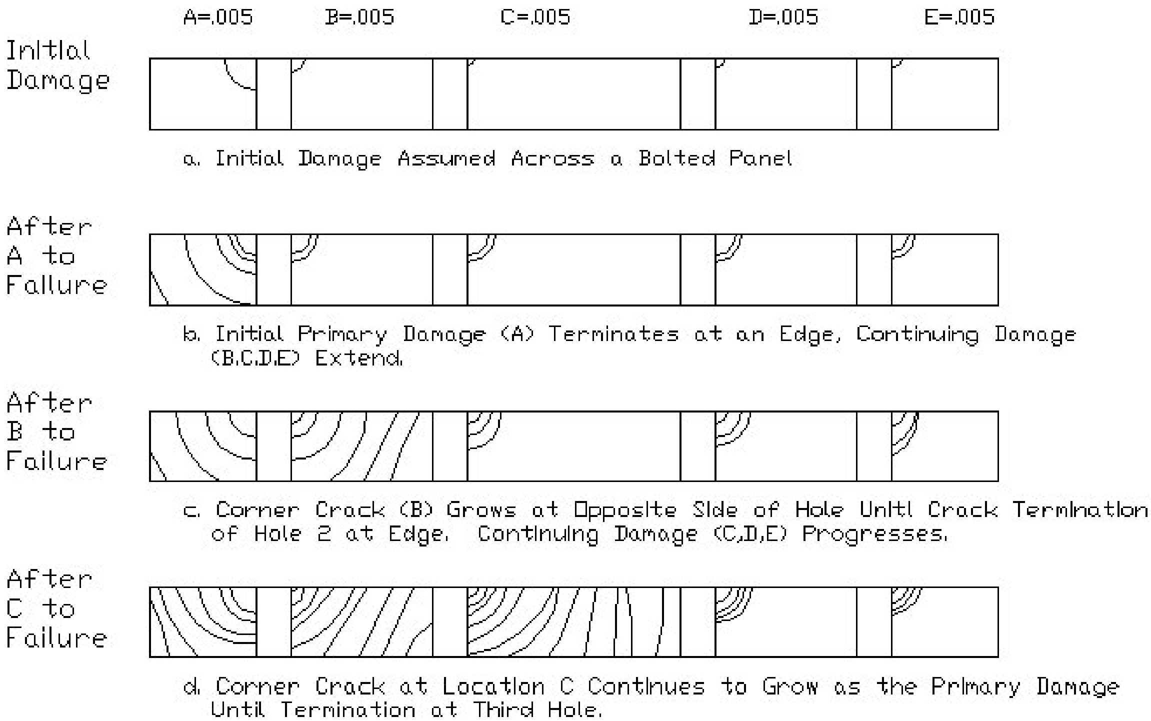

Figure 7.5.1. Primary and Secondary Damage Sites and Continuing Damage

In a AFRL/VA contracted study, Brussat et al. [1977] were able to show that the experimental fatigue lives of built-up structure with and without continuing damage flaws were about the same and that the primary crack damage chose the most effective path through the structure. Secondary cracks developed in a natural way during the test. Dormant periods when a crack ran into a hole could be estimated and subtracted if the results were used for a check of the analysis.

7.5.3 Residual Strength Testing

Residual strength tests of fail safe structure are of special importance. Interruption of a fatigue test at the critical crack size for intact structure is crucial. If the crack grows longer, the stress for rapid propagation is too low to give proper information on crack arrest capabilities and on the strength of the remaining structure at that stress (times the dynamic factor). Since these properties are essential for the qualification as fail safe structure, a proper evaluation is justified, even during design development tests.

After instability and arrest (or load path failure), if successful, fatigue testing should be continued. At that point the JSSG-2006 Damage Tolerance Requirements assume remaining structure damage. In testing, this poses the same problems as the continuing damage. Therefore, it is recommended that the remaining structure damage be developed in a natural way during damage tolerance testing; artificially induced damage may also be incorporated where necessary consistent with the initial flaw assumptions of the component. Again, fatigue cycling is discontinued when the (calculated) critical size for the remaining structure damage is reached. Then a final residual strength test is performed.

7.5.4 Damage Tolerance Test Articles

During the development cycle, the manufacturer will subject major assemblies and structural components to flight-by-flight fatigue loadings that approximate the operational environment. Some tests are specifically identified as damage tolerant tests or as durability tests, but other tests serve a dual function - first as a durability test (two lifetimes) and then as a damage tolerant test. Component durability tests or component dual function tests are normally scheduled to precede the full-scale durability test by a sufficient amount of time that would allow incorporating suggested structural modifications into the full-scale durability test article. The scheduling of the full scale damage tolerant test follows (and uses) the full scale durability test article.

The major assemblies and components selected for damage tolerant testing are chosen to provide further assurance that major elements will not fail during service and thus impact the operational readiness of the force due to safety-of-flight failures. Several examples of major assemblies and components selected during recent weapon system acquisition programs are listed in Table 7.5.1.

The damage tolerant articles will include artificially induced damage such as scratches, elox notches, sawcuts, and other types of non-crack damage, and are then subjected to an interval (about one-quarter lifetime) of flight-by-flight loading that is designed to initiate the desired starter cracks. The test interval subsequent to the precracking is up to one design lifetime with a P_{xx} loading applied at the end of the lifetime to verify residual strength capability. Crack growth should be monitored throughout the test. In-service inspection procedures should be employed whenever possible to evaluate the ability of these procedures to locate and measure the cracks.

Table 7.5.1. Major Assemblies and Components Tested to Support Damage Tolerant Design Verification

F–16	A–10	B–1A	KC–10
Wing/Fuselage Box Beam Components	Wing Lower Center Panel	Wing Carry Through Article*	Fuel Tank Panel and Fuselage Floor Beam Structure
Horizontal Tail Component	Engine/Nacelle Forward Support Frame Fuselage Support Lug	Aft Fuselage Article*	Aerial Refueling Boom
	Horizontal Tail Support Aft Frame Fitting and Attachment Lug		
	Nacelle Thrust Fitting Assembly		

* Damaged subsequent to durability test (2 lifetimes).

7.5.5 Evaluation and Interpretation of Test Results

Throughout the structural hardware test program, there is substantial attention given to cracking problems. Such problems, when they surface, identify areas where the design should be modified to ensure the soundness of the final product (see Figure 7.5.2). Each structural problem is analyzed to determine the specific cause of the problem so that appropriate candidate solutions can be incorporated into production aircraft.

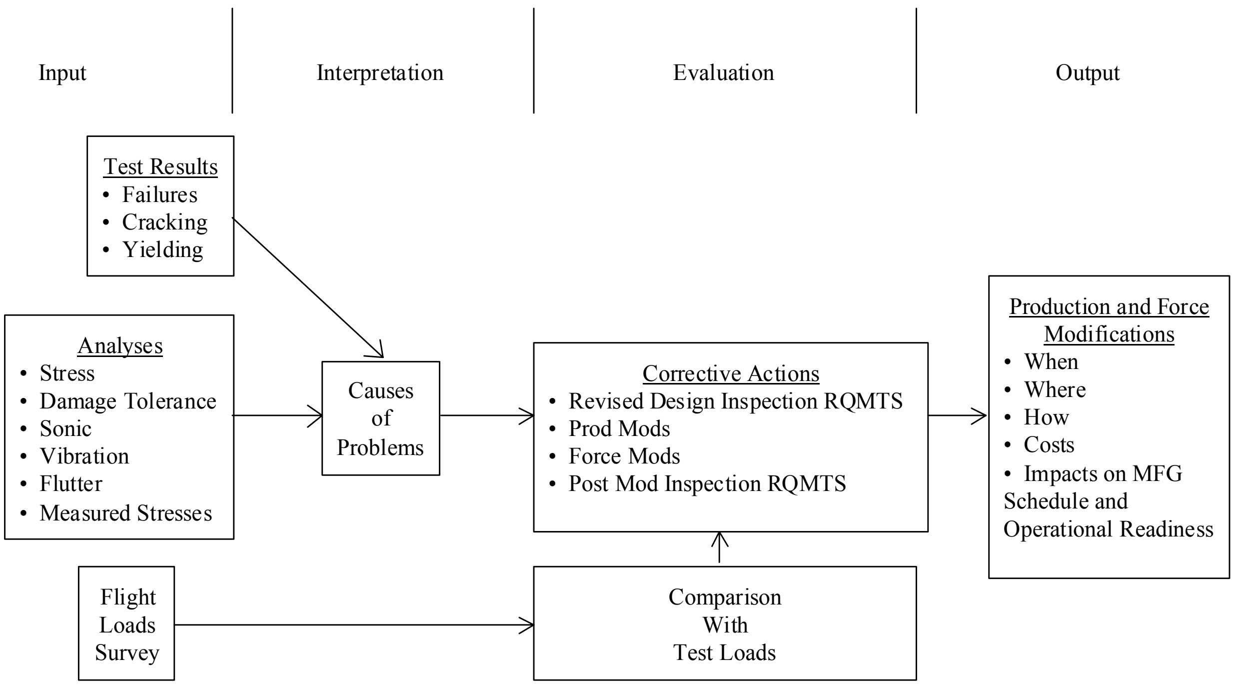

Figure 7.5.2. Summary of Interactions Resulting from Structural Failure Per JSSG-2006 Requirements

One final check on the adequacy of the structural design is the teardown inspection that follows the full-scale durability test (two lifetimes or economic life) and the damage tolerance test (one lifetime). The teardown inspection is required by JSSG-2006 paragraph 4.11.1.2.2.e to provide assurance that no critical area has been overlooked in the course of normal inspections, and to characterize the state of crack development in selected structural areas. In relation to the characterization of the state of crack development, the teardown inspection will typically include the sectioning of the structure for additional fatigue testing, residual strength testing, and/or microscopically tracking cracks back to the start of the durability test. The crack population at the end of the durability test and damage tolerance test becomes the basis for assessing the quality of the production structure through the use of the equivalent initial quality concept illustrated in Figure 7.5.3 (see Section 3 for more details).

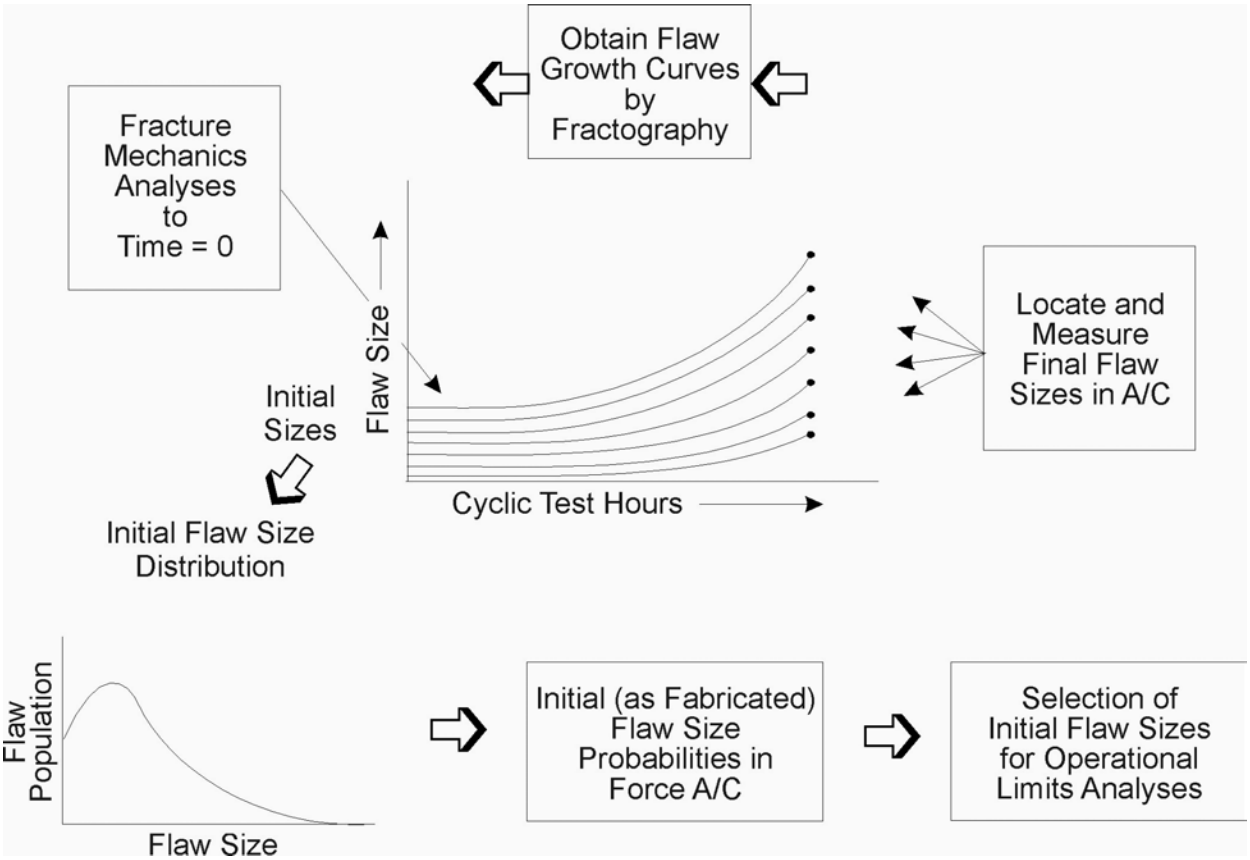

Figure 7.5.3. Equivalent Initial Quality Distribution Obtained by Backtracking Cracks Found in Durability Test Articles. Backtracking Procedures Involve Fractography and Fracture Mechanics Crack Growth Analyses