Some Thoughts on Strategies for Building Block Approach Development

Eric Pomerleau
Isabelle Paris

FAA/Bombardier/TCCA/EASA/Industry
Composite Transport Damage Tolerance and Maintenance Workshop

September 2015

BOMBARDIER
l'évolution de la mobilité

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.)

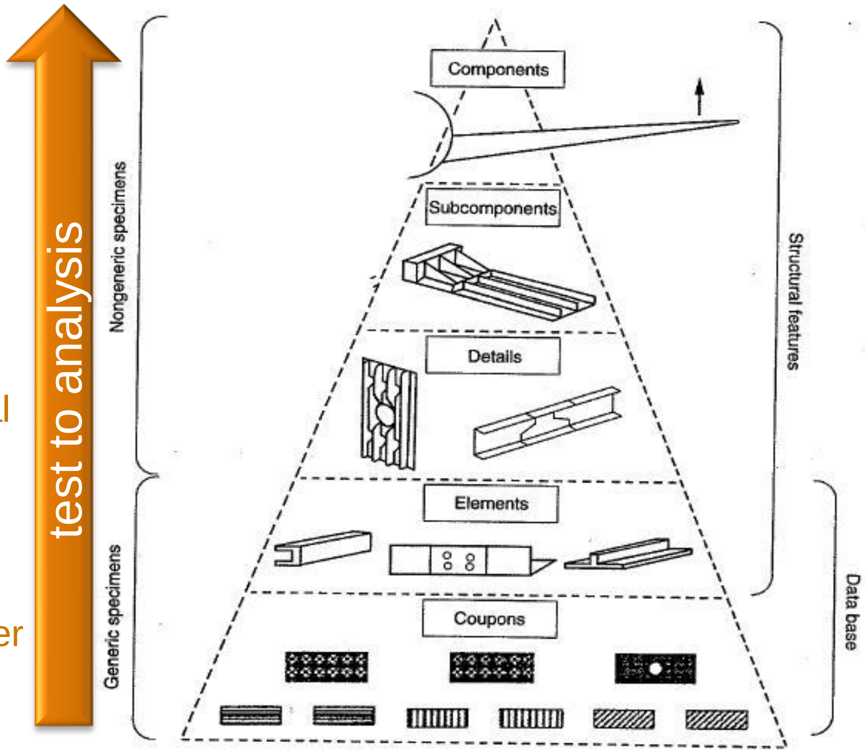
Bottom-up and Top-down approaches used concurrently to develop the building block program

Background (Building Block Pyramid)

Validate models:
Load Path, deflection, strains

Interrogate **design concepts, analysis calibration**, environmental effects.

Design allowables, scatter and environmental effects



The building-block pyramid for testing of composites

Structural **assemblies**

Laminate **discontinuities**
ex.: Open/Filled Holes, Damage, Bolted joints, Skin/Stringer, Radius…

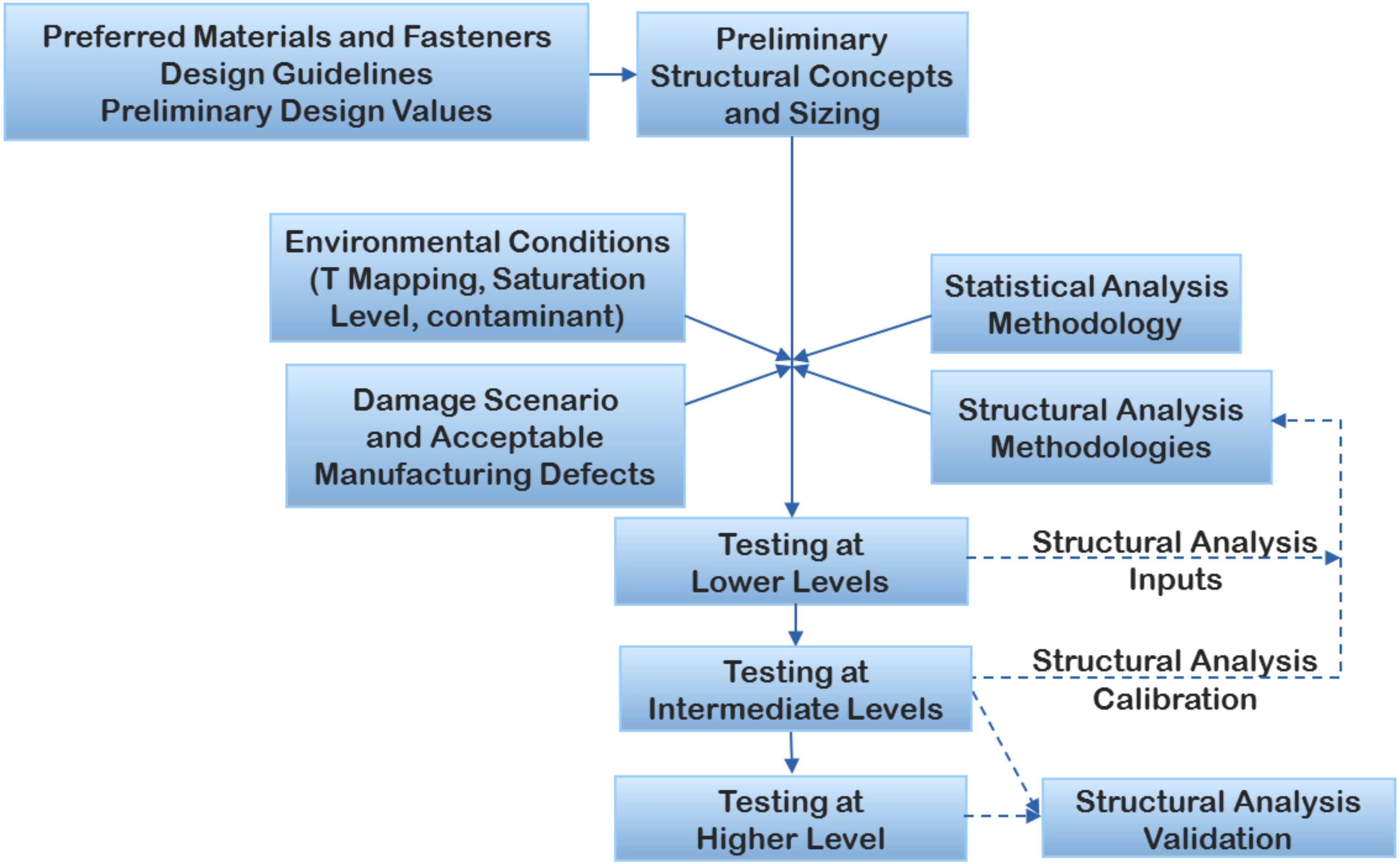
Lamina/Laminate
ex.: Tensile, compressive, shear strength and moduli, interlaminar strength…

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.

BOMBARDIER
l'évolution de la mobilité

Building Block development (Bottom-up)

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



BOMBARDIER
l'évolution de la mobilité

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.

BOMBARDIER
l'évolution de la mobilité

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 obejtives
  - 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

Analysis Type	Analysis Inputs			Calibration/Validation tests	
	Failure Modes	Analysis Methods	Influencing Parameters	L4/Env/Type	L3/Env/Type
Bolted Joint Analysis	Bearing	Brg/Bypass (Brg cut-off)	Layup, T, D, e/D, D/T, Csk/T, Env.		
	FHC	Brg/Bypass (Quad. Inter.)	Layup, T, D, W/D, Csk/T, Env.		
	OHC	Brg/Bypass (ByPass cut-off)	Layup, T, D, W/D, Csk/T, Env.		
	FHT	Brg/Bypass (BJSFM)	Layup, T, D, W/D, Csk/T, Env.		
	UNS Un-notched strength	Brg/Bypass (BJSFM)	Layup, Env.		
	Pull Through	Pull Through Analysis	Bolt Type, Head Style, Csk/T, Env.		

Partial table illustrative example

BOMBARDIER
l'évolution de la mobilité

Building Block development (Bottom-up)

Test Space Summary table in terms of influencing parameters for all failure modes

Covers Design Space and potential RNCs

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

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).

Test limitations at lower levels

- Multi-axial loading
- Fatigue Spectrum loading
- Secondary loading effect
- Limited load redistribution

Test limitations at upper level

- Environmental Strength degradation
- Thermally induced Stress
- Fuel pressure induced Stress
- Number of available Critical areas (failure modes, types of damages, damage categories, defects, Large Damage, repairs)

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

BOMBARDIER
l'évolution de la mobilité

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)

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

Illustrative example

FSTA: Full Scale Test Article

Building Block development (Top-down)

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

Sub-compnt	Failure Mode	Loadcase	Worst Env. (F/sat.)	Worst Env. Reserve Factor	Testing Env. (F/sat.)	ECLF	Testing Env. Reserve Factor	Worst Env. Fail. Sequence	Test Env. Fail. Sequence	Demonstrated % UL using ECLF only
Upper Skin	BRG	1301125	160/0.6	1.08	70/amb	1.20	1.30	1	3	95
Upper Skin	BUCK	1311175	160/0.6	1.10	70/amb	1.04	**1.14**	2	1	110
Upper Skin	FHT	1301125	-80/A.R.	1.15	70/amb	1.10	1.27	3	2	104
Upper Stringer										
Upper Stringer										
….										

Illustrative example

Maximum Applicable ECLF = 1.14

BOMBARDIER
l'évolution de la mobilité

Building Block development (Top-down)

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

Sub-compnt	Failure Mode	Loadcase	Worst Env. (F/sat.)	Worst Env. Reserve Factor	Testing Env. (F/sat.)	ECLF	Testing Env. Reserve Factor	Worst Env. Fail. Sequence	Test Env. Fail. Sequence	Demonstrated % UL using ECLF only
Upper Skin	BRG	1301125	160/0.6	1.08	70/amb	1.20	1.30	1	3	95
Upper Skin	BUCK	1311175	160/0.6	1.10	70/amb	1.04	**1.14**	2	1	110
Upper Skin	FHT	1301125	-80/A.R.	1.15	70/amb	1.10	1.27	3	2	104
Upper Stringer										
Upper Stringer										
....										

Illustrative example

BOMBARDIER
l'évolution de la mobilité

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.

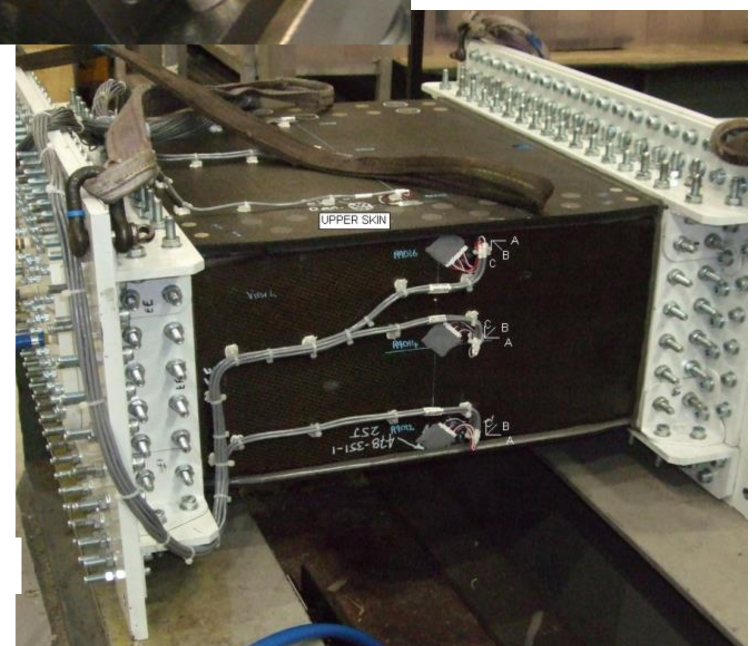
BOMBARDIER
l'évolution de la mobilité

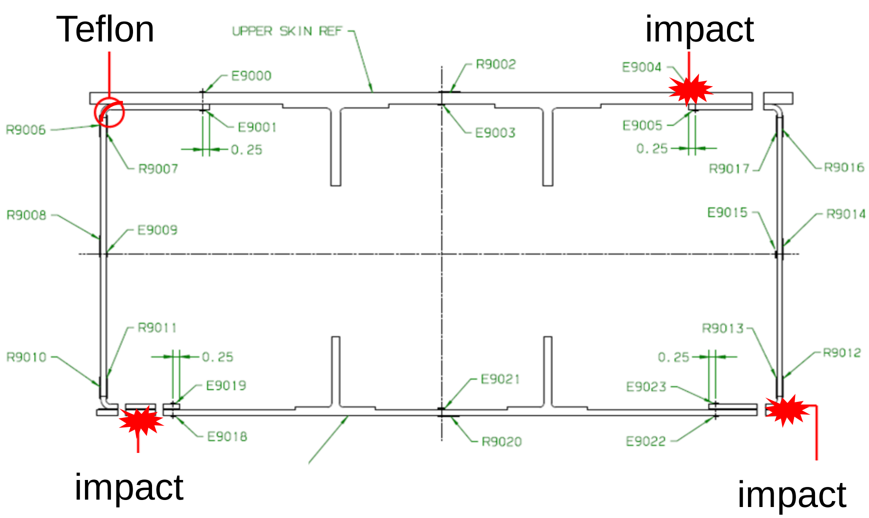
Example of Analysis Calibration/Validation

Spar Cap Radius (ILTS)

Fuel Pressure

Analysis Validation



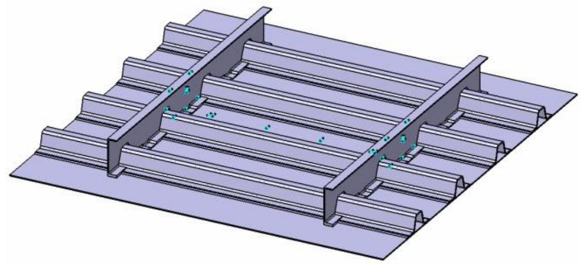


BOMBARDIER
l'évolution de la mobilité

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

Bottom-up

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"

Top-Down

BOMBARDIER
l'évolution de la mobilité