EASA

European Aviation Safety Agency

Composite Materials:

Composite Seats

(Developing Standardisation –

Background and Update)

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Your safety is our mission.

Composite Seats - Background

Issue: Composite* Seats – Developing Standardisation

- accelerating use of composite materials in significant airframe and passenger critical structural applications, e.g. large airframe fuselage, wing box structures, engines, undercarriages, <u>and seats</u>

- Note: Legally binding EC No 2018/1139 - 216/2008 annex 1.a.**Structures and materials**: …the **<u>integrity of the structure</u> must be ensured throughout, and <u>sufficiently beyond, the operational envelope for the aircraft</u>,** including its **Propulsion System**, and **<u>maintained for the operational life of the Aircraft</u>**… similarly for **<u>Systems and Equipment</u>**<u>.</u>

- consider any appropriate threats, e.g. **fatigue, manufacturing defects, environmental deterioration, or accidental damage** which may reduce 'performance' below regulatory references, e.g. static, fatigue, dynamic regs…

- priority… new organisations/organisations new to composites and/or seats…(particularly CS25)
  e.g. a new ETSO organisation without established TCH support or established applicable database

* long used in interiors structures iaw established guidance, e.g. GAMA Pub. No.13 etc.

Composite Seats - Background

Issue: Composite Seats – Developing Standardisation

- design and production changes should not reduce the existing 'acceptable' level of safety
- factors contributing to the existing acceptable level of safety include:
  - 'engineering judgement'
  - generic research and development
  - design specific test and analysis
  - in-service experience, including reaction to accidents and incidents
  - regulations in place at the time of design
  - in-house TCH design envelopes
  - threats which existed at the time of design (which may have changed)

Composite Seats - Background

Metallic experience – seat primary load paths:

- extensive successful experience - established metallic materials, processes, and configurations
- generally, safe metallic structure design is typically driven by Fatigue and Corrosion,
    - however, fatigue typically is not a driver for seat applications
    (vibration should be considered, e.g. windmilling)
    - cabin environment typically less challenging than for other structure applications
    - service experience – fatigue/corrosion typically not significant to dynamic performance
- robust structures, typically exhibiting easily detectable damage modes, e.g. corrosion, cracking

Regulations, standards, and testing:

- evolved regulations, standards, and testing typically address metallic experience
- existing acceptable level of safety typically defined by regulations and guidance supported by high pyramid level tests of seat structures 'as manufactured' e.g. CS2x.561, CS2x.562, and by other standards e.g. SAE etc and extensive experience etc (ref. points on previous slides)

Composite Seats - Background

Composite experience – seats:

- mostly non-primary load path seat structures

  Note: extensive successful experience with other interior structures, e.g. overhead bins, galleys etc. However, these often use redundant load paths and well established materials, processes, and configurations which are typically unrepresentative of seat primary load path applications

- safe composites design typically driven by Accidental Damage (AD) and Environmental Damage (ED)

  - no standardised AD threat survey data for seats, e.g. trolly impact?, dropped case?, maintenance practice?, transportation?, storage? etc

  - potentially many competing damage modes, some undetectable (see support slides)

  - many composite seat configuration design proposals, e.g. materials, processes, and design features

  - broad range of ETSO company experiences with composites and/or seats, but mostly non-TCH supported organisations with limited databases and experience

Composite Seats - Background

Composite experience – seats:

Regulations, standards, and testing:

- ‘as manufactured’ seats may pass 2x.561, 2x.562 when new, but may be subject to systemic and undetectable degradation e.g. impact, moisture, disbonded joints, impact damages etc such that many seats in a ships set may not function as expected.

Actions taken to standardise and improve regulations, standards, and testing:

- Draft Certification Review Item (CRI)* raised to identify and address potential gap between ETSO metallic experience, including guidance documents, and composite seat primary load path applications when installed on certified airframe (e.g. via STC)

- SAE Working Group formed to encourage industry to develop appropriate ‘level playing field’ standards icw regulator draft CRI development (lead by Allan Abramowitz, Cindy Ashforth - FAA)

* harmonised position with FAA Issue Paper

Composite Seats - Background

Draft CRI Development – current content outline (October 2015)**:**

EASA position – using AMC 20-29 'Composite Aircraft Structure' , which states:

' this AMC provides Acceptable Means of Compliance and Guidance Material for composite structures, particularly those that are essential in maintaining the overall flight safety of the aircraft'

Therefore, the current objective is to ensure that the applicant has **demonstrated overall robustness of the configuration selected such that the risk of a systemic manufacturing and/or poor in-service performance is minimised and the existing 'acceptable' level of safety is maintained.**

CRI addresses (identify gaps wrt established metallic practice and guidance documents)**:**

- material, process, and fabrication development
- crashworthiness
- flammability
- instructions for Continued Airworthiness

(including sampling/fleet leader programme
- potential mitigation supporting lack of an established database…)

Composite Seats - Update

Conclusions:

- composite seats not to reduce the existing acceptable level of safety
- **avoid systemic/ships set failure – seats are occupant safety critical structures**
- SAE Working Group
    - draft AIR 6337 written
    - CRI to be issued until AIR 6337 is released (CRI review to follow)

See support slides comparing original CRI text with current (Dec 2018) AIR 6337 text

Note: current ongoing discussion regarding inclusion of manufacturing and in-service Cat 1 defects in dynamic test

- need to improve understanding of relative static and dynamic performance of structures subject to a similar range of initial damages and defects

See following TCCA Presentation for Rotorcraft Discussion

Composite Seats

Questions

Composite Seats

Support Slides

- Comparison between existing CRI and developing AIR 6337

Green box – recent ARP rev wrt subject

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Material, process, and fabrication development:

- materials, proc ... ts etc
- primary load p...
- stable process ...
- defects and ac...
- environmental ...
  - moisture a ... nts (considerin ... nd also storage outside the ...
  - exposure to cabin fluids, including cleaning agents, beverages etc

SAE WG <u>Draft</u> ARP6337 Composite Seats (12. 2018):

- additional environmental considerations, service damage limits, and test evaluation criteria wrt AS8049, ARP5526, e.g. DO-160
- Tg > MOT + 50F (comp), Tg > MOT + 30F (adhesive)- <u>on/off aircraft</u> (considering local heat sources)
  - relative humidity 95+/- 4%
  - fluids exposure
  - on ramp, storage etc
  - variability iaw CMH-17 A-Basis, B-basis etc (1.15 variability factor accepted if supported by existing applicable database using similar material, process, and fabrication methods… as agreed with regulator)

K(total) = K(environment) x K(material variability) x K(damage* – as built)

K(total) = larger of 1.33 or K(total)

* effectively include Allowable Damage Limit (ADL) in the data

* regulator will accept factors for static test/analysis, not necessary for dynamic test/analysis

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Material, allowables, and design values:

- short test/analysis pyramid used
- mid-pyramid work difficult
- complex features, valid Boundary Conditions

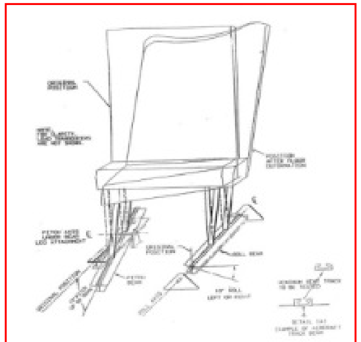
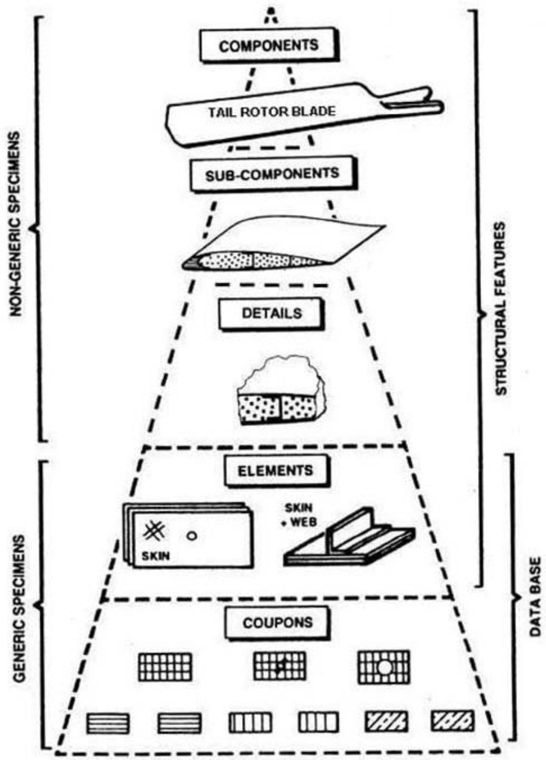


Figure 9-1. Schematic Floor Deformation Fixture— Seat Legs Attached at Floor Level



- challenge for static pre-chg 13 seats… applicant is required to provide data to support the argument that the existing acceptable level of safety, based upon static testing and metallic experience (as defined for a pre-Change 13 certification basis), has not been reduced

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Damage tolerance:

unless the applicant can ensure robust material selection (and until a standardised threat assessment is developed) :

- clearly define, and agree with the regulator, the likely threat sources, geometries, and energies appropriate to its proposed applications

and

- demonstrate that the materials and processes selected for its proposed configurations will provide a robust structure, including detectable damages, if damage occurs, and adequate residual strengths (in dynamic test) when exposed to the agreed threats, as appropriate to define a realistic and adequate ICA

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Damage tolerance:

then the applicant must consider as appropriate to seat structure exposed to impact:

- impacts of seat structure to visible damage* levels (also identify all associated non-visible damage)

- use a range of impactor energies and geometries (sharp and blunt)

- use of appropriate Boundary Conditions, e.g. complete and correctly mounted seat (access permitting)

Vibratory loads:

Although not PSE requiring full consideration per 25.571, the applicant should consider vibratory loads:

- including BVID (Cat 1 damage), or larger damage, including disbonded structure, which could remain undetected for any significant length of time

* or to substantiated NDI detectable levels, or as correlated with the use of witness structures

Green box – recent ARP rev wrt subject

Composite Seats

Draft CRI Development – current content outline (October 2015)**:**

Damage tolerance:

SAE WG Draft ARP6337 Composite Seats (12. 2018):

Threat Assessment:

- identify damage in service, during installation, removal, storage, and maintenance
- identify worst case manufacturing defects (iaw specifications etc) which may exist undetected/without repair

Substantiation of damage:

- include worst case acceptable defects, expected locations, in <u>static tests</u> (considered by one of 4 methods)

  1/ impact full scale test article (1 in dia. impactor up to 100 ft-lb, visual damage > 0.1in depth)

  2/ drill 1/4in holes in full scale test article

  3/ substantiation by analysis, use open hole (OHT, OHC etc) and impacted laminate design values

  4/ substantiation by test and analysis, apply overload factor defined by ratio mean solid laminate to open-hole or impacted laminate (AS APPROPRIATE TO LOAD CASE/DAMAGE MODE, including environmental and variability factors)

Green box – recent ARP rev wrt subject

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Crashworthiness:

Requires:
- the occupants be protected from the release of items of mass
- the occupants be protected from excessive loads
- living space be maintained
- escape routes be maintained

Dynamic seat (Post chg 13) testing:

SAE WG Draft ARP6337 Composite Seats (12 .2018):

Dynamic test – ambient temperature - no overload factor

Static test - plus environmental and overload factors

Structure should be tested using:

- Cat 1 manufacturing and in-service defects, including BVID, disbond etc*.

- more critical damages which may not be readily detected in service, but which may be detected during scheduled inspection, e.g. Cat 2 levels of damage. These damages should be applied at critical seat structure locations?

* also include in Head Impact Criteria (HIC) tests, ref. CS 25.562(c)(5)

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Crashworthiness:

Dynamic seat (Post chg 13) testing:

Structure should be tested using:

- Service impact threats that would result in damage that is immediately and visually apparent to operators need not be included in the static or dynamic test articles, as it is assumed any such damage will be repaired or replaced prior to further flight.

Note: the intention is to encourage a robust design. However, if the potential exists for extensive hidden damage to develop before becoming readily detectable, then the inclusion of such damage may significantly change the behaviour of the structure. Until a standardised impact threat is defined, the project risk is that impact testing to readily detectable damage levels is excessive and unrepresentative of the real threat, and subsequently may result an unrepresentative test of the structure. Therefore, testing with both impact damaged structure damaged to visible detectable levels and also an additional structure including only Cat 1 damages may be necessary.

Green box – recent ARP rev wrt subject

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Crashworthiness:

SAE WG Draft ARP6337 Composite Seats (12. 2018):

Bonded Joints - TBD

Dynamic seat (Post chg 13) testing:

- for seat structures including **bonded joints** in the primary load paths, the test should be completed with the most critical joint disbonded. This recognises that 'weak bonds' and tight disbonds cannot be located reliably in service. Therefore, the applicant will need to justify the selection of the most critical joint, noting that a disbonded joint may also have the potential to relieve the structure during the test, i.e. the potential exists for a structure without a disbonded joint to be more critical. Therefore, testing of structures both with the most critical joint disbonded and also structure without a disbonded joint may be necessary.

- address competing strength and stiffness issues:
    - Too weak – living space and escape routes compromised
    - Too stiff – excessive pulse

Green box – recent ARP rev wrt subject

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Crashworthiness:

Post dynamic seat testing:

SAE WG Draft ARP6337 Composite Seats (12.2018):

Post Dynamic RS Testing (difficult to visually assess damage) - options:

1/ scaled secondary dynamic tests (30% of existing regulation pulse peak)

2/ static test 3g fwd, 2g down

Visually evaluate for damage iaw AS8049 5.4.1

- define pass/fail criteria for post test assessment, equivalent to AC 2x.562-1B (deformation requirements retained)
- check for visual cracks alone is not adequate - non-visible damage etc?
- regulator proposals, one of four methods:
  - a second impact test of the same article at reduced energy
  - static test (less than 9g) after the dynamic test;
  - NDI inspection of the post-dynamic test article and an analysis that shows the required static residual strength; or
  - NDI inspection of the post-dynamic test article showing that the level of damage is less than the level of damage of the static test article
- abuse loads
- sharp edges, fibre release etc

Green box – recent ARP rev wrt subject

Composite Seats

- red text initial draft text

Draft CRI Development – current content outline (October 2015)**:**

Flammability: - applicant must demonstrate structure meets CS 2x.853

Instructions for Continued Airworthiness (ICA):

Scheduled inspections: - following installation, removal, storage, exposure to known threat

Fleet Leader Programme: - no previous experience of this application

- validate the initial certification design assumptions*, e.g. regarding impact threat assumptions, retained bonded joint integrity, etc, the applicant is required to develop:

- a user feedback process
- a fleet leader programme, including inspection and testing of fleet leader composite seat structures

SAE WG Draft ARP6337 Composite Seats (12. 2018):

Manufacturer to provide repair processes to seat installer/operator – include in CMM

- damage criteria correlated to substantiation, damage > allowed in seat production must be repair/seat replaced

*Bonded Joints and Structures - Technical Issues and Certification Considerations; PS-ACE100-2005-10038 Page 21, states: 'the long-term durability of bonded production aircraft structure is validated by service experience'

Composite Seats

Conclusions:

- Change not to reduce the existing acceptable level of safety
- **Avoid systemic/ships set failure – seats are occupant safety critical structures***
- SAE WG activity continues (draft due end of 2018+)
- Industry/Regulator Composite WG* input included
- Until SAE WG Standard is published, EASA will continue to issue the CRI
- improve understanding of the comparability between damage levels and static residual strength relative to damage levels and dynamic behaviour – R&D needed

* reminder … any structure required to meet the regulations should do so for its service life, and any damage which reduces residual strength below regulatory reference strengths should repaired/replaced accordingly

* Airbus, Boeing, Bombardier, FAA, TCCA, EASA + other individuals and organisations

Composite Seats

Note:

NPA 2013-20 'Seat crashworthiness improvement on large aeroplanes — Dynamic testing 16g' is in progress. Objectives include:

> *'(Part 26).. to add additional airworthiness requirements and specifications for operations in order to make …CS 25.562, specifications applicable also to newly produced aircraft of already approved type.'*

Confirmed by **Opinion No 02/2016** (transition period TBD):

— Option 1 requiring 16 g seats to be fitted on newly produced large aircraft used in CAT (Commercial Air Transportation):

http://www.easa.europa.eu/system/files/dfu/Opinion%2002-2016%20-%20Explanatory%20Note.pdf

Composite Seats

Support Slides

- Miscellaneous

Composite Seats

Draft CRI Development – current content outline (October 2015)**:**

EASA position – applicability of AMC 20-29 'Composite Aircraft Structure' (evolving discussion issue):

AMC 20-29 primarily addresses Primary/PSE structure:

Primary Structure: *'The structure which carries flight, ground, or pressurisation loads, and whose failure would reduce the structural integrity of the aircraft.'*

PSE: '...*are those which contribute significantly to carrying flight, ground, and pressurisation loads, and whose failure could result in catastrophic failure of the aeroplane.'*

Seats do not directly fit with these definitions. However,

seats are occupant safety critical

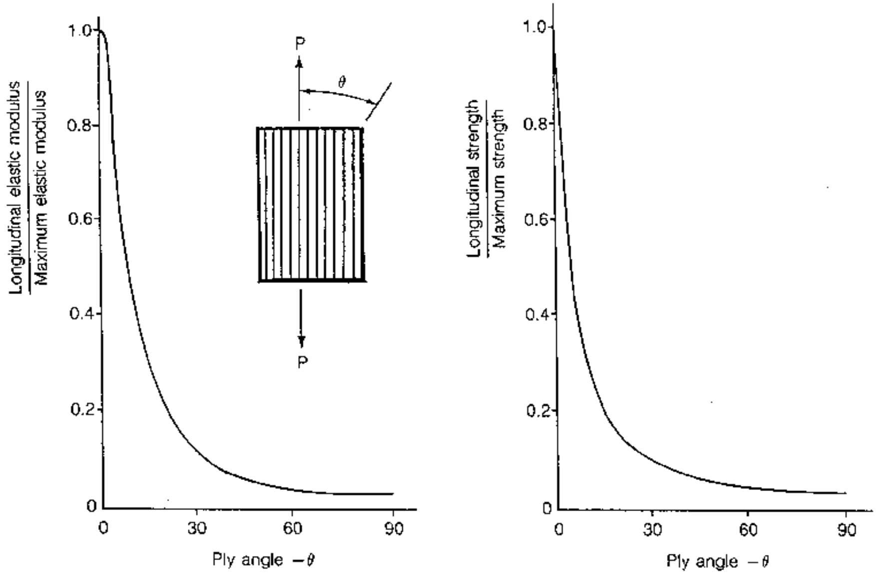
so, a systemic failure might result in a similar outcome to catastrophic airframe failure...

... a good reference database is important

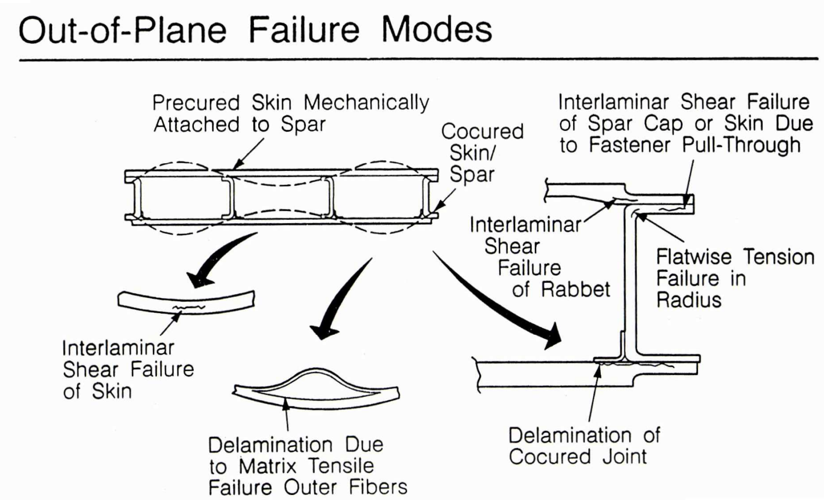
Recognising the Transition from Traditional Materials to Composites:

What are the potentially significant differences between typical metal and composite engineering properties?

Anisotropy: Significant strength/stiffness reduction with ply orientation relative to load



Strength/Stiffness v Ply Angle
(non-dimensionalised)



Anisotropy: potentially difficult to predict:

- **failure loads**
- **damage modes**
- **damage locations**

Recognising the Transition from Traditional Materials to Composites:

Damage – Inspection and Damage Tolerance:

Anisotropy:

Potential for significant Barely Visible/Non-Visible Damage….

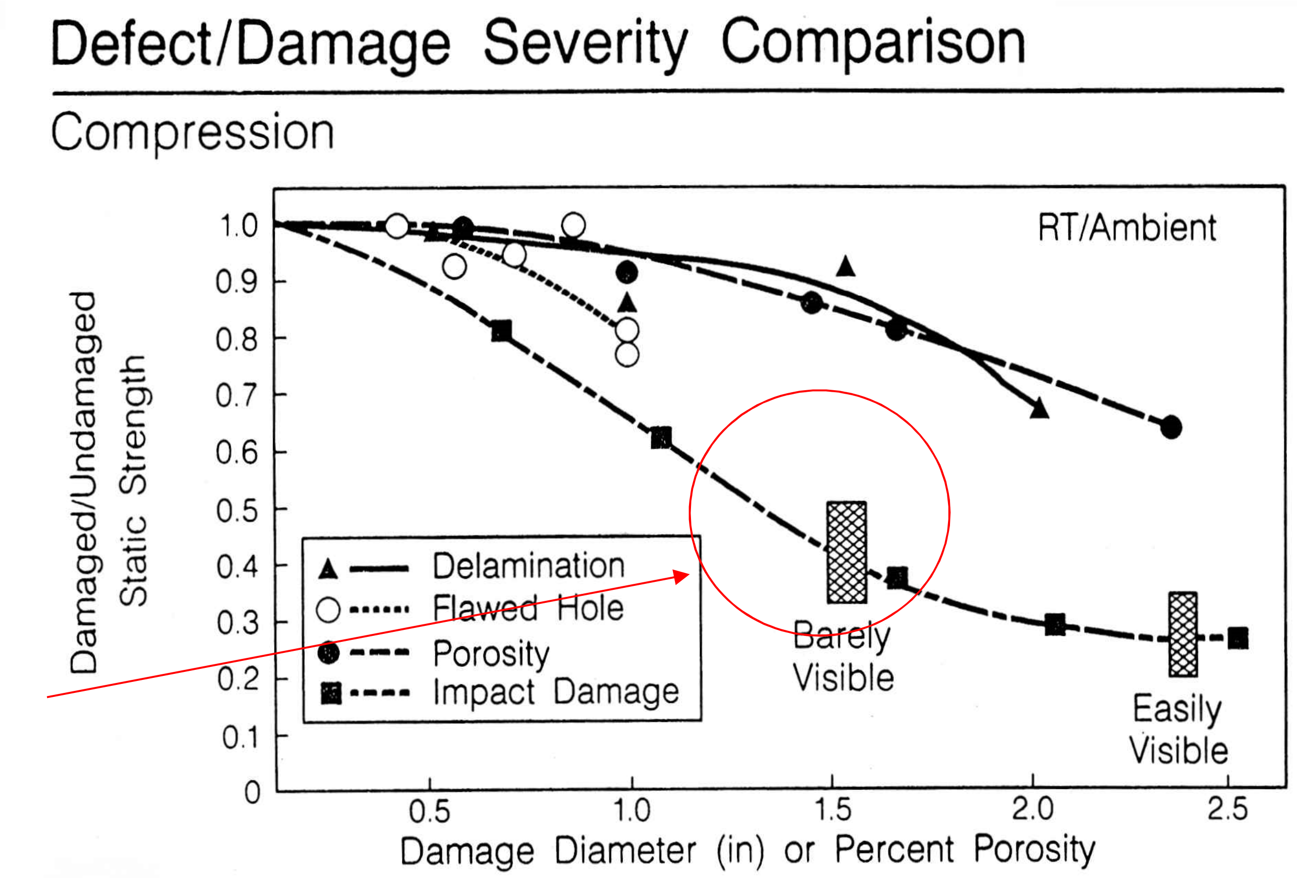
Composites:

- relatively low out of plane, compressive, and shear strength

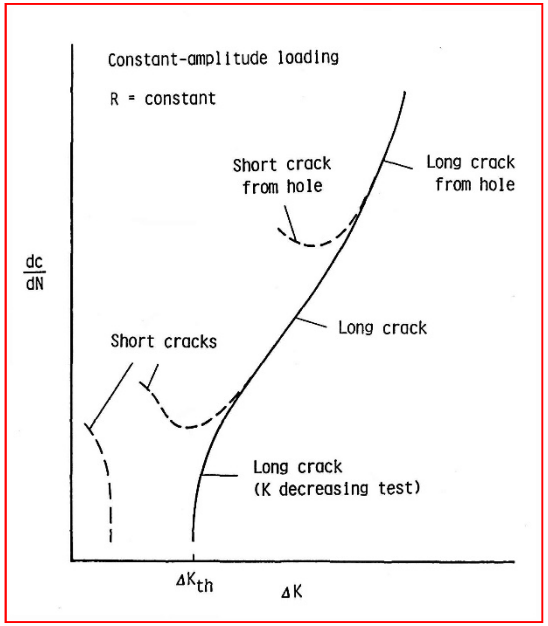
- impact sensitive

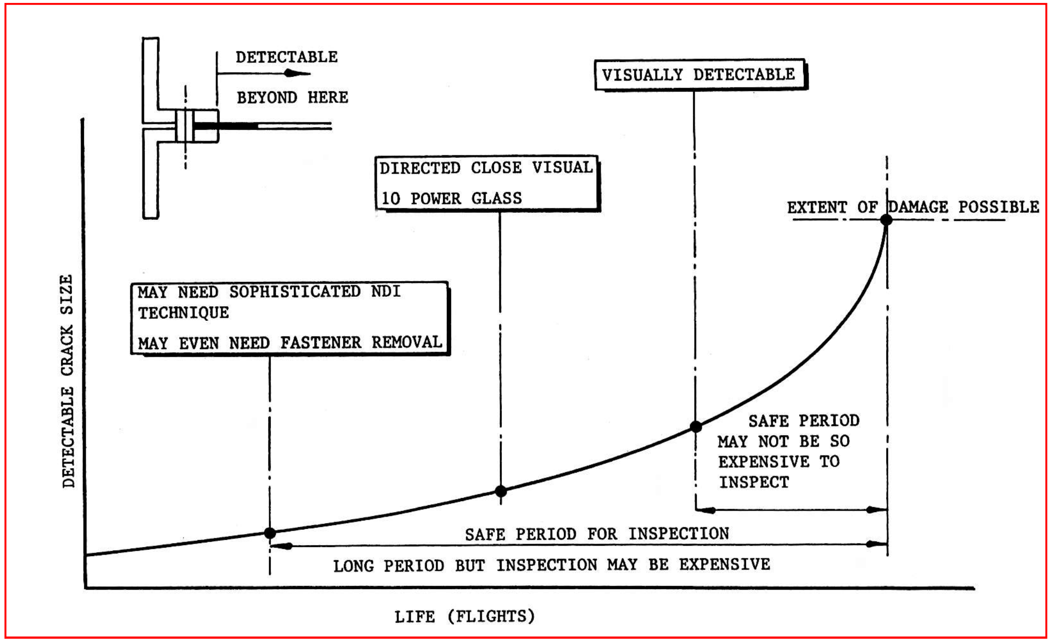
- strength/stiffness reduction for **critical damage modes**

- material relaxation



Damage – Inspection and Damage Tolerance:



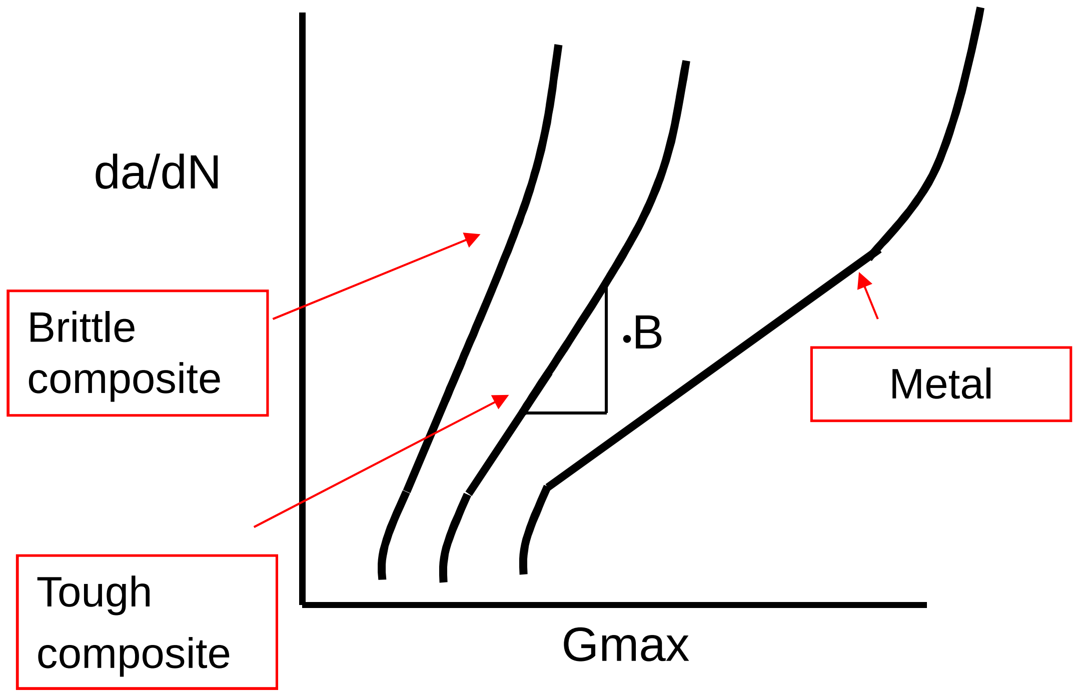


Metallic structure: Typically,

For airframe: crack growth (da/dN) vs stress intensity factor is **understood** (empirically), damage detectable – **damage tolerance** - maintenance schedule (MS) credit

For engines: crack growth (da/dN) vs stress intensity factor too steep, damage not readily detectable – **safe life**

Damage – Inspection and Damage Tolerance:



$$\frac{da}{dN} = AG^B \qquad G \propto P^2$$

$$\Rightarrow \frac{da}{dN} \propto P^{2B}$$

Material	B
Steel	1.6
Aluminium	2.2
Carbon/Thermoplastic	6.1
Carbon/Epoxy	12.2

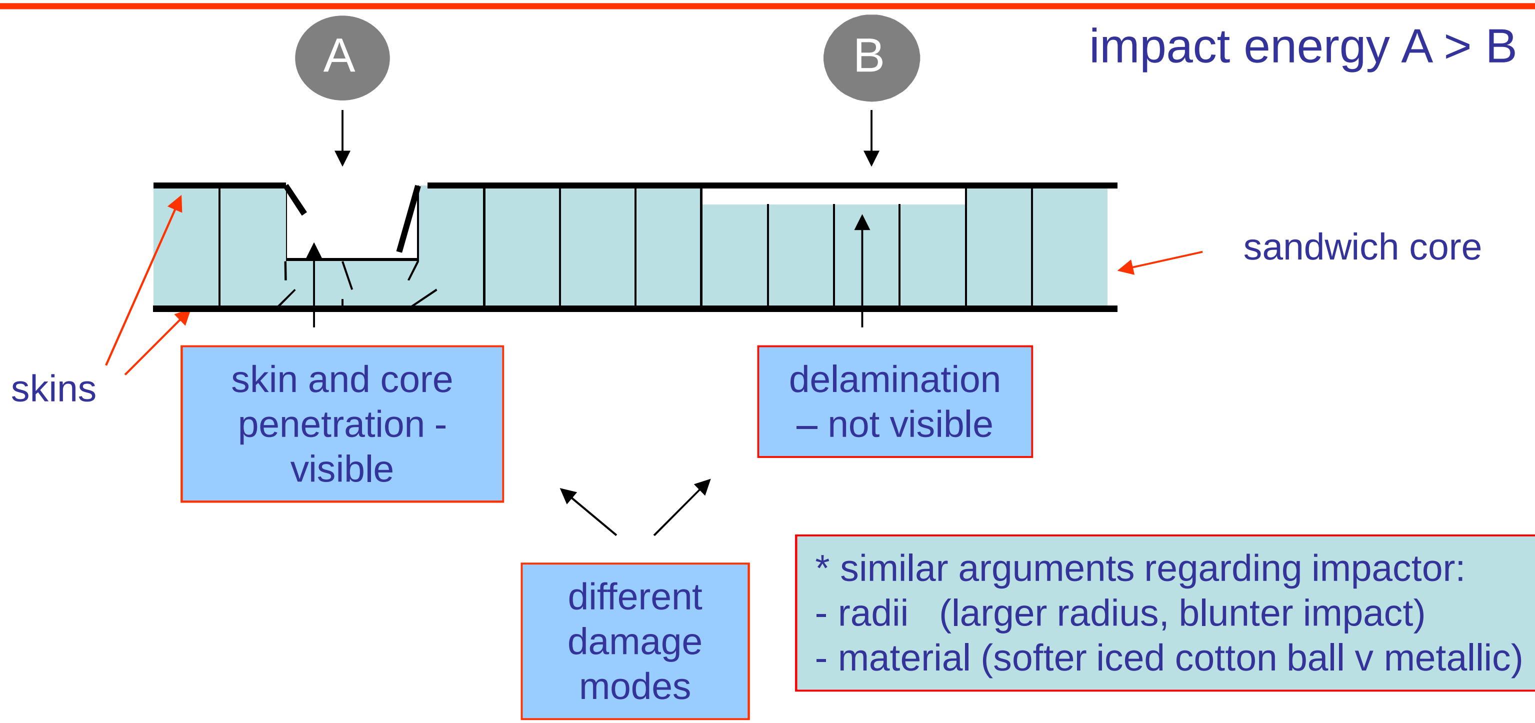
- Solution :- ensure that when damage is present, G is below a threshold value for crack growth

Composite structure: Typically, **crack growth (da/dN) not understood**, **some damages not detectable – mixed/competing damage modes**. **No-Growth philosophy necessary to comply** – substantiated damage threat survey necessary in MS development

Competing Damage Modes

Example - damage mode change problem (ref. previous slide): Hail Damage
(thicker skin sandwich structure)

Danger!: common to show no-damage growth with higher impact energy visible damage 'A', when lower impact energy invisible damage 'B' is potentially less conservative*!

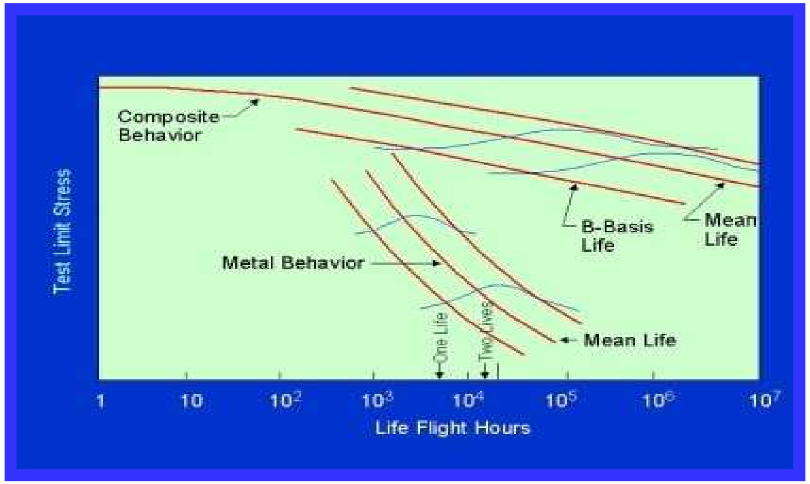


* similar arguments regarding impactor:
- radii (larger radius, blunter impact)
- material (softer iced cotton ball v metallic)

Composite Safety Issues

Furthermore: (experience/older materials):

manufacturing control important



- higher material property data scatter (static/fatigue)

- environment (moisture/temperature – manufacture/in-service)

- poor heat and electrical conduction (lightning strike)

- fire behaviour (toxic fumes, fibre release, strength/stiffness)

- quasi-brittle (vulnerable to load peaks, impact damage, strain rate etc)

- failure mode changes/mixed modes (ageing/temp, impact, fatigue growth etc)

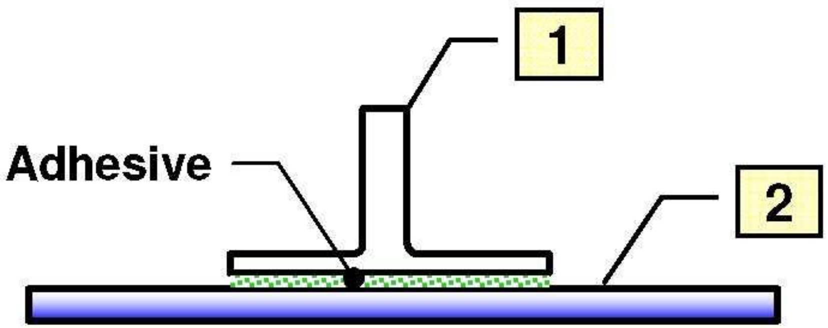
- repairs challenges (damage assessment, drying, cleanliness etc)

Many reasons for industry and the regulators to be interested…

AMC 20-29 Para.6. **MATERIAL AND FABRICATION DEVELOPMENT**

C. STRUCTURAL BONDING

- important existing rule regarding Bonded Structure – 23.573(a)(5)
    - approach used in other specifications, CS25, 27, 29, CS-P etc
      (now broader use formally recognised in AMC 20-29)



Structural Bonding:

- extremely sensitive to process
- particular caution is required if item 1 and/or 2 is pre-cured or metal, requiring:
- surface protection, cleaning, preparation etc

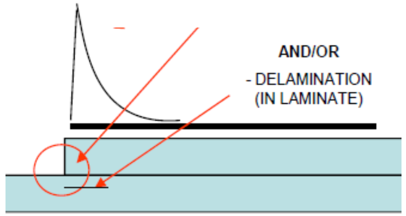
AMC 20-29 Para.6. **MATERIAL AND FABRICATION DEVELOPMENT**

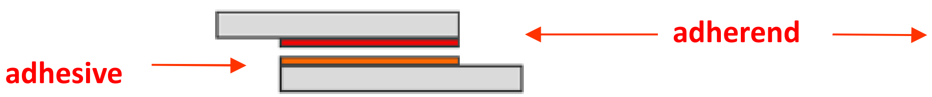
C. STRUCTURAL BONDING

Acceptable failure modes (one dominant repeatable mode preferred):

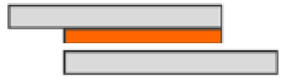
- Adherend failure (preferred)

- Cohesion failure in adhesive



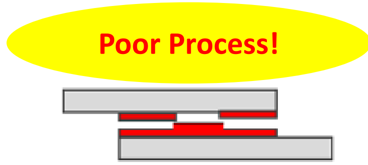


COHESION FAILURE



ADHESION FAILURE

- ADHESION FAILURE – UNACCEPTABLE (disbond*)
(at interface between adhesive and adherend)
    - contamination, compatibility etc



MIXED-MODE FAILURE

*'disbond' and 'debond' used interchangeably in lit.
However, 'disbond' – accidental, 'debond' – intended (access, repair)

Standardisation of Certification Requirements for Composites

23.573(a)(5): *'For any bonded joint, the failure of which would result in catastrophic loss of the aeroplane, the limit load capacity must be substantiated by one of the following methods:*

(i) The maximum disbonds of each bonded joint consistent with the capability to withstand the loads in paragraph (a)(3) (i.e. critical limit flight loads considered ultimate) of this section must be determined by analysis, tests, or both. ***Disbonds of each bonded joint greater than this must be prevented by design features;*** *or*

Not to be used to address poor process, poor process is unacceptable, ref. 2x.605

or

(ii) ***Proof testing*** *must be conducted on* ***each production article*** *that will apply the* ***critical limit design load*** *to each critical bonded joint;*

Not practical for large aircraft, does not address degradation, loading process damage

or

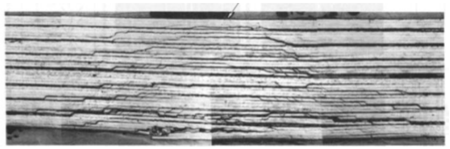
(iii) ***Repeatable and reliable non-destructive inspection techniques*** *must be established that ensure the strength of each joint.'*

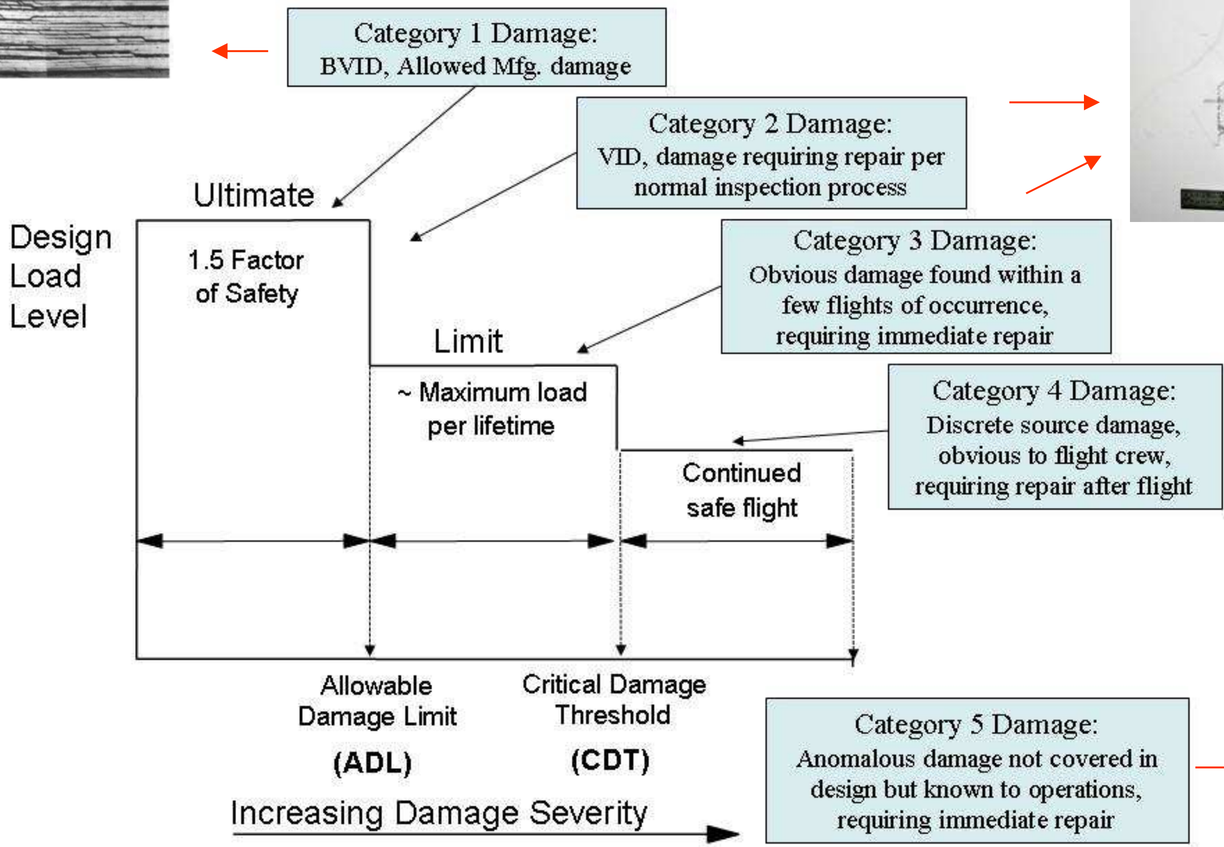
'Weak Bonds' and 'Tight Disbonds'

- *cannot be reliably detected by Visual Inspection*
- *have not been shown to be reliably detected by NDI at a production scale*

Composite Safety Issues

AMC 20-29 Para.8. **PROOF OF STRUCTURE - FATIGUE AND DAMAGE TOLERANCE**





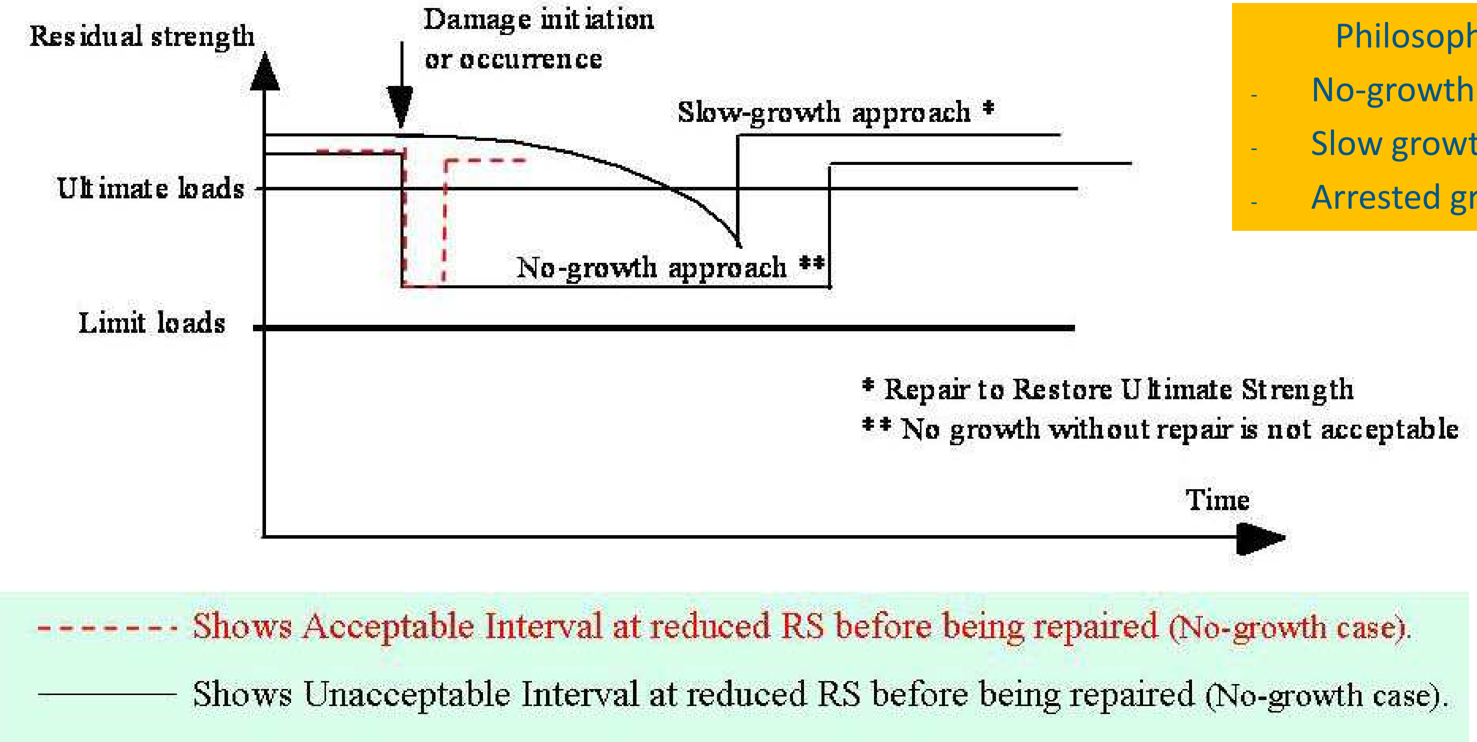
Notes:

1/ Cat 3 Ξ JAA 50 cycle detection

2/ Cat 5 – outside certification

Design Load Levels versus Categories of Damage Severity

AMC 20-29 Para.8. **PROOF OF STRUCTURE - FATIGUE AND DAMAGE TOLERANCE**



Philosophies:
- No-growth (typical)
- Slow growth
- Arrested growth

Figure 4 - Schematic diagram of residual strength illustrating that significant accidental damage with "no-growth" should not be left in the structure without repair for a long time.