Validation of Thermal Loads for Hybrid Structure

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Jean-Philippe Marouzé
Product Development Manager
Bombardier Aerostructures & Engineering Services
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
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
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).

**Diagram:**
- Level 4: Components
  - Level 3: Sub-components
    - Level 2: Details
      - Level 1: Elements
        - Level 0: Coupons

- Level 4: Aft fuselage GFEM
  - Level 3: Barrel convergence models
    - Level 2: Flat panel convergence models
      - Level 1: Strain compatibility equations
        - Level 0: CTE validation
Level 0: CTE validation

- CTE values, \( \alpha_{11} \) and \( \alpha_{22} \), 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
**Level 2: Flat panel convergence models**

- Correlate the thermal FEM results at 6 temperatures: 60°C, 45°C, -20°C, -30°C, -40°C and -50°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
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
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
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 approach are applied to full scale production demonstrator to validate our methodology.

Entire Model - boundary condition

Aluminium Elements

Composites Model - boundary condition
Objectives

- Correlate Thermal FEM with physical data
- 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 ranges: 75°C, 60°C, 45°C, -20°C, -30°C, -40°C, and -50°C
Full Scale Test Correlation: Longeron

FEM : Node to node connection

GFEM demonstrated a good prediction continuous aluminum elements
Full Scale Test Correlation – Skin Fyy Distributions

**Flat Regions (R=40")**

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

**FEM vs. DAS Strain distribution across bay at -50ºC**

- **Bay width ratio (i)**
- **µstrain**

**Poly. (28201)**

- **FEM**
- **28201**
- **Poly. (28201)**

**COMPOSITE LONGERON**

- **A12307x**
- **A22606x**
- **A22802x**
- **A22803x**

**DETAIL A**

- **28603x**
- **28604x**
- **24907x**
- **24908x**

**DETAIL B**

- **28107x**
- **28108x**
- **27007x**
- **27008x**

**FEM vs. DAS Strain distribution across bay at -50ºC**

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**Poly. (28103)**

- **FEM**
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- **Poly. (28103)**
Full Scale Test Correlation – Bearing / By-pass

Develop design rules and factor from DFEM (validated by test) apply to GFEM loads
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
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.
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 uses previous leanings and is validated.
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)

2. Complex fitting / CFRP interface analysis

3. Flange peeling from skin
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.
  o 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
  o Residual strength validation after cycling at critical temperature (composite & metallic structure)
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