Breakout Session on Substantiation of Structural Damage Tolerance

The following charts document the results of a session conducted at the July 2006 FAA Composite Damage Tolerance & Maintenance Workshop.

The basic charts were prepared in advance of the session to facilitate brainstorming and discussion, and the text and/or slides highlighted in red represent comments and feedback provided by workshop participants during the session.

Breakout Session on Substantiation of Structural Damage Tolerance

Primary objective: Address safety concerns & technical issues for substantiation of structural damage tolerance

Secondary objectives

1. Discuss design criteria
2. Discuss engineering practices used for substantiation
3. Discuss elements of safety management needed for selection of design criteria and engineering practices
4. Identify needs for regulatory requirements & guidance
5. Identify needs for standards (guidelines, databases and tests)
6. Provide directions for research and training development

Categories of damage

- Discussion of the types
  - Category 1: Allowable damage that may go undetected
  - Category 2: Damage detected by field inspection
  - Category 3: Obvious damage detected within a few flights
  - Category 4: Discrete source damage known to pilot
  - Category 5: Severe damage created by anomalous ground or flight events (not covered by design substantiation)
- Safety concern: if the associated technical issues for a given category of damage are not covered by current industry practices
- Other discussion points (as time allows)
  - Damage threat assessments
  - Structural design construction

Safety Concerns for Categories of Damage

- **Role of Fail-safety** with regard to damage tolerance – where does category 5 fit? Covered by category 3? Relates to definition of category 3
- **Feedback loop if damage occurs that is category 5** – need to either a) change criteria (make it a 2, 3, or 4) or b) change maintenance/operations practices, training
- Example of runway asphalt damage to horizontal stabilizer structure that was not completely inspected and repaired shows weak safety net (i.e., incomplete disposition of a rogue event).
- **Rely on category 4 damage to provide robustness** and some level of "fail-safety" – covers for categories 3 and 5
- **Legacy design criteria get lost?** Changing existing practices as new technologies are introduced can move damage threats from category 4 to category 5. Is experience from one application applicable to new/other composite designs?

Safety Concerns for Categories of Damage

- Implications on damage growth, including environmental degradation
- Design criteria relationship with loads and flight envelope? Need to have feedback loop to design? Should operators and load excursions beyond design drive design criteria?
- Rotorcraft example of change in mission, patterns of operation – should OEMs include in feedback loop?
- **Don't forget existing and/or non-PSE applications**. Expanding applications vs. damage/degradation of control surfaces leading to flutter/stiffness issues.
- Category 5 is used as "crutch" by saying that the design was not intended to cover it. Feedback to design is needed when there is significant service experience to show that the damage/issue is not covered by the design.

Safety Concerns for Categories of Damage

- **How much conservatism** are we piling up given the lack of real data on damage threats and POD? e.g., overlapping assumptions regarding material variability and damage threats. Also, are the same assumptions applicable across components? e.g., lug protected by bushing vs. leading edges. How do we **define equivalent reliability**?
- Need to relate damage tolerance requirements to realistic damage threats. Link to existing data including metal airplane experience.
- Each category should drive a design activity. Where does category 5 fit in the design world?

Safety Concerns for Categories of Damage

- Category 5 represents damage/manufacturing events that are outside of design considerations. **Category 5 does not drive stress analysis – relates more to feedback loop, training –** what can we do as a design community to address this type of damage?
- Category 5 damage may involve visual damage to one component that leads to non-visual damage to connected structure.
- Don't need to design to category 5 damage from day one – need to make sure the feedback loop is there and that maintenance and operations practices address it. For example, special directed inspections are needed for category 5 damage just as is the case when you get into an automobile accident.

Safety Concerns for Categories of Damage

- Category 5 is analogous to “battle damage” in that it may be outside of the design criteria and puts the responsibility of the response on the operator.
- **Feedback loop and visibility of in-service issues within OEMs is not always complete –** relates to the safety net and where design issues may fall through (not all engineers have experience and exposure to liaison activities, etc…)
- **If category 3 is covered by category 4, do we really understand growth behavior of category 3?**
- Do we apply category 4 everywhere? Need more definition of category 3 and where it should be considered.

Safety Concerns for Categories of Damage

- **The point of category 3 is that damage that takes you close to limit load needs to be found much sooner than damage just above BVID**.
- **Assume that all PSE structures have fail-safety** (multiple load paths), relates also to discrete source damage. Covered for ground events, etc… Safety net is built-in. Need to be careful not to let go of this approach as we move away from metal design practices.
- Maintenance operations and training are key to addressing other categories 3, 4, and 5.
- Implications of post-buckling – complicates things – may have damage growth implications. Matter of load redistribution – should be handled through analysis.

Discussions on Substantiation of Structural Damage Tolerance

- Other safety concerns (not addressed in the discussion on previous charts for categories of damage)
  - **Effects of repeated heating?** Multiple repairs in one location. How will material react? There are limits in the SRM with regard to multiple repairs, location limits. Design for material to be a certain amount below the Tg. Consider multiple cure cycles. Possible stiffness concern.
  - **Hybrid metal-composite structures** – more complicated than individual materials alone.
  - Should consider implications of failure for non-PSEs. **Criticality of failure and combinations of failures** (systems + structural), flutter and stability are often concerns (damage causing flutter).

Discussions on Substantiation of Structural Damage Tolerance

- Other safety concerns (not addressed in the discussion on previous charts for categories of damage)
  - **Reliability of material & process specifications**. If you deem specs are good then it becomes a QC issue. e.g., bonded joints – may deem that the joint is good (via spec) but what consideration should be made to process anomalies, inclusions, etc… These potential process breakdowns could potentially be far more serious (with regard to load capability) than errors in design and analysis

Discussions on Substantiation of Structural Damage Tolerance

- Present practices & associated challenges
  - Optimization of composite structures for performance BUT always **need to consider repairability**. Tension between the two. Difficult repairs more susceptible to error.
  - **Rationale definition of Inspection intervals with no-growth approach.** How are these defined (based on structure life divided by 'x'?) or better related to the structural performance.
  - **Structural health monitoring**. Sensors to drive inspections? If so, does this imply we can design to higher allowables.

Discussions on Substantiation of Structural Damage Tolerance

- Technical "Gaps"
  - Load history effects on damage growth. Historical experience with damaged fatigue curve shapes – how will these hold up as we move to new designs and applications.
  - Ability to predict failures of structures with damage, analysis methods are needed for making predictions under multi-axial loading. How well do we apply our uniaxial data to complex loading (predictions)
  - Components are normally not sized with uniaxial load – complex load conditions should be considered. Try and consider this at lower building block level?
  - Scale-up effects – ability of analysis to make predictions for damaged strength based on BVID coupons
  - Fail-safety issue is important – emphasized by "grey beards" but possibly getting lost as we apply new design practices for composites

Discussions on Substantiation of Structural Damage Tolerance

- Regulation needs (missing rules & guidance) – and further clarification of damage categories
  - **Category 3 damage - load requirements other than limit???** Potentially could depend on structure - something between continued safe flight and limit load???
  - How can we ensure damage near LIMIT is found quickly?
  - Dependency of categories of damage on the application and criticality?
  - **Ultimate vs. Limit 1.5 factor**. Consider Airbus practice of k*LL (k is between 1 and 1.5). In some cases a load more than LL is used depending on how long damage will exist and what loads are expected to occur during that interval (probabilistic approach).

Discussions on Substantiation of Structural Damage Tolerance

- Urgent issues for next workshop

Discussion on Damage Threat Assessments

- Accidental impact damage resistance (analysis role)
  - Low energy blunt impact of sandwich construction
  - Visibility of high-energy blunt impact of heavy structure.
- Extreme temperature, moisture & chemical resistance
  - Time-related, aviation fluid contaminated degradation of bonded joints
- Growth potential (+ when to use "growth" vs. "no-growth")
  - Growth of Category 3 damage?
- Detection (operations vs. maintenance) & characterization
  - Operations detection of significant damage
- Residual strength
- Structural testing & analyses *(scatter, scale-up, assemblies)*
  - Future analysis needs? estimates, interpolation, detail strength, DT, fatigue

Did not get to this chart during breakout session

Discussion on Effects of Design Construction
(Damage threats, design criteria and substantiation)

- Experience with sandwich concepts
- Experience with stiffened-skin concepts
- Experience with secondary bonding
- Substantiation of LEF used for large-scale tests
- Advanced material forms & manufacturing methods

Did not get to this chart during breakout session