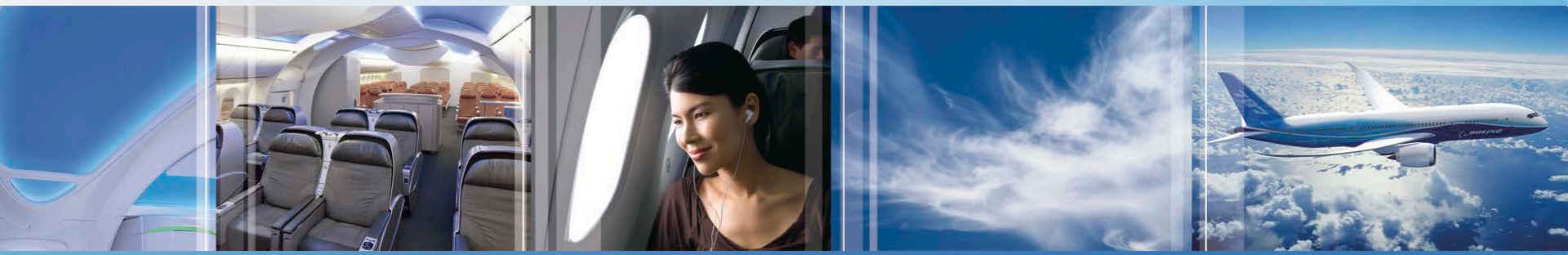


Smart Testing

Boeing Commercial Airplane
17 September 2015

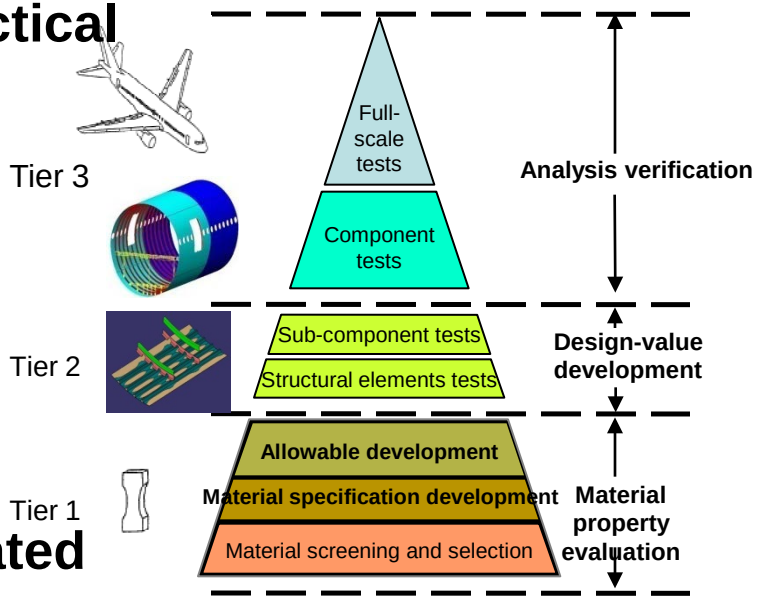
FAA/Bombardier/TCCA/EASA/Industry
Composite Transport Damage
Tolerance and Maintenance Workshop

What is Smarter Testing?

- **Leveraging Analysis**
  - **Integrated analysis and test**
  - **New tools and capabilities**
  - **Reduced testing**
- **Optimizing and Integration of Testing**
  - **Elements, sub-components, components, full scale**
  - **Efficient use of large scale components and full scale test**
- **Addressing Unique Issues**
  - **Environment effects**
  - **Hybrid structure**
- **Regulatory Acceptance**
  - **Guidance material**

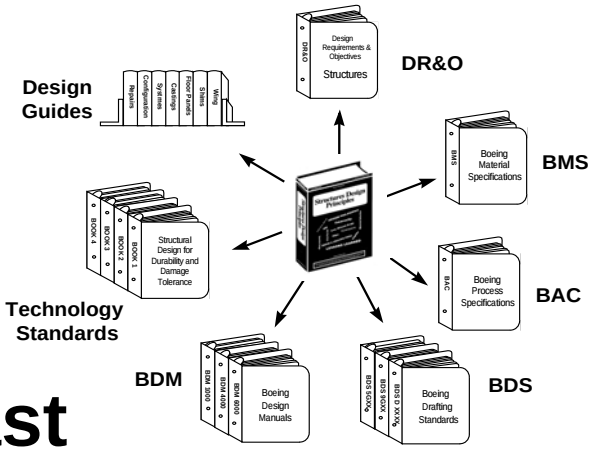
Structural Validation

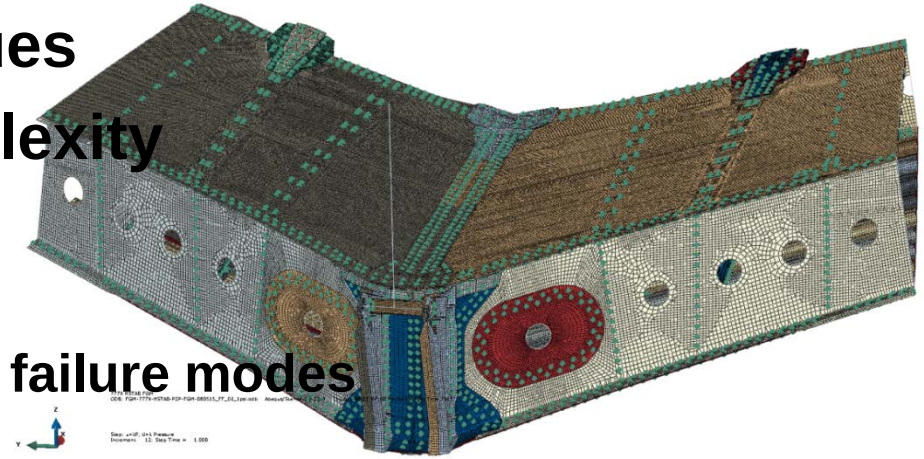
- **Analysis, supported by test evidence, is the primary means of compliance**
- **Engineering is limited in the number of tests that can be performed**
  - **Resources, budget and time form a practical limit**
- **Identify critical details/issues**
  - **Select or develop analytical approach**
  - **Determine need for test data**
  - **Develop plan to validate new analytical methods**
  - **The plan should include analysis integrated into the development of the test article (configuration), loading, boundary conditions, predicted failure modes**



Analysis Tools

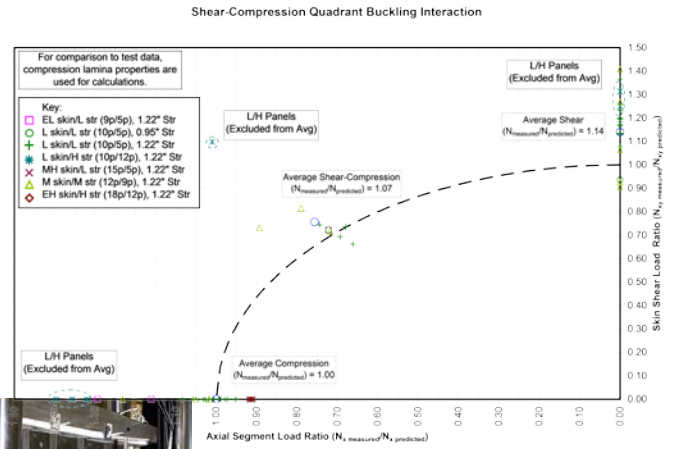
- **Historical analysis methods**
  - **Accepted classical methods**
  - **Previously validated methods**
- **Increasing use of FEA integrated with classical analysis over the last 50 years**
  - **Increasing number of validated FEA applications and techniques**
  - **Increasing levels of complexity**
    - **Non-linearity**
    - **Interaction of components**
    - **Complex multiple interacting failure modes**

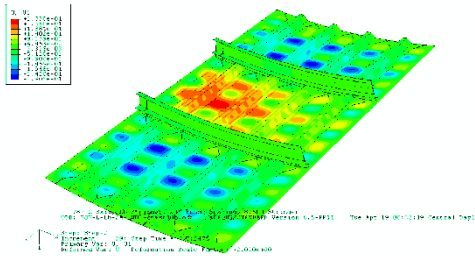


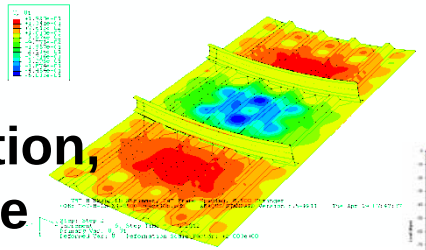


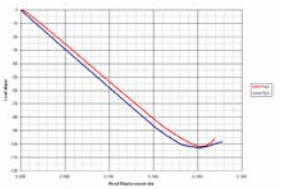
Smart Testing – Leveraging Analysis

- **Test what is needed to anchor or validate the analysis method**
- **Leverage analysis methods to interpolate and to extrapolate (where rational).**
  - **Analysis can be classical, methods developed with the assistance of FEA or purely FEA based.**
  - **Minimize number of test articles needed**
- **Utilize analysis to ensure test is configured correctly to achieve desired goals**
  - **Boundary conditions, article configuration, loading methods, expected failure mode**
  - **Ensure test achieves desired results**



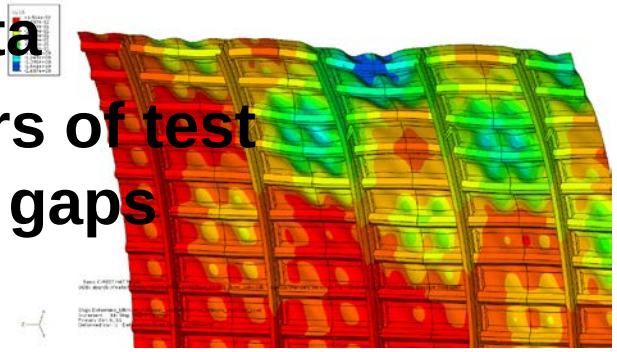


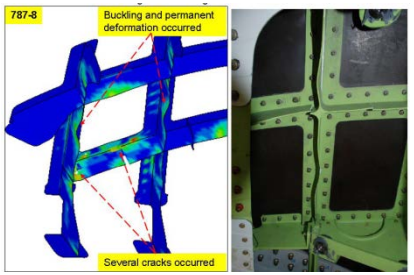




Leveraging Analysis – Reduced Testing

- **Boeing developing a greater acceptance of FEA for general application enhancing test data**
- **Opportunity to reduce general numbers of test specimens with FEA helping to fill the gaps**
  - **Address variations in configuration**
  - **Variations in loading**
- **Validated FEA can significantly reduce or eliminate repetitive complex larger scale testing**
  - **Fuselage General Instability**
  - **Birdstrike**
  - **Tire tread impact**
  - **Crashworthiness**



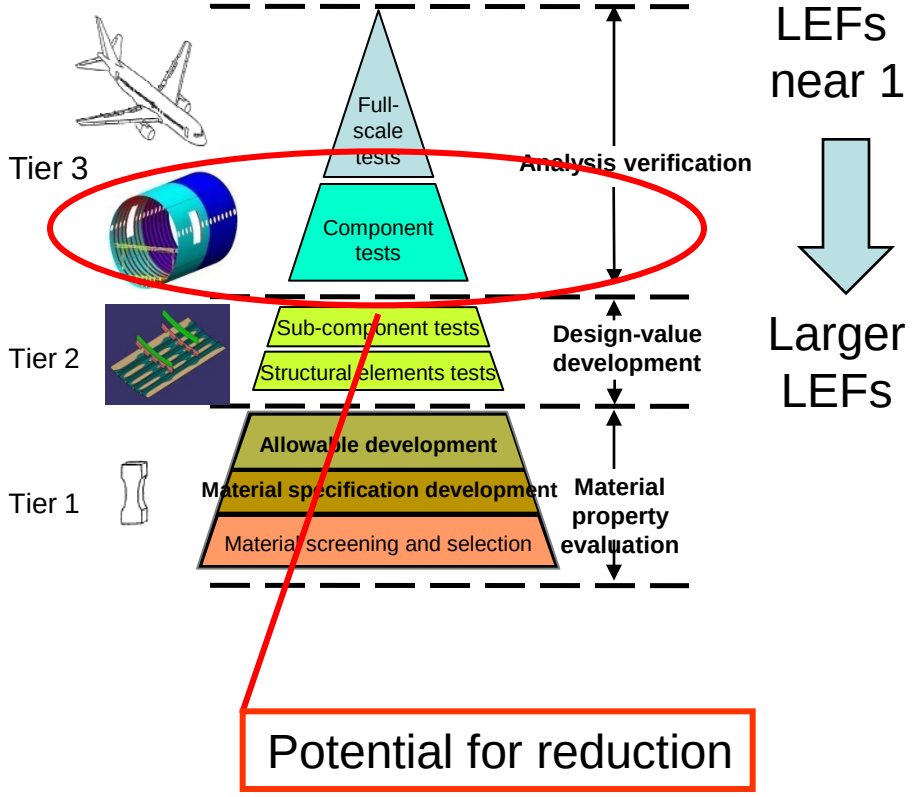


Optimized Testing

- **Current Approach – Hybrid Structure**
  - **LEFs are used on Component and lower scale testing**
    - **Fatigue spectrum is derived for CFRP structure**
    - **Testing typically includes subcomponent tests representative of the design details and incorporating manufacturing flaws and impact damage**
    - **Component level tests (wing box for example) are a final validation of the no-growth approach and usually include impact damage (BVID, VID, Discrete Source) and repairs**
  - **No LEFs on full scale airplane fatigue test**
    - **Full scale airplane fatigue tests run a typical metallic fatigue spectrum**
    - **Purpose is to understand metallic fatigue and in some cases metallic damage tolerance**

Optimized Testing – Alternate Approach

- **Use LEFs on lower scale testing with emphasis on interlaminar failure modes and bolted joints (details with typically higher LEFs)**
- **Preproduction article not required (in regards to LEF) as experience is gained with composite materials and assemblies**
  - **Representative full scale details in lower level testing**
- **Full Scale article can use LEFs for in-plane modes (which are nearer to 1.0) for final validation, which has little affect on hybrid structure in general and WFD**
  - **Supports showing of compliance for 14CFR 25.571**



Unique Issues - Thermal Effects

- **Difficult to address thermal stresses with load factors**
  - **Very difficult to apply to discrete parts depending on scale of test**
  - **Effect is unique from part to part**
- **Thermal stresses driven by local CTE differences act as a hardpoint which can not be simulated by increases in external loads**
  - **More than just composites issue**
- **Global thermal loads are also difficult to simulate with overload factors as they are critical in localized areas and can decrease loads in areas where thermal loads are not allowed to relieve**
- **Thermal effects are accounted for by analysis**
  - **Requires separate validation effort**

Unique Issues - Hybrid Structure

- **Combining Metallic and Composite test objectives for hybrid structure must consider the following:**
  - **Unique CFRP test spectrum requires specific analysis to determine viability on metallic parts and to identify critical parts that may fail pre-maturely.**
    - **Only minor truncation for the low stresses are allowed for the hybrid test due to metallic details**
  - **High magnitude survey loads early in the fatigue test can alter the performance of the metallic parts potentially invalidating any results. Loads near limit load are generally not accepted before or during fatigue cycling metallic details.**
    - **Even the addition of the A+ and A++ flights used in composite fatigue spectrums need to be understood in relation to metallic fatigue performance.**
  - **No detrimental damage approach and residual strength evaluation may require impacting the composite structure for BVID, VID and DSD damage states. The VID and DSD damage can create significant load redistribution altering the behavior of metallic parts.**

Unique Issues - Hybrid Structure

- **Combining Metallic and Composite test objectives for hybrid structure must consider the following (con't):**
  - **The idea of not applying LEFs to peak loads in a fatigue spectrum and using life instead is valid for the few peak loads, the time penalty is minor. This has been done before. Avoids yielding metallic crack tip as well.**
  - **Testing with a single article requires all objectives to be addressed in a serial manner. Risk to test down time extends test duration. Down time of test increases as test life increases.**
  - **Metallic parts are efficiently sized for the intended mission. Extended testing is expected to lead to fatigue failures. Repeated failures require repair or replacement and test stoppage. This adds significant time and cost to the test, eroding potential savings from a single test article.**
  - **Compliance to WFD requires a tear down and often destructive evaluation of critical metallic details. Continued testing at higher LEFs can damage test evidence.**

Closing Remarks

- **Current regulations and guidance material support smarter more efficient testing**
- **Current analysis tools and development pace of FEA is providing greater opportunities for integration of test and analysis**
- **Important to leverage validated analysis to minimize testing requirements**
- **Important to optimize the test program to include LEF, environment etc. at appropriate level**
  - **Maximize useful data for large component and full scale testing**
  - **Potential to reduce or eliminate large components**