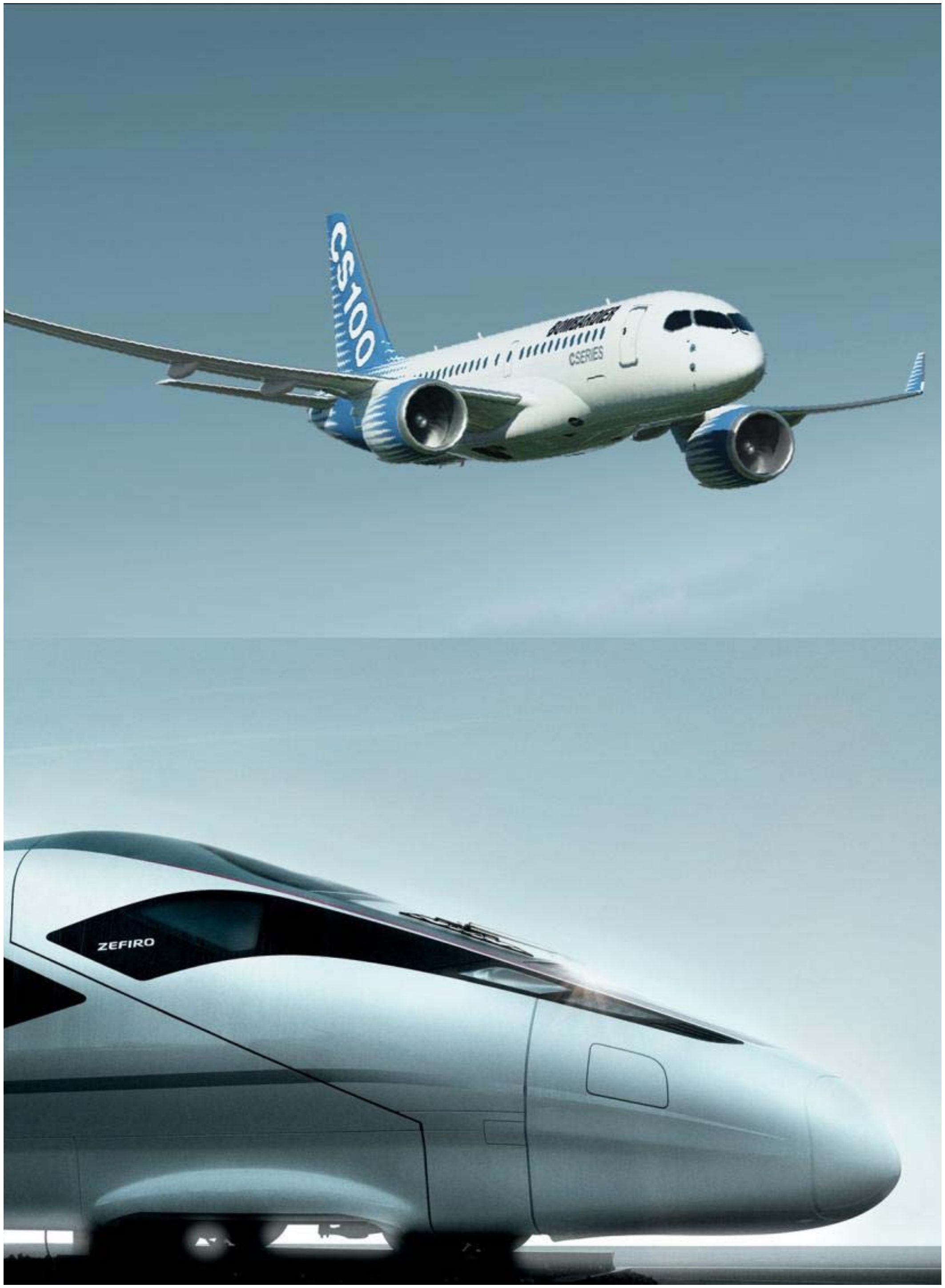

Validation of Thermal Loads for Hybrid Structure

Composite Transport Damage Tolerance and Maintenance Workshop, Montreal
September 2015

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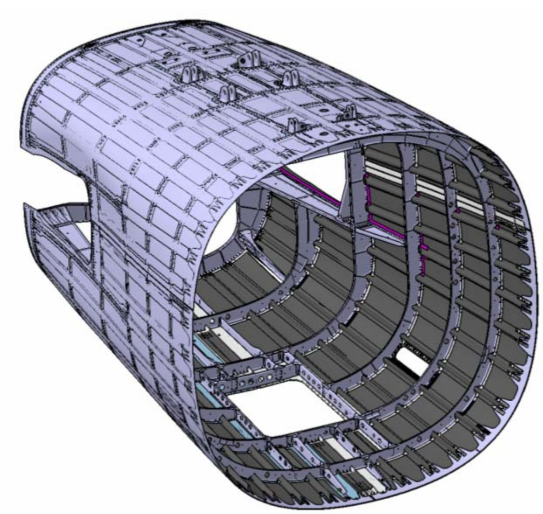
Validation of Thermal Loads for Hybrid Structure

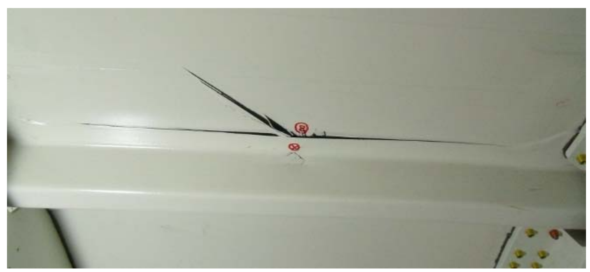
- CSeries Aft Fuselage overview
- Thermal stress methodology definition/validation
- Level 0: CTE validation
- Level 1: Strain compatibility
- Level 2: Flat panels
- Level 3: Barrels
- Level 4: Full Scale
- Sizing Methodology
- Fatigue aspect
- Conclusion

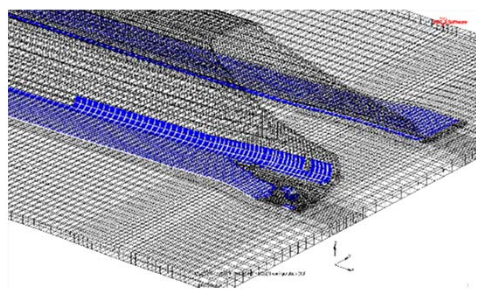
CSeries Aft Fuselage structure/material overview

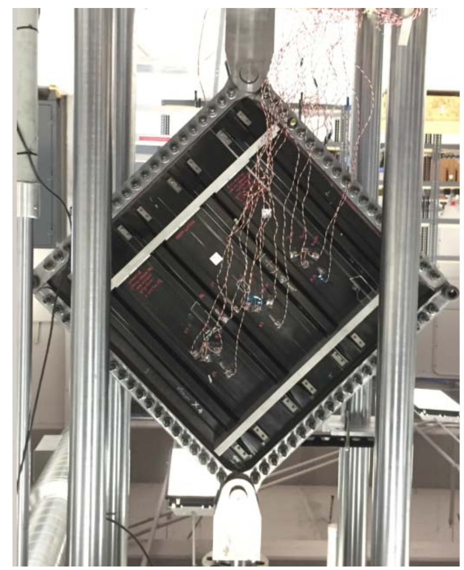
Maximise product benefit and minimize recurring cost with a smart material and process choice, robust design and advanced analysis:

- Automated processes
- Integrated composite parts
- Aluminum frames and longerons
- Minimise use of titanium (3 % in structural weight)
- Robust and Damage tolerant composite structures
- Strong test validated stress methodologies









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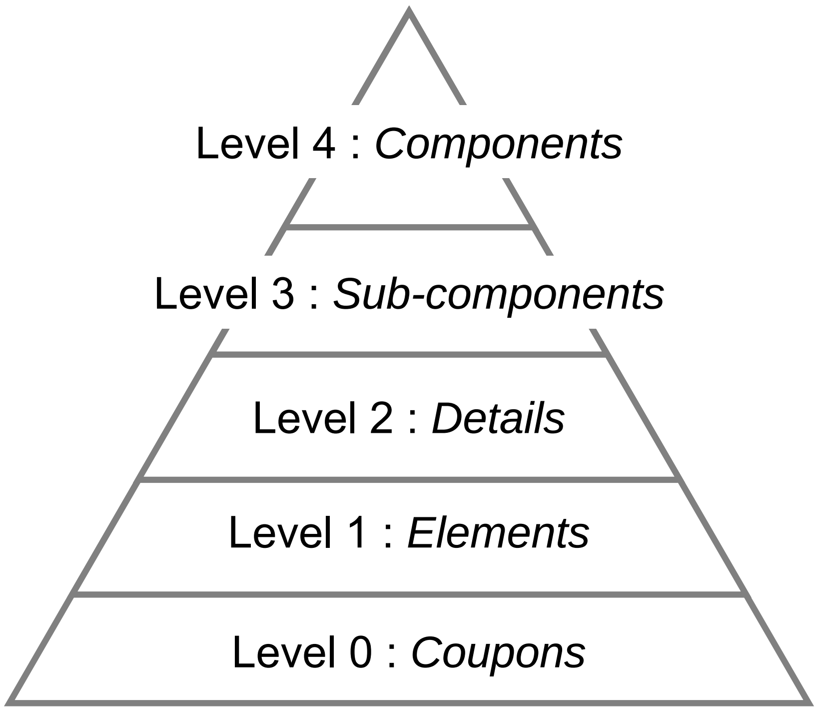
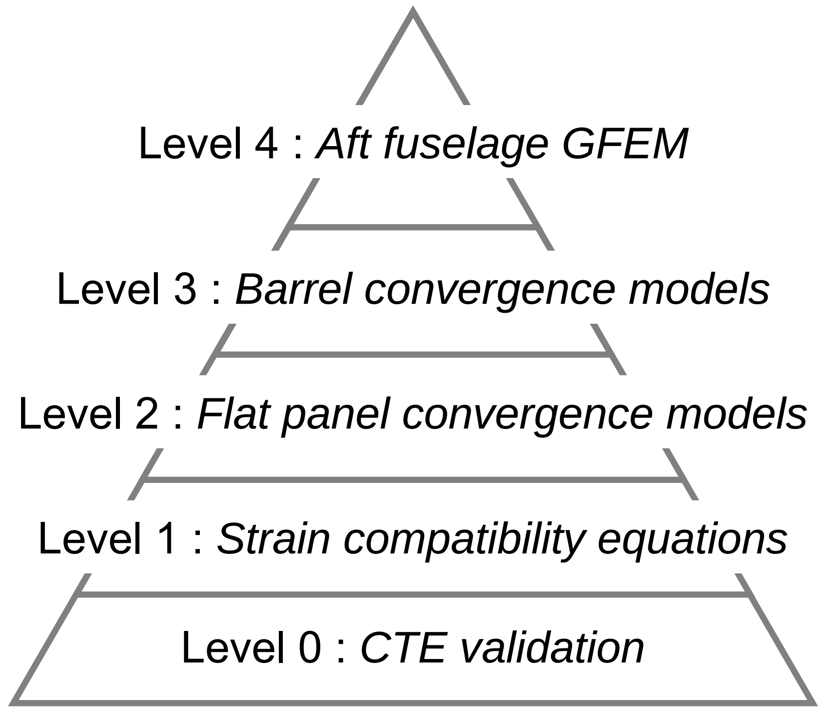
Thermal stress methodology definition/validation

Thermal stress methodology follow a building block approach with emphasis on understanding load and structure behavior rather than relying on a detail FEM for overall structure sizing (static and fatigue).



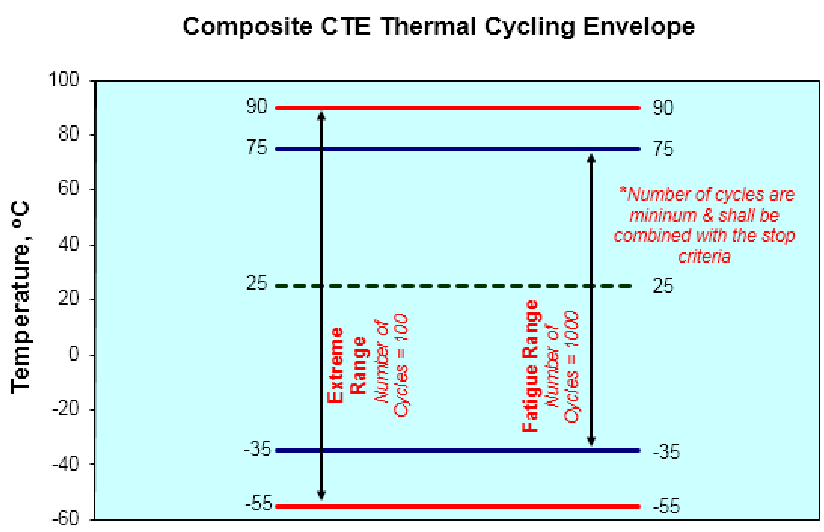
Testing Method

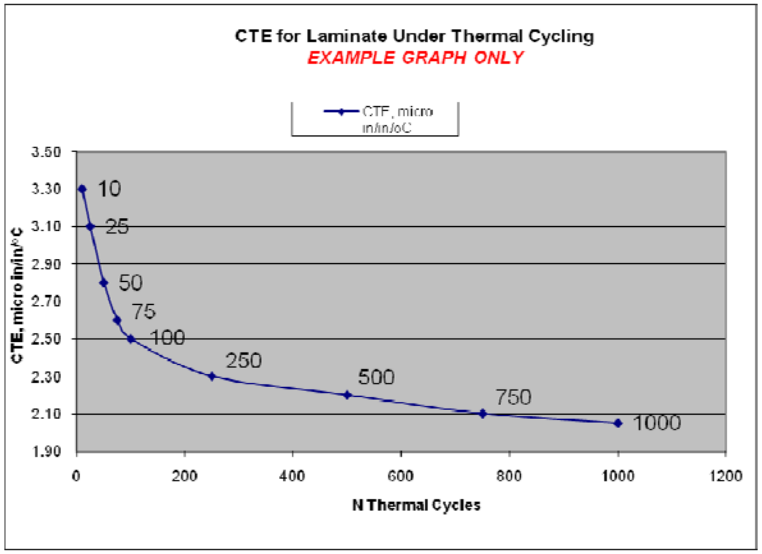


Analysis Method

Level 0: CTE validation

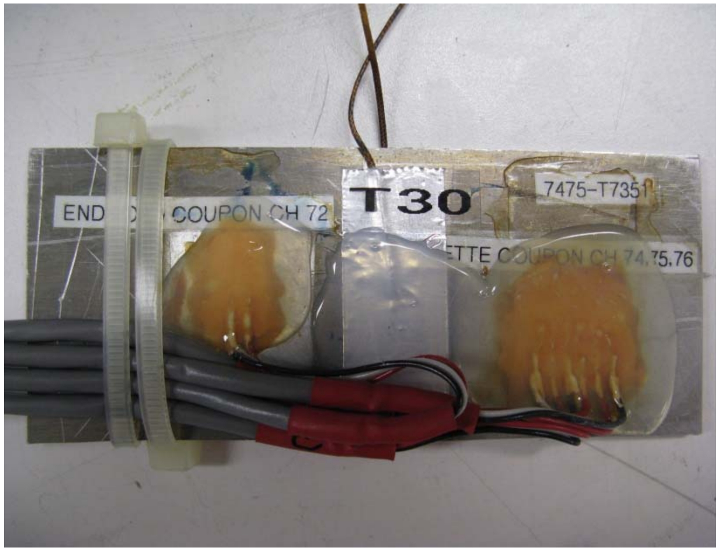
- CTE values, α_{11} and α_{22}, of the combined fiber and matrix at the *lamina* level
- Lamina CTE values are then applied to a laminate stacking sequence (LSS) at the *laminate* level
- Expected CTE fluctuation attributed to AFP process features included
- Effect of thermal cycle on micro-crack and CTE is assessed for fatigue and damage tolerance analysis on composite and aluminum structure
- Extreme and typical thermal fatigue envelope evaluated

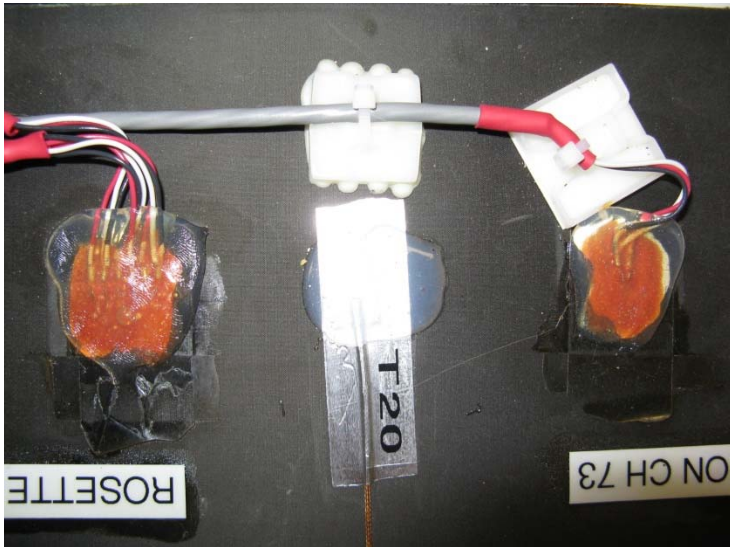




Level 1: Strain compatibility equations

- the CTE mismatch between a common strain gauge and the bonded material will produce erroneous strain results
- Self-Temperature Compensating (STC) gauges for both the Aluminum and Carbon Fiber/Epoxy materials with an appropriate STC number based on their respective CTE values
- A residual error will still be present despite using this method
- Additional test specimens done to subtract the error from the STC gauge measurements





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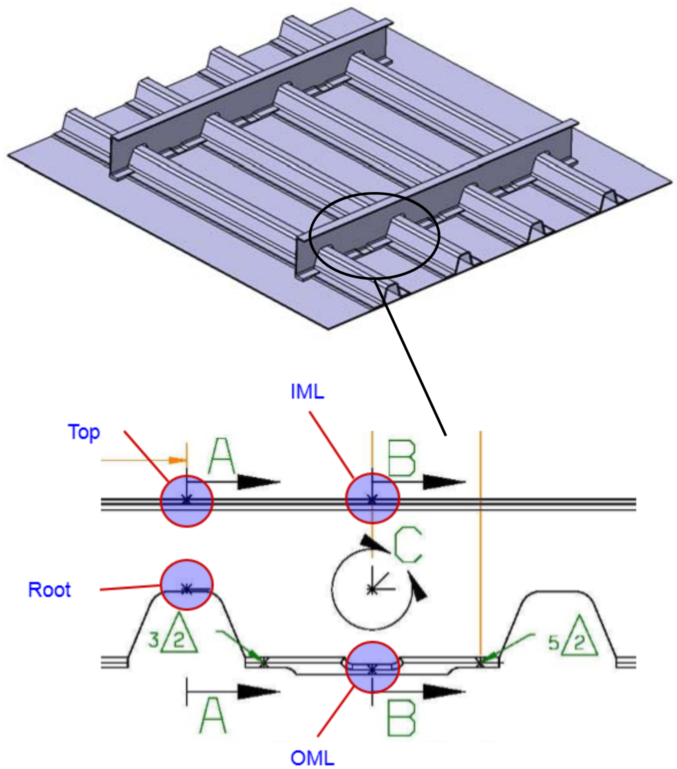
Level 2: Flat panel convergence models

- Correlate the thermal FEM results at 6 temperatures: 60^{o}C, 45^{o}C, -20^{o}C, -30^{o}C, -40^{o}C and -50^{o}C
- Replicate the production stringer-to-frame connection and frame cutout configurations
- Observe impact of liquid shim and faying surface sealant
- Mitigate risk & serve as a knowledge base prior to the Aft-Fuse Demonstrator test



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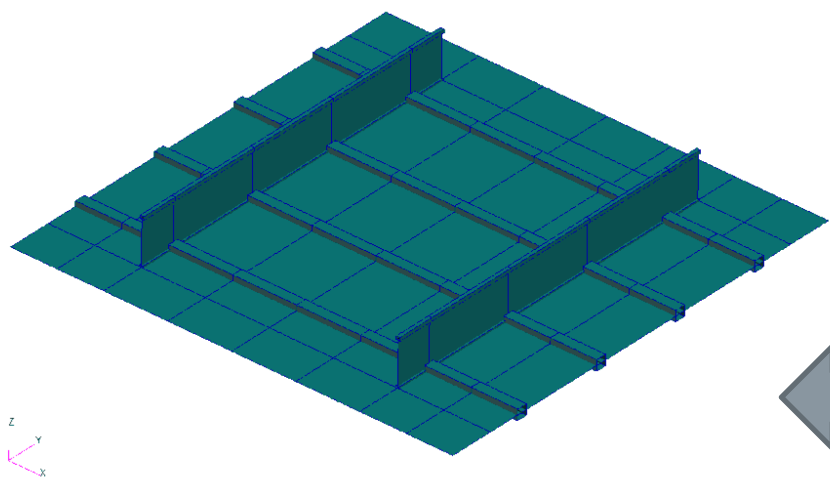
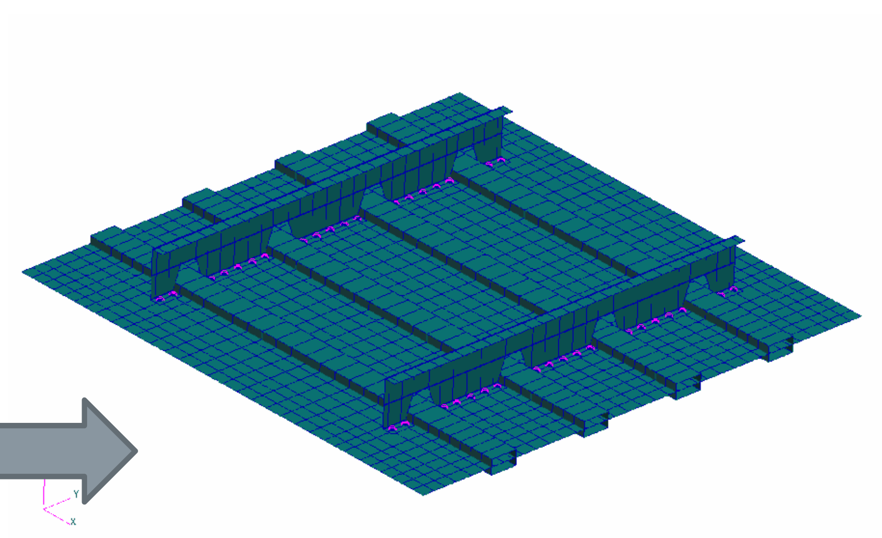
Level 2: Flat panel convergence models

GFEM vs. DFEM

- DFEM correlates frame stresses within less than 10%
- Define reasonable GFEM modification to capture skin / frame load distribution
- Observe and validate effect of:
  - Fastener flexibility
  - Frame cut-out



TFEM Configuration (GFEM)



DFEM

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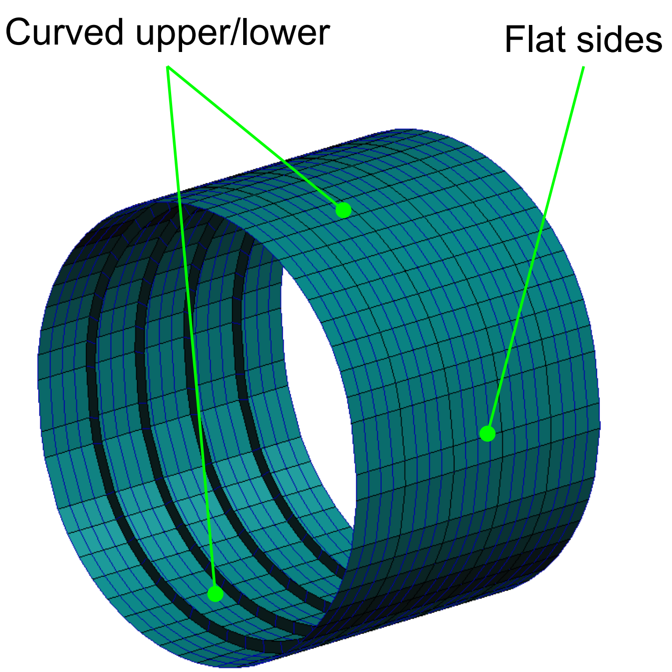
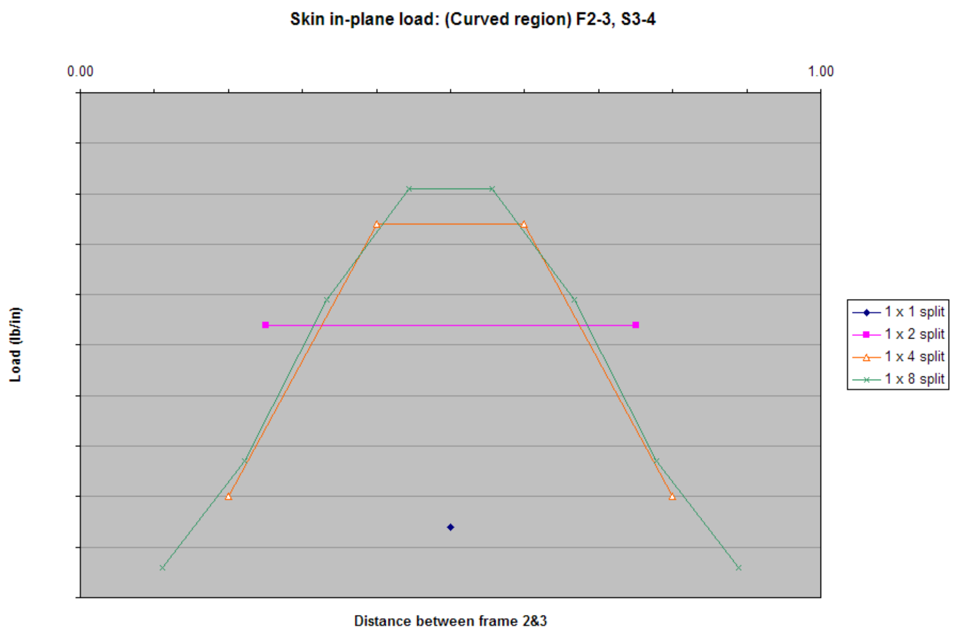
Level 3: Barrel convergence models

Flat panels conclusion is not valid for closed section structure and shall be investigated especially for a non-circular fuselage shape.

Design features are also investigated:

- Fastener flexibility
- Frame cut-out

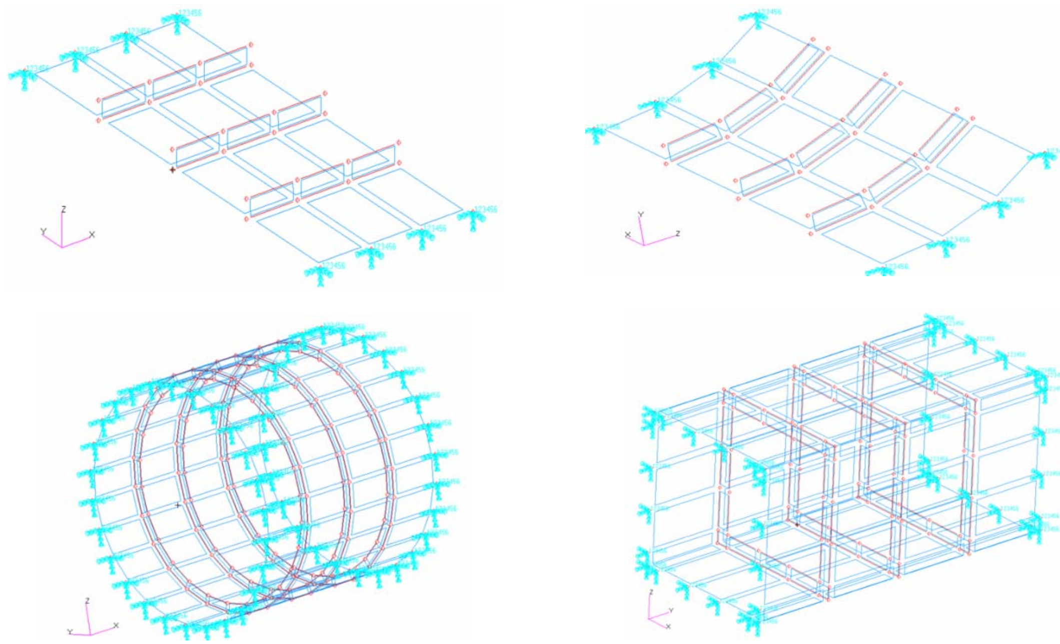




Level 4 Aft Fuselage Global FEM

The following shapes were explored for use in the test plan to substantiate the results and recommendations from the thermal stress FEM convergence analysis:

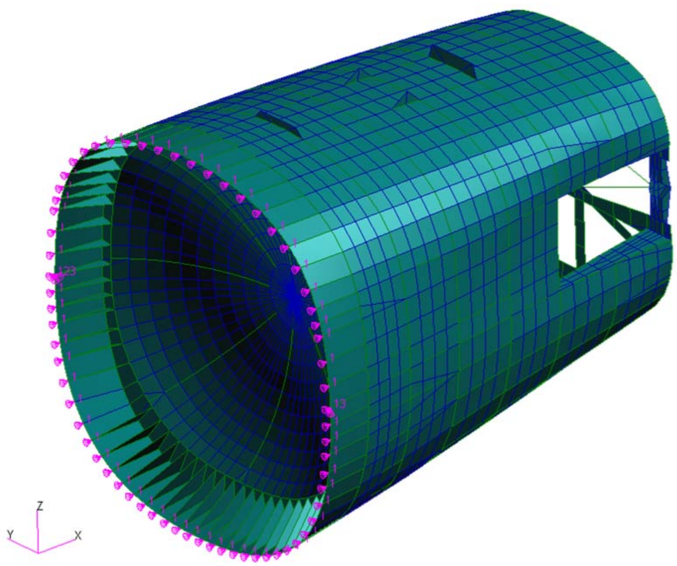
- Open Shapes
  - Flat Panels
  - Curved Panels
- Closed Shapes
  - Cylindrical Shape
  - Box Shape



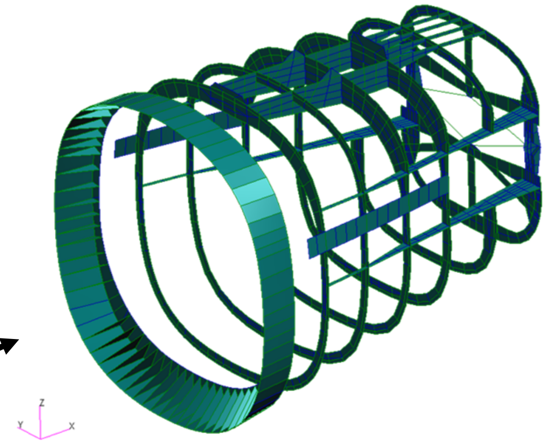
As explained, out of plane capability and boundaries have a significant impact on thermal induced stress. To validate our approach, a production representative test shall be used The production demonstrator is ideal candidate to validate methodology.

Level 4 Aft Fuselage Global FEM

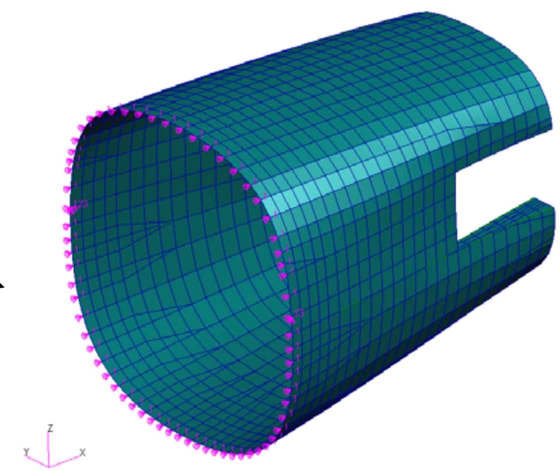
Learning from building block modeling approch are applied to full scale production demonstrator to validate our methodology



Entire Model - boundary condition



Aluminium Elements



Composites Model - boundary condition

Full Scale Test Correlation

Objectives

- Correlate Thermal FEM with physical datas
- Examine fasteners hole clearance on a full scale
- Evaluate the influence of crossing thermal load paths
- Verify predictions of distribution at key locations on Aft Fuse Demonstrator for application to skin and frame sizing
- Assess risks taken during component sizing by examining additional locations on aluminum structures
- Investigate several temperature range**: 75ºC, 60ºC, 45ºC, -20ºC, -30ºC, -40ºC and -50ºC**

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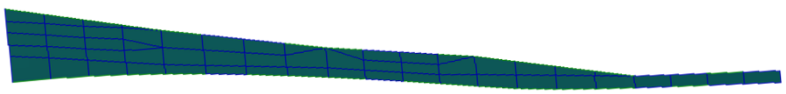
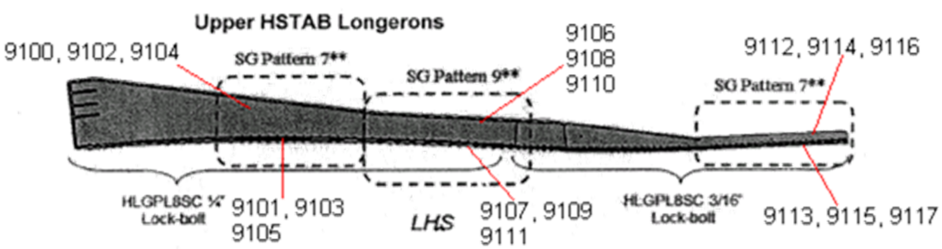
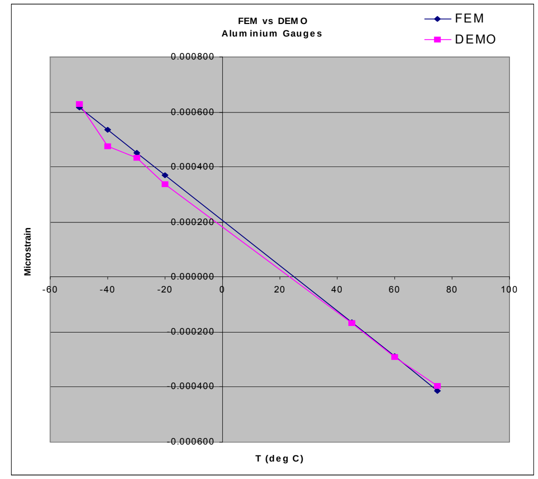
Full Scale Test Correlation: Longeron

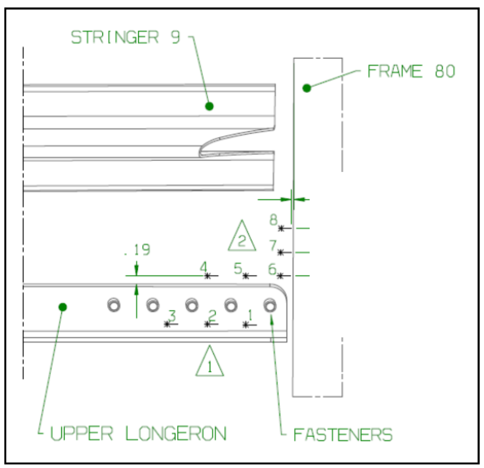
FEM : Node to node connection

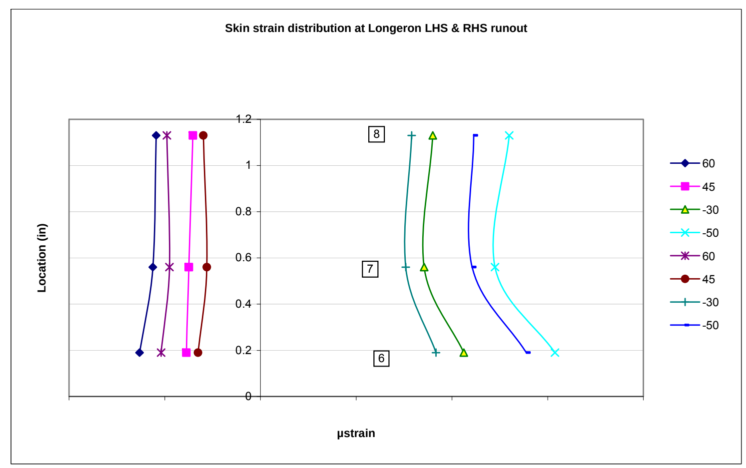




Upper HSTAB Longerons Strain Gauge Locations (LHS Shown Only)







GFEM demonstrated a good prediction continuous aluminum elements

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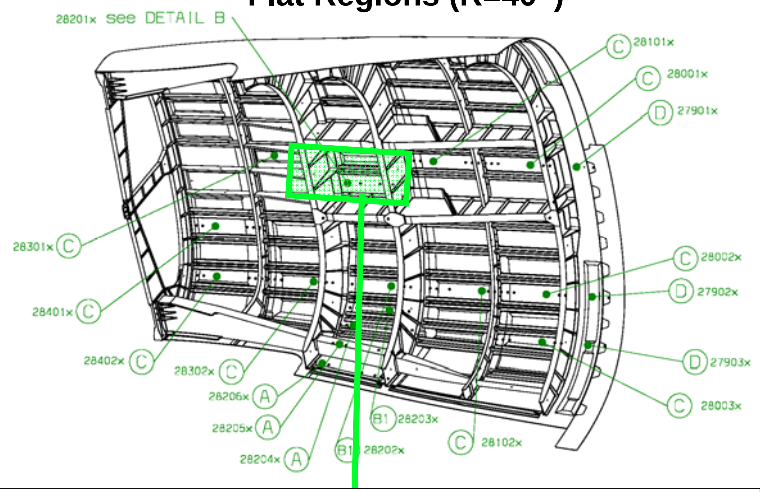
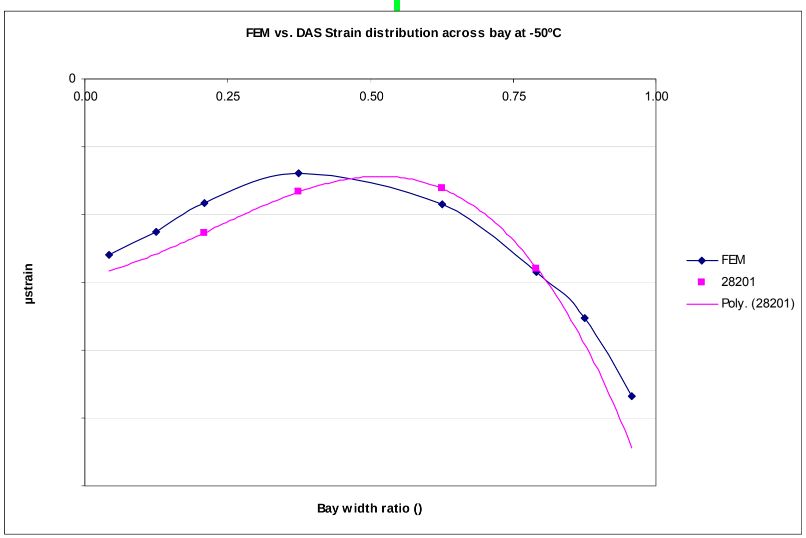
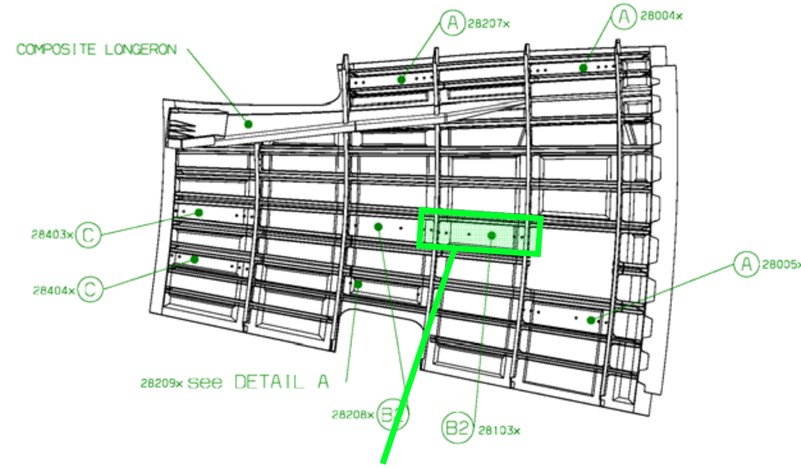
Full Scale Test Correlation – Skin Fyy Distributions

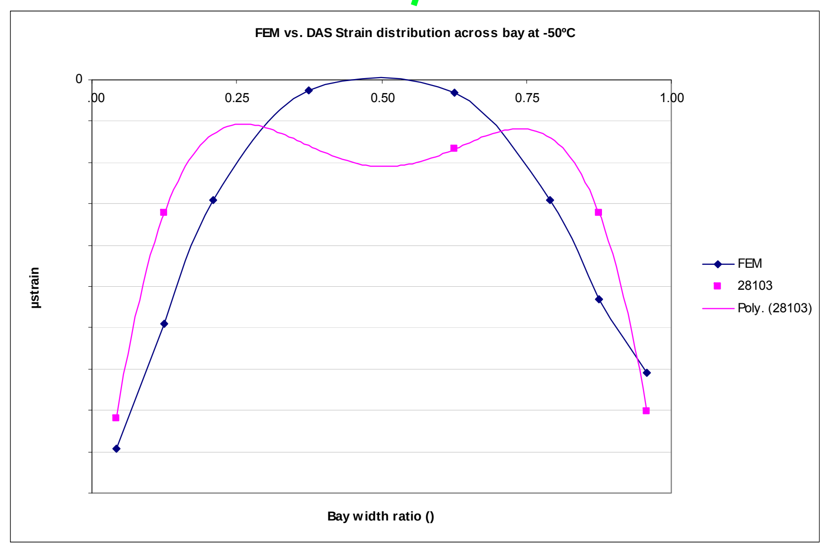
Flat Regions (R=40”)





Light frame/cut-out - Curved Regions (R=60”)





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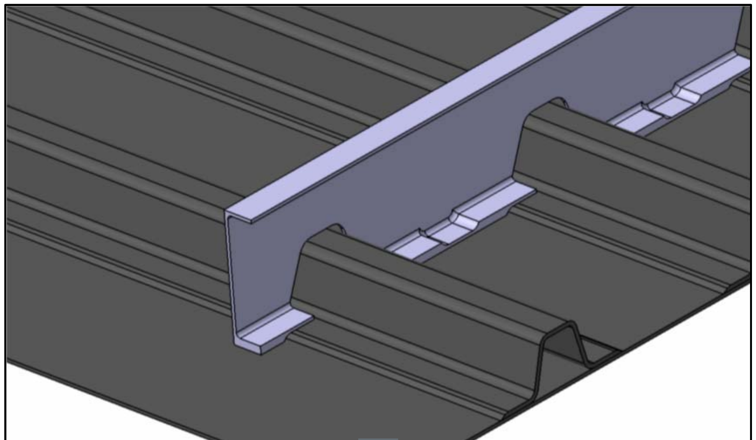
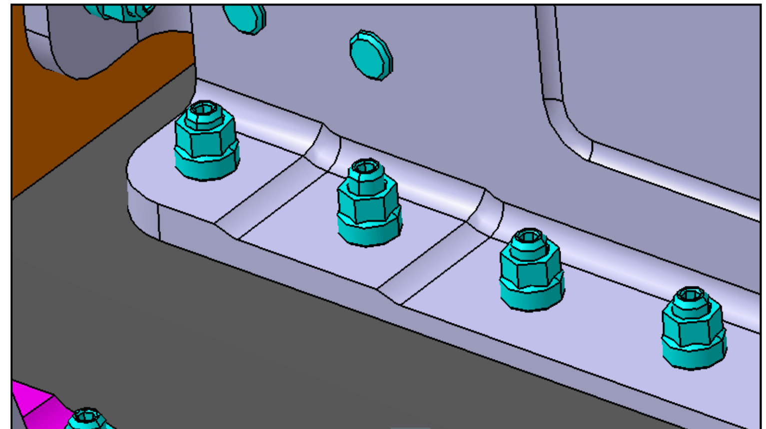
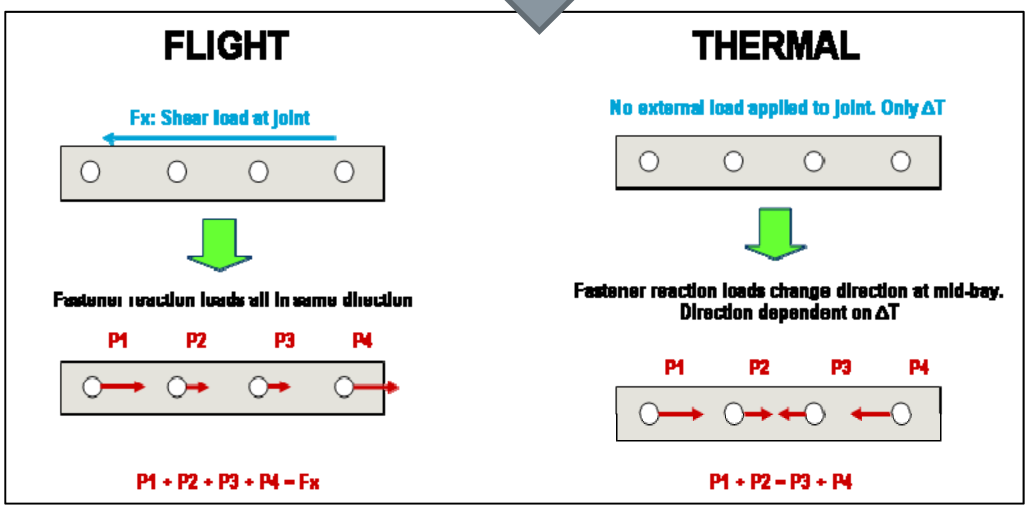
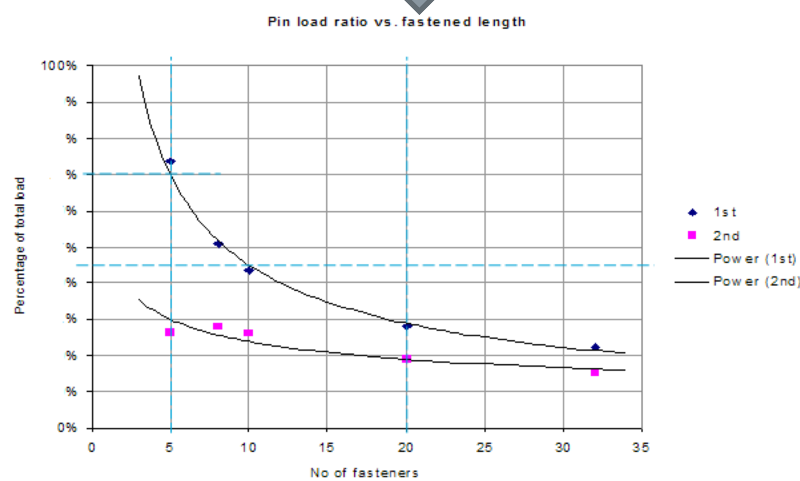
Full Scale Test Correlation – Bearing / By-pass









Develop design rules and factor from DFEM (validated by test) apply to GFEM loads

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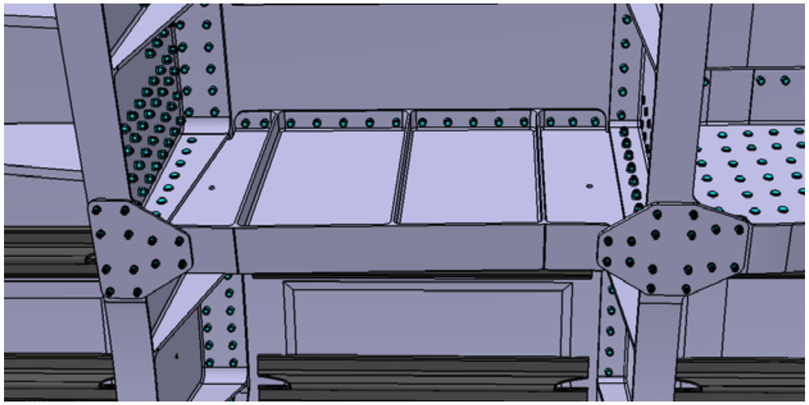
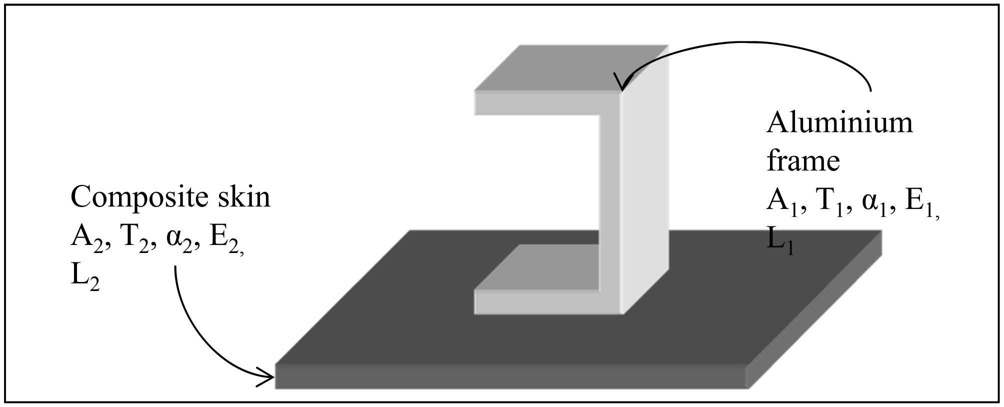
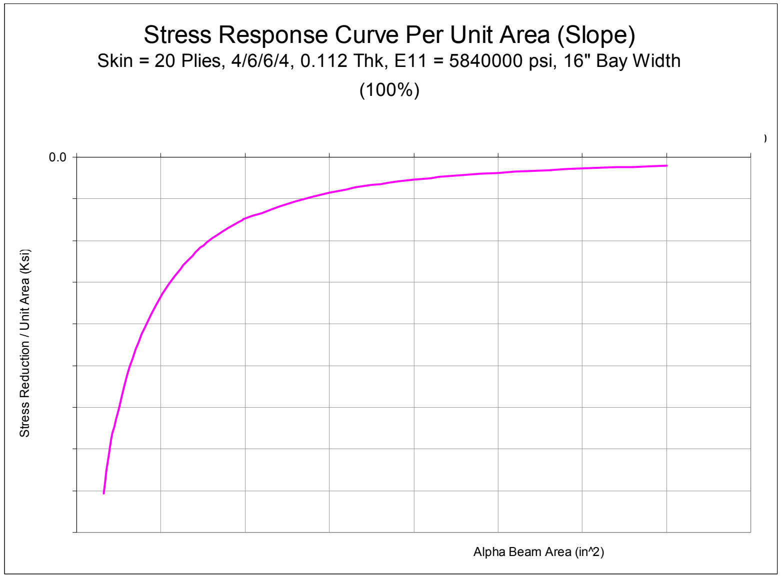
Sizing methodology for production aircraft
Stage 1: Analytical tools

VSTAB inner & outer cap locations





Understanding load path and not relying on DFEM to solve thermo-mechanical static / fatigue / damage tolerance challenge



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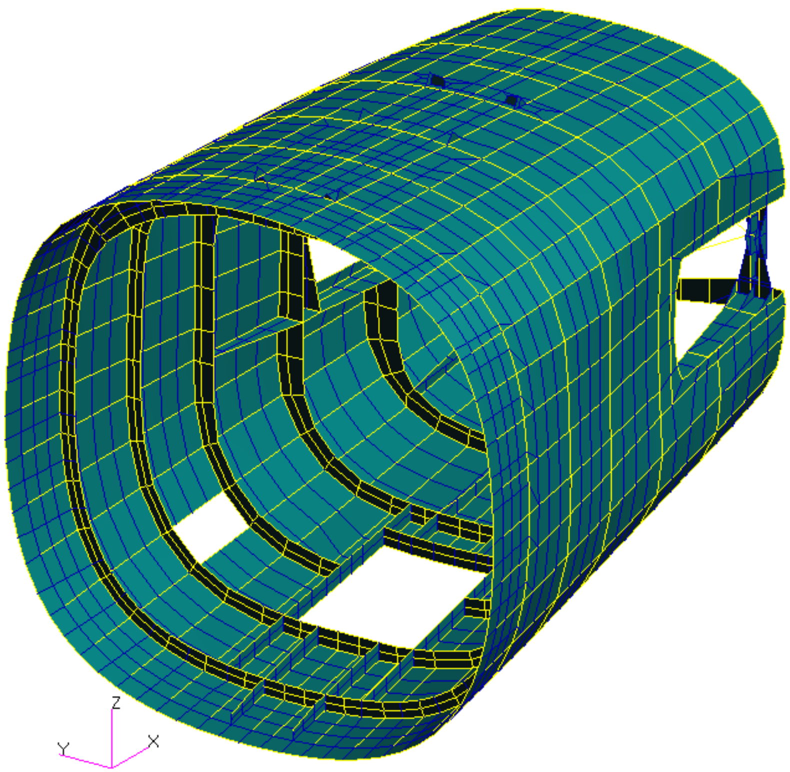
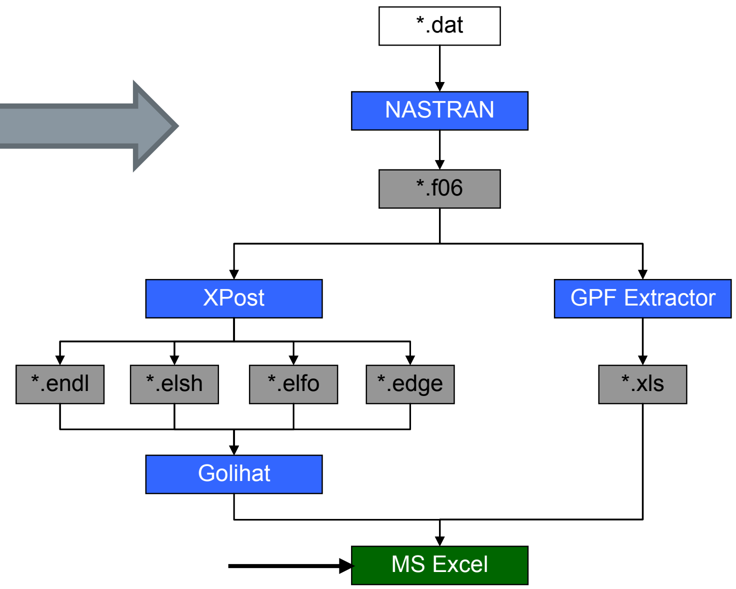
Sizing methodology for production aircraft
Stage 2: Global FEM (Flight and Thermal)

Global FEM is used to extract load for structure sizing (composite and metallic).
Knockdown factor to take into account frame cut-out are used and validated by test evidence.



Isometric View



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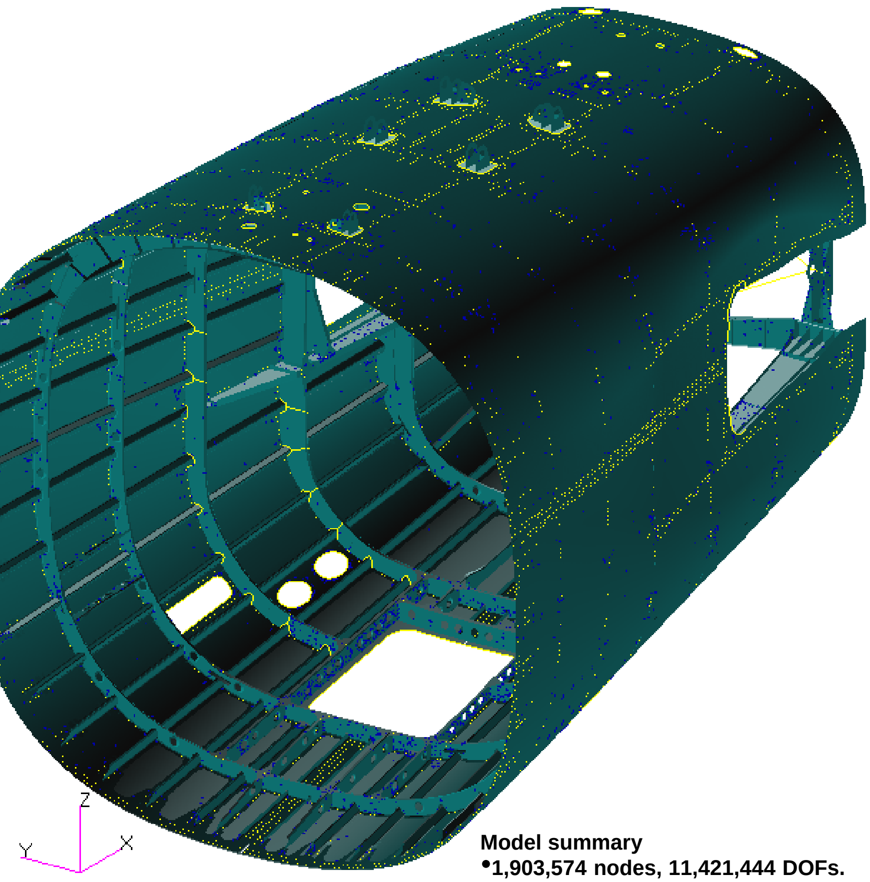
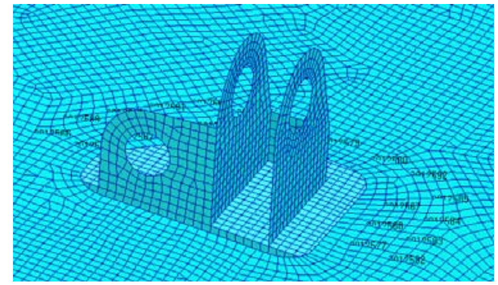
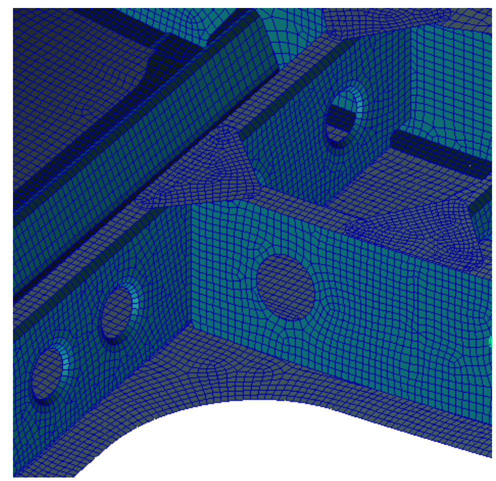
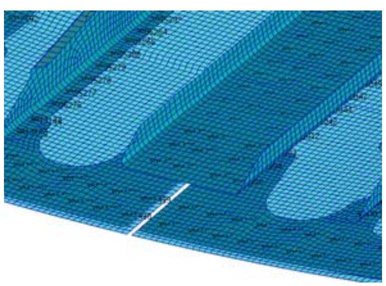
Sizing methodology for production aircraft
Stage 3: Detail FEM (Flight and Thermal)

Detail FEM is used for specific region detail analysis (V-Stab fittings, Mid/Aft joint, highly loaded cut-out). This model use previous leanings and is validated.







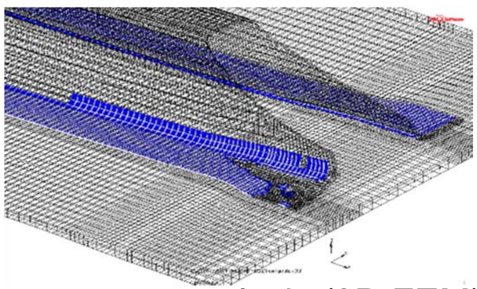


Model summary
- **1,903,574 nodes, 11,421,444 DOFs.**
- **8958 fasteners modeled with CBUSH.**

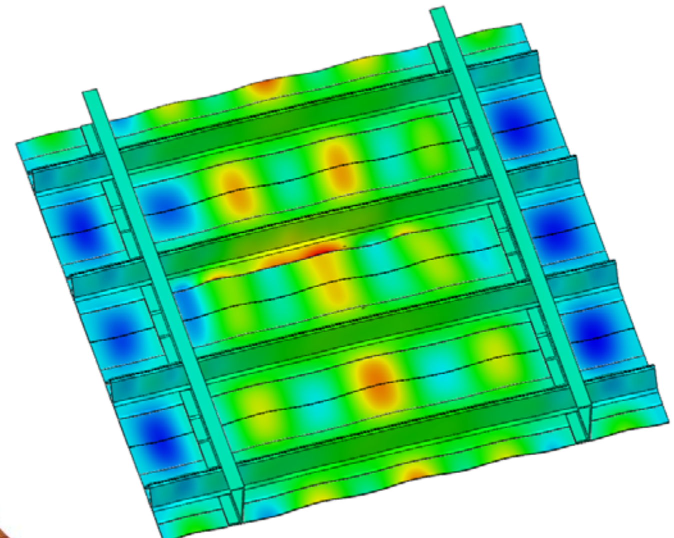
Sizing methodology for production aircraft
Stage 4: High Detail FEM (Flight and Thermal)

High definition FEM are used on complex load interaction area associated to complex failure mode (first stage is still classical analysis):

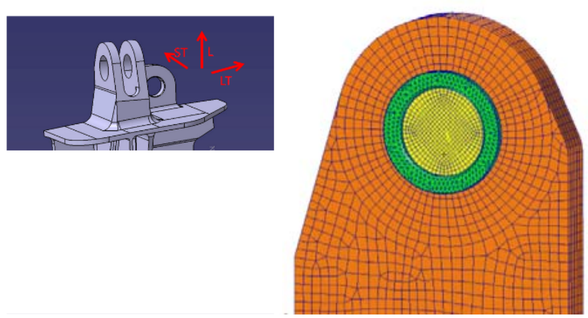
1. Stringer run-out (3D modelling and VCCT analysis)
2. Vertical Stabilizer fittings
3. Skin / Stringer interface



1. Stringer run-out analysis (3D FEM)



3. Flange peeling from skin

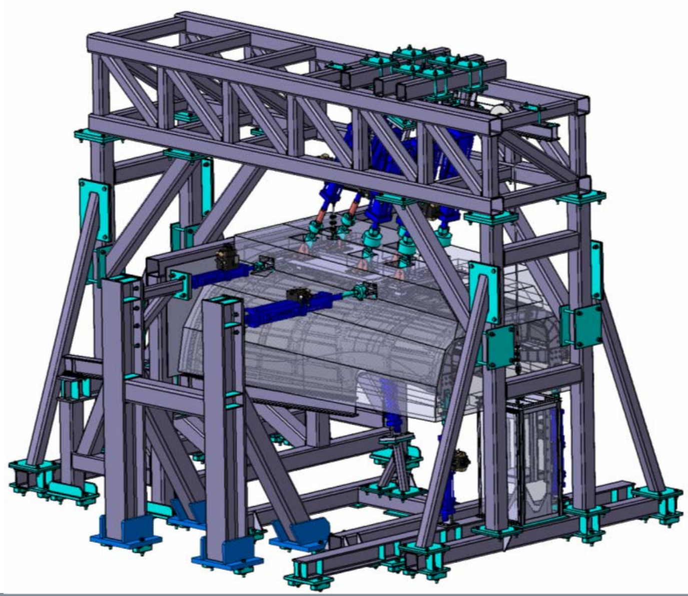


2. Complex fitting / CFRP interface analysis

Conclusions

Thermo-mechanical cycling effect on basic structural allowable can be complex and highly dependent on resin system. A sizing process supported validated by test is proposed.

- An improved FEM predict flight and thermal load associated to a standard sizing process using test validated factor for design features.
- A Detail FEM correlated on full scale test article for flight and thermal load allow critical location analysis.
- Component full-scale thermal and flight fatigue test ensure complete validation.
  - High ratio of thermal to mechanical internal loads and resulting complex interaction of failure modes, required analysis validation at full scale, large sub-component test
  - Residual strength validation after cycling at critical temperature (composite & metallic structure)



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