Smarter Testing Through Simulation for Efficient Design and Attainment of Regulatory Compliance

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Passenger safety is by far the most important consideration in the development and operation of commercial aircraft. How does Boeing ensure that the structure and systems on its aircraft meet regulatory requirements? A rigorous building block approach verifies and validates analysis by tests. Various types or levels of testing exist in the building block pyramid rubric (Figure 1), beginning with small coupon tests for foundational material property evaluation at or before the start of a program, moving to design detail evaluation and analysis method validation with mid-level element and sub-component parts, finally culminating with component and full-scale tests for high fidelity loads and analysis method verification. Best practices in tasks such as material characterization, finite element modelling and simulation methods are documented, standardized and applied to produce high quality predictive assessments. These assessments positively impact design and enable well-planned and informed *smart* testing. Smart testing through simulation maximizes the benefit of *necessary* tests, augments understanding of performance within and beyond the envelope of test data and minimizes unplanned tests in attaining certification.

Many validated analysis methods are available for various types of metallic and composite aircraft structure within Boeing Commercial Airplanes (BCA), but most of these are not fully general and have only been validated within specific areas of a design space. New materials, architectures, or regions of the design space necessitate additional method validation and expansion via test. This need typically results in testing at the mid to lower levels of the building block pyramid, in which various sub-component and structural element tests are carried out for development of structural design values. Very large costs (more than 50%, typically) and long flow times are associated with this middle region of the pyramid; validating methods or design data in this domain is risky since the tests are relatively complex, and require a relatively mature production system – both of which lead to results coming later in the development cycle.

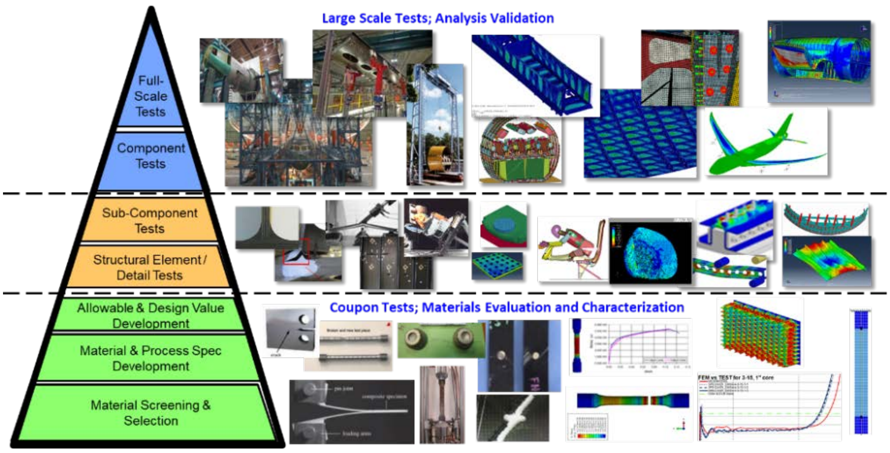


*Figure 1. The structural test pyramid, with a smarter level of certification testing.*

BCA Structures Engineering has developed a multi-year initiative that aims to standardize and simplify testing associated with methods and design values. Use of advanced analysis techniques using fundamental (coupon-derived) inputs can lead to reduced quantities of program-led mid-level structural tests, reducing Airplane Development costs and risks. The approach is referred to as "smarter testing." Smarter testing is built around some or all of the following key ideas and approaches: (i) virtual testing precedes physical tests, (ii) analysis-enhanced test point allocation across the design space to target specific failure modes after appropriate analyses, (iii) better test planning and execution; disciplined application of Design of Experiments (DOE) to reduce matrix sizes and focus on the important parameters, and (iv) replacement of complex sub-component tests by element or coupon tests while keeping the failure mode the same;

establishing the linkages between the various analysis scales. The fundamental set of ideas is to leverage advancing predictive abilities, reduce “brute force” testing and to go into remaining testing better informed, while using standard test approaches where possible. Figure 2 shows an example of this approach where dynamic simulation was successfully used evaluate airframe crashworthiness. This approach also moves the high risk tests to earlier phases of development, de-risking the tests that remain. Surprises in tests can lead to late design changes that are difficult to react to, and may require additional validation tests with associated schedule and budget challenges. Testing developed using the smarter testing approach is by definition less scattershot, more directed and timely, more cost effective, and therefore more valuable.

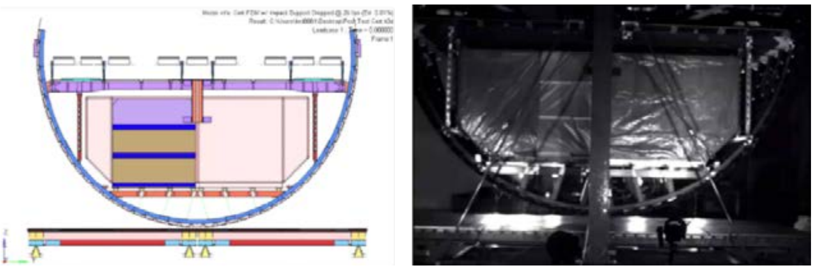

*Figure 2. Fuselage drop simulation (left) and test (right) demonstrating 787 airframe crashworthiness.*

Composite structures present some unique analytical challenges and BCA has laid out a road map for continuing analysis method development in the areas of stability, bolted joint, damage mechanics and residual strength evaluation. The strategy is to first mature traditional modeling approaches (e.g., Point Stress Failure criteria) for significant gains in cost reduction, followed by the use of failure-mechanism-based approaches (e.g., Peridynamics, Enhanced-Schapery-Theory) for further reductions.

Additive Manufacturing (AM) has large potential for weight savings as well as production cost reductions for metal parts and assemblies. The current most advanced AM structure in BCA products is the certified 787 aft galley fitting (Figure 3), which is built by Norsk Titanium using their wire-fed Rapid Plasma Deposition process. Looking ahead, AM presents new challenges for certification in that there are not traditional validated analysis methods suited to the arbitrary and organic nature of many AM parts. Moreover, fatigue and damage tolerance considerations currently pose significant challenges. The presence of inherent material defects randomly distributed throughout the volume, which may be below the threshold of detectability, means that due consideration has to be given to size effects and the possibility of cracks not always nucleating where they would ordinarily be expected based only on the magnitudes of local stresses associated with obvious macroscopic features such as geometric stress concentrations. This not only challenges the conventional understanding and characterization of crack nucleation properties but also, and more fundamentally, the principle of “safety by inspection” when it is tied to a presumption of certain crack morphologies and origins, which then define the means and frequency of inspections. The solution may lie in the application of probabilistic fatigue analysis methods and perhaps a stronger reliance on fail-safety or safe life rather than directed inspections and prescribed inspection intervals. The keys to certifying AM parts by FE analysis is understanding how to generate and incorporate allowables in the analysis as well as using proven and managed (potentially template based) FE modeling approaches and solution methods. The impact of surface roughness, flaw size, structure thickness, and other factors on the effect and detectability of defects is still being quantified.

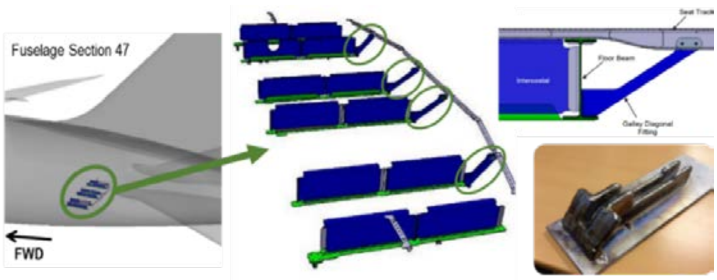


*Figure 3. The certified 787 aft galley diagonal additively manufactured fitting.*

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