Some Thoughts on Strategies for Building Block Approach Development

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Summary

Thoughts and conclusions drawn during the development, *in partnership with suppliers*, of new aircraft including a high percentage of composite materials.

Challenges mainly associated with:

- Pronounced environmental effects (temperature and humidity) on composite material properties (e.g. strength)
- Induced Thermal Loads in hybrid structures
- Durability and Damage Tolerance assessment specificities of composite structures
- *Suppliers with different* composite and hybrid structure backgrounds (e.g. materials, processes, analytical methods, etc.)

Bottom-up and Top-down approaches used concurrently to develop the building block program
Validate models:
Load Path, deflection, strains

Interrogate design concepts, analysis calibration, environmental effects.

Design allowables, scatter and environmental effects

Upper testing level may be used to validate the design concepts in terms of durability, damage tolerance and residual static strength but Full Scale Test limitations must be carefully addressed.
Building Block development (Bottom-up)

Bottom-up approach - to establish the lower level testing program

- Preferred Materials and Fasteners Design Guidelines Preliminary Design Values
- Preliminary Structural Concepts and Sizing
- Environmental Conditions (T Mapping, Saturation Level, contaminant)
- Damage Scenario and Acceptable Manufacturing Defects
- Statistical Analysis Methodology
- Structural Analysis Methodologies
- Testing at Lower Levels
- Testing at Intermediate Levels
- Testing at Higher Level
- Structural Analysis Inputs
- Structural Analysis Calibration
- Structural Analysis Validation
Building Block development (Bottom-up)

Bottom-up approach – Documents (per major component)

- Environmental Condition report: Temperature Mappings (Static and Fatigue. Normal and failure conditions), considered saturation levels, potential fluid contaminants.

- Damage Scenario report: Damage threats by zone (maintenance, runway debris, hail, lightning strike, heat damages, etc.) and allowed manufacturing defects

- Testing Program report:
  - Design space (M&P, structural concepts, layups, types of fasteners, design guideline deviations, typical repairs, etc.),
  - Structural Analysis Methods summary: List inputs (allowables and influencing parameters)
  - Statistical Analysis overview: Specifies statistical method, the number of specimens, batches and cure cycles used. Pooling method. LEF derivation method.
Building Block development (Bottom-up)

Bottom-up approach – Documents (per major component)

- Testing Program report (one per major component) (cont’d):
  - Test Space: Range of the Analysis inputs tested (Design + RNC provisions)
  - Selected Test Methods: Adapted to the design and objectives
  - Lower Level Test Matrices: Optimized
  - Intermediary Testing levels: overview of the test articles and their objectives.
  - Upper Testing level: Describe briefly the test article and the applied load factors (ECLF and LEF)

Top-Down
Building Block development (Bottom-up)

### Analysis Method Summary Table

<table>
<thead>
<tr>
<th>Analysis Type</th>
<th>Analysis Inputs</th>
<th>Influencing Parameters</th>
<th>Calibration/Validation tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure Modes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bearing</td>
<td>Brg/Bypass (Brg cut-off)</td>
<td>Layup, T, D, e/D, D/T, Csk/T, Env.</td>
</tr>
<tr>
<td></td>
<td>FHC</td>
<td>Brg/Bypass (Quad. Inter.)</td>
<td>Layup, T, D, W/D, Csk/T, Env.</td>
</tr>
<tr>
<td></td>
<td>OHC</td>
<td>Brg/Bypass (ByPass cut-off)</td>
<td>Layup, T, D, W/D, Csk/T, Env.</td>
</tr>
<tr>
<td></td>
<td>FHT</td>
<td>Brg/Bypass (BJSFM)</td>
<td>Layup, T, D, W/D, Csk/T, Env.</td>
</tr>
<tr>
<td></td>
<td>UNS</td>
<td>Brg/Bypass (BJSFM)</td>
<td>Layup, Env.</td>
</tr>
<tr>
<td></td>
<td>Pull Through</td>
<td>Pull Through Analysis</td>
<td>Bolt Type, Head Style, Csk/T, Env.</td>
</tr>
</tbody>
</table>

Partial table illustrative example
Building Block development (Bottom-up)

Test Space Summary table in terms of influencing parameters for all failure modes
Covers Design Space and potential RNCs

<table>
<thead>
<tr>
<th>Influencing Parameters</th>
<th>Min</th>
<th>Max</th>
<th>Failure Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>8HS Layup (45º %)</td>
<td>22%</td>
<td>66%</td>
<td>ALL</td>
</tr>
<tr>
<td>Temp./Sat.</td>
<td>-76F/AR</td>
<td>194F/Sat</td>
<td>ALL</td>
</tr>
<tr>
<td>T (in)</td>
<td>0.116</td>
<td>0.498</td>
<td>CAI, TAI, SAI</td>
</tr>
<tr>
<td>D (in)</td>
<td>0.1875</td>
<td>0.5000</td>
<td>OHC, OHT, FHT, Brg</td>
</tr>
<tr>
<td>D/T</td>
<td>0.66</td>
<td>1.61</td>
<td>Brg</td>
</tr>
<tr>
<td>e/D</td>
<td>1.5</td>
<td>3.0</td>
<td>Brg</td>
</tr>
<tr>
<td>W/D</td>
<td>3.0</td>
<td>8.0</td>
<td>OHC, OHT, FHT</td>
</tr>
<tr>
<td>Csk/T</td>
<td>0.00</td>
<td>0.67</td>
<td>OHC, OHT, FHT, Brg</td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Illustrative example
Building Block development (Top-down)

- **Top-down** approach is used in conjunction with bottom-up approach to identify the critical details and applicable test limitations (particularly the ones applicable to upper testing level).

<table>
<thead>
<tr>
<th>Test limitations at lower levels</th>
<th>Test limitations at upper level</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Multi-axial loading</td>
<td>- Environmental Strength degradation</td>
</tr>
<tr>
<td>- Fatigue Spectrum loading</td>
<td>- Thermally induced Stress</td>
</tr>
<tr>
<td>- Secondary loading effect</td>
<td>- Fuel pressure induced Stress</td>
</tr>
<tr>
<td>- Limited load redistribution</td>
<td>- Number of available Critical areas (failure modes, types of damages, damage categories, defects, Large Damage, repairs)</td>
</tr>
</tbody>
</table>

- Verify if limitations are well addressed in the building block. Typically using intermediary testing level (Load factor, conditioning, analysis calibration)
Building Block development (Top-down)

Environmental Effect Limitation (FST Strength)

Typically, testing under worst environment (T and R.H.) at the higher testing level is not a practical option.

- Conditioning duration,
- Thermal gradient,
- Thermal conditions specific to load cases (thermal inertia, max load not coincident with most critical temperature)

Environment effect limitation could be addressed using a combination of methods.

1. Using partial environmental conditioning and/or
2. Using localized environmental conditioning and/or
3. Using Extra Hot/Dry environment to mimic Hot/Wet condition
4. Environmental Compensation Load Factor (ECLF) and/or
5. Analytically using Finite Element Analyses.
Building Block development (Top-down)

Environment Compensation Load Factor (ECLF) may be used to compensate the environmental effect on residual strength of the critical failure modes.

Precautions and checks before applying ECLF:

- No anticipated premature failure due to overload (e.g. most severe failure mode ECLF may create over-conservative load conditions for the failure modes having lower ECLF)
- Load Path remains the same for the worst and the tested environment (e.g. buckling)
- Thermal stress (due to differential thermal expansion of attached parts) is accounted for separately.
- Temperature gradients are accounted for (e.g. upper skin temperature higher than in the lower skin).
- Non-linear load-strain (or load-displacement) response is considered when determining environmental compensation load factor.
**Building Block development (Top-down)**

**ECLF table could be used to rationalize applicable ECLF (FSTA)**

<table>
<thead>
<tr>
<th>Sub-compnt</th>
<th>Failure Mode</th>
<th>Loadcase</th>
<th>Worst Env. (F/sat.)</th>
<th>Worst Env. Reserve Factor</th>
<th>Testing Env. (F/sat.)</th>
<th>ECLF</th>
<th>Testing Env. Reserve Factor</th>
<th>Worst Env. Fail. Sequence</th>
<th>Test Env. Fail. Sequence</th>
<th>Demonstrated % UL using ECLF only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Skin</td>
<td>BRG</td>
<td>1301125</td>
<td>160/0.6</td>
<td>1.08</td>
<td>70/amb</td>
<td>1.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Skin</td>
<td>BUCK</td>
<td>1311175</td>
<td>160/0.6</td>
<td>1.10</td>
<td>70/amb</td>
<td>1.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Upper Skin</td>
<td>FHT</td>
<td>1301125</td>
<td>-80/A.R.</td>
<td>1.15</td>
<td>70/amb</td>
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<tr>
<td>Upper Stringer</td>
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**Illustrative example**

**FSTA: Full Scale Test Article**
Building Block development (Top-down)

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<td><strong>1.14</strong></td>
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Illustrative example

Maximum Applicable ECLF = 1.14
Building Block development (Top-down)

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Illustrative example
Building Block development (Top-down)

ECLF table may be used to determine:

- Changes in the Failure mode sequence between the tested environment and worst environmental condition
- Zones where test environmental limitations (strength) apply (zones and failure modes)
- Importance of existing gap (strength demo) if only ECLF is used
- Locations where special attention should be shown regarding the understanding of load level (zones with limitations).
- Zones where the test limitations must be addressed analytically and/or by test at intermediate testing level.

Note: ECLF table is less applicable in zones where thermal stress is relatively significant.
Example of Analysis Calibration/Validation

Spar Cap Radius (ILTS)

Fuel Pressure
Analysis Validation

Teflon

impact

impact
Example of Analysis Calibration/Validation

Aft Fuse Thermally induced Load

-58F to 140F

-58F to 167F
Conclusion

Lower testing level:
- Design guidelines,
- Preliminary sizing,
- Analysis Method inputs
- Environmental conditions

Intermediary testing levels:
- Critical Structural details
- To address FSTA limitations (Load factor, Environment, Analysis method correlation/validation)
- Risk mitigation

Upper testing level:
- Analysis validation,
- Inputs for intermediary testing level,
- D&DT and Strength “demo”