European Union Aviation Safety Agency

This project is funded from the European Union's Horizon Europe research and innovation programme.

DESIGN

EVOLUTIONS OF AIRWORTHINESS STANDARDS FOR NEW AIRCRAFT STRUCTURE DESIGN USING MATERIALS, PROCESSES, AND ADVANCED MANUFACTURING METHODS

DESIGN – D-1 – Current industry status report

Report on the current and developing aviation industry (and regulator) experience and practice regarding the use of sandwich structures, including a gap analysis

Date: 05.08.2025 Issue: 1.0

CONTRACT NUMBER - EASA.2024.C10

Disclamer

DELIVERABLE NUMBER AND TITLE: DESIGN-D1-Current industry status report on the current and developing aviation industry (and regulator) experience and practice regarding the use of sandwich structures, including a gap analysis

CONTRACT NUMBER: EASA.2024.C10
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IPR OWNER: European Union Aviation Safety Agency
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Objective

DESIGN – D-1 – Current industry status report

Report on the current and developing aviation industry (and regulator) experience and practice regarding the use of sandwich structures, including a gap analysis.
The project consortium provides a detailed view on industry sandwich part production and standards used to ensure robust, efficient and safe operational use of sandwich parts in aeronautical world-wide applications.
The consortium is a significant contributor in the CMH-17 organization to further enhance safety standards and knowledge sharing.

This project is funded from the European Union's Horizon Europe research and innovation programme.

Abbreviations

AC – Advisory Circular
AD – Accidental Damage
ADL Allowable Damage Limit
AMC – Acceptable Means of Compliance
BVID – Barely Visible Impact Damage
BRSL – Bonded Repair Size Limits
CACRC – Commercial Aircraft Composite Repair Committee
CDT – Critical Damage Threshold
CM Certification Memorandum
DCB-UBM - Double Cantilever Beam with uneven bending moment
DVI – Detailed Visual Inspection
DT – Damage Tolerance
DTA – Damage Threat Assessment
DoSS – Disbond of Sandwich Structure EASA Project
ED – Environmental Damage
ESDA - Energy-Based Sandwich Disbond Analysis
eVTOL - electric Vertical Take-Off and Landing
FD – Fatigue Damage
FEM – Finite Element Method
FOD – Foreign Object Debris or Damage
FSDA - Finite-Element-Based Sandwich Disbond Analysis
GA – General Aviation
GAG – Ground Air Ground Cycle
GSE – Ground service Equipment
GVI – General Visual Inspection
HEWABI - High Energy Wide Area Blunt Impact
IPT – Integrated Product Team
LDC – Large Damage Capability
LEWABI - Low Energy Wide Area Blunt Impact
LL – Limit Load
MLP – Multiple Load Path
NDI – Non-Destructive-Inspection
OEM - Original Equipment Manufacturer
PCS – Process Control Specimen
PS – Policy Statement
PSE Principal Structural Element
SCB – Single Cantilever Beam
SDC - Structural Damage Capability
SLP – Single Load Path
SRM – Structure Repair Manual
S-MMB – Sandwich Mixed Mode Bending
UL – Ultimate Load
VCCT – Virtual Crack Closure Technic
VID – Visible Impact Damage

This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

1. Overview of sandwich structure regulations, guidance, and design practice
    1.1 Certification Rules and Guidance
    1.2 Damage Threat Assessment
    1.3 Design Criteria & Inspection
    1.4 Substantiation with Analysis and Test
2. Industry experience and practice regarding the use of sandwich structures
    1.1 Leonardo
    2.2 Airbus Helicopter
    2.3 Airbus Commercial & other fixed wing OEMs
    2.4 In-Service experience (CACRC)
3. Sandwich structure R&D efforts
4. Summary of aviation sandwich panel related accidents & incidents
5. Sandwich structure safety enhancement gap & opportunity discussion

This project is funded from the European Union's Horizon Europe research and innovation programme.

Overview of Regulations, Guidance, and Design Practice

Certification

- PSEs and critical structure (per AMC 20-29) must meet damage tolerance requirements, typically based on Categories of Damage.
- ACs establish guidance for bonding – relevant to sandwich.
- EASA CM has specific guidance for sandwich structure.
  - e.g., 4-inch impactor, SDC approach
- CMH-17 covers Structural Damage Capability (SDC).

Damage & Defect Threats

- Impact damage threats depend on location and geometry.
  - Can be very different for aircraft vs. helicopters vs. engine.
  - Sandwich is highly sensitive to impact variables.
  - Structural impact surveys are used to establish link between damage threat, visibility, damage state.
- Many sandwich defect threats are related to bonding.
  - Co-bonded vs. Co-cured, potential "weak bonds"

Design Criteria & Inspection

- Criterial for Cat 1 and Cat 2 cover a wide range of accidental damage and defects.
  - *ADLs are also considered for sandwich structure for economic reasons (e.g., for in-service damage resistance).*
- No detrimental damage growth (NDDG) approach is typically used for both Static and Fatigue (includes sandwich disbond).
  - *No local buckling criteria can be used for disbonded face sheets.*
- Criteria for disbonds are key and may depend on inspection.
  - *Design criteria for arrestment are important.*

Substantiation & Engineering Approaches

- Building block testing and analysis are used for substantiation.
- Engineering approaches for sandwich disbond rely on conservative assumptions with repeatable, reliable analysis validated by test that can be efficiently used in design (i.e., design curves).
- Consider combined GAG pressure + mechanical loading for face sheet disbond no-growth (static and fatigue).

This project is funded from the European Union's Horizon Europe research and innovation programme.

Bonding Definitions – EASA Proposal for DESIGN Project

Proposed EASA Generic Bonding Definition for DESIGN Project*

Structural Bonding: A structural joint created by the process of adhesive bonding, comprising of one or more previously-cured composite or metal parts (referred to as adherends). (AMC 20-29).

- Co-Curing, Cocuring – Uncured components cured together in a single step (CM-S-005)
- Co-bonding, Cobonding: The joining together of one previously-cured composite part to an uncured composite part through the curing of the adhesive or the resin of the uncured part. (AC27/29.573). ***See next slide for specific sandwich structure considerations.***
- Secondary Bonding: The joining together, by the process of adhesive bonding, of two or more previously-cured composite parts or metal parts, during which the principal chemical or thermal reaction occurring is the curing of the adhesive itself.

<u>EASA DESIGN Project Position</u>

The application of the terminology above on sandwich part definition and the interpretation in relation to certification regulation is leading to controversial discussions. Recent ongoing discussion on CMH-17 sandwich working group meeting (e.g. TG2) pointed to this open discussion over decades, which resulted in specific application decisions between OEMs and AA.

The EASA DESIGN OEM partners acknowledge EASA's need for a bonding definition applicable within the DESIGN project. The EASA DESIGN project is focused on sandwich disbond-related details and the interpretation of structural bonding and sandwich part definition is outside the project scope and should be addressed, for example, within the ARAC (TAMCSWG) forum and follow-on regulatory guidance.

**Note that these definitions are being proposed for CM-S-005 Issue 02. Also note that the existing bonding definitions from regulatory guidance are summarized on a following slide for reference.*

This project is funded from the European Union's Horizon Europe research and innovation programme.

Considerations for Face Sheet Disbonds in PSE Sandwich Structure

Sandwich structure should be a semi-monocoque design unless experience and reliable process control demonstration show that SDC can be used in lieu of showing limit load for a disbond arresting between design features. It is understood that maintaining limit load capability with a disbond between arrestment features may be impractical for sandwich monocoque designs. In these cases, some mitigation should confirm the redundancy of load path and inherent load redistribution in case of large damage, which can typically be achieved through SDC criteria (see slide 17). For sandwich face sheet disbond, this should lead to Limit Load residual strength capability. Such cases need to be supported by robust manufacturing process controls to minimize the threat of weak bonds. In addition, such cases need to be supported by appropriate test and analysis work, other mitigating actions (in addition to practices indicated in DOT/FAA/AR-99/49 expected of MLP structure, and as also indicated in CM-S-010), including robust interpretation of design, production, and ICA practices, substantiated use of relevant databases, and experience, as agreed with the regulator. Meeting these expectations may be a challenge for organizations new to composites, and bonding in particular.

AMC20-29 section 6.C.3(a) states: “(iii) Repeatable and reliable non-destructive inspection techniques must be established that ensure the strength of each joint.”, which may allow process control specimens to support “reliable non-destructive inspection techniques” and therefore can be used as a mitigating factor to minimize the threat of weak bond.

ARAC 25.571 bonding report [1] states: “ ….inherent SDC for a given design may prove to be a replacement for structural redundancy when specific arrestment features are not required in achieving desired load levels when large, clearly obvious damage is present….”, which also addresses SDC in lieu of demonstrating disbond arrestment between design features for limit load.

ARAC 25.571 final report [2] states: “...use of SLP structure that is non-safe life and subject to in-flight loading is only allowed where multiple load path structure is established to be impractical.” Note for rotorcraft, SLP sandwich PSEs are often used, which has led to acceptance for certification of monocoque sandwich structures as PSE when supported by positive experience, reliable process control, and structural robustness (i.e., SDC as discussed above).

[1] Transport Airplane Metallic and Composite Structures Working Group (TAMCSWG) – Recommendation Report to FAA Structural Bonding” Revision Final, July 29th, 2021.
[2] Transport Airplane Metallic and Composite Structures Working Group (TAMCSWG) – Recommendation Report to FAA” Revision Final, June 27, 2018.

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Bonding Definitions – Existing Regulatory Guidance

EASA AMC 20-29 – Bonding Guidance

27. **Structural Bonding:** A structural joint created by the process of adhesive bonding, comprising of one or more previously-cured composite or metal parts (referred to as adherends).

c. **Structural Bonding.** Bonded structures include multiple interfaces (e.g., composite-to-composite, composite-to-metal, or metal-to-metal), where at least one of the interfaces requires additional surface preparation prior to bonding.

29. **Weak Bond:** A bond line with mechanical properties lower than expected, but without any possibility to detect that by normal NDI procedures. Such situation is mainly due to a poor chemical bonding.

EASA CM-S-0005 Issue 01

Co-bonded Structure	Components bonded together during cure of one of the components.
Co-cured Structure	Uncured components cured together.
Secondary Bond	The joining together, by the process of adhesive bonding of two or more previously-cured composite parts or metal parts, during which the principal chemical or thermal reaction occurring is the curing of the adhesive itself.[6] (CMH-17 Vol. 1 Chapter 1 rev. F)
Structural Bonding	A structural joint created by the process of adhesive bonding, comprising of one or more previously-cured composite or metal parts (referred to as adherends). (AMC 20-29) Also, see the definition of "Co-cured Structure".
Weak Bond	A bond line with mechanical properties lower than expected which cannot be detected reliably using non-destructive inspection (NDI) procedures currently applied by industry. Such situations result from poor chemical bonding.[7] (AMC 20-29)

EASA CM-S-010 Issue 01

Co-bonded structure	Components bonded together during cure of one, or more, of the components, but not all components, e.g. bonding to metallic or a pre-cured component.
Co-cured Structure	Structure obtained by a single cure of uncured components

AC 27.573 / AC 29.573 "Damage Tolerance and Fatigue Evaluation of Composite Rotorcraft Structures"

(11) Cocure. The process of curing several different materials in a single step. Examples include the curing of various compatible resin system pre-pregs, using the same cure cycle, to produce hybrid composite structure or the curing of compatible composite materials and structural adhesives, using the same cure cycle, to produce sandwich structure or skins with integrally molded fittings.

(50) Secondary Bonding. The joining together, by the process of adhesive bonding, of two or more already-cured composite parts, during which the only chemical or thermal reaction occurring is the curing of the adhesive itself. The joining together of one already-cured composite part to an uncured composite part, through the curing of the resin of the uncured part, is also considered for the purposes of this advisory circular to be a secondary bonding operation. (See COCURE).

This project is funded from the European Union's Horizon Europe research and innovation programme.

EASA Example of knowledge sharing

EASA knowledge dissemination by as example rotorcraft workshop or composite webinar

- Regulatory Framework
- Industry Guidance Development activities
- CMH-17 activities
- R&D efforts

- Presentation available for download at EASA web page

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EASA Rules and Regulations & Product Types

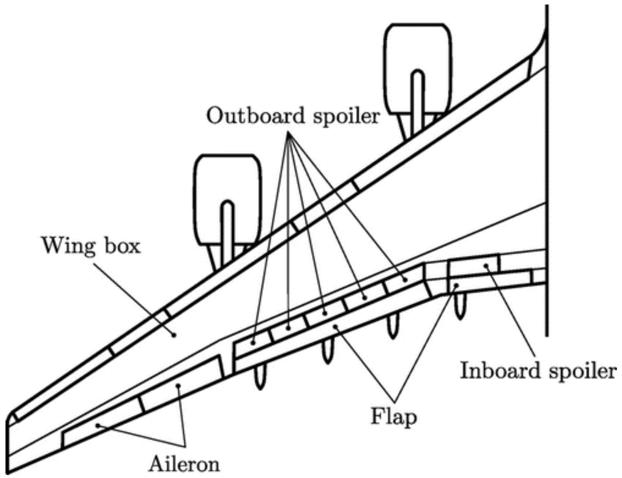
Focus is often on CS-25 aircraft, but rotorcraft structure, rotor blades, and engine nacelles have unique aspects. There are also new applications that use a mix of types (e.g., eVTOL).

General Procedures

- Part 21 – Easy Access Rules for Initial Airworthiness and Environmental Protection (Regulation (EU) No. 748/2012)

Aircraft Types (Airworthiness Standards)

- CS-23: Normal, Utility, Aerobatic and Commuter Aeroplanes
- CS-25: Large Aeroplanes
- CS-27: Small Rotorcraft
- CS-29: Large Rotorcraft



Other Product Types

- CS-E: Engines
- CS-P: Propellers

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Regulatory Guidance for Sandwich Composite Structures

FAA Advisory Circulars (AC)

- FAA AC 20-107B "Composite Aircraft Structure" (harmonized with EASA AMC 20-29)

Main guidance for composites, generic for all types of aircraft and rotorcraft

- FAA AC 29-2C "Certification of Transport Category Rotorcraft" (see Change 4, Subpart C, AC 29.573, which replaced MG8)
- FAA AC 27-1B "Certification of Normal Category Rotorcraft" (see Change 4, Subpart C, AC 27.573)

Some rotorcraft-specific aspects for composites but mostly covered by AMC 20-29

FAA Policy Statements (PS)

- PS-AIR-20-130-01 "Bonded Repair Size Limits" (BRSL) (harmonized with EASA CM-S-005 Issue 01)

Requires limit load for a failed bonded repairs between constraints of the arresting design features, including due to weak bonds.

- PS-ANM-25-20 "High-Energy Wide-Area Blunt Impact for Composite Structures"

Includes sandwich-specific guidance regarding core crush and springback

EASA Certification Memorandum (CM)

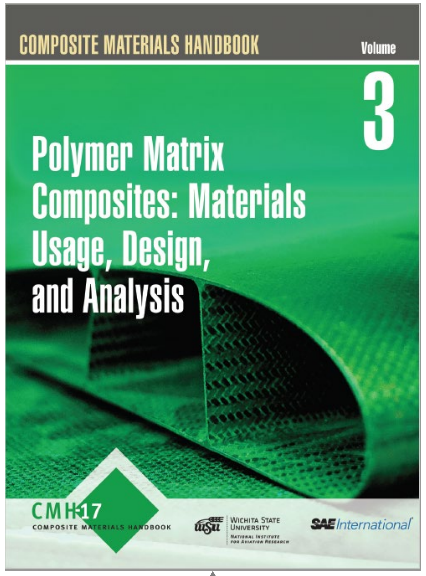
- CM-S-010 Issue 01 "Composite Materials - The Safe Design and Use of Monocoque Sandwich Structures in Principal Structural Element Applications"

Specific guidance for monocoque sandwich structure

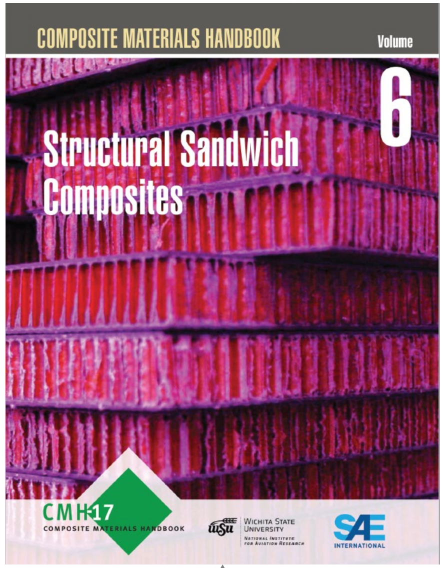
This project is funded from the European Union's Horizon Europe research and innovation programme.

Other Guidance – CMH-17 Volume 3 Chapters

1. General Information
2. Introduction to Composite Structure Development
3. **Aircraft Structure Certification and Compliance**
4. **Building Block Approach For Composite Structures**
5. Materials and Processes
6. Quality Control of Production Materials and Processes
7. Design of Composites
8. Analysis of Laminates
9. Structural Stability Analyses
10. Design and Analysis of Bonded Joints
11. Design and Analysis of Bolted Joints
12. **Damage Resistance, Durability, and Damage Tolerance**
13. **Defects, Damage, and Inspection**
14. **Supportability, Maintenance, and Repair**
15. Thick-section Composites
16. Crashworthiness and Energy Management
17. Structural Safety Management
18. ...



Main Durability and Damage Tolerance Content (Rev H).



Major updates in-work with specific coverage for sandwich disbond (Rev A)

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Categories of Damage and Load Requirements

Categories of Damage (per AC 20-107B)

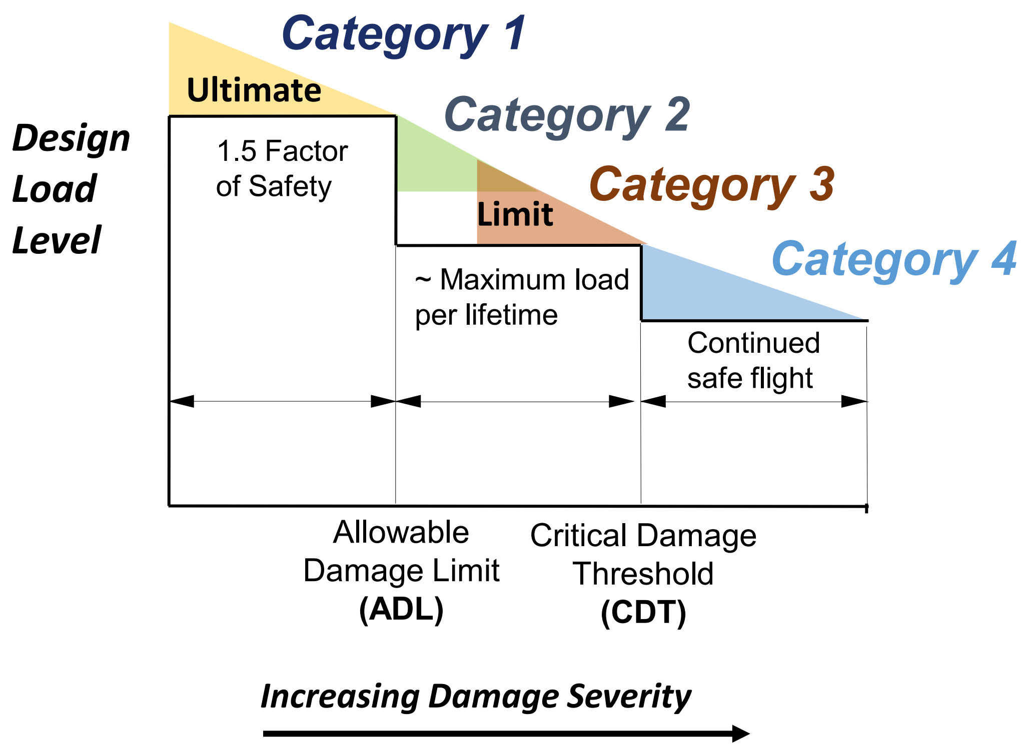
- Categories of Damage depend on damage or defect detectability and the ability to find it with the selected inspection method.
  - Varies depending on configuration, material and inspection type
- Other considerations (based on Category):
  - Repeated loads (Cat 1, Cat 2, and limited Cat 3)
  - Stiffness and flutter (Cat 1, Cat 2, Cat 3, Cat 4 - CSFL)
  - Critical vs. typical environment

Considerations for Sandwich Structure

FOCUS

- Bondlines – sandwich face sheet-to-core interface can be considered a bonded joint, disbonds occur due to damage or processing issues.
- Impact damage threats – relationship between impact variables and resulting damage visibility is complex.
- Economic issues – damage resistance often drives Cat 1 allowable damage limits (ADLs) for fixed and removable primary structure (e.g., for hail damage).

Load Requirements for Categories of Damage*



***Applies to Principal Structural Elements (PSEs) and Critical Structure (per EASA AMC 20-29)**

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Categories of Damage and Defects – Definitions

Category	Examples (not inclusive of all damage types)
Category 1: Allowable damage that may go undetected by scheduled or directed field inspection (or allowable mfg defects)	Barely visible impact damage (BVID), scratches, gouges, minor environmental damage, and allowable mfg. defects that retain ultimate load for life
Category 2: Damage detected by scheduled or directed field inspection @ specified intervals (repair scenario)	VID (ranging small to large), deep gouges, mfg. defects/mistakes, major *local* heat or environmental degradation that retain limit load until found
Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)	Damage obvious to operations in a "walk-around" inspection or due to loss of form/fit/function that must retain limit load until found by operations
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)	Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning, exploding gear tires, severe in-flight hail)
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	Damage occurring due to rare service events or to an extent beyond that considered in design, which must be reported by operations for immediate action

Cat 1 and Cat 2 can include sandwich face sheet disbond (with fatigue + GAG pressure loading)*

Cat 3 is "obvious" damage that will be found in a few flights (limited fatigue)

Cat 4 - Cat 5 will typically trigger conditional inspections (no fatigue)

***Weak bonds between arrestment features may fall under Cat 2 depending on selected damage and defect design criteria and selected inspection methods.**

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Structural Damage Capability (SDC) & Fail-Safety

CMH-17 V3 – 12.3.2.5 Structural damage capability (SDC)

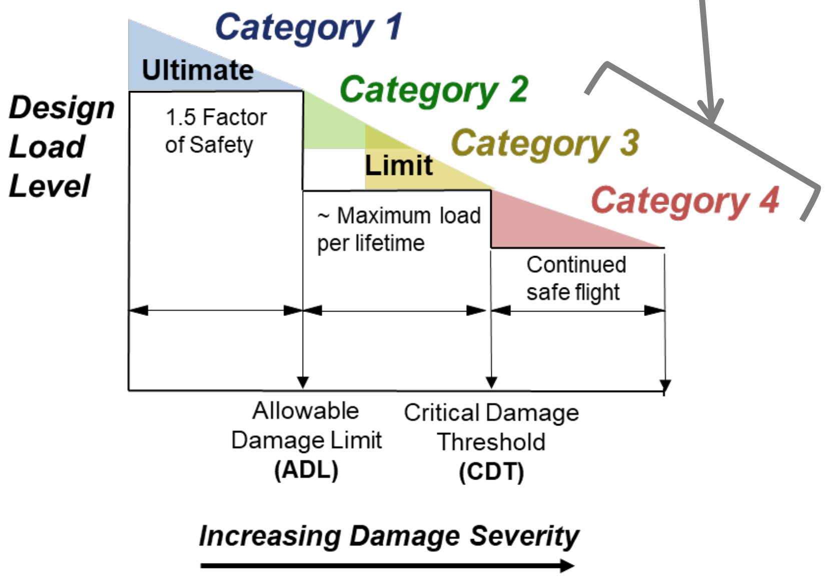
- OEM criteria that do not generate additional inspection.
- "...SDC criteria leads to structural configurations that in the event of a certain level of damage, the remaining intact structure is capable of carrying the applicable residual strength loads and can provide arrestment of damage growth before catastrophic failure..."
- "SDC is also used to: **1)** address the complexities and uncertainties of accidental impact damage (size vs. detectability, impactor variables, etc.), **2) ensure that very rare local weak bonds will not cause catastrophic failure**, and **3)** address possible interactions between damage threats."

Considerations for Sandwich Structure

- Bondlines – SDC can be used to cover sandwich disbond between arrestment features even if not a regulatory requirement**.**
- Impact and other threats –SDC can be used to cover complex damage from accidental impact, fluids, water ingression, heat damage, etc.

Structural Damage Capability (SDC) Criteria

SDC is good design practice that can cover more complex damage scenarios for Cat 3 and Cat 4.



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Structural Damage Capability (SDC) for Robust Design

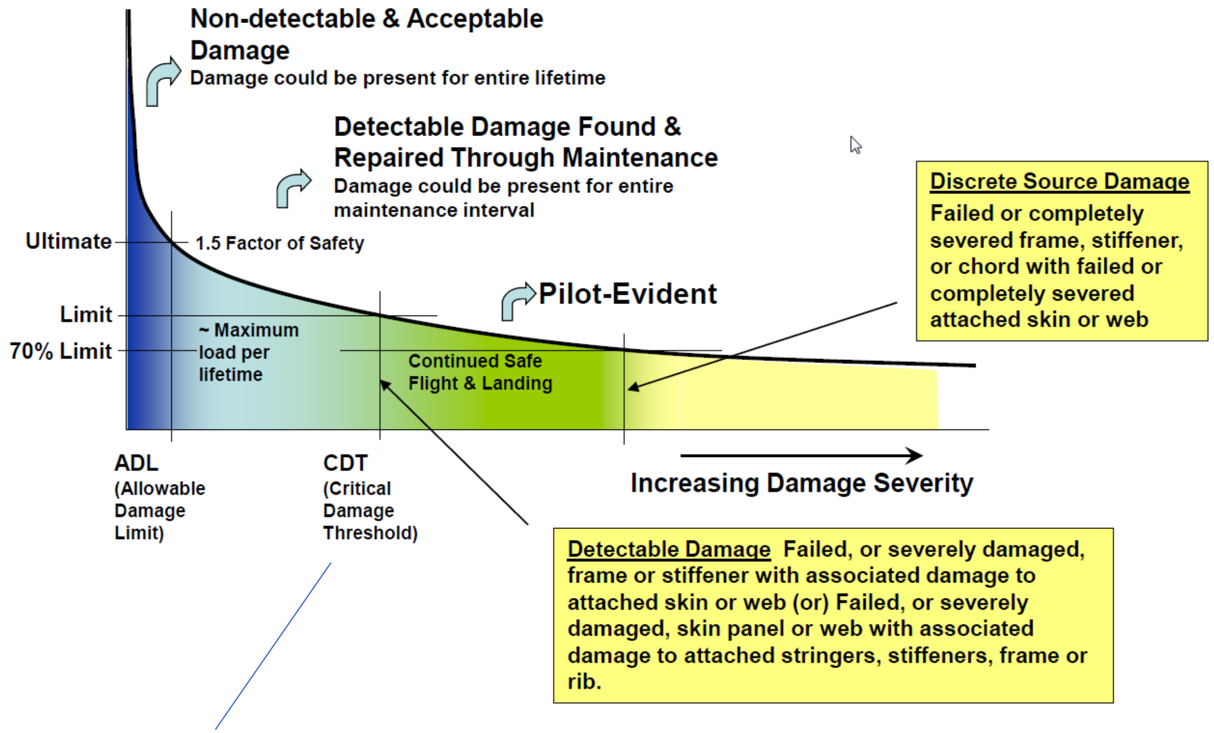
CMH-17 V3 – 12.3.2.6 Relationships among categories...

- "As shown in the figure, **the combination of damage design criteria used results in a <u>near "flat" residual strength curve for severe damage</u> such that a large increase in damage severity beyond the Critical Damage Threshold (CDT)** results in a small reduction in the residual strength capability."
- "In this example, this desired **shape of the residual strength curve is achieved by the application of a Limit Load requirement for "Detectable Damage".**

Sandwich Considerations

- **Criteria for <u>weak bonds</u>** between arrestment features and **<u>SDC</u> criteria** can both be used to drive **robust, fail-safe (<u>multi-load path</u>) sandwich structures**.
- <u>"Monocoque"</u> sandwich structures without design features to break up panels or arrest damage/disbond growth <u>need careful evaluation</u> (see EASA CM-S-010) to avoid "falling off a cliff" at large damage sizes.

SDC criteria will typically lead to designs with <u>multi-load path</u> structure (fail-safety)!



<u>Note:</u> For rotorcraft, the minimum residual strength is Limit Load capability.

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FAA AC 20-107B / EASA AMC 20-29 – Sandwich Guidance

9. Proof of Structure – Flutter and Other Aeroelastic Instabilities. The aeroelastic evaluations, which includes flutter, control reversal, divergence, and any undue loss of stability and control as a result of structural loading and resulting deformation, are required. Flutter and other aeroelastic instabilities must be avoided through design, quality control, maintenance, and systems interaction.

a. The evaluation of composite structure needs to account for the effects of repeated loading, environmental exposure, and service damage scenarios (e.g., large Category 2, 3 or 4 damage) on critical properties such as stiffness, mass, and damping. Some control surfaces exposed to large damage retain adequate residual strength margins, but the potential loss of stiffness or mass increase (e.g., sandwich panel disbond and/or water ingression) may adversely affect flutter and other aeroelastic characteristics. This is particularly important for control surfaces that are prone to accidental damage and environmental degradation. Other factors such as the weight or stiffness changes due to repair, manufacturing flaws, and multiple layers of paint need to be evaluated. There may also be issues associated with the proximity of high temperature heat sources near structural components (e.g., empennage structure in the path of jet engine exhaust streams or engine bleed air pneumatic system ducting). These effects may be determined by analysis supported by test evidence, or by tests at the coupon, element or subcomponent level.

The only sandwich-specific guidance in the AC addresses stiffness and flutter issues related to sandwich disbond (i.e., adequate residual strength also means being good for flutter).

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FAA AC 20-107B / EASA AMC 20-29 – Bonding Guidance

27. Structural Bonding: A structural joint created by the process of adhesive bonding, comprising of one or more previously-cured composite or metal parts (referred to as adherends).

c. Structural Bonding. Bonded structures include multiple interfaces (e.g., composite-to-composite, composite-to-metal, or metal-to-metal), where at least one of the interfaces requires additional surface preparation prior to bonding.

29. Weak Bond: A bond line with mechanical properties lower than expected, but without any possibility to detect that by normal NDI procedures. Such situation is mainly due to a poor chemical bonding.

(3) 14 CFR § 23.573(a) sets forth requirements for substantiating the primary composite airframe structures, including considerations for damage tolerance, fatigue, and bonded joints. Although this is a small airplane rule, the same performance standards are normally expected with transport and rotorcraft category aircraft (via special conditions and issue papers).

(a) For any bonded joint, § 23.573(a)(5) states in part: "*the failure of which would result in catastrophic loss of the airplane, 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) 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 (ii) Proof testing must be conducted on each production article that will apply the critical limit design load to each critical bonded joint; or (iii) Repeatable and reliable non-destructive inspection techniques must be established that ensure the strength of each joint.*"

Definitions for structural bonds discussing pre-cured parts and required surface prep.

Defines weak bonds that can't be found with production NDI.

Specifies limit load for disbonds between arrestment (design) features or must do proof testing or have NDI that can find weak bonds.

Note that proof testing is questionable for bonding and does not evaluate all load cases, fatigue loading, or durability.

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EASA CM-S-010 Issue 01 – Bonding Requirements

Co-bonded structure	Components bonded together during cure of one, or more, of the components, but not all components, e.g. bonding to metallic or a pre-cured component.
Co-cured Structure	Structure obtained by a single cure of uncured components
Monocoque	Thin shells which rely entirely upon the skins for the capacity to resist loads (Megson). Note: For the purposes of this CM a sandwich structure forming a shell comprising 2 skins and a core (e.g. fuselage or tail boom) is considered to be the 'thin shell', and thus described as a monocoque.

Specific to "monocoque" sandwich structure in PSE applications but also provides general guidance and approaches for multi-load path sandwich structure.

For example, to be confident regarding likely damage modes resulting from impact threats, it is considered to be appropriate to test throughout the threat impact energy range up to readily detectable damage using a range of appropriate impactor geometries, e.g. including sharp impactors and blunt impactors up to diameters agreed with EASA, e.g. for CS25, a range of impactors up to 4 inches diameter have been accepted, based upon typical protection device geometries carried by ground vehicles. Furthermore, it may be appropriate to consider a range of impactor stiffnesses, e.g. for hail, or ground vehicle rubber bumpers, such that all competing damage modes can be identified. Representative boundary conditions should be used in the substantiation test campaigns.

- **Guidance on impact energies and impactor types.**
- **Makes link between ground service equipment (GSE) and 4" impactors**

Note: In some cases, it may be possible to conservatively bound many damage types, and thus reduce the detailed substantiation workload, by demonstrating a larger structural damage capability. However, this will require demonstration that all likely damage modes have been bounded by the structural damage capability assumption, e.g. a large penetration could be used to address all likely damage modes within the bounds of the penetration.

- **Covers the use of SDC to conservatively bound many damage types**

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AC 27.573 / AC 29.573 "Damage Tolerance and Fatigue Evaluation of Composite Rotorcraft Structures"

(D) The use of composite secondary bonding in manufacturing or maintenance requires strict process and quality controls to achieve the reliability needed to use such technology in critical structures (see AC 21-26). Assuming good process and quality controls, service history has shown that additional damage tolerant design considerations are also needed to ensure the safety of structure with secondary bonds (i.e., random, but an unacceptable number of weak bonds discovered in service). Unless the ultimate strength of each critical bonded joint can be reliably substantiated in production by NDI techniques (or other equivalent, approved techniques), then the limit load capability should be ensured by any or a combination of the following:

(1) Consider isolated disbonds and weak bonds (represented by zero bond strength) in structural elements that use secondary bonding for primary load transfer. The associated disbond size should be up to the limitations provided by redundant design features (i.e., mechanical fasteners or a separate bonding detail). The structure containing such damage should be shown to carry limit load by tests, analyses, or some combination of both. For purposes of test or analysis demonstration, each disbond should be considered separately as a random occurrence (i.e., it is not necessary to demonstrate residual strength with all structural elements disbonded simultaneously).

(2) Each critical bonded joint on each production article should be proof-tested to the critical limit load.

(3) Critical bonded joints that have high static margins of safety (e.g., some rotor blades) may be accepted based on satisfactory service history of like or similar components.

Rotorcraft-specific ACs are generally consistent with EASA AMC 20-29 with limit load for disbonds between redundant design (arrestment) features (i.e., multi-load path).

However, co-cured sandwich structure is not considered bonded structure for the purpose of the AC.

Needs further discussion and standardization!

(11) Cocure. The process of curing several different materials in a single step. Examples include the curing of various compatible resin system pre-pregs, using the same cure cycle, to produce hybrid composite structure or the curing of compatible composite materials and structural adhesives, using the same cure cycle, to produce sandwich structure or skins with integrally molded fittings.

(50) Secondary Bonding. The joining together, by the process of adhesive bonding, of two or more already-cured composite parts, during which the only chemical or thermal reaction occurring is the curing of the adhesive itself. The joining together of one already-cured composite part to an uncured composite part, through the curing of the resin of the uncured part, is also considered for the purposes of this advisory circular to be a secondary bonding operation. (See COCURE).

This project is funded from the European Union's Horizon Europe research and innovation programme.

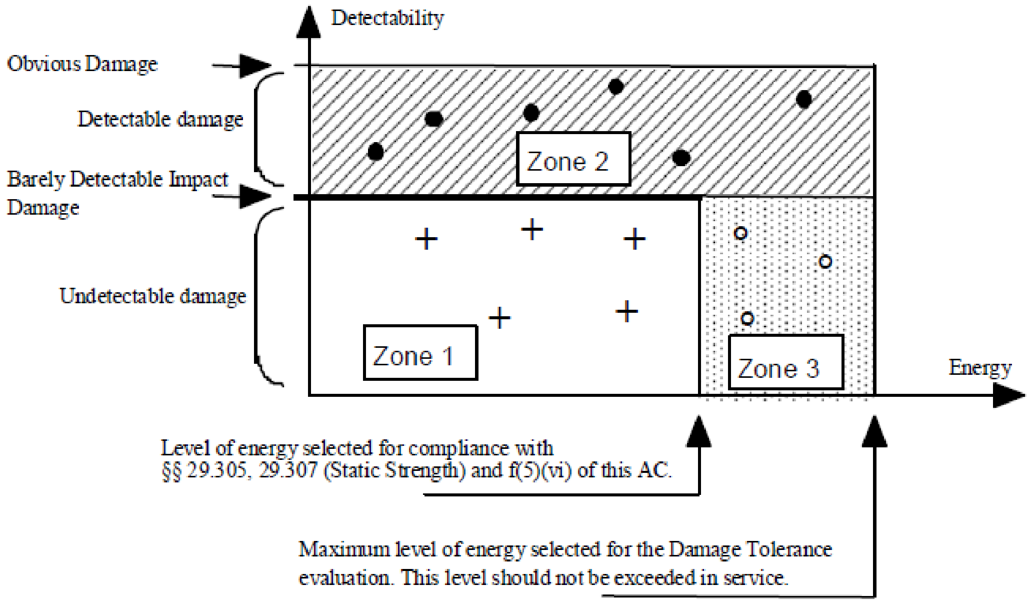
AC 27.573 / AC 29.573 “Damage Tolerance and Fatigue Evaluation of Composite Rotorcraft Structures” (cont’d)

Zone 3: Since the damage is not detectable with the proposed in-service inspection procedures, ultimate load capability is required, unless an alternate procedure can show an equivalent level of safety. For example, residual strength lower than ultimate may be used in association with improved inspection procedures or with a probabilistic approach showing that the occurrence of energy levels is low enough so that an acceptable level of safety can be achieved.

Of the three zones, only Zone 3 may have a residual strength requirement that can vary with alternate procedures or the probability of damage occurrence or both. In either case, any compromise for residual strength requirements less than the ultimate load requirement should only be considered when pursuing one of the options under the damage tolerant fail-safe means of compliance, as described in the following section, f.(6)(iii)(B). One example of the use of alternate procedures is for the rare damage threat from a high energy, blunt impact (e.g., service vehicle collision). Depending on the selected maintenance inspection scheme, such damage may fall under Zone 3. When considering such damage in the design of a part, it may be shown to be damage tolerant fail safe, even though the damage is not detectable, based on a very low probability of occurrence. As a result, the design may have sufficiently high residual strength (e.g., below Ultimate, but well above limit load capability to ensure safety without detection for long periods of time). If it is further determined that such impact events usually occur with the knowledge of maintenance or aircraft service personnel, then the alternate procedures may be added to the Instructions for Continued Airworthiness. For example, advanced inspection methods, which can detect damage from high-energy blunt impacts, may be used as alternate procedures to minimize the risk of catastrophic failure for such Zone 3 damage.

Rotorcraft-specific ACs discuss <u>blunt impact</u>, including residual strength, inspection, and Instructions for Continued Airworthiness.

Can be related to the guidance in EASA CM-S-010 for impact from Ground Service Equipment (GSE).



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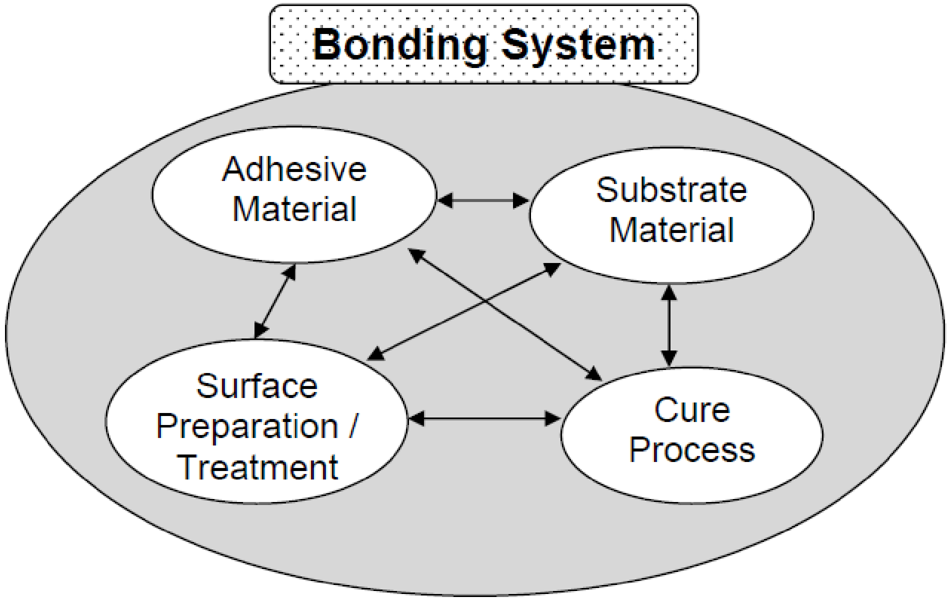
Structural Bonding as a System*

- Following AC20-107B/ AMC 20-29, CS 25.601, CS 25.603, CS 25.605 and AC 21-26A
  - Note: In addition to processing aspects, the assessment should also consider static, fatigue, and damage tolerance.

- Investigate the compatibility of each constituent "before" a bonding system can be used for a new structural application
  - If one or more of the key constituents are changed, the combination is considered to be a "new" bonding system
  - Consider mode I and mode II tests for all applicable environments

- The performance of the combined bonding system may be affected by process variations within each of the constituent categories



** "Structural Bonding Requirements for Composite Structure", Boeing/Airbus/Bombardier Group Presentation, 2016*

This project is funded from the European Union's Horizon Europe research and innovation programme.

Structural Bonding – Industry Practice*

Understand bonding system's sensitivity to the process variations. Establish appropriate process window for robust bonding system.

- Structural Bonding Process
  - "A qualified bonding process is documented after demonstrating repeatable and reliable processing steps such as surface preparation. It entails understanding the sensitivity of structural performance based upon expected variation permitted per the process. Characterization outside the process limits is recommended to ensure process robustness."
  - "Many bond failures and problems in service have been traced to invalid qualification or insufficient quality control of production processes."
  - "Shear test do not provide a reliable measure of long-term durability and environmental degradation associated with poor bonding processes (i.e. lack of adhesion). Some type of peel test has proven more reliable for evaluating proper adhesion." Establish proper test procedure to assess bonding system
  - "Adhesion failures, which indicate lack of chemical bonding between substrate and adhesive materials, are considered an unacceptable failure mode in all test types." Establish mode of failure as structural bonding requirement

* *"Structural Bonding Requirements for Composite Structure", Boeing/Airbus/Bombardier Group Presentation, 2016*

This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

1. Overview of sandwich structure regulations, guidance, and design practice
    1.1 Certification Rules and Guidance
    1.2 Damage Threat Assessment
    1.3 Design Criteria & Inspection
    1.4 Substantiation with Analysis and Test
2. Industry experience and practice regarding the use of sandwich structures
    2.1 Leonardo
    2.2 Airbus Helicopter
    2.3 Airbus Commercial & other fixed wing OEMs
    2.4 In-Service experience (CACRC)
3. Sandwich structure R&D efforts
4. Summary of aviation sandwich panel related accidents & incidents
5. Sandwich structure safety enhancement gap & opportunity discussion

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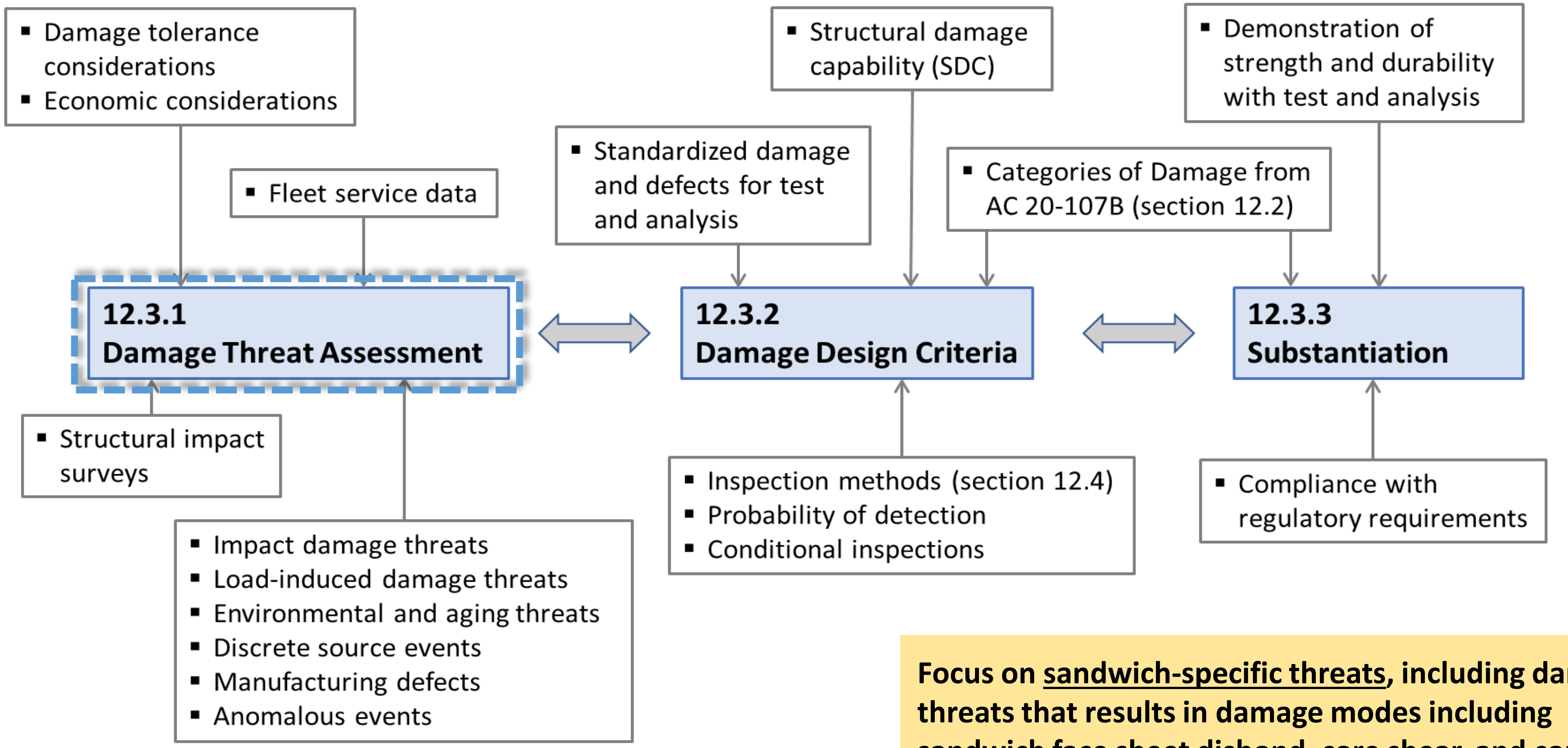
Damage Threat Assessment*



Focus on <u>sandwich-specific threats</u>, including damage threats that results in damage modes including sandwich face sheet disbond, core shear, and core crush (see later slide for additional damage modes)

**Ref. CMH-17 V3, 12.3 Design Development and Substantiation*

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Damage Threat Assessment (DTA) for Sandwich Structure

CMH-17 V3 – 12.3.1 Damage Threat Assessment

- *"...manufacturing and operational threats can be classified according to four broad areas as identified in AC 20-107B:* ***manufacturing threats, fatigue damage (FD), environmental deterioration (ED), and accidental damage (AD)****."*

General Considerations

- DTA is used to set impactor sizes and shapes.
- DTA can be used to set energy level cutoffs.
  - Often used for Cat 1, may not be relevant for many sandwich structures since cutoff energies may produce through-damage.
  - For Cat 2, normally increase energy until visible with larger diameter impactors (2-4").
- Zoning approach is typically used for each component based on specific threats identified.
  - A probability approach can be used to set energy levels by location.
- Structural impact surveys used to establish link between damage threat, detectability, and damage severity.

Key sandwich damage threats*:

- Accidental impact (e.g., tool drop, FOD)
- Ground service equipment (GSE), larger impactor diameters for Cat 2/VID
- Hail, in-flight and ground
- Manufacturing defects including weak bonds (if considered a bond!)
- Aging and durability threats (including thermal cycling, fatigue)
- Moisture ingression (design details)
- Overheating (nacelles, rotorcraft exhaust zones)
- Step loads (no step zones)
- Lightning and bird strike
- Tire rupture (flaps)
- Repair (sandwich panels, main rotor blades), consider BRSL Policy Statement

**Also identify which threats trigger Conditional Inspection (found and repaired before further flight, affects design criteria).*

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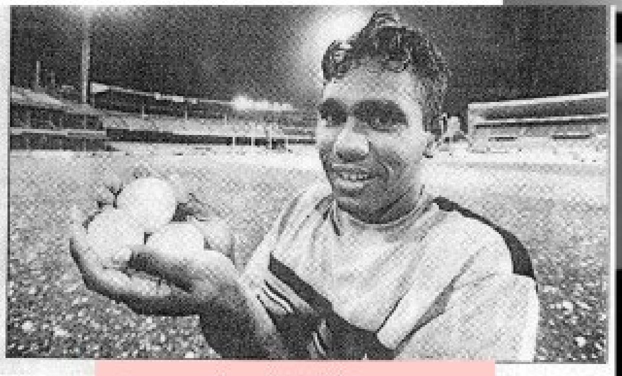
Damage Threats from Ground Service Equipment (GSE)

- <u>Sandwich structure</u> is particularly exposed to GSE (control surfaces, nacelles, winglets.
    - *Typical GSE damage threats include a <u>wide range of impactor geometries, velocities, and energies</u>.*
    - *Diameters of <u>2-4”</u> have been used for <u>VID</u> (ref. EASA CM-S-010).*
- <u>Helicopters</u> have unique exposure to GSEs (as do business jets, small aircraft, and eVTOL applications).
    - *Large vehicles have limited access near structure.*
    - *High Energy Wide Area Blunt Impact (HEWABI) may be less relevant (low energy blunt impact sometimes used instead, see AC 27.573 and 29.573 on earlier slide)*

This project is funded from the European Union's Horizon Europe research and innovation programme.

Damage Threats from Hail Strike

- Consider both <u>in-flight hail</u> and <u>ground hail</u>.
- Often triggers <u>conditional inspection</u>.
- If damage is found during the conditional inspection, need <u>NDI to find extent of damage</u> (can be tap test, e.g., thin face sheets).
- For large transport aircraft, ground hail threats typically also consider <u>economics</u> in terms of damage resistance and allowable damage limits (<u>ADLs</u>) and depend on types of structure. For example, for transport category aircraft:
  - *Fixed primary, fixed secondary*
  - *Removable primary, removable secondary*
- CMH-17 V3 – Content
  - *12.3.2 Damage design criteria*
  - *12.5.2.5 Ground hail*



Example of Hail Damage from 1999 Sydney Storm

Dents on Boeing 777 Aft Flap (thin skin metal bonded sandwich)

Dents and Punctures on Boeing 757 Inboard Aft Flap (thin skin of composite sandwich)

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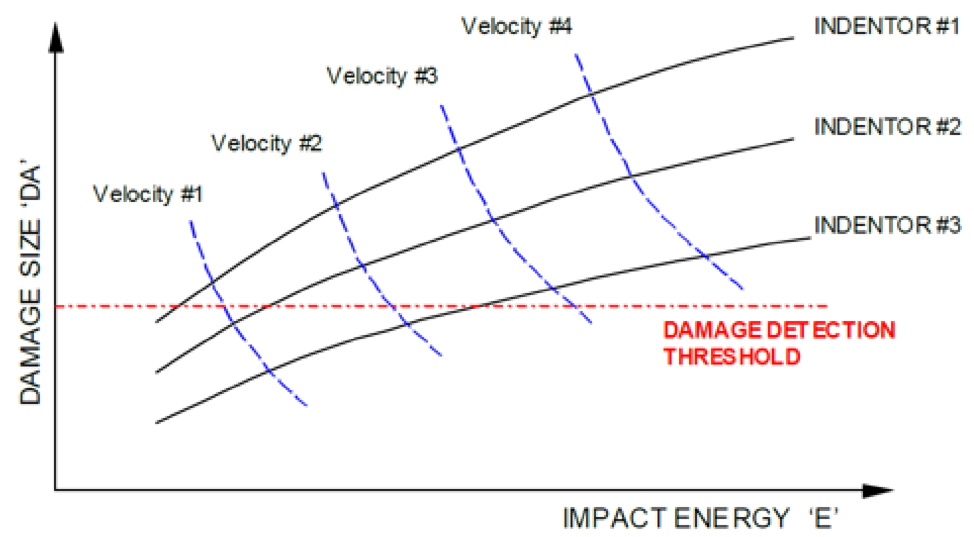
Impact Surveys – Sensitivity to Impact Variables

CMH-17 V3 – 12.5.1.8 Sandwich structure*

- CMH-17 section discusses unique aspects of sandwich impact and associated failure modes.
  - **Springback** – strongly affects visibility
  - Face sheet thickness effects
  - Core density and thickness effects
  - Sensitivity to impactor diameters and shapes
  - Interaction of damage modes, e.g., core damage leads to face sheet instability.
  - Panel size and boundary conditions
  - Panel curvature
- The figure shows an example of how the results of a sandwich panel impact study can be used to understand relationship of impact variables to damage sizes and detectability.

Ref. CMH-17 V3, 12.5 Damage Resistance

Impact Survey Showing Sensitivity of Sandwich to Impact Variables



The relationship between impact variables and resulting damage detectibilty can be more complex for sandwich structures than for solid laminates.

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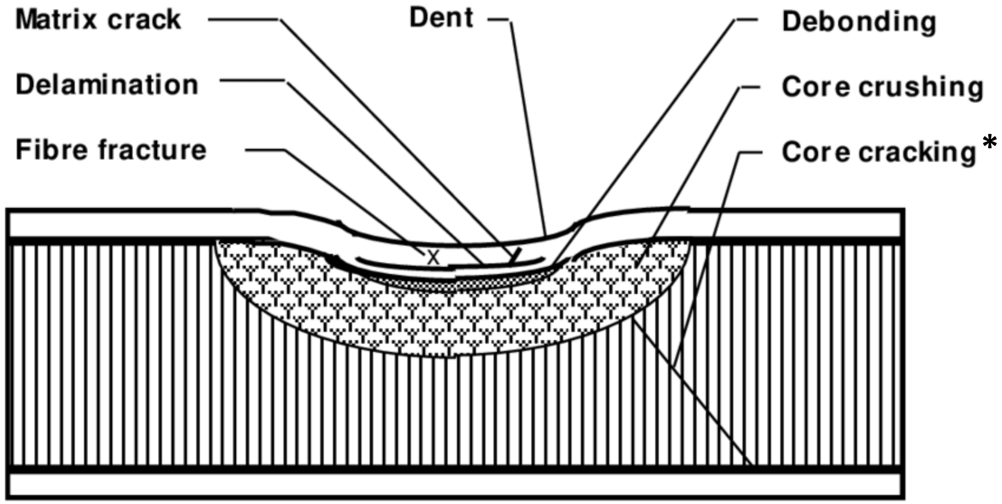
Impact Surveys – Damage and Failure Modes

Sandwich Damage Modes for Impacts

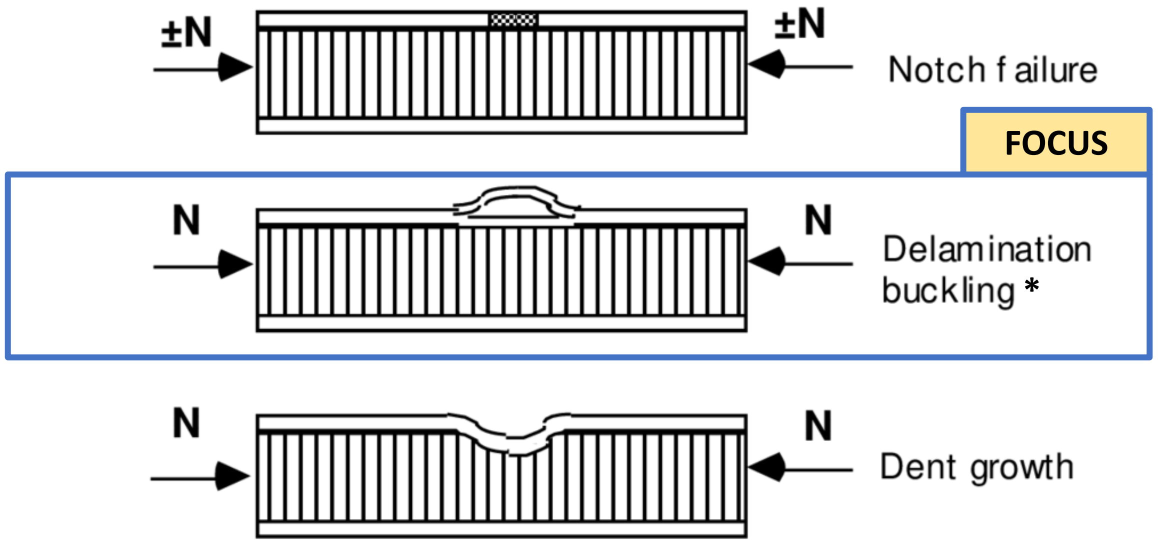
- Impact damage may results in a complex combination of damage modes.
- Important to understand detectability of each damage mode.
  - Consider both visual inspection and NDI.
  - Consider face sheet springback!
  - Some core damage types may be difficult to find.



**May also occur as "core shear" (vertical shear plane)*

Sandwich Failure Modes from Impact Damage

- Three typical failure modes (there are many more).
- Sandwich disbond is associated with face-sheet-to-core interface failure.
  - *Can be a delamination in the face sheet and/or a complete face sheet disbond.*



Can be a delamination in the face sheet and/or a face sheet disbond

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Outline

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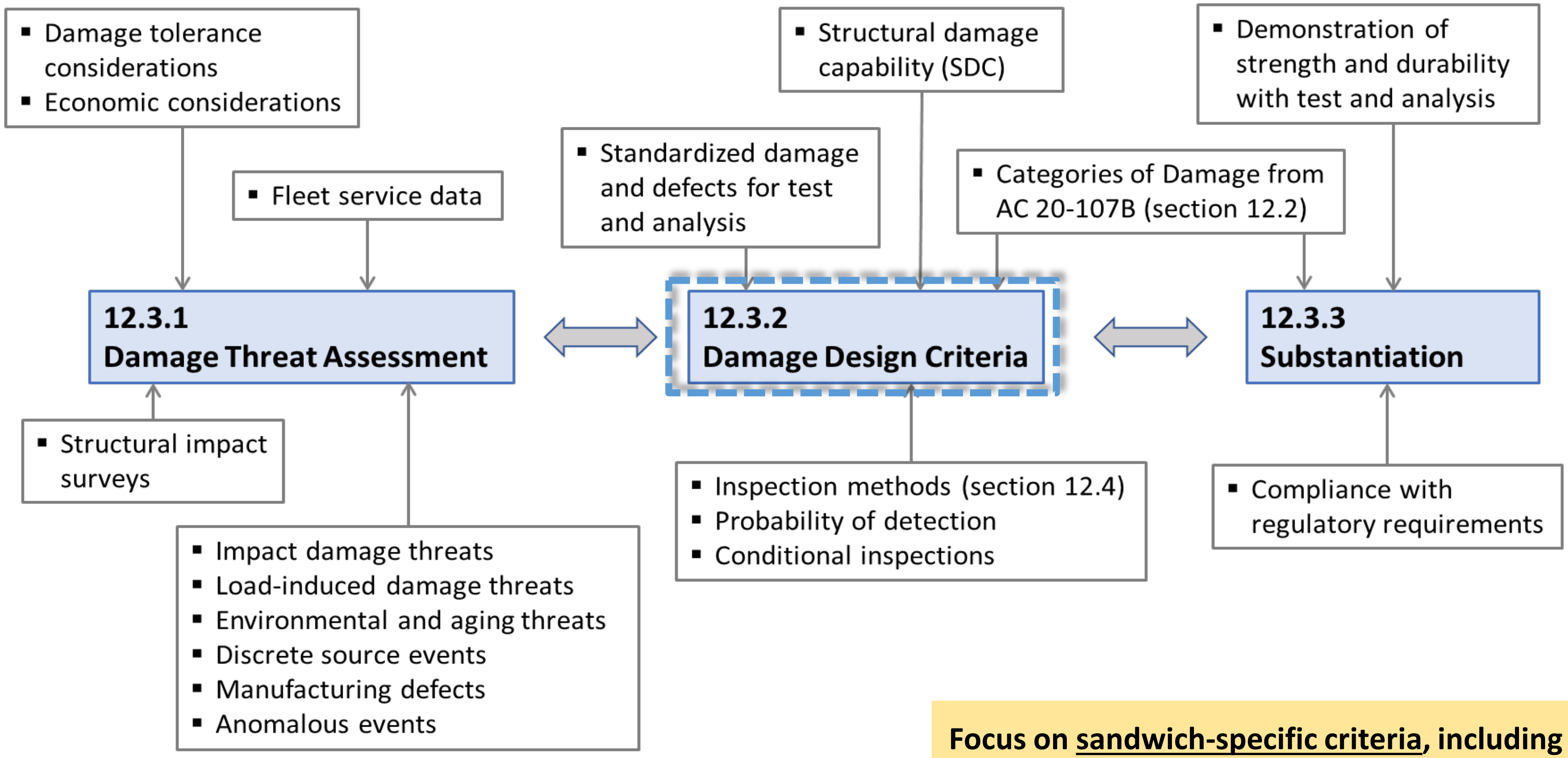
Design Criteria & Inspection*



Focus on sandwich-specific criteria, including criteria for sandwich face sheet disbond.

**Ref. CMH-17 V3, 12.3 Design Development and Substantiation*

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Sandwich Structure Design Criteria

Stiffness Loss and Flutter

- Any structure requiring limit load residual strength or higher must also retain adequate stiffness to maintain aero-elastic stability to avoid flutter.
- Flutter is also considered in Cat 4 with respect to CSF&L (per AC25-571-1D)

Secondary Structure

- Parts departing airplane
- Economic considerations

Engines

- Overheating
- Corrosion, erosion
- Fluids

Other Sandwich Design Issues

- Carefully design sandwich structures and associated design details such as core ramps and inserts.
- Evaluate design details for potential water ingress.
- Establish design guidelines for minimum core densities, minimum face sheet thicknesses, etc.

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Design Criteria for Sandwich Disbond – Size Criteria

Disbond Size Criteria for Accidental Damage

- Selected disbond sizes often cover a range of impact damage threats and resulting damage states based on impact surveys.
  - May also cover other damage threats (e.g., heat damage, water ingress).
- Cat 1 vs. Cat 2 based on detectability and ADLs.
  - Cat 2 if can be found with in-service inspection, otherwise Cat 1.
  - Larger damage sizes may be used for Cat 1 to increase ADLs for economic reasons (e.g., hail damage).
- Disbond no-growth criterion typically used for both Static and Fatigue.

- **Simplified disbond size criteria are often used to cover range of threats.**
- **Typical ~2-6" diameter disbond may be appropriate for Cat 1 or Cat 2 impact damage depending on inspection type and ADLs.**

Disbonds Size Criteria for Weak Bonds & Process Failures

- For weak bonds (undetected in production) – disbond size criteria is set between arrestment features (bonded joint criteria).
- Cat 1 vs. Cat 2 based on what can be found with in-service inspection?
  - See later slide regarding inspection
- Alternatively, SDC criteria can be used to drive robust, multi-load path design (and cover Cat 3 and Cat 4).

- **Criteria based on regulatory guidance for bonded joints.**
- **Arrestment features are key (see later slide).**

Note that the weak bond criterion might cover the other Cat 2 disbonds (if so, what is role of ~4" disbond if good between arrestment?)

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Design Criteria for Sandwich Disbond – In-Service Inspection

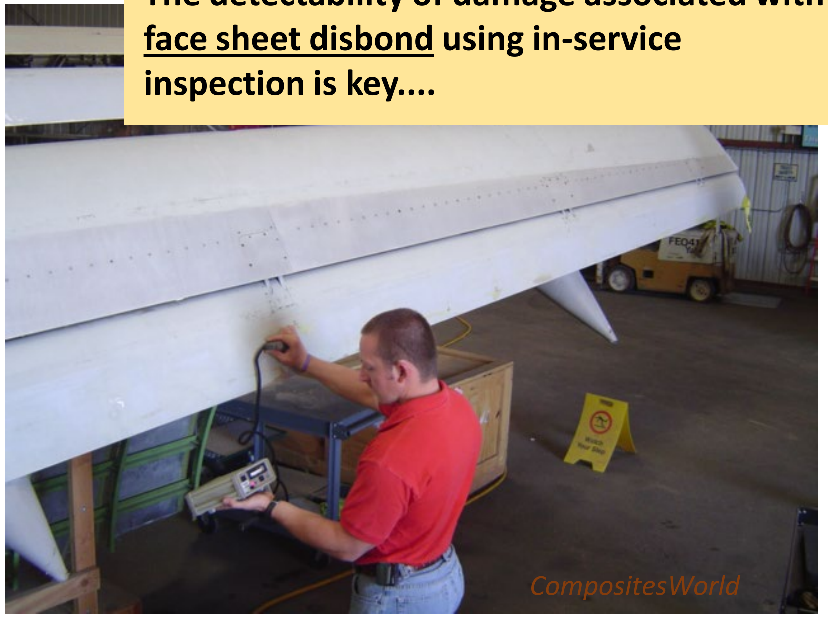
How In-Service Inspection Relates to Disbond Criteria

- Treating sandwich disbonds as Cat 2 damage requires that they can be reliably found during in-service inspection.
  - If the disbond is caused by impact or other accidental damage, the damage may be visible with GVI or DVI, which in turn would trigger an NDI inspection of the damage area to determine the disbond size.
- If the accidental damage cannot reliably be found with planned in-service inspection, it must be covered by Cat 1 (or must be found Unplanned Inspection).

How to Address Weak Bonds and Process Failures

- Will weak bonds between arrestment features eventually become visible during in-service inspection? If so, then → Cat 2.
  - *Will pressure or out-of-plane loading make the disbond visible with GVI or DVI?*
  - *Or will disbonds only become detectable with NDI (tap test or A-scan)?*
- If weak bonds cannot be found, must they be assumed to exist between arrestment features and treated as Cat 1? Or?
- Or use SDC criteria in some cases for disbond between arrestment (Limit Load, no fatigue, no associated inspection)?

The detectability of damage associated with face sheet disbond using in-service inspection is key....



Types of In-Service Inspection

- GVI - General Visual Inspection
- DVI - Detailed Visual Inspection
- NDI - Non-Destructive Inspection (includes “tap test”)
- Unplanned Inspection – triggered by an event that is obvious to flight or ground crew (hail, tire, bird, etc.)

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Design Criteria for Sandwich Disbond – Arrestment

Design Features for Arrestment

- Core ramps
- Frames
- Ribs
- Bolted Joints

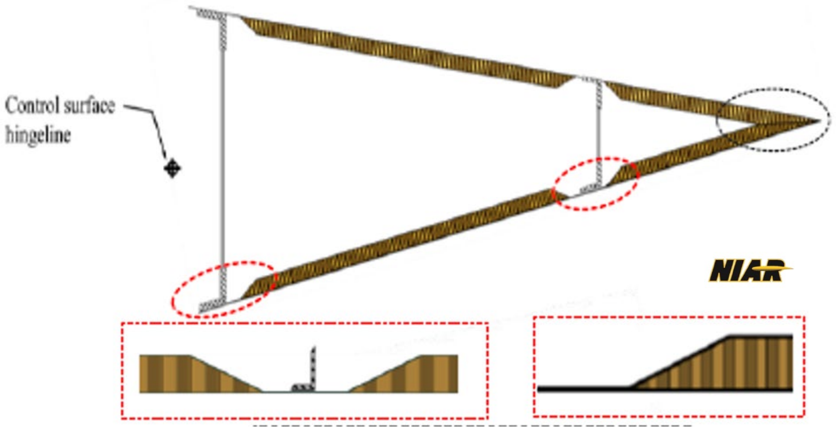
Geometric Features for Arrestme

- Corners, etc.
- Curvature

Other Forms of Arrestment

- Load changes
- Pad-ups, strain reduction

Whatever form of arrestment is used, it must be demonstrated by test and analysis for <u>static</u> and <u>fatigue</u> loading (if Cat 1 or Cat 2).



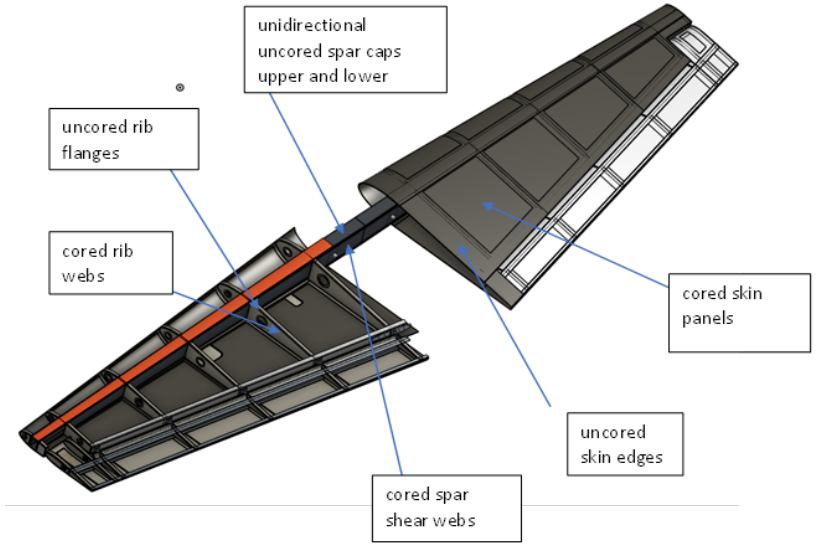


Fig.1.b: EC135 Sub floor group structure

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Design Criteria for Sandwich Disbond – Face Sheet Buckling

No Face Sheet Buckling for Static Loads and/or Fatigue Loads

- Can be used to avoid disbond growth for static mechanical loading for non-pressure cases.
  - No static buckling at Ultimate Load (Cat 1) or Limit Load (Cat 2).
  - Can also use Ultimate Load for Cat 2 (conservative).
- Can be used to avoid disbond growth for fatigue mechanical loading.
  - No fatigue buckling at operating loads.
  - Compare spectrum to constant amplitude no-growth thresholds.

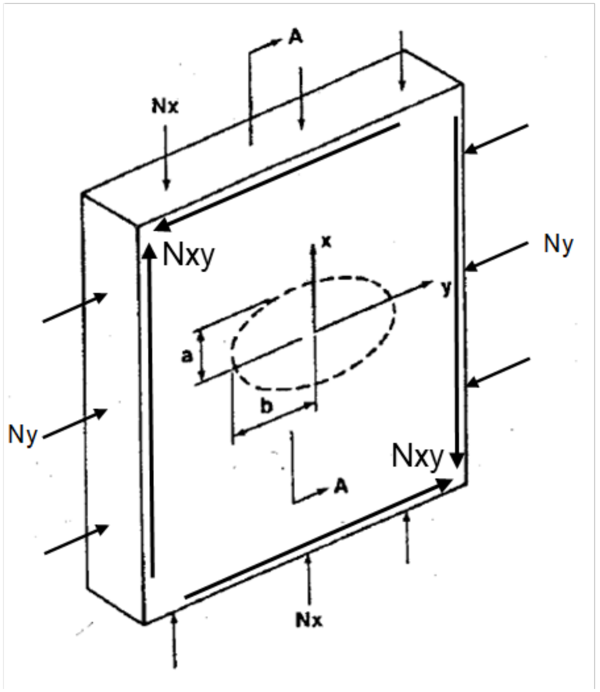
GAG Pressure Cycling Considerations

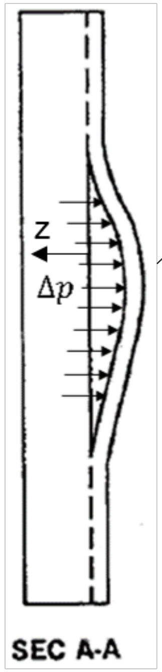
- Pressure causes out-of-plane displacement (similar to buckling)
- Need to consider combined mechanical + pressure with respect to buckling of face sheet (?)

Face Sheet Thickness Considerations

- "No local face sheet buckling" criteria can be overly conservative for larger disbonds of thin face sheets since not enough energy to "drive" disbond growth.

Generalized In-Plane Loads + Internal Pressure





Local face sheet buckling

Important to understand the relationship of buckling and disbond growth as a function of face sheet thickness.

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Outline

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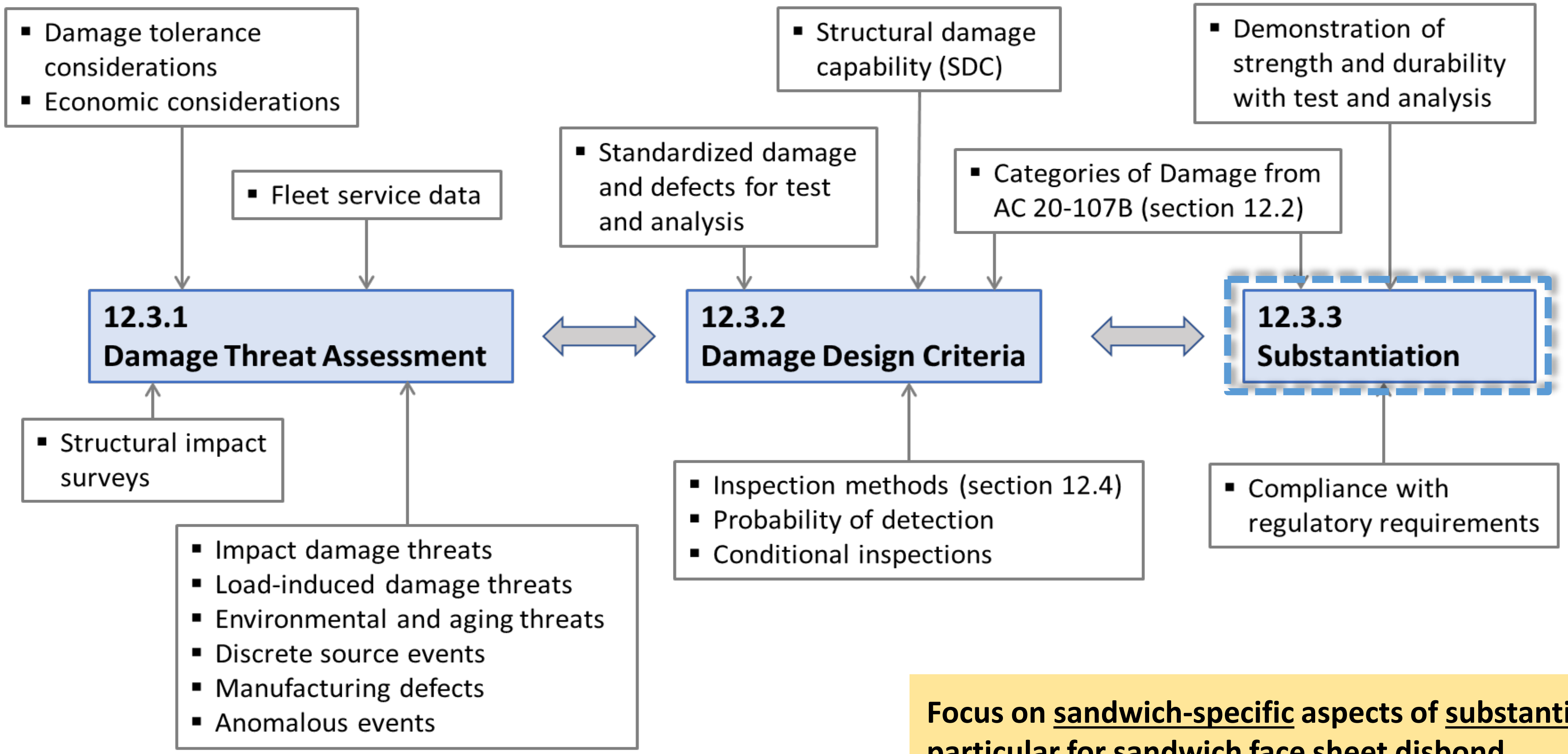
Substantiation*



Focus on sandwich-specific aspects of substantiation, in particular for sandwich face sheet disbond.

**Ref. CMH-17 V3, 12.3 Design Development and Substantiation*

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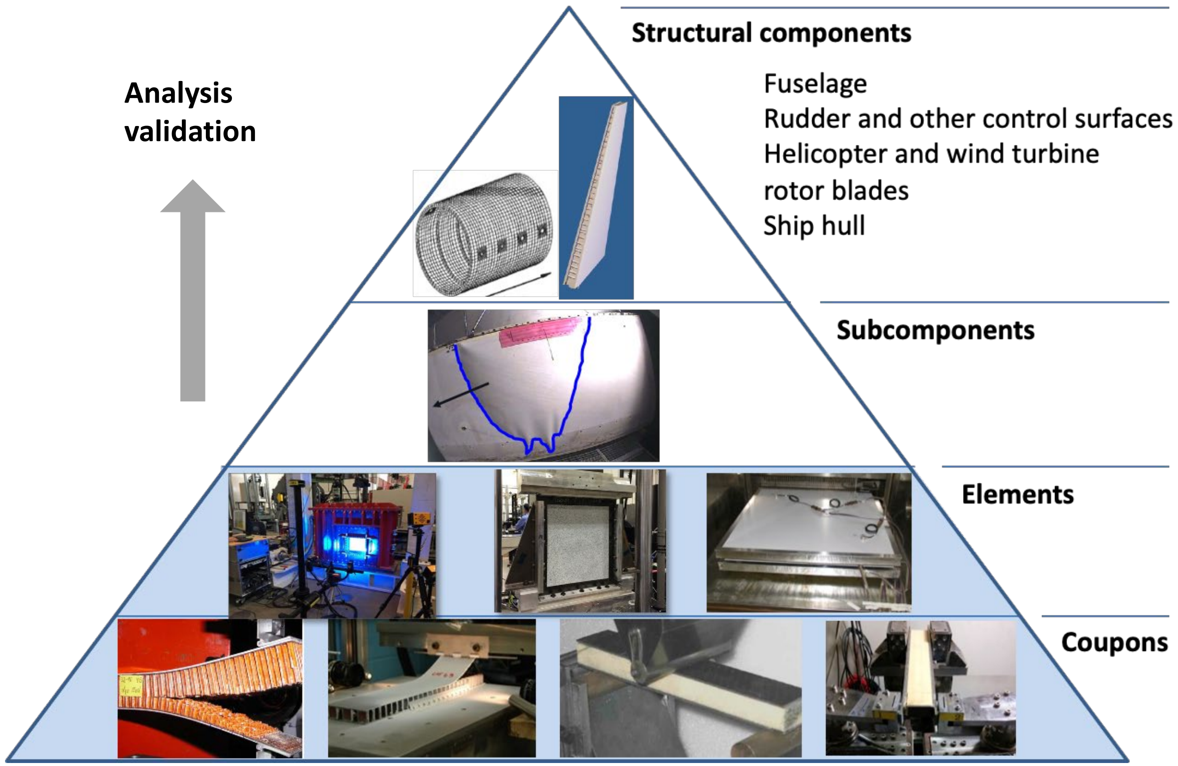
Substantiation Building Block – Analysis Supported by Test

"Certification by Analysis Supported by Test"

- This is the most common approach but there are many ways to do it.
  - Traditional building block vs. "top down, bottom-up" vs. hourglass, etc.
- Lower-level data is often used with simplifying assumptions to evaluate designs during trade studies and qualify materials.
- Higher-level testing validates analysis which is then used to write margins as part of substantiation.
- Full scale component testing is often used mainly to verify load paths and strain levels.

Test-Analysis Building Block for Sandwich Disbond



Courtesy of R. Krueger

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Engineering Approaches for Substantiation

Engineering Problems

- Engineering problems can have many solutions.
- Engineering problems can be complex, but their solutions don't have to be.
- The best solution for an application represents an appropriate balance between the level of complexity and the required accuracy.

Engineering Approach

- An engineering approach uses pertinent experience and good engineering judgement to produce practical solutions that meet all design requirements in a cost-effective manner.
  - Engineering approaches for analysis are reliable and repeatable.
- An engineering approach generally considers:
  - The need to reliably meet all safety requirements while considering the performance objectives of the application (not be overly conservative).
  - The objectives of all members of the Integrated Product Team (IPT), see CMH-17 Volume 3, Chapter 7.

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Loading Considerations for Sandwich Disbond

In-Plane Static Mechanical Loading

- Compression and shear drive disbond buckling (and growth).
- Use simplifying assumptions to conservatively envelop critical loads.
  - Assume peak panel strains exist over entire panel,
  - Envelop combined compression and shear.

In-Plane Fatigue Loading

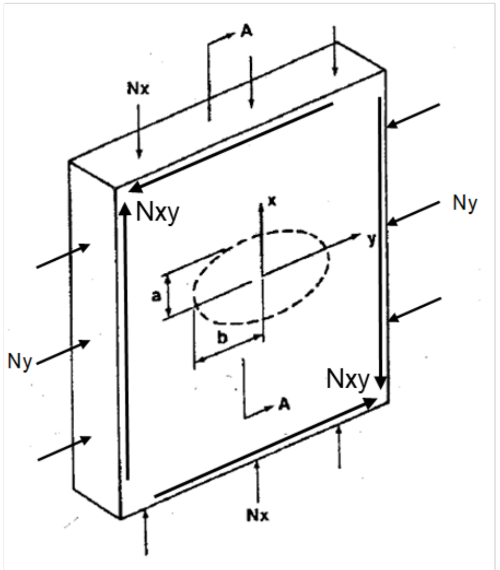
- Compression and shear drive disbond buckling (and growth).
- Envelop fatigue spectra with constant amplitude cycling to understand thresholds.

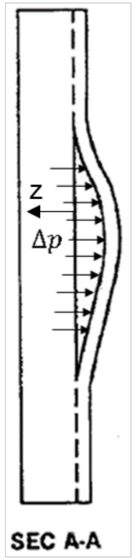
GAG Pressure Loading (cyclic)

- Can add to static or fatigue loading
- Differential cavity pressure dependent on altitude and temperature.
- Application specific (transport aircraft vs. rotorcraft).

Other Out-of-Plane Loading

- Aero pressure loads (add to GAG cavity pressure), Fuel loads? Secondary bending?





For combined mechanic and pressure loads, need to consider altitude during critical load cases and during fatigue loading.

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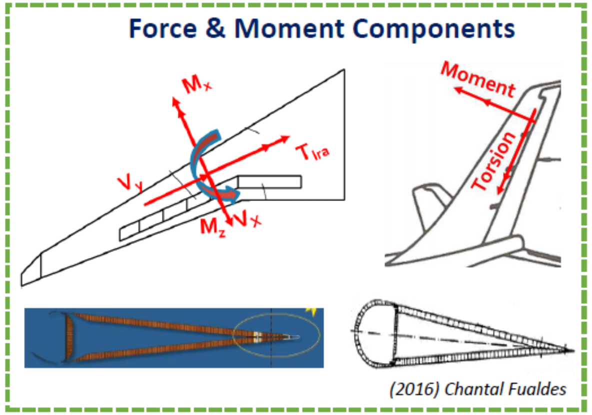
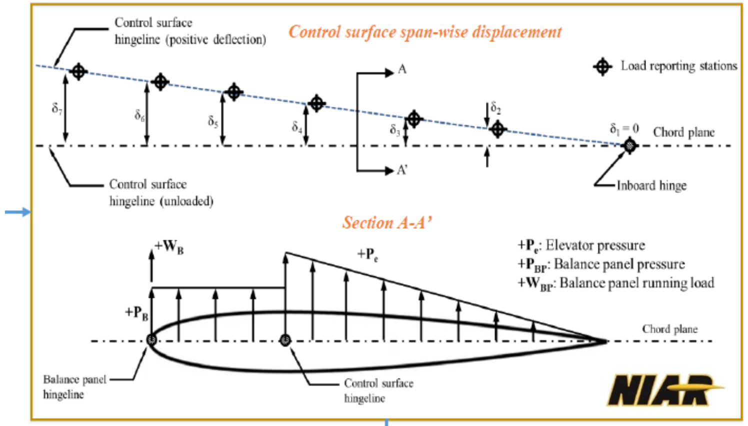
Complex Loading and Design Details for Sandwich Disbond

Variable loading

- Realistic <u>combined in-plane load conditions vary</u> over the control surface or other sandwich parts.
- <u>Internal pressure is not always matched</u> with a uniform compression and/or shear for large areas of a control surface box structures.





Shear loading

- Face sheet buckling under shear loading can drive disbond growth, but it is more difficult to analyze.
- <u>Shear-buckled face sheets can still carry shear loads</u> (aggressive analysis for disbond between arrestment?)
- Shear loading may be important for many GA applications where the outboard wings are sandwich construction and are driven by torsion loading.

Loading at Structural Details

- Core ramps, curvature, potted fittings
- Also need to consider loading at arrestment features.

<u>Engineering approaches</u> for complex loading may include <u>conservative simplifying assumptions</u> to envelop the realistic loading on the structure.

<u>How well can real load conditions be addressed</u> by uniform compression loading + internal pressure?

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Role of Large-Scale Testing for Sandwich Disbond

Large Scale Testing

- Large-scale certification testing has many purposes, including validation of load paths and strain levels.
- Top-down, bottom-up approach uses early (e.g., preproduction) large-scale testing to understand scaling effects, complex loading, and resulting failure mode(s).

Sandwich Disbond Considerations

- Sandwich disbond is not typically substantiated at full scale – relies on analysis supported by lower-level testing, uses strains from FEM validated at full scale.
  - Exceptions might be in cases where component level testing is needed to include complex combined loading and/or structural details (e.g., curvature).
- Large-scale analysis may look at local buckling stability of disbonded face sheets but difficult to implement fracture analysis (e.g., VCCT).

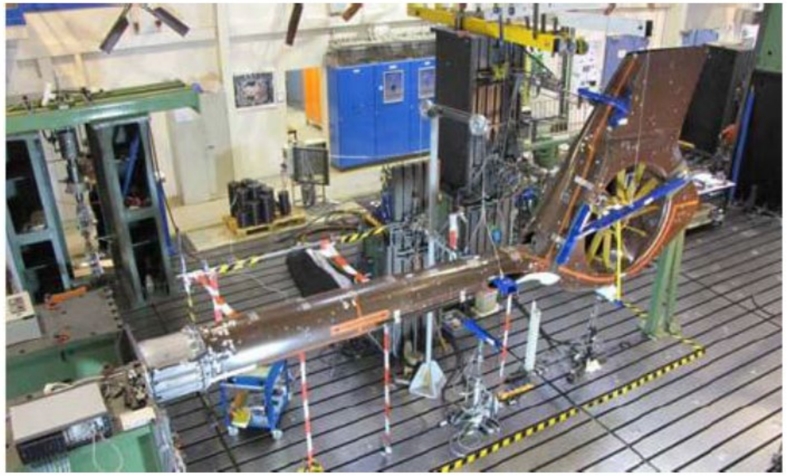

Fig.11: Static test article of tail boom structure *

Fig. 10: FEM Model of tail boom structure*

*A. Engleder, D. Strobel, Eurocopter, CMH-17 Meeting 2012 Boston "Common Local Instabilities of Composite Sandwich Structures with Honeycomb Cores."

This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

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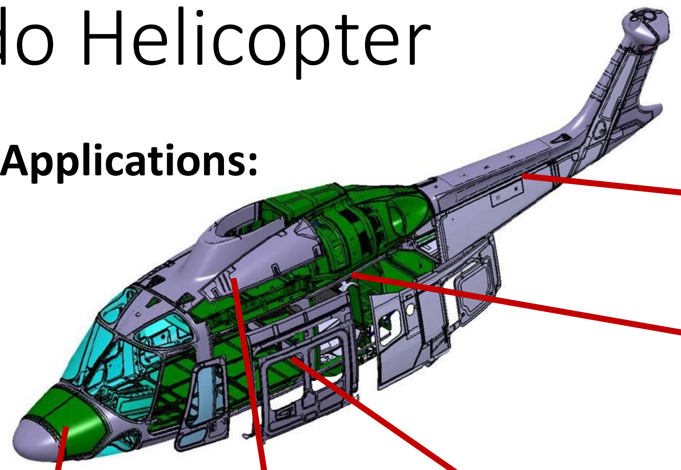
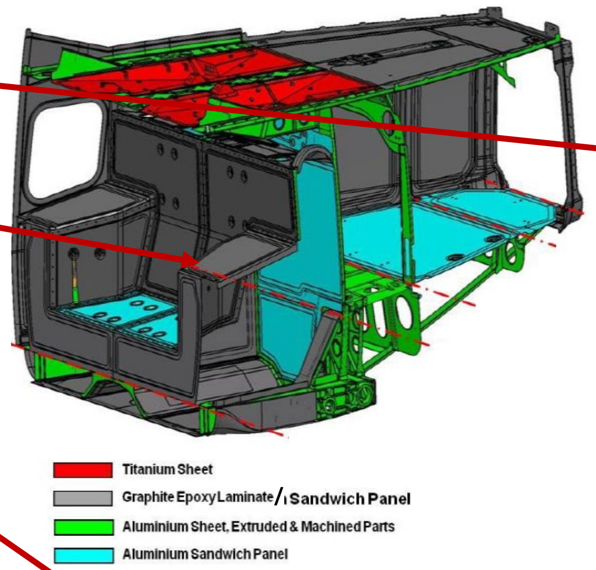
2.1 Leonardo Helicopter

Typical Sandwich Applications:

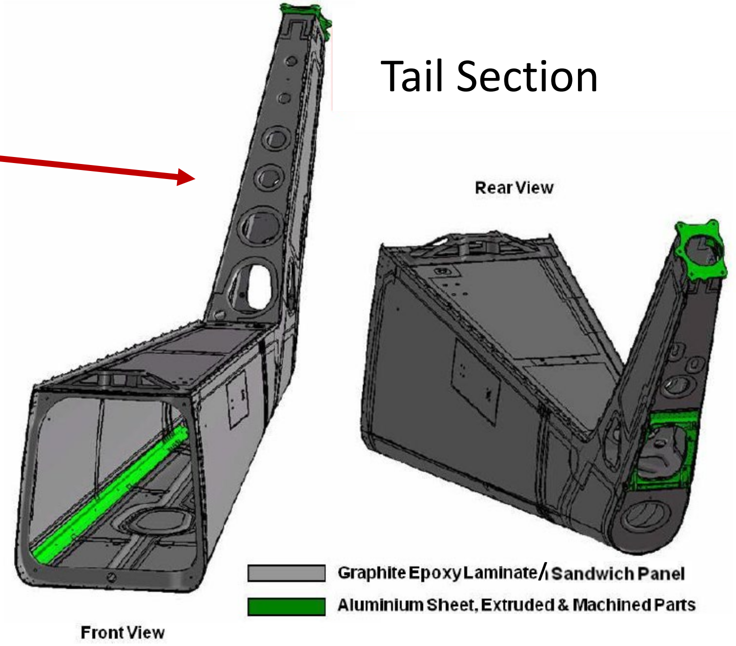
- Bulkheads
- Floor panels
- Upper Deck
- Subfloor
- Fairings
- Rear Section
- Tail Section



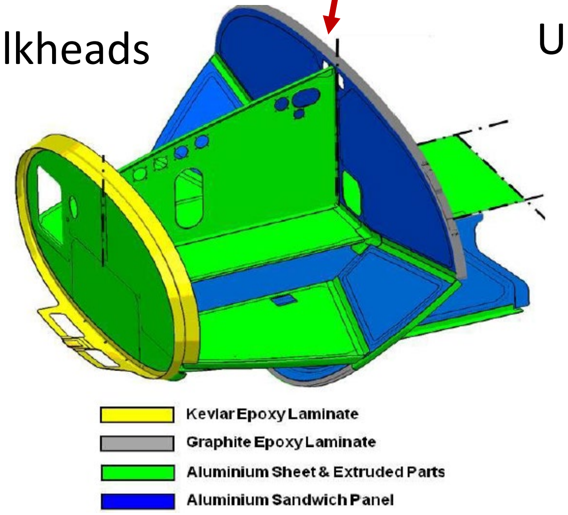
Rear Section



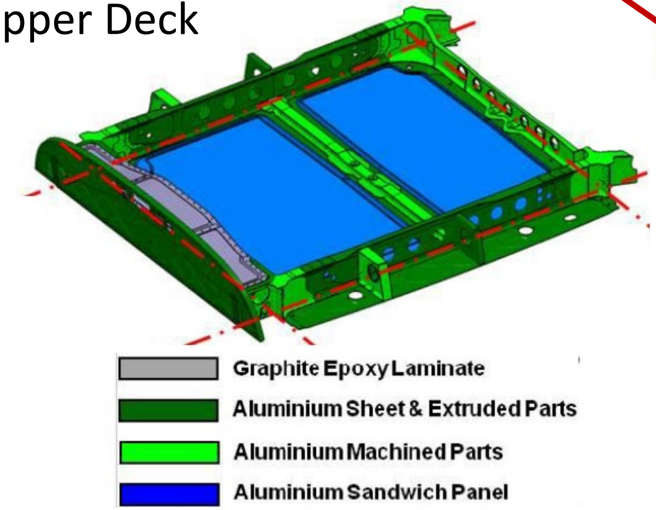
Tail Section



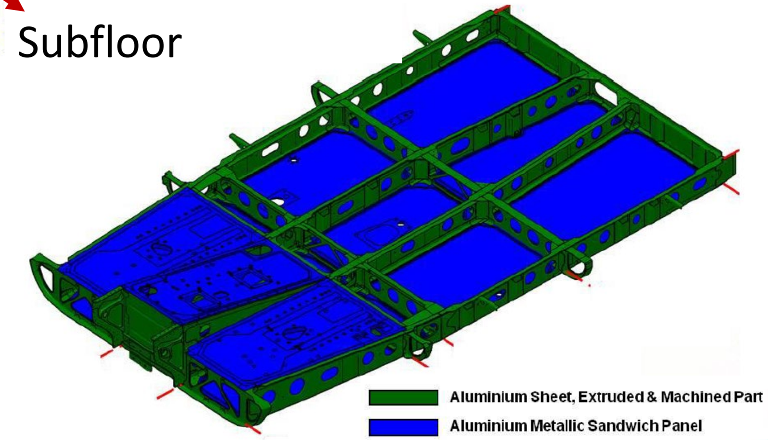
Bulkheads



Upper Deck



Subfloor



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2.1 Leonardo Helicopter

Typical Materials used:

- Core Materials:

	Description	Cell Dimension [mm]	Core Density [kg/m^3]
HRH-10-4.8-32	Non metallic aramidic	4.8	32
HRH-10-4.8-48	Non metallic aramidic	4.8	48
HRH-10-4.8-64	Non metallic aramidic	4.8	64
HRH-10-3.2-29	Non metallic aramidic	3.2	29
HRH-10-3.2-48	Non metallic aramidic	3.2	48
HRH-36-4.8-32	Non metallic aramidic +kevlar	4.8	32
CR III–4.8-5052	Metallic (Al 5052)	4.8	32
CR III–4.8-5052	Metallic (Al 5052)	4.8	49

- Facing Material (metallic):

	Description
Al 2024 – T3 Bare (AMS-QQ-A-250/4)	Flat metallic sheet
Al 2024 – T42 (AMS-QQ-A-250/5a)	Flat and curved metallic sheet

- Facing Material (composite):

	Description	Manufacturing Method
AGP 193 PW/8552S RC40	Fabric with intermediate modulus graphite fibers (AS4 fiber PW, 8552 epoxy resin)	High cure temperature+press autoclave; Hand layup
AGP 280 5H/8552S	Fabric with intermediate modulus graphite fibers (AS4 fiber 5H, 8552 epoxy resin)	High cure temperature+press autoclave; Hand layup
AS4 UNI/8552S	UD graphite fiber intermediate modulus (AS4 fiber UNI, 8552 epoxy resin)	High cure temperature+press autoclave; ATP/ALP
AS4 PW/3501-6	Fabric with intermediate modulus graphite fibers (AS4 fiber PW, 3501-6 epoxy resin)	High cure temperature+press autoclave; Hand layup

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2.1 Leonardo Helicopter

Typical Adhesive for Bonding Sandwich panels

	Material	Density	Curing Temp.	Application
AF163-2U.03 3M Company	Epoxy film adhesive	146 ± 25 g/m^2	+130°C or +177°C curing	For bonding sandwich panels use 2 layers of adhesive, by using only 1 layer a 60% reduction of drum peel and flatwise tensile properties is expected
AF163-2K.045 3M Company	Epoxy film adhesive, form 220k	220 ± 25 g/m^2	+130°C or +177°C curing	For bonding sandwich panels drum peel and flatwise tensile properties shall be lower than AF 163-2K.06
FM 300U.03 CYTEC	Epoxy film adhesive, form 146u	146 ± 25 g/m^2	+177°C curing	For bonding sandwich panels drum peel and flatwise tensile properties will be lower than FM300K.05
AF 191K.08 3M Company	Epoxy film adhesive, form 390k	390 ± 24 g/m^2	+177°C curing	For bonding sandwiches with metal adherents and honeycomb

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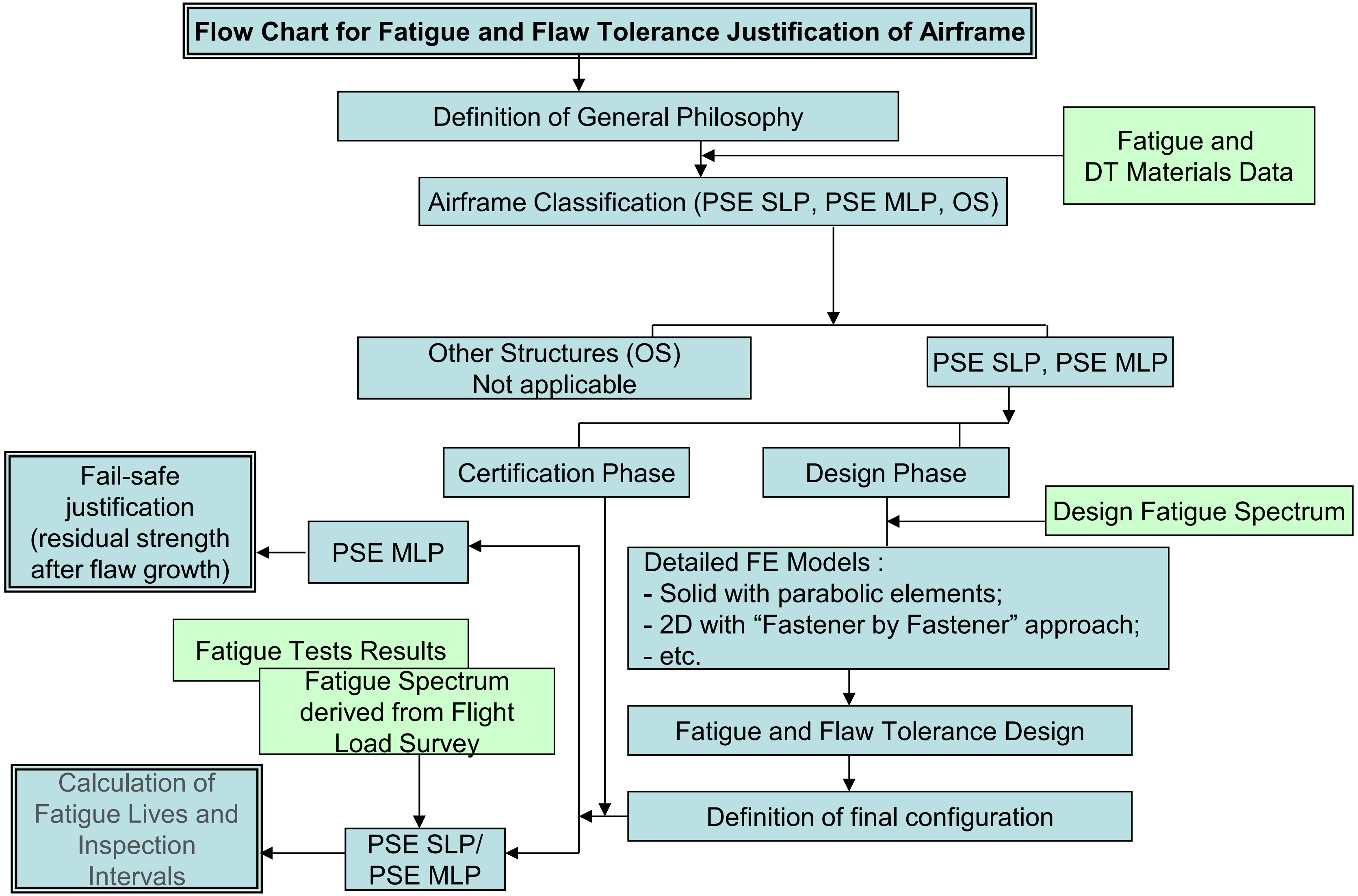
2.1 Leonardo Helicopter

General Approach for Fatigue and Flaw Tolerance of Airframe



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2.1 Leonardo Helicopter

Approach for Fatigue and Flaw Tolerance of Airframe Composite PSE

- Airframe Structure -
General Philosophy for the Fatigue and the Flaw Tolerance evaluation

Composite PSEs

Analyses

Flaw Tolerance / Fatigue

Static Strength justification against BVID Design Criteria covers Fatigue and Flaw Tolerance for:

- Airframe Composite Design Values are typically established with sufficient margins to ensure that damage growth due to repeated loads will not occur and will be fatigue insensitive;
- LH Service experience and tests have shown that airframe composite structure has excellent resistance to environmental deterioration and to fatigue damage, in particular when designed against BVID criteria;
- Airframe composite materials have good flaw and damage tolerance capabilities and, therefore the safe life option is not mandatory for the Airframe designed against BVID Criteria;

Fatigue Tests

Purpose

Define the sensitivity to flaw / damage growth under fatigue loads and to assess the effect of the environment on the flaw and damage growth

Configuration

The fatigue test includes damage levels typical of those that may occur during fabrication, assembly and in-service, consistent with the inspection techniques employed (threat assessment).
The extent of initially detectable damage is established and be consistent with the inspection techniques employed during manufacture and in service.

Building Block Approach

See next slide

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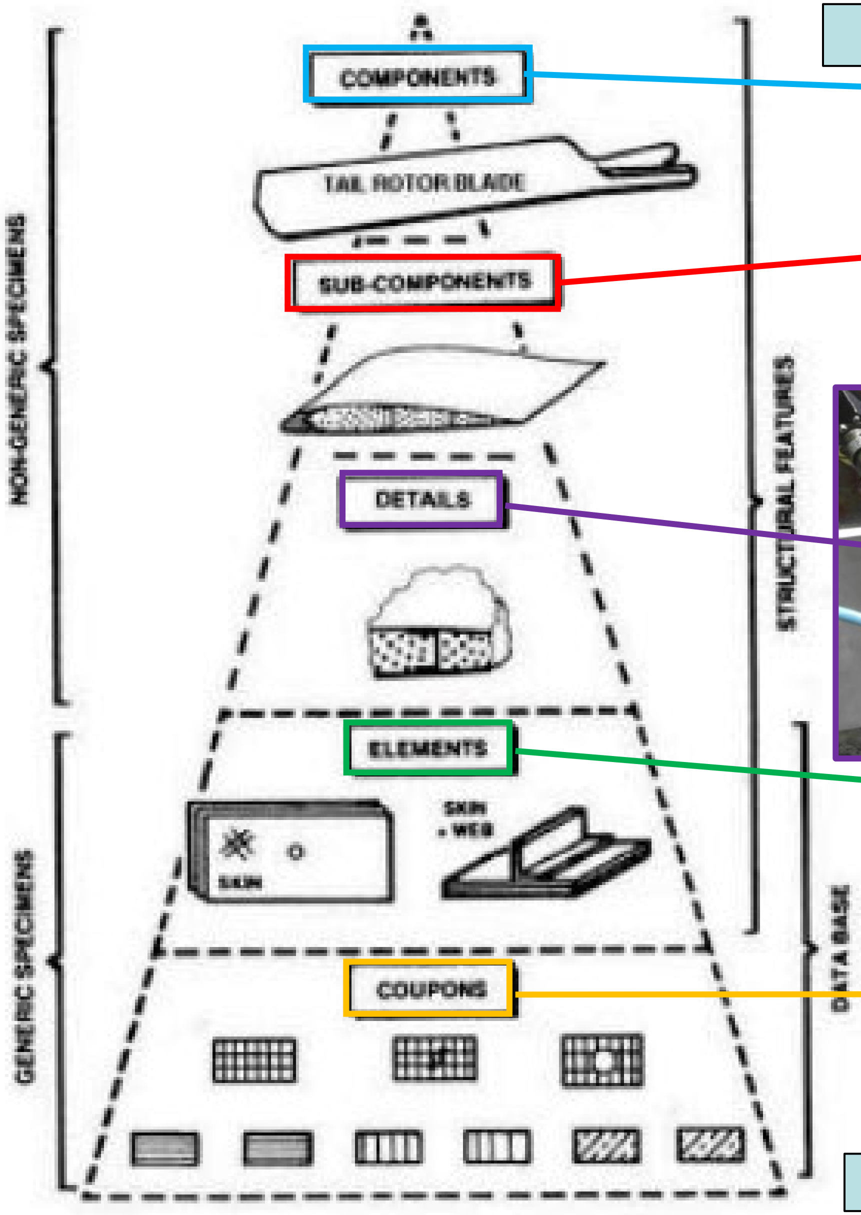
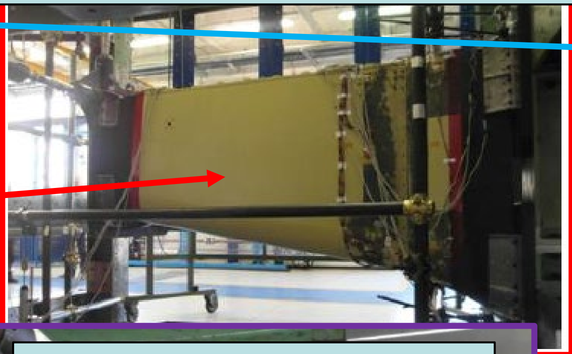
2.1 Leonardo Helicopter

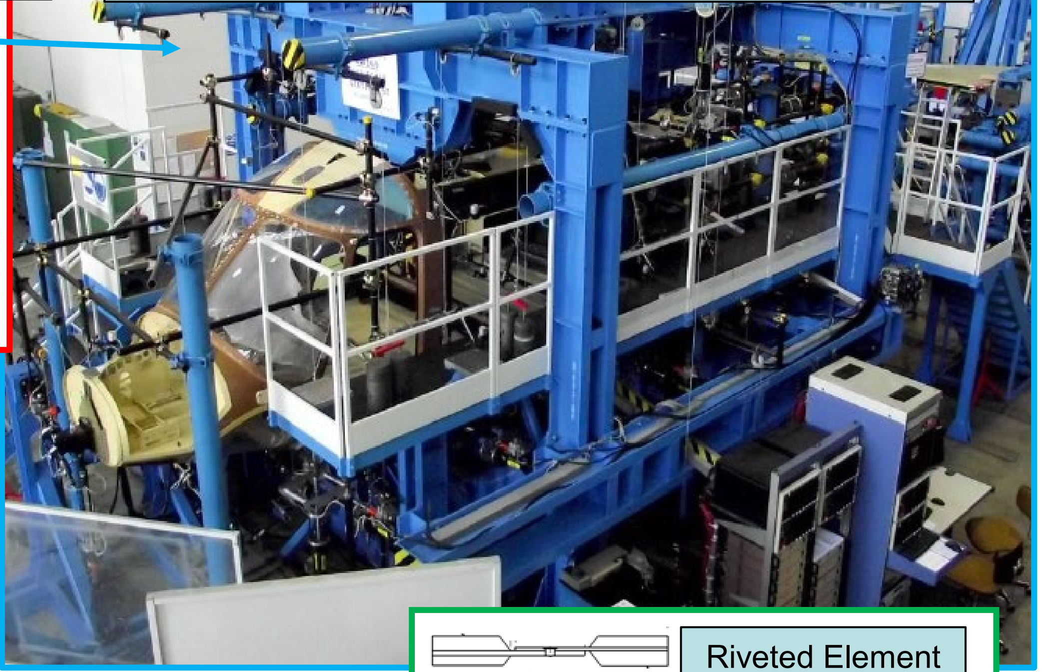
Building Block Approach



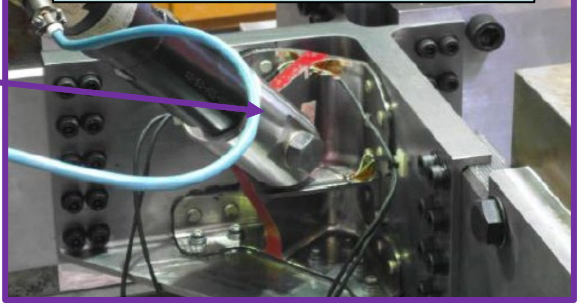
Fatigue & Static Test of Rear-Tail Joint

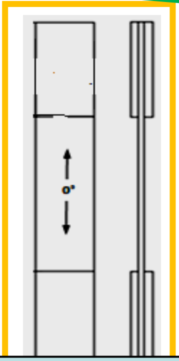


Full Scale Cabin Static & Fatigue Test



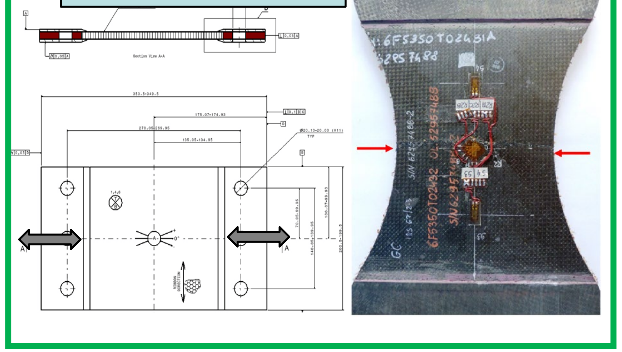
Fatigue Test of Rod Fitting



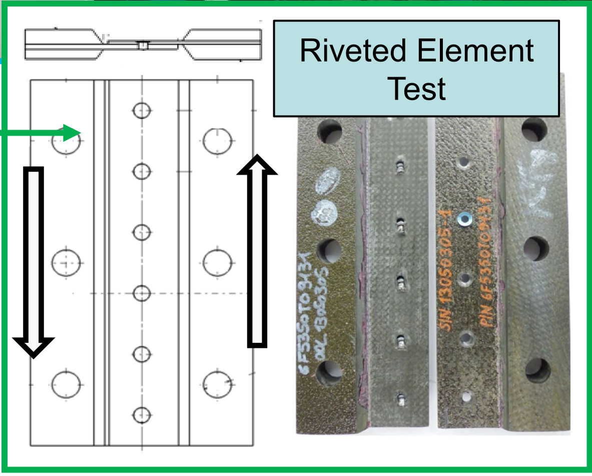


Coupon Test

Element Test



Riveted Element Test



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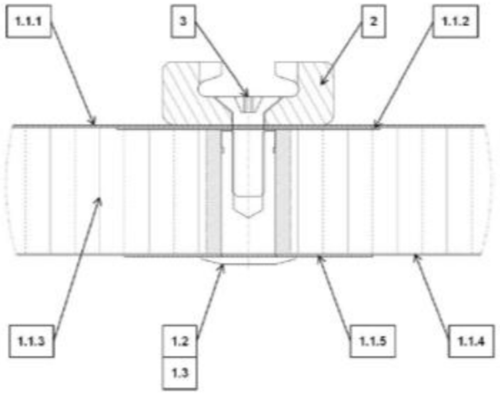
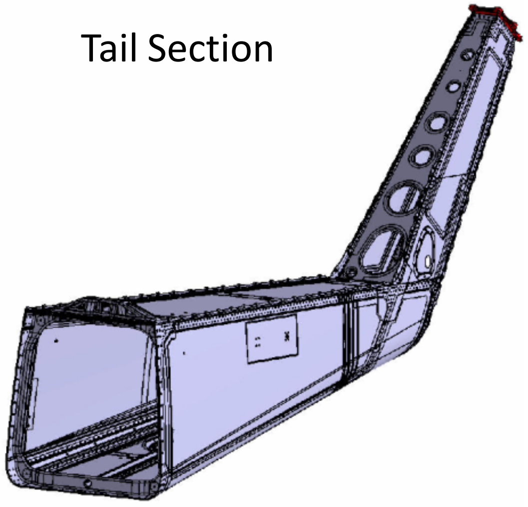
2.1 Leonardo Helicopter

Examples of Sandwich Detailed Design

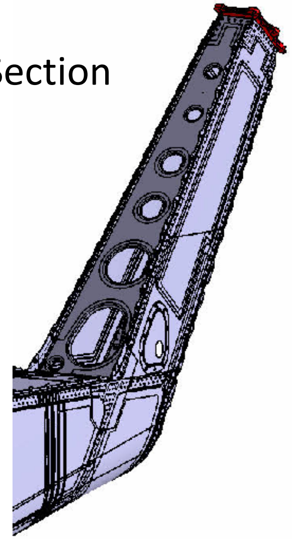
Floor Panel Insert installation



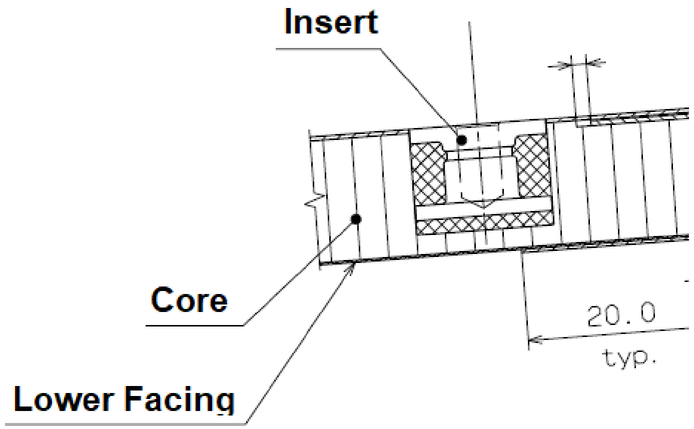
Tail Section

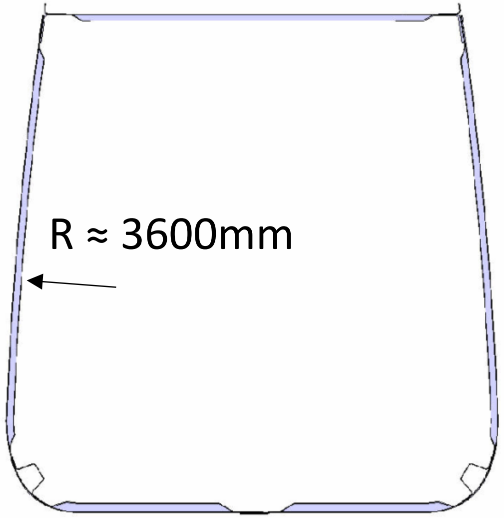


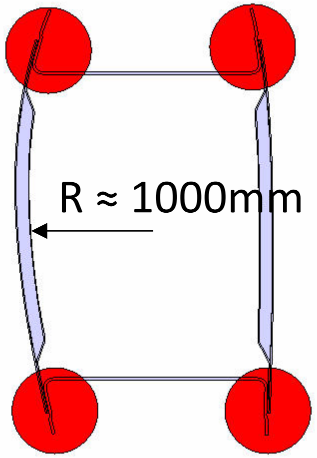
Fin Section



Panel Insert installation







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2.1 Leonardo Helicopter

Damage Classification and Substantiation Approach

Standard ADs for Civil Operators:

AD1) Ground Handling Equipments
AD3) Improper Maintenace and Operational Procedure
AD4) Rain, Hail
AD5) Runaway Debris
AD7) Ice Shed with system normal operation

AC 20-107B/ AC29 MG8
Damage Classification

Category 1:
-) BVID, allowable defects caused in manufacturing or service (Allowable Damages Limits "ADL"),
-) Undetected by scheduled inspections and allowable manufacturing defects;
-) Demonstrated of reliable service life retaining ultimate load capability.

Category 2:
-) VID or DID ranging from small to large, deep scratches, manuf. mistakes, detecting delamination or debonding;
-) Reliably detected by scheduled direct field inspections performed at specified intervals;
-) Demonstration of reliable inspection methods and intervals retaining at least Limit Load Capability (LL)

Category 3:
-) Large VID, DID or other obvious damages;
-) Damage can be reliable detected within a few flight occurrence by walk around inspection;
-) Demonstration of reliable and quick detection retaining limit or near limit load capability

Category 4:
-) Discrete Source Damage from a known "incident" as birdstrike, lightening strike, etc.
-) Demonstration of residual strength to complete the flight and grant a safe landing with limited maneuvers loads (less than Limit)
-) Appropriate structural repair or part replacement, prior to A/C re-entering service must be undertaken.

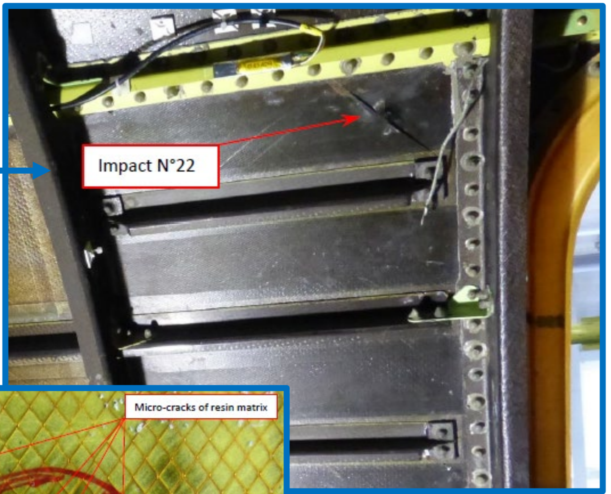
Category 5:
-) Severe damages created by anomalous ground or flight events not covered by design criteria;
-) Require suitable inspections based on engineering assessment of the anomalous event;
-) Appropriate structural repair or part replacement, prior to A/C re-entering service must be undertaken.

To be introduced in **FSFT** articles in the most critical and significant areas

Airframe Structure Fail Safe Analysis

Dedicated Test/ Analysis activities to demonstrante compliance with specific airworthiness requirements

Dedicated Repair required: analysis/test activities to support the compliance with airworthiness requirements of the repaired A/C.



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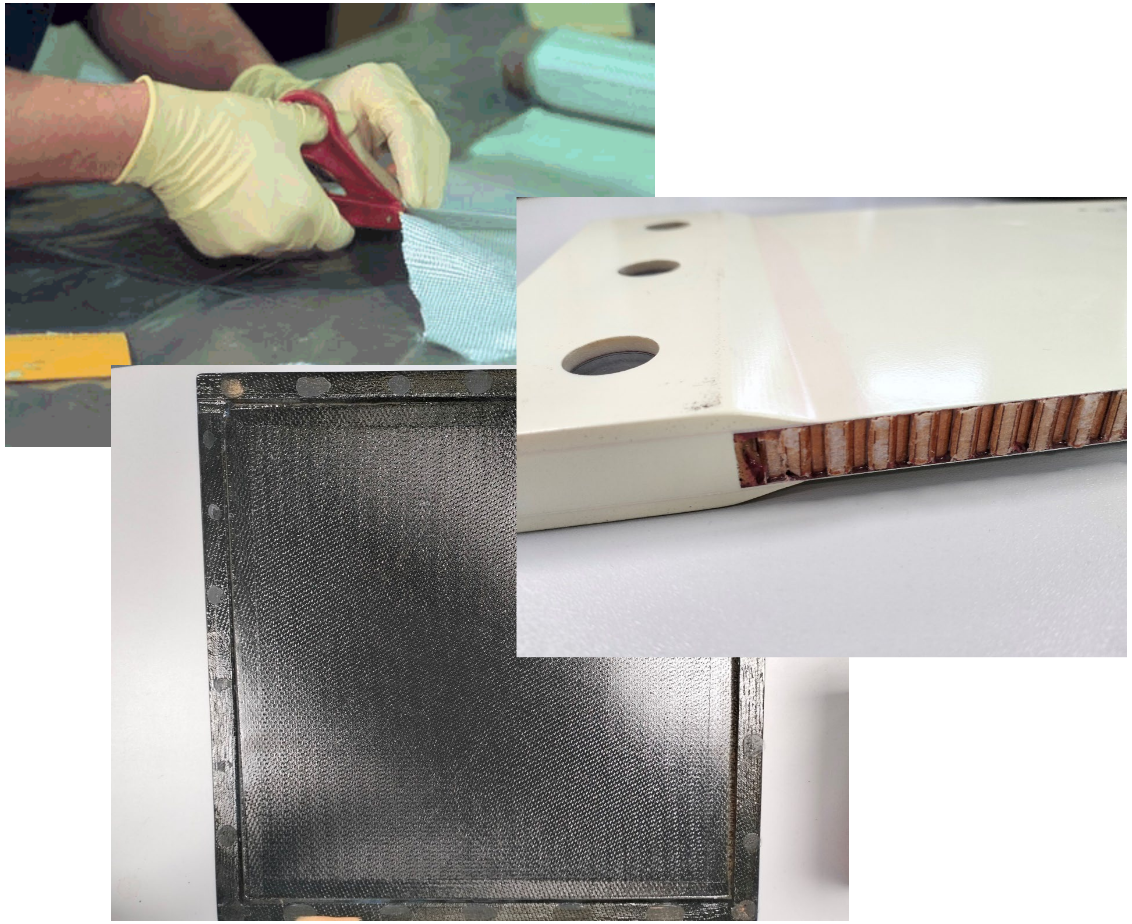
2.1 Leonardo Helicopter

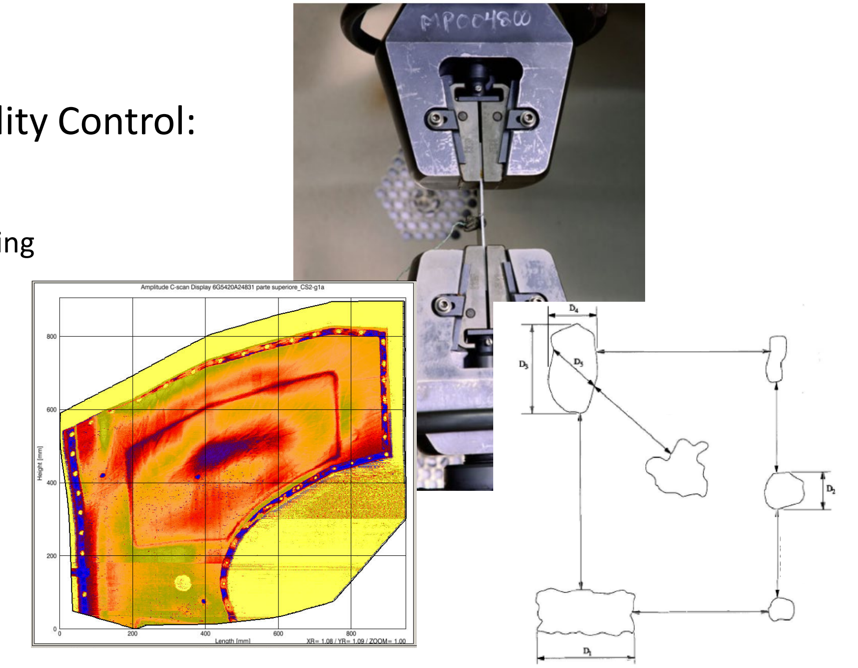
Processes, Manufacturing and Quality

Manufacturing



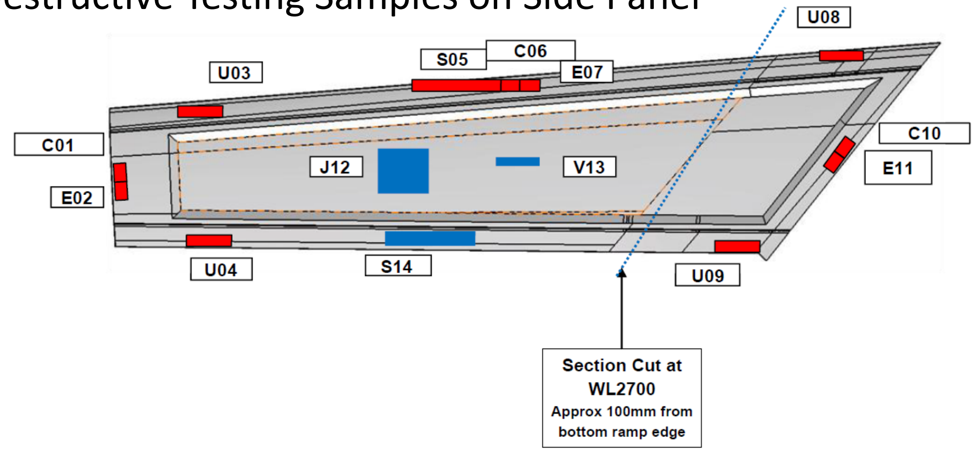
Inspection/Quality Control:

Weight Check
Dimensional Check
Non Destructive Testing
Destructive Testing
Acceptance Criteria
Etc..



DISBONDING ALLOWABLE DISTANCES

Destructive Testing Samples on Side Panel



This project is funded from the European Union's Horizon Europe research and innovation programme.

2.1 Leonardo Helicopter

Inspection Methods

Method	Structure	Damage Detected
Visual	All Monolithic Sandwich	Surface Damage Only, Drying, resin pockets, thickness, dimensions, Honeycomb offset, taper subsidence, telegraphing
Tap Test	Thin Laminate Sandwich	Surface Delamination, disbond, Skin to Core delamination/disbond (thin skin)
Ultrasonic A-Scan	Monolithic	Delaminations/Disbond, porosities and voids
Ultrasonic C-Scan	Monolithic Sandwich	Delaminations, disbond, voids and porosities, waviness Core: Crushed/Damaged/Water impregnated Skin to Core delamination and disbond
Thermography	All Sandwich	Disbond/Delaminations, Water Impregnated Core
Radiography	All Sandwich	Disbond/Delaminations, ply edge, crushed core/Water Impregnated Core, insert filling, inserts

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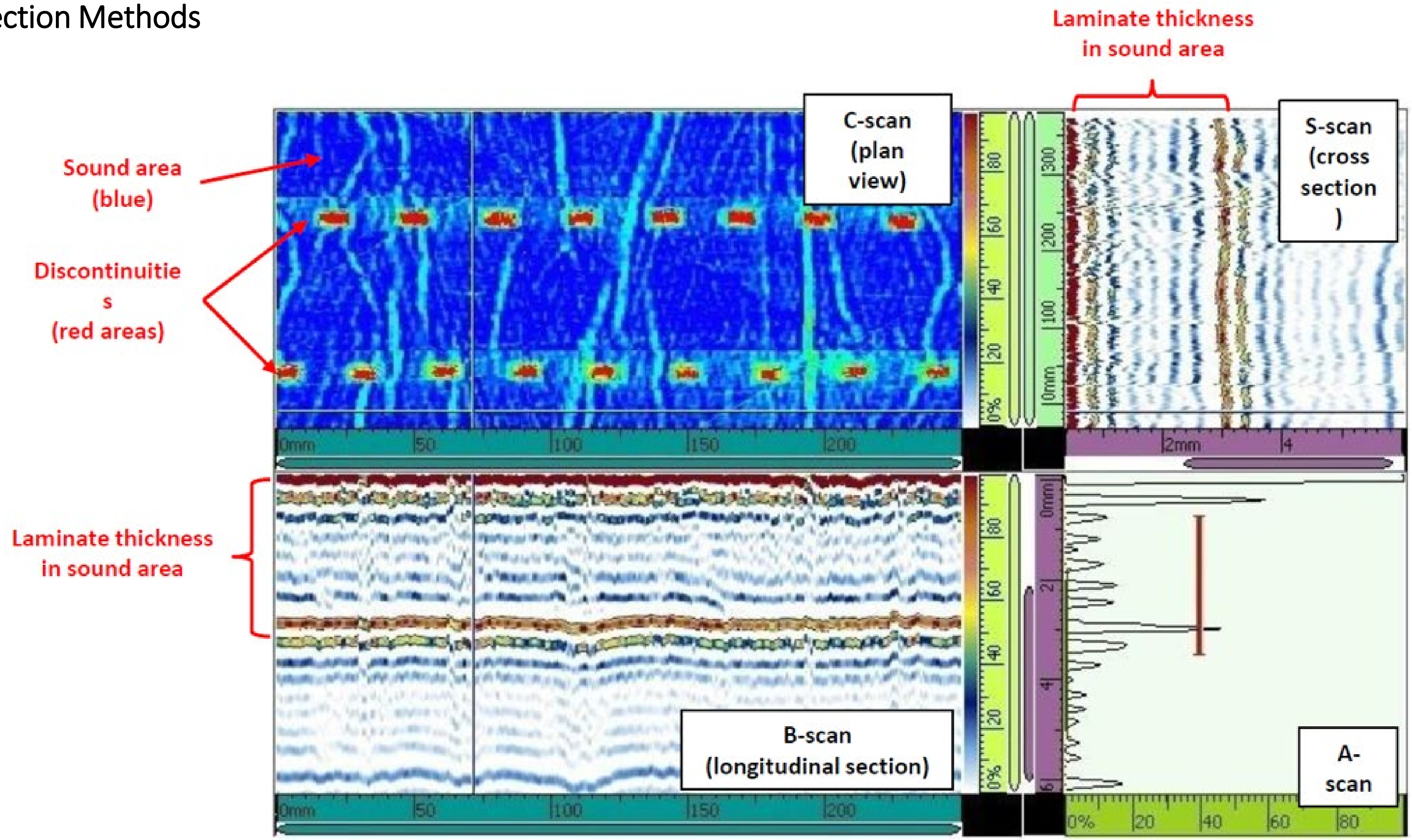
2.1 Leonardo Helicopter

Inspection Methods



This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

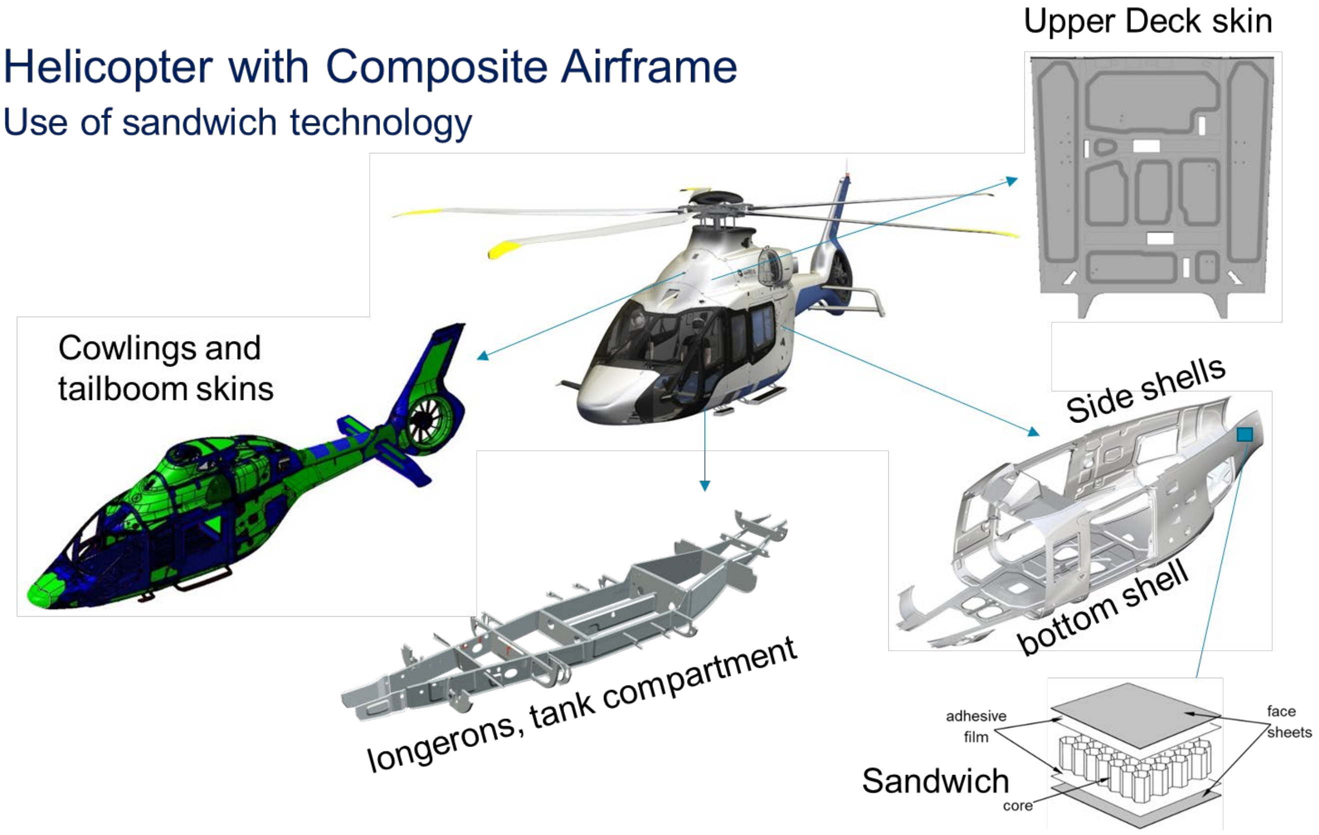
1. Overview of sandwich structure regulations, guidance, and design practice
    1.1 Certification Rules and Guidance
    1.2 Damage Threat Assessment
    1.3 Design Criteria & Inspection
    1.4 Substantiation with Analysis and Test
2. Industry experience and practice regarding the use of sandwich structures
    2.1 Leonardo
    2.2 Airbus Helicopter
    2.3 Airbus Commercial & other fixed wing OEMs
    2.4 In-Service experience (CACRC)
3. Sandwich structure R&D efforts
4. Summary of aviation sandwich panel related accidents & incidents
5. Sandwich structure safety enhancement gap & opportunity discussion

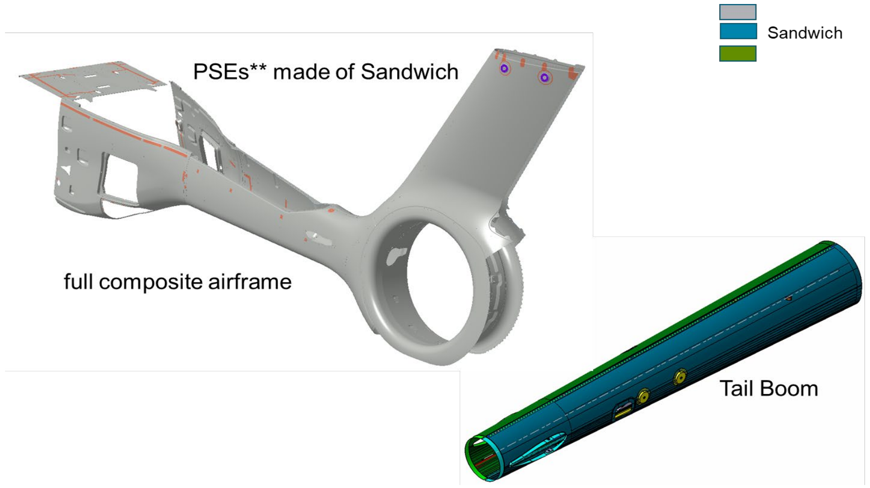
This project is funded from the European Union's Horizon Europe research and innovation programme.

2.2 Airbus Helicopter

Sandwich on all primary structures (Year 2020):

- Carbon Prepreg + Paper Honeycomb
- Highly integrated large size panels with local sandwich
- Monocoque structures (tailboom, intermediate airframe)





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2.2 Airbus Helicopter

Typical geometries and layups of sandwich in Helicopter airframe structures

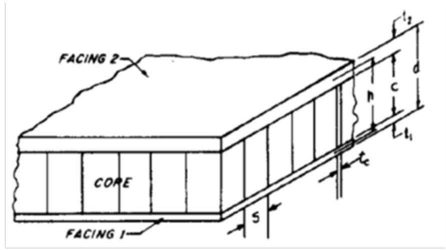
Core Materials: Honeycombs

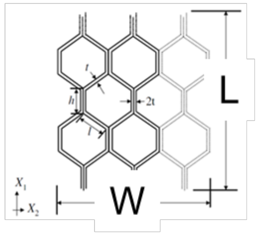
Core thickness: 10-15mm

Core densities: 32, 48, 64 kg/m³

Face sheets: (1-2mm, 45 – 65 GPa)

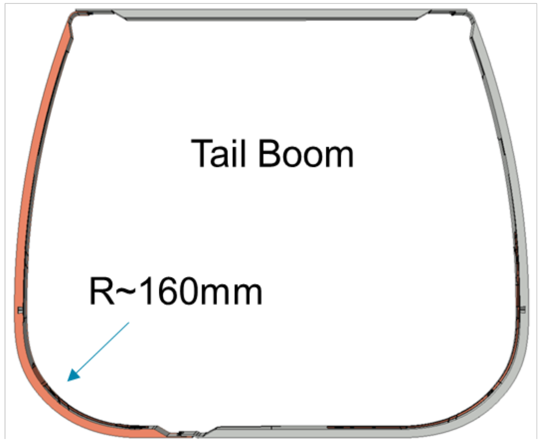
Curvatures: 120mm < R < 200mm

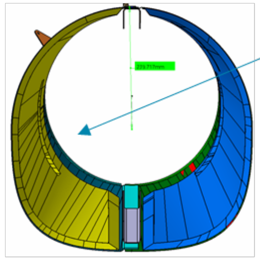




	Material	Ori.	T [mm]
1	Fabric M18/1 (G939)	0°	0.225
2	UD M18/1 (G947)	0°	0.163
3	UD M18/1 (G947)	0°	0.163
4	UD M18/1 (G947)	0°	0.163
5	Fabric M18/1 (G939)	45°	0.225
	FM300.35 (Cytec)	-	-
6	Honeycomb, LN 29967 A4 (48kg/m³ 3,2mm cell width)	L	12
	FM300.35 (Cytec)	-	-
7	Gewebe M18/1 (G939)	45°	0.225
8	Gewebe M18/1 (G939)	0°	0.225

Ref: DoSS-RESEA_2016_2





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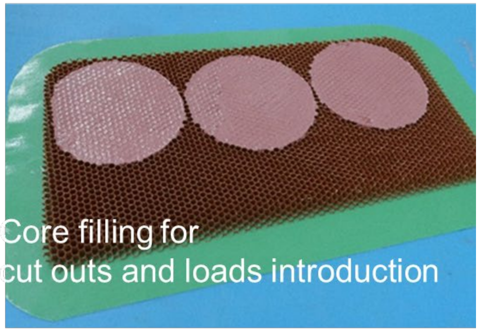
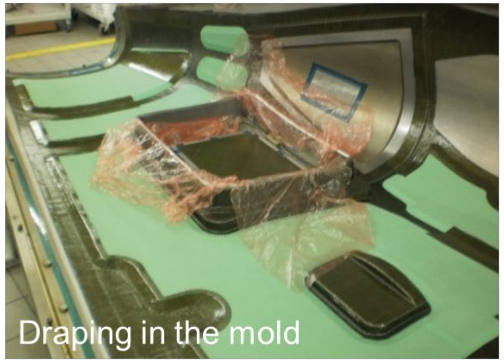
2.2 Airbus Helicopter

Manufacturing of Sandwich Structures

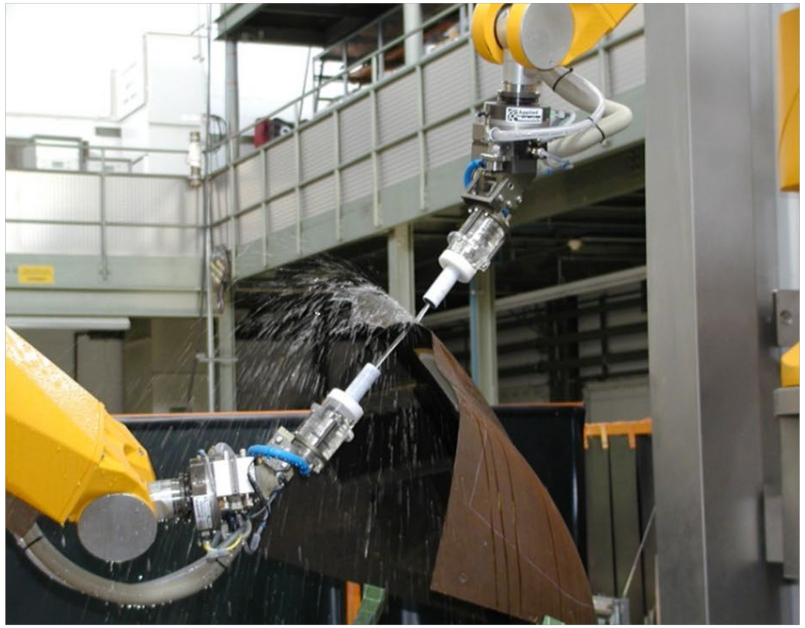

Shaping of core
by NC milling

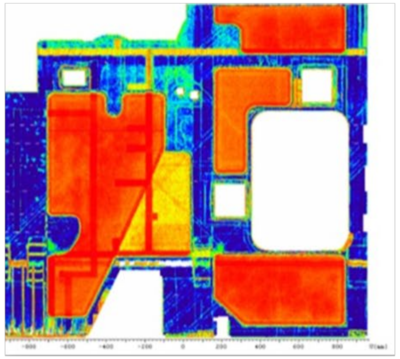

Core filling for
cut outs and loads introduction

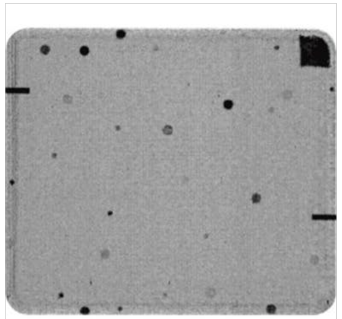

Draping in the mold


Core/ skin adhesion

Sandwich Quality Control


Dual-Robot System
Ultrasonic Through Transmission Inspection (Water Jet)


Surface is continuously scanned


High resolution of Ultra Sonic
(<<10mm)

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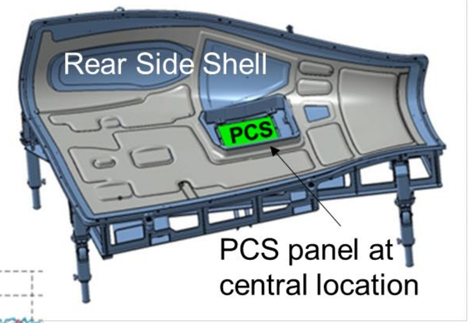
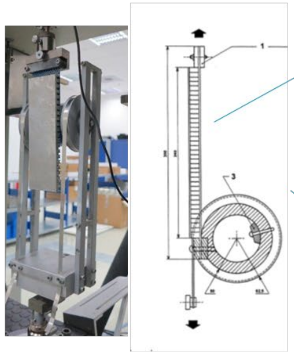
2.2 Airbus Helicopter

Process Control Specimen (PCS)

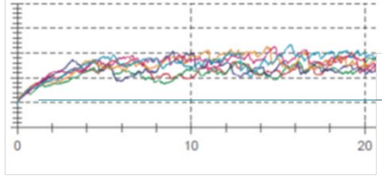
manufactured with sandwich PSEs



EN 2243-3 drumpeel test



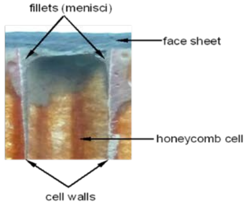
Test results



Minimum value is required

Qualitative assessment

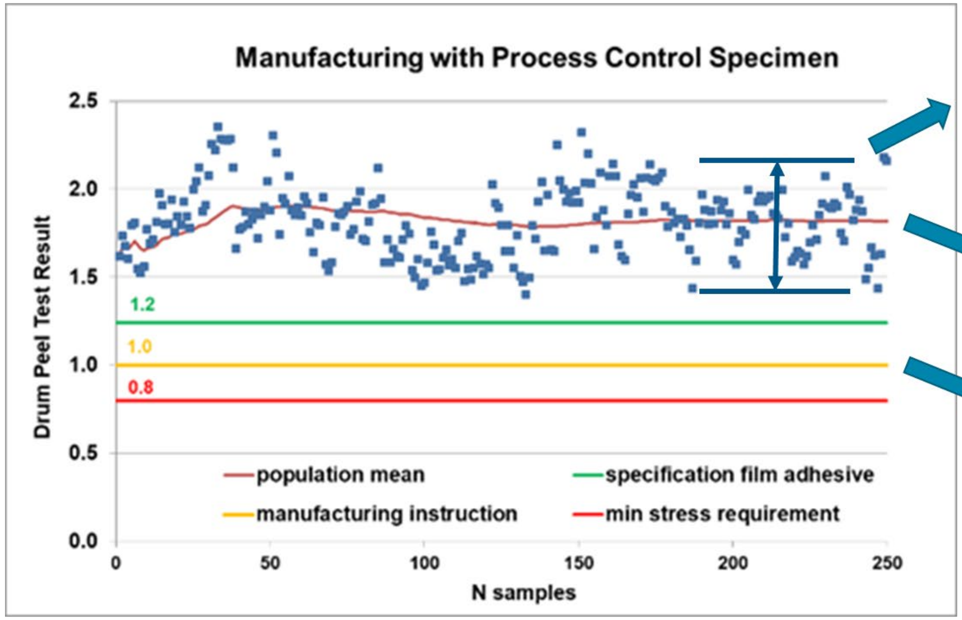
Residual of core -> strong link



- ➢ PCS as Drumpeel is sensitive to potential influences on adhesive strength of skin
- ➢ Go / NoGo for further processing of the part, monitoring the process conditions

Process Control Specimen (PCS)

Long term monitoring of PCS results



Low scatter of results

Stabile mean value

Usefull requirements and limits

- ➢ High process stability of the sandwich manufacturing process

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2.2 Airbus Helicopter

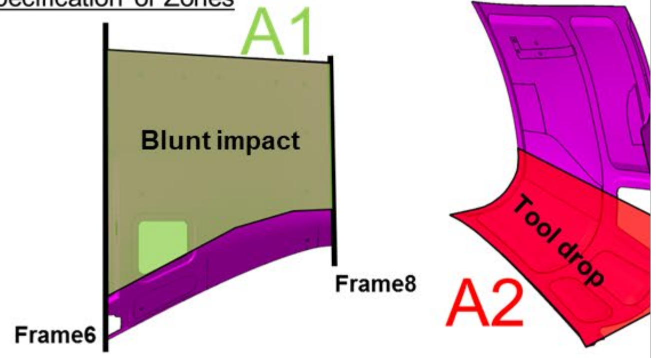
Damage Tolerance Substantiation for PSEs **

Threat Assessment

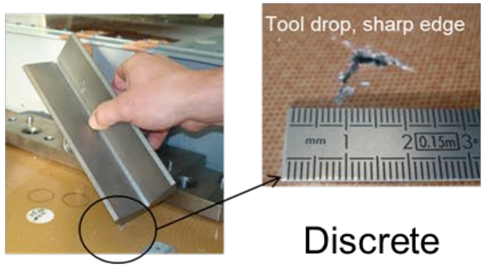
Scenarios

Threats specific to zones

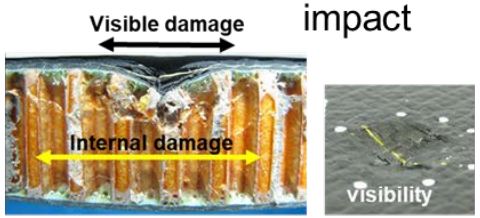
Specification of Zones



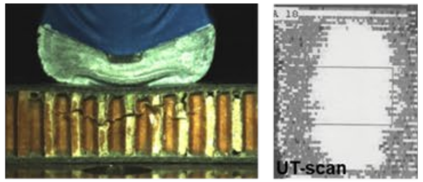
Type of impact



Discrete impact



Blunt impact



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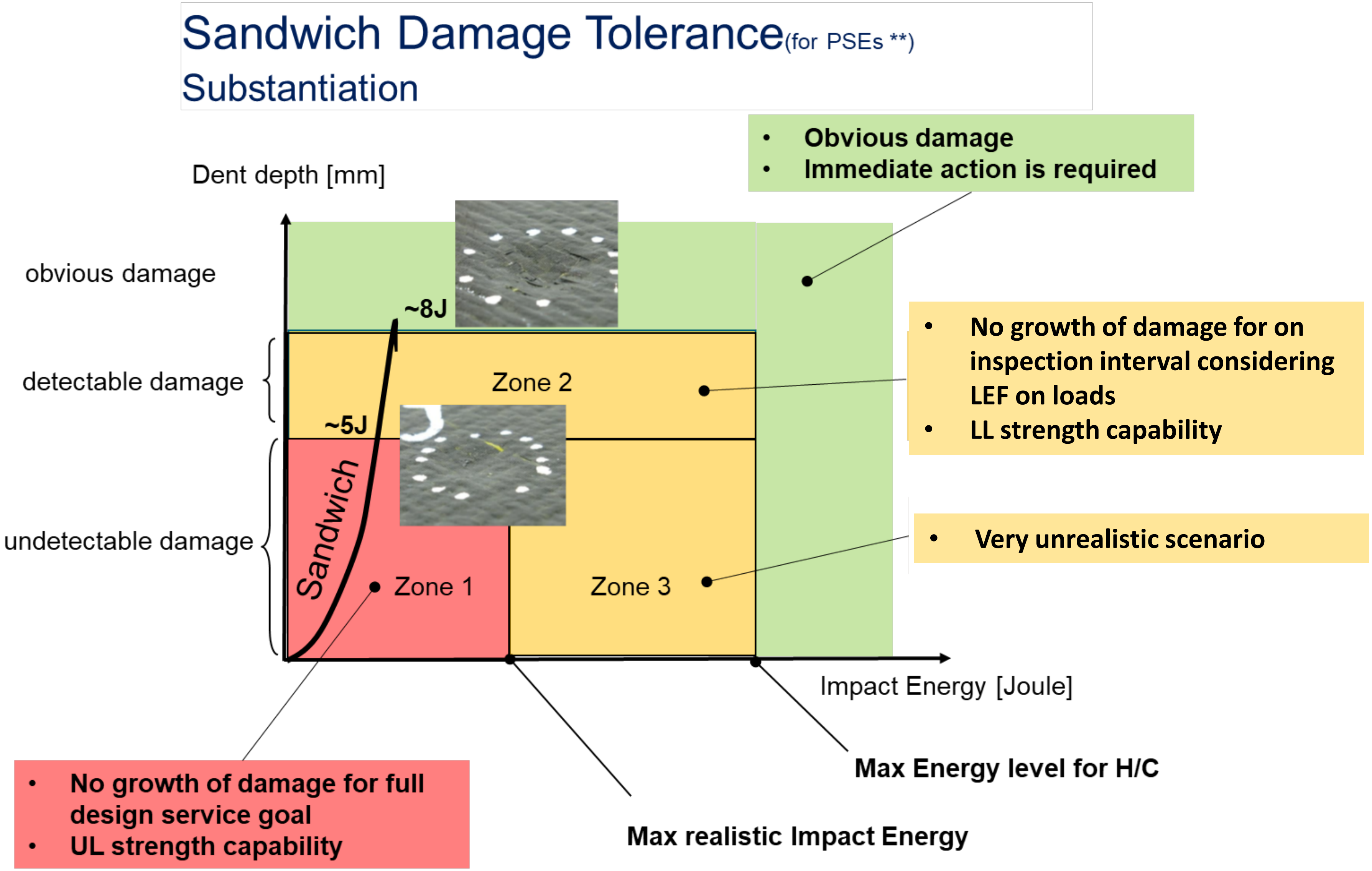
2.2 Airbus Helicopter



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Outline

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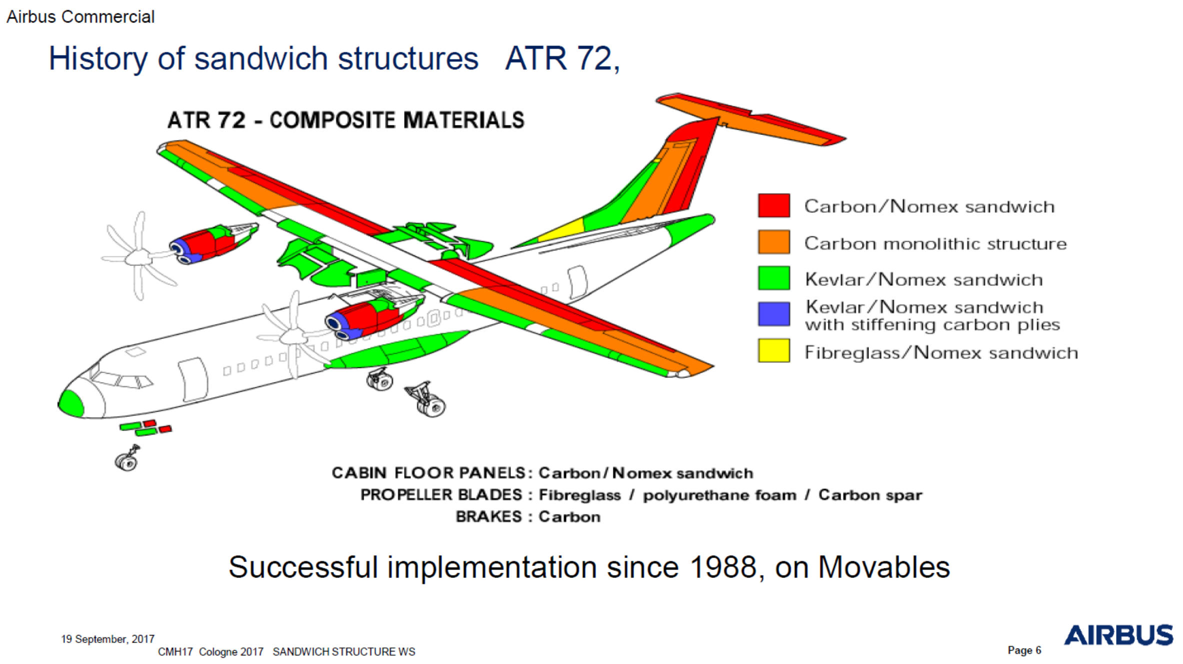
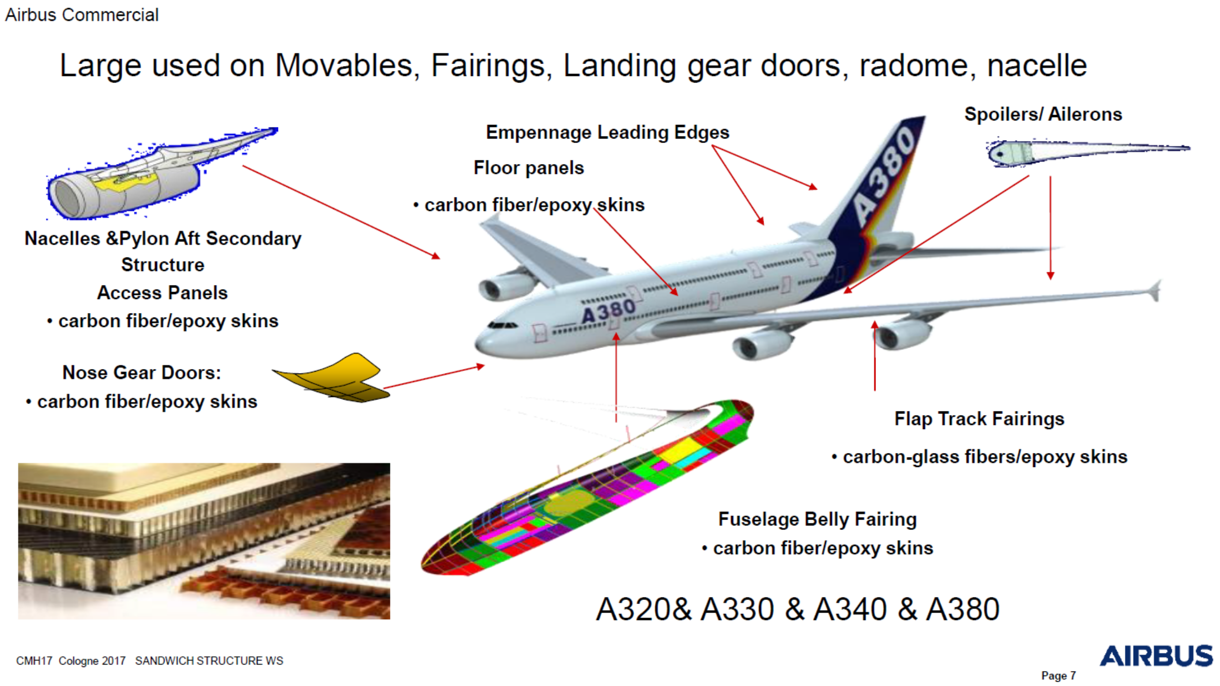
2.3 Airbus Commercial

Typical Sandwich Application





Extract from Airbus presentation held at CMH-17 sandwich disbond workshop Cologne September 2017

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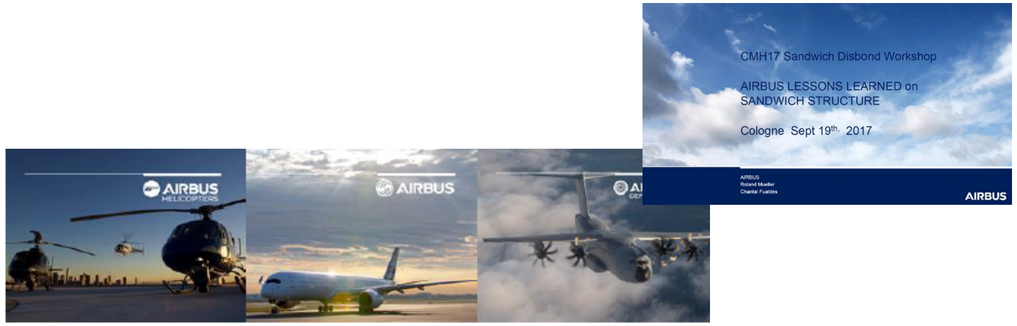
2.3 Airbus Commercial

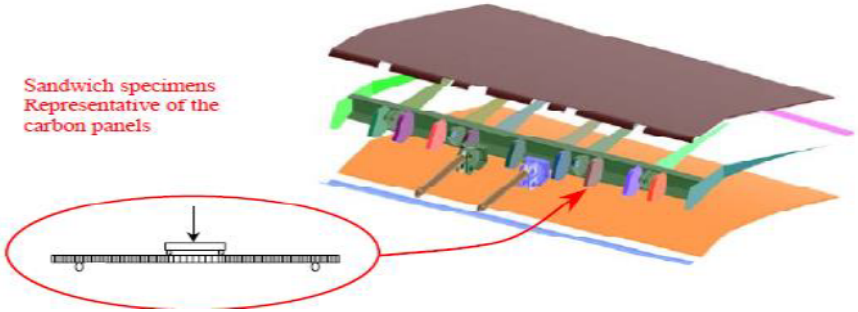


AI Helicopters &Airbus Commercial

Sandwich structure

Typical design validation (1/3)

- Sandwich structures (PSE) compile with CS 25.603, 25.605 and AMC 20.29 for Manufacturing process validation
- Design values:
  - Check of design allowable for change of curing cycles (pressure),
  - Influence of telegraphing, wrinkling,(co-cured face sheets)…
  - Honeycomb core buckling, shear…
- Bonding quality
  - Compatibility tests, adherence tests flatwise tension or climbing drum peeling test
  - Tightness test by immersion in hot water (potentially for new technologies)
- Quality control plan :
  - Process control specimen time limited for new technologies, check of process robustness. (adherence test)



This project is funded from the European Union's Horizon Europe research and innovation programme.

2.3 Airbus Commercial

AI Helicopters &Airbus Commercial

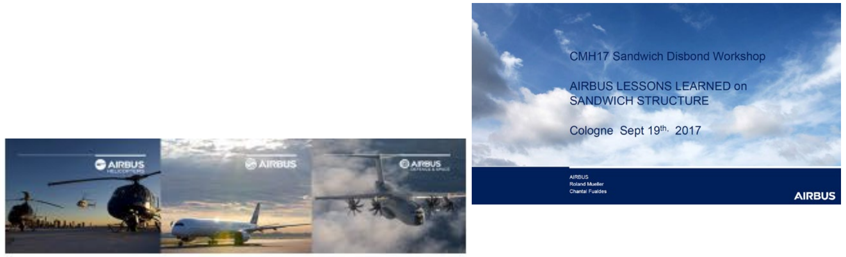
Sandwich structure

Substantiation Principles (2/3)

- Static Limit and Ultimate load demonstration (analysis supported by tests)
- Fatigue or damage tolerance demonstration for PSEs (analysis supported by tests)
- No-growth approach for composites
- Substantiation of inspection intervals
- Perform testing according building block approach
- Taking into account BVIDs (based on threat assessment) and allowable manufacturing defects
- Taking into account environmental effects
- Taking into account material variabillity

This project is funded from the European Union's Horizon Europe research and innovation programme.

2.3 Airbus Commercial



HELICOPTERS

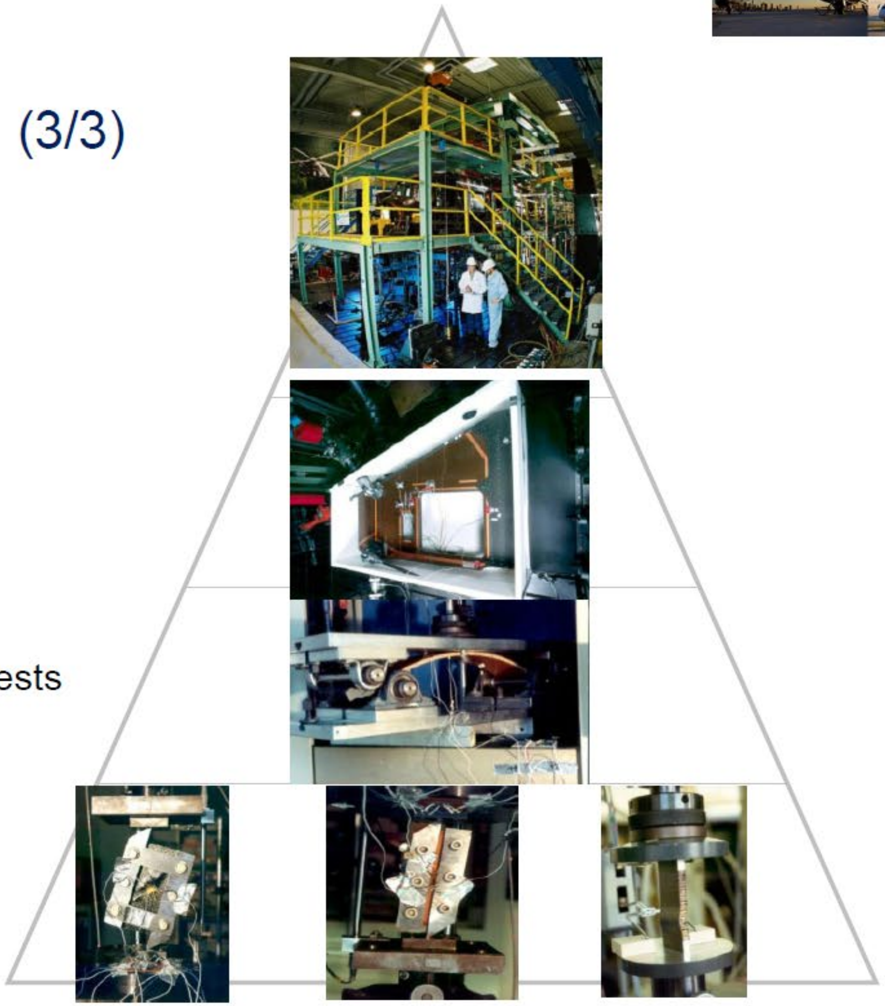
Sandwich structure
Building Block Approach (3/3)

Full Scale Tests

Component Tests

Structural Elements Tests

Coupon Tests



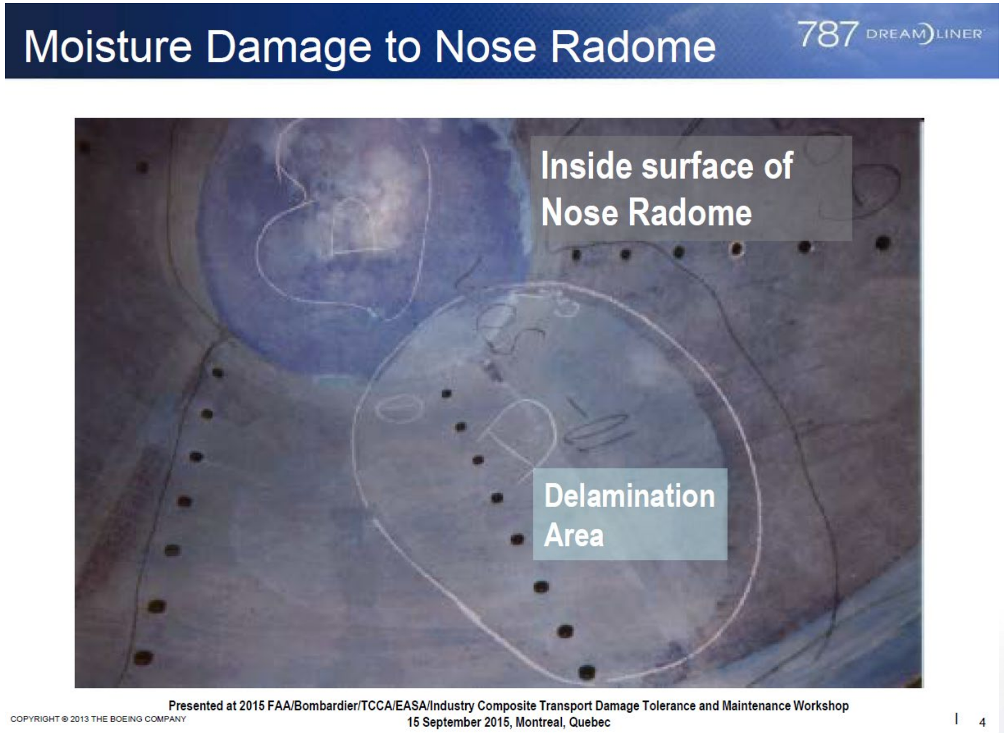
10 19 September, 2017 CMH17 Cologne 2017 SANDWICH STRUCTURE WS

AIRBUS

This project is funded from the European Union's Horizon Europe research and innovation programme.

2.3 Other OEM – Sandwich Design

Typical Sandwich Construction Issues



Extract from Boeing presentation
FAA/Bombardier/TCCA/EASA/Industry Composite Transport Damage Tolerance and Maintenance Workshop, Sept 2015

This project is funded from the European Union's Horizon Europe research and innovation programme.

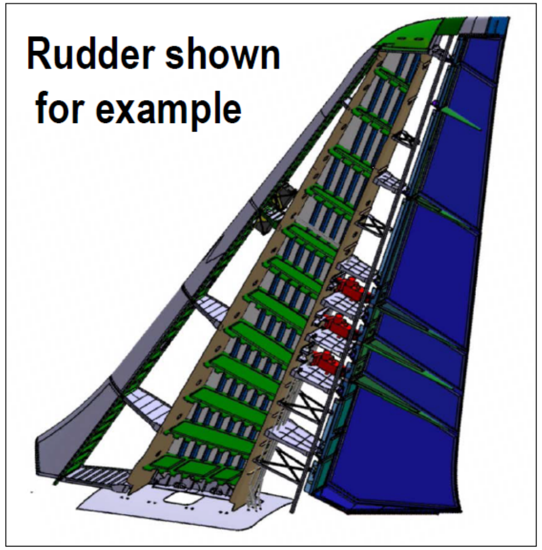
2.3 Other OEM – Sandwich Disbond

- **Sandwich Face Sheet Disbond**
  - Considered between arrestment features for PSEs
- **Loading and Analysis**
  - Compression and shear drive disbond buckling (and growth).
  - Analysis considers shear load reacted in diagonal tension in buckled face sheet.
- **GAG Pressure Loading**
  - Differential cavity pressure dependent on altitude and temperature.
  - Can add to static or fatigue loading
  - Addressed with <u>minimum core densit</u>y and minimum face sheet thickness

Design and Field Experiences – Sandwich Structure

787 DREAMLINER

- •PSE control surfaces
- •Failsafe approach to PSE Sandwich Construction
- •Limit load residual strength is demonstrated with a disbonded facesheet
- •Ribs are used as an arressment feature



Presented at 2015 FAA/Bombardier/TCCA/EASA/Industry Composite Transport Damage Tolerance and Maintenance Workshop
15 September 2015, Montreal, Quebec

5

This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

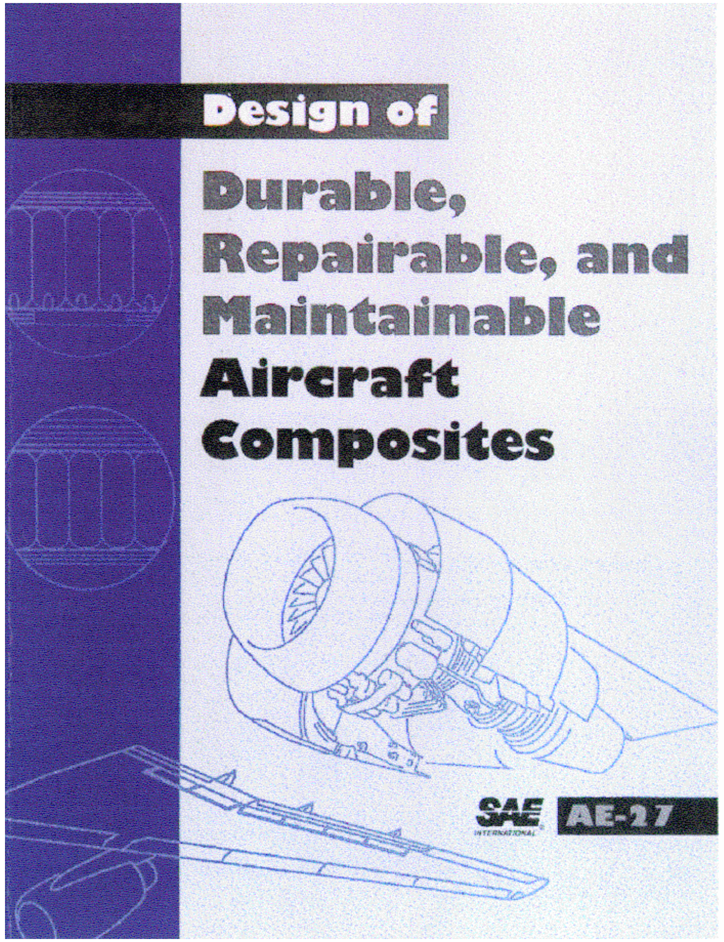
This project is funded from the European Union's Horizon Europe research and innovation programme.

In-Service Experience – CACRC Document

For the following slides reference CACRC document AE-27 for more information:

“Design of Durable, Repairable and Maintainable Aircraft Composites”

This document was prepared by the Design Task Group of the ATA/IATA/SAE Commercial Aircraft Composite Repair Committee (CACRC).



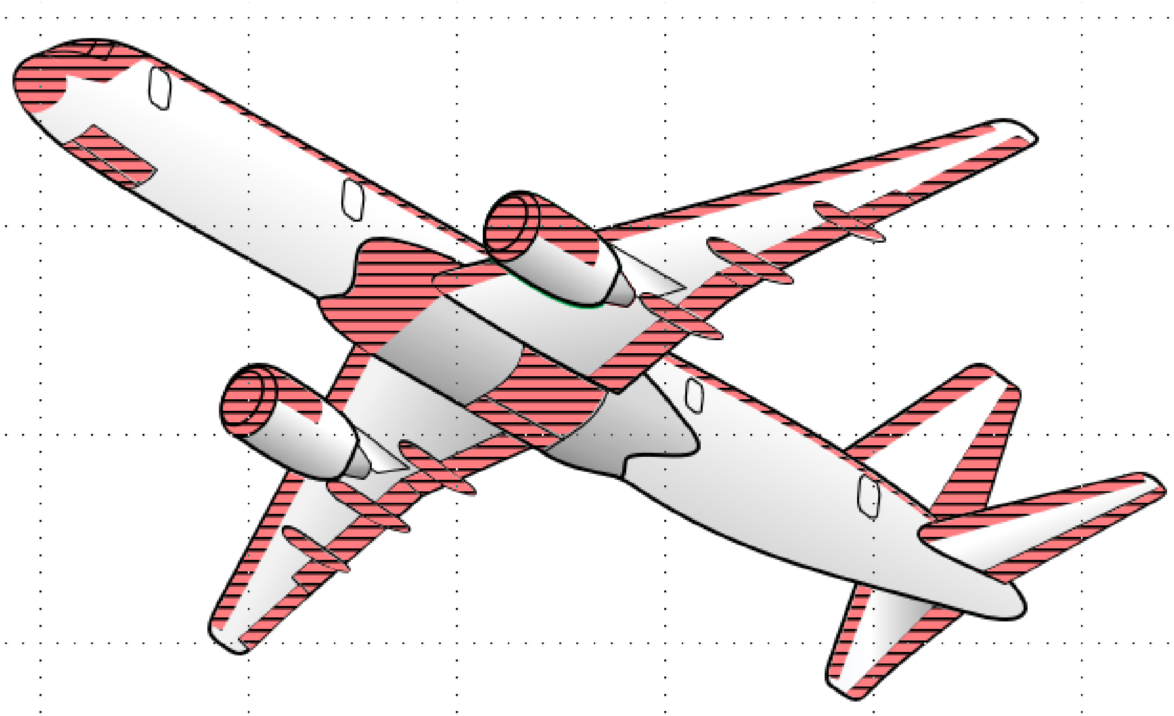
This project is funded from the European Union's Horizon Europe research and innovation programme.

In-Service Experience – Composites & Sandwich Structure

Airline survey:
“What are top concerns with composites?”

- *Durability & Impact Resistance*
- *Fluid Ingression*
- *Erosion*
- *Overheating*
- *Protective Finish (Paint)*
- *Complicated Repairs & Inspection Requirements*
  - *Interpretation of “complicated”:*
    - *Non-standardized, different repairs*
    - *Multiple people and skills required*
    - *Intermediate approvals or engineering needed*

Typical Structure Incorporating Sandwich Design Concepts



This project is funded from the European Union's Horizon Europe research and innovation programme.

In-Service Experience – Design Guidelines for Durability

2.4 Durability

The survey of in-service incidents shows a need to improve durability of composite components. This section lists recommendations for making improvements to structural design and processing and for mitigating specific types of damage.

2.4.1 Structure-Related Improvements

Durability can be improved in the areas of adhesive bonding, designing honeycomb sandwich structures, and in selecting appropriate material.

Adhesive Bonding

- Use a film adhesive at the interface between stiffener and skin to improve peel strength.
- Do not bond materials with different coefficients of thermal expansion such as structural aluminum parts to carbon fiber epoxy composites.

Honeycomb Sandwich

- Establish minimum face sheet thickness criteria based on realistic impact energy levels and handling criteria.
- Protect the inner face sheet from damage by establishing a minimum core thickness consistent with the outer face sheet damage threshold.
- Avoid the use of fasteners into the core whenever possible. If fasteners have to be used, potting of the holes must be done with a potting compound that does not become brittle over time.
- Avoid the use of square edged honeycomb close outs.
- Avoid the use of core geometry where the face sheets are bonded to the core at low pressure, leading to porosity in the bondline.

Material Selection

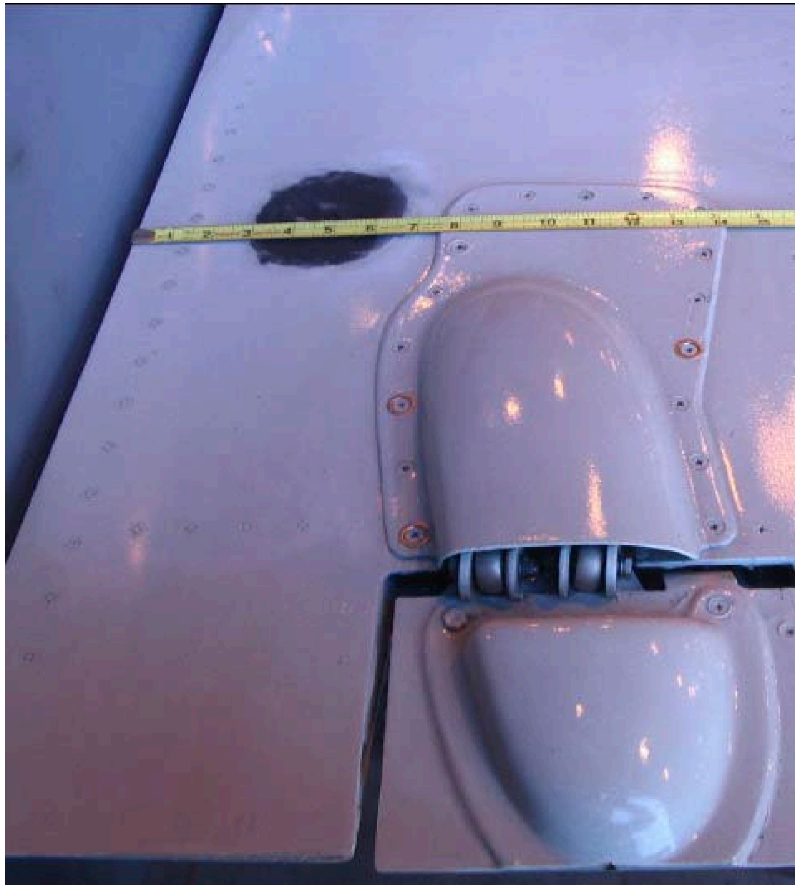
- Use composite materials that have a low porosity when cured.
- Consider carefully the use of aramid fiber composite; sandwich components with aramid facesheets have been known to have a problem with micro cracking and moisture absorption.

This project is funded from the European Union's Horizon Europe research and innovation programme.

In-Service Experience – Impact Resistance

Impact Resistance:

- ***FOD***
- ***Ground / Maintenance***
  - *Service vehicles*
  - *Service stands*
  - *Tools*
    - *Drop*
    - *Improper use*
- ***Normal line maintenance***
  - *Opening*
  - *Latching*
  - *Over-opening*
- ***Hail***



Elevator skin puncture in critical area

This project is funded from the European Union's Horizon Europe research and innovation programme.

In-Service Experience – Impact Resistance

Impact Resistance - Hail:

- ***Design considerations***
  - *Minimum skin gauge*
  - *Minimum honeycomb density*
  - *Skins less than minimum should not be in critical areas and should have large allowable limits.*
    - *Repair must be considered during design*
  - *Avoid thin skins in zones that are critical, or have no allowable damage, or not deferrable.*
  - *Min gauges dependent on part criticality and removability*
- ***SRM needs to cover:***
  - *Crushed core – "soft" but passes tap test*
  - *Removal of paint to evaluate damage*
  - *Seal against skin matrix and micro-cracking*

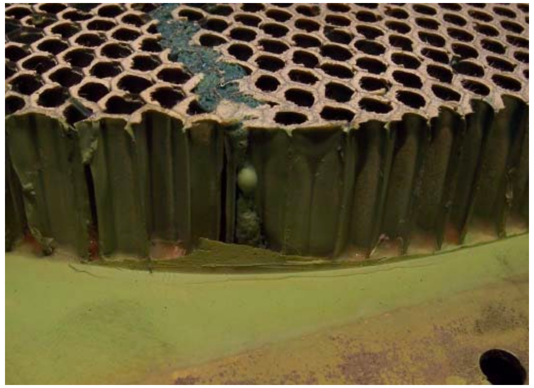
Hail damage to 3-ply graphite/honeycomb sandwich

This project is funded from the European Union's Horizon Europe research and innovation programme.

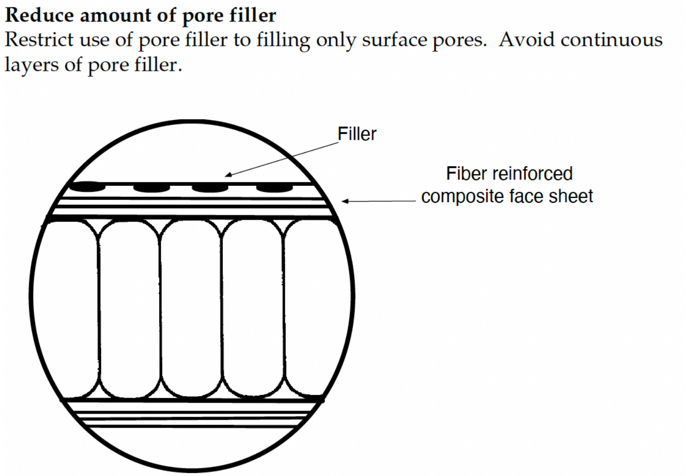
In-Service Experience – Fluid Ingression

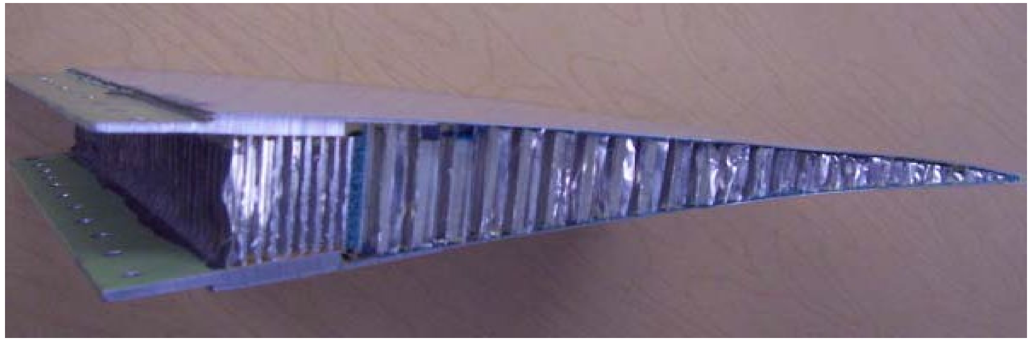
Fluid Ingression Causes:

- ***Square-edged panel close-out***
- ***Alum honeycomb edges inadequate close-out and finish***
  - *Alum honeycomb corrosion*
- ***Close-out of trailing edge wedges – aluminum metalbond***
- ***Ingress through square edge close-out and bondline (such as potting compound at square edge and porous adhesive)***
- ***Propagation via porous foaming adhesive***
- ***The use of too much pore filler***

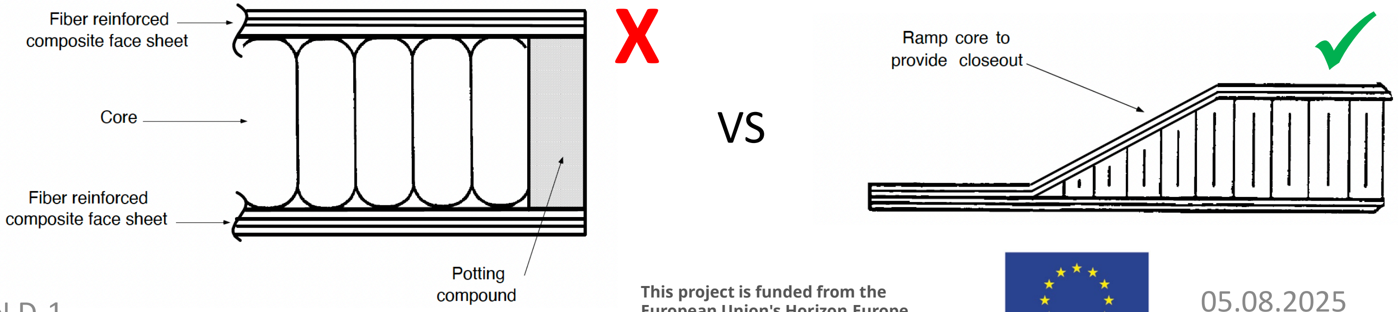


Foaming adhesive core join





Aluminum core edge with inadequate close-out



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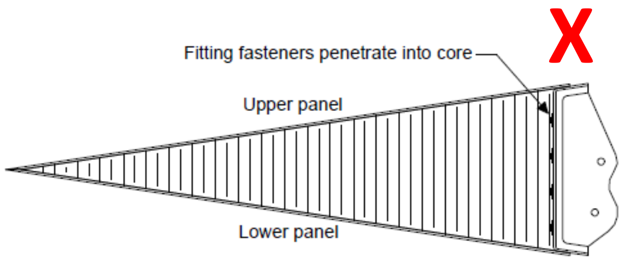
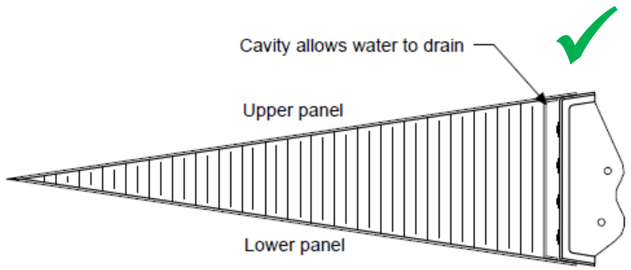
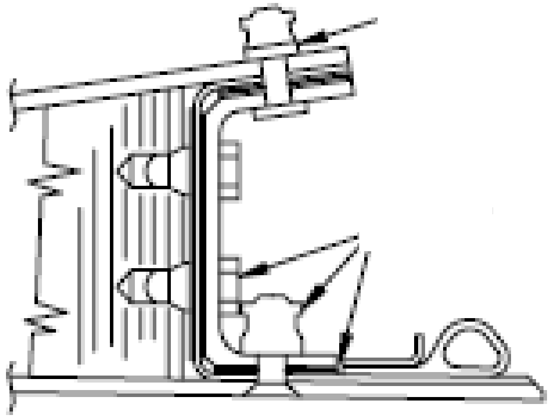
In-Service Experience – Fluid Ingression

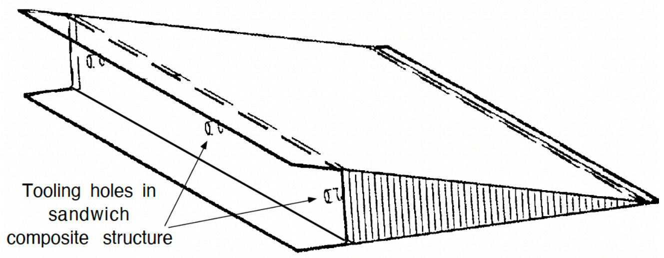
Fluid Ingression Causes:

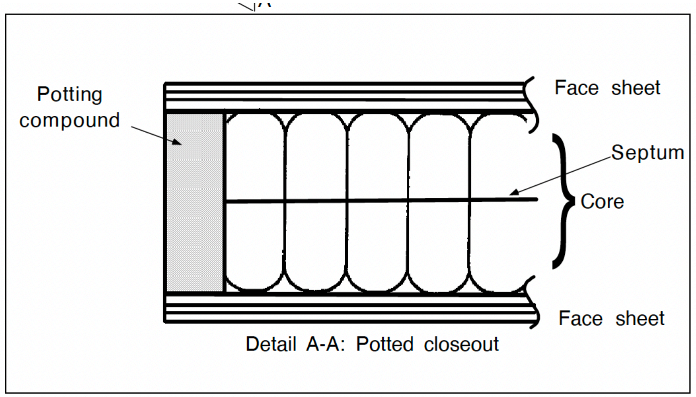
- ***Fasteners through skin into core***
- ***Porous Foaming Adhesive or potting – porous so acts as water path***
- ***Honeycomb splices and cavities not completely filled***
- ***Honeycomb septum has high porosity***
- ***Tooling holes in spar, aging of sealant***

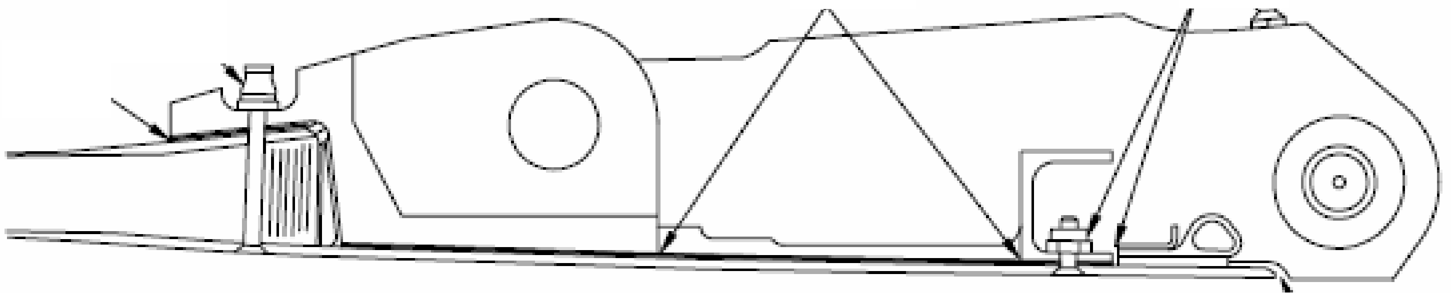












This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

This project is funded from the European Union's Horizon Europe research and innovation programme.

EASA sponsored R&D EPAS Project: DESIGN

EASA
European Union Aviation Safety Agency

This project is funded from the European Union's Horizon Europe research and innovation programme.

R&D EPAS Project DESIGN

Damage Tolerant Design of Sandwich Structures in PSE applications

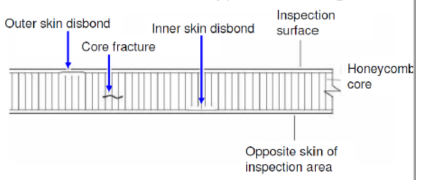
An Agency of the European Union

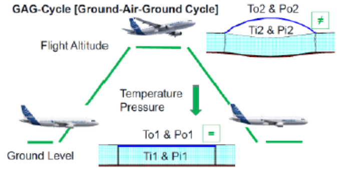
Sandwich Structures in PSE

- **Lightweight** structures with high stiffness and strength to weight ratios
- Several **safety issues** experienced during the past decades with composite sandwich across a range of products, due to sandwich disbond and damage growth.
- **Sandwich disbond and damage growth behavior** are critical aspects of Damage Tolerance of sandwich applications

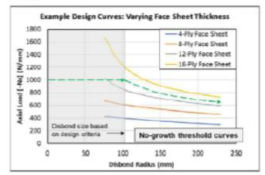
Some initiatives were launched by EASA:
- to better understand the influencing factors on sandwich disbond
- to develop some testing methods to characterize sensitivity to disbond
- **CM-S-010**: *The Safe Design and Use of Monocoque Sandwich Structures in Principal Structural Element Applications*
- R&D project **DoSS** "Disbond of Sandwich Structures" - 2016-2017
  - ...sbond of Sandwich Structures report EASA_REP_RESEA_2016_2 (online)
  - ...gineering approach for sandwich disbond analysis
  - ...sting method for sandwich fracture toughness

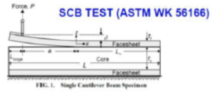
Sandwich structure typical damages





Design Curves





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Practical design solution e.g. closed form design solution developed for large aircraft (NSE / FAA)

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EASA R&D DESIGN Project

EASA Webpage

- **DESIGN**: *Evolutions of airworthiness standards for new aircraft structure design using materials, processes, and advanced manufacturing methods*
- Main **objective**: Develop key enablers for safe design and use of sandwich structures in PSE applications.
- Main **Tasks**:
  - **Task 1** Provision of a "Current industry status report"
  - **Task 2** Development of substantiated design solutions
  - **Task 3** Improvement of damage detection for typically difficult to detect damage
  - **Task 4** Development of Hybrid Structure Continued Airworthiness Strategies
  - **Task 5** Conclusions, recommendations implementation roadmap and cost-benefit analysis
- Consortium Members:

DTU | Fraunhofer IMWS | Università di Genova | NSE COMPOSITES | EASA | AIRBUS COMMERCIAL AIRCRAFT | AIRBUS HELICOPTERS | LEONARDO | DUPONT

2025-2027
3y

1 M€

Contractor
DTU

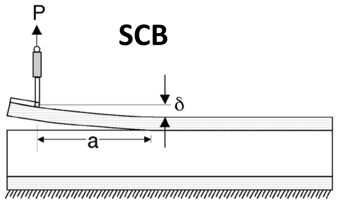
Project Lead
EASA

37

DESIGN D-1

This project is funded from the European Union's Horizon Europe research and innovation programme.

Engineering Approach for Sandwich Disbond Analysis



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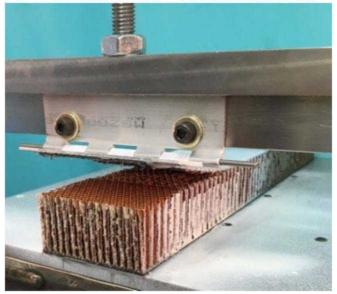
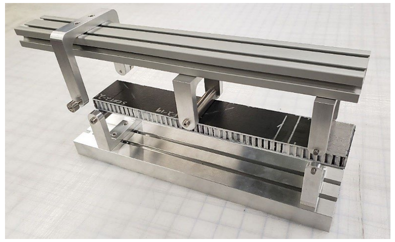


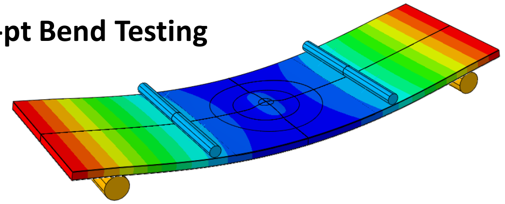
S-MMB

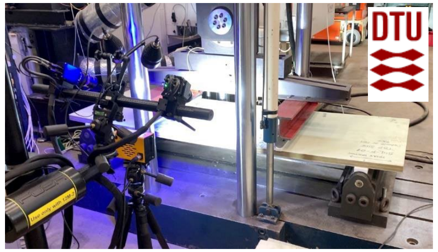


Courtesy of D. Adams (U of Utah)

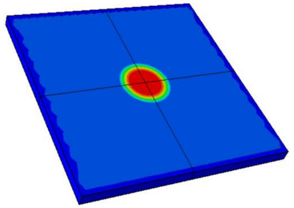
Coupon testing for static and fatigue Gs

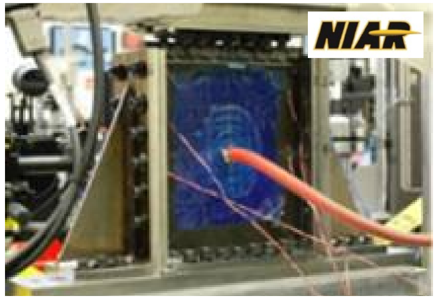
4-pt Bend Testing



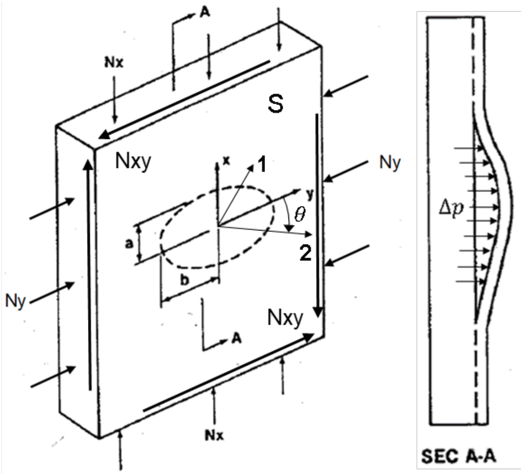


Panel Testing





ESDA Approach



FSDA Approach (FEA based)

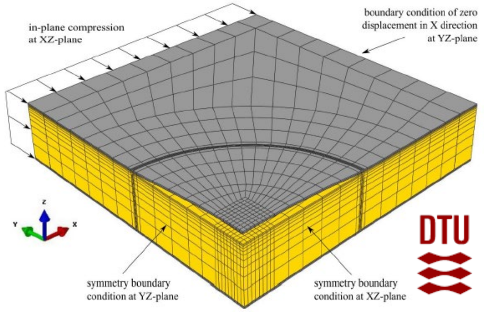
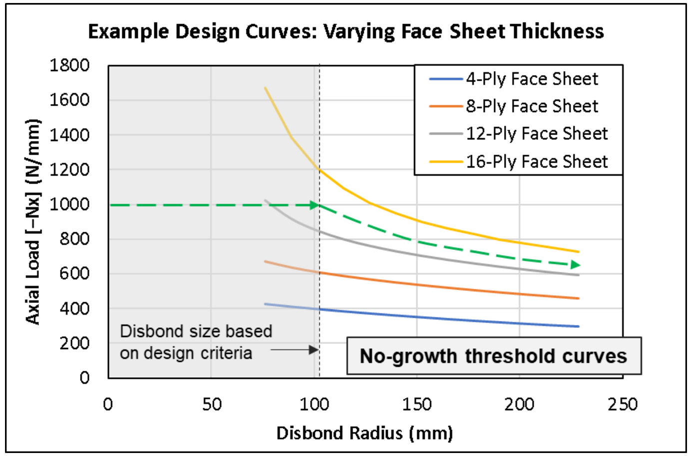


Figure 33: Global model of the disbonded sandwich used for the static parametric study.

<u>End result</u> = repeatable, reliable analysis output (i.e., design curves) validated by test data.

Design Curves

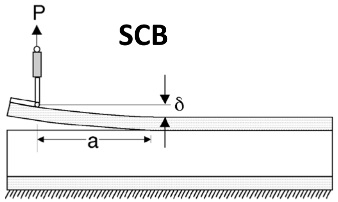


- **<u>Engineering approach</u> incorporates simplifying (conservative) assumptions and other constraints.**
- **Used for <u>design studies and sizing</u> to understand when sandwich disbond becomes critical (goal is to avoid).**

This project is funded from the European Union's Horizon Europe research and innovation programme.

Engineering Approach for No-Growth Fracture Allowables (Gs)

SCB



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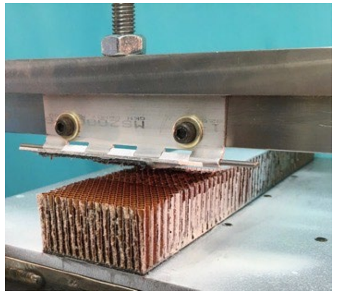
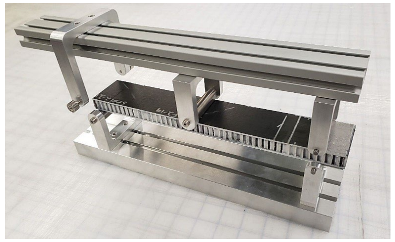
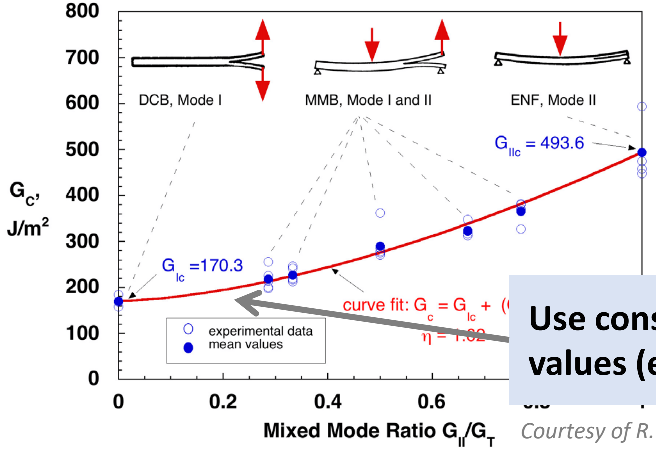


S-MMB



Coupon testing for static and fatigue Gs

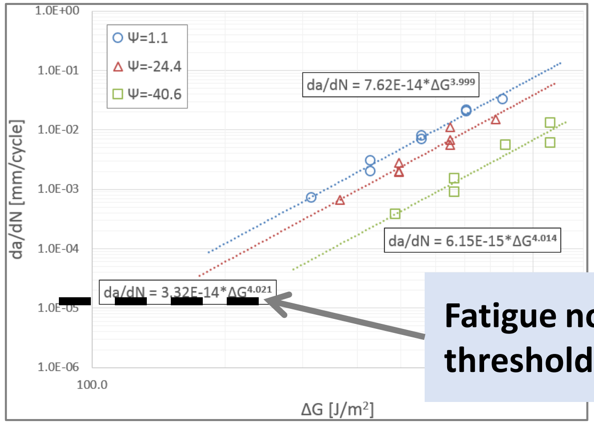
<u>Static</u> Gc (Mixed-Mode)



Use conservative values (e.g., Mode I)

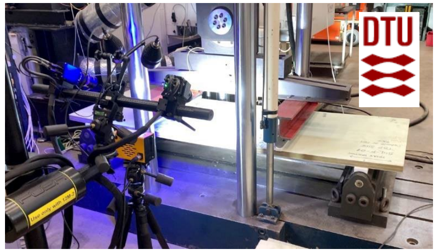
Courtesy of R. Krueger

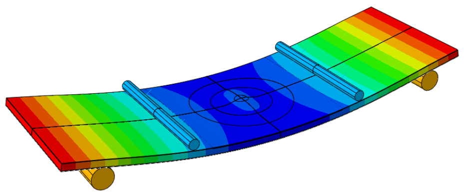
<u>Fatigue</u> G (da/dN)



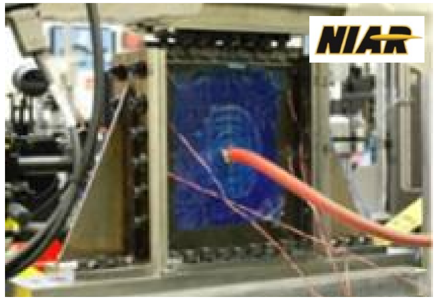
Fatigue no-growth threshold is needed

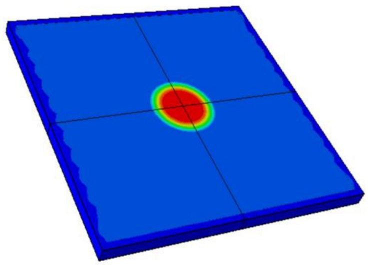
4-pt Bend Testing





Panel Testing



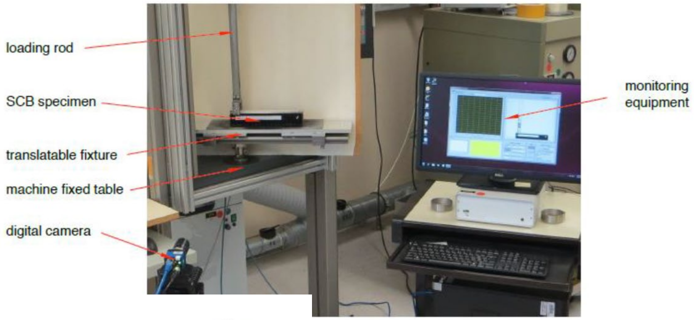


<u>Panel-level testing</u> can be used directly to back out "<u>Effective Gc</u>" values for static and fatigue.

This project is funded from the European Union's Horizon Europe research and innovation programme.

EASA R&D DoSS

- EASA funded one year project, duration Aug 2016 to Sept 2017
- Disbond of Sandwich Structure – DoSS
- Nomex honeycomb with different densities from 32 to 96kg/m³ and thin and thick face sheet
- Sandwich static & fatigue fracture toughness measurement
  - Single Cantilever Beam – SCB
  - Double Cantilever Beam with uneven bending moment – DCB-UBM
- SCB & DCB-UBM linear fracture mechanics finite element analysis



t fixture at DuPont, Geneva.

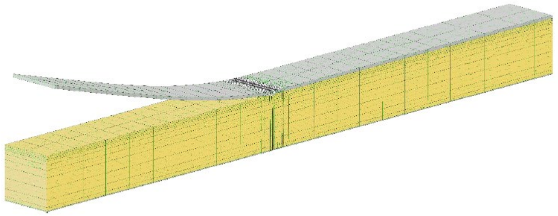


Figure 30. 3D FE-model of SCB sandwich specimen built in ABAQUS®.

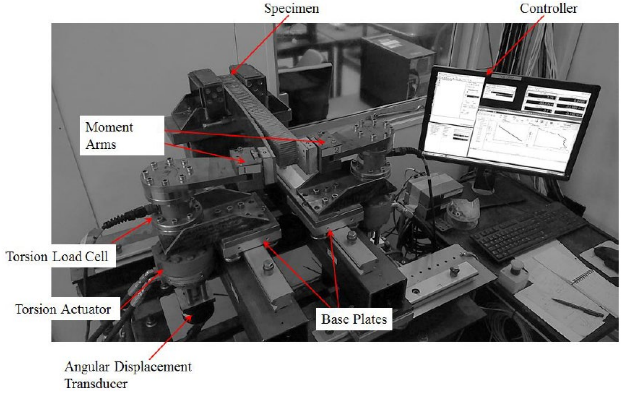


Figure 17. DCB-UBM Test set-up at DTU, Lyngby.

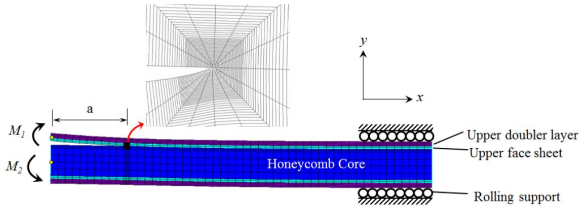


Figure 28. 2D FE-model of reinforced DCB-UBM sandwich specimen built using ANSYS® at DTU.

DTU

Fraunhofer IMWS

AIRBUS DUPONT AIRBUS HELICOPTERS

EASA R&D, e.g. reference report EASA_REP_RESEA_2016_2 – Disbond of Sandwich Structures (DoSS).

This project is funded from the European Union's Horizon Europe research and innovation programme.

ASTM D30.09 Sandwich Standards Development

CMH-17 Sandwich Disbond Working Group initiated with ASTM development of sandwich fracture toughness test methods

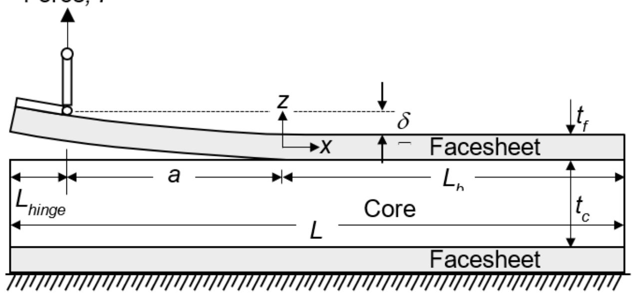
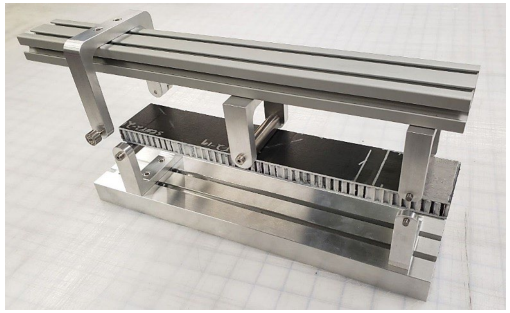


FIG. 1. Single Cantilever Beam Specimen

SCB Static (WK90368) Fatigue (WK90080)

- Standard Test Method for Mode I Dominant Facesheet-to-Core Fracture Toughness of Sandwich Constructions
- Draft standard available
- First Round Robin SCB data covered by NASA-TM-2024-0001178 report
- Second Round Robin Testing on fatigue testing organized by CMH-17 Sandwich Working Group/ASTM joint activity for 2025



S-MMB WK78832

- New Test Method for Mixed Mode I-Mode II Fracture Toughness of Sandwich Constructions
- Draft standard in discussion and definition
- First Round Robin scheduled for 2025, sandwich panel provided by Bell Helicopter and Airbus

This project is funded from the European Union's Horizon Europe research and innovation programme.

FAA Research & Development – JAMS

JAMS is a leader in international coordination of research, development, and standardization for structures constructed from composites and advanced materials. The common goal of this joint center, as with the other COEs, is to create a cost-sharing academic, industrial, and governmental partnership. The members are forging a union between the public sector, the private sector and academic institutions to create a world-class capability to identify solutions for existing and potential advanced materials and structures issues. The main focus of this partnership is the research, engineering and development of information used to assure safety and standardize certification of existing and emerging structural applications of composites and advanced materials. Specifically, projects include the evaluation of past applications, performance of applied research and the development of standard engineering practices. This Joint Center of Excellence, working with industry and government, also plays an important role in technology transfer, training, and continuing education for the aircraft industry and regulators. The group strives for international standardization; develops consensus for developed protocols; identifies standardized criteria for material and process control; and promotes shared material databases worldwide. COE members and industry affiliates have provided more than $15M in matching contributions.

SPONSOR: Office of Airport and Aircraft Safety, Research & Development Division
FAA PROGRAM MANAGER: Ahmet Oztekin, William J. Hughes Technical Center
CECAM DIRECTOR/UNIVERSITY LEAD: John Tomblin, Ph.D., Wichita State University
AMTAS DIRECTOR/UNIVERSITY LEAD: Mark Tuttle, Ph.D., University of Washington

This project is funded from the European Union's Horizon Europe research and innovation programme.

FAA Research & Development – AMTAS

The **Center of Excellence for Advanced Materials in Transport Aircraft Structures** (**AMTAS**) is a division of the FAA's Joint Advanced Materials and Structure Center of Excellence, established in 2004 to assist in ensuring the safe and reliable application of composites and other advanced materials to commercial aircraft.

Hosted by the University of Washington, the mission of AMTAS is to bring academia, industry, and government agencies together to develop solutions to problems associated with existing, near- and long-term applications of composites through a multifaceted program comprising:

- **Research**, **testing**, **certification**, and **technology transfer**
- **Coordination** with the Federal Aviation Administration, standards organizations, OEMs, material suppliers, and airline companies
- **Workforce education**

This project is funded from the European Union's Horizon Europe research and innovation programme.

FAA / AMTAS – R&D Projects

BONDED JOINTS AND SANDWICH STRUCTURES

1. Nanomechanical Characterization of Adhesive Bondlines - JAMS.UW.Bonding, Brian Flinn, University of Washington
2. Notch Sensitivity of Composite Sandwich Structures, Dan Adams, University of Utah
3. Durability of Bonded Aerospace Structure, Lloyd Smith, Washington State University
4. Test Method Development for Environmental Durability of Bonded Composite Joints, Dan Adams, University of Utah
5. Effects of Moisture Diffusion in Sandwich Composites, Mark Tuttle, University of Washington
6. Delamination/Disbond Arrest Features in Aircraft Composite Structure, Kuen Lin, University of Washington
7. Probabilistic Fracture Analysis of Disbond in Bonded-Bolted Composite Structures University of Washington, Kuen Lin, University of Washington
8. Durability of Adhesively Bonded Joints for Aircraft Structures, Dan Adams, University of Utah
9. Contamination and Moisture / Effect of Surface Contamination on Composite Bond Integrity, Dwayne McDaniel, Florida International University
10. The Effect of Surface Treatment on the Degradation of Composite Adhesives, Lloyd Smith, Washington State University
11. Adhesive Hot/Wet Creep Response, Lloyd Smith. Washington State University
12. Improving Adhesive Bonding of Composites through Surface Characterization, Brian Flinn, University of Washington

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

This project is funded from the European Union's Horizon Europe research and innovation programme.

FAA Research & Development – CECAM

The Center of Excellence for Composites and Advanced Materials (CECAM) is a division of the FAA's Joint Advanced Materials and Structure Center of Excellence, established in 2004 to assist in ensuring the safe and reliable application of composites and advanced materials to commercial aircraft. CECAM is headquartered at Wichita State University's National Institute for Aviation Research.

CECAM Mission:
To provide the nation with a center for the validation and quality assurance of composites and advanced materials to be applied in the construction of aircraft through:

- Research, testing, certification, and technology transfer
- Coordination and cooperation with the FAA, aircraft manufacturers, materials suppliers, and airline companies
- Education of the aircraft manufacturing and maintenance workforces

Core Members:

- Auburn University
- University of California
- Mississippi State University
- Wichita State University

FAA Sponsor: William J. Hughes Technical Center
Director: John Tomblin. Ph.D., National Institute for Aviation Research, Wichita State University
FAA COE CECAM Program Manager: Ahmet Oztekin
Primary CECAM Technical Advisors: Edward Weinstein, Larry Ilcewicz, Cindy Ashforth, Ahmet Oztekin, Dave Stanley, Lynn Pham, Danielle Stephens, Kevin Stonaker

This project is funded from the European Union's Horizon Europe research and innovation programme.

FAA / CECAM – R&D Projects

Current Projects:

- **Additive Manufacturing Guidance for Aircraft Design and Certification**
  John Tomblin, Rachael Andrulonis, Royal Lovingfoss, Joel White, Neville Tay
- **Advanced Fiber Reinforced Polymer Composite Materials Guidance for Aircraft Design, Certification and Process Control** *John Tomblin, Royal Lovingfoss, Rachael Andrulonis*
- **Bond Process Qualification Protocols for Aircraft Design and Certification**
  Waruna Seneviratne, John Tomblin, and Upul Palliyaguru
- **Ceramic Matrix Composite (CMC) Materials Guidance for Aircraft**
  John Tomblin, Matt Opliger, Rachael Andrulonis
- **Certification by Analysis / Full Scale Drop Tests / Effect of Defects / Effect of Disinfectants**
  Gerardo Olivares, Luis Gomez
- **Core Materials Qualification Guidelines for Aircraft Design and Certification**
  Rachael Andrulonis, Royal Lovingfoss, Nicole Stahl
- **Development of Guidance for a Technical Standard Order (TSO) for Composite Materials**
  John Tomblin, Royal Lovingfoss, Rachael Andrulonis
- **Development of Higher-Level Building Block Testing Standards**
  Waruna Seneviratne, John, Tomblin, Nalin Waas, and Reomal Vanderwall
- **Development of Process Specifications for AFP Tape Slitting**
  Waruna Seneviratne, John Tomblin, Alex Martens
- **Evaluation of Aged Composite Structures**
  Waruna Seneviratne, John Tomblin, Chris Trevino
- **Evaluation of Aged Structural Bonds on Rotor Blades**
  Waruna Seneviratne, Caleb Saathoff
- **Resin Infused Fiber Reinforced Materials Guidelines for Aircraft Design and Certification**
  John Tomblin, Royal Lovingfoss, Rachael Andrulonis, Michelle Man
- **Technology Readiness Assessment for Stitched and Unstitched Resin Infused Composites**
  Christopher O. Bounds, Wayne Huberty

NIAR®
WICHITA STATE UNIVERSITY

CECAM
center of excellence for composites and advanced materials

DESIGN

This project is funded from the European Union's Horizon Europe research and innovation programme.

Other relevant R&D efforts

Articles published in journals or conference proceedings:

- E. H. Glaessgen, J. R. Reeder, D. W. Sleight, J. T. Wang, I. S. Raju, and C. E. Harris, **“Debonding failure of sandwich-composite cryogenic fuel tank with internal core pressure**,” J. Spacecraft. Rockets, vol. 42, no. 4, pp. 613–627, 2005, https://doi.org/10.2514/1.5567

- S. Engelstad, M. Chen Zhi, V. Goyal, and Maghsoudy-Louyeh Sahar, **“Design Curves for Unvented Honeycomb Sandwich Structures Subject to In-Plane and Pressure Loads,”** in AIAA SCITECH 2022 Forum, 2022, vol. 1, pp. 532–541, https://doi.org/10.2514/6.2022-0668

- V. K. Goyal and S. Maghsoudy-Louyeh, **“Proof test methodology for reducing the risk of unvented honeycomb core failures in aerospace structures,”** Spec. Issue J. Sandw. Struct. Mater., vol. 25, no. 1, pp. 61–76, 2019, https://doi.org/10.2514/1.5567

- M. Rinker, F. W. Iwm, R. Krueger, and J. Ratcliffe, **“Analysis of an aircraft honeycomb sandwich panel with circular face sheet / core disbond subjected to ground-air pressurization,”** no. 2013, 2013. https://ntrs.nasa.gov/search.jsp?R=20130011132

This project is funded from the European Union's Horizon Europe research and innovation programme.

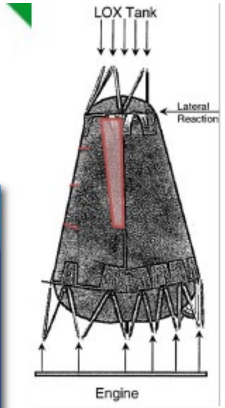
Outline

This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

The accidents & incidents presented in this section are (1/2):

- Concorde/951 G-BOAF BA9051C 1989 (March 1992)
- NASA X-33 Hydrogen Tank (November 1999)
- Airbus A310 – Rudder Loss Event in flight (March 2005)
- AW139 Helicopter Tail Boom Collapse (August 2009)
- Boeing service bulletin B757 (April 2011)
- FAA review on Bond-Related Aircraft Accidents/Incidents (April 2021)

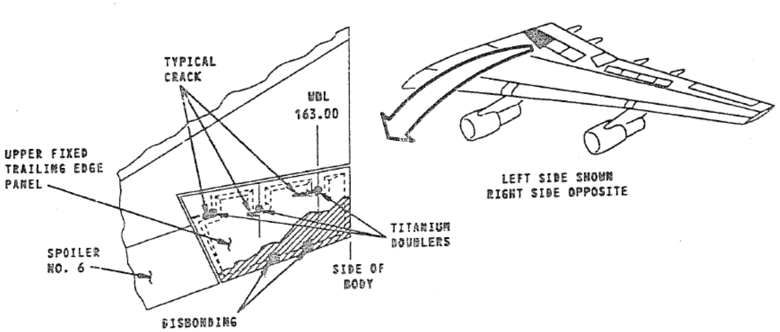


This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

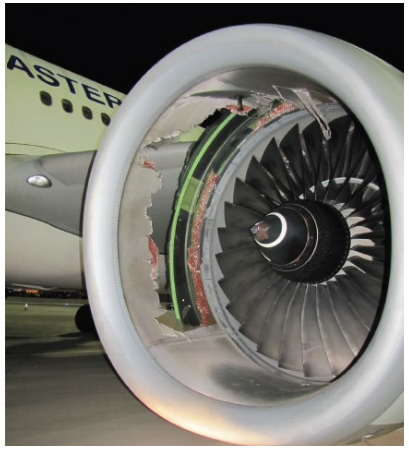
The accidents & incidents presented in this section are (2/2):

- Radome Collapse
    - FINAL REPORT Serious Incident Occurrence No: 619/1 Aircraft: F-100, D-AGPH 1 July 2010
    - A350 – Safety Magazine article, April 2024



- B747 Flying Panels, Feb 1991

- A330, B-6099 Investigation 11 June 2017 ATSB Transport Safety Report Aviation Occurrence Investigation AO-2017-059 Final – 20 November 2019

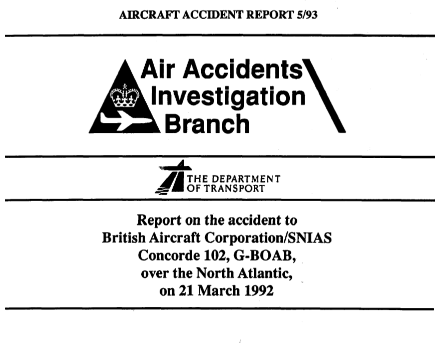


This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

BAC Concorde 102 – As Exemple Rudder Loss Event in flight (March 1992)

- Concorde 102 operated by British Airways registered as G-BOAB
- Loss of the upper rudder during the descend at Mach 1.4 caused severe vibrations due to a disbond in the facesheet/core interface.
- The aircraft was landed safely. Incident, no fatalities.
- The major portion of the failed rudder was never recovered.
- Possible accidental ingress of repair preparation materials (water, MEK) into the unvented honeycomb.
- The damaging effects of MEK and chromic/sulphuric acid mixture as well as the mechanical pressures exerted by a boiling liquid could have encouraged a slow disbond growth to a critical size.
- On April 1989, Concorde G-BOAF suffered an almost identical upper rudder failure to the one described in this report


AIRCRAFT ACCIDENT REPORT 5/93

Air Accidents Investigation Branch

THE DEPARTMENT OF TRANSPORT

Report on the accident to British Aircraft Corporation/SNIAS Concorde 102, G-BOAB, over the North Atlantic, on 21 March 1992

Source: Air Accidents Investigation Branch (AAIB) - Department of Transportation, “Report on the accident to British Aircraft Corporation/SNIAS Concorde 102, G-BOAB, on 21 March 1992,” Farnborough, United Kingdom, 1993.

G-BOAF – failed rudder


G-BOAB – failed rudder

This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

NASA X-33 program unexpected tank failure (November 1999)

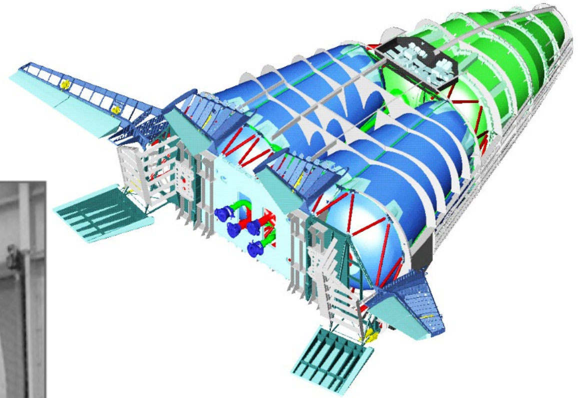
- Liquid hydrogen thank (LH_2) of the NASA X-33 experimental spacecraft
- Unexpected failure during protoflight testing on November 1999
- The tank was a conformal, load-bearing structure, consisting of four lobes. In composite sandwich structure (carbon/epoxy and korex core)
- Infiltration of liquid and gaseous nitrogen into the core (due to facesheet microcracking) triggered cryo-pumping and a subsequent rise in pressure during the tank drain.
- The cracks grew larger under pressure. When pressure was removed cracks closed slightly

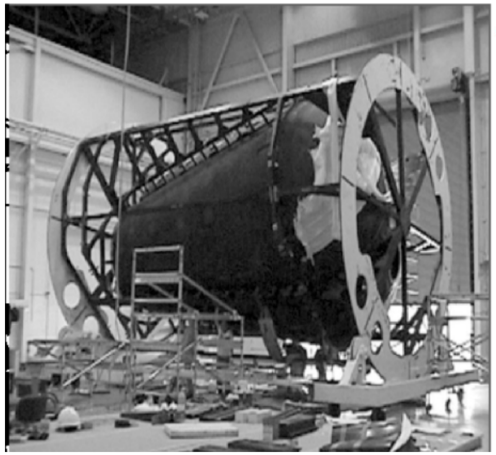
Source: E. H. Glaessgen, J. R. Reeder, D. W. Sleight, J. T. Wang, I. S. Raju, and C. E. Harris, "Debonding failure of sandwich-composite cryogenic fuel tank with internal core pressure," J. Spacecr. Rockets, vol. 42, no. 4, pp. 613–627, 2005, doi: 10.2514/1.5567.

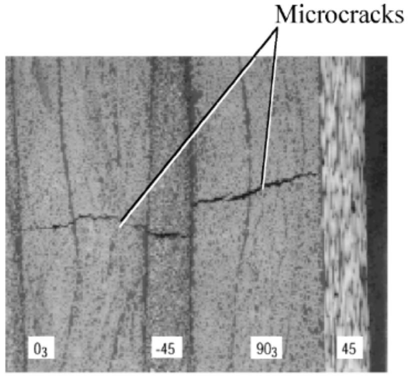
JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 42, No. 4, July–August 2005

Debonding Failure of Sandwich-Composite Cryogenic Fuel Tank with Internal Core Pressure

Edward H. Glaessgen,* James R. Reeder,† David W. Sleight,* John T. Wang,* Ivatury S. Raju,‡ and Charles E. Harris§
NASA Langley Research Center, Hampton, Virginia 23681







a) Inner facesheet microcracking (sectioned at 45 deg)

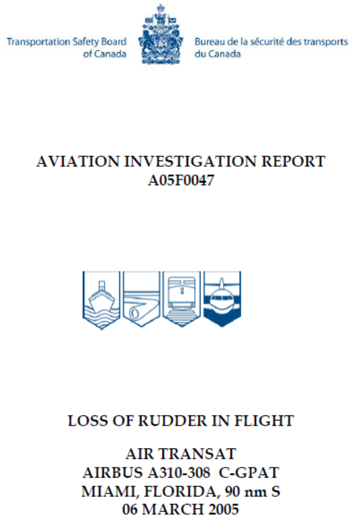
This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

Airbus A310 – Rudder Loss Event in flight (March 2005)

- A310-308 operated by Transat (Flight 961)
- Lost the rudder during flight at 35000 ft and went into a Dutch roll
- The pilots recovered control and safely landed the aeroplane at a nearby airportIncident. Incident, no fatalities.
- Rudder failure occurred due to the flutter which was caused by a large disbond damage in the rudder side panels. Stiffness degradation over time
- Sandwich Side Shell constructed from a non-metallic Nomex® aramid-based honeycomb core, with CFRP face sheets.
- The vacuum test suggested that the sandwich disbond (face sheet to core separation) grew due to GAG pressure differential.

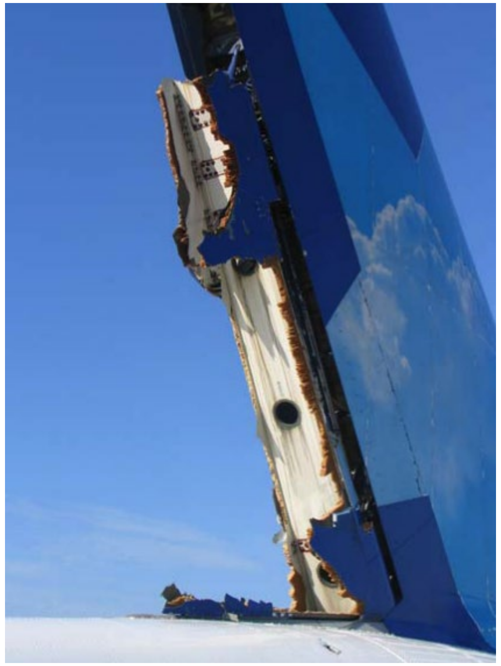
Source: The Transportation Safety Board of Canada, "AVIATION INVESTIGATION REPORT A05F0047 - LOSS OF RUDDER IN FLIGHT," 2007.


Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A05F0047

LOSS OF RUDDER IN FLIGHT

AIR TRANSAT
AIRBUS A310-308 C-GPAT
MIAMI, FLORIDA, 90 nm S
06 MARCH 2005



This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

AW139 Helicopter Tail Boom Failure (August 2009)

- Tail boom collapse during taxing on ground, no fatalities
- Most probable root cause was determined in a tail boom strength degradation caused by hidden honeycomb internal damage induced by a previous tail strike event suffered on March 2009 before the accident.
- At the time of tail strike event the damage assessment did not identify the internal honeycomb core failure mode.
- Tail boom full scale tests confirmed damage tolerance capability for damaging extension extremely higher than actual repair allowable
- Static full scale disbond panel test showed a buckling load level comparable to a ground taxing

Source: Aircraft Accident Investigation Final Report – Gulf Helicopter Company Augusta Westland AW139 Helicopter S/N31225 with Registration Marks A7-GHC, Doha, Stae of Qatar 25th August 2009

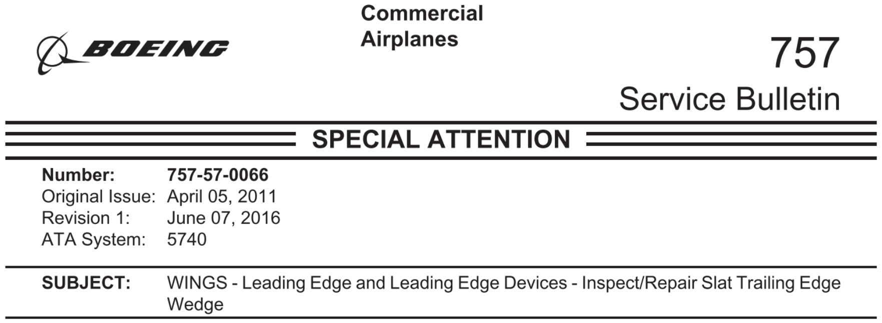
This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

Boeing 757 – Service bulletin 757-57-0066 (April 2011)

- The leading-edge slat trailing edge wedges may disbond on 757-200 airplanes.
- Contamination with moisture ingression as there was evidence of aluminum oxide powder on the core and the adhesive had failed at the skin-to-core bondline.
- One operator reported major skin-to-core disbonding of a trailing edge wedge after the airplane had accumulated thousands of total flight cycles
- In this SB actions have been established such as ultrasonic test, tap test, or TTU test together with monitoring repairs size and location at time intervals.

Source: Boeing, BOEING SERVICE BULLETIN 757-57-0066: WINGS - Leading Edge and Leading Edge Devices - Inspect/Repair Slat Trailing Edge Wedge, on April 2011," Farnborough, United Kingdom, 1993.


BOEING Commercial Airplanes

757 Service Bulletin

SPECIAL ATTENTION

Number: 757-57-0066
Original Issue: April 05, 2011
Revision 1: June 07, 2016
ATA System: 5740

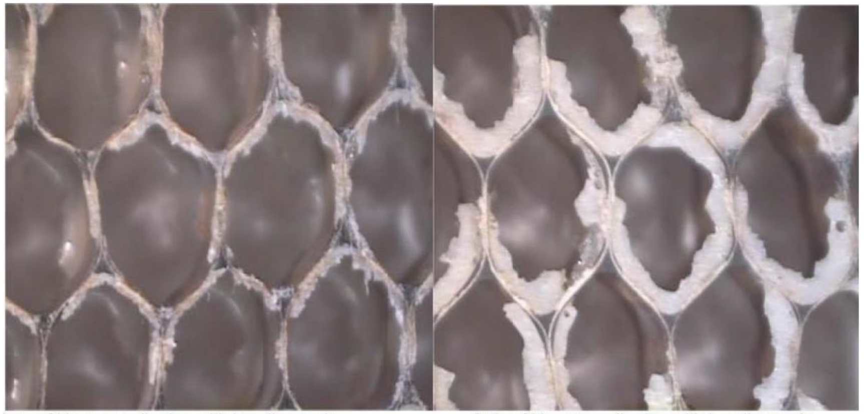
SUBJECT: WINGS - Leading Edge and Leading Edge Devices - Inspect/Repair Slat Trailing Edge Wedge

The rear of the slate is de-laminating on this American Airlines Boeing 757 on flight 1990.

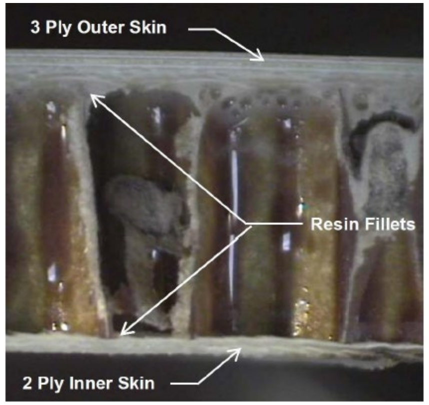
4. Summary of aviation sandwich panel related accidents & incidents

F100 radome collapse

- FINAL REPORT Serious Incident Occurrence No: 619/10 Aircraft: F-100, D-AGPH 1 July 2010
- After take-off at FL 70 the crew could hear an impact sound from the nose bottom part of the fuselage. The flight crew stopped climbing and decided to return to the take off aerodrome
- Reduced strength of the radome sandwich structure caused by gradual (over time) degradation of the material in fiberglass epoxy composite structures and their bonds.
- Probable factor contributing to the incident is maintenance related. Inspection after an event is key.



Inner Skin core cell edge with bonding resin   Outer Skin core cell edge with bonding resin

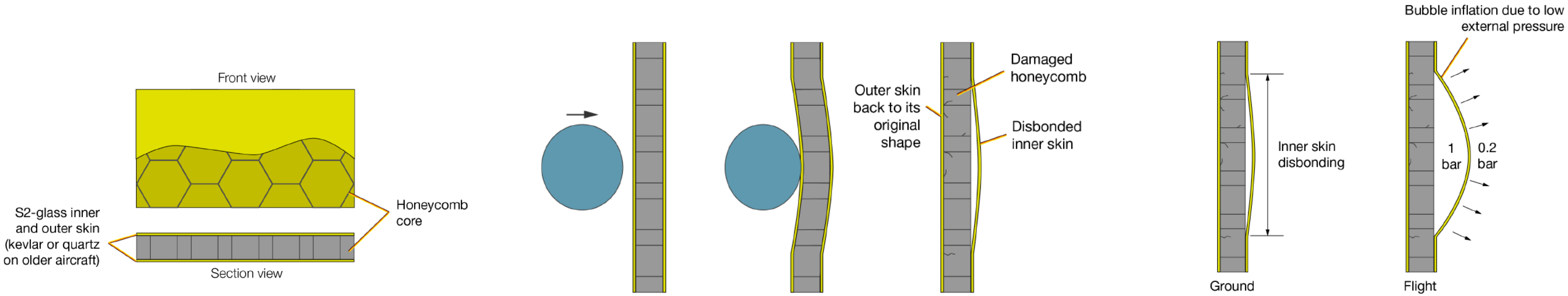


This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

A350 – Bird or Hail Strikes on the Radome- Safety Magazine article, April 2024

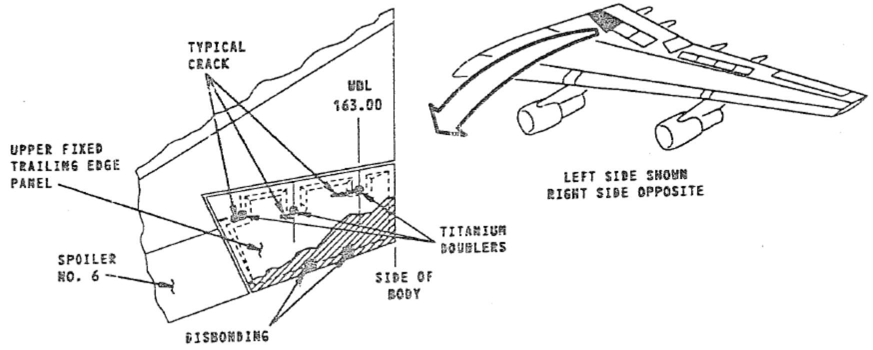
- Abnormal events such as bird strikes and hail strikes can occur at any time.
- focuses on the effect that a bird or hail strike can have on the radome of the aircraft.
- Effect of an impact on the radome – Impact may lead to a disbond damage on the inside face sheet
- During flight the bulging of the disbond may lead to disbond progration and may affect the weather radar
- Undetected disbond propagation may of a number of flight cycles lead to collapse of radome
- Maintenance considerations – inspect radome after reported hail or bird strike

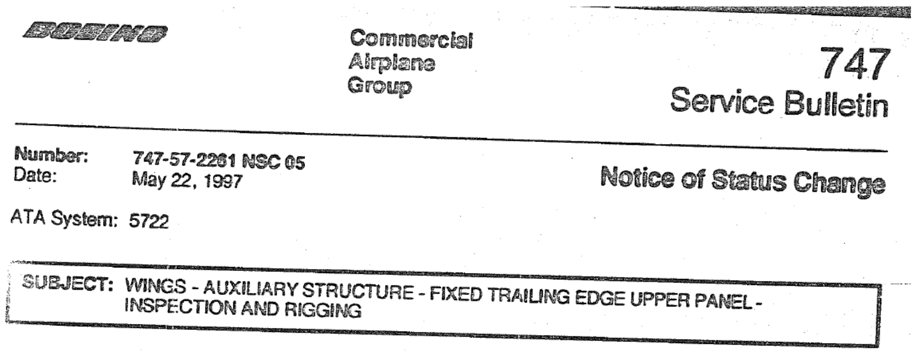


4. Summary of aviation sandwich panel related accidents & incidents

B747 Flying Panels, Feb 1991 – Wing fixed trailing edge Upper panel – Delaminated honeycomb panel

- Flight History – at FL290 vibration was reported from the area of the centre galley - at FL310 a passenger noticed that a part of the wing panel had separated.
- As per BOEING service bulletin 747-57-2261 (1991) is stated that operator reported on 95 parts that pieces of the panel separated during flight.
- BOEING investigation showed that stepping, walking, kneeling or dropping objects on these panels could have cause failures. Water contamination is also a cause for failure.





BOEING

Commercial Airplane Group

747 Service Bulletin

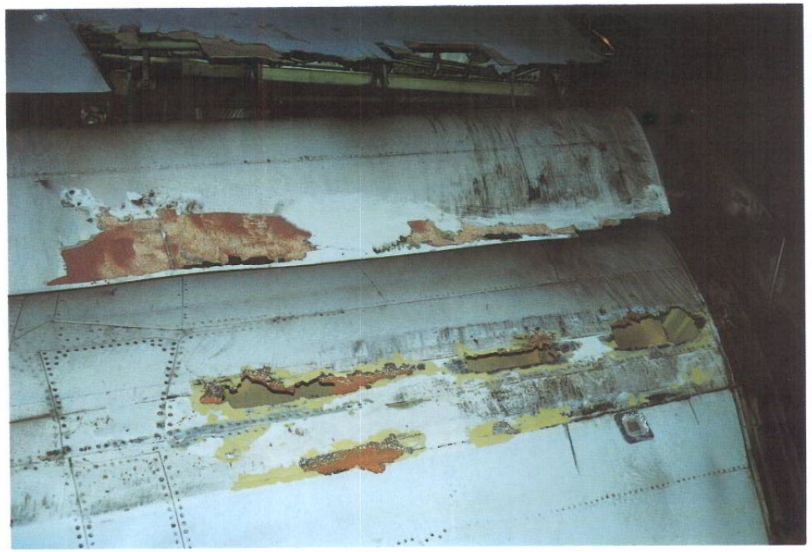
Number: 747-57-2261 NSC 05

Date: May 22, 1997

Notice of Status Change

ATA System: 5722

SUBJECT: WINGS - AUXILIARY STRUCTURE - FIXED TRAILING EDGE UPPER PANEL - INSPECTION AND RIGGING



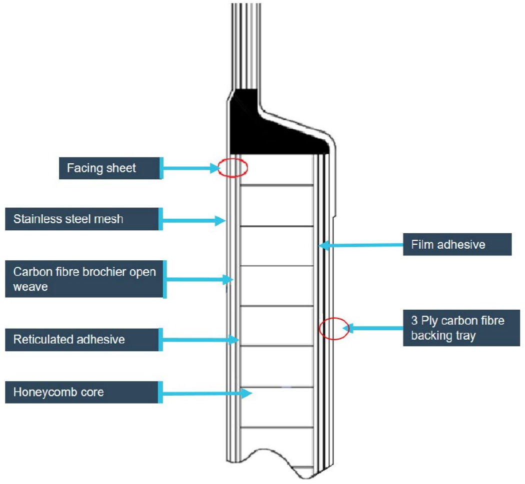
G-BDXH - Damage to mid-and fore-flap due to break-up of trailing edge panel

This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

A330, B-6099 Investigation 11 June 2017 ATSB Transport Safety Report Aviation Occurrence Investigation AO-2017-059 Final – 20 November 2019

- During take-off, one of the three structural acoustic panels of the aircraft's left engine inlet cowling, and the inboard outer skin failed.
- There was limited physical evidence available, as the panel and other cowling debris was ingested into the engine. Therefore, despite extensive testing conducted by the engine and cowling manufacturers, the reason for the failure could not be conclusively determined. However, it was considered that the most likely reason for the failure was a localised disbond between the acoustic panel facing sheet and the honeycomb core.
- As a result of this incident, Rolls-Royce amended service bulletin RB 211-71-AG419 R2 (now R3), which related to the inspection of the inlet acoustic panels. This service bulletin included increasing the initial and follow-on inspections by reducing the interval from 24 to 12 months (thereby increasing the frequency of inspections), the introduction of revised damage limits, and referencing a newly introduced training video that demonstrated how to conduct a 'tap test' to identify acoustic panel damage, including delamination.



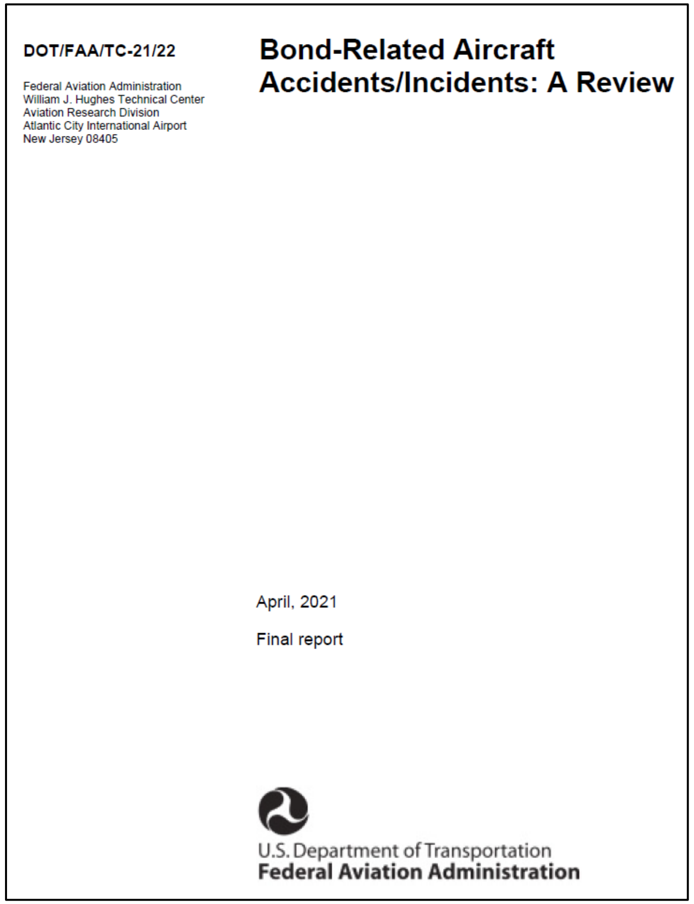
Source: Bombardier Aerospace, modified by the ATSB

This project is funded from the European Union's Horizon Europe research and innovation programme.

4. Summary of aviation sandwich panel related accidents & incidents

FAA review on Bond-Related Aircraft Accidents/Incidents (April 2021)

- This study examined aviation accidents and incidents where adhesive bond failure played a role. A total of 73 cases involving bond-related issues were analyzed.
- Key sources included official investigation findings, safety recommendations, and regulatory airworthiness directives related to bond integrity failures.
- The scope of this analysis was confined to civil, type-certified aeronautical equipment, regardless of brand, model, dimensions, or service life.
- Underlying causes were classified into four main groups: design, manufacturing, operation, and maintenance.
- A significant number of the incidents involved shortcomings in either the maintenance or manufacturing processes.
- The findings suggest that no single protective strategy—such as redundant load paths, crack arresting features, environmental safeguards, maintenance based on damage tolerance, or sophisticated non-destructive evaluation techniques—can independently assure the intended structural performance of bonded joints.


DOT/FAA/TC-21/22

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Bond-Related Aircraft Accidents/Incidents: A Review

April, 2021

Final report

U.S. Department of Transportation
Federal Aviation Administration

Source: Bond-Related Aircraft Accidents/Incidents: A Review, DOT/FAA/TC-21/22, Federal Aviation Administration, William J. Hughes, New Jersey, April 2021

This project is funded from the European Union's Horizon Europe research and innovation programme.

Summary

- Sandwich disbond driven in-service failures occurred and are documented in investigation reports publicly available.
- A summary of them, which might not cover all relevant cases is shown in this presentation
- The cases show the relevance of sandwich disbond as a to be considered and evaluated failure mechanism in sandwich, beside other key potential design driving failure modes
- The awareness of sandwich disbond failure is essential to learn and further improve sandwich design safety for aerospace application
- It is key to improve the CMH-17 handbook by the presented case studies
- This presentation is focused on sandwich disbond as one possible failure mode for sandwich structures. It needs to be reminded that other sandwich failure modes, like core shear failure, exists and need to be addressed during design and substantiation.

This project is funded from the European Union's Horizon Europe research and innovation programme.

Outline

This project is funded from the European Union's Horizon Europe research and innovation programme.

5. Sandwich structure safety enhancement gap & opportunity discussion

Overview of “Gaps and Opportunities“

- Address the subjects listed in the EASA DESIGN Tender Specifications (see bullets below)
- Focus on:
  - EASA DESIGN Project objectives related to CMH-17 Vol 6 support
  - General sandwich structure issues and design guidance
  - Future regulatory and guidance opportunities relative to industry current (and future) best practices, including harmonizing definitions.

- identification of gaps and opportunities for progress regarding the safe design, manufacture, and use of sandwich structures;
- identification of perceived limitations and roadblocks to the implementation of sandwich structures in new applications;
- highlights on key resources like CMH-17 and EASA's reference report EASA_REP_RESEA_2016_2 on Disbond of Sandwich Structures (DoSS).

This project is funded from the European Union's Horizon Europe research and innovation programme.

5. Sandwich structure safety enhancement gap & opportunity discussion

EASA DESIGN Project - Evolutions of airworthiness standards for new aircraft structure designs using materials, processes, and advanced manufacturing methods (1 of 3)

- 3 years project (2024-2027) funding under Horizon Europe program.
- Improve, standardize, assess, and investigate existing and novel methods for characterizing fractures in sandwich coupons under static and fatigue loads, building upon the ongoing initiatives within the CMH-17 workgroup and the ASTM D30.09 committee.
- Outcomes from this project enable European partners to participate and contribute to the development of further regulatory and industrial content for the safe design, and in-service use of sandwich structures in aviation through the ongoing activities in the international CMH-17 sandwich disbond working group and the ASTM sandwich test method development.
- Enhancing the understanding and control of sandwich disbonding by employing more reliable standardized test methods, analysis models, and design curves, improves the safety level of such structures.

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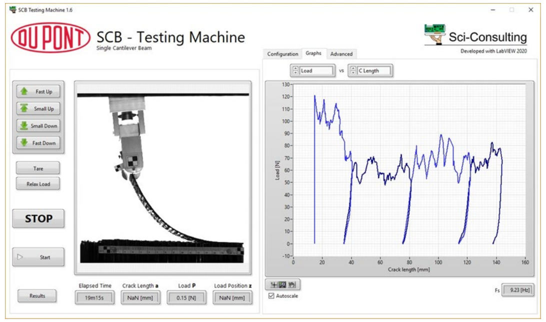
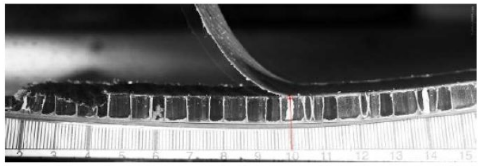


Curved sandwich panel testing & assessment



This project is funded from the European Union's Horizon Europe research and innovation programme.

EASA DESIGN Project - Evolutions of airworthiness standards for new aircraft structure designs using materials, processes, and advanced manufacturing methods (2 of 3)

- The application of the methods on existing sandwich structures will enable the industry to show the robustness or sensitivity related to sandwich disbond damage propagation.
- Development of further regulatory and industry guidelines for the safe design, manufacture, and in-service use of bonded and sandwich structures in critical applications.
- **ESDA[1] and FSDA[2] tools enhancements*:**
  - Rotorcraft applications
  - Complex load cases (biaxial + shear)
  - Curved sandwich panels
  - Panel test validation

[1]ESDA = Energy-Based Sandwich Disbond Analysis

[2]FSDA = Finite-Element-Based Sandwich Disbond Analysis

(formerly Crack Surface Displacement Extrapolation (CSDE) method in proposal)

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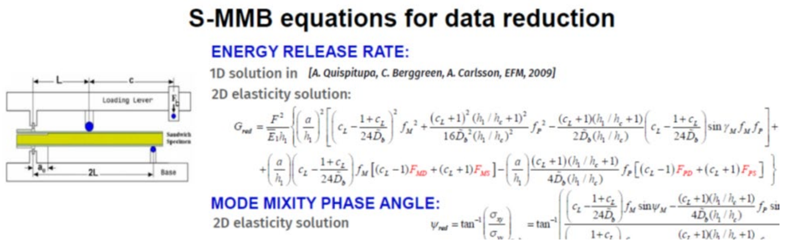

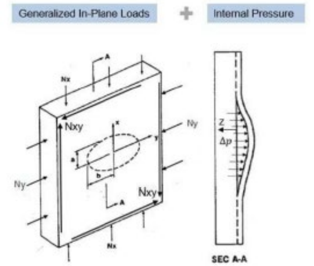

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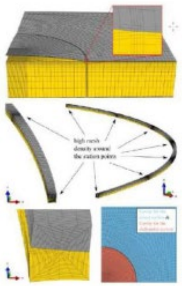

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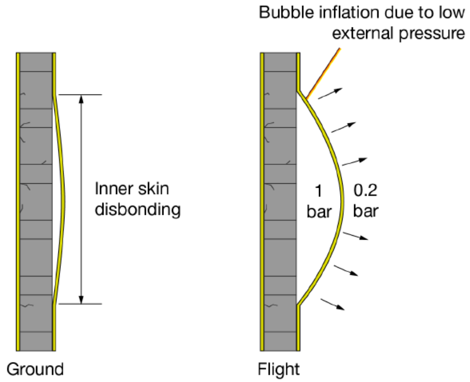
EASA DESIGN Project - Evolutions of airworthiness standards for new aircraft structure designs using materials, processes, and advanced manufacturing methods (3 of 3)

- The sandwich disbond analytical tool ESDA and FSDA enhancements allow future application on other sandwich structures, like radome and engine cowling as shown in the accident & incident chapter.



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5. Sandwich structure safety enhancement gap & opportunity discussion

Sandwich structure safe design depends on reliable processing/ bonding, careful design of structural details, and selection of appropriate materials:

- Stable and reliable material and process controls
- Impact damage resistance
  - FOD, maintenance, lightning strike, and hail
- Aging, durability, and damage tolerance
  - Disbond growth
  - Erosion
  - Protective Finish (Paint) robustness
  - Thermal cycling
- Fluid ingression
  - Minimum facesheet thickness, honeycomb edge closeout and finishes
- Overheating
- Designing for repair
  - Repairs & Inspection Requirements
    - Non-standardized, different repairs
    - Multiple people and skills required
    - Intermediate approvals or engineering needed
- Reliable inspection methods (during manufacturing and in-service)

- Safe sandwich structure design requires a high level of technical understanding and awareness of in-service issues.
- Perceived limitations and roadblocks to sandwich implementation in new applications can be overcome by addressing these items.

This project is funded from the European Union's Horizon Europe research and innovation programme.

5. Sandwich Disbond Certification – Future Discussion Topics (1 of 3)

Bonded Structure Criteria Questions to be Discussed in Future Guidance and Best Practice Material

- When is sandwich structure a bonded Joint and when do weak bond criteria apply?
  - A pre-cured face sheet bonded to core is considered a bonded joint susceptible to weak bonds.
  - An uncured face sheet joined during cure to core has, for some previously certified PSEs, not been considered as a bonded joint with respect to the limit load substantiation per AMC 20-29 6.c.(3)(a). In these cases, the structural design was multi-load path with load redistribution capability and damage arrestment features. However, these designs have many of the same attributes as a bonded joint. How the substantiation expectations per AMC 20-29 6.c.(3)(a) are addressed during certification is design and application dependent and generally must be agreed with the regulatory authority.
- Sandwich “monocoque” vs. “semi-monocoque” (multi-load path) – definitions?
  - Monocoque sandwich structure relies entirely on the shell.
  - Semi-monocoque sandwich structure includes backup structure and/or other design features to arrest damage growth and/or carry redistributed load.
- When is fatigue “no growth” demonstration needed for large sandwich disbonds?
  - Treat large disbond between arrestment as Structural Damage Capability (SDC, static only)?
    - Can sandwich disbond be covered as SDC with limit load only requirement with no fatigue and associated inspection?
  - Or consider it as Category 2 (prove “no growth” and consider inspection)?
    - Inspection – Is in-service inspection setup to find disbonds (to support Cat 2)?
  - Does it depend on precured facesheet vs. uncured facesheet (i.e., definitions of co-cured vs. co-bonded)?
  - Does it depend on monocoque vs. multi-load path?

This project is funded from the European Union's Horizon Europe research and innovation programme.

5. Sandwich Disbond Certification – Future Discussion Topics (2 of 3)

Bonded Structure Criteria Questions to be Discussed in Future Guidance and Best Practice Material

Threat Associated with Sandwich Disbond

- More likely to occur in sandwich structure with precured face sheets due to bond prep required (chemical weak bond)?
    - Precured face sheet sandwich designs should have the capability for limit load with a full disbond between arrestment due bonding process issues (based on regulatory guidance).
- Less likely to occur in sandwich structure joined during cure of an uncured facesheet?

Design - Semi-Monocoque vs. Monocoque Sandwich

- If the risk (threat) of process issues is low, but the threat of blunt impact damage (resulting in non-visual wide area damage) is significant, does this force a semi-monocoque approach?
    - Is a multi-load path design needed to arrest damage growth and/or redistribute load?
- If there is no significant blunt impact damage threat, can a monocoque approach be used when joining uncured face sheets to core? If so, this puts great importance on the accuracy of threat assessment. It must be very well thought out and with proven service experience.
    - Is monocoque construction for PSEs a valid option?

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5. Sandwich Disbond Certification – Future Discussion Topics (3 of 3)

Bonded Joints and Structures - Technical Issues and Certification Considerations; PS-ACE100-2005-10038'

3.5 Service Experience

Service experience of bonded structures and repairs provide the final proof of a reliable bonding process that has been properly executed. Discovery of bond adhesion failures in service justify immediate directed inspections and repair. Thorough production or repair records are important to tracing the probable cause of such a problem.

Some experts believe that service monitoring of bonded structures or repairs, including selected NDI, and teardown inspections for retired aircraft, provides data to correlate accelerated test results from qualification and in-process control with real-time service exposure. The FAA plans to continue to work with industry in this area of life assessment.

This Policy Statement (PS) refers to the challenge that some structure cannot truly be represented at certification, e.g. mechanical loads in combination with thermal cycling, etc.

Some form of 'fleet leader' or 'sampling' strategy may be necessary for new M&P, configurations etc.

This "gap and opportunity" is linked to the EPAS DESIGN project Task 4, which addresses the possible need to consider mitigations if more extensive use of sandwich structure is used in critical and "new and novel" monocoque applications.

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EASA DESIGN Project – End of D-1 Deliverable

European Union Aviation Safety Agency

DESIGN – Evolutions of airworthiness standards for new aircraft structure design using materials, processes, and advanced manufacturing methods

Consortium

Project Lead: Technical University of Denmark - DTU

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Link to EASA web page

https://www.easa.europa.eu/en/research-projects/design

Scan QR Code to follow the project on EASA web page

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