be expected. The primary issue for these tests is the pre-cracking required to achieve a well-behaved fatigue crack before data is collected. Effective pre-cracking procedures (e.g. 'load shedding') have been established and are described in the public domain. Care must be taken to ensure that subsequent crack growth is not affected by the prior pre-cracking.

In order to minimise the test time for actual structural components and/or full-scale test articles, the test loading spectrum may be modified by eliminating small magnitude load events or by replacing them with a fewer number of larger load events that give equivalent crack growth.

Crack-growth behaviour may be obtained from actual structural components and/or full-scale test articles. However, inducing active fatigue cracks of the desired initial size and at the desired locations can be extremely difficult. Past success in obtaining useful data has been achieved on an opportunistic basis when natural fatigue cracks have developed in the course of normal cyclic testing. Naturally occurring and artificially induced fatigue cracks may be monitored and data collected for at least a portion of the overall crack-growth period to be used for setting inspection requirements. This data can be extremely useful in supplementing and validating the analytical predictions, in some cases it may be the sole basis for the establishment of inspection requirements. Where fatigue test crack growth data is used, the results should be corrected to address expected operational conditions.

[Amdt 25/19]

Appendix 2 – Full-scale fatigue test evidence

ED Decision 2017/015/R

(a) Overview

CS 25.571(b) requires that special consideration for widespread fatigue damage (WFD) be included where the design is such that this type of damage could occur. This Appendix focuses on the test evidence in support of establishing the LOV and applicants will also need to consider and agree with EASA the extent of testing required in support of compliance with CS 25.571 in general, in particular for validation of hot spots, areas of complex loading exhibiting crack growth, single load path components, and safe-life items. CS 25.571(b) requires the effectiveness of the provisions to preclude the possibility of widespread fatigue damage occurring within the limits of validity of the structural maintenance programme to be demonstrated with sufficient full-scale fatigue test evidence. The determination of what constitutes 'sufficient full-scale test evidence' requires a considerable amount of engineering judgment and is a matter that should be discussed and agreed to between the applicant and EASA early in the planning stage for a certification project. In general, sufficient full-scale test evidence to support an LOV consists of full-scale fatigue testing to at least two times the LOV, followed by specific inspections and analyses to determine that widespread fatigue damage has not occurred. It may be appropriate to allow for three life times of testing, especially if inspection may not be practical for areas subject to WFD and requiring SMPs to be established. The following factors should be considered in determining the sufficiency of evidence:

Factor 1: The comparability of the load spectrum between the test and the projected usage of the aeroplane.

Factor 2: The comparability of the airframe materials, design and build standards between the test article and the certified aeroplane.

Factor 3: The extent of post-test teardown inspection, residual strength testing and analysis for determining if widespread fatigue cracking has occurred.

Factor 4: The duration of the fatigue testing.

Factor 5: The size and complexity of a design or build standard change. This factor applies to design changes made to a model that has already been certified and for which full-scale fatigue test evidence for the original structure should have already been determined to be sufficient. Small, simple design changes, comparable to the original structure, or changes that are derived from the original design using the same basic design configuration and where very similar load paths and similar operating stress levels are retained could be analytically determined to be equivalent to the original structure in their propensity for WFD. In such cases, additional full-scale fatigue test evidence should not be necessary.

Factor 6: In the case of major changes and STCs, the age of an aeroplane being modified. This factor applies to aeroplanes that have already accumulated a portion of their LOV prior to being modified. An applicant should only be required to demonstrate freedom from WFD up to the LOV in place for the original aeroplane.

(b) Elements of a full-scale fatigue test programme

The following guidance addresses elements of a test programme that is intended to generate the data necessary to support compliance. It is generally applicable to all certification projects.

(1) Article. The test article should be representative of the structure of the aircraft to be certified (i.e. ideally a production standard article). The attributes of the type design that could affect MSD/MED initiation, growth and subsequent residual strength capability

should be replicated as closely as possible on the test article. Critical attributes include, but are not limited to, the following:

— material types and forms;

— dimensions;

— joining methods and details;

— coating and plating;

— use of faying surface sealant;

— assembly processes and sequences; and

— influence of secondary structure (e.g. loads induced due to proximity to the structure under evaluation).

(2) Test set-up and loading. The test set-up and loading should result in a realistic simulation of expected operational loads.

(i) Test set-up. The test set-up dictates how loads are introduced into the structure and reacted. Every effort should be made to introduce and react loads as realistically as possible. When a compromise is made (e.g. wing air loading), the resulting internal loads should be evaluated (e.g. using finite element methods) to ensure that the structure is not being unrealistically underloaded or overloaded locally or globally.

(ii) Test loading. The test loading spectrum should include loads from all damaging sources (e.g. cabin pressurisation, manoeuvers, gusts, engine thrust, control surface deflection, and landing impact) that are significant for the structure being evaluated. Supporting rationale should be provided when a source is not represented in a sequence. Additionally, differences between the test sequence and expected operational sequence should be justified. For example, it is standard practice to eliminate low loads that are considered to be non-damaging and clip high infrequent loads that may non-conservatively bias the outcome, but care should be taken in both cases so that the test results are representative. Paragraph 9.2.2(f) provides some guidance on justifying the test loading sequence.

(3) Test duration. AMC 20-20 includes guidance on how to establish mandatory maintenance actions for WFD-susceptible structure needed to preclude WFD occurrence in that structure. For any WFD-susceptible area the average time in flight cycles and/or hours to develop WFD must first be determined. This is referred to as the WFD average behaviour for the subject area. The AMC 20-20 guidance states that the area should be modified/replaced at one third of this time unless inspection for MSD/MED is practical. If inspection is practical the guidance states that inspection should start at one third of the WFD average behaviour with modification/replacement at one half of that time. It is standard practice to interpret the non-factored fatigue life of one specimen as the average life. It follows that if a full-scale fatigue test article survives a test duration of X without WFD occurrence, it can be conservatively assumed that the WFD average behaviour of all susceptible areas is equal to X. Based on this, and assuming that the susceptible areas are impractical to inspect for MSD/MED, the guidance of AMC 20-20 would require that replacement/modification would have to be implemented at X/3. For areas where MSD/MED inspections were practical replacement/modification could be deferred until X/2, but MSD/MED inspections would have to start at X/3. The preceding should be kept in mind when deciding what the test duration will be.

(4) Post-test evaluation. One of the primary objectives of the full-scale fatigue test is to generate data needed to determine the absolute WFD average behaviour for each susceptible area, or to establish a lower bound. Recall that the definition of WFD average behaviour is the average time required for MSD/MED to initiate and grow to the point that the static strength capability of the structure is reduced below the residual strength requirements of CS 25.571(b). Some work is required at the end of the test to determine the strength capability of the structure either directly or indirectly.

(i) Residual strength tests. One acceptable way to demonstrate freedom from WFD at the end of a full-scale fatigue test is to subject the article to the required residual strength loads specified in CS 25.571(b). If the test article sustains the loads it can be concluded that the point of WFD has yet to be reached for any areas. However, because fatigue cracks that might exist at the end of the test are not quantified it is not possible to determine how far beyond the test duration WFD would occur in any of the susceptible areas without accomplishing additional work (e.g. teardown inspection). Additionally, metallic test-articles may be non-conservatively compromised relative to their future fatigue performance if static loads in excess of representative operational loads are applied. Residual strength testing could preclude the possibility of using an article for additional fatigue testing.

(ii) Teardown inspections. The residual strength capability may be evaluated indirectly by performing teardown inspections to quantify the size of any MSD/MED cracks that might be present or to establish an upper bound on crack size based on inspection method capability. Once this is done the residual strength capability can be estimated analytically. Depending on the results crack-growth analyses may also be required to project backwards or forwards in time to estimate the WFD average behaviour for an area. As a minimum, teardown inspection methods should be capable of detecting the minimum size of MSD or MED cracking that would result in a WFD condition (i.e. residual strength degraded below the level specified in CS 25.571(b)). Ideally it is recommended that inspection methods be used that are capable of detecting MSD/MED cracking before it degrades strength below the required level. Effective teardown inspections required to demonstrate freedom from WFD typically require significant resources. They typically require disassembly (e.g. fastener removal) and destruction of the test article. All areas that are or may be susceptible to WFD should be identified and examined.

(c) Examples of fatigue test evidence for various types of certification projects.

The following examples offer some guidance on the types of data sets that might constitute ‘sufficient evidence’ for some kinds of certification projects. The scope of the test specimen and the duration of the test are considered.

(1) New type certificates. Normally this type of project would necessitate its own full-scale fatigue test of the complete airframe to represent the new structure and its loading environment. Nevertheless, prior to full-scale fatigue test evidence from earlier tests performed by the applicant, or others, may also be used and could supplement additional tests on the new model. Ultimately, the evidence needs to be sufficient to conclude with confidence that, within the LOV of the airframe, widespread fatigue damage will not occur. Factors 1 through 4 should be considered in determining the sufficiency of the evidence.

A test duration of a minimum of twice the LOV for the aeroplane model would normally be necessary if the loading spectrum is realistic, the design and construction for the test article principal structure is the same as for the certified aeroplane, and the post-test teardown is exhaustive. If the conformance to Factors 1 through 3 is less than ideal, a significantly longer test duration would be needed to conclude with confidence that WFD will not occur within the LOV. Moreover, no amount of fatigue testing will suffice if the conformance to Factors 1 through 3 above is not reasonable. Consideration should also be given to the possible future need for life extension or product development, such as potential weight increases, etc.

(2) Derivative models. The default position would be to test the entire airframe. However, it may be possible to reliably determine the occurrence of widespread fatigue damage for part or all of the derivative models from the data that the applicant generated or assembled during the original certification project. Nevertheless, the evidence needs to be sufficient to allow confidence in the calculations that show that widespread fatigue damage will not occur within the LOV of the aeroplane. Factors 1 through 5 should be considered in determining the sufficiency of the evidence for derivative models. For example, a change in the structural design concept, a change in the aerodynamic contour, or a modification of the structure that has a complex internal load distribution might well make analytical extrapolation from the existing full-scale fatigue test evidence very uncertain. Such changes might well necessitate full-scale fatigue testing of the actual derivative principal structure. On the other hand, a typical derivative often involves extending the fuselage by inserting ‘fuselage plugs’ that consist of a copy of the typical semi-monocoque construction for that model with slightly modified material gauges. Normally this type of project would not necessitate its own full-scale fatigue test, particularly if very similar load paths and operating stress levels are retained.

(3) Type design changes — Service bulletins. Normally this type of project would not necessitate the default option of a full-scale fatigue test because the applicant would have generated, or assembled, sufficient full-scale fatigue test evidence during the original certification project that could be applied to the change. Nevertheless, as cited in the previous example, the evidence needs to be sufficient to allow confidence in the calculations that show that widespread fatigue damage will not occur within the LOV of the aeroplane. In addition, Factor 5 ‘The size and complexity of a design change’ should be considered. Therefore, unless otherwise justified, based on existing test data or a demonstration that the design change is not susceptible to WFD, the applicant should perform full-scale tests for the types of design changes listed in Appendix 4.

(4) Supplemental type certificates (STCs)

Unless otherwise justified according to the guidance below or based on existing test data or a demonstration that the design change is not susceptible to WFD, the applicant for an STC should perform full-scale tests for the types of design changes listed in Appendix 4.

(i) Sufficient full-scale test evidence for structure certified under an STC may necessitate additional full-scale fatigue testing, although the extent of the design change may be small enough to use Factor 5 to establish the sufficiency of the existing full-scale fatigue test evidence. The applicant for an STC may not have access to the original equipment manufacturer’s full-scale fatigue test data. For aircraft types where an LOV has been published, the STC applicants may assume that the basic structure is free from WFD up to the LOV, unless:

— EASA has issued an airworthiness directive (AD), or intends to take such action (proposed AD), to alleviate a WFD condition; or

— inspections or modifications exist in the ALS relating to WFD conditions.

For the purpose of the STC applicant's demonstration, it may be assumed that the aeroplane to which the LOV is applicable has received at least two full LOV of fatigue testing under realistic loads, and has received a thorough post-test inspection that either did not detect any WFD or the ALS includes from the outset details of modifications required to address WFD that will need specific consideration by the STC applicant. With this knowledge, and considering the Factors 1 through 5, the STC applicant may be able to demonstrate that WFD will not occur on its modification (or the underlying original structure) within the LOV or a suitably revised value. If, however, the modification significantly affects the distribution of stress in the underlying structure, or significantly alters loads in other parts of the aeroplane, or significantly alters the intended mission for the aeroplane, or, if the modification is significantly different in structural concept from the certified aeroplane being modified, additional representative fatigue test evidence would be necessary.

(ii) In addition, Factor 6 'The age of the aeroplane being modified' could be considered for modifications made to older aeroplanes. The STC applicant should demonstrate freedom from WFD up to the LOV of the aeroplane being modified. For example, an applicant for an STC to an aeroplane that has reached an age equivalent to 75 % of its LOV should demonstrate that the modified aeroplane will be free from WFD for at least the remaining 25 % of the LOV. Although an applicant could attempt to demonstrate freedom from WFD for a longer period, this may not be possible unless the original equipment manufacturer cooperates by providing data for the basic structure. A short design service goal for the modification could simplify the demonstration of freedom from WFD for the STC applicant.

(5) Repairs. New repairs that differ from the repairs contained in the original equipment manufacturer's structural repair manual, but that are equivalent in design to such repairs, and that meet CS-25 in other respects, would not necessitate full-scale fatigue testing to support freedom from WFD up to the LOV. Concerning major repair solutions (that may be susceptible to WFD) which utilise design concepts that are different from previous approved repair data (e.g. new materials, other production processes, new design details), further testing may be required.

(d) Use of existing full-scale fatigue test data

In some cases, especially for derivative models and type design changes accomplished by the type certificate holder, there may be existing full-scale fatigue test data that may be used to support compliance and mitigate the need to perform additional testing.

Any physical differences between the structure originally tested and the structure being considered that could affect its fatigue behaviour must be identified and reconciled. Differences that should be addressed include, but are not limited to, differences in any of the physical attributes listed under section (b)(1) of this Appendix and differences in operational loading. Typical developments that affect the applicability of the original LOV demonstration data are:

(1) gross weight (e.g. increases);

(2) cabin pressurisation (e.g. change in maximum cabin or operating altitude); and

(3) flight segment parameters.

The older the test data, the harder it may be to demonstrate that it is sufficient. Often test articles were not conformed, nor were test plans or reports submitted to EASA as part of the compliance data package. Loading sequence rigor varied significantly over the years and from applicant to applicant. Additionally, testing philosophies and protocols were not standardised. For example, post-test evaluations, if any, varied significantly and in some cases consisted of nothing more than limited visual inspections. However, there may be acceptable data from early full-scale fatigue tests that the applicant proposes to use to support compliance. In order to use such data the configuration of the test article and loading must be verified and the issue of the residual strength capability of the article (or teardown data) at the end of the test must be addressed.

(e) Use of in-service data. There may be in-service data that can be used to support WFD evaluations. Examples of such data are as follows:

— Documented positive findings of MSD/MED cracks that include location, size and the time in service of the affected aircraft along with a credible record of how the aircraft had been operated since original delivery.

— Documented negative findings from in-service inspections for MSD/MED cracks on a statistically significant number of aircraft with the time in service of each aircraft and a credible record of how each aircraft had been operated since original delivery. For this data to be useful, the inspections methods used should have been capable of detecting MSD/MED crack sizes equal to or smaller than those sizes that could reduce the strength of the structure below the residual strength levels specified in CS 25.571(b).

— Documented findings from the destructive teardown inspection of structure from in-service aircraft. This might be structure (e.g. fuselage splices) removed from aircraft that were subsequently returned to service, or from retired aircraft. It would also be necessary to have a credible record of the operational loading experienced by the subject structure up to the time it was taken out of service.

— Prior to using in-service data any physical and usage/loading differences that exist between the structure of the in-service or retired aircraft and the structure being certified should be identified and reconciled as discussed above.

[Amdt 25/19]

Appendix 3 – Methods for inspection threshold determination

ED Decision 2017/015/R

Different approaches have been used to calculate inspection thresholds, although these are essentially variants of one of two methods, being:

(a) the fatigue (stress-life or strain-life) method, which uses fatigue endurance data collected under constant stress or constant strain conditions, and a linear damage accumulation model (Palmgren-Miner rule);

(b) the crack growth method, which uses crack propagation and residual strength data to calculate the growth from an assumed initial crack size to a critical crack length, according to fracture mechanics principles.

CS 25.571(a)(4) requires certain types of structure to have thresholds based upon crack growth analyses or test assuming the maximum probable flaw due to manufacturing or service-induced damage. This approach applies to:

(a) single load path structure; and

(b) multiple load path 'fail-safe' structure and crack arrest 'fail-safe' structure, where it cannot be demonstrated that the resulting load path failure or partial failure (including arrested cracks) will be safely detected and repaired during normal maintenance, inspection, or operation of an aeroplane prior to failure of the remaining structure.

Paragraph 8(c) of this AMC provides further details on identifying this structure.

In lieu of other data, an acceptable threshold for inspection for cracks emanating from the maximum probable manufacturing flaw at a fastener hole may be obtained for aluminium alloy airframe structure if an initial corner crack of radius 0.05'' (1.27 mm) is assumed and the total crack growth life is divided by 2. Whether this approach is also sufficient to conservatively address all probable forms of manufacturing and service-induced damage needs careful consideration and is highly design dependent. Where specific test or service data for service damage exists that can be used to reliably establish an appropriate threshold for all likely types of service damage then crack growth analysis may only need to consider the manufacturing flaw.

For structure susceptible to WFD specific methods for setting inspection thresholds are applicable when agreed to be practical; see Section 11 and Appendix 2 to this AMC.

Regardless of the approach used, the calculated thresholds should be supported with appropriate fatigue test evidence. The best sources of fatigue test evidence are from service experience and large component or full-scale fatigue tests. Large component and full-scale fatigue test specimens are generally constructed using the same manufacturing processes as on the actual aircraft. The results of such tests should provide sufficient information to reliably establish the typical manufacturing quality and possibly its lower bound, especially when those results are combined with service experience. Conversely, simple test specimens used to generate fatigue endurance and crack growth data, which are typically assembled under laboratory or workshop conditions, may not be representative of the actual range of manufacturing quality in the structure under consideration. Therefore, in the absence of information from the full-scale fatigue tests and service experience, consideration should be given to generating fatigue endurance and crack growth data on simple test specimens which include artificial damages that are introduced at the beginning of the test, and are representative of the lower bound of manufacturing quality.

[Amdt 25/19]

Appendix 4 – Examples of changes that may require full-scale fatigue testing

ED Decision 2017/015/R

The following are examples of types of modifications that may require full-scale fatigue testing:

(1) passenger-to-freighter conversions (including addition of cargo doors);

(2) gross weight increases (e.g. increased operating weights, increased zero-fuel weights, increased landing weights, and increased maximum take-off weights);

(3) installation of fuselage cut-outs (e.g. passenger entry doors, emergency exit doors or crew escape hatches, fuselage access doors, and cabin window relocations);

(4) complete re-engine or pylon change;

(5) engine hush kits;

(6) wing modifications (e.g. installation of winglets, changes in flight-control settings such as flap droop, and change of wing trailing-edge structure);

(7) modified or replaced skin splice;

(8) any modification that affects three or more stiffening members (e.g. wing stringers and fuselage frames);

(9) a modification that results in operational-mission change, which significantly changes the original equipment manufacturer’s load/stress spectrum (e.g. extending the flight duration from 2 hours to 10 hours); and

(10) a modification that changes areas of the fuselage from being externally inspectable using visual means to being non-inspectable (e.g. installation of a large, external fuselage doubler that results in hiding details beneath it).

[Amdt 25/19]

Appendix 5 – PSE, FCS, and WFD-susceptible structure

ED Decision 2017/015/R

(a) Overview

Four key terms used when showing compliance to the damage tolerance and fatigue requirements of CS-25 and EASA guidance for the continued structural integrity of ageing aircraft in AMC 20-20 are: 'principle structural element (PSE)', 'fatigue critical structure (FCS)', 'widespread fatigue damage (WFD)-susceptible structure' and 'design detail point (DDP)'.

This Appendix provides clarification on the intended meanings of these terms and how they relate to each other.

(b) Principal structural element (PSE)

(1) The term 'principal structural element (PSE)' is defined in this AMC as follows:

'Principal structural element (PSE)' is an element that contributes significantly to the carrying of flight, ground or pressurisation loads, and whose integrity is essential in maintaining the overall structural integrity of the aeroplane.

(2) While this definition does not specifically address the fatigue susceptibility of the structure, or environmental or accidental damage, it is intended to address the majority of the structure that must be evaluated according to CS 25.571. CS 25.571(a) states the following:

'This evaluation must be conducted for each part of the structure that could contribute to a catastrophic failure'.

(3) Examples of PSEs are found in paragraph 7(f) of this AMC.

(4) The above reinforces the notion that the identification of PSEs should be based solely on the importance of the structure to assure the overall aeroplane integrity.

(5) Paragraph 7(f) of this AMC provides guidance for identifying PSEs. Many manufacturers use this list as a starting point for their list of Fatigue Critical Structure (FCS). CS 25.571(b) is intended to address all structure that could contribute to a catastrophic failure resulting from fatigue, environmental and accidental damage, and, therefore, may include some structure that is not considered FCS. Nevertheless, all PSE should be considered when developing a list of FCS.

(6) The definitions used by applicants to identify PSEs have not been consistent among applicants and, in some cases, among models produced by the same applicant. The lack of standardisation of the usage and understanding of the term 'PSE,' and the resulting diversity that exists between type design PSE lists, led authorities to introduce the new term 'Fatigue Critical Structure (FCS)' in the 'Ageing Aircraft Requirements and Guidance Material'.

(c) Fatigue Critical Structure (FCS)

(1) 'Fatigue critical structure (FCS)' is defined as aircraft structure that is susceptible to fatigue cracking, which could contribute to a catastrophic failure. Fatigue critical structure also includes structure which, if repaired or modified, could be susceptible to fatigue cracking and contribute to a catastrophic failure. Structure is most often susceptible to fatigue cracking when subjected to tension-dominated repeated loads during operation. Such structure may be part of the baseline structure or part of a modification. 'baseline structure' means structure that is designed under the original type