AAWG Structural Damage Capability Recommendation Document

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Acronyms

AAWG	Airworthiness Assurance Working Group
AC	Advisory Circular
AIA	Aerospace Industries Association
ARAC	Aviation Rulemaking Advisory Committee
CFR	Code of Federal Regulations
CS	Certification Specifications
DSG	Design Service Goal
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
GSHWG	General Structures Harmonization Working Group
LDC	Large Damage Capability
LOV	Limit of Validity
MLP	Multiple Load Path
NAA	National Aviation Authorities
OEM	Original Equipment Manufacturer
PS	Policy Statement
SDC	Structural Damage Capability
SLP	Single Load Path
TAMCSWG	Transport Airplane Metallic and Composite Structures Working Group
TOGAA	Technical Oversight Group on Aging Aircraft

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	

1. Executive Summary

The FAA formally tasked the Aviation Rulemaking Advisory Committee (ARAC); Transport Airplane Metallic and Composite Structures Working Group (TAMCSWG) to provide recommendations on § 25.571 and associated regulatory guidance material. As part of this effort, the TAMCSWG assigned the Airworthiness Assurance Working Group (AAWG) to re-introduce some fail-safe concepts (in the form of Structural Damage Capability (SDC)) into Part 25 of the Code of Federal Regulations (CFR). This report documents the findings, conclusions, and recommendations of the Working Group for this Task.

The AAWG met a total of six times (including a face-to-face meeting in March 2016) to accomplish the work set forth in the Tasking Statement. The AAWG reviewed the regulations and guidance material with respect to SDC and reached the following six conclusions, **though it should be noted the AAWG did not reach consensus on all these conclusions (we have captured points of dissention in Sections 6 and 7 of this report)**:

1. SDC is strictly a design requirement and does not include any new maintenance program or inspection threshold requirements; it complements damage tolerance based inspection programs but is a separate requirement.

2. SDC requirements are related to specific explicit damage sizes not directly linked to the shape of the residual strength curve.

3. Single load path (SLP) structure does not have inherent SDC capability; if the applicant wants to incorporate SLP designs, they must demonstrate usage of multiple load path (MLP) designs to be impractical.

4. For SLP structure, in addition to the demonstration of impracticality requirement, we recommend a fatigue reliability standard along with tighter controls on manufacturing and part tracking.

5. The level of SDC to be assessed for panelized MLP structure includes failure of a damage containment feature/stiffener or failure of a single bay between damage containment features/stiffeners.

6. For integral MLP structure there is no requirement that the damage containment features should be able to significantly reduce or stop the damage under operational loads.

Considering the conclusions reached by the AAWG, the AAWG recommends that the ARAC, TAMCSWG consider adopting the following as recommendations to provide to the NAAs for re-introducing fail-safe concepts in the form of SDC to Part 25 of the CFR:

A. Introduce new regulatory guidance material addressing provisions for SDC which include the following:
   1. Definitions of SDC and how it complements, but does not replace Damage Tolerance requirements
   2. Examples of the types of damage that SDC may protect against

3. Specification of full limit in-flight loads used in assessment of residual strength requirements
4. Category A or SLP structure definition, examples and, if found to be impractical to use MLP designs, additional requirements to justify usage of SLP structure
5. Category B or integrated MLP structure definition, examples and SDC requirements
6. Category C or discrete element/built-up MLP structure definition, examples and SDC requirements

B. Define performance-based SDC requirements similar to the high-level, safe-life requirements specified in § 25.571(c) if the TAMCSWG determines that a rule change is required. The supporting regulatory guidance material is the same as indicated in recommendation A. above.

2. Introduction and Background

In July of 1995, ARAC originally tasked the General Structures Harmonization Working Group (GSHWG) to develop harmonized requirements and advisory material for Damage Tolerance and Fatigue Evaluation of Structure, §25.571. Technical agreement of the full Harmonization Working Group (HWG) was achieved in March of 1998 and a draft NPRM and revision to existing advisory material were developed. In August of 1999 the GSHWG agreed to withdraw the previously submitted harmonized draft NPRM and advisory material and accept a re-tasking to reach harmonization between the JAR and FAR requirements with respect to Amendment 96 while re-introducing fail safe requirements back into the rule and advisory material and embodying the work of the AAWG with regard to continued airworthiness.

In June of 2002, technical agreement was again reached within the full GSHWG on harmonized rule and advisory material for FAR/JAR §25.571, Damage Tolerance and Fatigue Evaluation of Structure. The proposed harmonized rulemaking included the establishment of evaluation criterion for the amount of structure that must be considered as damaged with the remaining structure still able to carry residual strength loads (i.e. a damage-capability level that must be demonstrated to ensure that the airplane maintenance program will not be defeated by unforeseen damage sources). In July of 2003, The GSHWG submitted their Working Group Report containing proposed rule and advisory material for §25.571, Damage Tolerance and Fatigue Evaluation of Structure, as the culmination of eight years of continuing and often controversial effort by the group to reach consensus on a very significant requirement in regard to overall and continuing aircraft safety.

However, the FAA decided to delay addressing the 2003 recommendations from the GSHWG related to SDC and inspection thresholds. This was in part due to the controversy related to Technical Oversight Group on Aging Aircraft (TOGAA) concerns. Such concerns included purging of the term “fail-safety” from the proposed rule and Advisory Circular (AC), not addressing period of unrepaired usage and elimination of the rogue flaw concept to establish inspection thresholds by crack growth for SLP structure. Subsequently, the FAA decided to re-task ARAC to re-evaluate the 2003 GSHWG proposal and add composites to the evaluation.

This report summarizes the AAWG recommendation on new guidance material to re-introduce fail-safe concepts in the form of SDC to Part 25 of the CFR.

3. AAWG Tasking

The TAMCSWG has been tasked by ARAC to provide recommendations on § 25.571 and associated regulatory guidance material with respect to reintroducing fail-safe concepts back into Part 25 of the CFR. The TAMCSWG has assigned the AAWG to collaborate on and propose such recommendations, including an in-depth evaluation of the 2003 GSHWG proposal. To meet this challenge, the AAWG took on a number of sub-tasks (assignees are indicated in parentheses):

1. Identify benefits and shortcomings of adding a requirement to show a certain level of SDC, including a determination of whether the 2003 GSHWG proposal would increase the level of safety. (Operators, OEMs, NAAs)
2. State whether existing OEM practices already capture fail-safe practices (OEMs)
3. Determine whether SDC/fail-safe provisions be limited only to certain structure, such as acreage or widespread fatigue damage (WFD) susceptible structure. Also determine whether SDC should be applicable to both built-up and integrated structure. (Operators, OEMs)
4. Determine whether OEM best practices can be captured in AC materials (OEMs)
5. Initially, the AAWG focused on rulemaking approaches – three options were considered (it should be noted that the option presented by the identified OEM did not necessarily reflect their preferred approach):
    a. Revision to § 25.571, similar to the 2003 GSHWG proposal (Gulfstream)
    b. A new design-based rule, to be included in § 25.6xx (Boeing)
    c. No revision to Part 25 of the CFR, rely only on changes to AC materials (Airbus)
6. When consensus could not be reached on the rulemaking approach, the AAWG decided to focus instead on guidance materials (OEMs)
7. Compare the new recommendation with the 2003 GSHWG proposal; identify and explain rationale for differences (All)

Section 5 of this report contains AAWG findings for each of the above assigned tasks. Section 6 of this report contains AAWG conclusions and issues with the findings contained in Section 5. Lastly, Section 7 contains the AAWG recommendations and documents any dissenting opinions.

4. Research Information – 2003 GSHWG Proposal

The following includes extracts from the 2003 GSHWG proposal concerning rule changes and associated guidance for SDC.

4.1 2003 GSHWG Proposed Rule Change to § 25.571

(f) Structural damage capability.

1) Except as noted in subparagraph f(2), for structure evaluated according to the damage tolerance requirements of paragraph (b) of this section, it must be shown by analysis, supported by test evidence, that the structure is able to withstand the loads specified in paragraphs (b)(1) to (b)(6) of this section in the presence of damage equivalent to:

i) the complete failure of any single element, or

ii) partial failure between damage containment features that significantly retard or arrest a crack

2) For SLP structure, the intent of the SDC requirement shall be achieved through the demonstration of slow crack growth, an upper bound inspection threshold of 50% DSG and consideration of the quality control procedures used in manufacture. The requirement for an upper bound inspection threshold of 50% DSG may be extended based upon a rational analysis that is approved by the Administrator.

4.2 2003 GSHWG Proposed Guidance for SDC

4.2.1 General definition and applicability

Per the 2003 GSHWG proposal, **Structural Damage Capability (SDC) is the attribute of the structure which permits it to retain its required residual strength in the presence of large damage. It is a characteristic of the design of a structure, and is therefore not associated with the inspectability of that structure.** Furthermore, SDC should exist regardless of the type and source of the damage. The residual strength analysis required to demonstrate SDC complements that performed to establish a structural maintenance program, and the analysis methods should be based on similar existing test evidence. An SDC assessment should be performed for each Principal Structural Element (PSE) considered under paragraph (b) of §25.571.

4.2.2 Definition of categories of structure

The evaluation of a given PSE for SDC is intended to ensure that, in the event of a large damage that results in partial failure of the structure, the remaining intact structure is capable of carrying the required limit loads. The extent of SDC to be demonstrated should be consistent with the type of PSE under evaluation. To this end, the structure is further classified under the following categories:

(1) Category A. Exclusively SLP structures, such as fittings, single lugs, etc.

(2) Category B. Structure with significant crack arrest or crack retardation features, i.e. monolithic structures which incorporate ‘damage containment features’, such as the integral crack stoppers in machined wing spars and cast doors. Some other examples of this classification are: Skin Cutouts & Discontinuities, Window & Door Frames, Window Posts, Control Surfaces

(3) Category C. MLP structures, including lugs, fittings, door stops, Stiffened Panels, Skin Joints, Wingbox Ribs, Door Latches, Control Surface Attachments, Engine Mounts, Thrust Reversers

NOTE: A stiffened panel structure, as used in conventional fuselage, wing and empennage construction, is considered to be a MLP component.

4.2.3 SDC requirements

In general, structure meeting the SDC criteria must be able to withstand the required residual strength load in the presence of damage equivalent to either the complete failure of any individual load path, or partial failure of a load path between damage containment features. For the different structural categories introduced previously, the required SDC is as follows:

(1) Category ‘A’ Structure. Slow crack growth must be demonstrated, i.e. the time for the growth of a crack from detectable to critical is at least one Design Service Goal (DSG). A quality control/quality assurance plan that ensures the parts are controlled during design and manufacture so that the risk of failure in service is minimized must be provided to the administrator. There is also an inspection threshold requirement for Category ‘A’ Structure, which is typically 50% of the DSG, unless certain rational analyses are provided.

(2) Category ‘B’ Structure. The required SDC is defined by the maximum extent of damage that may develop between the damage containment features. In the case of a machined wing spar, this would be equivalent to a crack extending from a failed spar flange, through the spar web, to the integral crack stopper. For areas of major skin cutouts (passenger and emergency exit doors, cargo doors, undercarriage bays, wing box access panels, etc.), SDC should be equivalent to a skin crack that extends from the edge of the cutout to the adjacent stiffening member (stringer, frame, spar, etc.) or crack stopper. The damage containment features should control the rate of crack growth and provide adequate residual strength. Crack growth should be shown to be arrested, or significantly retarded, by the crack stopper, as compared to the case where the crack stopper is omitted.

(3) Category ‘C’ Structure. MLP design includes sufficient structural redundancy to allow for the failure of one complete load path e.g. multiple hinges and multiple doorstops. For stiffened panels, it should be demonstrated that the structure can sustain residual strength load following the failure of any individual load path, but in the absence of other damage, i.e.

i. the complete failure of any one stiffening member (stringer, frame, etc.) without any additional damage in the skin or adjacent stiffeners, or

ii. the failure of a single skin bay (i.e. a crack between two adjacent stiffeners) without any additional damage in the stiffeners or adjacent skin bays.

4.2.4 Elaboration on methodologies used to show compliance

The methodologies used to demonstrate SDC compliance should be based on analysis supported by test experience. The nature and extent of tests will depend upon applicable previous design, construction and test experience.

For category 'B' structure, in which the SDC consists of the partial failure of the structure between damage containment features, the simulated damage should be represented as a fatigue crack with active crack tips. In this case, the analysis methods should be those used in a conventional fracture mechanics calculation, as undertaken during existing damage tolerance assessments.

For category 'C' structure the following applies:

(i) If the failed load path for SDC is a discrete element, the analysis will be limited to the static assessment of the ability of the remaining intact load paths to carry residual strength load. No fracture mechanics calculations are required.

(ii) If the failed load path for SDC is part of a continuous element, such as a skin element which extends over several stiffening elements or features of an integrally stiffened panel, the simulated damage should be represented as a fatigue crack with active tips.

5. Assignments and Findings

This section contains the results and findings of the tasks identified in Section 3 of this report.

5.1 Identification of benefits and shortcomings (including level of safety)

The OEMs, regulators and operators identified benefits and shortcomings of adding a Part 25 requirement to have applicants show a certain level of SDC.

The benefits include the following:

1. Provide a common basis for the level of SDC
2. Add robustness to design; maintain a level of safety against unexpected events
3. Less reliance on computational damage tolerance and NDT based inspections
4. May improve detectability

The shortcomings include the following:

1. Burden and cost associated with the compliance demonstration
2. Cost/weight could be increased – note that the AAWG identified this shortcoming before we established details on SDC guidelines
3. SDC criteria as defined in the 2003 GSHWG proposal may not be appropriate or clear enough (e.g. SDC criteria in 2003 proposal are defined more for metallic than composite)
4. Operators stated that large damage threats should be based on expected damage from historic data – there could be difficulty in trying to have SDC account for unexpected damage

5. Operators stated there may be an impact on repairs and their approvals due to the potential for operators not having criteria or data related to SDC. In such cases, the operators would need more OEM involvement in order to receive major repair approvals.
6. Potential for interpretation, application and implementation difficulty

The OEMs, regulators, and operators also gave their opinion on whether the 2003 GSHWG proposal would increase the level of safety.
The OEMs stated that they already account for some level of SDC from internal design requirements and that a new standard would not necessarily increase safety for existing designs. It could decrease future risk that some OEMs design to the strict minimum required by damage tolerance only, and produce significantly less robust aircraft. The operators stated in principle the proposed standard should increase the level of safety. However, since incorporation of SDC is not well defined and implementation practices over the entire industry are unknown, determining a level of safety relative to industry practice cannot be adequately ascertained. The regulators state in general, the proposed standard would result in an increased level of safety since there would be a rule requirement that has been missing since Amendment 25-45. Also, a safety-by-inspection approach enhanced with a safety-by-design approach may overcome some of the limitations associated with an inspection-only requirement. However, the regulators expressed concern that if the new standard is lower than existing OEM design practices, the OEMs will subsequently lower their design practices leading to a decrease in structural robustness.

5.2 Existing OEM practices

The OEMs indicated whether existing OEM practices already capture fail-safe practices. All of the OEMs stated that their existing practices provide some level of SDC though not necessarily to the proposed 2003 GSHWG standard. The OEMs collectively cited utilization of the following in their designs: MLP structure/structural redundancy, damage containment features, materials with high fracture toughness, and/or more stringent damage detection criteria for single element designs. Five OEMs presented overviews of their use of SDC practices at the March 2016 AAWG meeting in Everett Washington and the presentations are included in Appendices B through F of this report.

5.3 SDC/fail-safety applicability to structure

The OEMs and operators determined whether SDC/fail-safe provisions should be limited to only certain structure, such as acreage or widespread fatigue damage (WFD) susceptible structure. They also gave opinions on whether SDC should be applicable to both built-up and integrated structure.

The OEMs and operators stated that fail safety provisions are not practical for all structure. Collectively, the OEMs/operators conveyed that there should be allowances for certain exceptions where fail safety would not be beneficial, feasible or practical. Regulators should include fail-safety of traditional built-up and multiple discrete element structure in their standards but should also provide for conditional allowances for integrated structure. While SLP structure is by definition not fail-safe, the majority of OEMs believe there should be provisions for its use (even in flight loaded applications).

5.4 Capture practices in AC materials

The OEMs gave their opinions on whether OEM best practices can be captured in AC materials. The OEMs stated that practices or general parameters of practices could be provided to help generate guidance material. However, all OEMs expressed concerns that publishing the data used by select OEMs could be challenging, and may have undesirable implications for the rest. In other words, some OEMs may not be able to meet the high standards set by other OEMs. They also raised concerns that much of the useful data could be deemed proprietary by their respective management. Over time, the OEMs developed draft guidance material with inputs and consideration of their practices as further detailed in Section 5.6 of this report.

5.5 Three rulemaking options

In February of 2016, just prior to the face-to-face meeting in March, three OEMs developed alternatives to affirmatively show how rulemaking could be approached. Each of the three OEMs addressed one of the following options (it should be noted that the option presented by the identified OEM did not necessarily reflect their preferred approach):

1. Modification of 2003 GSHWG proposed change to 14 CFR 25.571 (Gulfstream)
2. Design-based change to Part 25 (14 CFR 25.6xx) (Boeing)
3. Leave Part 25 as is, revise guidance material only (Airbus)

Each OEM provided presentations including the benefits and drawbacks of each approach (reference Appendices G through I). At the face-to-face meeting, the members of the AAWG reviewed the information and voted for their choice amongst the three options. The AAWG did not reach consensus, at the end of voting there were four votes for option 1 comprised of operators; there was one vote for option 2 from an OEM; and there were nine votes for option 3 from four OEMs, four operators, and one regulator.

5.6 Focus on guidance material

As shown in Section 5.5, the AAWG did not reach consensus on whether and/or how to codify an SDC regulation. The AAWG reviewed the results of the voting exercise described in Section 5.5 at the March 2016 meeting in Everett Washington and decided to focus on developing the guidance material first. The AAWG felt that the development of the guidance material would provide further clarity relative to specific recommendations on any rule change. Proceeding in this manner, the focus shifted to developing the guidance material and trying to obtain consensus on the content.

The OEMs agreed to use the 2003 GSHWG guidance material proposal (reference Section 4) as a starting point for developing new guidance. One OEM modified much of the proposal by including its existing internal design requirements. The other OEMs, upon review of the initial proposal, voiced concerns, stating that many proposed aspects went well beyond the 2003 GSHWG recommendations. Another OEM proposed an alternative approach by staying closer to the 2003 GSHWG proposal. In response, we revised the guidance material to more closely resemble that from the 2003 GSHWG proposal. However, all parties agreed to clearly document points of contention or non-concurrence, which we have included in Sections 6 and 7 of this report. Please refer to Appendix J for the new guidance material proposal.

5.7 Comparison of new guidance material proposal with 2003 GSHWG guidance proposal

This section of the report contains the following comparison between the new recommendation and the 2003 GSHWG proposed guidance for SDC. Section 6 of this report elaborates on the rationale for the differences between the two proposals.

5.7.1 Similarities

1. Regarding the definition of SDC, both proposals state that SDC addresses the attribute of a structure which permits it to retain its required residual strength in the presence of large damage.
2. Both proposals state that SDC is a characteristic of the design of a structure and is not associated with the inspectability/maintenance of the structure. SDC requirements complement damage tolerance requirements.
3. Both state that SDC should exist regardless of the type and source of damage.
4. §25.571(b) contains the full limit load requirements for evaluating damage levels.
5. PSE structure is classified as Category A, B or C in order to establish the extent of SDC to be demonstrated for each category. Similarities exist with regard to the structure included in each category.
6. Both proposals do allow provisions for usage of Category A SLP structure.
7. Regarding the level of SDC for Category B structure, both proposals require evaluation of damage extending between damage containment features.
8. For Category B structure, both proposals explicitly require that the residual strength evaluation of damage levels for integral structure must include active damage tips/sites.
9. Category C includes multiple discrete element and traditional built-up structure.
10. Regarding damage levels for Category C structure - both proposals establish that the level of SDC for discrete element structure includes failure of one complete load path to be evaluated using a static strength assessment. They also require that stiffened panels must be evaluated for the failure of an individual stiffening element without any additional damage in the skin or adjacent stiffeners, and separately for residual strength with the failure of one bay of skin between stiffeners and active crack tips with intact stiffening element.
11. For Category C structure, both proposals limit damage level to a single element failure.

5.7.2 Differences

1. Potential sources of damage have been added to the new proposal, along with a disclaimer that SDC may not necessarily protect against all levels of severity for these types of damage.
2. The new proposal limits the SDC assessment to Principal Structural Elements (PSEs) subject to in-flight loads under (b)(1) to (b)(5) of §25.571, whereas the 2003 proposal also includes structure subject to ground loads under (b)(6). The majority of landing gear and directly affected PSE structure critical for ground loads has been certified as safe life under §25.571(c). However, in isolated cases, the AAWG OEMs have some of this structure which have instead been certified under the damage tolerance requirements of §25.571(b). Such structure would be subject to SDC requirements with the inclusion of §25.571(b)(6) in the SDC regulation and guidance. However, we considered the existing §25.721 requirements for capability to safely land with any combination of landing gear not extended, the excellent safety record in landing gear failure events and the adequacy of existing damage tolerance requirements, in deciding to not establish additional SDC robustness requirements for this structure critical for ground loads under §25.571(b)(6).
3. Examples of structure in each category have been improved in the new proposal.
4. For Category A SLP structure:
    a. The new proposal only allows using Category A SLP structure after establishing impracticality in the usage of Category B or C structure.
    b. The 2003 proposal of a slow crack growth requirement has been replaced by a fatigue requirement to demonstrate the operational life of the airplane with a specified reliability and confidence.
    c. The 2003 GSHWG proposed requirement for inspection threshold limits of 50% DSG has been removed.
    d. The new proposal requires a manufacturing and process control plan document which is a more stringent requirement than that of the 2003 proposal.
5. For Category B integral structure:
    a. The new proposal expands applicability to include composite structure.
    b. Regarding damage level, in addition to evaluating damage between damage containment features, the new proposal requires evaluation of damage to the damage containment feature itself.
    c. The 2003 proposal states that damage containment features must be capable of controlling the rate of crack growth; this has been removed from the new proposal.
6. For Category C structure:
    a. The new proposal more explicitly defines two sub-types of structure: Type 1 (discrete element MLP) and Type 2 (built-up MLP).
    b. The new proposal explicitly addresses other built-up structure in Category C besides stiffened panels and requires evaluation of failure of an individual element.

7. The new proposal does not contain the 2003 proposal Section 12.0 d. Explicit requirements for testing have been removed except in the case of SLP structure.
8. The new proposal contains figures to complement the text and more clearly illustrate residual strength requirements.

5.8 Evaluation of new guidance material proposal against Technical Oversight Group on Aging Aircraft (TOGAA) recommendations

This section of the report addresses two of the concerns raised by TOGAA in response to the 2003 GSHWG recommendation. The first concern from TOGAA states "SDC does not address the fact that the remaining structure must be able to retain its required residual strength for a period of unrepaired usage." The GSHWG responded by stating it did not consider it part of their task to completely re-evaluate the adequacy of the Amendment 45 damage tolerance requirement. They felt their task should only **add** to the damage tolerance requirement some essential features of the fail-safe concept which were omitted at Amendment 45.

The AAWG position builds off of the GSHWG response by stating the majority of damage covered in the current proposal should be obvious or malfunction evident. For these cases, period of unrepaired use does not come into play; period of unrepaired use becomes more important for less obvious damage. We do acknowledge there are some cases where damage would not be so obvious (especially for fatigue driven damage) – but as stated by the GSHWG, such damage should be adequately covered by damage tolerance based maintenance requirements. Conclusion 1 under Section 6 below elaborates on the AAWG position regarding period of unrepaired use.

The second concern raised by TOGAA states "these (fail-safe damage) sizes are smaller than most current large transport aircraft can tolerate." The GSHWG understood that TOGAA wanted to impose the best-case fail-safe characteristics on all structure (e.g. "completely severed stringer and adjacent skin bays"). The GSHWG responded by stating that the largest SDC sizes are not always feasible, even for manufacturers who strive to achieve the sizes of damage promoted by TOGAA. The proposed sizes reflect the minimum that manufacturers are currently achieving in applying in-house fail-safe principles to their designs. The GSHWG further elaborated that the damage sizes recommended by TOGAA were never required, even under the pre-Amendment 45 requirement. Lastly, the GSHWG stated that as with any regulation, some applicants may choose to exceed the regulatory minimums.

Conclusion 5 under Section 6 below documents the AAWG approach to determining required damage size; the OEMs differed in their opinion regarding these requirements. One OEM concurred on the TOGAA position, the remaining OEMs felt such a large damage size goal should be left as an internal design practice, left up to the discretion of each OEM.

6. Conclusions/Issues with Findings

1. SDC is strictly a design requirement and it does not include any new maintenance program or inspection threshold requirements; it complements damage tolerance based inspection programs but is a separate requirement. The 2003 GSHWG proposal states that "Structural Damage Capability (SDC) is the attribute of the structure which permits it to retain its required residual strength in the presence of large damage. SDC is a characteristic of the design of a structure, and is therefore not associated with the inspectability of that structure." It also states that "...the residual strength analysis required to demonstrate SDC complements that performed to establish a structural maintenance program, according to paragraph (b) of §25.571…" The AAWG has chosen to adhere to these basic tenets in the new guidance material proposal.

   While the 2003 GSHWG proposal states that SDC is an attribute of the structure and independent of inspectability, it deviates from this approach in several instances. It contains somewhat arbitrary inspection threshold requirements based on detectability during normal maintenance. As described in Conclusion 4 of this section, the 2003 proposal includes a slow crack growth and arbitrary threshold requirement for SLP structure. It also contains a requirement for damage containment features in multiple load path monolithic structure to be capable of arresting or retarding a crack. Such requirements blur the line between SDC as a design feature and damage tolerance/inspection programs. For these reasons, the new proposal does not include these requirements.

   The proposed new guidance establishes that for MLP structure (integral with damage containment features, discrete element, or built-up MLP), SDC must be inherent to the structural design and provide a level of robustness for unforeseen damage that can occur at any time. It requires static or residual strength evaluations for specified damage sizes that may be larger than those accounted for in the damage tolerance analyses required by §25.571(b).

   One potential drawback with strictly adhering to SDC as a design feature includes limitations on how to address SLP structure which has no inherent SDC capability. Alternate requirements, not necessarily tied directly to robustness, must be established to allow its use. In order to remain independent of damage tolerance requirements, the AAWG opted not to include crack growth and "period of unrepaired use" (see Conclusion 6) approaches for any category of structure. Such approaches would prescribe capability to withstand damage for some specified duration potentially linked to maintenance/inspection intervals. The AAWG identified several issues with addressing "period of unrepaired use" within SDC:

   1. No agreement could be reached on a specified maintenance/inspection interval during which non-detected damage should not lead to catastrophic failure;
   2. Even if such an interval were identified, one could question the appropriateness of having a single standard interval. Conversely, a proposal that accounts for period of unrepaired use would be too complex if it included customized intervals, dependent on the nature and severity of the damage;

3. For accidental-type damage that is obvious or malfunction evident and should be detected by walk-around type inspections, period of unrepaired use becomes less relevant; and
4. For less obvious damage, similar to the conclusion reached by GSHWG in 2003, SDC complements damage tolerance requirements that establish inspections to detect cracks before they become critical.

For these reasons, the AAWG decided to hold steadfast to the basic tenets described above, keeping SDC design requirements separate from damage tolerance/inspection requirements.

Another perceived drawback with the current proposal includes the omission of the linkage between SDC requirements and inspection thresholds. The AAWG decided that because SDC is supposed to protect against damage that can occur at any time, inspection threshold requirements should be separate from SDC. Furthermore, the AAWG noted that inspection threshold requirements will be addressed through other TAMCSWG activity.

The FAA does not agree with the point that SDC is not associated with maintenance of PSE structure. One operator contends that for SDC to be effective the damage/failure has to be obviously detectable. We have captured these dissenting opinions in Section 7 of this report.

2. <u>SDC requirements are related to specific explicit damage sizes not directly linked to the shape of the residual strength curve.</u> The FAA has stated that damage sizes addressed in an SDC assessment should correlate to the flat part of the residual strength curve. They further state that the residual strength of a particular structure should be somewhat insensitive to changes in the damage size. Based largely on input from the OEMs, the proposal does not include an approach that directly links the required level of SDC to the residual strength curve; it instead contains explicitly defined damage sizes more in line with the 2003 GSHWG proposal based on the principle of one loadpath failure. The majority of OEMs state that basing SDC on explicit damage sizes is more straightforward to apply, covers all structures, and provides for a sufficient level of robustness. Conversely, an approach tied to the residual strength curve would be more nebulous and variable among the different structural configurations. The OEMs did hold considerable discussion on the explicit size of the damage to use for residual strength assessments (see Conclusion 5).

   The primary drawback with the chosen approach includes the potential that the assumed damage size may in fact not be on the flat part of the residual strength curve. Hence, robustness would be based upon idealized failure scenarios without considering the actual performance of the structure. However, the proposal recognizes that SDC requirements complement damage tolerance inspection requirements which exist to detect damage prior to critical structural failure. The explicit damage sizes chosen (see Category B and C examples) do represent a damage state that is past the steep part of the residual strength curve and for composite structure should incorporate Category 2 and 3 damages as defined in FAA AC 20-107B. So although these damage states may not be on the flat part of the residual strength curve, they do cover accidental damage that relieves concerns for those OEMs using energy level cutoffs for Category 2 damage and impactors that do not cover all threats.

The FAA contends that there should be a focus on being on the flat part of the residual strength curve, deviating from the 2003 GSHWG approach. The FAA does not agree with the approach taken and we have captured their dissenting opinion in Section 7 of this report.

3. SLP structure does not have inherent SDC capability; if the applicant wants to incorporate SLP designs, they should demonstrate usage of MLP designs to be impractical. The 2003 GSHWG proposal implied that SLP could meet the intent of SDC by meeting certain requirements. However, because SLP contains no effective damage containment features, we wanted to clearly state that by definition, SLP has no inherent SDC capability. Rather than demonstrating any type of SDC capability, the applicant should demonstrate that usage of MLP structure would be impractical for their particular design. The advantage with this approach includes the option to allow for usage of SLP on a case-by-case basis, ***but only if the applicant works closely with the regulatory authority in demonstrating impracticality***, to not promote widespread usage of SLP. There is also some precedent in using the impractical approach as evidenced by § 25.571(c) for safe-life designs. The primary drawback with the proposal includes no definition of what "demonstration of impracticality" should entail; this could introduce a level of subjectivity when trying to demonstrate compliance to the regulatory authority.

4. For SLP structure, in addition to the demonstration of impracticality requirement, we recommend a fatigue reliability standard along with tighter controls on manufacturing and part tracking. Per the 2003 GSHWG proposal, SLP needed to meet the following three requirements:
    a. Slow crack growth – the time of growth from detectable to critical be no less than one DSG
    b. Quality control/quality assurance plan provided to the regulatory authority
    c. An inspection threshold limit of 50% of DSG, unless certain rationale are provided

    These requirements were not carried over into the proposal for several reasons. We discarded the slow crack growth approach because SDC is supposed to be independent of maintenance programs. The slow crack growth approach would blur the line between SDC and damage tolerance. The term "DSG" may greatly vary, depending on aircraft mission requirements. Regarding the requirement for a quality control/quality assurance plan, OEMs already require this for all PSEs. This would provide no additional level of protection for SLP structure. Lastly, the inspection threshold limit adds no level of robustness to SLP; it appears to be a randomly chosen requirement meant to deter usage of SLP structure in aircraft designs. Similar to the slow crack growth requirement, the inspection threshold seems fatigue driven and would provide no level of protection for unanticipated damage that could occur prior to 50% of DSG.

One OEM originally proposed that SLP structure be required to be either safe-life or certified in a manner approved by the regulatory authority. The original rationale from this OEM included severe limitations regarding usage of SLP for flight load critical PSEs, but some allowance for flexibility if the applicant really desired to use SLP for certain limited applications subject to approval by the regulatory authority on a case-by-case basis.

However, the majority of OEMs deemed this to be too restrictive and open-ended. The OEMs subsequently revised the guidance to allow usage of SLP structure where it can be shown to be impractical to use MLP designs. The requirement to have a manufacturing process control document (MPCD) appears to be similar to the quality control/quality assurance plan contained in the 2003 GSHWG proposal. However, an MPCD is typically limited to a few select critical parts and must be approved and maintained by the OEM (as opposed to any potential suppliers). There may also be enhanced article inspection requirements, such as non-allowance of sampling. This could provide a significant level of protection against manufacturing induced defects and damage.

The proposed fatigue reliability requirement specifies no detectable cracks during operational life with 99% reliability and 95% confidence – operational life implies equivalency with Limit of Validity (LOV), a term more universally recognized, from a regulatory standpoint. However, the OEMs raised concerns that an official LOV may not yet be fully established at the time of original type certification. Hence the more generic "operational life" term has been proposed. The OEMs intended for this requirement to be more stringent than typical requirements for PSEs, but not to the extent of safe life requirements. The primary benefit includes potential reduction in stress levels seen by the SLP structure.

Most of the drawbacks with the proposed approach center around the fatigue reliability requirement. Similar to slow crack growth, we acknowledge that fatigue reliability may only address fatigue induced damage. It provides no additional level of robustness or protection against accidental damage. Some of the OEMs also pointed out that by replacing slow crack growth with fatigue reliability, they can no longer use special crack growth factors to account for the lack of inherent SDC in SLP thereby allowing for some level of protection against accidental/environmental damage. Due to this, we have captured a dissenting opinion from an OEM on the use of fatigue reliability in lieu of slow crack growth approaches for SLP in Section 7 of this report.

5. The level of SDC to be assessed for panelized MLP structure includes failure of a damage containment feature/stiffener or failure of a single bay between damage containment features/stiffeners.

Originally, one OEM suggested larger damage size requirements for SDC assessments than those contained in the current proposal. The original draft proposed to the other OEMs defined the damage size as a failed central stiffener or damage containment feature plus the two adjacent skin bays. The OEM proposed that this level of damage be used in conjunction with full limit load except for obvious damage, in which case use of continued safe flight and landing (CSF&L) loads from Section 9 of AC 25.571-1D would be allowed, effectively balancing the larger size of damage with reduced residual strength level.

Some OEMs stated that they use the failed central stiffener plus 2 bays of skin criterion as a general design practice. However, they also stated exceptions to this internal requirement exist. Other OEMs stated that they typically cannot meet this level of SDC and questioned why three elements would be used (e.g. stringer plus 2 skin elements) in lieu of one element. In addition, these OEMs observed this level of damage exceeds that included in the 2003 GSHWG proposal and they are reluctant to propose codification of internal design practices into regulatory requirements. Lastly, one OEM remarked that by making load level dependent on detectability, we would be deviating from the tenet to make SDC independent of inspection programs.

The OEMs, with one exception, determined that the 2003 GSHWG proposal provides a sufficient level of SDC. Therefore, the OEMs (consensus not achieved) decided to move forward with the SDC level based on damage sizes similar to those contained in the 2003 proposal. This level of SDC includes active damage sites/tips as defined in the text and figures of the new guidance proposal (reference Appendix J) and will be evaluated under the full limit flight load requirements of §25.571(b).

The drawback of the new guidance proposal as written is that for some OEMs, it may not provide any robustness beyond what is already provided by damage tolerance and other internal OEM design requirements, and result in additional work to show compliance without any added benefit. Due to this, we have captured a dissenting opinion from an OEM and regulator on the required damage size for panelized structure in Section 7 of this report.

6. For Category B integral MLP structure there is no requirement that the damage containment features should be able to significantly reduce or stop the damage under operational loads. The majority of OEMs opted to remove this requirement from the proposal due to the concern that such a requirement would introduce crack growth and "period of unrepaired use" and blur the line between SDC and damage tolerance. We held steadfast to the tenet that SDC is a design feature not linked to crack growth and inspection programs; such requirements are already adequately covered by damage tolerance requirements.

   Most OEMs further state that with regard to SDC, the defined residual strength requirements (including active damage tips/sites) provide adequate robustness against a certain level of unforeseen damage. Lastly, the OEMs raised issues with how to define what "significantly reduce damage" really means and that showing compliance against a vague requirement could be problematic.

   Two OEMs and EASA contend that a high level requirement (specific to Category B structure) for the damage containment features to be able to significantly reduce or stop the damage under operational loads should be included in the guidance material and as such dissenting opinion statements have been recorded in Section 7 of this report.

7. Recommendations

Considering the regulatory objectives to re-introduce fail-safe concepts in the form of SDC to Part 25 of the CFR, the AAWG recommends new guidance material to assist the applicants in showing compliance. To this end, the AAWG recommends that the TAMCSWG make the following recommendations to the FAA:

A. Introduce new guidance material addressing provisions for SDC which include the following:
   1. Definitions of SDC and how it complements, but does not replace Damage Tolerance requirements
   2. Examples of the types of damage that SDC may protect against
   3. Specification of full limit in-flight loads used in assessment of residual strength requirements
   4. Category A or SLP structure definition, examples and, if found to be impractical to use MLP designs, additional requirements to justify usage of SLP structure
   5. Category B or integrated MLP structure definition, examples and SDC requirements
   6. Category C or discrete element/built-up MLP structure definition, examples and SDC requirements

Points of Dissention

The following contains points of dissention raised by AAWG members on the proposed SDC guidance. Many of these points were raised just a few weeks prior to finalization of this report; hence the AAWG did not have the time to deliberate over them. Such points have been captured for further deliberation by the TAMCSWG. A few of these points were deliberated at great length prior to issuance of this report; we have elaborated more on how these particular points have been addressed, though not necessarily resolved.

<u>Disassociating SDC from Maintenance and Reliance on Damage Tolerance</u>

The FAA and EASA do not concur on disassociating SDC from maintenance of PSEs. They recommend that our guidance should not imply that SDC does not enhance maintenance practices. The ability to sustain larger damage provides a greater opportunity for damage to be found during normal maintenance tasks, including daily walk-around inspections and MSG-3 inspections. The FAA and EASA view SDC as complementing inspection programs derived through damage tolerance evaluations.

Similarly, EASA does not believe the proposed provisions for SDC will adequately prevent catatastrophic failure from damage not accounted for in damage tolerance. For example, a portion of the existing rule allows diversion to safe-life if damage tolerance is impractical. Where both MLP and inspections for crack growth are impractical, either the DT evaluation or SDC should provide crack and flaw tolerance before defaulting to a pure fatigue life basis. For example, Barely Visible Impact Damage (BVID) in composites, with whole at life ultimate load capability, is already consistent with this approach.

Regarding the first point of dissention (no link between SDC and maintenance), the FAA proposed wording to the guidance that softened the separation between SDC and maintenance. The OEMs and FAA mutually agreed to clarify that SDC does not add any new inspection or inspection threshold requirements and that SDC can provide robustness above what damage tolerance can provide. Therefore, as of the publication date of this report, the AAWG may have reached general consensus on defining the link between SDC and damage tolerance based maintenance programs.

Detectability of Damage

Delta Airlines, ANAC and British Airways believe that for SDC to be effective the damage/failure has to be considered to be obviously detectable. Otherwise, if the damage/failure of a single member were undetectable, the scenario would fall under damage tolerance evaluation with a different considered damage threat. In other words, the damage would simply be a larger damage threat for which residual strength requirements would be satisfied through a DT-based maintenance program. Without the SDC requirement that the partial failure of a load path be obvious, then damage tolerance appears to be ensured only by maintenance programs.

Level of detectability received a fair amount of discussion while the OEMs drafted the guidance material. An initial draft of the guidance included provisions for obvious or malfunction evident damage by allowing for a reduction in residual strength loads. However, we received comments that distinguishing between obvious and non-obvious damage introduces an element of subjectivity. Additional commenters stated that SDC should be independent of inspection programs, and that including “detectability of damage” provisions in the guidance would be counter to this tenet. Lastly, some commenters stated that SDC is supposed to account for unexpected damage; that not all such damage would be necessarily obvious (especially fatigue-driven damage occurring in the wing skin upper panel, lap splice internal to the fuselage, etc.). In keeping with the spirit to have SDC provide protection against **any** unanticipated damage, we did not include any provisions for obvious damage in the final version of the guidance.

Applicability of SDC

ANAC suggests to expand applicability of SDC from PSEs to include Fatigue Critical Structure (FCS) as well. According to AC 120-93, FCS could contribute towards a catastrophic failure and should be assessed per §25.571. ANAC notes they have discussed with the FAA the differences between PSEs and FCS; they reiterate that any structure which could contribute to a catastrophic failure should be considered in the SDC evaluation.

SLP Structure

As a whole, the AAWG recommends that regarding SLP structure, the guidance should contain examples of structure where an MLP design would be impractical or even result in a less safe design. The AAWG states that for safe-life structure, the existing AC 25.571-1D cites an example (landing gear) where damage tolerant structure may not be practical – they suggest a similar citation of examples for impractical MLP design could be included as well. We did not have time to come up with such examples – we recommend that the TAMCSWG follow up on this recommendation.

Embraer does not concur on the fatigue reliability requirement for SLP structure – they believe this approach does not properly address unexpected damage. Embraer further states that robustness of SLP structure can be more properly addressed by including slow crack/damage growth as an inherent structural attribute, not associated with additional inspections or other maintenance procedures. The majority of the OEMs opted not to recommend a slow crack growth approach for many of the reasons cited for not addressing period of unrepaired use – refer to Section 6 above.

ANAC recognizes that the applicant may assume an operational life as part of their fatigue reliability analysis for SLP structure because they may not have yet established the LOV. ANAC therefore proposes that once LOV has been established (post type certification), that the applicant re-evaluate the assumed operational life and ensure that it is in line with the newly established LOV. The AAWG recommends that the TAMCSWG look into the feasibility of this proposal.

Category B Structure

The FAA does not concur that by definition, damage containment features for Category B structure function to contain the damage so that the structure can retain its residual strength capability. This involves classifying redundant design features for co-cured, co-bonded, and secondarily bonded structures as SDC. The FAA further states that disbonds and delaminations between arrestment features may not be easily found without special, directed inspections.

The FAA also does not concur on the approach of defining specific damage size for evaluating residual strength capability of composite Category B structure. Rather than approaching the requirements from a damage size standpoint, the FAA recommends assessing where one is on the residual strength curve. In other words, the applicant should ensure that they are on the flat portion of this curve.

Specific to Category B structure, Boeing, EASA and Embraer do not concur on the removal of the requirement that damage containment features significantly reduce or stop damage under operational loads. Boeing, EASA and Embraer believe that without such a requirement, an applicant may incorporate damage containment features that are completely ineffective with respect to retarding or stopping damage. Similar to the comment above concerning damage size, without effective damage containment features, robustness of structure would not be enhanced.

One of the reasons cited for removal of this requirement was, similar to the concerns of including slow crack growth for SLP structure, evaluation of effectiveness of damage containment features could force the applicant to consider period of unrepaired use. We therefore ask the TACMSWG to consider the possibility of including this as a general design requirement, that the applicant use good design practices to ensure damage containment features for Category B structure work effectively under operational loading as opposed to meeting specific damage-tolerance type requirements.

Airbus does not concur on the inclusion of co-cured, co-bonded or secondarily bonded composite structures under the definition of Category B. AC20-107B addresses in a complete manner the damage scenarios for composite structures to be considered. Categories 1, 2, 3 and 4 from Chapter 8.a of AC20-107B describe the damages to be considered, and sufficient details can be found to guide the applicant in performing the required assessment for composite structures. Adding another layer of damage definitions under SDC in different Advisory Material will lead to confusion and potentially conflicting requirements. Therefore, Airbus proposes to remove the reference to composite structures in the proposed SDC guidance material and rely fully on AC20-107B to ensure unique definition of damages to be considered.

Damage Size for Panelized Construction

Boeing and EASA do not concur on the damage size specifications for panelized Category B and C structure. The proposal requires residual strength for the failure of a single damage containment feature or failure of the portion of structure between damage containment features. Boeing and EASA believe that such small damage size requirements will add little to no robustness to the structural design. In other words, SDC will add nothing beyond what is already provided by damage tolerance or other existing requirements.

The issue of required damage size for panelized construction received much attention, especially amongst the OEMs. One of the primary concerns included some OEMs' inability to show residual strength capabilities for a two-bay and single stiffener failure for their existing designs. For those OEMs who do include such a requirement within their design practices, some also raised a concern with making this a hard requirement for all panelized structure. Lastly, they raised concerns with the challenge of converting this from a design practice into a hard regulatory requirement and the associated findings of compliance. For this reason, the AAWG has recommended to the TAMCSWG that SDC requirements be at a high level, to alleviate concerns with showing compliance.

B. As stated in Sections 5.5 and 5.6 of this report, the AAWG could not reach consensus on whether any proposed rule change should be included within § 25.571 or if it should reside within § 25.6xx as a purely design-driven requirement. The AAWG notes that the inability to reach consensus on specific rule changes was due to time constraints, as opposed to reaching an impasse. The AAWG recommends to the TAMCSWG that if a rule change were required, that it be at a high level, similar to the safe-life requirements specified in § 25.571(c). The AAWG further recommends that the details of the means of compliance be specified in the guidance as indicated in recommendation A. above.

One OEM (Airbus) proposed that no rule change should be needed and that SDC requirements could be addressed purely by guidance material. However, they agreed that they could support a rule change, provided it contains only high level provisions as indicated above. It should be noted that at the AAWG face-to-face meeting, nine members, including four OEMs, four operators and one regulator voted for the option of no rule change.

Appendix A – 2003 GSHWG Proposal

Appendix B – Airbus Philosophy for Fail-Safety

Appendix C – Boeing Existing Fail-Safe/SDC Practices

Appendix D – Bombardier SDC/LDC Compliance

Appendix E – Embraer Fail-Safe Design and SDC Philosophy and Practices

Appendix F – Gulfstream Large Damage Capability

Appendix G – Option 1 – Modified 2003 GSHWG proposed rule change to § 25.571 (presented by Gulfstream)

Appendix H – Option 2 – 25.6xx rule change (presented by Boeing)

Appendix I – Option 3 – No rule change, rely on guidance only (presented by Airbus)

Appendix J – AAWG proposed guidance for SDC