12.0 STRUCTURAL DAMAGE CAPABILITY

a. **General.** 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. The overall purpose is to prevent catastrophic failure resulting from damage not accounted for in damage tolerance analysis. SDC is a characteristic of the design of a structure, and is therefore not specifically tied to any one aspect of a maintenance program.

Damage tolerance is the ability of structure to sustain anticipated loads in the presence of damage until it is detected through inspection or malfunction, and repaired. It should be emphasized that SDC is not a replacement for damage tolerance – SDC adds robustness to the inherent structural design. SDC addresses unforeseen damage and complements existing damage tolerance inspection requirements. It does not generate any additional inspection or inspection threshold requirements; these should already be accounted for by existing baseline and damage tolerance based maintenance programs.

SDC is an inherent design attribute and complements more formal inspection programs derived through damage tolerance evaluation (DTE). At a high level, types of damage could include wear, environmental deterioration, impact, heat damage, disbond and delamination. General sources of damage could be from loading in service, the environment, accidental damage, maintenance errors, discrete events and manufacturing defects. Specific examples of possible damage scenarios that SDC may protect against include but are not limited to the following:

- Chemical spillage affecting resin strength
- Failure of a composite element due to a manufacturing processing error that causes fiber distortion
- Severe wear of the fuselage crown skin from vertical stabilizer aerodynamic seals
- Damage to structure from excessive pull-up or mis-drilled holes in manufacturing or maintenance
- Accidental damage in the fuselage skin
- Damage from runway debris
- Damage from departure of small access covers in flight
- Damage from high load events

It should be noted that structure with an SDC design will not be able to withstand damage from all of the above scenarios in all cases – this would be dependent on the severity of the damage and the level of conservatism or robustness provided by the applicant's SDC philosophy.

An SDC assessment should be performed for Principal Structural Elements (PSE) subject to in-flight loads under paragraphs (b)(1) through (b)(5) of §25.571.

b. The evaluation of a given PSE for SDC is intended to ensure that, in the event of a certain level of damage, the remaining intact structure is capable of carrying the required residual strength loads as defined in paragraph a. The extent of SDC to be demonstrated may be used to mitigate the thoroughness** of the threat assessment and the type of PSE under evaluation. To this end, the structure is classified as Category A, B or C as follows (note that the following guidance applies to conventional type structure, and SDC for non-conventional structure may need to be addressed on a case-by-case basis):

Category A - Single Load Path (SLP) Structure
Category B – Co-cured, Co-bonded or Secondarily Bonded Multiple Load Path (MLP) Structure
Category C – Discrete Element or Built-up MLP Structure

(1) Category A – Single Load Path Structure
By definition, Category A structure does not have inherent SDC capability. However, for cases where the applicant

a. establishes that Category B or C designs would be impractical; and
b. conducts a thorough** threat assessment

usage of Category A structure which is non-safe life and subject to in-flight loading may be considered.

i. Definition: Single load path PSE structure which contains no geometrical (cannot rely on material behavior alone) damage containment features and the failure of which may lead to a catastrophic loss of the aircraft.

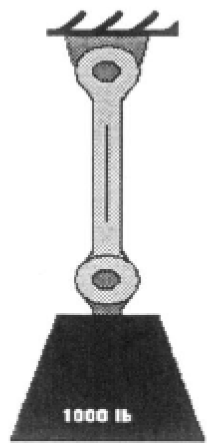


FIG. 1 – Category A single load path structure

ii. Example: A single element fitting, such as a single link or lug, with no integral features to contain damage and retard propagation, and which upon failure the remaining structure cannot withstand the required residual strength load.

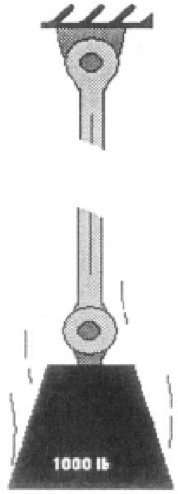


FIG. 2 – Category A single load path structure does not have SDC capability

iii. The structure must be able to withstand the loads defined in paragraph a with the extent of damage determined by the threat assessment.

The applicant should consider the following:

- 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 a test or analysis based on test to demonstrate no detrimental damage growth
- Develop a manufacturing process control and tracking plan document

(2) Category B – Co-cured, co-bonded or secondarily bonded Multiple Load Path Structure

i. Definition: Multiple load path structure with damage arrest features, *i.e.* bonded composite structures which incorporate 'damage containment features'. The majority of composite structure designs will be classified as category B.

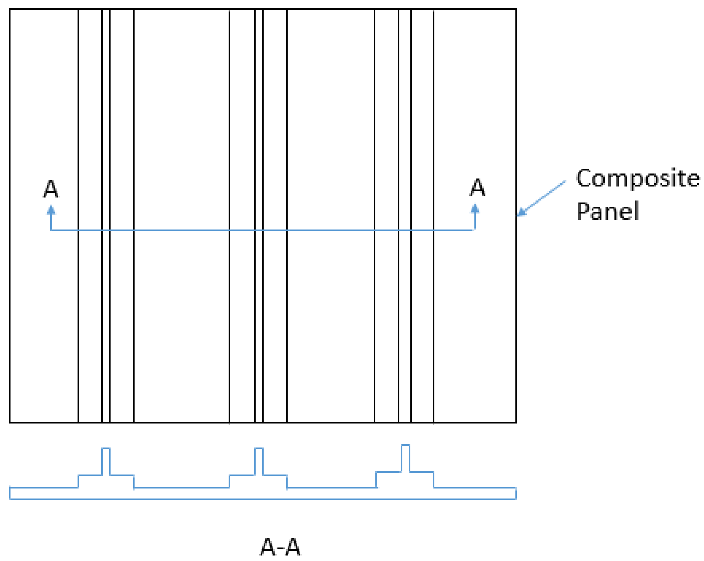


FIG. 3 – Category B MLP structure with damage retardation features

ii. Example:

- A co-cured, co-bonded or secondarily bonded composite panel with stiffening elements that are intended to preclude detrimental damage growth, i.e. contain the damage to an area/size that allows the structure to retain its residual strength capability with the loads as defined in paragraph a.

iii. Minimum level of SDC for panelized construction is capability to withstand the loads defined in paragraph a with the following level of damage:

- With only a partial/limited threat assessment in place, as a minimum*, each of the following should be evaluated:
    - o A one bay cut skin bay between stiffeners (see Fig. 4 and Section A-A)
    - o Readily detectable skin/stringer impact damage represented by a defined damage state (see Fig. 4 and Section B-B and Note 3)

Other Considerations: When addressing Category 2 damage, the applicant will not be allowed to use an energy level cutoff below which would limit the required detectability (typically through visual means).

Notes: 1* - In rare cases, the threat assessment may yield a realistic damage size leading to a level of SDC greater than described above. 2 - The damage state can be simulated by cuts. When determining the residual static strength of the part using a machined cut to simulate the damage state, load induced damage extension from the cut before final failure is preferable so the residual strength of the part is not influenced by the cut end geometry and finish. Analysis supported by testing is acceptable. 3 – Readily detectable damage (RDD) is defined as “failure or partial failure that would be apparent from pre-flight or post-flight visual observations or they would be visually obvious during a scheduled maintenance action conducted within the predicted safe period of unrepaired usage." Examples of readily detectable damage include failed or severely damaged skin panel or web with associated damage to attached stringers, stiffeners, frame or rib. Sandwich construction RDD could manifest itself as through penetration, dents or significant fracture, depending on the material, facesheet thickness and core weight.

- With a thorough** threat assessment in place the level of SDC is the realistic damage size as determined by the threat assessment.

  Other considerations: When addressing Category 2 and 3 damages, the applicant may consider energy level cutoffs that may not yield a visual indication when supported by the threat assessment.

Minimum level of SDC for <u>other</u> Category B structure (such as an integral composite wing spar) is capability to withstand the loads defined in paragraph a with the following level of damage:

- With only a partial/limited threat assessment in place, as a minimum*, each of the following should be evaluated:
    - the failure of the equivalent to a single element for multi-element construction(see Fig. 5A)
    - damage between arrest features (see Fig. 5B).

  *Note: In rare cases the threat assessment may yield a realistic damage size leading to a level of SDC greater than described above.

- With a thorough** threat assessment in place the level of SDC is the realistic damage size as determined by the threat assessment.

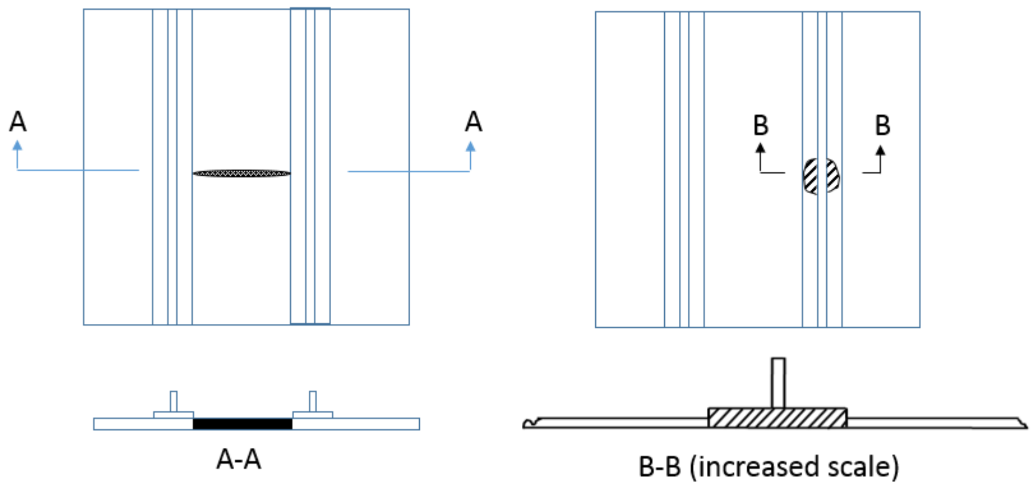


FIG. 4 – Example of minimum level of SDC for Category B composite panel which is appropriate where the applicant has completed a partial/limited threat assessment. Evaluation would include both damage scenarios shown (evaluated separately): (A-A) One bay cut skin, (B) Readily detectable skin/stringer impact damage represented by a defined damage state. **These pictures only illustrate typical configurations and damage scenarios. The applicant should consider scenarios specific to their design configuration.**

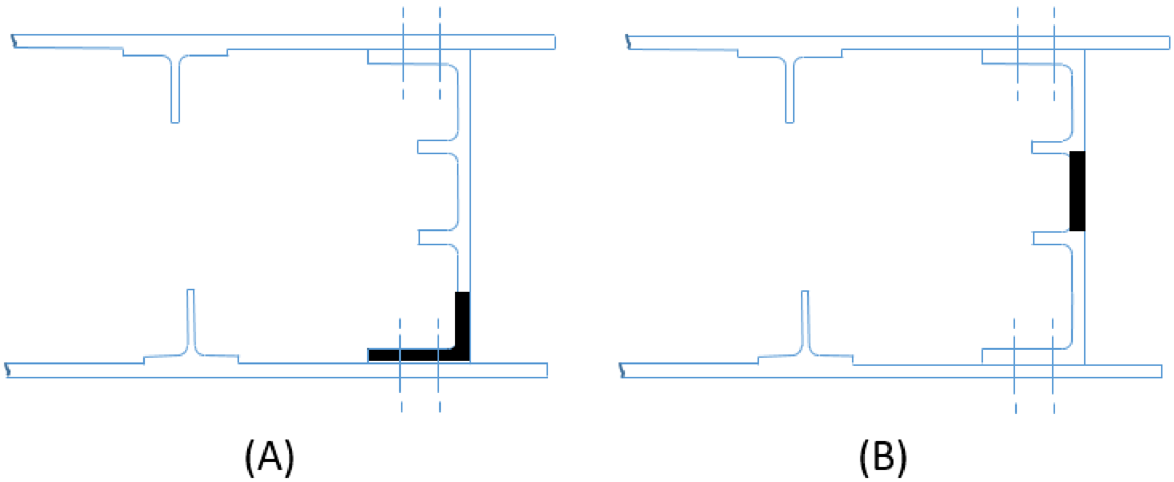
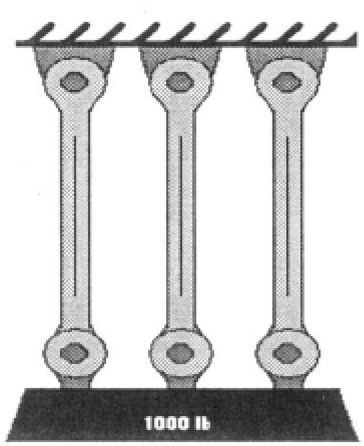


FIG. 5 – Example of minimum level of SDC for Category B composite spar structure with damage containment features which is appropriate where the applicant has completed a partial/limited threat assessment. Evaluation would include both damage scenarios shown: (A) Equivalent to single element damage for multi-element construction, (B) Damage between arrest features. **These pictures only illustrate typical configurations and damage scenarios. The applicant should consider scenarios specific to their design configuration.**

Category C – Discrete Element or Built-Up Multiple Load Path (MLP) Structure:

i. Definition: Structure made up of multiple, independently fastened or bonded structural members that are part of a larger redundant system with multiple load paths; the remaining damage free members can carry the required load. There are two types of Category C structure:
   - Type 1: Discrete Element MLP Structure, i.e. multiple independent element structure where one member of that system could be completely broken.
   - Type 2: Built-up MLP structure (includes structure consisting of discrete stiffening members and a continuous element).



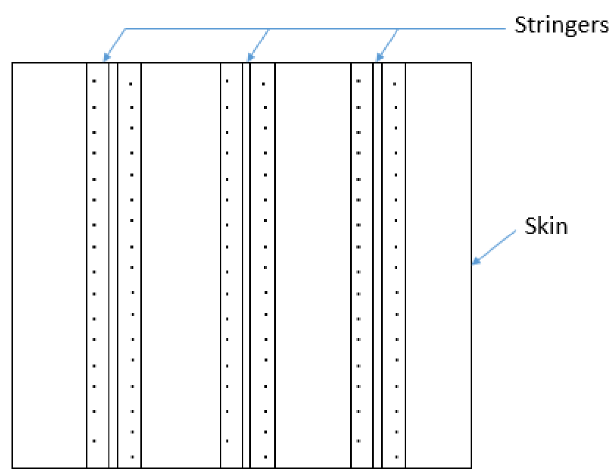


FIG. 6 – Category C multiple load path structures

ii. Examples:

Type 1 -

- Back-to-back or multiple redundant lugs and fittings.
- Multiple redundant attachments for structure such as control surface hinge ribs, engine strut attachments, thrust reverser attachments and door latches, stops and hinges.
- Finite width fastened multiple panels where required loads can be maintained with the loss of one panel.

Type 2 -

- Stiffened panels with separately fastened stiffening members such as stringers, longerons or frames. Note that each individual skin bay between stiffeners or damage containment features is assumed to be a separate load path.
- Built-up structure such as doorway frames and spars with separately fastened skins, chords, webs and straps.

iii. Minimum Level of SDC -

Type 1 –

- With only a partial/limited threat assessment in place, as a minimum, it should be ensured that the multiple load path design includes sufficient structural redundancy to allow for the failure of a single element. (see Fig. 7A). Analysis should be performed and limited to the static assessment of the ability of the remaining intact load paths to carry the loads defined in paragraph a.
- With a thorough** threat assessment in place the level of SDC is the realistic damage size as determined by the threat assessment (see Fig. 7B).

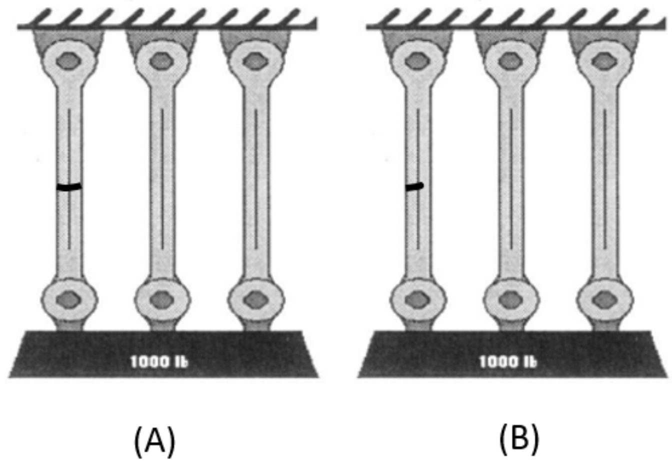


FIG. 7 – (A) Example of minimum level of SDC for Category C Type 1 multiple load path composite structure where the applicant has completed a partial/limited threat assessment. Level of SDC is failure of one complete load path. (B) Example of level of SDC for Category C Type 1 multiple load path structure where the applicant has completed a thorough threat assessment. Level of SDC may be partial failure of one load path.

Type 2 – For built up panelized construction the level of SDC is the capability to withstand the loads defined in paragraph a with the following level of damage:

- With only a partial/limited threat assessment in place, as a minimum*, each of the following should be evaluated:
  - o A one bay cut skin bay between stiffeners (see Fig. 8 and A-A)
  - o Readily detectable skin/stringer impact damage represented by a defined damage state (see Fig. 8 and B-B and Note 3)

Other Considerations: When assessing Category 2 damage, the applicant will not be allowed to use an energy level cutoff below which would limit the required detectability (typically through visual means).

Notes: 1* - In rare cases, the threat assessment may yield a realistic damage size leading to a level of SDC greater than described above. 2 - The damage state can be simulated by cuts. When determining the residual static strength of the part using a machined cut to simulate the damage state, load induced damage extension from the cut before final failure is preferable so the residual strength of the part is not influenced by the cut end geometry and finish. Analysis supported by testing is acceptable. 3 – Readily detectable damage (RDD) is defined as “failure or partial failure that would be apparent from pre-flight or post-flight visual observations or they would be visually obvious during a scheduled maintenance action conducted within the predicted safe period of unrepaired usage.” Examples of readily detectable damage include failed or severely damaged skin panel or web with associated damage to attached stringers, stiffeners, frame or rib. Sandwich construction RDD could manifest itself as through penetration, dents or significant fracture, depending on the material, facesheet thickness and core weight.

- With a thorough** threat assessment in place the level of SDC is the realistic damage size as determined by the threat assessment.

  Other considerations: When addressing Category 2 and 3 damages, the applicant may consider energy level cutoffs that may not yield a visual indication when supported by the threat assessment.

For other built-up Type 2 structure (such as a built-up wing spar), the minimum level of SDC is the capability to withstand the loads defined in paragraph a with the following level of damage:

- With only a partial/limited threat assessment in place, as a minimum*, the applicant should evaluate the failure of a single element (refer to Fig. 9).

  *Note: In rare cases, the threat assessment may yield a realistic damage size leading to a level of SDC greater than a single element.

- With a thorough** threat assessment in place the level of damage is the realistic damage size as determined by the threat assessment (refer to Fig. 10).

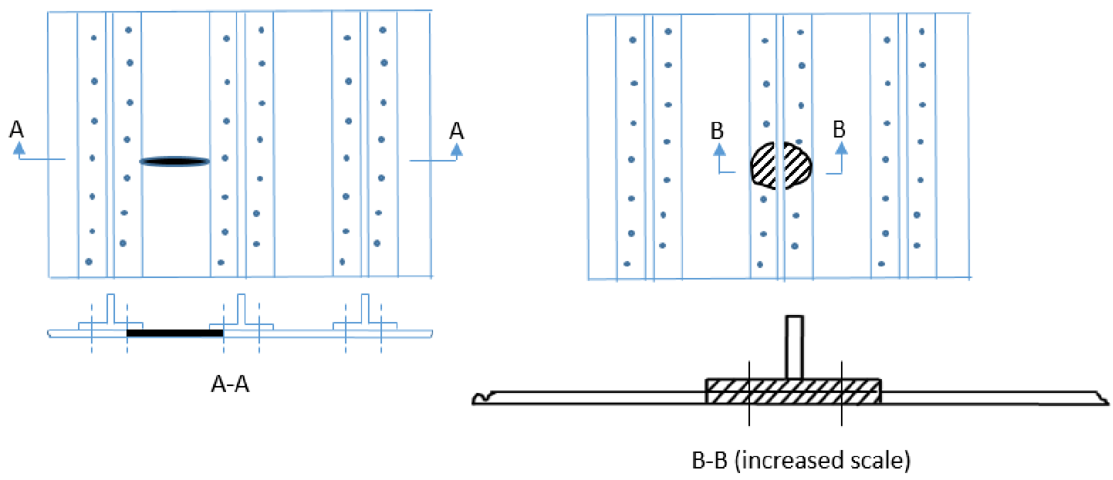


FIG. 8 – Example of minimum level of SDC for Category C Type 2 built up multiple load path composite panel which is appropriate where the applicant has completed a partial/limited threat assessment. Evaluation would include both damage scenarios shown: (A-A) One bay cut skin, (B) Readily detectable skin/stringer impact damage represented by a defined damage state. **These pictures only illustrate typical configurations and damage scenarios. The applicant should consider scenarios specific to their design configuration.**

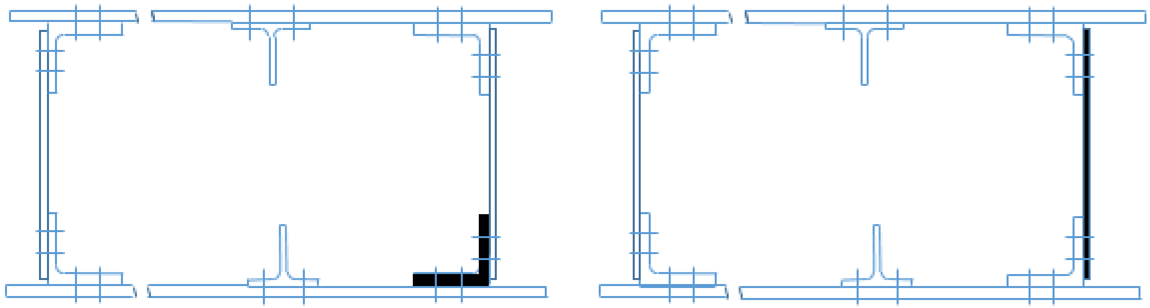


FIG. 9 – Example of minimum level of SDC for Category C Type 2 multiple load path composite structure which is appropriate where the applicant has completed a partial/limited threat assessment. SDC assessment would include both damage scenarios shown for the built-up spar. **These pictures only illustrate typical configurations and damage scenarios. The applicant should consider scenarios specific to their design configuration.**

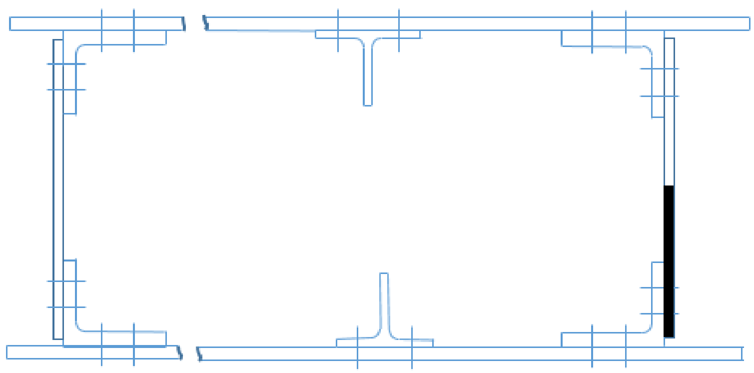


FIG. 10 – Example of level of SDC for Category C Type 2 multiple load path composite structure which may be appropriate where the applicant has completed a thorough threat assessment. SDC assessment may include the web damage scenario shown for the built-up spar. **These pictures only illustrate typical configurations and damage scenarios. The applicant should consider scenarios specific to their design configuration.**

**A thorough threat assessment is defined as a thorough investigation of damage threats, supported by service history, to mitigate the likelihood of catastrophic loss.