Presented by
Stephane Mahdi
Airbus Engineering Composites Structural Analysis Department - ESAC

Composites Repair Analysis

Spring 2007 CACRC Meeting
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AIRBUS

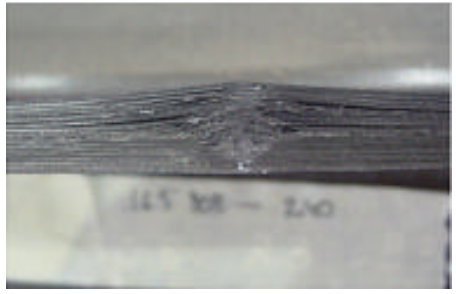
Agenda

- Need for Repairs is a reality
- Airbus Methodology for Repairs
- Bolted and Bonded Repairs Calculation Methods
  - Bolted Repairs
  - Bonded Repairs
- Summary and Conclusions

Need For Repairs is a Reality

Airbus a/c structures state-of-the-art robust process:

- Design for durability
  - Impact resistance via visual inspection.



Damage

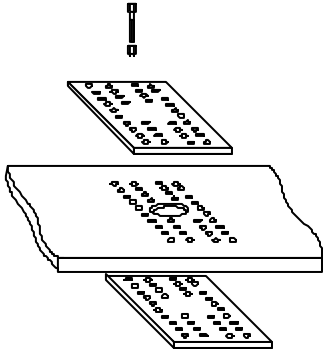
(Not addressed in this presentation.)

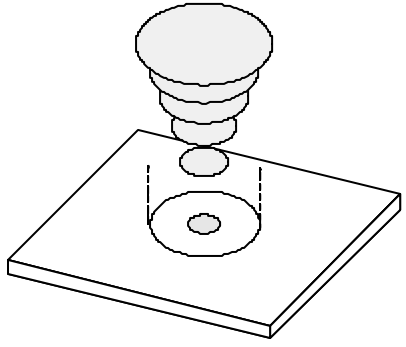
- Design for repairability:
  - Cosmetic repairs

  (Not addressed in this presentation.)
  - Structural repairs:

    Depending on requirements:

Bolted patch:
- Flush
- Protruding

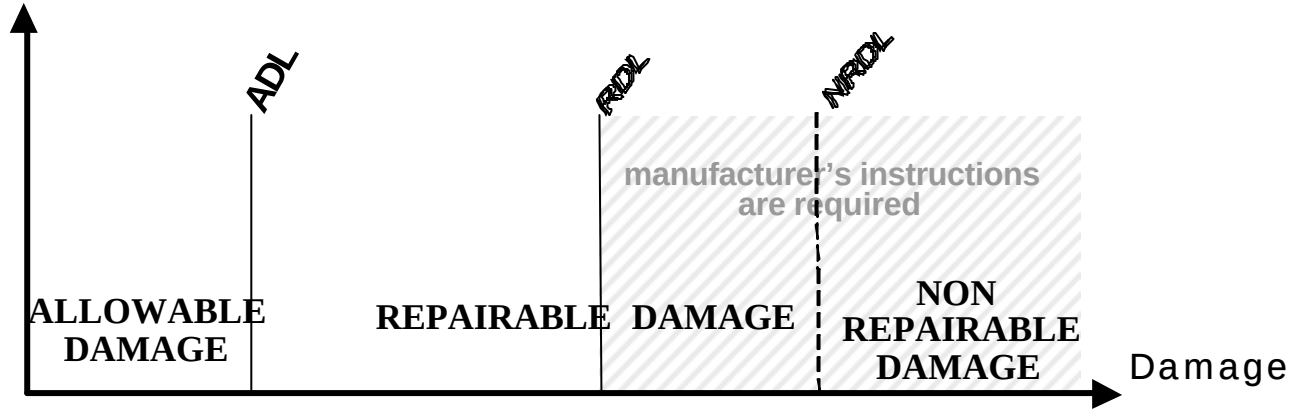




Bonded patch:
- Wet lay up
- Prepreg

Airbus Methodology for Repairs

- **Allowable damage**, when the damage does not affect the structural integrity nor decrease the function of the component.
  - These do not need structural repairs. In some cases, require cosmetic repairs.
- **Repairable damage**, when the damage exceeds the 'allowable damage' size, but is below the 'Non-repairable' damage size.
  - Damage leading to strength degradation below UL must be repaired.
- **Non-repairable damage**, when the replacement of the component is required, as the repair cannot be substantiated or due to feasibility (deformations, etc.).
  - For bonded repairs, the size limit is determined by damage size that can sustain LL without repair. For bolted repairs, it is constrained by feasibility and UL re-distribution assessment.

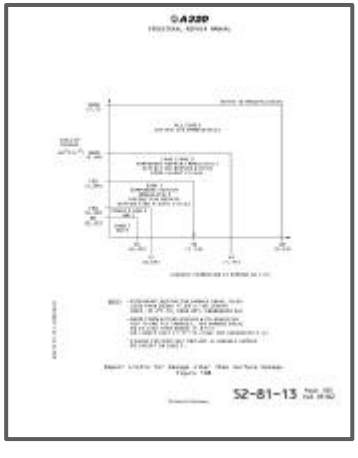


Airbus Methodology for Repairs

Upon event, → Visual inspection for damage assessment

- Undetectable damage are covered by static and fatigue requirements, e.g., UL capability after application of repeated loading.
- Visually detectable damage (e.g., DET / GVI): NDT (US) inspection are required to assess the extent of delaminated area.

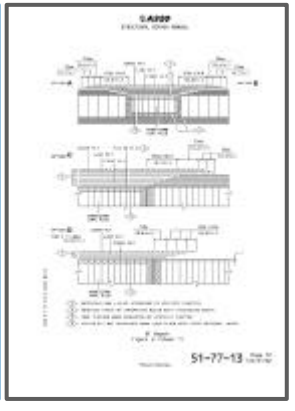
- The extent is compared with ADL/RDL published limits and actions are taken as per SRM.



Allowable or Repairable

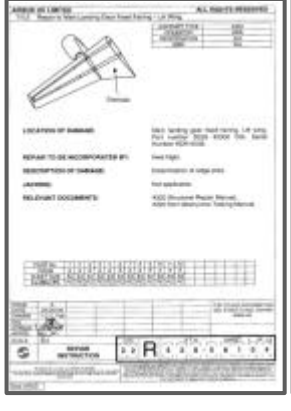
Beyond RDL

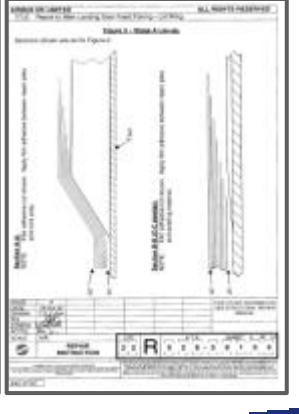
SRM Standard Repair



Damage outside RDL

Damage report sent to OEM, and then forwarded to the relevant repair groups.





Airbus Methodology for Repairs

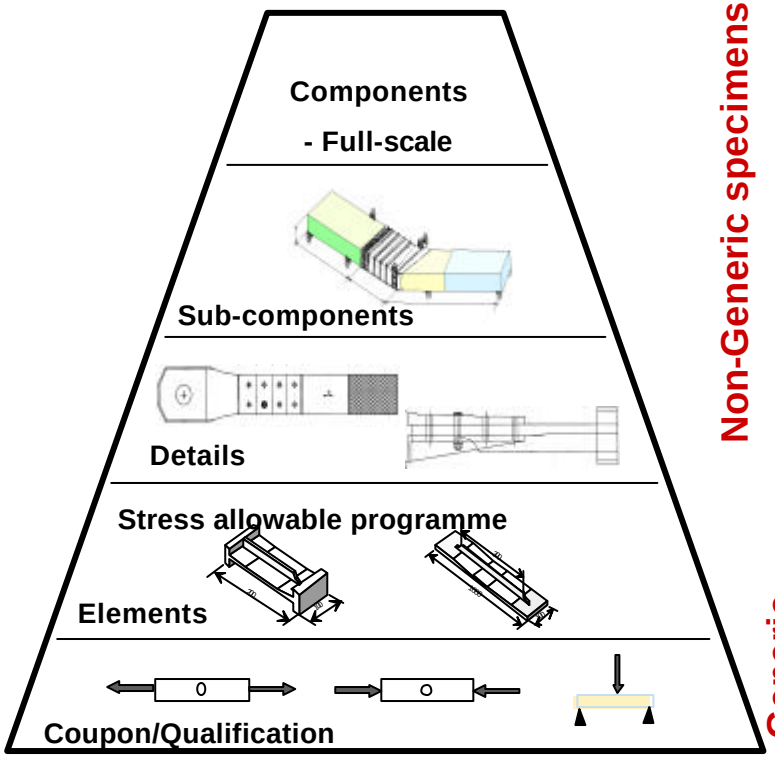
- ACJ25.603 §8.8: *Substantiation of Repair:* … it should be demonstrated by analysis and/or test, that methods and techniques of repair will restore the structure to an airworthy condition.

- Substantiation of repairs is done by analysis supported by tests:
  - The repair fulfils the same requirements as the parent structure.
  - Representative damage sizes are introduced in full scale test specimens to prove the maximum allowable damage size for each part of the structure. Full scale test specimen also includes representative repair solutions.
  - From coupons to elements, tests are dedicated to substantiate repair solutions (mats allowable/generic failure criteria, methods validation, special repair solutions).
  - Analysis is performed to demonstrate their structural capability (SRM justifications).

➢ Building Block Approach / Pyramid of tests:

Airbus Methodology for Repairs

- Building Block Approach / Pyramid of tests:



Non-Generic specimens

Generic specimens

Final validation

•Validation and exploitation on full scale or component tests

Methodology & Computing validation

• Validation against coupon and smaller specimen allowables

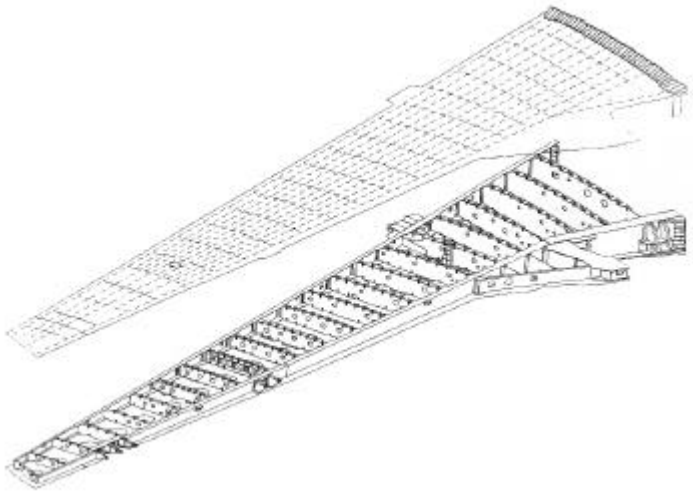
• At detail level, 'B' values are determined.

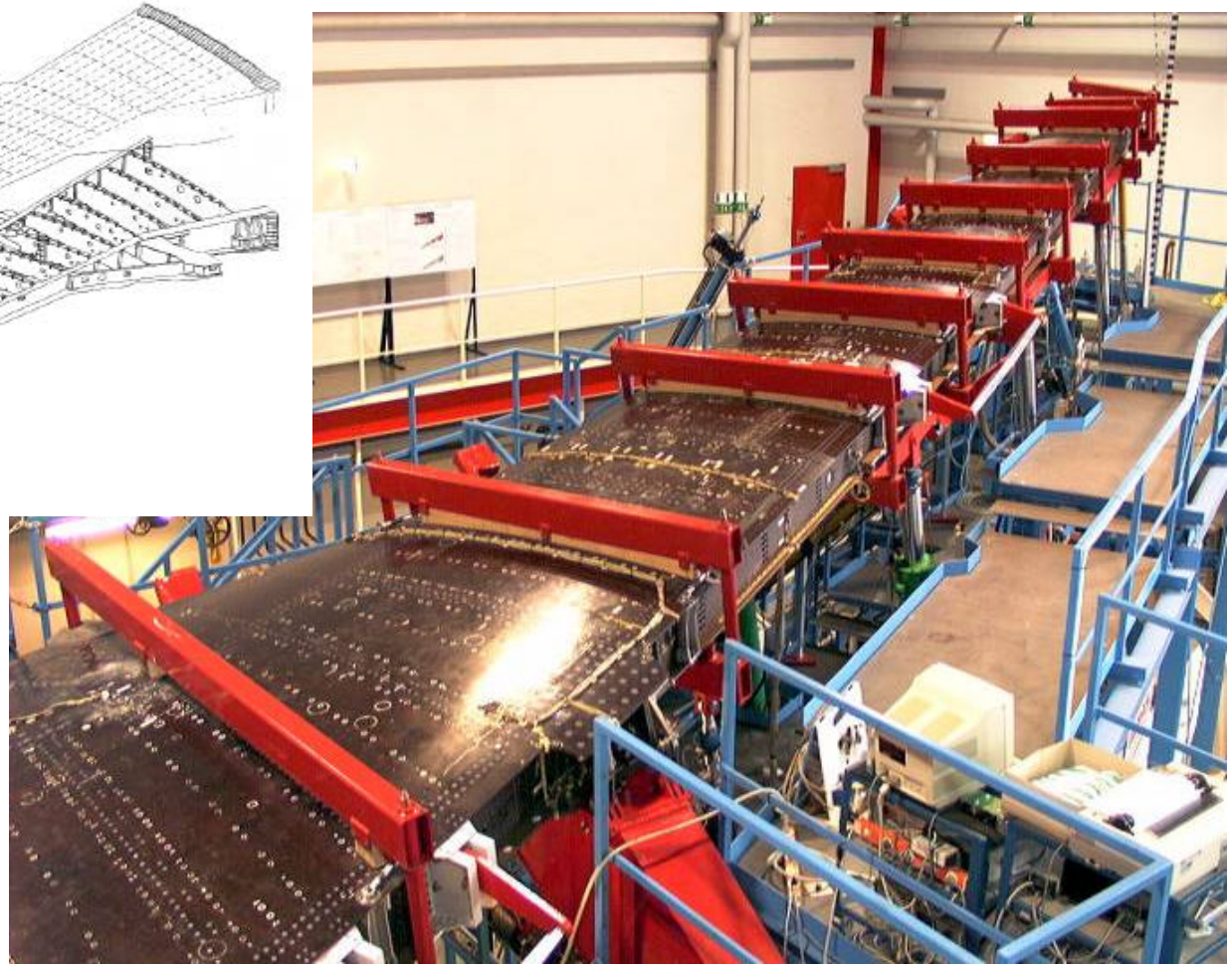
Definition of generic allowables set

• Statistical treatment large and small populations 'B' values

• In general 1 typical feature per specimen (hole, impact damage, lay-up..)

Airbus Methodology for Repairs

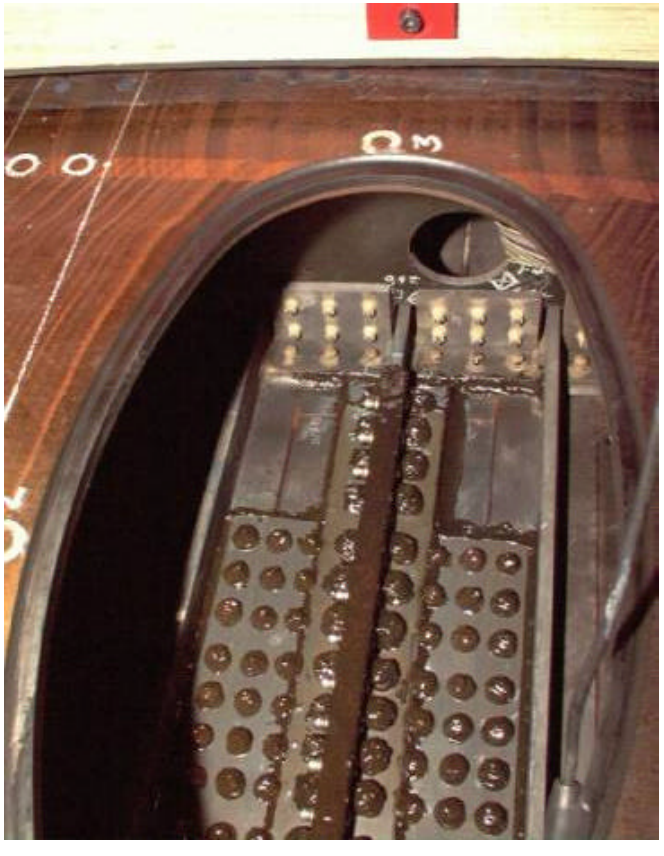




e.g.,Composite Wing Box

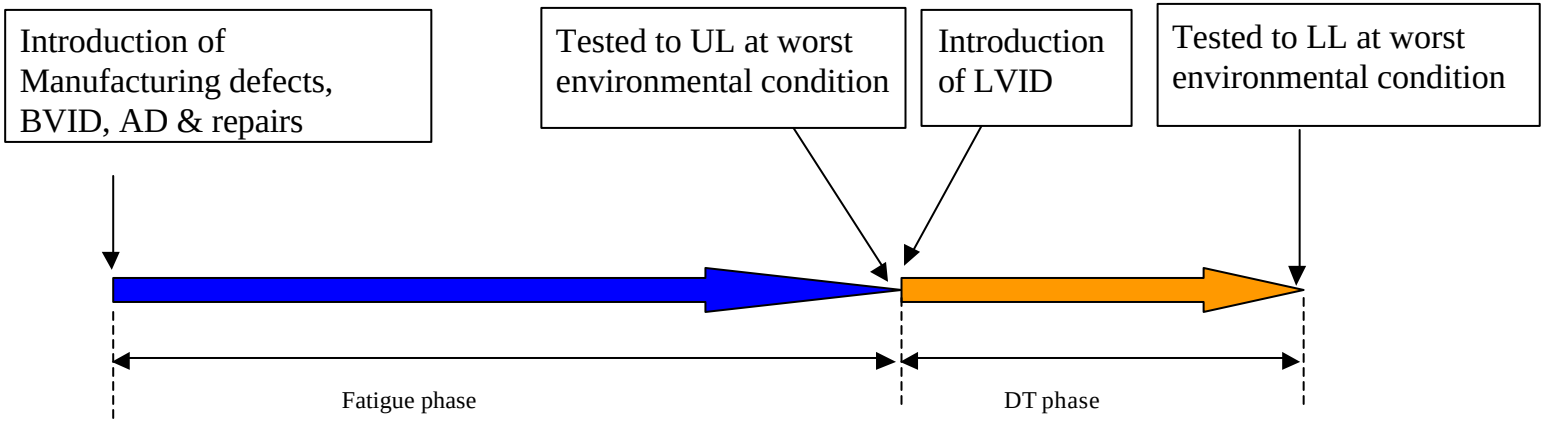
Airbus Methodology for Repairs

Bolted Repair



Airbus Methodology for Repairs

- Example of a possible test sequence:



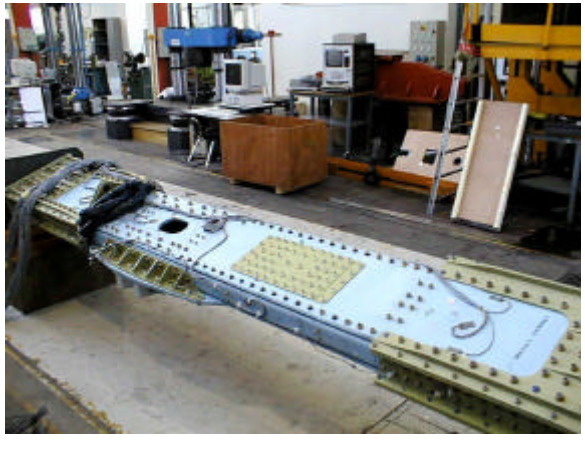
Airbus Methodology for Repairs

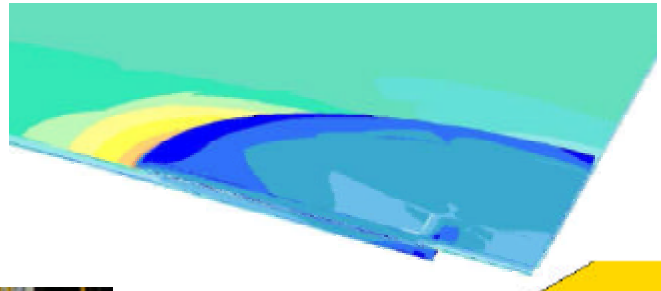
- The objective of the Repair Calculation methods is to provide a robust mean of analysis for generic structural repairs.

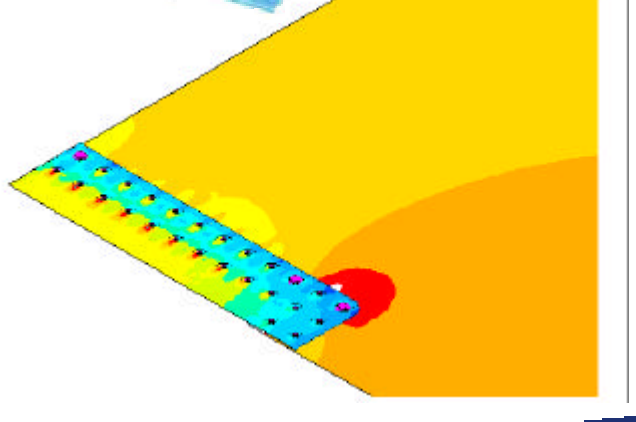
Structural testing → **Calculation methods**

- From coupons to full-scale

- From coupons to full-scale

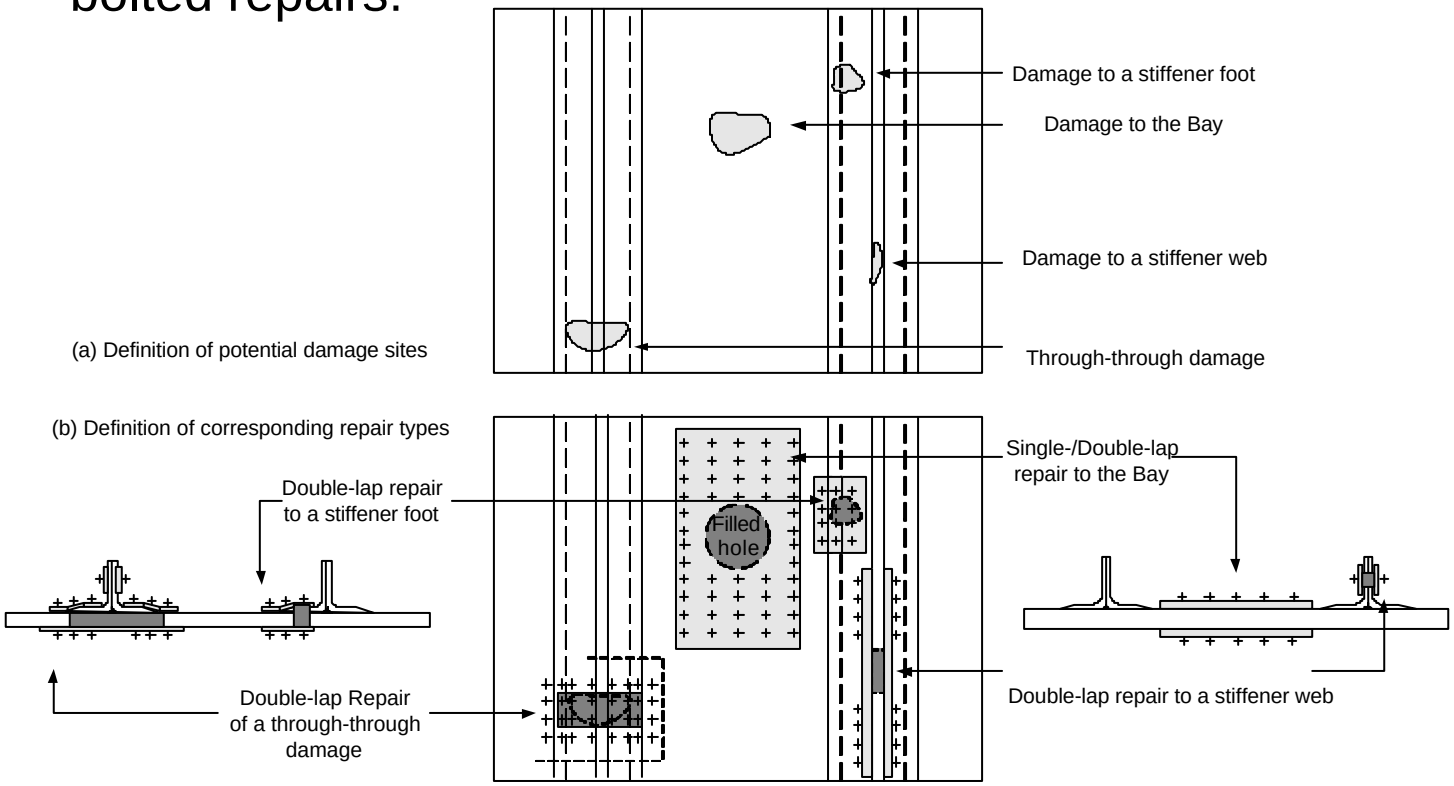






Bolted and Bonded Repairs Calculation Methods

- The objective of the repair calculation methods is to provide a robust mean of analysis for generic structural repairs.
  - Assumption about damage sites, and typical corresponding bolted repairs:

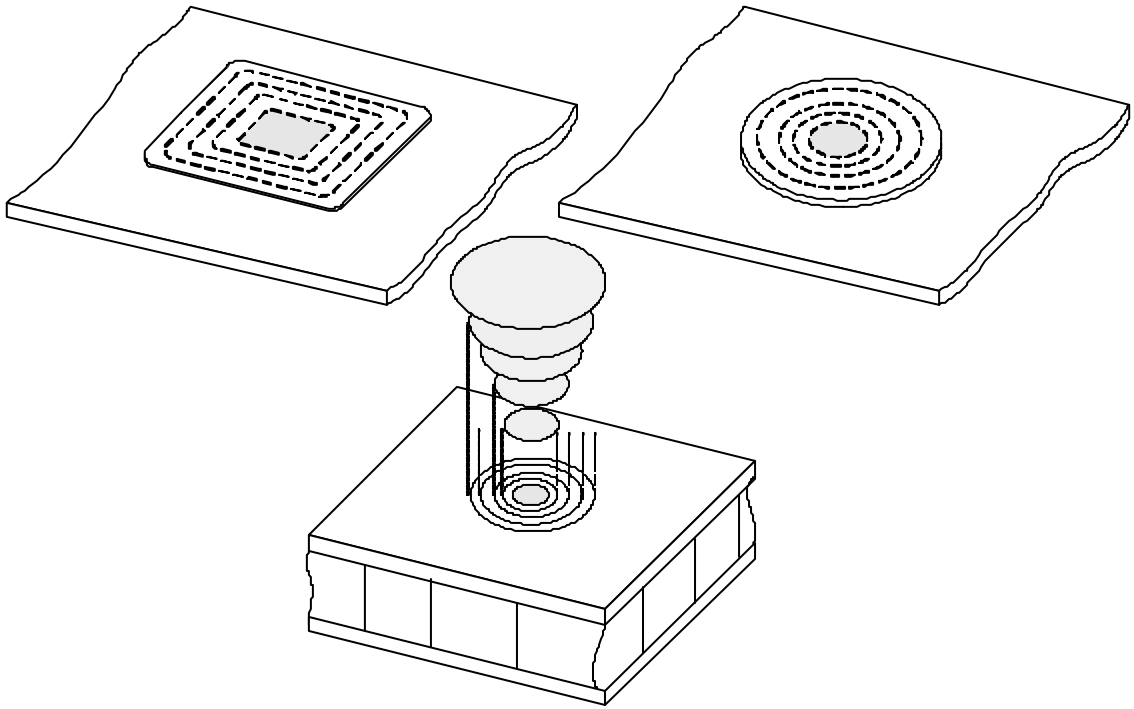


Bolted and Bonded Repairs Calculation Methods

- The objective of the repair calculation methods is to provide a robust mean of analysis for generic structural repairs.
  - Assumption about damage sites, and typical corresponding bonded repairs:

(a) Rectangular repair patch

(b) Circular repair patch



Bolted and Bonded Repairs Calculation Methods

- Repairs calculation methods are a two-step process:

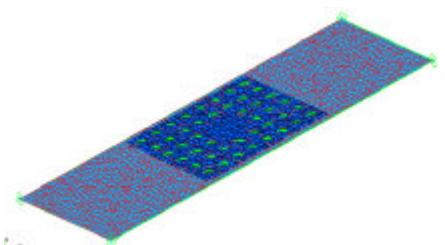
1. Internal load transfer calculation,
    a. Quick sizing approach
    b. Advanced sizing approach

2. Stress process.

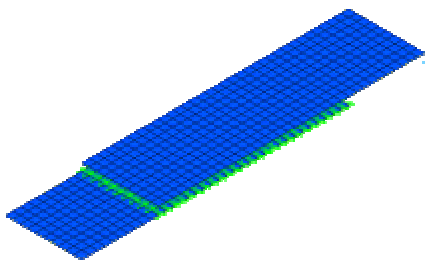
Bolted and Bonded Repairs Calculation Methods

1. Internal load transfer calculation:
   a. Quick Sizing: 1D analytical approach
      - The calculation of the load transfer is done analytically,
      - Repair patch size effect may affect the internal load redistribution.
   b. Advanced sizing: 2D parametric FE approach
      - Fast and robust parametric-FE, transparent to the user.
      - Applicable to various repair types and representative of structural elements. Influence of stiffeners, repair patch geometry may be included,
      - Directly applicable to 2D stress fields.

Bolted



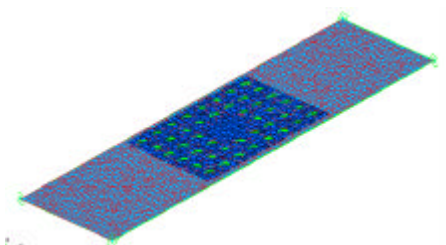
Bonded



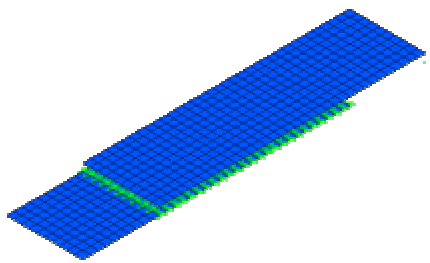
Bolted and Bonded Repairs Calculation Methods

2. The stress process is done based on the calculated internal loads.

Bolted

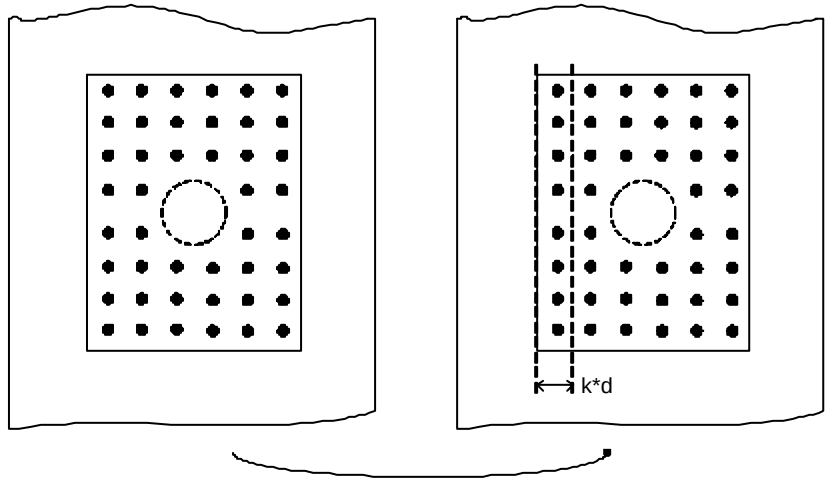


Bonded



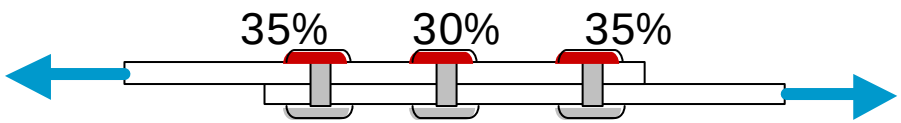
Bolted Repairs Internal Load Calculation
Quick Sizing

- The analysis is done on a fastener pitch. (The repair efficiency is taken into account.)



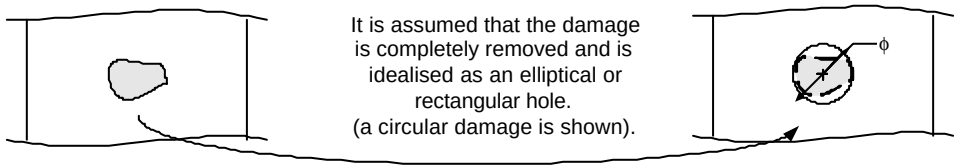
The fasteners are analysed per fastener rows

- A load transfer calculation is then done:

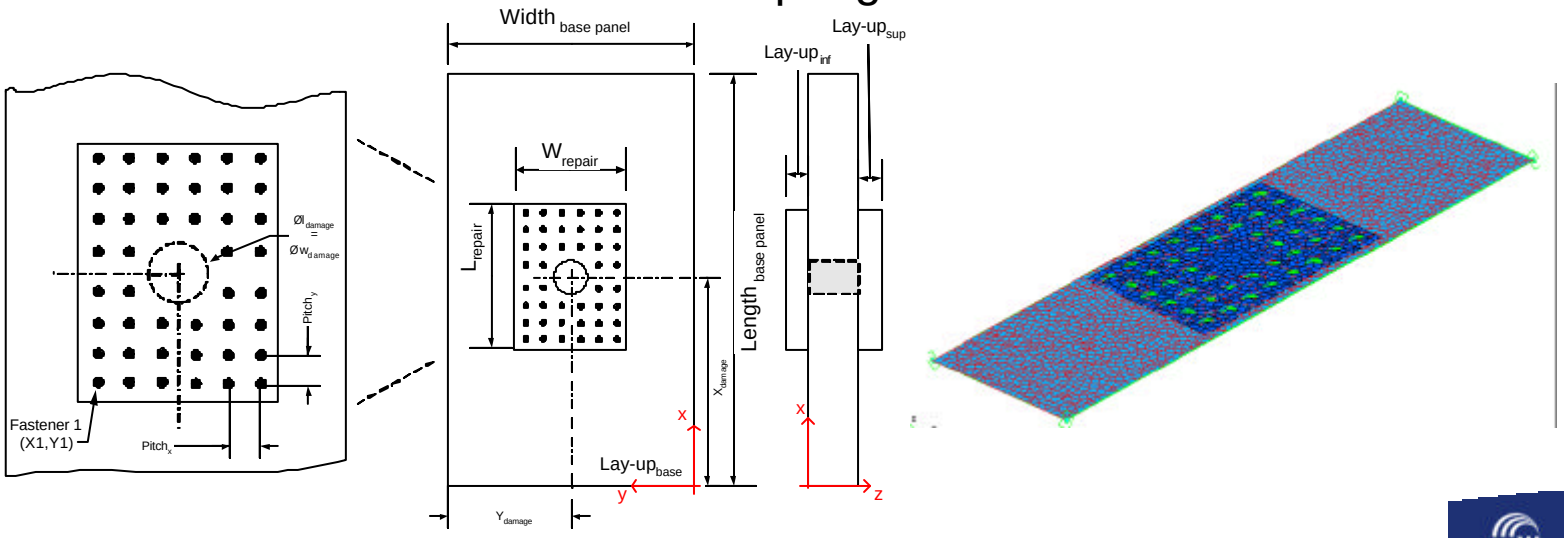


Bolted Repairs Internal Load Calculation
Advanced Sizing

- Idealisation of Damage:

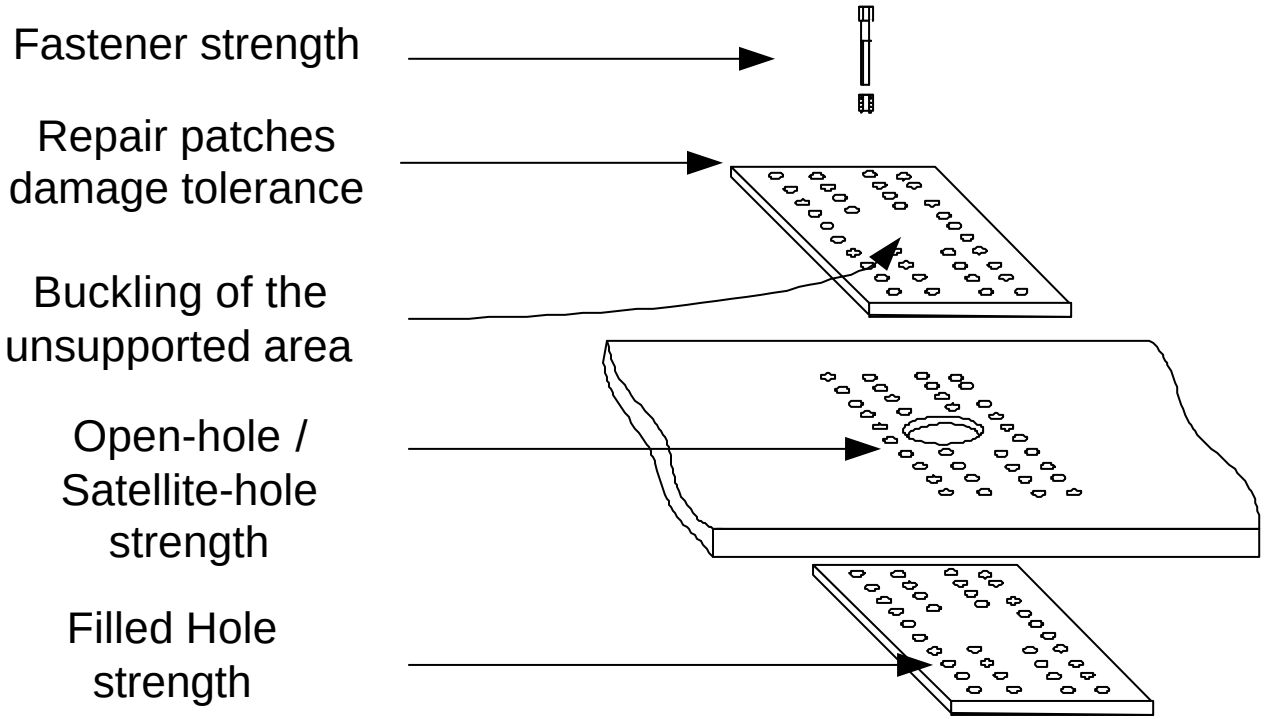


- User Inputs, Design checks, parametric FE-Idealisation:
  - The parent/repair are modeled with plate elements.
  - The fasteners are modeled with springs-like elements.



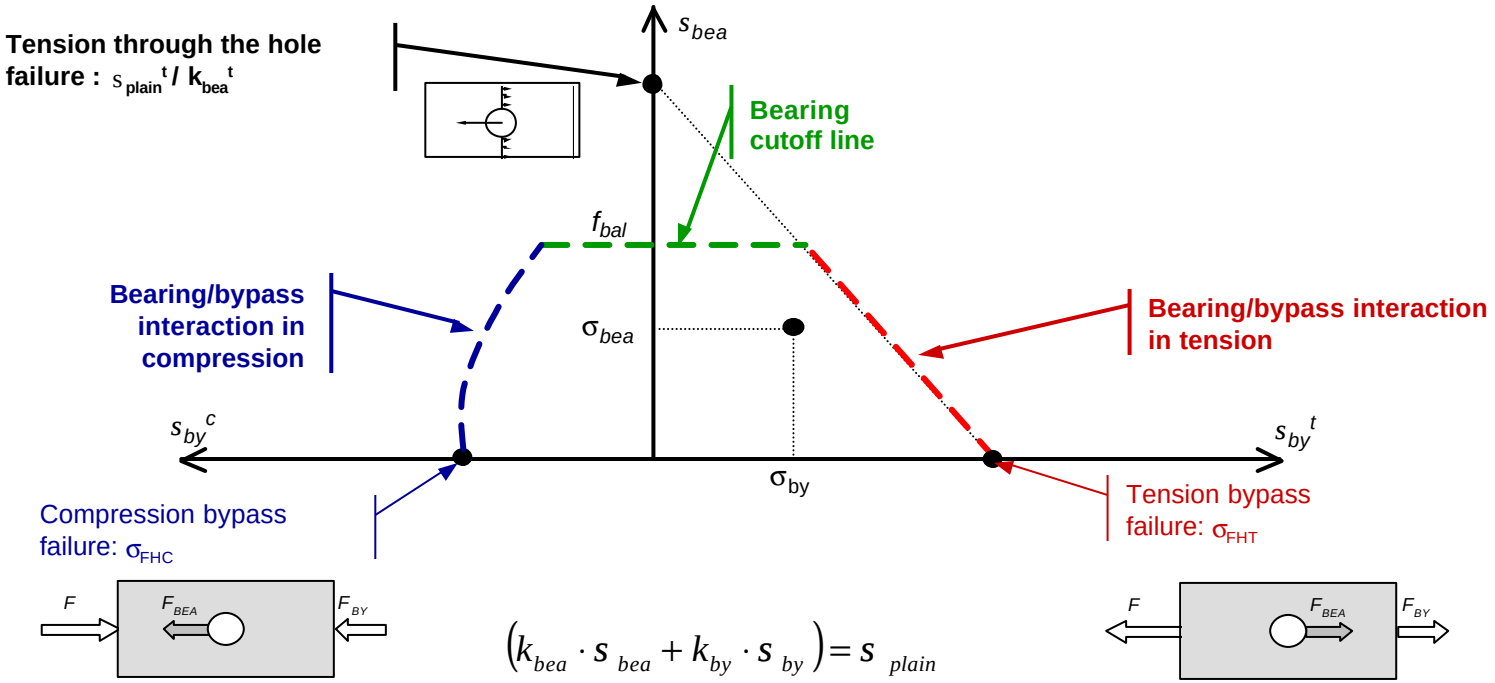
Bolted Repairs Stress Process

- In the most general sense, the stress process comprise the calculations of :



Bolted Repairs Stress Process
Filled Hole Calculation

- Filled holes calculations (bearing + bypass) are done and RF outputs. The approach considers bi-axial loadings. It is based on a stress concentration formulation and calibrated by tests on uni-axial and bi-axial coupons:



$$\left(k_{bea} \cdot s_{bea} + k_{by} \cdot s_{by}\right) = s_{plain}$$

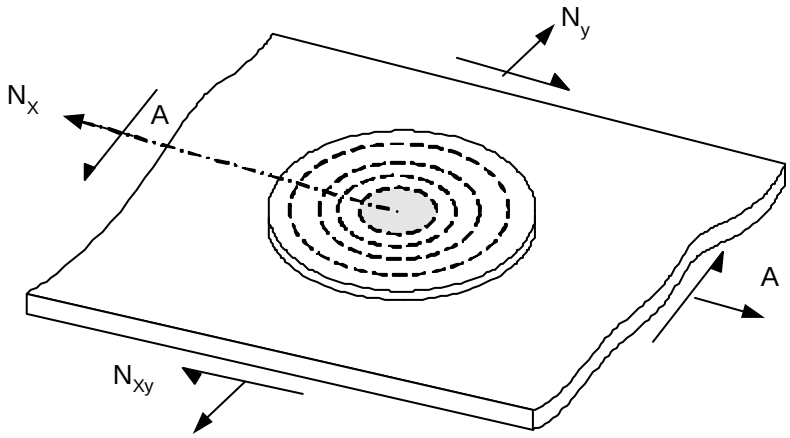
$s_{by} = \frac{F_{by}}{W \cdot t}$: bypass stress $\quad s_{bea} = \frac{F_{bea}}{d \cdot t}$: bearing stress $\quad s_{plain}$: laminate plain strength

k_{by} and k_{bea} : stress concentration factors

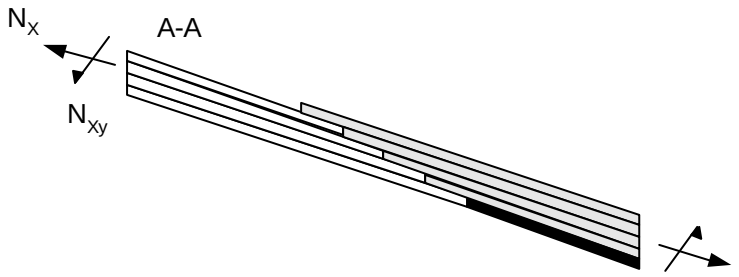
Bonded Repairs Internal Load Calculation Quick & Advanced Sizings

- A 1D analytical approach, representative of a cross-section of a repaired panel,
- A 2D parametric FE approach.

(a) 2D Parametric-FE (here circular) repair patch to a monolithic panel



(b) 1D Analytical repair patch to a monolithic panel



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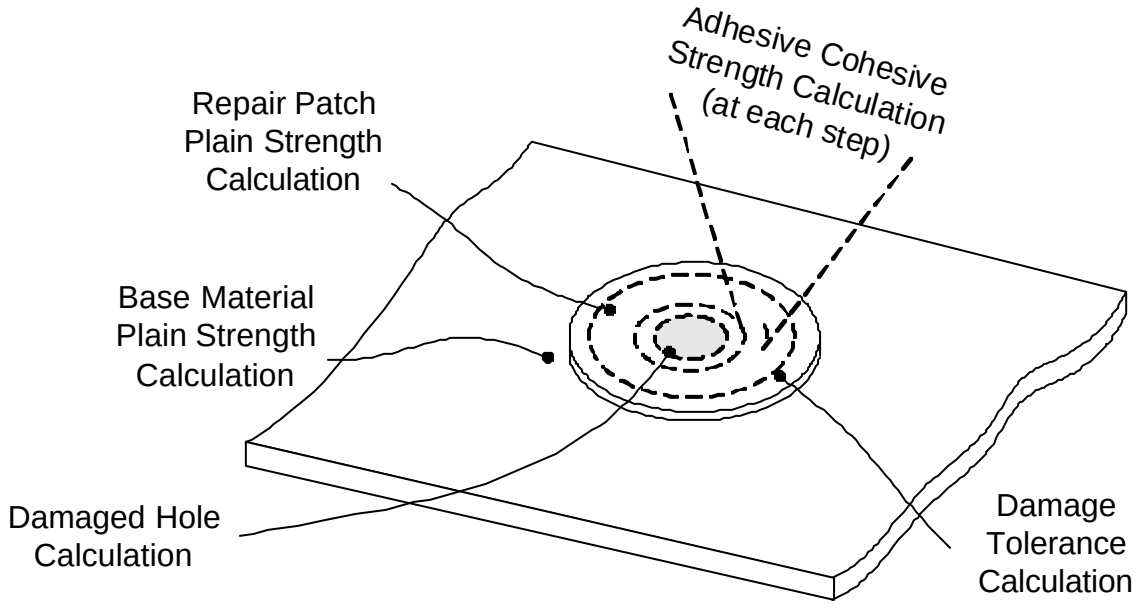
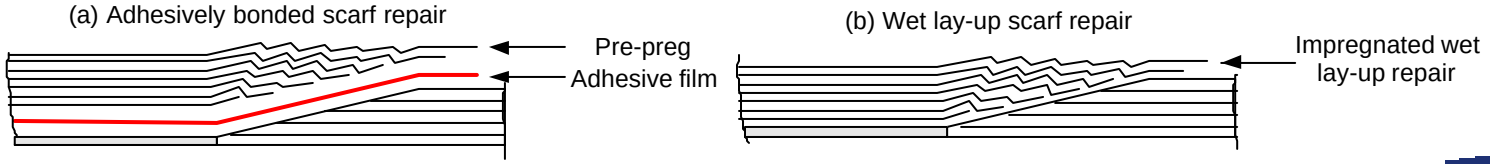
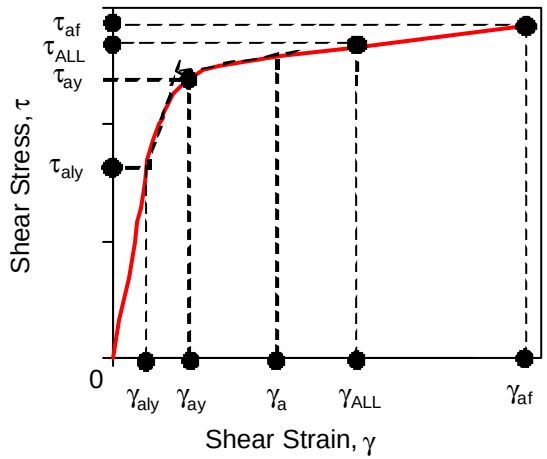


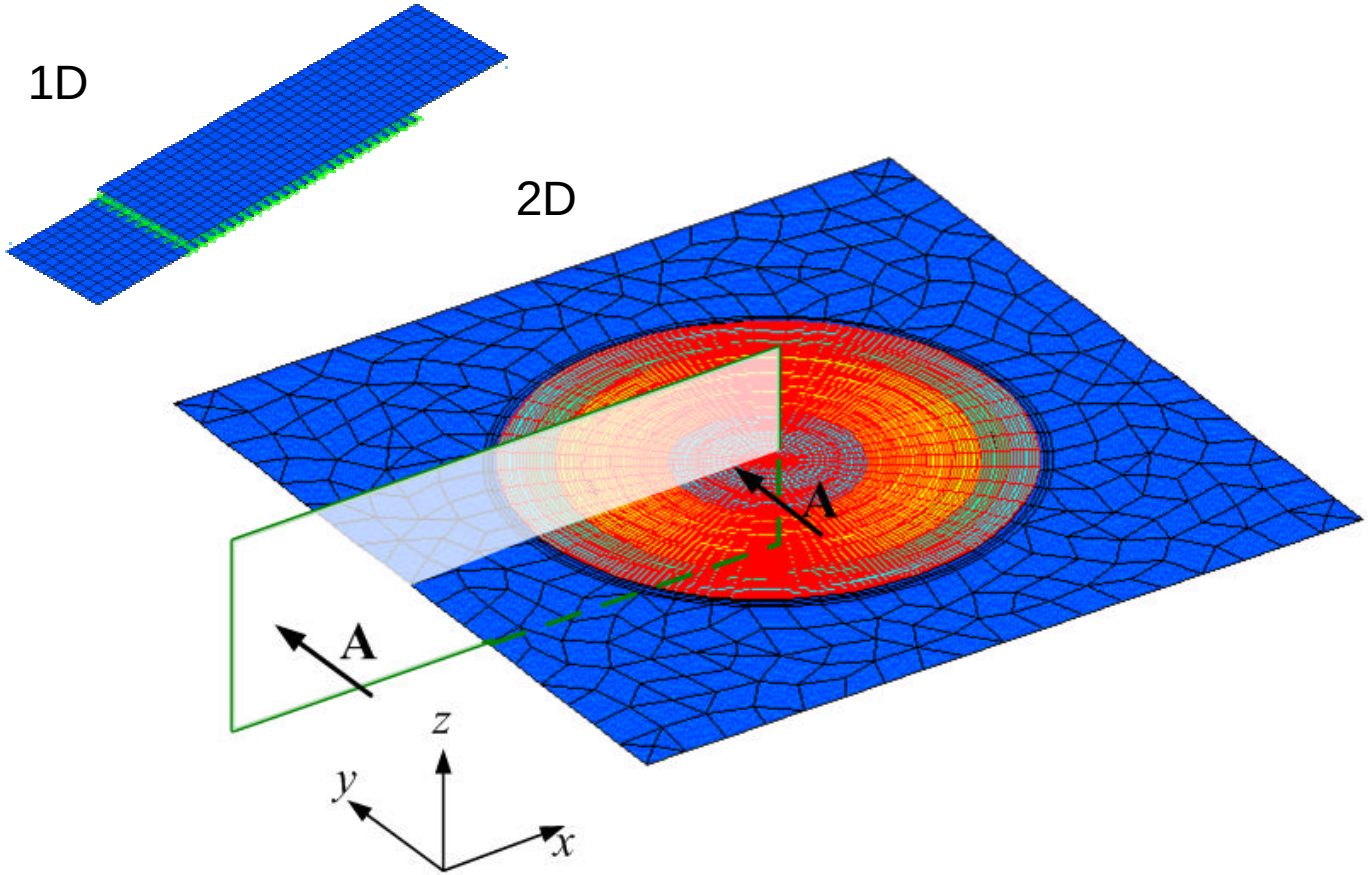


Bonded Repairs Stress Process
Bond Strength Calculation

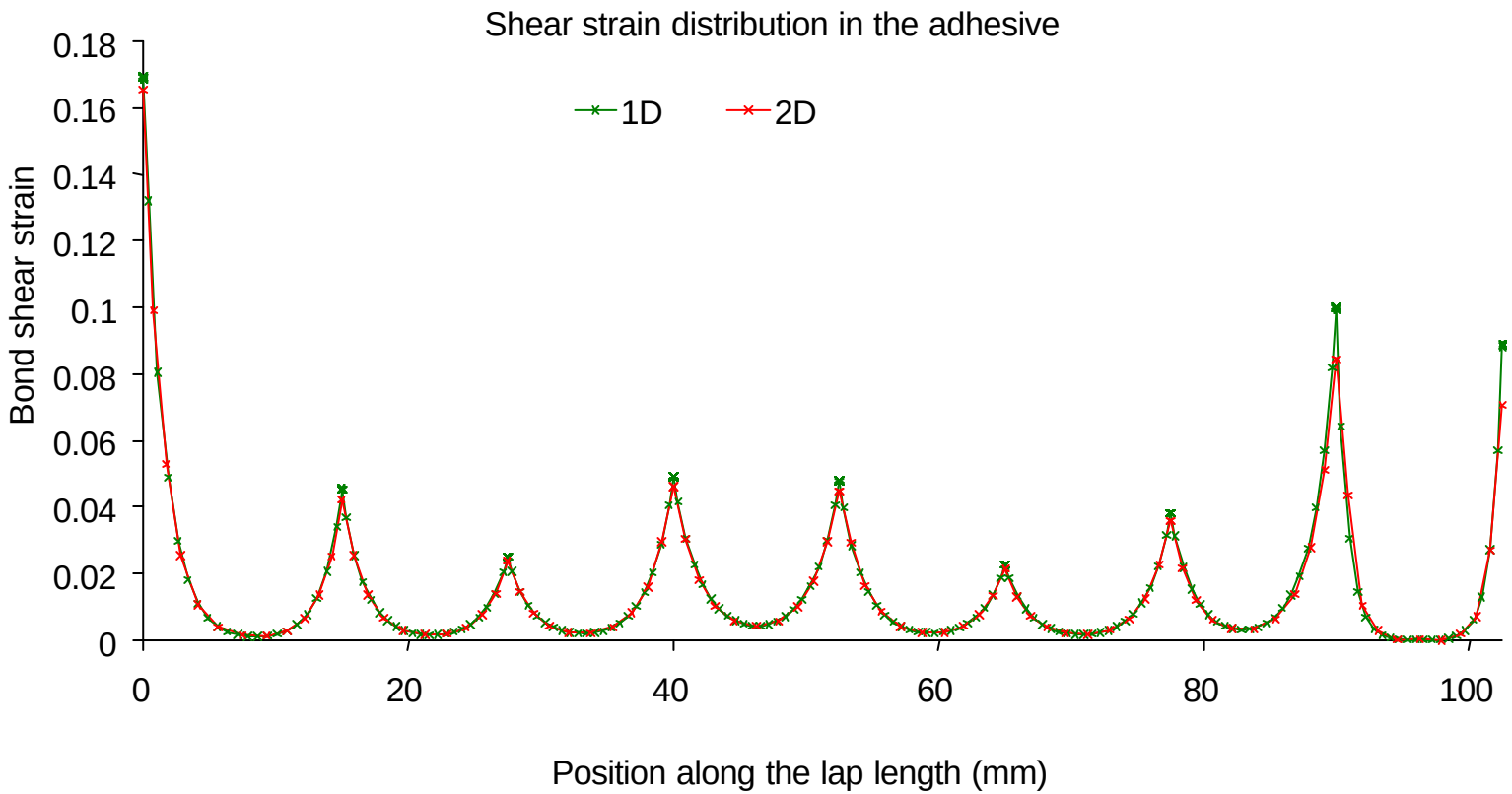
- Building block approach is used for static and fatigue validation.
- Strong experience built on good design practises to alleviate peel stresses (PDO, SRO, etc.).
- The cohesive bond strength calculation is based on:
  - Bondline through-thickness averaged properties,
  - Strength calibrated from tests with theoretical bondline thickness.
- The calculation is based on well controlled M&P parameters that are crucial for interfacial and cohesive bond properties.
- Linear and NL bond material properties are established:
- The allowable are defined taking into account durability parameters:



Bonded Repairs Stress Process
Calculation Example



Bonded Repairs Stress Process
Bond Strain Calculation



Bonded Repairs Stress Process
Current Developments

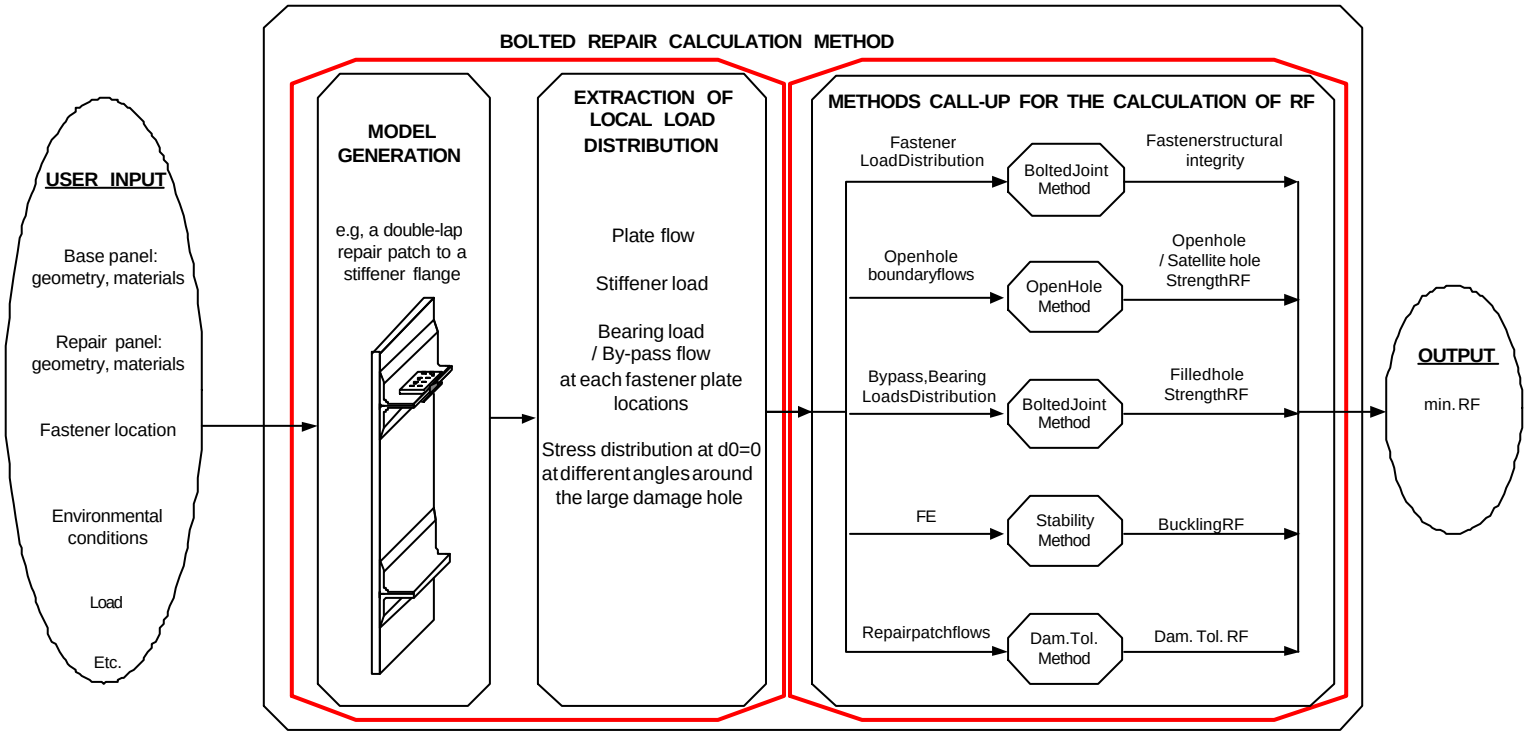
- Development of strength of materials approach, taking into account bond deformation and fracture and implementation of shear/peel iterative criteria.

- Development of fracture mechanics / damage mechanics approaches for the assessment of impact damages / delamination.

- Airbus understanding of regulatory requirements restricts introduction of bonded repairs on composite primary structures.

- Innovative NDI/SHM techniques are being looked at for introducing bonded repairs on PSE.

Bolted Repairs Summary



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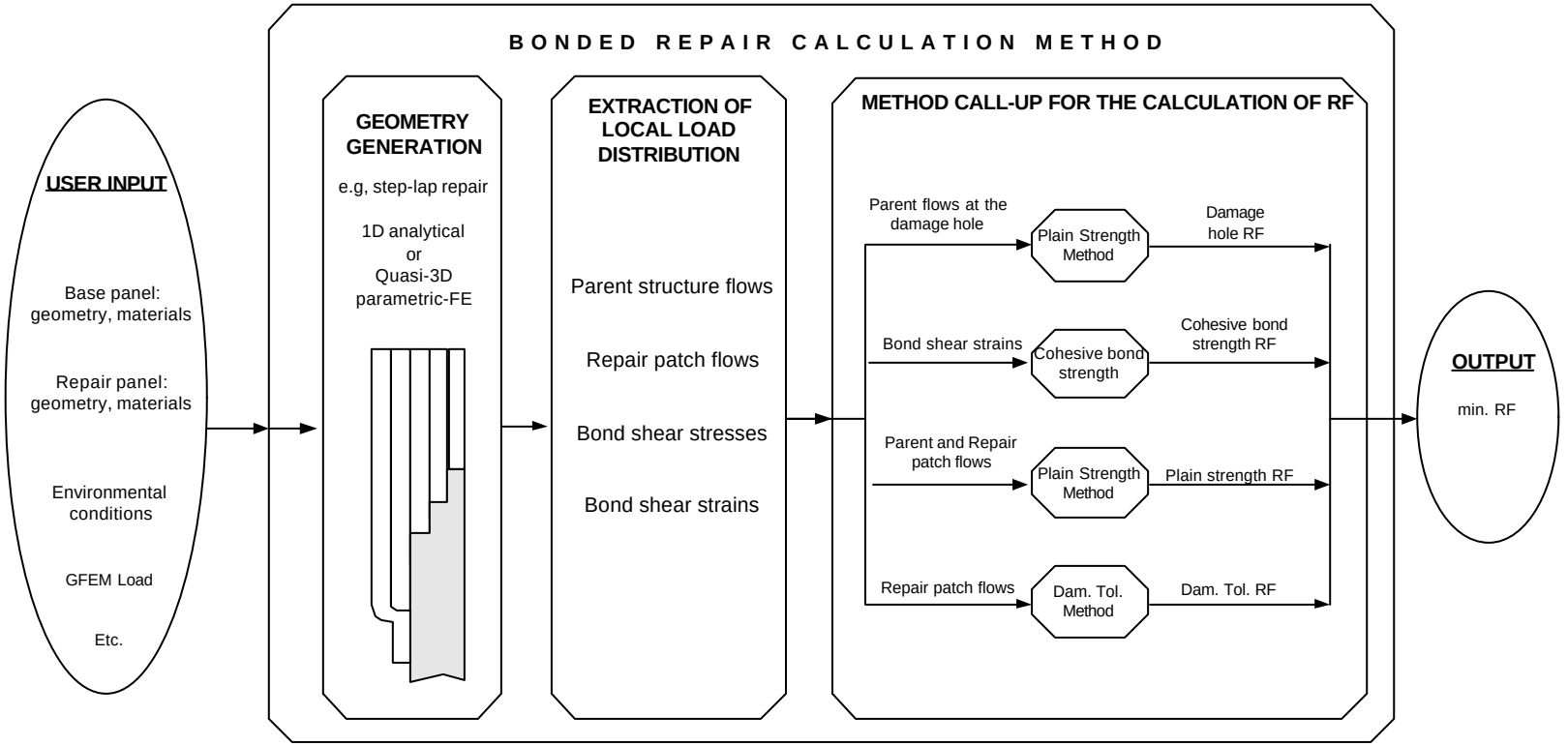

Bonded and Bolted Repairs Summary

- Airbus repair methodology ensures proper maintainability by considering repair philosophy at the design stage.

- Design for repairable structures:
  - Criteria for robustness - economical and structural:
    - ADL/RDL are defined taking into account service history,
    - Structures are inspectable and repairable using common techniques,
  - Standardised structural repairs (SRM):
    - Materials and allowable are based on controlled, qualified, materials and processes satisfying regulatory requirements and offering long-term reliable usage,
    - Design and calculation criteria are defined taking into account robustness and durability,

Composites Repair Analysis

Thank you - Questions ?