Transport Airplane Metallic and Composite Structures Working Group – Recommendation Report to FAA

Single Load-Path Structures

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NEW

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Executive Summary

On January 26, 2015, the FAA published a notice of a new task assignment for the Aviation Rulemaking Advisory Committee (ARAC). In short, the FAA assigned and ARAC accepted the task to provide recommendations regarding revision of the damage tolerance and fatigue requirements of Title 14, Code of Federal Regulations (14 CFR), part 25, including subparts C and E of 14 CFR part 26, and development of associated advisory material for metallic, composite, and hybrid structures (structure that includes a combination of composite and metallic parts and assemblies). Under the Transport Airplane and Engine (TAE) Subcommittee, the Transport Airplane Metallic and Composite Structures Working Group (TAMCSWG) was assigned to provide advice and recommendations on the tasking. The TAMCSWG provided an initial report providing various recommendations on a broad variety of related topics to TAE and ARAC, which was released on June 27, 2018 and has been made available to the general public (https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAMCSWG%20Recommendation%20Report.pdf).

During the review and acceptance of this report by ARAC, three separate follow-on tasks were requested to be addressed in an extension of the original tasking. These three topics include:

- Develop requirements and guidance material for single load path (SLP) structure
- Provide further clarification on how to address disbonds and weak bonds as a manufacturing defect
- Provide requirements and guidance on how to address crack interaction when establishing inspection programs

Each of these three topics are addressed using the same approach applied in the original tasking effort, which includes:

- Evaluate current § 25.571, subparts C and E of part 26, and guidance material
- Recommend Rule or Guidance changes
- Estimate the Costs and Benefits associated with any changes

With concurrence from TAE and ARAC the Working Group decided to address each of the three extension topics in standalone reports supplemental to the original report released in 2018.

This report provides the recommendations for rule and guidance changes, the rationale behind the proposed recommendations, and lastly the cost and benefit analyses associated with the recommendations for the topic of Single Load Path (SLP) structures. As detailed in the final 2018 TAMCSWG report, Section 3.2.3, at that time the majority of the WG members recommended a focus only on the primary area of concern with respect to SDC by addressing Single Load-Path (SLP) structure. Section 3.2.4 of that report then makes the following recommendations and conclusions to be considered by a subsequent detailed review of SLP structural design and evaluation requirements. Note that there were no specific regulatory or guidance changes given in that 2018 TAMCSWG report.

- *In this approach, use of SLP structure that is non-safe life and subject to in-flight loading is only allowed where multiple load path structure is established to be impractical.*
- *Detail these specific actions for structures identified as SLP*
    - *Minimization of environmental and accidental damage (i.e. consider protection, different materials, etc.)*
    - *Perform a fatigue test or complete fatigue analysis based on test to demonstrate an acceptable level of fatigue reliability*
    - *Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with high residual strength*
    - *Develop a manufacturing process control and tracking plan document*
- *Consider these challenges to the proposed approach*
    - *Make a clear delineation between SLP and integral MLP structure*
    - *Definition of what constitutes a demonstration of impracticality for usage of MLP design*
    - *Regulatory basis for focusing on SLP structure*

The ARAC tasking schedule was therefore extended to review these recommendations and challenges in detail. Each proposal was therefore reviewed to determine if a rule change would be required if that proposal were adopted. The evaluation criteria and rationale for final recommendations for changes to the regulations generally fell within the following three categories:

- Enforceability
- Performance Based vs. Prescriptive Requirement
- Cost/Benefit Evaluation

The WG specifically reviewed the recommendations for SLP structures from the SDC sub-team documented in the original TAMCSWG report released in 2018. The primary recommendation from that report states the "use of SLP structure that is non-safe life and subject to in-flight loading is only allowed where multiple load path structure is established to be impractical." The WG has determined that a rule change would be necessary to restrict the design in such a manner. However, when looking at the implications of such a rule change, the WG determined that it would be difficult to enforce uniformly, was too prescriptive, and would significantly increase certification costs without a defined benefit or identified safety issue. The WG therefore does not agree with this proposal because it would require a rule change, and that such a change would be too problematic without providing sufficient benefit.

With respect to the other proposed changes in the 2018 TAMCSWG report related to SLP structure, the WG determined that those proposals could be addressed with changes to guidance supported by the current regulatory wording or wording previously proposed in the 2018 TAMCSWG report. The specific changes recommended to guidance to address SLP structures are discussed in Section 4 of this report.

Therefore, the WG does not recommend any changes to the regulations to address SLP structures beyond those already documented in the 2018 TAMCSWG report. The current regulations sufficiently achieve the safety objective while retaining the flexibility needed to accommodate differences in design philosophy. SLP structures are acceptable if the inspection program is properly designed, and this requirement is already reflected in the regulations.

However, AC 25.571-1D does not provide specific information for SLP structures, and the WG recommends that the FAA clarify key elements of the DTE of these more critical structures. The guidance in AC 25.571-1D should be revised to provide specific instructions for the DTE of SLP structures. As part of the means of compliance, the guidance should tell applicants to evaluate and classify their structure and determine which are SLP. For those structures that are SLP, the WG recommends the following be included in the means of compliance:

- Perform a specific evaluation of environmental and accidental damage beyond that typically employed by the Maintenance Steering Group (MSG-3) process
- Perform a fatigue test, or analysis based on tests, to demonstrate an acceptable level of reliability
- Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with the appropriate residual strength
- A new section should be added to AC 25.571-1D to address material and process specifications approved under 25.603 and 25.605 as they relate to the DTE.

These changes would also ensure that key aspects of the DTE of emerging materials and processes such as Additive Manufacturing (AM) would be properly identified and addressed in the guidance.

Integrally Stiffened / Monolithic Structures
The WG spent considerable time working to develop evaluation criteria for integrally stiffened and monolithic structures to address the challenges raised by the SDC sub-team in the 2018 report. The goal was to define guidance changes to AC 25.571-1D to establish a clear delineation between SLP and integrally stiffened/monolithic structures. At a high level, the WG agreed that the guidance should be revised to recommend that the applicant perform a fail-safe evaluation of these structures. The current definition of 'fail-safe' in AC 25.571-1D is acceptable, but new definitions for integrally stiffened panels and monolithic structures are proposed. The WG did not agree on concise criteria for this fail-safe evaluation but did outline the types of evaluations and key considerations to be included for any proposed future guidance. The report describes in detail the differences in WG member positions on the application of these criteria and the fail-safe evaluation. If this evaluation shows the structure does not have fail-safe capability, then it should be classified as SLP with the associated considerations for SLP structures described above.

Composite Materials and Bonded Structures

The recommendations in this report are applicable to metallic materials only. Adequately addressing the five Categories of Damage, as outlined in FAA AC 20-107B, achieves the safety objective for composite materials and construction.

Additional guidance and discussion regarding SLP applications for bonded structures (including metallic bonded structures), as well as general considerations for bonded structural applications, are provided in a separate recommendation report ("Transport Airplane Metallic and Composite Structures Working Group – Recommendation Report to FAA – Structural Bonding," dated 7/29/2021).

1 Introduction

This report documents the recommendations of additional tasking the Transport Airplane Metallic and Composite Structures Working Group (TAMCSWG).

The final TAMCSWG report, 6/27/18, made several recommendations regarding additional focus and requirements for single load-path structures used as Principal Structural Elements (PSE) of the airframe. Many of these recommendations were derived from the SDC AAWG report, Revision 1, 6/23/17, and were intended to address the lack of consensus on a standard for Structural Damage Capability (SDC) or fail-safety.

All industry and regulatory members of the WG agree that fail-safety/SDC is important to safety. However, industry has traditionally incorporated fail-safety as a design practice, dependent on many factors including internal service databases, other design attributes, product inspection goals, and specific PSE locations. The TAMCSWG concluded that the structural robustness of future designs can be best addressed by developing specific recommendations for SLP structure which, unlike multiple load path structure, has no inherent fail-safety.

Consistent with the 2018 report, Section 3.2.3, this report considers MLP as inherently fail-safe, and does not recommend a formal showing of that capability:

> *Assume inherent SDC for MLP structure, focus only on how to address Single Load Path structure*

This report will therefore focus on the specific recommendations from the final TAMCSWG report, Section 3.2.4, related to SLP, as well as any additional considerations related to that review. The primary elements of those prior recommendations are as follows:

- *The use of SLP structure that is non-safe life and subject to in-flight loading is only allowed where multiple load path structure is established to be impractical*
  - *Provide examples in the guidance of structures where a MLP design would be impractical or even result in a less safe design*
- *If MLP structure is impractical, the applicant should consider these items to support the DTE of a SLP design*
  - *Minimization of environmental and accidental damage (i.e. consider protection, different materials, etc.)*
  - *Perform a fatigue test or complete fatigue analysis based on test to demonstrate an acceptable level of fatigue reliability*
  - *Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with high residual strength*
  - *Develop a manufacturing process control and tracking plan document*
- *Develop evaluation criteria and guidance for the evaluation of integral structures to determine if they should also be treated as SLP structures.*

- *Tie these recommendations with the work being done by the bonding Working Group*

A sub-team of WG OEM and NAA members was assigned to review these points in detail and make recommendations to the wider WG. Several face-to-face and virtual meetings lead to the results documented in this report. In general, consensus was reached on all of the high-level recommendations, but there were differing opinions on several of the details. Each proposal was therefore reviewed to determine if a rule change would be required if that proposal were adopted. The evaluation criteria and rationale for final recommendations for changes to the regulations generally fell within the following three categories:

- Enforceability
- Performance Based vs. Prescriptive Requirement
- Cost/Benefit Evaluation

The sub-team prepared a draft report of the results of their evaluation and it has been discussed and reviewed by the full WG. The opinions and conclusions documented in this report reflect the views of the full WG. All members were able to provide comments and document areas of dissention.

The WG specifically reviewed the recommendations for SLP structures in the original TAMCSWG report released in 2018. The primary recommendation from that report states the “use of SLP structure that is non-safe life and subject to in-flight loading is only allowed where multiple load path structure is established to be impractical.” The WG concluded that a rule change would be necessary to restrict the design in such a manner, but as discussed in Section 3.2.1, the WG has now decided that such a change would be too problematic without providing sufficient benefit.

Therefore, the WG does not recommend any changes to the regulations to address SLP structures beyond those already documented in the 2018 TAMCSWG report. The current regulations sufficiently achieve the safety objective while retaining the flexibility needed to accommodate differences in design philosophy. SLP structures are acceptable if the inspection program is properly designed and ensures that there is a high reliability of confidently detecting the damage before catastrophic structural failure. That requirement is reflected in the current regulations and the recommended rule text for threshold inspections in the 2018 TAMCSWG report.

However, the regulatory guidance does not sufficiently define a means to properly design an inspection program or any additional attention to manufacturing controls for SLP structures. The WG agrees in principal with the recommended key considerations for the DTE of SLP structures proposed in the 2018 TAMCSWG report, but in some cases revised certain aspects as discussed in Section 4.2 of this report. The WG determined that those proposals could be addressed with changes to guidance supported by the current regulatory wording or wording previously recommended in the 2018 TAMCSWG report.

As discussed in Section 4.1 of this report, the guidance in AC 25.571-1D should be revised to provide specific instructions for the DTE of SLP structures. The guidance should recommend that the applicant evaluate and classify their structure and determine which structures are SLP. For those structures that are determined to be SLP, the following actions and evaluations are recommended to ensure the DTE complies with the regulations:

- Perform a specific evaluation of environmental and accidental damage beyond that typically employed by the MSG-3 process
- Perform a fatigue test, or analysis based on tests, to demonstrate an acceptable level of reliability
- Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with the appropriate residual strength
- A new section should be added to AC 25.571-1D to address material and process specifications approved under 25.603 and 25.605 as they relate to the DTE.

These changes would also ensure that key aspects of the DTE of emerging materials and processes such as Additive Manufacturing (AM) would be properly identified and addressed in the guidance.

Integrally Stiffened / Monolithic Structures

The WG spent considerable time working to develop evaluation criteria for integrally stiffened and monolithic structures to address the challenges raised by the SDC sub-team in the 2018 report. The goal was to define guidance changes to AC 25.571-1D to establish a clear delineation between SLP and integrally stiffened/monolithic structures. At a high level, the WG agreed that the guidance should be revised to recommend that the applicant perform a fail-safe evaluation of these structures. As discussed in Section 4.2.6, this position is supported by current industry practice and an FAA policy statement. The current definition of 'fail-safe' in AC 25.571-1D is acceptable, but new definitions for integrally stiffened panels and monolithic structures are proposed for inclusion in that AC.

The WG did not agree on concise criteria for this fail-safe evaluation but did outline the types of evaluations and key considerations to be included in any proposed future guidance. These considerations include fail-safe evaluations that focus on residual strength analysis of prescribed damage sizes, or damage growth analysis for prescribed inspection methods and intervals, or both. This report describes the differences in WG member positions on the details of these considerations. If this evaluation shows the structure does not have fail-safe capability, then all WG members agree it should be classified as SLP with the associated considerations for SLP structures. The guidance change proposed by the WG in Section 4.1.1 is left at this high-level statement, with the intention that the FAA will ultimately use the discussions in Sections 4.2.6 and 5.5 to craft more detailed information as necessary.

The WG compared the current definition of 'fail-safety' to the previously proposed definitions of SDC and determined that 'fail-safe' best describes the desired attributes and evaluation goals. SDC was first introduced by the General Structures Harmonization Working Group (GSHWG) in their 2003 recommendation report which was not, or has not yet been, adopted into guidance. This report was not widely disseminated to the industry until the FAA requested input in 2014. SDC was also evaluated extensively in the 2018 TAMCSWG report, but no consensus on a definition or evaluation criteria was reached. Therefore, although they are not opposed to the use of the SDC terminology, the WG generally recommends that SDC be removed from future discussions and that 'fail-safe' be retained in the guidance. Where the term SDC appears in this report, it is generally in reference to a previous discussion from the TAMCSWG 2018 report, or the associated AAWG supporting information.

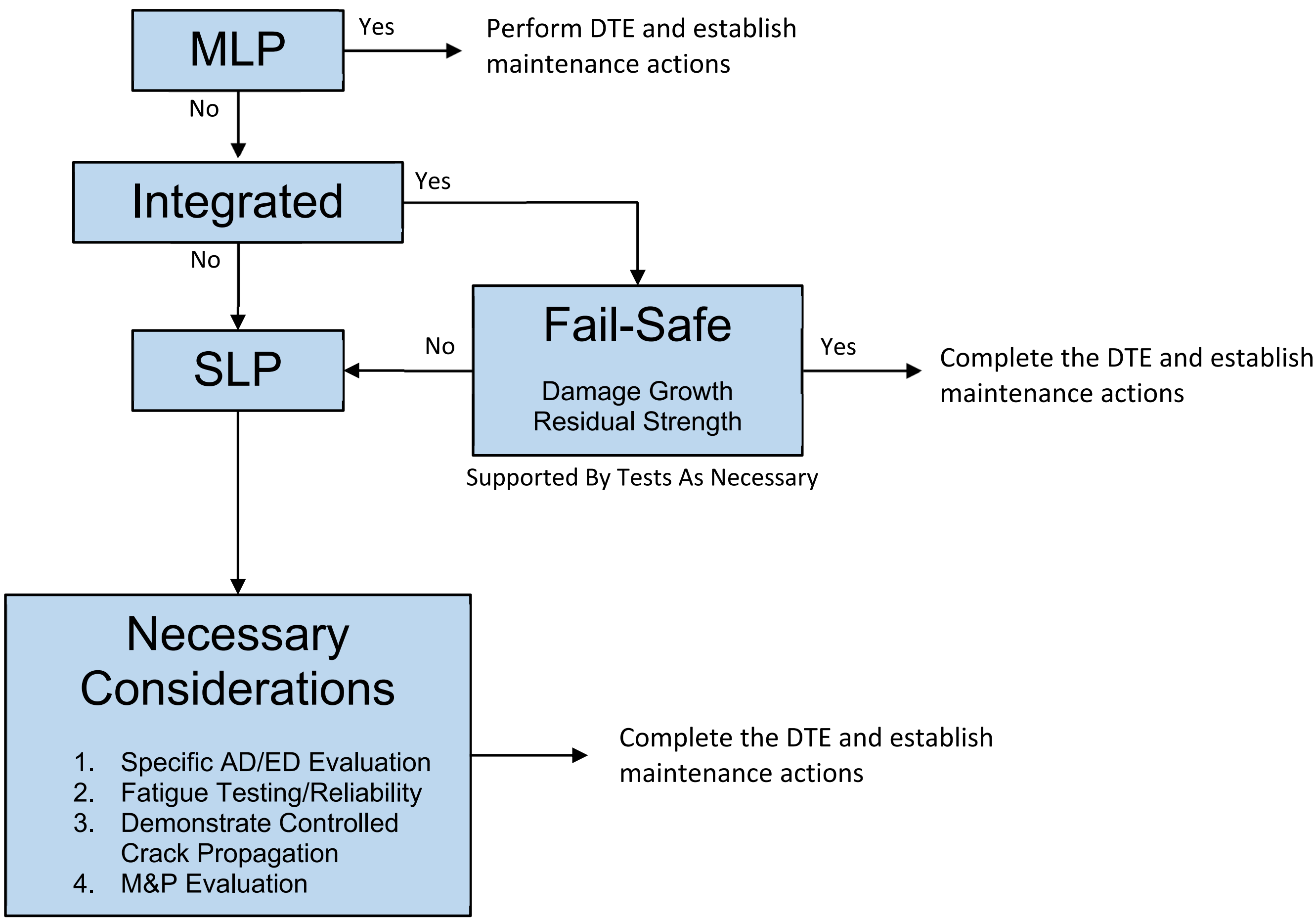
Composite Materials and Bonded Structures

The recommendations in this report are applicable to metallic materials only. Adequately addressing the five Categories of Damage, as outlined in FAA AC 20-107B, achieves the safety objective for composite materials and construction.

Additional guidance and discussion regarding SLP applications for bonded structures (including metallic bonded structures), as well as general considerations for bonded structural applications, are provided in a separate recommendation report ("Transport Airplane Metallic and Composite Structures Working Group – Recommendation Report to FAA – Structural Bonding," dated 7/29/2021).

Evaluation Flowchart

The flowchart below summarizes the high-level topics addressed in the recommendations for guidance given in Section 4.1 of this report and provides a description of the evaluation steps for PSEs as envisioned by the WG. It is intended as an aid to understanding the discussions in this report but is not necessarily recommended for inclusion in the guidance.



1. Multiple Load Path Structure: As stated in the TAMCSWG 2018 report, MLP structure is inherently fail-safe.

2. Integrally Stiffened Panels and Monolithic Structure: The applicant should perform an evaluation of these structures using the definition of fail-safe given in AC 25.571-1D. Those structures that do not have fail-safe capability should be treated as SLP. Key elements of the evaluation should be supported by tests and processing controls as necessary. For example, an integrally stiffened wing lower cover using a completely new material or processing method may need fracture/crack growth rate testing, fatigue testing, and/or special M&P evaluations to support the fail-safe evaluation. This topic is discussed in detail in Section 4.2.6.

3. Considerations for SLP Structure: Specific attention is needed to these considerations to support the subsequent DTE. Each of these elements is discussed in detail in Sections 4.2.1 through 4.2.5.

4. Appendix 3 of AC 25.571-1D outlines the general steps to perform the DTE and the means to establish maintenance actions.

2 TAMCSWG Tasking

TAMCSWG specific tasking as defined in the Federal Register is shown below. The Working Group's recommendations relative to future rule and guidance are contained in Sections 3 and 4, respectively with the cost and benefit assessment in Section 5. Dissenting positions are captured in the section relative to the issue. Unless otherwise noted all cited language in CFRs, ACs or policy statements contained in this report are at the amendment or revision level current as of June 22, 2020.

Below is an excerpt of the specific tasking taken from the January 26, 2015 Federal Register identifying the 3 main elements:

Element #1 - Evaluate current § 25.571, subparts C and E of part 26, and guidance material

1. Evaluate § 25.571, subparts C and E of part 26, and associated regulatory guidance material (*e.g.,* advisory circulars and policy statements) to determine whether any changes to the airworthiness standards and/or guidance material are required to address transport airplanes being constructed of metallic, composite, and hybrid structures. The working group is also tasked to evaluate whether any changes to part 25 and the associated regulatory guidance material are required to provide consistency with the damage-tolerance and fatigue airworthiness standards and associated guidance material for parts 23, 27, and 29. The working group is requested to include in its evaluation a review of the following advisory circulars (AC) and policy statements (PS):

   a. Advisory Circulars: AC 25.571–1, Damage Tolerance and Fatigue Evaluation of Structure; AC 20–107, Composite Airframe Structure; AC 120– 93, Damage Tolerance Inspections for Repairs and Alterations; AC 120–104, Establishing and Implementing Limit of Validity to Prevent Widespread Fatigue Damage; AC 27–1, Certification of Normal Category Rotorcraft (specifically, Subpart C—Strength Requirements); and AC 29–2, Certification of Transport Category Rotorcraft (specifically, Subpart C— Strength Requirements).
   b. Policy Statements: PS–ANM100–1989–00048, Policy Regarding Impact of Modifications and Repairs on the Damage Tolerance Characteristics of Transport Category Airplanes; PS– ACE100–2001–006, Static Strength Substantiation of Composite Airplane Structure; PS–AIR–100–120–07, Guidance for Component Contractor Generated Composite Design Values for Composite Structure; PS–ACE100– 2002–006, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems; PS–ANM– 100–1991–00049, Policy Regarding Material Strength Properties and Design Values, § 25.613; PS–ANM100–1993, Compliance with § 25.571(e) Discrete Source Damage (Uncontained Engine Failure).

Element #2 - Recommend Rule or Guidance changes

2. Advise and make written recommendations on whether to change 14 CFR part 25, subparts C and E of 14 CFR part 26, and related regulatory guidance material, such as ACs 25.571– 1, 20–107, 120–93, and 120–104, to address the use of metallic, composite, and hybrid structures in transport airplanes. In developing the recommendations, the working group is requested to consider:

a. The threats associated with fatigue, environmental exposure, and accidental damage that must be addressed per § 25.571.
b. Applicability to emerging technology materials.
c. The recommendations contained in the 2003 General Structures Harmonization Working Group (GSHWG) report entitled, ''Damage Tolerance and Fatigue Evaluation of Structures, FAR/JAR § 25.571.'' You can find the GSHWG report at *http:// www.faa.gov/regulations_policies/ index.cfm/document/information/ documentID/384.* The working group recommendations should include whether it is appropriate to:
    i. Require applicants to assume the structure contains an initial flaw of the maximum probable size that could exist as a result of manufacturing or service- induced damage.
    ii. Add a requirement for showing structural capability in the presence of damage, so that even if the structure fails partially, there will still be enough structure remaining to be safe.
d. The continued operational safety of composite and hybrid structures as they age, including any airworthiness limitations in the structural maintenance program.
e. The testing of hybrid structure, including, but not limited to, addressing thermal effects, test duration, load enhancement factors, and crack-growth retardation.
f. The bonding or bolting of repairs to metallic, composite, and hybrid structures.
g. The certification of large structural modifications on transport airplanes constructed of composite or hybrid structures.
h. The EASA rulemaking activity on aging aircraft for harmonization purposes.

3. Provide recommendations on appropriate performance-based requirements to address the results of the evaluations above, with consideration of applicability not only to metals and known composites, but also other emerging technology materials.
4. Provide recommendations on any new guidance or changes to existing guidance, including AC 25.571–1D, and AC 20–107B to address the results of the evaluations above.

Element #3 - Estimate the Cost and Benefit associated

5. Provide initial qualitative and quantitative costs and benefits. Based on the recommendations, perform the following:

    a. Estimate the costs to implement the recommendations;
    b. Estimate the benefits of the recommendations in terms of potential fatalities averted;
    c. Estimate any other benefits (*e.g.,* reduced administrative burden) that would result from implementation of the recommendations.

2.1 Working Group Members

The Working Group membership consisted of voting members, subject matter experts and regulatory advisors and participants. The population reflected OEMs, operators and both foreign and domestic regulatory agencies.

Voting members:

1.	Michael Gruber	(Boeing)
2.	Chantal Fualdes	(Airbus)
3.	Salamon Haravan	(Bombardier)
4.	Benoit Morlet	(Dassault Aviation)
5.	Antonio Fernando Barbosa	(Embraer)
6.	Kevin Jones	(Gulfstream)
7.	Toshiyasu Fukuoka	(Mitsubishi Aircraft)
8.	David Nelson	(Textron Aviation)
9.	Ryan Higgins	(British Airways)
10.	Doug Jury	(Delta Air Lines) – Chairperson
11.	Mark Boudreau	(FedEx)
12.	Eric Chesmar	(United Airlines)
13.	Walt Sippel	(FAA Representative)

Subject matter experts (Non-Voting):

1.	Steve Chisholm	(Boeing)
2.	David Polland	(Boeing)
3.	Kevin Davis	(Boeing)
4.	Al Fawcett	(Boeing – Retired)
5.	Rick Kawaguchi	(Boeing)
6.	John van Doeselaar	(Airbus)
7.	Tom Harrison	(Textron)

Regulators (Non-Voting):

1.	Larry Ilcewicz	(FAA)
2.	Michael Gorelik	(FAA)
3.	Patrick Safarian	(FAA)
5.	Richard Minter	(EASA)
6.	Simon Waite	(EASA)
7.	Pedro Caldeira	(ANAC)
8.	Fabiano Hernandes	(ANAC)
9.	Marco Villaron	(ANAC)
10.	Jackie Yu	(TCCA)
11.	Natasa Mudrinic	(TCCA)
12.	Hiroshi Komamura	(JCAB)
13.	Philip Ashwell[1]	(UK CAA)

[1] Philip Ashwell represented British Airways as a voting member until October 2020 when he transitioned to the CAA. Ryan Higgins replaced him as the British Airways voting member at that time.

2.2 Determination of Consensus

This document uses the terms full consensus and general consensus and are defined per the ARAC Manual which states *"full consensus"* as a situation where all voting members are in agreement with a position and *"general consensus"* as a situation where although there may be disagreement, the group has heard, recognized, acknowledged, and reconciled the concerns or objections to the general acceptance of the group. Although not every member fully agrees in context and principle, all members support the overall position and agree not to object to the proposed recommendation report.

Dissenting positions, where the entire group could not reach agreement on a recommendation are explained and captured in the report.

3 Rule Recommendations

This section addresses the second element of the ARAC Tasking detailed in Section 2 for SLP structures. It focuses on Task 2 of the ARAC Tasking and summarizes the review, recommendations and supporting rationale. This task requires the WG to advise and make written recommendations on whether to change the damage-tolerance and fatigue evaluation requirements of parts 25 and 26 to address SLP structures.

The 2003 GSHWG report recommended, among other things, that a new section of the damage tolerance rule be created establishing a specific requirement for Structural Damage Capability (SDC, see ARAC Task 2.c.ii). The proposed regulation did allow for SLP structures with the caveat that additional considerations be applied to the DTE and resulting inspection thresholds. These additional considerations were apparently intended to provide a SLP structure with equivalent performance of SDC.

The AAWG SDC sub-team reviewed this recommendation under the current ARAC tasking and documented their initial conclusions in the report "AAWG SDC Recommendation Document", June 23, 2017, Revision 1, Section 6. Specifically related to SLP, the AAWG emphasized that "SLP has no inherent SDC capability" and that the 2003 GSHWG proposed additional considerations did not result in equivalent SDC for a SLP structure. The AAWG instead recommended that the regulation be changed to require that "the applicant should demonstrate that usage of MLP structure would be impractical for their particular design". The AAWG also recommended several changes to guidance with respect to SLP structures.

The full TAMCSWG did not agree with the AAWG when presented the SDC recommendations in that June 23, 2017 report. After several meetings attempting to reach a consensus, the AAWG described the roadblocks and proposed several options to overcome them in a subsequent report, "AAWG SDC Recommendation Document - Supplement", September 15, 2017. The report identified the following primary roadblocks to adoption of the proposed rule changes:

1. Compliance burden of a requirement without an appreciable gain in safety.
2. Conflict between having explicitly defined guidance and allowing for flexibility with resulting interpretation issues.
3. No working group agreement on linking level of SDC with certain variables.
4. Problems with developing industry guidance to address "other considerations".
5. Period of unrepaired use.
6. Effectiveness of crack retardation features in monolithic metallic MLP structure.

And it proposed these four high-level options to address the roadblocks:

1. Draft up elements of rule and guidance changes that include SDC as an "other consideration" as part of the DTE.
2. Conclude there is no practical approach, due to the major points of dissention.

3. Seek a different approach, perhaps re-visit a change to the design rules, 25.6xx, which was a previous proposal.
4. Assume inherent SDC for MLP structure and focus only on how to address SLP structure.

As detailed in the final 2018 TAMCSWG report, Section 3.2.3, the full WG in the end decided to focus only on SLP structures which is essentially option 4 above. Section 3.2.4 of that report then makes the following recommendations and conclusions. Note that there were no specific regulatory or guidance changes given in that 2018 TAMCSWG report.

- *In this approach, use of SLP structure that is non-safe life and subject to in-flight loading is only allowed where multiple load path structure is established to be impractical.*
- *Use Appendix L and N of the June 23, 2017 AAWG SDC Recommendation Document as the starting point for discussions on the evaluation and classification of MLP/SLP structures.*
- *Propose the following four items to be considered for structures identified as SLP*
    - *Minimization of environmental and accidental damage (i.e. consider protection, different materials, etc.)*
    - *Perform a fatigue test or complete fatigue analysis based on test to demonstrate an acceptable level of fatigue reliability*
    - *Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with high residual strength*
    - *Develop a manufacturing process control and tracking plan document*
- *Consider these challenges to the proposed approach*
    - *Make a clear delineation between SLP and integral MLP structure*
    - *Definition of what constitutes a demonstration of impracticality for usage of MLP design*
    - *Regulatory basis for focusing on SLP structure*

The ARAC tasking schedule was therefore extended to review these recommendations and challenges in detail. Each proposal was therefore reviewed to determine if a rule change would be required if that proposal were adopted. The evaluation criteria and rationale for final recommendations for changes to the regulations generally fell within the following three categories:

- Enforceability
- Performance Based vs. Prescriptive Requirement
- Cost/Benefit Evaluation

The results of that review follow.

3.1 Rule Changes

The WG reviewed the specific recommendations for SLP structures from the 2018 TAMCSWG report, Section 3.2.4, to determine if the changes proposed were enforceable under the current regulations or if new rules were needed. Any rule changes previously recommended in the 2018 TAMCSWG report were also considered.

The proposal given the most emphasis in the 2018 TAMCSWG report was a restriction on SLP structure to only those instances where an MLP design was shown to be impractical. Under the extended tasking, the WG determined that this proposal would require a change to the current regulations if adopted. However, after looking at the implications of such a rule change, the WG has now decided that it would be difficult to enforce uniformly, was too prescriptive, and would significantly increase certification costs without a defined benefit. The WG therefore does not agree with this proposal because it would require a rule change, and that such a change would be too problematic without providing sufficient benefit.

With respect to the other proposed changes in the 2018 TAMCSWG report related to SLP structure, the WG determined that those proposals could be addressed with changes to guidance as they are already supported by the current regulatory wording or wording previously proposed in the 2018 TAMCSWG report. The specific changes recommended to guidance to address SLP structures are discussed in Section 4 of this report.

Therefore, the WG does not recommend any changes to the regulations to address SLP structures beyond those already documented in the 2018 TAMCSWG report. The current regulations sufficiently achieve the safety objective while retaining the flexibility needed to accommodate differences in design philosophy. SLP structures are acceptable if the applicant has established, through sufficient manufacturing controls, analysis and testing, that the damage tolerance aspects of the structure are such that cracking will be detected by a properly designed inspection program. Section 4 describes key considerations and changes to guidance material for applicants to incorporate in designs and follow for developing such inspection programs. The WG recommends that the FAA incorporate those key considerations and proposed changes into regulatory guidance for certification and standardization purposes. There is full consensus on this conclusion.

3.2 Rationale

The overall objective for SLP structures has been discussed by the FAA as part of previous rulemaking. The WG agrees with these objectives, highlighted for emphasis, and they will be used to support the subsequent recommendations in this report.

Preamble to Amendment 45 Notice of Proposed Rulemaking, August 15, 1977

"… the applicant would be allowed to apply the damage-tolerance approach to both single load path and multiple load path structure. The FAA believes the applicant can, by sufficient analysis and testing, establish that a single load path structure has sufficiently slow crack growth properties so that, if a crack were to develop, it would be discovered during a properly designed inspection program."

Preamble to Amendment 96 Notice of Proposed Rulemaking, July 19, 1993

"The FAA therefore concludes that it is necessary to account for undetected manufacturing defects when establishing thresholds for inspections. Initial inspection thresholds should be established based on cracks growing from likely defects developed during manufacture such as machining marks, improper installation of fasteners, etc. This should be substantiated by crack growth analyses and supported by test evidence. Under the fail-safe design philosophy, heavy reliance is placed on the fact that fatigue cracks, including those resulting from rogue flaws, will become obvious before they become critical because of the required redundancy of structure load paths. This practice is not appropriate for structures designed to the current damage tolerance requirements because cracks may not necessarily become obvious before they become critical."

Single load-path designs have been acceptable where necessary, but because the critical crack sizes are generally smaller than what could be considered obviously detectable, specific evaluations and procedures are necessary to properly design the inspection program.

3.2.1 Proposal to Require MLP Unless Shown to be Impractical

The WG reviewed in detail the primary recommendation from the 2018 TACMSWG report to impose a standard whereby SLP is allowed only if a MLP design was shown to be impractical. The WG determined that such a standard would necessitate a change to the regulation, which primarily addresses inspection requirements, to add a restriction on design. However, the WG determined that such a change to the regulation would ultimately be difficult to enforce, be too prescriptive and increase costs without a defined benefit. This challenge was also highlighted in the 2018 TACMSWG report.

Developing a uniform standard of 'impracticality' to be applied in a regulation is a roadblock to incorporation. A standard MLP design for one OEM of large aircraft might not scale to the products or design history of a business jet OEM. Of particular concern is the application of back-to-back parts in lieu of a single member. Each OEM has a different philosophy as to the merits of this approach, and the service record is unclear. There currently is no consensus on which design is superior, and therefore use of this approach to achieve MLP is not entirely supported. It might be *practical* to convert a single member to dual elements, but the performance relative to the safety objective has not been demonstrated. As previously discussed in Section 3, these issues are very similar to roadblocks preventing incorporation of SDC/fail-safety identified in the report, "AAWG SDC Recommendation Document - Supplement", September 15, 2017.

The WG also notes that 25.571(c) currently includes a requirement for the "showing of impracticality" when using the safe-life requirements. It would therefore appear that there is already a regulatory basis for such a requirement. However, FAA policy (PS-ANM100-1988-00040) currently limits the safe-life option to landing gear only (although it is still allowed to address in-service issues such as those discussed in AC 91-82A). Therefore, while the safe-life regulation appears to allow a wide range of options, policy and practice have limited the scope to only a single application. It would be very difficult to establish similar policy or guidance to define acceptable uses of SLP structures as they vary greatly across the industry.

A rule change that requires MLP structure unless shown to be impractical would also create a compliance issue for composite materials where the concepts of MLP and SLP are not as well defined as they are for metallic construction. The benefits of fastened vs. co-cured structures are not fully established, and so the preferred design solution (MLP vs. SLP) is not obvious. The safety objectives for composite materials are outlined in AC 20-107B and require no rule change to support them. It would be difficult to justify excluding composite material construction from a regulation that required MLP designs, particularly in a performance-based rule.

The service record shows that SLP structures have historically performed successfully giving an indication that the objectives envisioned by 25.571 Amdt. 25-45 can be satisfied. The WG conducted a review of the published transport aircraft accident records since the Dan-Air event in 1977 (see Appendix B) and found only one of the twelve events was related to a SLP structure (propeller). In the case of this propeller failure, a formal DTE had not been originally performed and the inspection program was insufficiently detailed to detect cracking that initiated from corrosion pits. In general, proper application of the principles of damage tolerance and WFD evaluations would have prevented many of these accidents in addition to the SLP propeller fracture, and there is no clear indication that the design philosophy (SLP vs. MLP) was a primary factor. The OEM WG members were also polled for their own experience relating to issues with SLP structures. No issues were indicated for designs where the principles of damage tolerance have been properly applied.

Integrally stiffened panels and monolithic structures have historically been successfully fielded with a ‘fail-safe’ design philosophy such as ‘2 Bay Crack’ or slow growth of obvious damage. There are numerous examples of previously certified integrally stiffened wing covers. This philosophy already meets the safety objective where cracks are obvious before they become critical. However, it is not likely that one could formally classify many of these integrally stiffened panels and monolithic structures as MLP, although it would certainly be practical to design the same structure as conventional built-up MLP. A rule change to specify ‘MLP unless shown to be impractical’ would therefore add additional compliance burden without increasing safety. It would likely have the effect of prohibiting integrally stiffened or monolithic designs despite the current service record showing acceptable performance.

The WG also reviewed the other Part 25 regulations concerning SLP structures. SLP structures are accepted and provisions for their use are provided in the Design (25.615 Amdt -, subsequently revised to 25.613 Amdt. 25-72) and Static Strength (25.307 Amdt. 25-23) sections of the regulations. These regulations do provide a ‘penalty’ to be applied to the evaluation of SLP structures, but do not specify one design philosophy over another. The wording and application of these regulations is such that the structural category of SLP vs. MLP has historically been determined through a qualitative evaluation of the design attributes and fail-safe performance. The industry has adopted acceptable processes to address these regulations despite their prescriptive nature. The WG generally agrees that adding a new requirement to the damage tolerance rule to use MLP design unless shown to be impractical implies a quantitative evaluation. This evaluation would come with increased certification costs as well as a reduction in flexibility.

In summary, enforcing a requirement that would prohibit SLP structures unless a MLP design was shown to be impractical would necessitate a change to the regulation. The WG concludes that such a change would not provide a defined benefit, but it would increase the certification costs and reduce the flexibility in the design. Such a change would also move the regulation towards a more prescriptive design requirement which is not in keeping with the original ARAC tasking (Task 3). The WG therefore does not agree with this proposal and recommends that it be dropped from consideration.

3.2.2 Proposal to Define Key Considerations for the Evaluation of SLP Structures

The WG reviewed these four recommended evaluation considerations for SLP from the 2018 TACMSWG report to determine if a rule change is needed to support them:

- Minimization of environmental and accidental damage (i.e. consider protection, different materials, etc.)
- Perform a fatigue test or complete fatigue analysis based on test to demonstrate an acceptable level of fatigue reliability
- Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with high residual strength
- Develop a manufacturing process control and tracking plan document

The WG agrees that these four considerations are supported by the current regulatory wording, or through the proposed changes to the regulations in the 2018 TACMSWG report. Emphasis on these key aspects of the DTE of SLP can be addressed through changes in guidance. The supporting rationale is provided below. The specific proposed guidance changes to address these four items are discussed in detail in Section 4.

Minimization of environmental and accidental damage

25.571(b) currently requires consideration accidental and environmental damage as part of the damage tolerance evaluation. The guidance for metallic materials could therefore be revised to detail the specific evaluations to be performed for SLP structures.

Perform fatigue testing to demonstrate an acceptable level of reliability

The 2018 TAMCSWG report, Section 3.5.1, makes the following proposed change to 25.571(a):

When inspections are required to prevent catastrophic failure, inspection thresholds must be established to ensure that damage in a PSE will be detected before it results in a catastrophic failure. The inspection thresholds must account for the expected range of damage threats to the structure and use methods substantiated by representative tests or in service data.

To support the recommendation to change section 25.571, the WG determined additional guidance was necessary to document the expected fatigue testing and ensure that the inspection thresholds for SLP structures are sufficiently reliable.

Perform testing to demonstrate a controlled rate of crack growth and residual strength

25.571(a)(1)(iii) currently requires ‘an analysis, supported by test evidence’ as part of the DTE. A guidance change will document the expected means to comply with this requirement for SLP structures and ensure that the inspection program is properly designed.

Develop a manufacturing process control and tracking plan document

25.603 and 25.605 currently provide the regulatory basis for materials and process controls and approved specification. A guidance change will document the expected means to comply with these requirements for SLP structures using the current industry practices. The guidance should detail the expected coordination between the approved materials and process specifications and the assumptions made in the DTE.

The WG notes that most elements of these four steps are already incorporated in the guidance for composite materials (AC 20-107B) under today's part 25 requirements. Current industry practices related to metallic materials also include most of those elements. However, as described in the 2018 TAMCSWG report and herein, AC 25.571-1D does not have a standardized approach that defines a means of compliance related to SLP structure for metallic materials. It is the WG's position that the FAA does not need to change the rule to support any changes to the guidance for SLP structures constructed from metallic materials which are similar to the guidance already contained in AC 20-107B for composite materials. Recommendations for these guidance changes are given in Section 4.1.

4 Guidance Recommendations

The 2018 TAMCSWG report emphasized the inherent value of MLP in design to overall safety and recommended that it be promoted to the largest extent possible. The current guidance in AC 25.571-1D also promotes MLP designs:

Although this evaluation applies to either single- or multiple-load-path structure, the use of multiple load path structure should be given high priority in achieving a damage-tolerant design.

The adoption of the 'rogue flaw' concept for calculating inspection thresholds in Amdt. 25-96 imposed a perceived penalty to SLP structures and those MLP structures that behaved like SLP. It was believed that the requirement to use a crack growth analysis approach would limit the incorporation of SLP structures because the threshold inspections would be sooner than previously calculated for MLP structures. In practice, however, the 'rogue flaw' crack growth criteria provided a clear path for certification of SLP structures by using a relatively simple analytical approach. The guidance provided in 1998 at Amdt. 25-96, AC 25.571-1C, while emphasizing MLP structures and their attributes, did not provide any additional focus or compliance objectives for SLP structures.

Based on the service history discussed in Section 3.2.1, the 'rogue flaw' concept appears to have the desired effect of maintaining safety by reducing stress levels to provide an adequately robust design. However, if future designs continue the trend of incorporating more integrated structures, that record of acceptable performance may not remain valid if the key aspects and limitations of the contemporary damage tolerance approach discussed in Section 4.2 are not considered. New applicants may not have the knowledge and experience necessary to design and evaluate airframes with a large proportion of SLP and integral structure. The 2018 TAMCSWG report recommended that the guidance should therefore be updated to ensure that critical aspects of the DTE for SLP structures are properly addressed in general, and integrally stiffened and monolithic structures in particular.

Additional work has been added to this sub-team tasking to investigate the damage containment aspects of integrally stiffened panels and monolithic structures. The general approach commonly used by WG members for these structures has been a showing of 'fail safety' whereby the capability to withstand partial failures is demonstrated. This capability is currently beyond what is required by the regulations and AC 25.571-1D but has been seen to keep an upper bound on design limit stresses and to prioritize materials with good fracture toughness. Fail-safe capability should continue to be used in the design of integrally stiffened panels and monolithic structures, and that capability should be reinforced in the guidance. If these structures do not have fail-safe capability, they should be classified as SLP.

The WG agrees in principle with the recommended considerations for SLP structures listed below from the final 2018 TAMCSWG report, Section 3.2.4, and that they can be addressed by guidance changes:

- Use Appendix L and N of the June 23, 2017 AAWG SDC Recommendation Document as the starting point for discussions on the evaluation and classification of MLP/SLP structures.

- Propose the following four considerations for structures identified as SLP
  - Minimization of environmental and accidental damage (i.e. consider protection, different materials, etc.)
  - Perform a fatigue test or complete fatigue analysis based on test to demonstrate an acceptable level of fatigue reliability
  - Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with high residual strength
  - Develop a manufacturing process control and tracking plan document
- Consider these challenges to the proposed approach
  - Make a clear delineation between SLP and integral MLP structure

The development of emerging materials and manufacturing methods that rely on advanced process controls such as Additive Manufacturing (AM), etc. has also been considered as directed by ARAC Task #3. The 2018 TAMCSWG report, Section 3.10, recommended no new rule changes to address these new technologies. Invariably, however, new SLP structures will be fielded using these new methods and the guidance should adequately address this possibility. The WG agrees that the recommended actions listed above, and detailed in Section 4.1, are sufficient to demonstrate compliance with the damage tolerance requirements for SLP structures developed using these new methods.

Discussion of the proposed changes to guidance and policy to address these points and their rationale follows below.

4.1 Recommendations for Guidance and Policy Changes

The following summarizes the recommended changes to guidance and policy as a result of the WG review. Example text for the recommended changes is highlighted below in red text. The suggested text for changes to the guidance follow the existing formatting of AC 25.571-1D. Some WG members suggested that a new section be created to address SLP structures. Understanding that the FAA will possibly make many changes to this suggested text before incorporating into final form the WG is not opposed to such changes in formatting or wording if the concepts presented here are captured.

The rationale for these changes is given in Section 4.2.

4.1.1 Changes To AC 25.571-1D

Para. 6(a): Damage-Tolerance Evaluation

Although this evaluation applies to either single- or multiple-load-path structure, the use of multiple load path structure should be given high priority in achieving a damage-tolerant design. Single load-path structures are acceptable where necessary, but because cracks may not necessarily become obvious before they become critical, specific consideration is necessary to properly design the inspection program. SLP structures should be shown to have the highest reliability compared to MLP and integral fail-safe structures.

Reliability is defined as the ability of the structure to perform its function without failure throughout the operational life of the airplane. Performance can be established based on evaluations of fatigue endurance, or of damage growth from initial damage or defects, or both. Key considerations for the reliability demonstration include material selection, manufacturing process controls, stress levels, damage tolerance evaluations, fatigue tests, and published maintenance instructions. Safety or scatter factors applied to the results of the evaluation should reflect the confidence level in the engineering data used.

Design features that should be considered in attaining a damage-tolerant structure include the following:

(1) Multiple load path construction, and the use of damage containment features ~~crack stoppers~~ to control the rate of crack growth and to provide adequate residual strength;

(2) Materials and stress levels that, after initiation of cracks provide a controlled slow rate of crack propagation combined with high residual strength;

(3) Arrangement of design details to ensure a high probability that a failure in any critical structural element will be detected before the strength of the element has been reduced below the level necessary to withstand the loading conditions specified in § 25.571(b), thereby allowing timely replacement or repair of the failed elements.

Para. 6(f): Testing of principal structural elements

f. Testing of principal structural elements

The nature and extent of residual strength tests on complete structures or on portions of the primary structure depends upon applicable previous design, construction, tests, and service experience with similar structures. Simulated cracks should be as representative as possible of actual fatigue damage. Where it is not practical to produce actual fatigue cracks, damage can be simulated by cuts made with a fine saw, sharp blade, guillotine, or other suitable means. If saw cuts in primary structure are used to simulate sharp fatigue cracks, sufficient evidence should be available from element tests to indicate equivalent residual strength. In those cases where bolt failure or its equivalent is to be simulated as part of a possible damage configuration in joints or fittings, bolts can be removed to provide that part of the simulation.

Guidance for full-scale fatigue test to demonstrate that WFD will not occur within LOV is included in appendix 2 of this AC[2]. Guidance for the testing of SLP structures is included in Section xxx of this AC.

Para. 6(h): Damage-tolerance analysis and tests.

(1) Analysis, supported by test evidence, should determine that:

(a) The structure with the extent of damage established for residual strength evaluation, and in the case of bonded structure, any reduction in strength as a result of aging[3], can withstand the specified design-limit loads (considered as ultimate loads);
and
(b) The damage-growth rate under the repeated loads expected in service – between the time the damage becomes initially detectable and the time the extent of damage reaches the value for residual-strength evaluation – provides a practical basis for development of the inspection program and procedures described in section 6j of this AC.

(2) The repeated loads should be as defined in the loading, temperature, and humidity spectra. The loading conditions should take into account the effects of structural flexibility and rate of loading where they are significant.

(3) The damage-tolerance characteristics can be shown analytically by reliable or conservative methods, such as the following:

(a) Demonstrating quantitative relationships with structure already verified as damage tolerant;
(b) Demonstrating that the damage would be detected before it reaches the value for residual-strength evaluation; or
(c) Demonstrating that the repeated loads and limit-load stresses do not exceed those of previously verified designs of similar configuration, materials, and inspectability.

In the absence of analysis supported by previous testing, specific testing should be performed to verify the assumptions in the evaluation of SLP structures. Attributes to be considered in the test program include:

- Crack growth rate including spectrum loading effects under flight-by-flight loading.
- Fracture toughness for as-produced parts
- Stress Intensity Functions for non-standard geometries

Para. 6(i)(3): Inspection

[2] Previouly recommended in the 2018 TAMCSWG report.
[3] Previouly recommended in the 2018 TAMCSWG report.

Comparison with past successful practice is the primary means of substantiating inspections or other procedures for accidental and environmental damage. For a new-model transport category airplane, the Maintenance Review Board generally conducts such comparison to substantiate inspections or other actions using the Air Transport Association of America, Inc. (ATA) Maintenance Steering Group's MSG-3 or other accepted version of the "Operator/Manufacturer Scheduled Maintenance Development" procedures. If this process is used, the required maintenance actions for accidental and environmental damage must be documented in the Maintenance Review Board Report for the airplane model and must be complete not later than when the first airplane enters service. These inspections or other procedures, as necessary to prevent catastrophic failure of the airplane, must be included in the Airworthiness Limitations section of the ICA. Alternatively, the applicant may reference, in the ALS of the ICA, the maintenance documents that contain those tasks. The ALS should also contain reference to any corrosion prevention and control program (CPCP) developed to maintain corrosion to "Level 1" or better for that airplane model. "Level 1" corrosion is damage occurring between successive inspections that is local and can be reworked/blended-out within allowable limits as defined by the manufacturer's service information, such as structural-repair manuals and service bulletins.

In addition to the MSG-3 evaluation, a specific damage tolerance review for AD and ED should be performed for SLP structures. Protection should be added where feasible. Otherwise, if the visual inspections of the MSG-3 process are not sufficient to detect damage from AD and ED threats, special DTE based inspections are required. In this case, an initial flaw crack growth approach described in para. 6(j)(1) may be used to develop the special inspections. These special inspections should be specified in the ALS in addition to those given in the MRBR.

New Section: Fatigue Testing of SLP Structures

Fatigue reliability is defined as the ability of the structure to perform its function without failure due to fatigue throughout the operational life of the airplane. The DTE of SLP structures should show them to be more reliable than MLP and integral fail-safe structures. Fatigue testing or analysis based on testing should show acceptable performance within the operational life/DSG. Test durations should be long enough to validate that all fatigue critical locations have been addressed in the DTE and the associated maintenance program. Analysis may be used if correlated to previous test evidence.

Fatigue test factors should be sufficient to demonstrate that the performance and reliability goals have been achieved. Determining the specific test duration is dependent upon considerations such as inherent material fatigue scatter (e.g., steel vs aluminum), scatter in fatigue performance of the design details (e.g. fastener holes vs fillets), the number of representative details contained in the test, and the range of manufacturing quality. The level of reliability demonstrated can be increased by residual strength tests following cycling, tear-down inspections, or by test load enhancement factors.

It is acceptable to include these structures in the full-scale test used to show compliance to the WFD requirements, or a dedicated component or separate full-scale test article may be used. These fatigue test results do not necessarily need to be included in the WFD evaluation supporting the aircraft LOV. However, the maintenance program supported by those results should be applicable up to the LOV unless additional procedures are implemented.

New Section: Material and Process Controls

Key material and processing parameters should be defined in the materials and process specifications approved under 25.603 and 25.605. These specifications should also identify what key characteristics and parameters are to be monitored for in-process quality control. The material and process specifications should form the basis of the DTE. If stricter control of processing parameters is required for SLP structures to achieve the intended reliability and meet the objectives of the DTE (e.g. the expected inspection threshold), those controls should be detailed in the process specification. Once established these processes should not be changed without further qualification and engineering approval.

The applicant should have a defined process for the serialization/traceability, quality control, and handling of critical parts. All parts identified as SLP should have this process invoked in the type design data.

New Section – Integrally Stiffened Panels and Monolithic Structures

The applicant should perform a fail-safe evaluation of these structures to support the subsequent DTE. If this evaluation shows the structure does not have fail-safe capability, then it should be classified and evaluated as SLP, using the associated SLP considerations defined in this AC.

Integrally stiffened panels and monolithic structures may also be identified as being susceptible to WFD and should be evaluated according to AC 25.571-1D, Section 7, when establishing the LOV for the airplane.

Appendix 1 – References and Definitions

New Definitions

Integrally Stiffened Panel – Structures forming part of a surface or shell that are constructed by integrating skins, doublers and stiffeners into a single piece of material. For example, a wing skin formed by machining the skins and stringers from a single plate.

Monolithic Structure – Structural elements forming part of a larger assembly that are constructed by integrating chords, webs, stiffeners and fittings into a single piece of material. Examples include single-piece wing spars, and longerons with integrated attachment lugs.

Damage Containment Feature – A design element such as a stiffener or pad-up intended to reduce the stress intensity of an active crack and is used to control the rate of crack growth and to provide adequate residual strength.

4.1.2 Policy Changes

PS-ANM100-1993-00047, "Policy regarding fail-safe features of structures designed to the damage tolerance requirements of § 25.571"

The recommended additions to AC 25.571-1D concerning integrally stiffed panels and monolithic structures would address the issues raised in the policy statement PS-ANM100-1993-00047. The contents of this policy statement will then be superseded by the revised guidance and it should be cancelled.

4.2 Rationale for Guidance Changes

The 2018 TAMCSWG report recommended that the guidance should be updated to ensure that critical aspects of the DTE for SLP structures are clarified. While the current service history for SLP structures shows good performance, if future designs continue the trend of incorporating more integrated structures, that record of acceptable performance may not remain valid if the key aspects and limitations of the contemporary damage tolerance approach discussed below are not considered. This is also true for applications of emerging technologies such as additive manufacturing. New applicants may not have the knowledge and experience necessary to design and evaluate airframes with a large proportion of SLP or integral structure, or SLP structures constructed from advanced processes.

Using the high-level requirements already in 25.571(a), the guidance for metallic structures should continue to emphasize MLP and fail-safe designs for the major portions of the airframe. Applicants should evaluate and classify their structure and determine which structures are SLP. The guidance should also provide recommendations on the evaluation of integrally stiffened/monolithic structures to demonstrate a fail-safe design; otherwise those structures should be considered SLP.

SLP structures should be shown to be more reliable than MLP and integral fail-safe structures. The guidance should be changed to show how that high level of reliability is to be achieved. For those structures classified as SLP, the following specific actions and evaluations are recommended to ensure the DTE complies with the regulations. Each of these elements is detailed in the following sections.

- The guidance should recommend that the applicant perform a specific evaluation of environmental and accidental damage beyond that typically employed by the MSG-3 process. Protection should be added where feasible. Otherwise, if the visual inspections of the MSG-3 process are not sufficient to detect damage from accidental damage (AD) and environmental damage (ED) threats, special DTE based inspections are required.
- The guidance should recommend that the applicant perform a fatigue test, or complete fatigue analysis based on tests, to demonstrate a high level of fatigue reliability. The tests are intended to show that fatigue cracks do not form earlier than expected, or in locations not anticipated by the DTE. Fatigue test factors should address such key aspects as material scatter and the range of manufacturing quality.
- The guidance should recommend that the applicant perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with appropriate residual strength. Specific testing should be performed to verify the assumptions in the analysis.
- The guidance should outline the evaluation procedures to be applied to the material and process specifications of metallic structures. Key material and processing parameters should be defined in the material and process specifications approved under 25.603 and 25.605.

To be consistent with AC 20-107B, the WG recommends the FAA revise AC 25.571-1D to include these four considerations for SLP structures identified above. They provide the elements necessary to define an acceptable means of compliance with the existing part 25 rules or with those rule changes recommended in the 2018 TAMCSWG report. There is full consensus on this point.

Some WG members suggested that the 'default' crack growth analysis method using an 0.05" initial flaw be included in the guidance as an alternative to the elements listed above. The 0.05" rogue flaw crack growth approach was accepted as a default for the calculation of thresholds in the recommended guidance changes listed in Appendix E of the 2018 TAMCSWG report and has historically provided acceptable performance. But the WG determined that this approach would not address each of the considerations proposed for SLP. This is because the use of this analysis method alone would not verify that all fatigue susceptible locations have been addressed in the DTE, or that all aspects of the crack growth methods are sufficiently conservative. It would not necessarily address many of the concerns related to emerging materials and process such as AM. It would also not encourage the fail-safe design of ISP/monolithic structures. A rogue flaw crack growth approach could be one aspect of an acceptable means of compliance for the DTE of SLP structures, but each of the specific elements listed here should also be considered.

The guidance should also recommend that integrally stiffened panels and monolithic structures be designed and evaluated to a fail-safe criteria using the current definition of fail-safe as given in AC 25.571-1D. If the structure does not have this capability then it should be classified as SLP.

Note: The 2018 TAMCSWG report recommended several revisions and additional definitions (LOV, Manufacturing Defect, etc.) be added to the guidance in AC 25.571-1. The WG reviewed those as part of the evaluation of SLP structures and determined that they would still be applicable and they should be included with the new definitions proposed in this report, Section 4.1.1.

4.2.1 Reliability

The 2018 TAMCSWG report, Section 3.5.2, recommends introducing the concept of target reliability into the guidance as a performance measure supporting inspection thresholds. While specific reliability targets were not recommended, the relevant aspects necessary for an applicant to consider were defined. Specifically, SLP structures should be shown to have the highest reliability compared to MLP and integral/monolithic fail-safe structures. There is full consensus on this point.

The WG held specific discussions on the definition of reliability and reviewed the term target reliability in detail. Because target values are not recommended, either in this report or the 2018 TAMCSWG report, reliability as discussed in this report does not imply a specific quantitative measure. The WG decided to define it in generic terms as proposed in Section 4.1.1, and to measure it by key elements of the evaluation:

> *Reliability is defined as the ability of the structure to perform its function without failure throughout the operational life of the airplane. Performance can be established based on evaluations of fatigue endurance, or of damage growth from initial damage or defects, or by both fatigue and damage growth assessments. Key considerations for the reliability demonstration include material selection, manufacturing process controls, stress levels, damage tolerance evaluations, fatigue tests, and published maintenance instructions. Safety or scatter factors applied to the results of the evaluation should reflect the confidence level in the engineering data used.*
>
> *Fatigue reliability is defined as the ability of the structure to perform its function without failure due to fatigue throughout the operational life of the airplane.*

The wording on confidence levels was in response to a concern raised by the FAA and is similar to wording given in AC 120-104, pg. A8-14. It is intended to convey the expectation that higher safety factors are also necessary when there is limited data supporting the assessment of SLP structures. The WG does not recommend publishing safety or scatter factors in the guidance, because they tend to become requirements that may increase costs. See Sections 4.2.3 and 4.2.6.3 for more information.

The WG specifically discussed the illustration linking reliability to structural configuration given in the 2018 TACMSWG report, Figure 3-1, to determine if it was appropriate for inclusion in the guidance. Most members of the WG agree with the ranking presented in the 2018 report shown below. They believe that MLP has inherent robustness regardless of whether it is visible or hidden and thus would fall lower in the ranking than integral structure.

- SLP (hidden & visible) — Higher reliability
- Fail-Safe ISP (hidden)[4]
- Fail-Safe ISP (visible)
- MLP built up (hidden)
- MLP built up (visible) — Lower reliability

Hidden = non-normal visual access such as behind an APU or requires NDI

However, three OEM members disagreed with the relative placement of hidden MLP and visible fail-safe ISP shown above. The accident review in Appendix B of this report shows 3 accidents where hidden damage in fail-safe designs did not provide an acceptable period of unrepaired use. Integral structure that has fail-safe capability and gives a visible indication of damage should be treated more favorably. Two other members had similar positions but believed both structural configurations should be treated equally.

Given these differences in viewpoints, voting was nearly evenly divided (6 for, 7 against) including this figure in a revision to AC 25.571-1D. Those voting for inclusion in the guidance generally advocated for clarification of expectations it would provide. Those voting against highlighted the lack of consensus on the ranking. Therefore, there is no proposal to include this figure in the guidance. It is used only to support the discussions that follow in the next sections.

[4] The description of integral structure, ‘Fail-Safe ISP’, is changed here from the previous WG recommendation shown in Figure 3-1 in the 2018 TAMCSWG report: ‘MLP integral’. During the SLP discussions, the WG realized that it is not entirely correct to refer to integral/monolithic structures as ‘MLP’. The term ‘Fail-Safe ISP’ is intended to cover integral/monolithic structures that have been shown to be fail-safe, and that term better conveys the intentions of this figure.

4.2.2 Minimization of AD and ED

The current guidance in AC 25.571-1D, shown below, relies on the MSG-3 process and the Maintenance Review Board Report (MRBR) for protection against accidental and environmental damage. This process results in a listing of scheduled maintenance inspections, nearly all using visual inspection methods. The MSG-3/MRBR process and the relationship with the DTE is also described in detail in the final TAMCSWG report, Section 3.8.

AC 25.571-1D, Para. 6.i(3):

> *Comparison with past successful practice is the primary means of substantiating inspections or other procedures for accidental and environmental damage. For a new-model transport category airplane, the Maintenance Review Board generally conducts such comparison to substantiate inspections or other actions using the Air Transport Association of America, Inc. (ATA) Maintenance Steering Group's MSG-3 or other accepted version of the "Operator/Manufacturer Scheduled Maintenance Development" procedures. If this process is used, the required maintenance actions for accidental and environmental damage must be documented in the Maintenance Review Board Report for the airplane model and must be complete not later than when the first airplane enters service. These inspections or other procedures, as necessary to prevent catastrophic failure of the airplane, must be included in the Airworthiness Limitations section of the ICA.*

However, as discussed in the final TAMCSWG report, Section 3.8.3.1, SLP structures will often require additional DTE to address locations susceptible to AD and ED where that damage and associated cracking may not be visually detected before critical crack sizes are reached. An example of this scenario is discussed in Appendix B where an accident was attributed to cracking of a propeller blade that started from a corrosion pit.

The FAA should therefore revise the guidance to recommend that the applicant perform a specific review for AD and ED of SLP structures. The applicant should suitably protect the structure as part of the compliance with 25.609. In locations where the visual inspections of the MSG-3 process are not sufficient to detect fatigue damage that originates from AD and ED threats, special DTE based inspections are required to ensure continued airworthiness. In this case an initial flaw crack growth approach may be used to develop the special inspections. These special inspections should be specified in the ALS in addition to those given in the MRBR. This is similar to the existing guidance in EASA AMC 25.571, para. 8(b):

> *Inspections that are designed to detect fatigue cracking resulting from AD or ED, where the originating damage cannot otherwise be demonstrated to be detected prior to the development of the fatigue cracks, must also be directly included in the ALS.*

The WG reviewed the initial flaw size discussion for locations that are susceptible to accidental damage in EASA AMC 25.571, Amdt. 19, para. 8(c):

> *For the locations addressed by CS 25.571(a)(4) that are also susceptible to accidental (manufacturing or service induced) damage, the assumed initial flaw size*

for crack growth determination of the threshold should not be less than that which can be supported by service experience or test evidence. For example, if the type of damage expected is well defined, e.g. it is limited to dents, then there may be data that supports a longer threshold than would be derived by the assumption of a crack that is similar in size to the dent. However, in this case, the worst case manufacturing flaw should still be considered as a crack and the most conservative resulting threshold adopted. If supporting data is not available (e.g. for a completely new design where no specific investigation of the accidental damage threats or their influence on fatigue has been made), then the fatigue cracking inspection threshold should be set equal to the repeat interval derived for a crack detectable by general visual inspection means, since the initial damage and its growth is not well defined and could occur at any time.

The WG concluded that similar instructions for AC 25.571-1D for SLP are not needed. The statement "an initial flaw crack growth approach may be used …" sufficiently defines the objective when combined with the proposed guidance in the 2018 TAMCSWG report, Appendix E:

For Damage-growth analyses the assumed initial flaw chosen must be recognized to produce conservative results. Historically starting flaw sizes such as 10 times the size of the manufacturing flaw size established at 90% reliability and 95% confidence assuming log-normal distribution have been used, or use 0.05" if no other data is available. Refer to AC 91-82A, Fatigue Management Programs for In-Service Issues for additional referenced background and guidance on establishment of initial flaw size.

The damage and crack sizes discussed in the EASA AMC above are generally not applicable to compact SLP structures. Most applicants currently use a 'rogue flaw' as the initial crack size to envelope the more common AD/ED threats to SLP such as dings and corrosion pits that could be missed by the MSG-3 based visual inspections. However, typical 'rogue flaw' sizes currently used may not cover all scenarios, and the applicant should justify the initial flaw size used in their evaluation. The examples given in the EASA AMC are just some of the scenarios to consider.

4.2.3 Fatigue Testing or Analysis Based on Testing

Initially, as a means to establish the reliability objective the WG considered possible guidance that recommended fatigue test factors approaching those used for safe-life requirements. It was proposed that the same evaluation philosophy as applied to establishing the 'safe-life' of WFD susceptible structures through a full-scale test would be understood. However, the term 'safe-life' implied a customary 5-lifetime fatigue test to some OEMs and NAAs and that confusion led to the wording being removed.

In general, there are two philosophies used by the individual OEMs to define the reliability objectives for their designs and either approach could be used to define the test program:

1. A design requirement used in a statistical analysis of the fatigue endurance or damage tolerance performance of a part. These evaluations are usually quantitative, and more often associated with a target probability of failure within the operational life. Stress levels, design details and manufacturing processes are chosen and controlled to ensure the appropriate fatigue performance is achieved and maintained. Fatigue test factors should be chosen to demonstrate this prescribed high level of reliability.
2. A demonstration of the overall reliability through damage tolerance analysis, testing and published maintenance intervals. These evaluations are often qualitative, and more often described as relative to some baseline. The design stress levels, fracture properties, initial flaw sizes, and part geometry are selected to achieve a desired crack growth interval or critical crack size. Fatigue test factors are chosen to envelope the range of manufacturing quality.

The majority of the OEM WG members employ the second, qualitative approach to establishing the performance of the design, unless the design is susceptible to WFD or is evaluated to the safe-life requirements of 25.571(c). Since fatigue targets for non-WFD susceptible structures are not required by the current regulations, these members have not incorporated them into their design process. Many of these members did not agree that the term 'target reliability' should be applied specifically to the fatigue test duration. This term is used to define the full range of considerations such as structure type, inspectability and material process variation necessary to establish the inspection threshold in the 2018 TAMCSWG report, Section 3.5.2. General consensus was reached by instead using the term 'relative reliability' following the logic of the chart shown in Section 4.2.1.

However, concern was raised by a member regarding the effectiveness of this less prescriptive "graduated scale" that the WG recommended above. It was noted that there is no assurance a new applicant would have the ancillary data necessary to appropriately establish a fatigue test goal reflective of the high reliability expected for a SLP or hidden ISP designs. Differentiating these designs from the more traditional MLP redundant design in terms of expected reliability is the basis of the concern raised.

Ultimately, a clear consensus on guidance for specific reliability targets, test configurations and scenarios was not reached. Instead, the WG recommends listing the elements to be considered in designing the test program. This is consistent with the recommendation in the final TAMCSWG report, Section 3.5.2, to leave specific reliability numbers undefined. The WG recommendation in this report defines the relevant aspects necessary that all applicants regardless of experience level must account for when establishing their test goals. The elements to be considered were selected to support both of the reliability philosophies discussed above. There is general consensus on this recommendation.

Fatigue test factors should be sufficient to demonstrate the reliability targets that were established for the design, philosophy #1 above, and/or the overall performance objectives of the DTE, philosophy #2, have been achieved. Determining specific test goals is dependent upon considerations such as inherent material fatigue scatter (e.g., steel vs aluminum), scatter in fatigue performance of the design details (e.g. fastener holes vs fillets), the number of representative details contained in the test and the range of manufacturing quality (e.g. as may be defined by a manufacturing quality flaw, not a maximum possible 'rogue' flaw). The level of reliability demonstrated can be increased by residual strength tests following cycling, tear-down inspections, or by test load enhancement factors.

The full-scale testing established to show compliance for WFD susceptible structures under the current regulation would be sufficient to also address any SLP structures that are included in that test article and are representatively loaded. There is no justification or recommendation to extend those test durations to address the reliability of damage tolerant[5] SLP structures as the increased costs become significant relative to the benefits. However, if a single component test of a SLP structural element were to be performed and there were two or more components on the actual airplane, then consideration of the number of representative test specimens would be needed.

The WG specifically chose the terms DSG and operational life instead of LOV when discussing the objectives and duration of this testing. DSG is still defined in AC 25.571-1D and the WG determined that this term is better applied to SLP structures. This was to show a clear distinction from WFD compliance[6]. It is generally assumed that the DSG/operational life will be at least as long as the LOV for new certification projects[7]. However, the maintenance program for an extended LOV should consider the reliability demonstration of both SLP structures as well as locations susceptible to WFD.

[5] i.e. with controlled crack growth rates and crack sizes forming the basis of an inspection program

[6] See also the 2017 AAWG report on SDC, page 23, for their discussion on LOV and 'operational life'

[7] The LOV, in effect, is the operational life of the airplane. Although it is established based on WFD considerations, it is intended that all maintenance actions up to the LOV are identified in the structural-maintenance program. It is recommended that the DSG be used as a "candidate LOV" during initial design, with final LOV being dependent on the full-scale fatigue test findings, and associated maintenance actions to preclude WFD. See AC 25.571-1D, paras. 5(a)(2) and 7(c)(2)(a) for more details.

Application of the safe-life requirements of 25.571(c) to damage tolerant SLP is not intended. The safe-life criteria "… without detectable cracks" does not apply. If cracks are found during this testing, suitable inspections should be developed following the guidance recommended in the TAMCSWG report, Section 3.12, "Cracking during Full-Scale Fatigue Test". Life limits would not generally be applicable unless an inspection program for a specific cracking scenario were not feasible, or if fatigue critical parts could be transferred between aircraft without regard to the original LOV[8].

The guidance should therefore recommend that the applicant perform fatigue testing of SLP structures to support the DTE. The testing is intended to ensure that fatigue cracks do not form earlier than expected, or in locations not anticipated by the DTE. Analysis may be used if supported by previous test evidence. The test duration should be sufficient to demonstrate the reliability goals of the design considering the other aspects of the DTE.

[8] The WG agrees with this recommendation but notes that it is not required by regulation. This would be an uncommon case involving rotable SLP parts that developed fatigue cracks during testing and where cracking could be expected in-service. The WG does not recommend changing the regulation to address this issue and does not recommend more changes to guidance beyond those already given in the 2018 TAMCSWG Report, Section 3.12.

4.2.4 Demonstrate Controlled Rate of Crack Growth

The final TAMCSWG report, para. 3.2.4, recommended the following specific action for SLP structure:

> *Perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen do indeed provide a controlled slow rate of crack propagation combined with high residual strength*

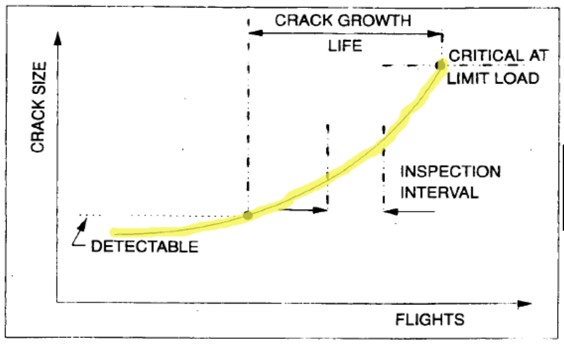
Currently, 25.571(a) already requires an applicant to provide an analysis supported by test evidence as part of the DTE. AC 25.571-1D has some discussion on testing to validate the analysis in para. 6(f), but it is at a very high level and only relates to residual strength of large components with fail-safe capability. It does not offer any guidance on the testing of SLP structures.

> *6(f.) Testing of principal structural elements*
>
> *The nature and extent of residual strength tests on complete structures or on portions of the primary structure depends upon applicable previous design, construction, tests, and service experience with similar structures. Simulated cracks should be as representative as possible of actual fatigue damage. Where it is not practical to produce actual fatigue cracks, damage can be simulated by cuts made with a fine saw, sharp blade, guillotine, or other suitable means. If saw cuts in primary structure are used to simulate sharp fatigue cracks, sufficient evidence should be available from element tests to indicate equivalent residual strength. In those cases where bolt failure or its equivalent is to be simulated as part of a possible damage configuration in joints or fittings, bolts can be removed to provide that part of the simulation.*

EASA AMC 25.571 (Amdt. 19) Appendix 1 also has some information as well, but it is primarily focused on pre-cracking of specimens and components. It provides no specific instructions for SLP structures.

AC 91-82A describes a means for the calculation of inspection intervals for SLP structures using crack growth analysis but does not provide any details on a supporting test program.

The guidance for SLP structures should therefore be revised to clearly define specific aspects of the DTE that are key to the development of a successful inspection program. These more critical aspects of the damage propagation and residual strength analysis, highlighted in the figure below, should be verified by testing.



Ref. FAA DT Handbook, Vol 1

Figure 1-16. Crack growth in response to cyclic loads.

In the absence of analysis supported by previous testing, specific tests should be performed to verify the crack growth and residual strength assumptions in the analysis:

- Crack growth rate including spectrum loading effects under flight-by-flight loading
- Fracture toughness for as-produced parts
- Stress Intensity Functions for non-standard geometries

EASA proposed that the guidance on SLP testing also include consideration of the fabrication aspects of the structure that would have influence on the macro crack propagation rates. This was intended to address processes that can introduce significant residual stresses through the cross-section of the part such as welding, additive manufacturing and some forging and heat-treating operations. The other members of the WG agree that these effects could be important but were concerned that this statement was unnecessarily explicit. There are many other parameters that would also influence the results. It was therefore agreed to omit this consideration from the final recommended guidance but include the discussion here. It is expected that the applicant will consider the significant effects of the fabrication processes, as appropriate, when defining the configuration of their crack growth rate test programs.

4.2.5 Manufacturing Process Controls

The final TAMCSWG report recommended the development of “a manufacturing process control and tracking plan document” be required for SLP structures. This was based on the original GSHWG recommendation detailed in Appendix 5 of the 2003 report, “Quality Assurance and Control for Single Load Path Critical Parts”. The differences between these two recommendations are discussed in the AAWG SDC report, 2017 R1, pages 22 & 23.

The current rules and guidance related to the development of a manufacturing process control document were reviewed by the WG. Several NAAs suggested the WG also consider the regulations for engines and rotorcraft relating to critical parts. These regulations and guidance are summarized below.

33.70 Engine life-limited parts

The applicant will establish the integrity of each engine life-limited part by:

- *(a) An engineering plan that contains the steps required to ensure each engine life-limited part is withdrawn from service at an approved life before hazardous engine effects can occur …*
- *(b) **A manufacturing plan** that identifies the specific manufacturing constraints necessary to consistently produce each engine life-limited part with the attributes required by the engineering plan.*
- *(c) A service management plan that defines in-service processes for maintenance and the limitations to repair for each engine life-limited part that will maintain attributes consistent with those required by the engineering plan. These processes and limitations will become part of the Instructions for Continued Airworthiness.*

29.602 – Critical parts (Transport Rotorcraft)

- *(a) Critical part. A critical part is a part, the failure of which could have a catastrophic effect upon the rotorcraft, and for which critical characteristics have been identified which must be controlled to ensure the required level of integrity.*
- *(b) If the type design includes critical parts, a critical parts list shall be established. Procedures shall be established to define the critical design characteristics, identify processes that affect those characteristics, and identify the design change and process change controls necessary for showing compliance with the quality assurance requirements of part 21 of this chapter.*

25.603 – Materials

The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must—

(a) Be established on the basis of experience or tests;

(b) Conform to approved specifications (such as industry or military specifications, or Technical Standard Orders) that ensure their having the strength and other properties assumed in the design data; and

(c) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.

25.605 – Fabrication methods

(a) The methods of fabrication used must produce a consistently sound structure. If a fabrication process (such as gluing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification.

(b) Each new aircraft fabrication method must be substantiated by a test program.

AC 20-107B, Section 6.a(5)

Key characteristics and processing parameters will be monitored for in-process quality control. The overall quality control plan required by the certifying agency should involve all relevant disciplines, i.e., engineering, manufacturing, and quality control. A reliable quality control system should be in place to address special engineering requirements that arise in individual parts or areas as a result of potential failure modes, damage tolerance and flaw growth requirements, loadings, inspectability, and local sensitivities to manufacture and assembly.

AC 33.70-1 GUIDANCE MATERIAL FOR AIRCRAFT ENGINE LIFE-LIMITED PARTS REQUIREMENTS

Series of AC's That Cover The Evaluation Process

- AC 33.4-1, Instructions for Continued Airworthiness
- AC 33.4-2, Instructions for Continued Airworthiness: In-Service Inspection of Safety Critical Turbine Engine Parts at Piece-Part Opportunity
- AC 33.14-1, Damage Tolerance for High Energy Turbine Engine Rotors

Manufacturing plan: A plan that identifies the part specific manufacturing process constraints which must be included in the manufacturing definition (drawings, procedures, specifications, etc.) necessary to consistently produce each engine life-limited part with the attributes required by the engineering plan.

Elements of a Manufacturing Plan. The part specific manufacturing plan should consider the attributes of the part delivered by the manufacturing process, and should highlight the processing parameters that affect the life of the part. The plan should also identify the process parameters that should not be changed without proper verification and engineering approval. Many of the parameters may be included by reference to other documents

AC 29-2C CERTIFICATION OF TRANSPORT CATEGORY ROTORCRAFT

AC 29.602 Critical Parts

The objective of identifying critical parts is to ensure that critical parts are controlled during design, manufacture, and throughout their service life so that the risk of failure in service is minimized by ensuring that the critical parts maintain the critical characteristics on which certification is based.

The SLP sub-team reviewed the rules and guidance related to critical parts for engines and transport category rotorcraft. A brief summary and comparison of each is provided below.

Parts 29 and 33 have a similar definition of a critical part which is used to classify structure:

- *Part 33: … structural parts whose primary failure is likely to result in a hazardous engine effect*
- *Part 29: A critical part is a part, the failure of which could have a catastrophic effect upon the rotocraft.*

The manufacturing plan required by Part 33 is a specific compliance document that outlines all the processes required to support the safe-life calculations for each critical part. This plan is one element of a formal three-pronged approach to certification of these parts (the other elements being engineering and maintenance plans). The manufacturing plan required by Part 29 is part of the procedures used to establish and define the critical design characteristics and quality control processes. The Part 33 and Part 29 requirements are different criteria and the SLP sub-team prefers the approach used by Part 29.

AC 20-107B, Section 6, highlights the materials and process control provisions necessary to support compliance to parts 25.603 and 25.605 for composite materials. There is no requirement for a complete manufacturing process plan as a compliance document, although those have been used for new processes in TC projects.

Certain elements of AC 33.70-1 and 29-2C appear to be applicable to metallic SLP airframe structure. However, AC 33.70-1 is specifically more applicable to safe-life components. The WG prefers the higher level requirements of AC 29-2C. Also, the application of the compliance process in AC 20-107B appears to be more suited to the Part 25 regulatory framework.

The WG does not recommend that the definition of 'Critical Parts' used in Parts 29 and 33 be applied to transport category airplanes. That definition is too broad and could be interpreted to apply to all PSE. See 45.15(c) for an example. The recommendations for manufacturing process control in this report are to be applied to SLP structures only, not all PSEs.

The WG also does not recommend that the application of the rotorcraft requirement in 29.602(b) should be applied to Part 25. This is because design and process change controls are more appropriate for Part 21, particularly if they are to be applied after type certification. The current wording in 25.605 is sufficient to enforce the specific process control provisions for SLP. This is similar to the approach specified for composite materials in AC 20-107B.

After further consideration, the WG finds it needs to revise the original 2018 TAMCSWG recommendation that "a manufacturing process control and tracking plan document" be developed as a compliance action. Instead, the guidance in AC 25.571-1D should be revised to add a new section that outlines the evaluation procedures to be applied to the material and process specifications of metallic structures. Key material and processing parameters should be defined in the process specifications approved under 25.603 and 25.605. These specifications should also identify what key characteristics and parameters are to be monitored for in-process quality control. The material and process specifications should form the basis of the DTE and range of quality used to establish the inspection thresholds. If stricter control of processing parameters is required to meet the objectives of the DTE, and commensurate with the intended reliability discussed in Section 4.2.1, those controls should be detailed in the process specification. Once established these processes should not be changed without further qualification and engineering approval.

The WG reviewed the guidance concerning changes the material and process specifications for composite materials given in AC 20-107B, Appendix 3 (shown below) to determine if it would be applicable for metallic SLP structures in AC 25.571-1D. The WG generally agrees that this is good information, but at too high of a level to be of direct use for SLP structures. However, expanding the scope to address the range of issues related to SLP structures would require too much detail. Also, many of these considerations could be applicable to MLP structures, not just SLP. Therefore, the WG recommends that this information be expanded to cover critical metallic structures and be documented in a different AC or a policy statement, but it should not necessarily be included in AC 25.571-1x or applied only to SLP structures:

AC20-107B, Appendix 3 (reference only):

Changes to the material and process specifications are often major changes in type design and must be addressed as such under 14 CFR part 21, subpart D.

The qualification and structural substantiation of new or modified materials and/or processes used to produce parts of a previously certified aircraft product requires:

a. *The identification of the key material and/or process parameters governing performances;*
b. *The definition of the appropriate tests able to measure these parameters; and*
c. *The definition of pass/fail criteria for these tests.*

"Qualification" procedures developed by every manufacturer include specifications covering:

a. *Physical and chemical properties,*
b. *Mechanical properties (coupon level), and*
c. *Reproducibility (by testing several batches).*

Several WG members noted that the provisions discussed above could be applied to all PSE parts, not just SLP. The final recommendation for guidance provided in Section 4.1.1 is primarily intended to be applied to SLP parts but that distinction was not included in the title. A connection between strict process controls and the ability to achieve the necessary reliability was added to Section 4.1.1 to place the emphasis on SLP structures.

Finally, the applicant should have a company defined process for the serialization and traceability, quality control, and handling of ‘critical’ parts. The definition of what structure is ‘critical’ varies between the individual companies, but all parts identified as SLP should have this process invoked in the type design data. Most WG OEM members already have such a process and a means to classify their ‘critical’ parts.

4.2.6 Integrally Stiffened/Monolithic Structures

The final TAMCSWG 2018 report, Section 3.2.4, outlines the objective and highlights the difficulty in determining the classification and evaluation of integrally stiffened structures:

> *It is important to make a clear delineation between SLP and integral multiple load path structure (MLP) and it could be a challenge to demonstrate that integral MLP structure does not behave as SLP. In order to do so, the applicant would likely have to consider effectiveness of crack stopping features and period of unrepaired use.*

The WG reviews of the safety objectives and definitions led to the conclusion that a specific focus on integrated structures was necessary. While integrated structures have been fielded for some time now, there is a concern that the increased use of integrally stiffened panels and monolithic parts may require additional focus. A DTE for these structures that is limited to only a crack growth analysis from some initial rogue flaw may not provide protection from the full range of foreseeable threats. The guidance should therefore be revised to include additional evaluations necessary for the DTE of these structures.

4.2.6.1 Background

In 1993 the FAA issued Policy Statement ANM100-1993-00047, “Policy regarding fail-safe features of structures designed to the damage tolerance requirements of § 25.571” to address this issue. However, this policy statement addressed fuselage pressure structures only and discussed the relative merits of integral pad-ups compared to bonded tear straps. It concluded by directing applicants to “continue the current practice of designing for a two bay crack with a broken central frame”. The WG reviewed this policy statement and concluded there were several issues with it. The primary issue relates to the 2-bay crack criteria which has not been universally applied. For example, AC 25-20 provides a crack growth based DTE for the evaluation of the pressure cabin of aircraft certified for operation above 45,000 ft.:

Additionally, the arguments for and against machined pads in place of bonded fuselage tear straps discussed in PS-ANM100-1993-00047 have been addressed by the industry

8. <u>FUSELAGE STRUCTURE</u>.

a. Higher operational altitudes could make the loss of cabin pressure due to fuselage skin cracks catastrophic even though the structure remains capable of supporting flight loads. Therefore, pressure-loaded structures for high altitude operation should be designed to be more reliable than those of present airplanes. Additional damage-tolerance requirements are necessary to prevent fatigue and corrosion damage which could result in a rapid depressurization.

b. The cabin altitude/time history should not exceed the limitations of § 25.841(a) after the maximum pressure vessel opening resulting from an initially detectable crack propagating for a period encompassing four normal inspection intervals. Cracks through skin-stringer and skin-frame combinations should be considered. A higher level of structural integrity in the pressure vessel is necessary for high altitude operations.

and both designs have been successfully fielded. That specific concern has now been resolved and the singular focus is no longer necessary. However, the higher-level points regarding testing and analysis considerations raised in the policy statement remain valid. Those points are captured in the residual strength discussion that follows in Section 4.2.6.2.

The WG compiled their experiences and design practices related to integrated structures as a starting point to the development of higher-level guidance recommendations. Several of the OEM members have examples of integrated lower wing panel structures certified to the damage tolerance requirements. These members were polled for their design and evaluation philosophy related to these structures:

> *For those designs, did compliance to 25.613 use A- or B-basis static strength properties? If B-basis, did you perform a quantitative evaluation to show 'failure of individual elements would result in applied loads being safely distributed to other load carrying members'?*
>
> *Did you perform a LDC/SDC (residual strength up to a fixed damage size) or similar damage tolerance assessment (period of unrepaired use) to support the design?*

Some members reported using A-basis material design values, while others used B-basis. The selection depended on individual design philosophy and how each member derived the classification through their own qualitative evaluation.

All members performed some fail-safe evaluation of their integrally stiffened designs that consisted of one or more of the following analyses:

> MLP Fail-Safe – Multiple panels: static strength for loss of a single panel
>
> Fail-Safe – Static strength for loss of stiffening element and skin
>
> Fail-Safe – Residual strength for crack up to adjacent stiffening element
>
> Damage Tolerance – Period of unrepaired use with initially detectable skin/stiffener crack
>
> Damage Tolerance – Demonstration of the ability of the stiffening elements to retard crack growth

The WG reviewed the current definition of 'fail-safe' given in AC 25.571-1D, which was introduced in 1998 with AC 25.571-1C in conjunction with Amdt. 25-96, and most OEM members agreed that it sufficiently describes these types of evaluations and establishes the high-level objectives of an evaluation criteria:

> ***Fail-safe*** — *The attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural element.*

The WG did consider adding additional bounds on this definition by including such things as a requirement for 'obvious failure or partial failure', and by defining the period of unrepaired use to be associated with 'normal maintenance interval'. At a high level, these additional bounds could be described using the older definition of fail-safe published in AC 25.571-1A in 1986:

> ***Fail-safe*** *means that the structure has been evaluated to assure that catastrophic failure is not probable after fatigue failure or obvious partial failure of a single, principal structural element.*

In the end, the majority of the WG members did not agree these changes were necessary and there is no recommendation to change the definition of 'fail-safe' for the purposes of evaluating integral structures. However, some WG members still believe 'obvious damage' should be considered and those opinions are discussed further in Section 4.2.6.5.

The WG then compared this current definition of 'fail-safety' to the previously proposed definitions of Structural Damage Capability (SDC) and determined that 'fail-safe' best describes the desired attributes and evaluation goals. SDC is a relatively new concept first introduced by the GSHWG in their 2003 recommendation report. It was also evaluated extensively in the 2018 TAMCSWG report, but no consensus on a definition or evaluation criteria was reached. 'Fail-Safe' has been defined in AC 25.571-1 since 1986, and the current definition was introduced in 1998. While the WG is not opposed to the use of the SDC terminology, the WG generally recommends that SDC be removed from future discussions and that 'fail-safe' be retained in the guidance. Where SDC appears in this report, it is generally in reference to a previous discussion in another report.

The WG also reviewed the existing guidance concerning residual strength capability for larger damage and found that there are currently MLP and fail-safe evaluation criteria already in AC 25.571-1D. Paragraph 6(a), shown below, emphasizes MLP design and provides considerations that could be applied to integrally stiffened and monolithic structures without any changes to the text. The WG does recommend that 'crack stoppers' in paragraph 6(a)(1) shown below be revised to 'Damage Containment Features' which is also similar to a recommendation of the 2003 GSHWG report, page 13. More discussion is provided later in Section 4.2.6.4.

Para. 6(a) "Damage Tolerance Evaluation - General":

> *Although this evaluation applies to either single- or multiple-load-path structure, the use of multiple load path structure should be given high priority in achieving a damage-tolerant design. Design features that should be considered in attaining a damage-tolerant structure include the following:*
>
> *(1) Multiple load path construction, and the use of* ***crack stoppers*** *to control the rate of crack growth and to provide adequate residual strength;*
>
> *(2) Materials and stress levels that, after initiation of cracks provide a controlled slow rate of crack propagation combined with high residual strength;*
>
> *(3) Arrangement of design details to ensure a high probability that a failure in any critical structural element will be detected before the strength of the element has been reduced below the level necessary to withstand the loading conditions specified in § 25.571(b), thereby allowing timely replacement or repair of the failed elements.*

Paragraph 6(d), shown below, provides guidance on large damage cracking scenarios. The WG reviewed this list in detail and many members agreed that, except for 6(d)(4), it would be applicable to integrally stiffened and monolithic structures. However, many members of the WG did not agree that this list alone was sufficient to fully define a fail-safe evaluation criteria. More discussion on this topic is provided later in Section 4.2.6.2.

Para. 6(d) “Extent of Damage”:

> *This determination should consider the expected stress redistribution under the repeated loads expected in service at the expected inspection frequency. Thus, an obvious partial failure could be the extent of the damage for residual-strength assessment, provided that the fatigue cracks will be detectable at a sufficiently early stage of crack development. The following are examples of partial failures that should be considered in the evaluation:*
>
> *(1) Detectable skin cracks emanating from the edge of structural openings or cutouts;*
>
> *(2) A detectable circumferential or longitudinal skin crack in the basic fuselage structure;*
>
> *(3) Complete severance of interior frame elements or stiffeners in addition to a detectable crack in the adjacent skin;*
>
> *(4) A detectable failure of one element of components in which dual construction is used, such as spar caps, window posts, window or door frames, and skin structure;*
>
> *(5) A detectable fatigue failure in at least the tension portion of the spar web or similar element; and*
>
> *(6) The detectable failure of a primary attachment, including a control surface hinge and fitting.*

4.2.6.2 Fail-Safe Evaluation Criteria

The WG agrees that integrally stiffened and monolithic structures should be treated as SLP unless they have been shown to be fail-safe using the current definition of fail-safety given in AC 25.571-1D.

The WG review found that there are several means and criteria OEMs have used in their fail-safe evaluations of structure. As discussed previously, both residual strength and damage growth criteria have been employed. Attempts were made to adapt these criteria to integrally stiffened structure through examples of damage scenarios and construction details such as the examples proposed in the AAWG SDC report, Appendix L. However, most of the same roadblocks to incorporating SDC/fail-safety identified in the 2018 TACMSWG report, Sect. 3.2.2, also prevented the WG from arriving at a specific recommendation able to cover the various practices of each OEM. In the end, these attempts resulted in more confusion and are not included in this final report (see Appendix A for the discussion and issues raised).

Instead, the focus was placed on evaluating the residual strength and damage tolerance performance aspects of the structure to determine if it possesses sufficient fail-safe capability using the existing definition in AC 25.571-1D. Many WG members encourage specifically for integral structure, both a residual strength assessment assuming obvious damage AND an estimate of how long the obvious damage can remain undiscovered at operating loads is necessary in order to produce a meaningful fail-safe evaluation. Performing both of these assessments allow for robustness comparisons with traditional MLP configurations and the desirable period of unrepaired use offered by re-initiation of damage in adjacent redundant parts.

However, most of the OEM WG members believe a fail-safe demonstration can be by either a residual strength OR a damage growth criteria. Either capability contribute to increase reliability which is necessary to classify the structure as fail-safe integrated structure, and either of the two is sufficient for this purpose. Requiring both criteria could lead to the situation where integrated structure with large damage capability would still be classified as SLP because access to the structure during normal maintenance is difficult. An applicant in this situation may choose to forego any fail-safe features and rely only on 'slow crack growth' from an initial defect as the means of compliance.

The FAA commented that either of the two evaluation should be sufficient with the proper criteria for each evaluation. However, the FAA was concerned about whether the current list of criteria for each demonstration of fail-safety is sufficient (see Appendix C for discussion). As a result, the fail-safe demonstration may need to include both approaches, unless the WG provided further clarification. The guidance is intended for all companies, including new type and supplemental type certificate (STC) applicants, existing TC and STC holders, independent designees, and aircraft maintenance, repair, and overhaul (MRO) organizations.

As a go forward approach, the WG proposed high level guidance recommendations for assessing whether integrally stiffened/monolithic structure should be classified as SLP. Acceptable evaluation criteria could be established by these two categories:

- those associated with the integral structure's capability to sustain large damage (residual strength)
- those with the verification of detectable slow growth behavior (damage growth)

If this evaluation shows the structure does not have fail-safe capability, then it should be classified as SLP with the associated considerations for SLP structures. There is general WG consensus on this specific point.

The key considerations that were proposed for the evaluation of **residual strength** capability are:

- Consider the extent of damage discussed in AC 25.571-1D, para. 6(d)
- Partial/Obvious[9] failure defined by the limits of the Damage Containment Features
- Capability of the damaged structure to withstand the required residual strength loads of 25.571(b)
    - Strength of the adjacent DCF as well as the fracture toughness of the overall panel[10]
    - Verification that the DCF remains free from fatigue wear-out and, if applicable, WFD[11]
- Test validation of the analytical models

The key considerations that were proposed for the evaluation of **damage growth capability** are:

- Consider the visually detectable damage scenarios given AC 25.571-1D, para. 6(d)
- Establish a period of unrepaired use that is consistent with the normal maintenance[12] program:
    - Initially detectable damage sizes consistent with visual inspection methods
    - Damage growth rates are sufficiently slow such that the time from detectable to critical, appropriately factored, is greater than the normal maintenance interval

Note that some aspects of the considerations necessary for SLP structures described earlier in this report may also be needed to support these fail-safe evaluations. In particular, aspects of the crack growth testing and M&P controls described in Sections 4.2.4 and 4.2.5 may be necessary to support the fail-safe evaluation of new materials and configurations and to achieve sufficiently high confidence in the results.

The considerations proposed for a residual strength evaluation were intended to address the points raised throughout the 2017 AAWG SDC report for integral structures as well as the issues discussed in policy statement PS-ANM100-1993-00047. The considerations establish a minimum damage size that is sufficiently large to warrant treating the structures as MLP. However, as discussed previously and in Section 4.2.6.4, the WG could not agree on a definition of that minimum damage size.

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[9] See Section 4.2.6.5 for discussion on obvious damage
[10] High-level objective raised in PS-ANM100-1993-00047
[11] High-level objective raised in PS-ANM100-1993-00047
[12] See the 2018 TAMCSWG report, Appendix E and G.3, for the WG discussions on ‘normal maintenance’

The considerations proposed for a damage growth evaluation were intended to be in addition to the standard DTE required to develop the inspection program. The fail-safe damage growth evaluation is more restrictive in that it requires visual detectable damage without reliance on detailed inspections. It would be equivalent to the case where 'no special inspections' are required as recommended in the 2018 TAMCSWG report, Appendix E:

> *An example of where no special inspection is required would be when:*
>
> *(i) the critical damage size is greater than readily detectable damage size that can be found during a Zonal Inspection, and*
>
> *(ii) the time from detectable to critical is greater than the GVI interval.*

During these discussions, the FAA requested the WG consider and respond to these issues raised for the fail-safe evaluation of Part 23 aircraft given in AC 23-13A to ensure that all points had been addressed by the proposed criteria:

> *In the more than 45 years since CAR Amendment 3-2 first introduced the fail-safe option for addressing fatigue requirements, the redundant structure provided by fail-safe design has prevented otherwise catastrophic failures. However, there are well-documented cases in which a design thought to be fail-safe was not, and the design failed to prevent a catastrophic failure. Several references, …, identify the following potential problems of designs mistakenly thought to be fail-safe:*
>
> *(1) Potential loss of fail-safe attributes with time due to normal fatigue wear-out.*
>
> *(2) Difficulty in making an accurate prediction and validation of failure modes.*
>
> *(3) Incorrect assumptions that a design is sufficiently and consistently self-annunciating.*
>
> *(4) Loss of type design strength due to inadequate crack detection. If a crack or other damage is not found by inspections or is not so obvious as to be detected before further flight, the capability of the structure may be below the design limit and ultimate load capability.*
>
> *(5) Inadequate residual life with obvious damage present. Redundant structure may not have sufficient safe-life to ensure that damaged structure will be found by inspections.*
>
> *The historical guidance provided in Reference 3 described the importance of repeated inspections in maintaining the continued airworthiness of a fail-safe design. Detecting fatigue cracks before they become dangerous is the ultimate control to ensure the fail-safe characteristics of flight structure and pressurized cabin. For a fail-safe design, applicants should develop an inspection program capable of detecting fatigue cracks and other partial failures. Applicants should provide enough guidance information to aid operators in establishing the frequency and extent of the repeated inspections of the critical structures or critical areas. Include instructions for these inspections, including inspection schedule and inspection methods, in the information required for § 23.1529.*

The WG response to each point is below.

1. Fatigue endurance of the Damage Containment Feature (DCF) is addressed in the bullets that outline the key points for the residual strength evaluation. This issue is also pertinent to MLP structures and was one of the drivers for the full-scale fatigue test requirement introduced into Part 25 at Amdt. 25-96. The DCF should be capable of providing fail-safe capability throughout the operational life of the aircraft.
2. The WG agrees that it can be difficult to predict and validate the analytical models necessary to evaluate integrally stiffened and monolithic structures, but many of these methods were developed in the 1960's. It is expected that difficulty in developing an analytical model would necessitate more supporting test data. A specific bullet to address this, as well as the same issue raised in policy statement PS-ANM100-1993-00047, is provided: Test validation of the analytical models.
3. This appears to be concern with omitting special inspections and 'self-annunciation' is not recommended by the WG as a means to comply with Part 25. If damage is not obvious, then an inspection is needed.
4. This appears to be a hazard associated with the reliance on the Part 23 Fail-Safe criteria alone to detect damage. The fail-safe evaluation proposed for Part 25 integrated structure would still require a DTE that must show reliable crack detection.
5. For Part 25 integrally stiffened and monolithic structures in this case, a special inspection would also be necessary to detect damage before it becomes critical.

The fail-safe recommendation proposed for integrally stiffened and monolithic structures is intended to be a design requirement used to classify the structure. Regardless of that classification, the applicant must still perform a DTE and establish inspection requirements, part replacements, or other procedures to find damage before it becomes critical. If the structure has fail-safe capability, then the DTE can proceed like that for MLP structures. Otherwise, without that capability, the DTE should include the considerations recommended for SLP structures.

The WG members agree that the fail-safe evaluation of integrally stiffened and monolithic structures should consist of residual strength analysis or damage growth analysis, or both, showing the ability to withstand large damage. The members also generally agree that the guidance should contain the high-level details on this fail-safe evaluation. There were numerous WG discussions on this topic, with each member's viewpoint based in their company's philosophy with respect to fail-safe design (see Appendix C for details). Ultimately, the WG could not reach a consensus on the minimum requirements for these evaluations and therefore there is no proposed guidance change. The primary roadblock to consensus on the minimum fail-safe performance is summarized as follows:

- Five of the WG members believe that **BOTH** a residual strength evaluation of damage that extends to the adjacent DCF **AND** a damage growth evaluation showing initially detectable damage will be found during operation or normal maintenance are necessary to demonstrate fail-safe capability.
- Seven other WG members believe that **EITHER** a residual strength evaluation of damage that extends to the adjacent DCF **OR** a damage growth evaluation showing initially detectable damage will be found during normal maintenance is sufficient to demonstrate fail-safe capability.

The WG has been unable to resolve the dissenting views and therefore presents this data as a summary of discussions and key points for further consideration for future guidance.

4.2.6.3 Inspection Reliability

The WG considered a recommendation that the inspection reliability, to be achieved through increased life (inspection) factors, be included as another key consideration for evaluating the damage growth capability discussed previously in Section 4.2.4. Some members believed that the inspection frequencies or opportunities for detection should be increased for integrally stiffened and monolithic structures compared to MLP structures. This was primarily driven by the fact that the structure is constructed from a single material element that may not have defined controls of the fracture properties.

The other WG members believe these bullets alone provided as key considerations for the damage growth capability adequately address this concern:

- *Establish a period of unrepaired use that is consistent with the normal maintenance program:*
    - *Initially detectable damage sizes consistent with visual inspection methods*
    - *Damage growth rates are sufficiently slow such that the time from detectable to critical, **appropriately factored**, is greater than the normal maintenance interval*

Also, adding a focused consideration for inspection reliability creates confusion between what should be shown for a fail-safe design evaluation and what should be addressed by the subsequent DTE. Inspection reliability is a topic that pertains to the calculation of repeat intervals which has already been addressed in the 2018 TAMCSWG report, Section 3.5. Also, as discussed in Section 4.2.1 of this report, the in-service reliability of hidden MLP structures may not be better than fail-safe ISP/monolithic structures that gives a visual indication of cracking. So, added focus on the inspection intervals for ISP/monolithic structures is not warranted and specific mention is not recommended.

However, all members do agree that the life or safety factors applied to the results of the DTE should be graduated based on the relative risk and structural categories presented in Section 4.2.1. As discussed in Appendix 4 of AC 91-82A, inspection interval safety factors should normally be at least 2.0. It should be greater where needed for higher risk structures or lower confidence in the supporting data, or both.

The WG does not recommend fixed factors be published in guidance however, as they tend to become requirements that may increase costs (through increased inspections) without any justification. The inspection interval factor of 4.0 recommended in AC 25-20 (High Altitude Operation) was provided without any rationale and does not appear to consider the current requirement for full-scale testing, nor does it offer a means to evaluate fleet performance. There have been several decades of good service experience for business jets certified to 51,000 ft. with no indications of decompression events or even large cracks found during inspections. Also, the 2000 ARAC recommendation concerning pressurized compartment loads discussed changing this factor to 2.0, but the recommendations were not adopted. Therefore, the WG recommends that any future guidance changes to address the fail-safe criteria discussed in Section 4.2.6.2 present only the high-level considerations for establishing safety factors but omit fixed factors as they become difficult to change.

4.2.6.4 Damage Containment Feature

The WG specifically discussed the definition of the term Damage Containment Feature (DCF). This term was originally introduced in the 2003 GSHWG report:

> ***Damage containment features*** *are specific design characteristics of a load-carrying member within the structure which are introduced in order to significantly retard or arrest a crack and enhance the capability to carry the applied loads in the event of partial failure of that member.*

Early in the discussion on SLP, a sub-team of the WG applied this definition in an attempt to develop a concise criteria for the fail-safe evaluation of integrally stiffened and monolithic structures. This team found that there were several definitions of the ‘crack arrest’ concept and one example is given in Appendix A where a crack that is undergoing stable tearing is stopped at the adjacent stiffener. Other members defined it by the ability to hold a dynamically (unstable) propagating crack. The sub-team did agree on the understanding that the objective of the fail-safe evaluation was to show that the remaining structure could ‘hold under limit loads’.

Therefore, the WG decided to omit the term ‘crack arrest’ from the definition to avoid this confusion and expand on the current performance objective for ‘crack stoppers’ already given in AC 25.571-1D:

> *…to control the rate of crack growth and to provide adequate residual strength*

This forms the basis of the recommended definition for DCF as given in this report, Section 4.1.1:

> ***Damage Containment Feature*** *– A design element such as a stiffener or pad-up intended to reduce the stress intensity of an active crack and is used to control the rate of crack growth and to provide adequate residual strength.*

The terms ‘stress intensity’ and ‘active crack’ are included in the definition to highlight that the evaluation is to be performed using the principles of fracture mechanics not static strength. The analysis, supported by tests, should show that the DCF provides adequate performance including all the effects that influence the failure modes.

Note that this definition specifically applies to metallic structure, including metallic structures with bonded DCF. Similar definitions are discussed in AC 20-107B for composite structures as related to ‘arrested growth’ and Cat 3 damage. In this case, a definition of ‘damage arrest’ has been provided that is specific to composite materials.

4.2.6.5 Obvious Damage

WG members reviewed several definitions of damage criteria that include ‘obvious damage’ of as part of the discussions on this fail-safe evaluation:

1. EASA AMC 25.571: A general visual inspection is a visual examination of an interior or exterior area, installation, or assembly to detect obvious damage, failure, or irregularity.
2. FAA AC 20-107B: Category 3 Damage in composite materials - Includes large impact damage or other obvious damage that will be caught during walk-around inspection or during the normal course of operations (e.g., fuel leaks, system malfunctions or cabin noise).
3. AC 25.571-1D, Para. 6(d): Thus, an obvious partial failure could be the extent of the damage for residual-strength assessment, provided that the fatigue cracks will be detectable at a sufficiently early stage of crack development.
4. AC 25.571-1A introduced a definition of ‘fail-safe’: … *the structure has been evaluated to assure that catastrophic failure is not probable after fatigue failure or obvious partial failure of a single, principal structural element*. This definition was revised with AC 25.571-1C removing the term ‘obvious’ among other changes.

EASA suggested the WG consider the definition given in 1) with a consideration that ‘obvious damage’ is that damage that could be found during normal maintenance.

Many WG members believe ‘obvious damage’ should be defined by larger damage sizes (e.g. 2-bay crack) in association with an assessment of the period necessary to discover the defined obvious damage condition. They believe that the definition given in 2) above should be given in the guidance to define the damage size criteria for the fail-safe evaluation. Many of these WG members have incorporated the older definition of ‘fail-safe’ given in 4) above into their design philosophies. Unexpected damage that occurs pre-threshold would not be discovered if it were not obvious. Without some expectations identified in the guidance, the deliberate “robustness assessment” of integrally stiffened and monolithic structures might turn out to be meaningless for its intended purpose: to identify those structures that should be classified as SLP.

However, most OEM WG members believe the guidance listing examples of extent of damage in AC 25.571-1D, para. 6(d), supported by the current definition of ‘fail-safe’, is sufficient to define the extent of damage in conjunction with residual strength up to the DCF. This provides for ready detection of damage through visual means and follows Definition #3 above. The damage extent given in 2) (Category 3 Damage) is associated with a residual strength capability that retains ‘limit or near limit load capability’. Extending this concept to the fail-safe evaluation of integrally stiffened and monolithic structures is not supported by the current regulation. The damage extent defined by 1) would generally provide for the same size of damage as 3). However, most OEM WG members do not believe a residual strength demonstration showing large damage up to the adjacent DCF needs to be further constrained by a specific inspection task. Those tasks remain part of the DTE.

4.2.6.6 Conclusions

Integrally stiffened and monolithic structures are accepted under the current regulations and their performance has been adequate to date. However, there is a concern that the increased use of integrally stiffened panels and monolithic parts may require additional focus. A DTE for these structures that is limited to only a crack growth analysis from some initial rogue flaw may not provide protection from the full range of foreseeable threats. The guidance should therefore be revised to include additional evaluations necessary for the DTE of these structures. It should recommend that integrally stiffened and monolithic structures should be treated as SLP unless they have been shown to have fail-safe capability.

The final TAMCSWG 2018 report anticipated that it would be a challenge to establish criteria showing integrally stiffened and monolithic structures do not behave as SLP. The TAMCSWG spent considerable time in the ensuing two years working to find a consensus position. While all objectives were not met, the WG did make significant progress and has documented the key considerations and identified opposing views. These are summarized below:

- The WG identified several methods companies have used in the past to develop fail-safe integral stiffened and monolithic structures
    - Prescribed residual strength evaluations showing large damage up to the adjacent DCF
    - Damage growth evaluations showing a period of unrepaired use that is consistent with the normal maintenance program
- The WG proposed a new definition for DCF to be included in the guidance. These design features are key to the fail-safe evaluation of integrated structure.
- The WG outlined key elements of each of these evaluation methods but could not agree on the minimum level of elements necessary to show that the structure is fail-safe. Some members believe both the residual strength and damage growth evaluations are necessary. Other members believe only one or the other is necessary.
- The WG did not agree on a standard for the minimum damage size for the fail-safe evaluation. Some members believe that it should be defined as ‘obvious damage’ while others believe the current AC wording of ‘partial failure’ is acceptable.

The WG generally agrees that the FAA should ultimately develop and publish guidance that defines the acceptable performance criteria of these key elements of the fail-safe evaluation using the information provided in this report.

Upon release of that revised guidance, these clarifications should also address the high-level issues raised in the policy statement PS-ANM100-1993-00047, which should then be cancelled.

5 Cost & Benefit Analysis

This section addresses the third element of the ARAC Tasking detailed in Section 2 for SLP structures. It focuses on Task 3 of the ARAC Tasking and summarizes the estimated costs and benefits of the proposed changes. As the WG recommended no changes to the regulations in Section 3, this section addresses only the costs and benefits of each of the changes to guidance discussed in Section 4. These changes proposed for the guidance are seen as actions necessary to show compliance for SLP structures. These proposed changes capture the current industry practices employed by the companies supporting the TAMCSWG. The report identifies the collective efforts of the WG member's companies to create a standardized means of compliance based on today's industry practices. The primary benefit of incorporating these changes is the standardization of the tests, analysis and evaluation procedures of these critical components thereby improving certification efficiency and enhancing safety.

As discussed in Section 3.1, the TACMSWG did not recommend a rule change that would mandate MLP or prohibit SLP structures as suggested by the GSHWG in 2003. The WG recommends that the FAA continue with the current rule in that selecting a SLP structure remains an option available to an applicant and that the decision would be part of their engineering development and business case review. The costs given in this section due to the recommended guidance changes are provided as reference information and would only be incurred if an applicant selected a SLP structure for their program. The WG recommends that those costs be evaluated as part of the design selection process. The TAMCSWG has determined that these costs are a necessary part of the compliance actions for SLP structures and, as such, are including them for future reference. The TAMCSWG also recognizes that guidance is not mandatory, but also understands that most applicants will follow AC 25.571-1x as the total certification costs to develop another alternate means of compliance would generally be prohibitive.

Cost estimates are provided by assuming the number of TC and amended TC programs that would be affected over a 20-year span, a duration requested by the FAA as typical for their evaluations.

5.1 Minimization of AD and ED

In Section 4.2.1, the WG recommended that the guidance be changed to clarify that the applicant should perform a specific evaluation of environmental and accidental damage for SLP structures beyond that typically employed by the MSG-3 process. The regulation already requires the applicant to consider AD and ED in the DTE, but the guidance currently only describes how those threats would be addressed by the baseline normal maintenance program which typically consists of visual inspections. Visual inspections may miss damage or cracking in SLP structures with limited critical crack sizes. Therefore, damage tolerance-based inspections should be developed and listed in the ALS.

This recommended change to guidance would describe the items to consider when establishing a structural maintenance program for SLP structures and to not erroneously rely on the baseline MSG-3 inspections only. The current regulation requires that inspection thresholds be calculated using crack growth analysis considering an initial ‘rogue’ flaw. Continued use of this approach, if correctly applied to all locations that are susceptible to AD or ED, would typically meet these recommendations for SLP structures and therefore no additional costs would be incurred.

Appendix B describes a summary of significant accidents reviewed by the WG. One accident involving the failure of a propeller, a SLP component, was attributed to fatigue that initiated from corrosion pitting. There were 8 fatalities in that accident. While not a Part 25 product, the circumstances surrounding this accident could also apply to SLP transport aircraft structure if the maintenance program erroneously relied on only the baseline MSG-3 inspections. This proposed change in guidance would address those circumstances.

This change in AC 25.571-1D would also better harmonize the guidance with the recommendations given in EASA AMC 25.571 at Amdt. 19 providing improved certification efficiency.

Costs and benefits of this proposed change to guidance appear to be balanced.

5.2 Fatigue Testing or Analysis Based on Testing

In Section 4.2.2, the WG proposed that the guidance be changed to recommend the applicant perform a fatigue test of each SLP structure, or complete fatigue analysis based on tests, to demonstrate a high level of fatigue reliability. The tests are intended to show that fatigue cracks do not form earlier than expected, or in locations not anticipated by the DTE. The 2018 TAMCSWG report, Section 3.5.1, proposed a performance based requirement for developing the inspection threshold. Revising the guidance to include fatigue testing of SLP structures is recommended to ensure compliance to this proposed rule for these critical structures.

Applicants for new TC’s must already perform full-scale fatigue testing on major portions of the airframe to show compliance with WFD requirements. It is expected that these full-scale test article will include many of the SLP structures in the design and therefore there is no additional cost associated with testing are anticipated. Costs may be incurred in the development and justification of the reliability factors necessary to show the test duration is sufficient, or if additional cycling is required to achieve the required reliability beyond what would be necessary to address WFD. But, those costs could be offset by the savings in certification analysis that leverage the full-scale test results to derive inspection thresholds as discussed in the 2018 TAMCSWG report, Section 4.2.

There are many structures that may not typically be included or representatively loaded on the full-scale fatigue test. Examples include engine mounts, landing gear attachment fittings, and flap support structures. Applicants for a new TC typically perform component fatigue tests on these structures, but that is not always the case, particularly for amended TC projects. Also, previous typical test durations may not be sufficient to show the high level of reliability necessary for SLP structures. It is estimated that at least one additional component fatigue test would be required for each amended TC program. One WG OEM member compiled the estimated cost of such a test using a recent amended TC project:

Large component fatigue test: $665,000 (includes test article, test fixtures and labor).

That same OEM has had 2 large amended TC programs over the past 10 years resulting in a total cost of $1,330,000. The projected costs over 20 years would therefore be $2.66M. This is only one example and could be considerably higher for other manufacturers.

It should be noted that these tests are standard industry practice, and therefore would only be experienced by applicants that either were not already performing these tests or performing them to a shorter duration. The WG sees these costs as acceptable given the benefits to safety and standardization.

5.3 Demonstrate Controlled Rate of Crack Growth

In Section 4.2.4, the WG proposed that the guidance be changed to recommend the applicant perform testing, or analysis based on testing, to demonstrate that the materials and stress levels chosen in the design of SLP structures do indeed provide a controlled slow rate of crack propagation combined with appropriate residual strength. Specific testing should be performed to verify the assumptions in the analysis.

The current regulation already requires an 'analysis based on test evidence' and many applicants have already adopted processes to develop the required data. However, the current guidance, while emphasizing MLP designs and their attributes, does not provide any additional focus or compliance objectives for the SLP structures. There are numerous publicly available data sets containing crack growth and fracture material data and stress intensity factors. Those sources of data are acceptable if the applicant establishes their suitability to their own design and manufacturing processes. Otherwise, the DTE may not be calibrated to the particular application. The primary benefit of the proposed changes would be the standardization of the level of test data required to support the DTE of these critical structures.

The costs of developing the necessary test data have been estimated by one OEM on a recent TC certification program:

- Crack growth rate including spectrum loading,
  - 2 materials and 4 stress spectra: $75,000
- Testing for non-standard Stress Intensity Factors
  - 1 configuration: $20,000

Fracture toughness data is obtained as part of the material certification under 25.603 and was therefore not included. Assuming a new TC program every 7 years, the total cost over 20 years would be $285,000 which is relatively small compared to the overall costs associated with development of new materials. Also, these tests are already common practice in the industry and the recommended guidance change documents this. However, this is only one example and could be considerably higher for other manufacturers. The WG sees these costs as acceptable given the benefits to safety and standardization.

5.4 Manufacturing Process Controls

In Section 4.2.5, the WG proposed that the guidance be changed to outline the evaluation procedures to be applied to the material and process specifications of metallic structures. Key material and processing parameters for SLP parts should be defined in the process specifications approved under 25.603 and 25.605. This recommendation captures the current practice of the industry and therefore costs are expected to be minimal. The primary benefit of the proposed changes would be the standardization of the level of material and process review required to support the DTE of these critical structures. This review would be particularly important for the evaluation of emerging technologies such as AM.

5.5 Integrally Stiffened/Monolithic Structures

In Section 4.2.6, the WG proposed that the guidance be changed to recommend that integrally stiffened panels and monolithic structures be designed and evaluated to a fail-safe criteria using the current definition of fail-safe as given in AC 25.571-1D. If the structure does not have this capability then it should be classified as SLP. A DTE for these structures that is limited to only a crack growth analysis from some initial rogue flaw, as required by the current regulations and guidance, may not result in inspections or sufficient residual strength capability to address all applicable threats. However, most OEM WG members that employ these construction methods already incorporate a fail-safe design philosophy. This philosophy was reinforced by an FAA policy statement, PS-ANM100-1993-00047. However, this policy statement was too focused on details of fuselage design and contained information conflicting with other advisory circulars and the WG recommends it be cancelled as discussed in Sections 4.1.2 and 4.2.5.

The primary benefit of the proposed changes would be the standardization of the industry practice and to broaden the applicability of fail-safe design beyond integrated pressurized fuselage structure.

If the applicant chose to forego the fail-safe evaluation, or was unable to field a fail-safe design, then the costs associated with SLP structures discussed in the preceding sections could be incurred. The likelihood of this is increased if the fail-safe evaluation required demonstrations of both the prescribed residual strength and damage growth criteria discussed in Section 4.2.6.2. Requiring both criteria could lead to the situation where integrated structure with large damage capability would still be classified as SLP because access to the structure during normal maintenance is difficult, or where incorporation of a DCF is not possible. Costs that were expected to be minimal, such as those associated with manufacturing process controls, could now be significant due to the scope and number of parts now classified as SLP.

Note however that large ISP construction would still possibly be considered susceptible to WFD and would require full-scale fatigue testing. In that case, the costs discussed in Section 5.2 would not be applicable.

References

FAA Advisory Circular AC 25.571-1D, "Damage Tolerance and Fatigue Evaluation of Structure", dated January 13, 2011
FAA Advisory Circular AC 20-107B, "Composite Aircraft Structure", dated September 8, 2009
General Structures Harmonization Working Group (GSHWG) Report on Damage Tolerance and Fatigue Evaluation of Structures FAR/JAR §25.571, dated July 2, 2003
Transport Airplane Metallic and Composite Structures Working Group – Recommendation Report to FAA, Final Report, dated June 27, 2018
Damage Tolerance Assessment Handbook, Volume I, FAA Technical Center, dated October 1993 http://www.tc.faa.gov/its/worldpac/techrpt/ct93-69-1.pdf

Appendix A Fail-Safe Evaluations for Integrally Stiffened/Monolithic Structures

This appendix is intended to document the WG discussions seeking to define acceptable evaluation criteria to be applied to integrally stiffened structures. The intention was to define guidance on the minimum fail-safe performance of an integrally stiffened design and thus show it should not be treated as SLP.

Initially, example cracking scenarios similar to those shown in the AAWG SDC Recommendation, Appendix L, were used as a starting point for WG discussions. Use of these examples quickly created confusion and disagreements similar to those faced by the AAWG SDC team.

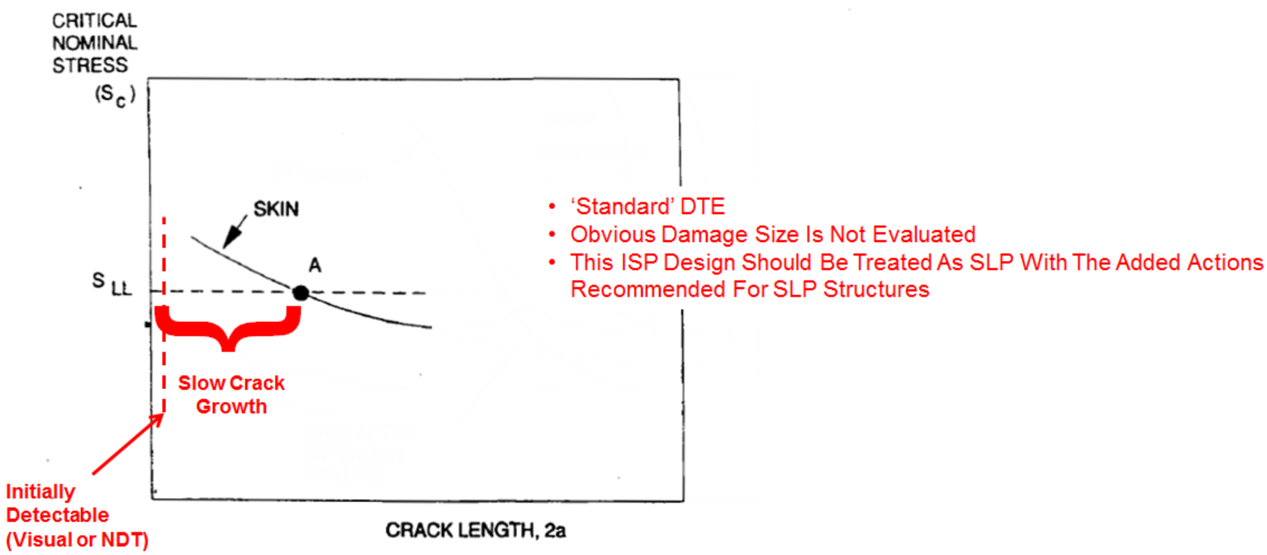
Instead of example scenarios, the focus was then shifted to residual strength curves as a means to describe the various concepts and criteria. These curves and the discussion points are shown in the following figures.

In the end, these curves also created confusion. It becomes difficult to separate the fail-safe evaluation recommended to show an integral structure is not SLP from the DTE required of all structures. And some of the curves shown represented minimum capability that was below the standards of several OEM members.

These curves are shown below to document the issues raised. The original source is the FAA Damage Tolerance Handbook, Vol. II. They are not recommended for guidance.

<u>Single Load-Path</u>

The residual strength curve below is typical of SLP structures. The four specific actions recommended for SLP defined in this report would be applied to these structures, including those integrally stiffened structures that do not meet the fail-safe evaluation criteria discussed in the main body.



The WG generally agreed that this type of residual strength behavior could described SLP structural performance.

Fail-Safe, Residual Strength Criteria

Demonstrate obvious damage with arrest at a Damage Containment Feature (DCF). The intention is to show that the adjacent DCF can contain large damage sufficient to withstand the required limit loads.

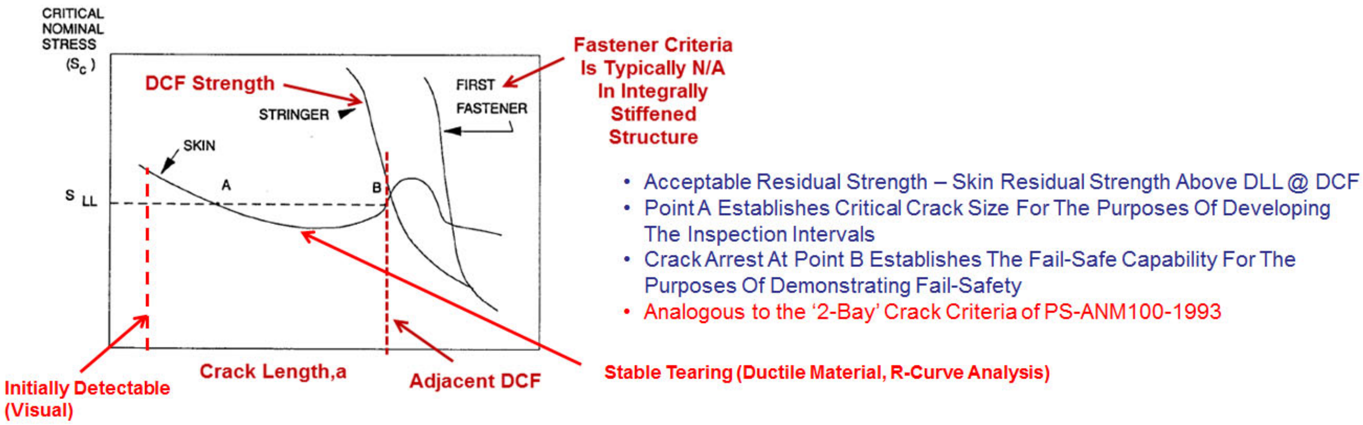
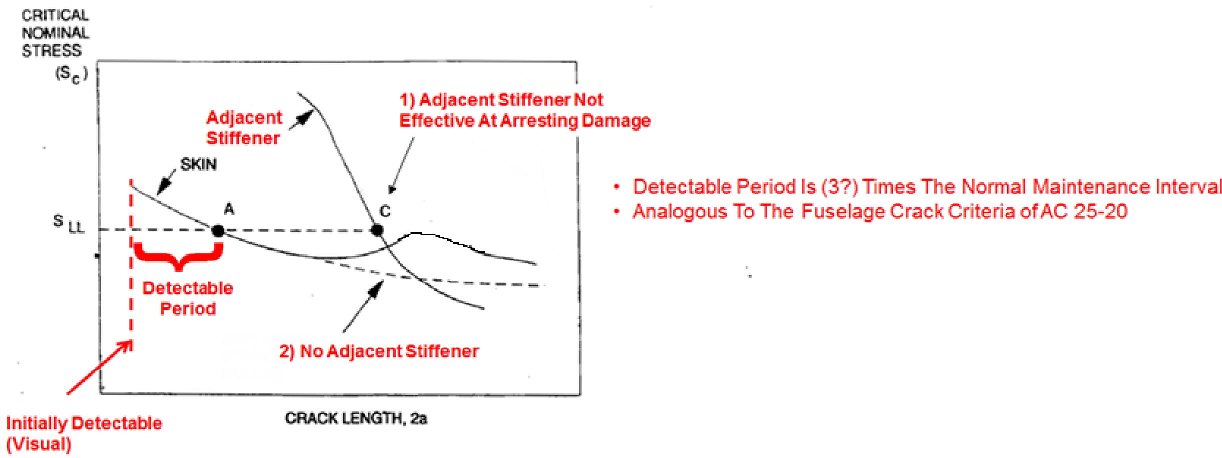


Figure 4-59. Panel strength diagram. Metallic Structure

Most of the WG agreed that a residual strength criteria with arrest at the adjacent DCF was acceptable with the understanding that arrest implied 'to hold under limit load'. However, some WG members were not comfortable with an intermediate residual strength capability below limit load (between Points A and B above), while others had extensive experience with this behavior.

<u>Fail-Safe, Crack Growth Criteria</u>

Obvious damage for a period of unrepaired use; see AC 25-20 for an example of this criteria applied to the pressurized fuselage aircraft certified for high-altitude operation. That criteria imposes a safety factor of 4, which would be applied to integrally stiffened and MLP structures. A reduced safety factor is indicated for other applications of integrally stiffened structure. Ultimately, the intention is to show that the structure can tolerate reasonably large damage for a significant period regardless of the design of the adjacent stiffeners.



Many WG members agreed that this design concept and evaluation criteria would provide acceptable fail-safe performance. However, there was some confusion on how to differentiate the fail-safe evaluation from the baseline DTE. Some WG members do not believe the fail-safe capability should be tied to an inspection program. Other members were not comfortable with the fact that the adjacent stiffener did not arrest damage, or that there was no DCF. Also, there were concerns on how an applicant would show that the crack size defined by Point A was ‘obvious’.

Additional discussions centered on the safety factor to be applied to the period of unrepaired use. EASA suggested an increased safety factor for integral structure to address the scatter in the material properties such as fracture and strength (where average material properties were used to establish residual strength). Several OEM members disagreed with that suggestion since the same aspect would apply to a MLP design where the toughness and growth rates of the wing or fuselage skin material is the key parameter.

Appendix B Review of Accident History

This appendix is documents the WG review of available accident history with a focus on the performance of SLP structures.

Ref. FAA Transport Aircraft Accident Database:
https://lessonslearned.faa.gov/transport.cfm

https://lessonslearned.faa.gov/ll_main.cfm?TabID=3&CategoryID=7

12 Significant Accidents Detailed Since the Dan-Air Event in 1977

- Autogenous Fatigue
    - 3 Due to Normal Fatigue of Fail-Safe Designs
    - 1 Due to Anomalous Fatigue of Single Load-Path (Propeller) From Corrosion Pit
- Improper Maintenance
    - 2 Due to Anomalous Fatigue Attributed to Improper Repairs; Fail-Safe Design
    - 1 Due to Accidental Damage from To Improper Engine Removal Procedure; Fail-Safe Design
    - 1 Due to Maintenance Error (Task Left Incomplete; Fastener Not Installed)
- Discrete Source Damage
    - 1 Due to Tire Burst and Fuel Tank Penetration
- Systems
    - 1 Due to Cargo Door Latching / Rapid Decompression
    - 1 Due to Common Wear of Fail-Safe Mechanical Elements (Improper Maintenance)
- Static Overload
    - 1 Due to Excessive Pilot Input

All four of the fatigue related events occurred on aircraft or types that were not subjected to the damage tolerance requirements introduced at Amdt. 25-45. A damage tolerance based inspection or part replacement program was the corrective action for all four them. Additionally, a properly applied DTE based inspection would have prevented one of the two accidents attributed to fatigue failure from improper repairs. The propeller failure (SLP) highlights the need to address AD/ED in the DTE, but the subsequent corrective actions also show that damage tolerance based inspections are feasible and safe.

Appendix C Voting Summary

The following presentation summarizes the points of dissention and their respective WG voting positions related to reliability and obvious damage criteria from July 2020.

Single Load-Path: Comments to ISP/Obvious Damage

The WG has agreed that ISP/monolithic structures should be treated as SLP unless they have been shown to be fail-safe. However, the sub-team did not reach a consensus on the details of the fail-safe evaluation.

1. **Most sub-team members believe the fail-safe evaluation can be by either a residual strength evaluation <u>or</u> by a crack growth evaluation. However, some believe both are required. Do you agree that one of the two is sufficient, or do you believe both are required?**
2. **Most OEM sub-team members believe the current guidance in AC 25.571-1D, para. 6(d), is sufficient to establish the criteria for a residual strength evaluation of ISP/monolithic structures. Some, however, believe the evaluation should consider 'obvious damage' sizes defined by larger damage sizes in association with an assessment of the period necessary to discover the defined obvious damage condition. What is your position?**
3. **Indicate if you agree these criteria should be included in the guidance.**

If you do not agree with any of the choices listed in the draft text, please provide a corresponding statement and rationale that describes your position.

Single Load-Path: Comments to ISP/Obvious Damage

1. Most sub-team members believe the fail-safe evaluation can be by either a residual strength evaluation <u>or</u> by a crack growth evaluation. However, some believe both are required. Do you agree that one of the two is sufficient, or do you believe both are required?

Boeing, Delta, FedEx, British Airways, United Airlines, (ANAC)

<u>Both</u> a residual strength assessment assuming obvious damage AND an estimate of how long the obvious damage can remain undiscovered at operating loads is necessary in order to produce a meaningful fail-safe evaluation. Performing both of these assessments allow for robustness comparisons with traditional MLP configurations and the desirable period of unrepaired use offered by re-initiation of damage in adjacent redundant parts.

Single Load-Path: Comments to ISP/Obvious Damage

1. Most sub-team members believe the fail-safe evaluation can be by either a residual strength evaluation or by a crack growth evaluation. However, some believe both are required. Do you agree that one of the two is sufficient, or do you believe both are required?

Gulfstream, Airbus, Embraer, Mitsubishi, Textron, *Dassault,* Bombardier
The fail-safe evaluation of ISP/monolithic structures is additional to the requirements of the DTE performed IAW 25.571(b). A "Residual Strength Evaluation" addresses a design attribute where the remaining structure with damage up to the adjacent DCF shall sustain the prescribed loads. The "Damage Growth Evaluation" is same as the standard DTE in terms of methodology, but a damage size criterion of "detectable in normal maintenance by visual inspection" is more restrictive.

Either capability contribute to increase reliability which is necessary to classify as the structure as Fail-Safe ISP, and either of two is sufficient for this purpose. Requiring both criteria could lead to the situation where integrated structure with Large Damage Capability (SDC) would still be classified as SLP because access to the structure during normal maintenance is difficult. An applicant in this situation may choose to forego any fail-safe features and rely only on 'slow crack growth' from an initial defect as the means of compliance.

Single Load-Path: Comments to ISP/Obvious Damage

1. Most sub-team members believe the fail-safe evaluation can be by either a residual strength evaluation or by a crack growth evaluation. However, some believe both are required. Do you agree that one of the two is sufficient, or do you believe both are required?

FAA
Either of the two evaluation should be sufficient with the proper criteria for each evaluation. However, the FAA is concerned about whether the current list of criteria for each demonstration of fail-safety is sufficient. As a result, the fail-safe demonstration may need to include both approaches, unless the working group provides further clarification. The guidance is intended for all companies, including new type and supplemental certificate (TC) applicants, existing supplemental TC holders, independent designees, and aircraft maintenance, repair, and overhaul (MRO) organizations.

Single Load-Path: Comments to ISP/Obvious Damage

2. Most OEM sub-team members believe the current guidance in AC 25.571-1D, para. 6(d), is sufficient to establish the criteria for a residual strength evaluation of ISP/monolithic structures. Some, however, believe the evaluation should consider 'obvious damage' sizes defined by larger damage sizes in association with an assessment of the period necessary to discover the defined obvious damage condition. What is your position?

Boeing, Delta, British Airways, United Airlines

Include the term 'obvious damage' in the evaluation criteria and define it as damage that is "*large enough to be detected by **obvious visual indications** during walk around, or by indirect means such as cabin pressure loss, cabin noise, or fuel leakage".*

Unexpected damage that occurs pre-threshold would not be discovered if it were not obvious. The WG agreed in principal that a level of fail-safety needs to be demonstrated (allowing to not be treated as SLP), but without some expectations identified the deliberate "robustness assessment" might turn out to be meaningless for its intended purpose.

Single Load-Path: Comments to ISP/Obvious Damage

2. Most OEM sub-team members believe the current guidance in AC 25.571-1D, para. 6(d), is sufficient to establish the criteria for a residual strength evaluation of ISP/monolithic structures. Some, however, believe the evaluation should consider 'obvious damage' sizes defined by larger damage sizes in association with an assessment of the period necessary to discover the defined obvious damage condition. What is your position?

Gulfstream, Airbus, Embraer, Mitsubishi, Textron, *Dassault,* Bombardier

Omit the term 'obvious damage' from the evaluation criteria and use the damage sizes defined by AC25.571-1D, para 6.d. to define fail-safe.

'Obvious Damage' already has a basis in AC 25.571-1D, but is primarily used in conjunction with the discrete source damage evaluation of 25.571(e): immediately obvious damage. AC 20-107B also has a definition of 'obvious damage' similar to what has been proposed by some WG members, but it is applied to Category 3 damage. The extent of damage as currently defined in these AC's is beyond what should be considered in a fail-safe evaluation showing residual strength for limit loads. Extending this concept to the fail-safe evaluation of ISP/monolithic structures is not supported by the current regulation.

Note: EASA AMC 25.571 has the following criteria for 'obvious damage':

A general visual inspection is a visual examination of an interior or exterior area, installation, or assembly to detect obvious damage, failure, or irregularity.

Single Load-Path: Comments to ISP/Obvious Damage

2. Most OEM sub-team members believe the current guidance in AC 25.571-1D, para. 6(d), is sufficient to establish the criteria for a residual strength evaluation of ISP/monolithic structures. Some, however, believe the evaluation should consider 'obvious damage' sizes defined by larger damage sizes in association with an assessment of the period necessary to discover the defined obvious damage condition. What is your position?

FAA, (ANAC)
Obvious damage should not be considered in the ISP/monolithic structures discussion, but it is not evident that the examples of AC 25.571-1D, Section 6.d, are also applicable to that discussion. Therefore, the description of the damages specifically to ISP/monolithic structures should be added to the guidance.

Single Load-Path: Comments to ISP/Obvious Damage

3. Indicate if you agree these criteria should be included in the guidance.

Gulfstream, Delta, FedEx, Boeing, Mitsubishi, British Airways, FAA, United Airlines, Airbus, Bombardier, (ANAC)
Include these criteria in the guidance to ensure a meaningful fail-safe evaluation.

Embraer
Criteria for fail-safe evaluation are not necessary as they are implied by the definition and guidance in AC 25.571-1D, para. 6(d).

Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendation

Embraer, Gulfstream, Airbus, Dassault, Mitsubishi, Bombardier

Damage Growth Evaluation*

A period of unrepaired use that is consistent with the normal maintenance program (1)

- Initially detectable damage sizes consistent with visual inspection methods
- Damage growth rates are sufficiently slow that they provide the ability for detection during normal maintenance
- ~~Obvious critical crack sizes *(not necessarily defined by a DCF)*~~

1 - See the 2018 TAMCSWG report, Appendix E and G.3, for the WG discussions on 'normal maintenance'

Rationale: The first 2 bullets adequately describe the key considerations. Obvious damage is difficult to define beyond the limits established for the discrete source damage evaluation; the 4th bullet is confusing.

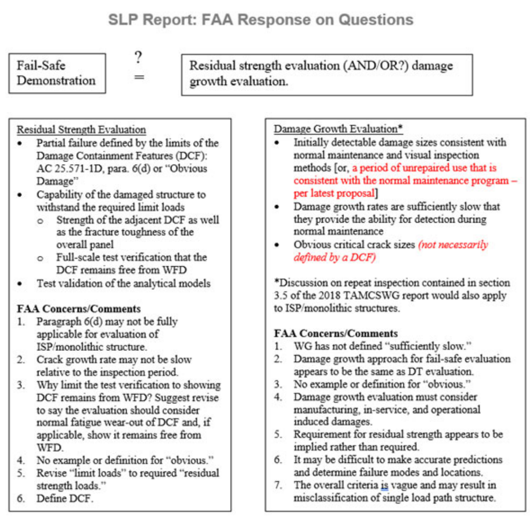
Delta

I suggest "cracks are obvious at sizes less than critical for residual strength".

Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations
FAA

Also, if AC25.571-1D 6(d) is to be used as the damage scenario, both of these evaluation criteria should clearly point to that list of examples.



SLP Report: FAA Response on Questions

Fail-Safe Demonstration ? = Residual strength evaluation (AND/OR?) damage growth evaluation.

Residual Strength Evaluation

- Partial failure defined by the limits of the Damage Containment Features (DCF): AC 25.571-1D, para. 6(d) or "Obvious Damage"
- Capability of the damaged structure to withstand the required limit loads
  - Strength of the adjacent DCF as well as the fracture toughness of the overall panel
  - Full-scale test verification that the DCF remains free from WFD
- Test validation of the analytical models

FAA Concerns/Comments

1. Paragraph 6(d) may not be fully applicable for evaluation of ISP/monolithic structure.
2. Crack growth rate may not be slow relative to the inspection period.
3. Why limit the test verification to showing DCF remains from WFD? Suggest revise to say the evaluation should consider normal fatigue wear-out of DCF and, if applicable, show it remains free from WFD.
4. No example or definition for "obvious."
5. Revise "limit loads" to required "residual strength loads."
6. Define DCF.

Damage Growth Evaluation*

- Initially detectable damage sizes consistent with normal maintenance and visual inspection methods [or, a period of unrepaired use that is consistent with the normal maintenance program – per latest proposal]
- Damage growth rates are sufficiently slow that they provide the ability for detection during normal maintenance
- Obvious critical crack sizes *(not necessarily defined by a DCF)*

*Discussion on repeat inspection contained in section 3.5 of the 2018 TAMCSWG report would also apply to ISP/monolithic structures.

FAA Concerns/Comments

1. WG has not defined "sufficiently slow."
2. Damage growth approach for fail-safe evaluation appears to be the same as DT evaluation.
3. No example or definition for "obvious."
4. Damage growth evaluation must consider manufacturing, in-service, and operational induced damages.
5. Requirement for residual strength appears to be implied rather than required.
6. It may be difficult to make accurate predictions and determine failure modes and locations.
7. The overall criteria is vague and may result in misclassification of single load path structure.

Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations
FAA
ISP Residual Strength Criteria

- Paragraph 6(d) may not be fully applicable for evaluation of ISP/monolithic structure. 6(d) is a list of example scenarios. Most items are applicable to integrated structure, but some may not be.
- Crack growth rate may not be slow relative to the inspection period. AC 25.571-1D already addresses:
  Para. 6(d) "Extent of Damage":
  This determination should consider the expected stress redistribution under the repeated loads expected in service at the expected inspection frequency.
- Why limit the test verification to showing DCF remains from WFD? Suggest revise to say the evaluation should consider normal fatigue wear-out of DCF and, if applicable, show it remains free from WFD. Agree; to discuss
- No example or definition for "obvious." Understood; would need to add Mike's definition if the wording is included.
- Revise "limit loads" to required "residual strength loads." Ok; intention was to clarify that the criteria is 25.571(b), not Category 3 "near limit load', and not 'return to base' of 25.571(e).
- Define DCF. DCF = Damage Containment Feature: An design element of integrated structure such as a stiffener or pad-up intended to reduce the stress intensity of an active crack. **Note: explain why 'crack arrest feature' was not considered in this definition. See 'crack stopper' in 25.571-1D.**

Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations
FAA
ISP Damage Growth Criteria

*** - Include examples or discussion of appropriate safety factors (2-3, point to AC91-82A, missed inspection similar to AC20-107B, etc.).**

- WG has not defined "sufficiently slow." Suggest similar to the text from the 2018 Report, Appendix E:
  - *The time from detectable to critical, appropriately factored*, is greater than the normal maintenance interval*
- Damage growth approach for fail-safe evaluation appears to be the same as DT evaluation. It is more restrictive as it requires visual inspections and 'no special inspections' according to the text of the the 2018 Report, Appendix E: **This discussion to be included in Section 4.2.**
  An example of where no special inspection is required would be when:
  (i) the critical damage size is greater than readily detectable damage size that can be found during a Zonal Inspection, and
  (ii) the time from detectable to critical is greater than the GVI interval.
- No example or definition for "obvious." Understood; would need to add Mike's definition if the wording is included.
- Damage growth evaluation must consider manufacturing, in-service, and operational induced damages. Assumption that 'initially detectable" damage size would envelop all of these threats.
- Requirement for residual strength appears to be implied rather than required. See bullet #1 above.
- It may be difficult to make accurate predictions and determine failure modes and locations. It is difficult, but the SIF methods have been developed since the 1960's.
- The overall criteria is vague and may result in misclassification of single load path structure. Criteria is intended to match AC 25-20 which has been used successfully for 30 years.

Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations
FAA

In each approach, one common element is the size of the damage or critical crack size(s). Is there a way to modify each to establish one criteria?

High-Level Criteria: The applicant should perform a fail-safe evaluation of these (integrated) structures to support the subsequent DTE. If this evaluation shows the structure does not have fail-safe capability, then it should be classified as SLP with the associated SLP considerations defined in this AC.

Fail-safe *— The attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural element*

Policy Memo PS-ANM100-1993-00047 is an example of a residual strength criteria for pressurized fuselages.

AC 25-24 is an example of a damage growth criteria for pressurized fuselages.

Single Load-Path: Comments to ISP/Obvious Damage

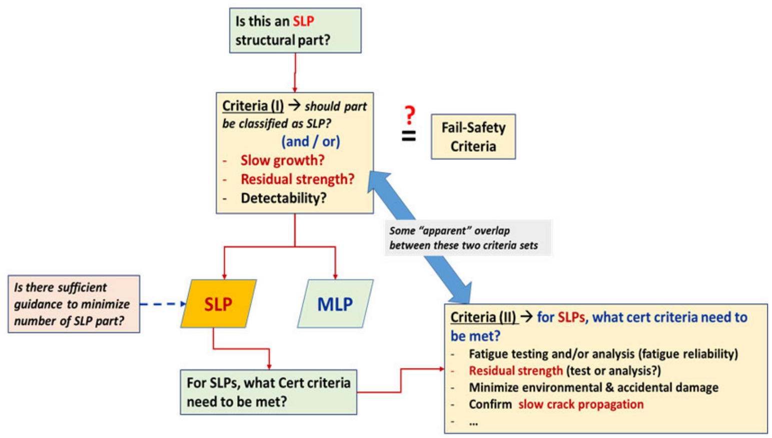
Additional Recommendations
FAA

AC 23-13A (small airplane standards) provides additional considerations related to a fail-safe check. Those are as follows:

(1) Potential loss of fail-safe attributes with time due to normal fatigue wear-out. Addressed previously.
(2) Difficulty in making an accurate prediction and validation of failure modes. Addressed previously.
(3) Incorrect assumptions that a design is sufficiently and consistently self-annunciating. This appears to be a criteria for omitting special inspections and is not recommended by the WG for Part 25. If damage is not obvious, then an inspection is needed.
(4) Loss of type design strength due to inadequate crack detection. If a crack or other damage is not found by inspections or is not so obvious as to be detected before further flight, the capability of the structure may be below the design limit and ultimate load capability. This appears to be a hazard associated with the reliance on the Part 23 Fail-Safe criteria to detect damage. The fail-safe evaluation proposed for Part 25 integrated structure would still require a DTE that must show reliable crack detection.
(5) Inadequate residual life with obvious damage present. Redundant structure (*or structural area between DCF*) may not have sufficient safe-life to ensure that damaged structure will be found by inspections. For Part 25 integrated structure, a special inspection would also be necessary in this case.

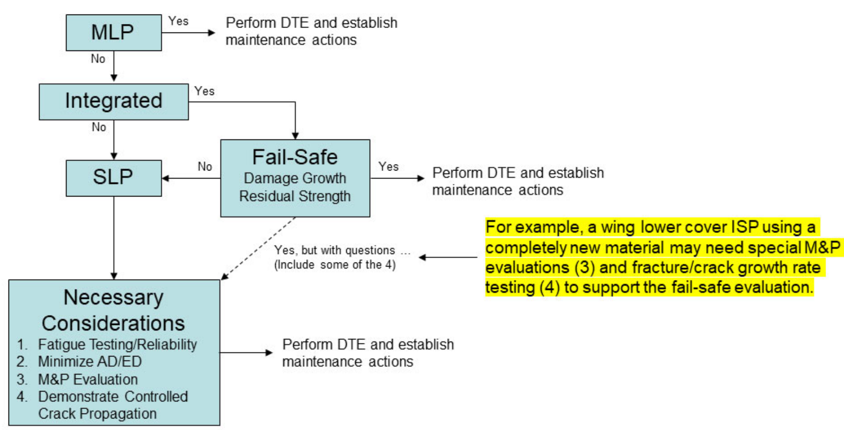
Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations
FAA



Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations
FAA



Single Load-Path: Comments to ISP/Obvious Damage

Additional Recommendations

FAA

Note: DCF = 'Crack Stopper'

Para. 6(a) "Damage Tolerance Evaluation - General":

Although this evaluation applies to either single- or multiple-load-path structure, the use of multiple load path structure should be given high priority in achieving a damage-tolerant design. Design features that should be considered in attaining a damage-tolerant structure include the following:

*(1) Multiple load path construction, and the use of **crack stoppers** to control the rate of crack growth and to provide adequate residual strength;*
(2) Materials and stress levels that, after initiation of cracks provide a controlled slow rate of crack propagation combined with high residual strength;
(3) Arrangement of design details to ensure a high probability that a failure in any critical structural element will be detected before the strength of the element has been reduced below the level necessary to withstand the loading conditions specified in § 25.571(b), thereby allowing timely replacement or repair of the failed elements.

Para. 6(d) "Extent of Damage":
This determination should consider the expected stress redistribution under the repeated loads expected in service at the expected inspection frequency. Thus, an obvious partial failure could be the extent of the damage for residual-strength assessment, provided that the fatigue cracks will be detectable at a sufficiently early stage of crack development. The following are examples of partial failures that should be considered in the evaluation:
(1) Detectable skin cracks emanating from the edge of structural openings or cutouts; Applicable to both MLP and integrated structure
(2) A detectable circumferential or longitudinal skin crack in the basic fuselage structure; Applicable to both MLP and integrated structure
(3) Complete severance of interior frame elements or stiffeners in addition to a detectable crack in the adjacent skin; Applicable to both MLP and integrated structure
(4) A detectable failure of one element of components in which dual construction is used, such as spar caps, window posts, window or door frames, and skin structure; Only applicable to MLP
(5) A detectable fatigue failure in at least the tension portion of the spar web or similar element; and Applicable to both MLP and integrated structure
(6) The detectable failure of a primary attachment, including a control surface hinge and fitting. Applicable to both MLP and integrated structure

Intended that 'detectable' = visually detectable.
Clarify that these scenarios should be considered for fail-safe evaluations of ISP/integrated structure.
Tie in with discussion on repeat intervals and scatter factors in 2018 TACMSWG report.

Single Load-Path: Comments to Reliability Questions

Do you agree with these 3 aspects of reliability discussed in the draft SLP report, para. 4.1.1 and that they be included in the guidance:

1. **SLP designs should therefore be shown to have the highest reliability compared to MLP and integral structures with fail-safe capability.**
2. **Reliability Figure**
3. **Reliability may be defined on the basis of evaluations of fatigue endurance, or by assessments of initial damage or defect sizes.**

If you do not agree with any of the choices listed in the draft text, please provide a corresponding statement and rationale that describes your position.

Single Load-Path: Comments to Reliability Questions

1. **SLP designs should therefore be shown to have the highest reliability compared to MLP and integral structures with fail-safe capability.**

Gulfstream, Embraer, Mitsubishi, Textron, Boeing, FAA, (ANAC), FedEx, Delta, British Airways, Dassault, United, Airbus, Bombardier
Agree with statement and it should be included in the guidance.

FAA Caveat
The working group (WG) should explain that there is an associated confidence level with a given reliability and further clarify the definition of reliability.

Single Load-Path: Comments to Reliability Questions

2. **Reliability Figure**

Gulfstream, Mitsubishi, Dassault
The current SLP draft with emphasis on visual vs. hidden. The accident review in Appendix B of the draft SLP report shows 3 accidents where hidden damage in fail-safe designs did not provide an acceptable period of unrepaired use. The final figure is not needed in the guidance.

Boeing (?), FAA, (ANAC), Delta, British Airways, United
The original 2018 version, and it should be included in the guidance (note: Boeing did not indicate a view w.r.t. the guidance)

Textron
Hidden MLP and visible ISP (integral) would be treated the same. The figure does not need to be in the guidance.

FedEx
Hidden MLP and visible ISP (integral) would be treated the same. The figure should be in the guidance.

Embraer, *Airbus*, Bombardier
The original 2018 version, but it should not be included in the guidance

Single Load-Path: Comments to Reliability Questions

3. Reliability may be defined on the basis of evaluations of fatigue endurance, or by assessments of initial damage or defect sizes.

Do you agree that the above statement is sufficiently clear to enable you to derive an appropriate test duration?
Do you agree that the above statement should be given in the guidance?

Gulfstream, FedEx, Airbus
Yes and yes

Boeing, FAA, (ANAC), Embraer, British Airways, Mitsubishi, Textron, United, Dassault , Bombardier
No and yes.

Delta
? and yes.

Single Load-Path: Comments to Reliability Questions

3. Reliability may be defined on the basis of evaluations of fatigue endurance, or by assessments of initial damage or defect sizes.

Additional FAA Discussion
The FAA recommends the report include a basic definition(s) at a minimum. The report should include a statement to the effect: "For the purposes of this document, the term 'reliability' is defined as…" Open literature commonly uses several generic definitions of *reliability* and *fatigue reliability*. The FAA has included the two below for the working group's consideration.

- *Reliability* is defined as a probability of the structure to acceptably perform its function.
- *Fatigue reliability* is defined as the probability that structure will perform its intended function throughout its lifetime without any fatigue failure.

Suggest **Fatigue reliability = same def'n but applied to fatigue failures only.**

Reliability is defined as the ability of the structure to perform its function without failure throughout the service life of the airplane. Performance can be established based on evaluations of fatigue endurance, or of damage growth from initial damage or defects, or both. Key considerations for the reliability demonstration include material selection, manufacturing process controls, stress levels, damage tolerance evaluations, fatigue tests, and published maintenance instructions. Safety or scatter factors applied to the results of the evaluation should reflect the confidence level in the engineering data used (ref. AC 120-104, pg. A8-14).

The following presentation summarizes the WG comments to the nearly completed draft report compiled in October 2020 and has background information reflected in the final report.

Single Load-Path: Comments to 06OCT20_r3 Draft

Throughout:

Airbus Comment: The wording SLP design was changed into SLP structures, see 4.1.1 . So please adopt this wording also here.

Response: Most instances of 'SLP designs' have been changed to 'SLP structures' unless it makes more sense to keep 'SLP design' or where referencing the 2018 report.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 6 (Executive Summary):

- **Mitsubishi Comment**: Probably missed to update. In other paragraphs, "25.603 and 25.605" shows up.
- **ANAC Comment**: Under 25.603 and 25.605

Response (several locations):
A new section should be added to AC 25.571-1D to address material and process specifications approved under 25.603 and 25.605 as they relate to the DTE.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 8 (Introduction):

- **Dassault Comment**: These recommendation applies to PSE only, while reading some paragraph it [is] worth reminding it: for example in §4.2.5 :, "*The definition of what structure is 'critical' varies between the individual companies, but all parts identified as SLP should have this process invoked in the type design data*" => "*…but all PSE parts identified as SLP should have this process invoked….*"

Response:
The final TAMCSWG report, 6/27/18, made several recommendations regarding additional focus and requirements for single load-path structures used as Principal Structural Elements (PSE) of the airframe.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 9 (Introduction):

Boeing Comment: I notice we are missing mention of the second part regarding the importance of the added manufacturing controls needed on SLP designs. Should not cause any controversy as we have agreed to recommend a new section be added to the AC regarding this.

However, the regulatory guidance does not sufficiently define a means to properly design an inspection program or any additional attention to manufacturing controls for SLP structures.

Response: Accepted

We want to be clear that the attention we are paying to 25.603 and 25.605 is only with regards to the DTE and their effect on the inspection program. We are not saying SLP needs more emphasis in 25.603 or 25.605.

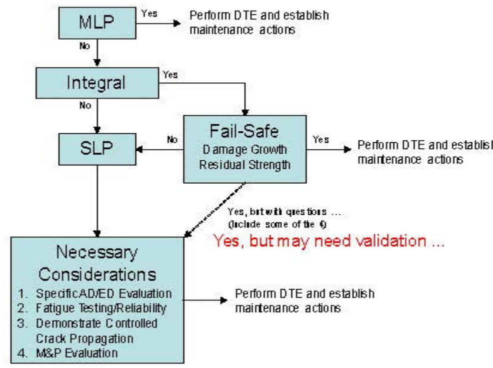
Single Load-Path: Comments to 06OCT20_r3 Draft

Page 12 (Introduction):

Boeing Comment: In the flow chart, the "Yes, but with questions…" part is a little odd looking. Perhaps we try "Unclear or Uncertain"

If there are questions about the confidence or certainty in the fail-safe evaluation, some aspects of the specific considerations for SLP could be necessary.

Response: See Slide 8

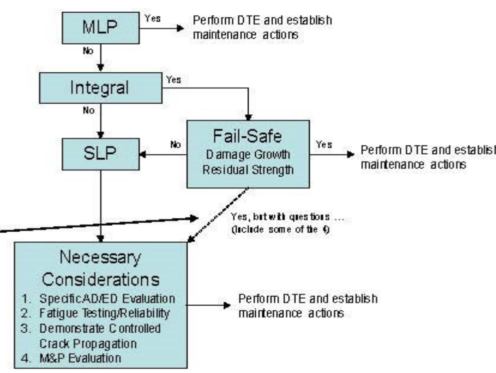


Single Load-Path: Comments to 06OCT20_r3 Draft

Page 12 (Introduction):

Airbus Comment: Airbus would not like to create such an intermediate solution for Integral structures: *If there are questions about the confidence in the fail-safe evaluation, some aspects of the specific considerations for SLP could be necessary.* The fail safe assessment will have a binary conclusion: either to be considered as SLP or not. If we allow this type of intermediate solution, the OEMs will end up in questioning and discussing halfway solutions with the authorities case by case. Also please delete the dotted arrow in the figure above

Response: The figure is included as reference only as a guide to the rest of the report, and not intended for the guidance. The dotted line 'with questions' was suggested by the FAA. These 'questions' are elements of the key considerations for the fail-safe evaluation (see next slide).



Single Load-Path: Comments to 06OCT20_r3 Draft

Page 12 (Introduction):

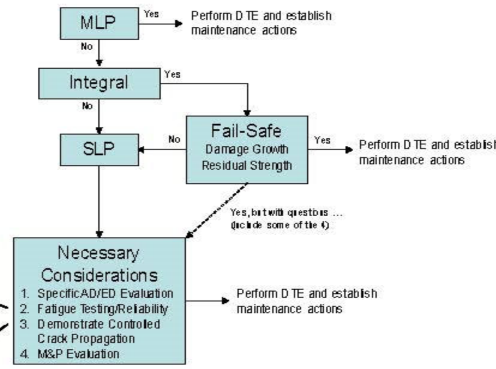
Response: Section 4.2.6.2 Eval. Criteria

The key considerations that were proposed for the evaluation of **residual strength** capability are:

- Consider the extent of damage discussed in AC 25.571-1D, 6(d)
- Partial/Obvious failure defined by the limits of the Damage Containment Features
- Capability of the damaged structure to withstand the required residual strength loads of 25.571(b)
    - **Strength of the adjacent DCF as well as the fracture toughness of the overall panel (3 & 4)**
    - **Verification that the DCF remains free from fatigue wear-out and, if applicable, WFD (2)**
    - **Test validation of the analytical models (3)**

The key considerations that were proposed for the evaluation of **damage growth capability** are:

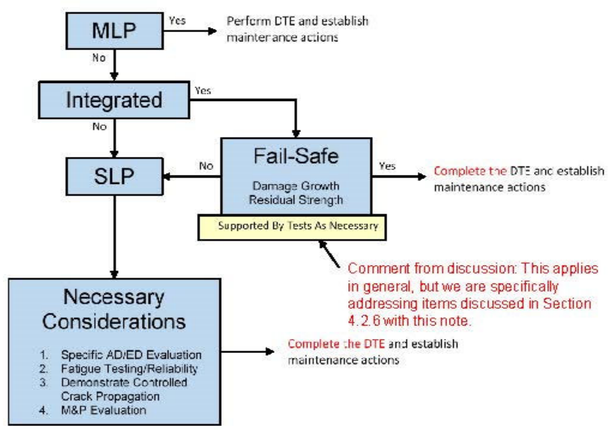
- Consider the ~~initially~~ (visually) detectable damage scenarios given AC 25.571-1D, para. 6(d)
- Establish a period of unrepaired use that is consistent with the normal maintenance program:
    - Initially detectable damage sizes consistent with visual inspection methods
    - **Damage growth rates are sufficiently slow (3)** such that the time from detectable to critical, appropriately factored, is greater than the normal maintenance interval



Single Load-Path: Comments to 06OCT20_r3 Draft

Page 12 (Introduction):

Response: Integrally Stiffened Panels and Monolithic Structure: The applicant should perform an evaluation of these structures using the definition of fail-safe given in AC 25.571-1D. Those structures that do not have fail-safe capability should be treated as SLP. Key elements of the evaluation should be supported by tests and processing controls as necessary. For example, an integrally stiffened wing lower cover using a completely new material or processing method may need fracture/crack growth rate testing, fatigue testing, and/or special M&P evaluations to support the fail-safe evaluation. This topic is discussed in detail in Section 4.2.6.



Single Load-Path: Comments to 06OCT20_r3 Draft

Page 16 (Working Group Members):

Voting members:

1.	Michael Gruber	(Boeing)
2.	Chantal Fualdes	(Airbus)
3.	Salamon Haravan	(Bombardier)
4.	Benoit Morlet	(Dassault Aviation)
5.	Antonio Fernando Barbosa	(Embraer)
6.	Kevin Jones	(Gulfstream)
7.	Toshiyasu Fukuoka	(Mitsubishi Aircraft)
8.	David Nelson	(Textron Aviation)
9.	Ryan Higgins	(British Airways)
10.	Doug Jury	(Delta Air Lines) – Chairperson
11.	Mark Boudreau	(FedEx)
12.	Eric Chesmar	(United Airlines)
13.	Walt Sippel	(FAA Representative)

Subject matter experts (Non-Voting):

1.	Steve Chisholm	(Boeing)
2.	David Polland	(Boeing)
3.	Kevin Davis	(Boeing)
4.	Al Fawcett	(Boeing – Retired)
5.	Rick Kawaguchi	(Boeing)
6.	John van Doeselaar	(Airbus)

Regulators (Non-Voting):

1.	Larry Ilcewicz	(FAA)
2.	Michael Gorelik	(FAA)
3.	Patrick Safarian	(FAA)
5.	Richard Minter	(EASA)
6.	Simon Waite	(EASA)
7.	Pedro Caldeira	(ANAC)
8.	Fabiano Hernandes	(ANAC)
9.	Marco Villaron	(ANAC)
10.	Jackie Yu	(TCCA)
11.	Natasa Mudrinic	(TCCA)
12.	Hiroshi Komamura	(JCAB)
13.	Philip Ashwell	(UK CAA)

Philip Ashwell represented British Airways as a voting member until October 2020 when he transitioned to the CAA. Ryan Higgins replaced him as the British Airways voting member at that time.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 20 (Section 3.1):

Boeing Comment: We need to be clear that there is more than just standard DT inspections for SLP to be acceptable so I added the "and specific changes recommended…". We agreed that the Section 4 recommendations must also be incorporated so I feel we need to state that here:

> *With respect to the other proposed changes in the 2018 TAMCSWG report related to SLP structure, the WG determined that those proposals could be addressed with changes to guidance as they are already supported by the current regulatory wording or wording previously proposed in the 2018 TAMCSWG report. The specific changes recommended to guidance to address SLP structures are discussed in Section 4 of this report.*
>
> *Therefore, the WG does not recommend any changes to the regulations to address SLP structures beyond those already documented in the 2018 TAMCSWG report. The current regulations sufficiently achieve the safety objective while retaining the flexibility needed to accommodate differences in design philosophy. SLP structures are acceptable if the inspection program is properly designed and the specific changes recommended in Section 4 of this report are incorporated ~~and this requirement is already reflected in the regulations~~. There is full consensus on this conclusion.*

Response: Embraer expressed concern that this was included in the discussion on the regulation and could imply that Section 4 is 'mandatory':

SLP structures are acceptable if the inspection program is properly designed, and the specific changes recommended in Section 4 outline a proposed means to accomplish this.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 29 (Section 4.1.1):

Mitsubishi Comment: I think this paragraph is also related to Para.6 (j) of AC25.571-1D, since the initial flaw approach seems to establish inspection threshold.
So I would suggest similar statement to be added in Para.6 (j) which is now proposed change to allow both "fatigue based" and "crack growth based" in 2018 TAMSWG report, in Appendix E.

If this paragraph is only addressing inspection interval, it is not necessary to link to Para.6(j), but in this case, my question is how to establish special DTE based inspection interval other than normal DTE. Is the higher factor required?

Response: This paragraph details the expectations for the AD and ED evaluation, including inspection thresholds. Agreed to keep in para. 6(i)(3) with the clarification added below:
A specific damage tolerance review for AD and ED should be performed for SLP structures. Protection should be added where feasible. Otherwise, if the visual inspections of the MSG-3 process are not sufficient to detect damage from AD and ED threats, special DTE based inspections are required. In this case, an initial flaw crack growth approach described in para. 6(j)(1) may be used to develop the special inspections. These special inspections should be specified in the ALS in addition to those given in the MRBR.

Also expanded these details in the discussion in Section 4.2.2.

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Page 29 (Section 4.1.1):

Dassault Comment: It seems that AD, ED are specific to SLP. AD, ED are considered also for damage tolerance evaluation of MLP, but particular effort should be made for SLP structures.

Response: *In addition to the MSG-3 evaluation, a specific damage tolerance review for AD and ED should be performed for SLP structures. Protection should be added where feasible. Otherwise, if the visual inspections of the MSG-3 process are not sufficient to detect damage from AD and ED threats, special DTE based inspections are required. In this case, an initial flaw crack growth approach described in para. 6(j)(1) may be used to develop the special inspections. These special inspections should be specified in the ALS in addition to those given in the MRBR.*

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 30 (Section 4.1.1):

Airbus Comment: Airbus find it outside of the group tasking to define a new chapter for Material and Process Controls applicable to all structure. The tasking and new guidance should be focused on SLP structure. So, exactly like is done for the identification aspect, the word SLP should appear in this text. It could be either straightforward in the title, or at the place identified here. See also the discussion in the last paragraph of chapter 4.2.5 which explains the section 4.1.1 is primarily intended to be applied to SLP parts.

Key material and processing parameters should be defined in the materials and process specifications approved under 25.603 and 25.605. These specifications should also identify what key characteristics and parameters are to be monitored for in-process quality control. The material and process specifications should form the basis of the DTE. If stricter control of processing parameters is required for SLP Structure to achieve the intended reliability and meet the objectives of the DTE (e.g. the expected inspection threshold), those controls should be detailed in the process specification. Once established these processes should not be changed without further qualification and engineering approval.

Response: Accepted, however M&P controls of integral structures may need to be considered as part of any final fail-safe criteria as discussed in Section 4.2.6.2.

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Page 36 (Section 4.2.2): Minimization of AD and ED

Airbus Comment: Airbus challenge if this example of a propeller is relevant for typical airframe structure. Design, material choice, requirements, etc are not the same: *An example of this scenario is discussed in Appendix B where an accident was attributed to cracking of a propeller blade that started from a corrosion pit.*

Response: While propellers are not considered PSE's under 25.571 (they are covered under 25.905), the details of this accident are pertinent to SLP airframe structure:

https://lessonslearned.faa.gov/ll_main.cfm?TabID=3&LLID=75&LLTypeID=2

The WG agrees that the scenario is applicable to metallic SLP airframe structure, and the following information is retained to document the discussion.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 36 (Section 4.2.2): Minimization of AD and ED

Response: While propellers are not considered PSE's under 25.571 (they are covered under 25.905), the key aspects of this accident are pertinent to SLP airframe structure:

- The propeller spar is constructed of a single piece of 7075-T73 aluminum; the spar failed due to fatigue
- The critical crack size was small (not obvious)
- The fatigue initiated at corrosion pits
- The corrosion was due to production process errors that introduced chlorine into the interior of the spar: *As part of the investigation into crack formation in the taper bore, it was determined that the cork used to retain the lead balance wool in the taper bore contained a chlorine residue that could cause corrosion in the taper bore.*

Photo of pitting in taper bore surface

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 36 (Section 4.2.2): Minimization of AD and ED

Response: While propellers are not considered PSE's under 25.571 (they are covered under 25.905), the details of this accident are pertinent to SLP airframe structure:

- Shot peening was removed as a production process without evaluating the impact on DT and protection from the corrosion threat: *During early production of the blades, the taper bores underwent a shotpeen surface treatment process in order to improve their resistance to surface cracking. This process was later deemed unnecessary by [the manufacturer] and was discontinued.*

- The original NDT inspection program was not reliable: *According to the investigation, the entire inspection process relied heavily on an assumption that the borescope inspection method was effective at detecting a crack. However, once a blade had been inspected and determined to be crack free, no repeat inspections were required for the remainder of the blade's service life.*

- The subsequent fleet fatigue management plan was derived using a damage tolerance evaluation: *[The manufacturer] also performed a risk analysis using results from a NASA-developed fracture mechanics FASTRAN program which found that the 1,250 cycle inspection interval using the original ultrasonic technique provided insufficient safety margins for the detection of taper bore cracks. As a result, The FAA issued AD 96-01-01, which required an improved ultrasonic inspection technique and reduced the inspection interval to 500 cycles.*

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 36 (Section 4.2.2): Minimization of AD and ED

Airbus Comment: To the letter of the requirement, Accidental Damage is not specifically mentioned under 25.609. So Airbus prefer to delete this new sentence as it goes beyond the literal reading of the requirement 25.609. Alternatively, the literal text could be taken for the sentence stating: The applicant should suitably protect the structure as part of the compliance with 25.609.

The applicant should protect the structure from AD and ED as part of the compliance with 25.609.

Response: 25.609 states: "loss of strength in service due to any cause …".

That said, the suggestion "The applicant should suitably protect the structure as part of the compliance with 25.609" will be presented as it is a true statement.

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 36 (Section 4.2.2): Minimization of AD and ED

Airbus Comment: Airbus believe it is not the fact to be able to find AD or ED damage as this is well covered already by MSG3. The issue is to find fatigue damage growing from ED or AD where you might need special DTE based inspections. Airbus propose to add the wording fatigue damage originating from AD or ED.

In locations where the visual inspections of the MSG-3 process are not sufficient to detect damage from AD and ED threats, special DTE based inspections are required to ensure continued airworthiness.

Response: *In locations where the visual inspections of the MSG-3 process are not sufficient to detect fatigue damage originating from AD and ED threats, special DTE based inspections are required to ensure continued airworthiness.*

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Page 39 (Section 4.2.3): Fatigue Testing

Airbus Comment: Airbus note that this is not the case for many legacy aircraft where the LoV is > then the DSG, therefore Airbus propose to delete this sentence:

BA Comment: BA experience is that the declared DSG is typically less than the LOV and in some case cases significantly. Could we not say DSG or LOV whichever is greater? This would equate to the operational life and remove any ambiguity and is more akin as to what is being implied by the statement.

It is generally assumed that the DSG will be at least as long as the LOV.

Response: Understood for pre-Amdt. 25-96 aircraft following AC 120-104, but going forward this will not be typical. Ref. AC 25.571-1D, para. 7(c)(2)(a) - *Early in the certification process, applicants typically establish design service goals or their equivalent and set a design service objective to have structure remain relatively free from cracking, up to the design service goal. A recommended approach sets the "candidate LOV" equal to the design service goal…*

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Page 39 (Section 4.2.3): Fatigue Testing - Continued

Response: Also, AC 25.571-1D, para. 5(a)(2): *The LOV, in effect, is the operational life of the airplane consistent with evaluations accomplished and maintenance actions established to prevent WFD.*

It is generally assumed that the DSG/operational life will be at least as long as the LOV for new certification projects.[1]

1 – The LOV, in effect, is the operational life of the airplane. Although the it is established based on WFD considerations, it is intended that all maintenance actions up to the LOV are identified in the structural-maintenance program. It is recommended that the DSG be used as a "candidate LOV" during initial design, with final LOV being dependent on the full-scale fatigue test findings, and associated maintenance actions to preclude WFD. See AC 25.571-1D, paras. 5(a)(2) and 7(c)(2)(a) for more details.

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Page 40 (Section 4.2.3): Fatigue Testing

Airbus Comment: In the below note 11, Airbus has proposed to delete the last sentence. Removable Structural Components and the link to LoV is not in the tasking for the SLP topic, and the group should not pretend to give a recommendation to FAA to address this ICA topic outside of the SLP tasking

Life limits would not generally be applicable unless an inspection program for a specific cracking scenario were not feasible, or if fatigue critical parts could be transferred between aircraft without regard to the original LOV.

Footnote: The WG agrees with this recommendation but notes that it is not required by regulation. This would be an uncommon case involving rotable SLP parts that developed fatigue cracks during testing and where cracking could be expected in-service. The WG makes no recommendations beyond those already given in the 2018 TAMCSWG Report, Section 3.12. The FAA may wish to address this issue further as part of developing guidance for the ICA of removable structural components.

Response: Sentence deleted and the preceding sentence revised:
The WG does not recommend changing the regulation to address this issue and does not recommend changes to guidance beyond those already given in the 2018 TAMCSWG Report, Section 3.12.

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Page 41 (Section 4.2.4): Demonstrate Controlled Rate of Cracking

Boeing Comment: Why did this get removed? As a compromise can we keep both residual strength and crack growth given that was the specific recommendation out of the TAMCSWG report.

f. Testing of principal structural elements

~~***Since the title of this paragraph is confusing, the WG recommends it be changed to better reflect the content, and suggests the following:***~~

~~***f. Residual strength testing of fail safe structures***~~

Response: The WG was reminded previously that there is proposed wording in the 2018 report adding WFD testing and the LOV to this paragraph. Recommendation is that we leave the title alone.

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Page 41 (Section 4.2.4): Demonstrate Controlled Rate of Cracking

Textron Comment: On p.11 "However, the regulatory guidance does not sufficiently define a means to properly design an inspection program for SLP structures." There is some guidance in AC91-82A, Appendix 4, though I would agree this is not sufficient:

Single Load Path Structure. The time for a detectable crack (aDET) to grow to critical size (aCRIT) in a structure is denoted as L in Figure 4-1. The inspection interval would be established as L divided by an inspection safety factor, K1, of not less than 2.0. This provides at least two opportunities to find a crack between the time it reaches a detectable size and before it grows to a critical size.

Response: Added a sentence to the discussion on the state of the current guidance with respect to supporting tests:

AC 91-82A describes a means for the calculation of inspection intervals for SLP structures using crack growth analysis but does not provide any details on a supporting test program.

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Page 42 (Section 4.2.4): Demonstrate Controlled Rate of Cracking

Airbus Comment: Airbus believe the effect could be important, but this is depending case by case and is not necessarily the case Therefore, Airbus propose that the wording 'are important' is replaced by 'could be important'.

Boeing Comment: Be clear on the definition of the crack growth rate test programs (duration, or ?)

EASA proposed that the guidance on SLP testing also include consideration of the fabrication aspects of the structure that would have influence on the macro crack propagation rates. This was intended to address processes that can introduce significant residual stresses through the cross-section of the part such as welding, additive manufacturing and some forging and heat-treating operations. The other members of the WG agree that these effects could be ~~are~~ important but were concerned that this statement was unnecessarily explicit. There are many other parameters that would also influence the results. It was therefore agreed to omit this consideration from the final recommended guidance but include the discussion here. It is expected that the applicant will consider the significant effects of the fabrication processes, as appropriate, when defining the configuration of their crack growth rate test programs.

Response: Incorporated

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 53 (Section 4.2.6.2): ISP Fail-Safe Evaluation Criteria

Boeing Comment: Why does poor access drive classification of SLP?

Either capability contribute to increase reliability which is necessary to classify the structure as fail-safe integrated structure, and either of the two is sufficient for this purpose. Requiring both criteria could lead to the situation where integrated structure with large damage capability would still be classified as SLP because access to the structure during normal maintenance is difficult. An applicant in this situation may choose to forego any fail-safe features and rely only on 'slow crack growth' from an initial defect as the means of compliance.

Response: The part may have residual strength up to the DCF but may not be accessible during normal maintenance for visual inspections (but still would need access for any special DT inspections). So, it meets only the residual strength criteria.

No change to the document; clarification only

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Page 53 (Section 4.2.6.2): ISP Fail-Safe Evaluation Criteria

Airbus Comment: The word "and" does not reflect the outcome of the discussion where the majority of the OEMs use or instead of and. To avoid restarting this discussion that we had in the WG since the beginning, Airbus propose to make simply 2 bullets without mentioning "and" or "or". This is then well explained at the end of this chapter 4.2.6.2

Acceptable evaluation criteria could be established by ~~either of~~ these two categories: those associated with the integral structure's capability to sustain large damage (residual strength), and those with the verification of detectable slow growth behavior (damage growth).

Response: Incorporated
Acceptable evaluation criteria could be established by these two categories:

- *Those associated with the integral structure's capability to sustain large damage (residual strength),*
- *Those associated with the verification of detectable slow growth behavior (damage growth).*

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 54 (Section 4.2.6.2): ISP Fail-Safe Evaluation Criteria

Airbus Comment: Para6d gives guidelines for both initial detectable damages and also damage for residual strength assessments. So Airbus propose to delete the word initially in this sentence to avoid confusion. The crack growth aspect is covered in the second bullet with the first sub-bullet referring to initial detectable damage.

The key considerations that were proposed for the evaluation of damage growth capability are:

- *Consider the ~~initially (~~visually~~)~~ detectable damage scenarios given AC 25.571-1D, para. 6(d)*
- *Establish a period of unrepaired use that is consistent with the normal maintenance program:*
  - *Initially detectable damage sizes consistent with visual inspection methods*
  - *Damage growth rates are sufficiently slow such that the time from detectable to critical, appropriately factored, is greater than the normal maintenance interval*

Response: Incorporated

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Page 54 (Section 4.2.6.2): ISP Fail-Safe Evaluation Criteria

Airbus Comment: This sentence is not understood in the context of the topic here, and it leads to confusion to make the link between the high altitude operation criteria and the ISP residual strength. Airbus propose to delete the sentence.

The considerations proposed for a damage growth evaluation were intended to be in addition to the standard DTE required to develop the inspection program. The fail-safe damage growth evaluation is more restrictive in that it requires visual detectable damage without reliance on detailed inspections~~. It is based on the large damage criteria recommended for high altitude operations in AC 25-20.~~ It would be equivalent to the case where 'no special inspections' are required as recommended in the 2018 TAMCSWG report, Appendix E:

Response: Incorporated; discussed sufficiently in Section 4.2.6.1.

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Page 62 (Section 5.2): Cost/Benefits of Fatigue Testing

Boeing Comment: I think for Boeing we might need to look at 2 or 3x that.

Large component fatigue test: $665,000 (includes test article, test fixtures and labor).

Response: Added 2 sentences to 5.2 explaining costs could be higher:
Costs may be incurred in the development and justification of the reliability factors necessary to show the test duration is sufficient, or if additional cycling is required to achieve the required reliability beyond what would be necessary to address WFD.

The projected costs over 20 years would therefore be $2.66M. This is only one example and could be considerably higher for other manufacturers.

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Page 63 (Section 5.3): Cost/Benefits of Crack Growth Rate Testing

Boeing Comment: For a simple part this may be correct but anything complicated validating a SIF would be possibly several orders of magnitude larger. It is okay to leave it as you have stated one OEM.

Testing for non-standard Stress Intensity Factors
1 configuration: $20,000

Response: *Assuming a new TC program every 7 years, the total cost over 20 years would be $285,000 which is relatively small compared to the overall costs associated with development of new materials. Also, these tests are already common practice in the industry and the recommended guidance change documents this. However, this is only one example and could be considerably higher for other manufacturers. The WG sees these costs as acceptable given the benefits to safety and standardization.*

Single Load-Path: Comments to 06OCT20_r3 Draft

Page 63 (Section 5.3): Cost/Benefits of M&P Controls

Boeing Comment: What about the added costs of extra process control docs and serialization and etc. up in section 4.1.1?

Response: I believe the WG has said they already do them: "This recommendation captures the current practice of the industry and therefore costs are expected to be minimal".

Note: Recall from Section 5: *The costs given in this section due to the recommended guidance changes are provided as reference information and would only be incurred if an applicant selected a SLP structure for their program.*

Acronyms

AAWG	Airworthiness Assurance Working Group
AC	Advisory Circular
AD	Accidental Damage
AIA	Aerospace Industries Association
ANAC	Brazilian National Civil Aviation Agency
ARAC	Aviation Rulemaking Advisory Committee
CFR	Code of Federal Regulations
CS	Certification Specifications
DCF	Damage Containment Feature
DSG	Design Service Goal
DTE	Damage Tolerance Evaluation
EASA	European Aviation Safety Agency
ED	Environmental Damage
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
GSHWG	General Structures Harmonization Working Group
ICA	Instructions for Continued Airworthiness
ISP	Integrally Stiffened Panel
JCAB	Japan Civil Aviation Bureau
LDC	Large Damage Capability
LOV	Limit of Validity
MLP	Multiple Load Path
MRBR	Maintenance Review Board Report
NAA	National Aviation Authorities
OEM	Original Equipment Manufacturer
PS	Policy Statement
PSE	Principal Structural Element
SDC	Structural Damage Capability
SLP	Single Load Path
TAE	Transport Aircraft and Engine
TAMCSWG	Transport Airplane Metallic and Composite Structures Working Group
TCCA	Transport Canada Civil Aviation
TOGAA	Technical Oversight Group on Aging Aircraft
WG	Working Group

Revision Record

Release/Revision	**A**
Contract Number (if required)	N/A
Limitations	N/A
Description of Change	Revision to pages 7 & 11 to reflect release and brief summary of Structural Bonding Report. Other minor updates to change font color on pages 6, 42, 50. Updated material is reflected with revision bars in left hand column.
Authorization for Release	

AUTHOR:	Kevin Jones	
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	Gulfstream	10/20/2021
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	Delta Air Lines	10/20/2021
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	FAA	10/20/2021
	Organization	Date