Probabilistic Approaches

Boeing Commercial Airplane

17 September 2015

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

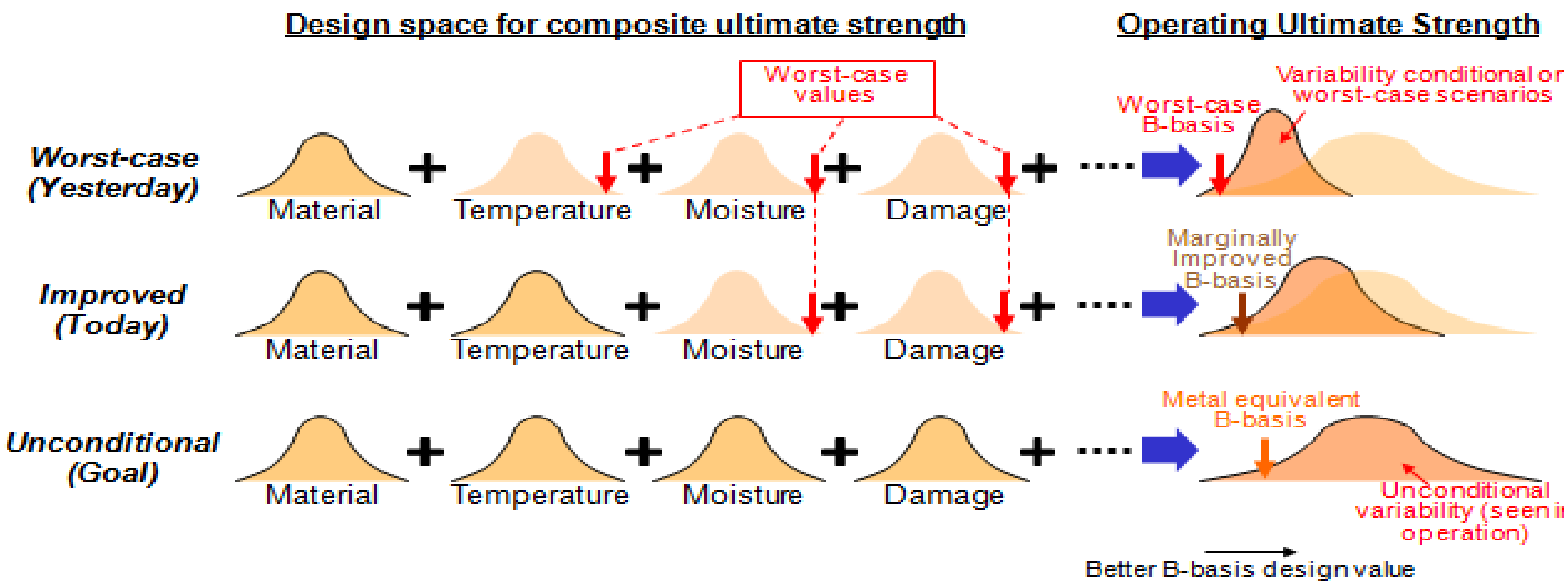
Probabilistic Approaches

- **Agenda**
  - **Moving Toward a Metals Equivalent B-basis**
  - **Probabilistics used for Structural Temperatures**
  - **Probabilistics Proposed for Moisture Content**
  - **Probability of Detection, Energy Levels and Inspection Intervals**
  - **Can we Determine Limit and Ultimate Load Probabilities**
  - **Tire Impact – Using Probabilities to Delay Full Inspection**
  - **Probabilistics and other Impact Threats**

Probabilistic Approaches

Temperature and Moisture, First Studies Towards a Probabilistic Approach

Toward Metal Equivalent B-basis



Design Criterion: *At least as safe as metal (i.e., Metal equivalent B-basis)*

*Metal equivalent B-basis: In general for metal static strength design, compression strength variability in operation is **unconditional** on environments, damage, etc.*

Probabilistic Approaches

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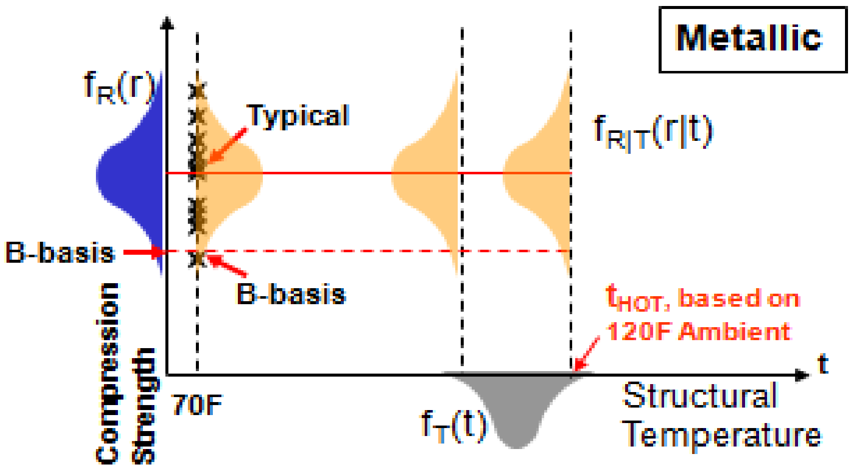
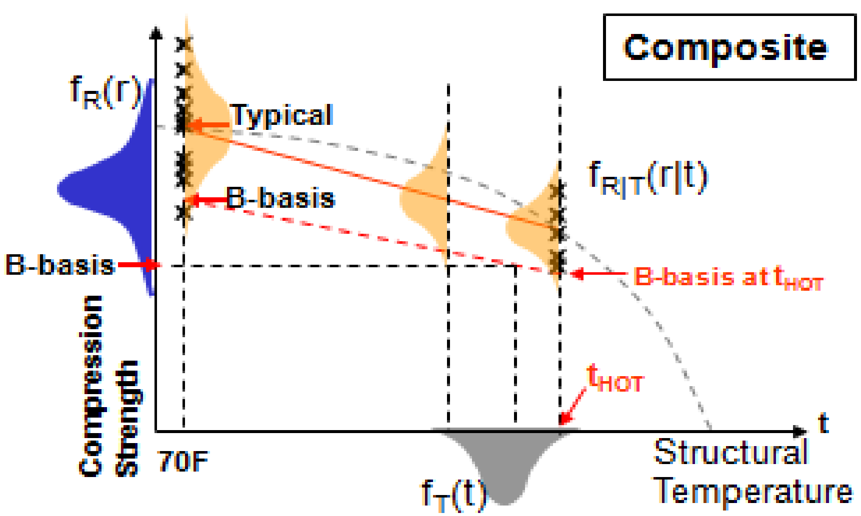
Effect of Temperature Variability on Design Values



- In general, strength variability insensitive to temperature.
- Expected operating strength variability $f_R(r)$ = weighted average of conditional strength variability $f_{R|T}(r|t)$ w.r.t. $f_T(t)$.
- Expected operating strength variability unchanged, same as the variability at any given temperature.
- Same B-basis design value (at 90% reliability) at 70F and t_{HOT}.



- Strength variability sensitive to temperature.
- Linear approximation of strength degradation.
- Expected operating strength variability differen from the variability at any given temperature.
- Design to B-basis at t_{HOT} renders a reliability greater than 99.9% (= 90% only when operating at temperature t_{HOT}).
- Using expected operating strength variability to design to same reliability as for metal.

Probabilistic Approaches - Temperature

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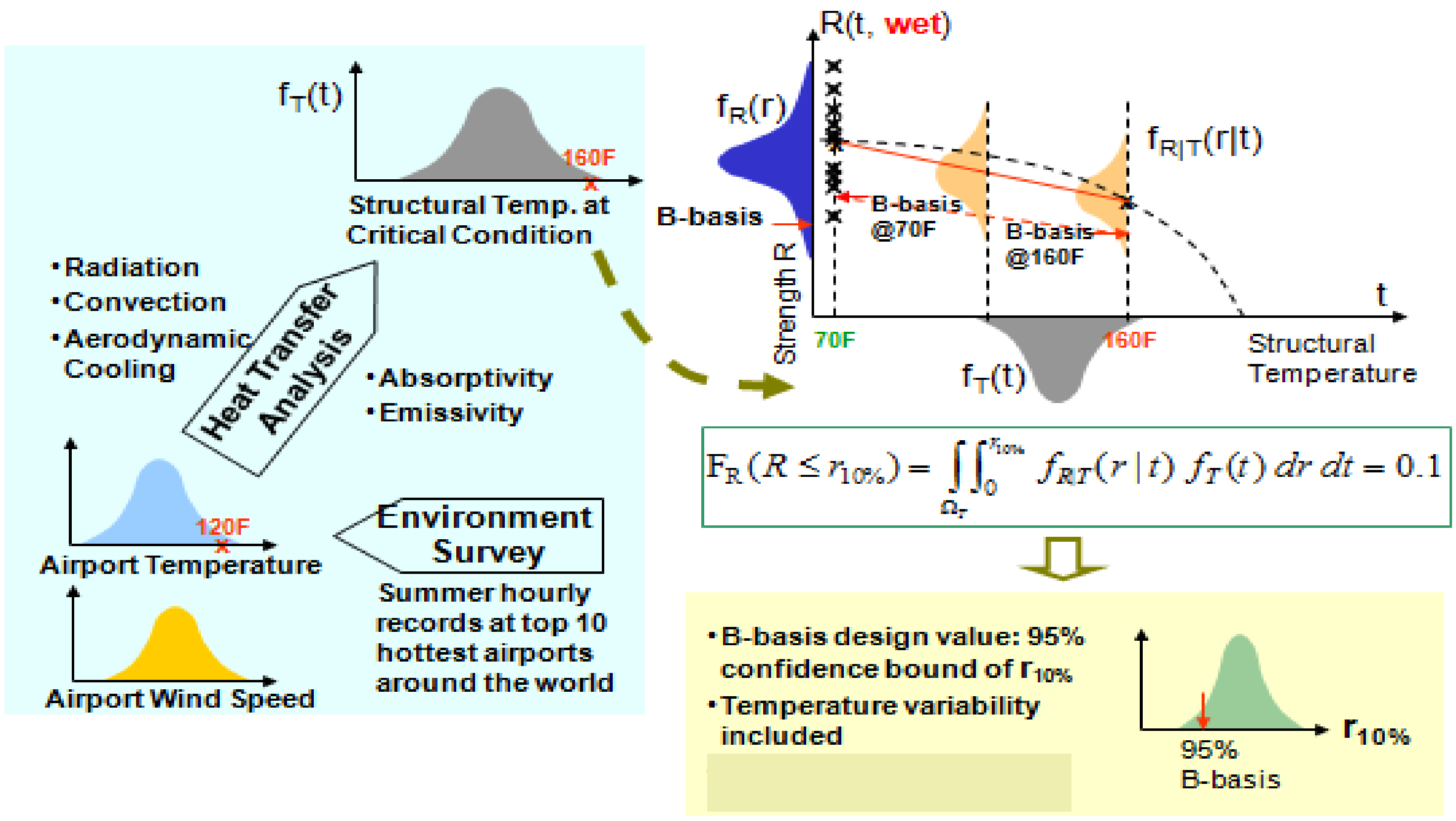
Temperature and Moisture, First Studies Towards a Probabilistic Approach

Phase I: Reliability-Based Design Temperature Knockdown



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Probabilistic Approaches - Temperature

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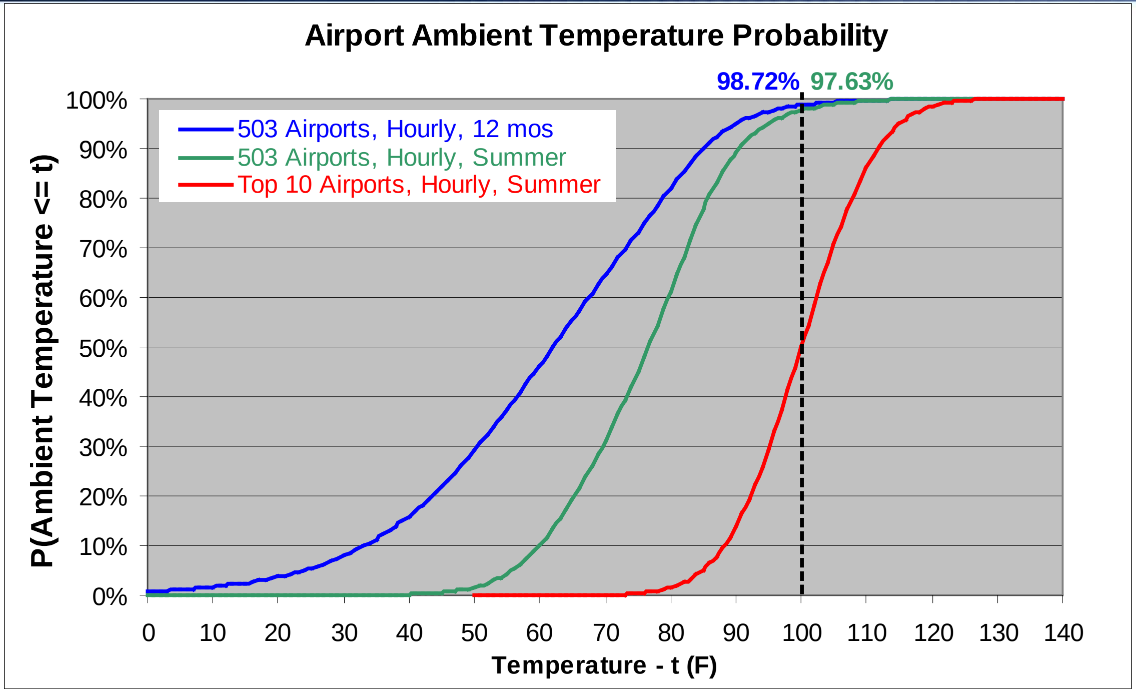
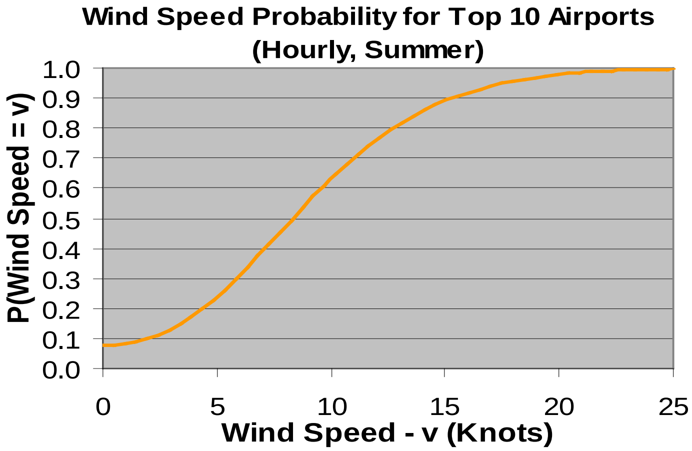


Airport Temperatures and Wind Speeds Considered



Probabilistic Approaches - Temperature

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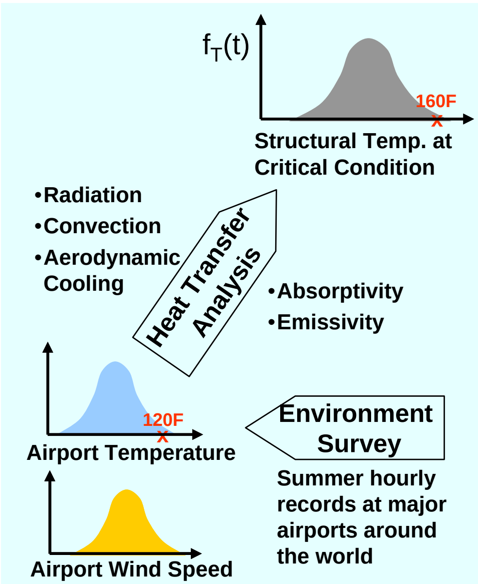
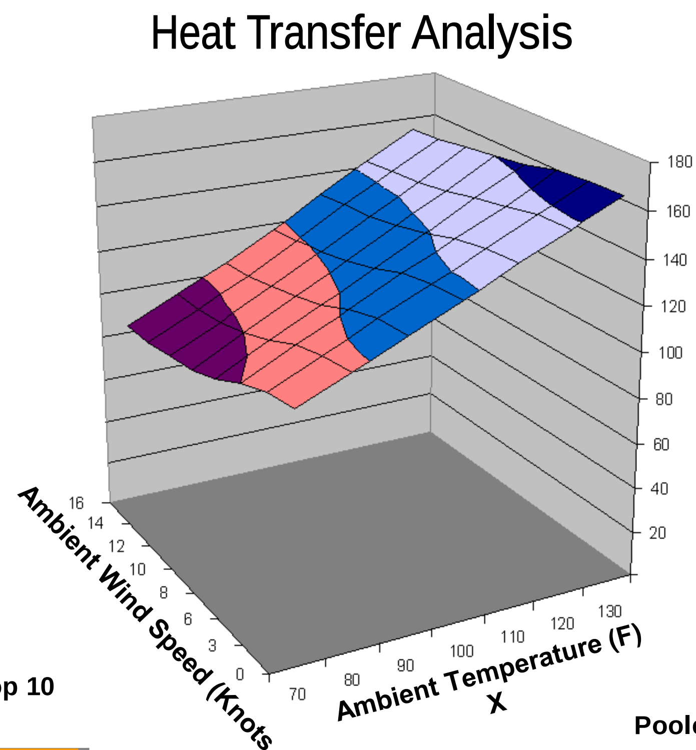
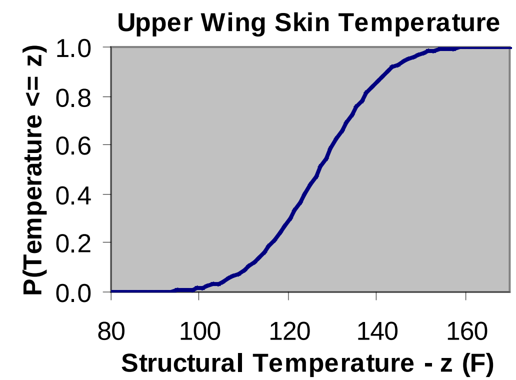
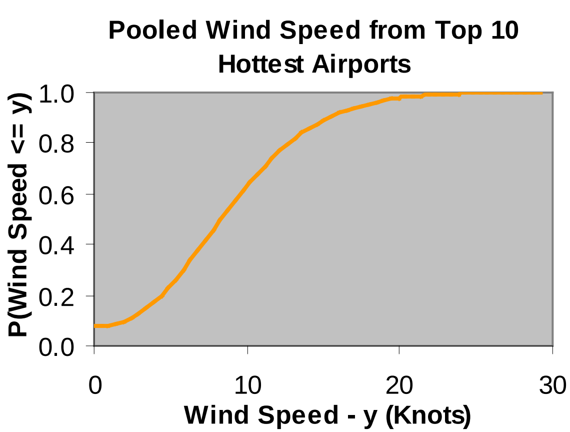
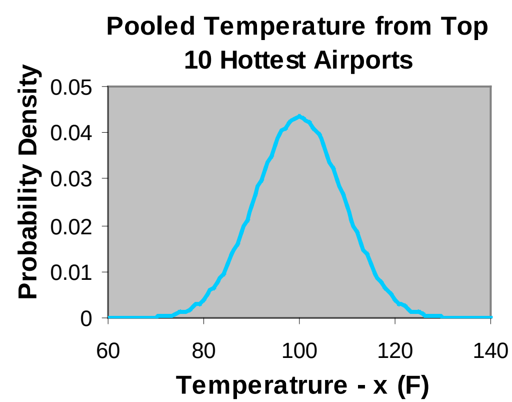




- **Probability integration or Monte Carlo simulations**







Probabilistic Approaches - Moisture

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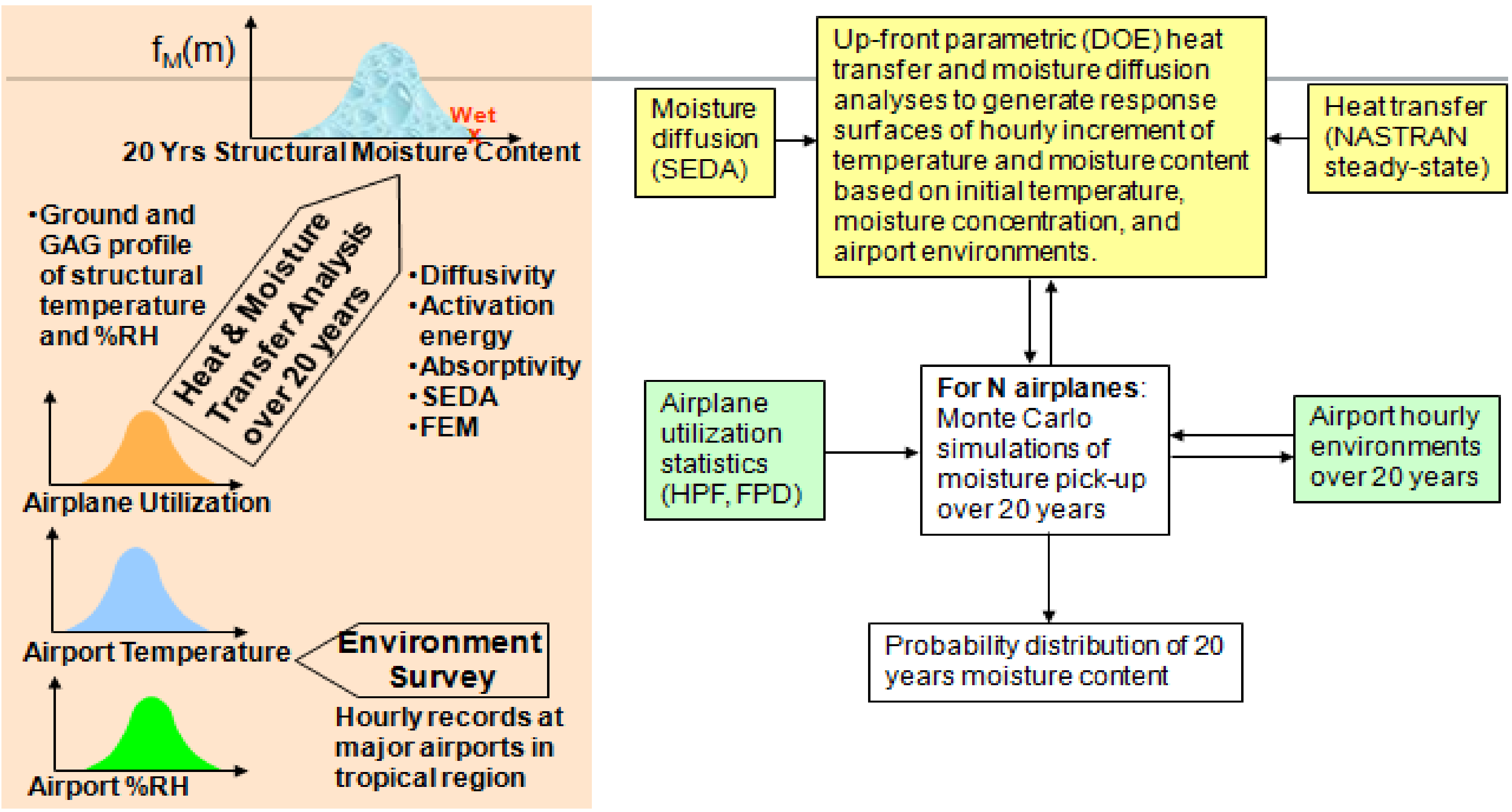
Temperature and Moisture, First Studies Towards a Probabilistic Approach

Probabilistic Approach: Lifetime (20 Yrs) Moisture Content Simulation



Probabilistic Approaches - Moisture

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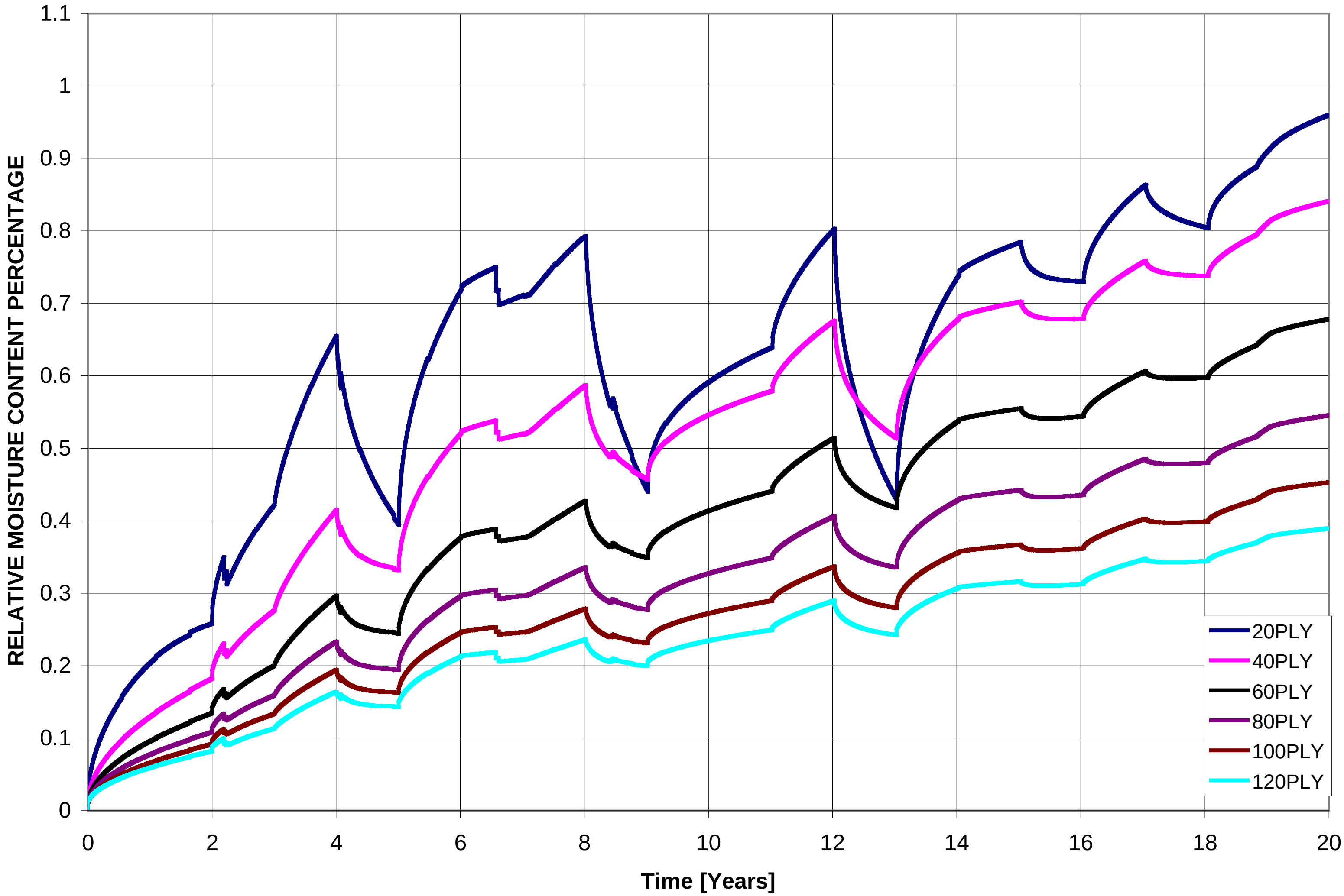
- **Total Moisture Content over 20-year Service Life:**



Probabilistic Approaches - Impacts

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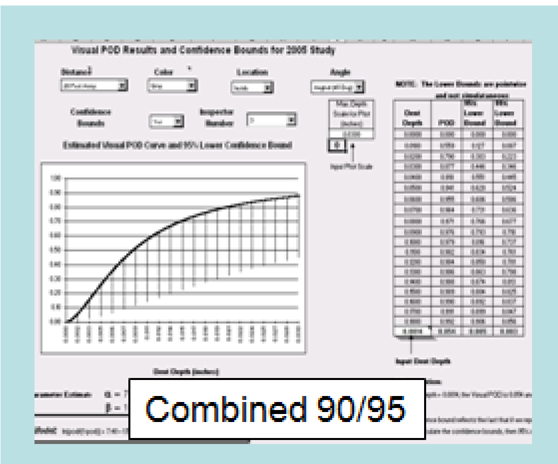
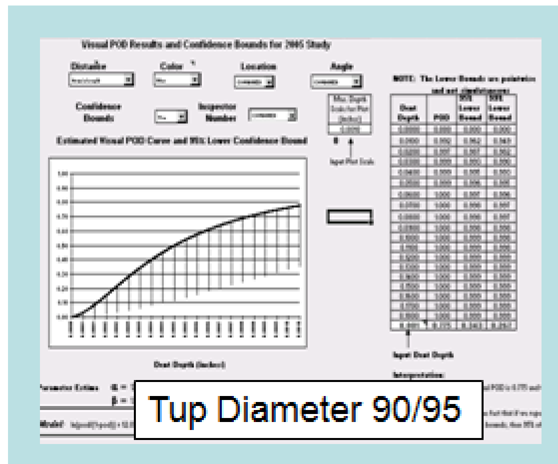
Probability of Detection, Energy Levels and Inspection Intervals

POD Results





Dent Geometry

Angle and Depth

Color

Surface Texture

Distance

Probability of Detection Linked to Inspection Interval is Similar to Metallic Approach

Energy Level Based on Threat and Location is Derived. Manufacturing Flaws may also be Accounted for

Probabilistic Approaches - Loads

Can we Determine Limit and Ultimate Load Probabilities

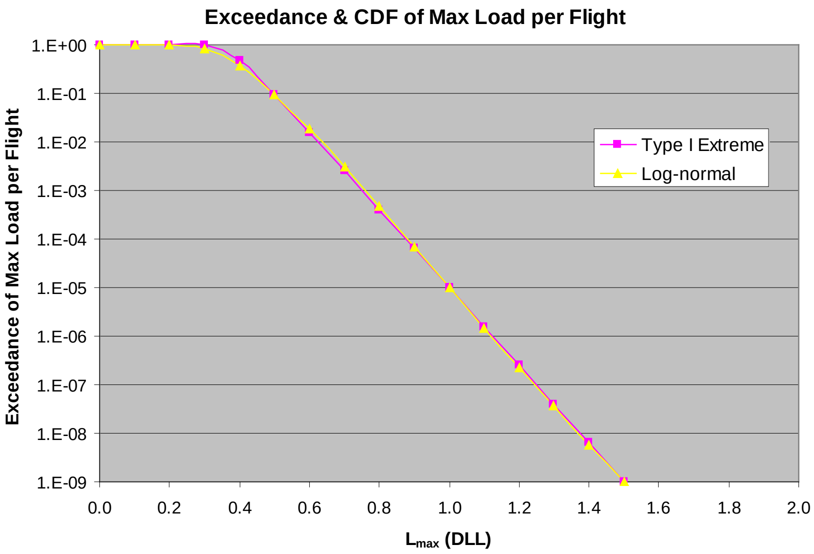
- Loads may be the difficult part as the probabilities have not been calculated for all load cases at limit load levels
- How the various structural details react to the loads is different depending on whether it's a flap or a vertical stabilizer for example
- Has to be handled like exceedance curves for fatigue evaluation but taken to limit load

Probabilistic Approaches - Loads

- Exceedance of max load per flight L_{max}

$$E(L_{\max} > s) = 1 - P(L_{\max} \le s)$$

$$\text{Let } E(L_{\max} > s) = \begin{cases} 10^{-5} & \text{at } L_{\max} = DLL \\ 10^{-9} & \text{at } L_{\max} = 1.5\,DLL \end{cases}$$



- $P(L_{max} \leq s)$ can be approximated by a *Lognormal* distribution

$$f_{L_{\max}}(s) = \frac{1}{s\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln(s) - \mu)^2}{2\sigma^2} \right] \qquad \text{(pdf)}$$

$$P(L_{\max} \le s) = \int_0^s f_{L_{\max}}(s)\, ds = \Phi\left(\frac{\ln(s) - \mu}{\sigma} \right) \qquad \text{(CDF)}$$

where $\Phi(\cdot) = CDF$ for standard normal distribution

$$\mu = -0.998\ DLL$$

$$\sigma = 0.234\ DLL$$

Probabilistic Approaches – Impact Event

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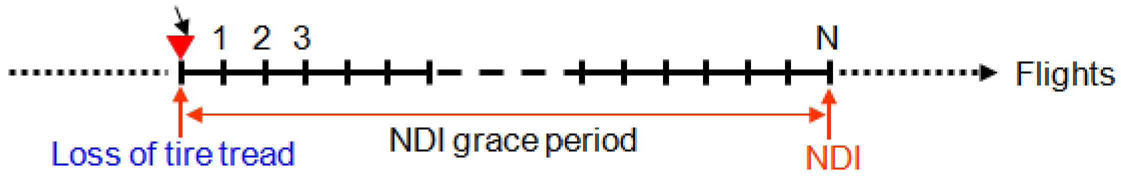
Risk of Tire Event

Probability distribution of damage after inspection



Loss of tire tread
Visual inspection

- If no tire mark -> NDI wing zonal area no later than grace period N -> repair
- Tire mark w/ visible damage -> immediate NDI -> repair

- Risk = P(Loss of tire tread ∩ Tire tread impact to PSE ∩ No tire mark with internal non-visible damage ∩ Operating load exceeds residual strength in N flights)
- Risk allowed ≤ 10^{-9} (at the end of grace period)
- Assume no additional tire loss and zero damage growth (i.e., insignificant material degradation) during the grace period.

Probabilistics and Other Impact Threats

- Barely Visible Impact Damage (Category 1): Tool Boxes, Drill Motors, Maintenance or Service Equipment, Manufacturing Environment
- Ground Hail: Removable Primary Structure and Non-removable Primary Structure
- Wheel and Tire Threats: Tire Burst, Wheel Well Over-pressure, Thrown Tread, Rim Release, Loose Tread, Flailing Tread, Brake Temps
- In-flight Hail: All Primary Structure with Exposed Frontal Area
- Lightning Strike
- Bird Impact
- Accidental Impacts ~ Detectable Damage (Category 2/3): VID (Visible Impact Damage)
- Accidental Impacts Discrete Source Damage (Category 4): Deterministically Defined, Thru-Penetration, Obvious Damage.
- Accidental Damage: Large Scale Breaching of a Pressurized Fuselage Compartment – Areas Subject to Threats from Rotating Machinery
- Accidental Damage: Large Scale Breaching of a Pressurized Fuselage Compartment – Decompression Venting