Structural Safety Substantiation Method for HUMS Usage Credits

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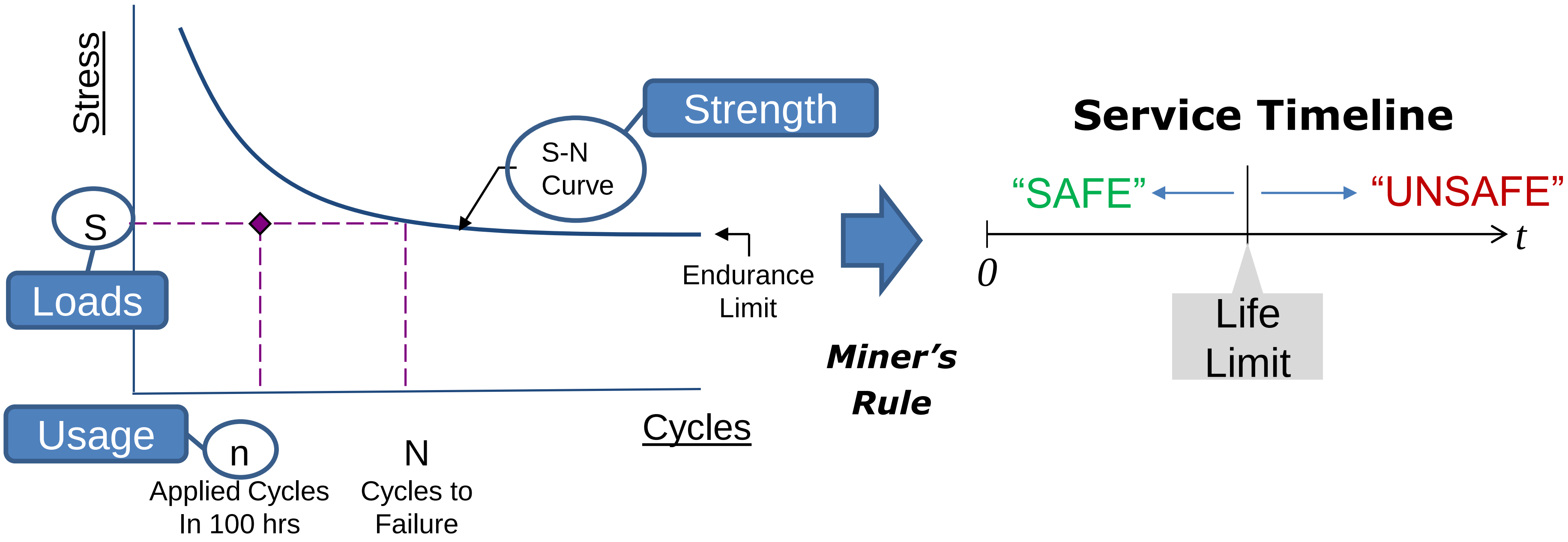
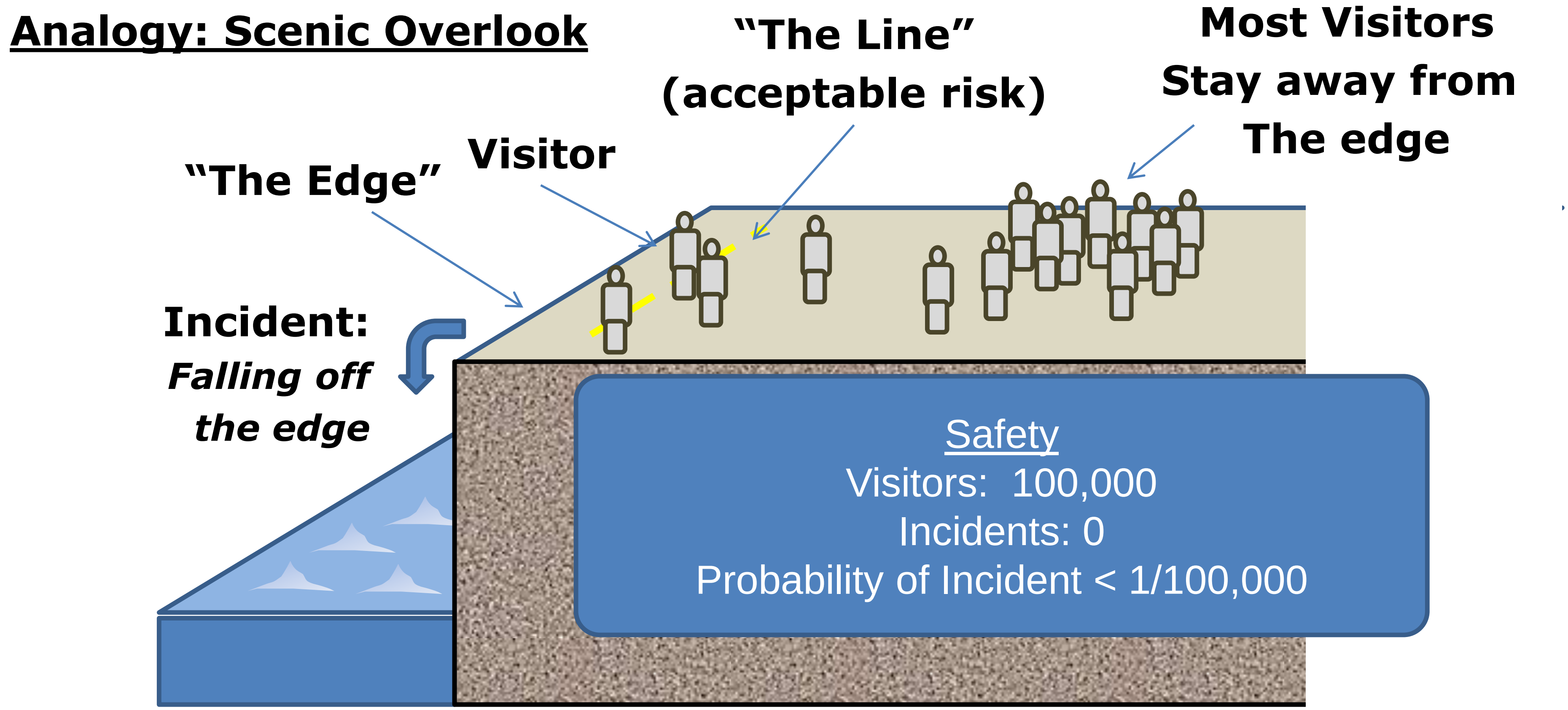
Safe Life Fatigue

- **Safe life fatigue methodology uses conservative values for strength, loads, usage**
- **70 years of history shows this approach is safe**
- **Usage credit – how do we change usage without affecting safety?**



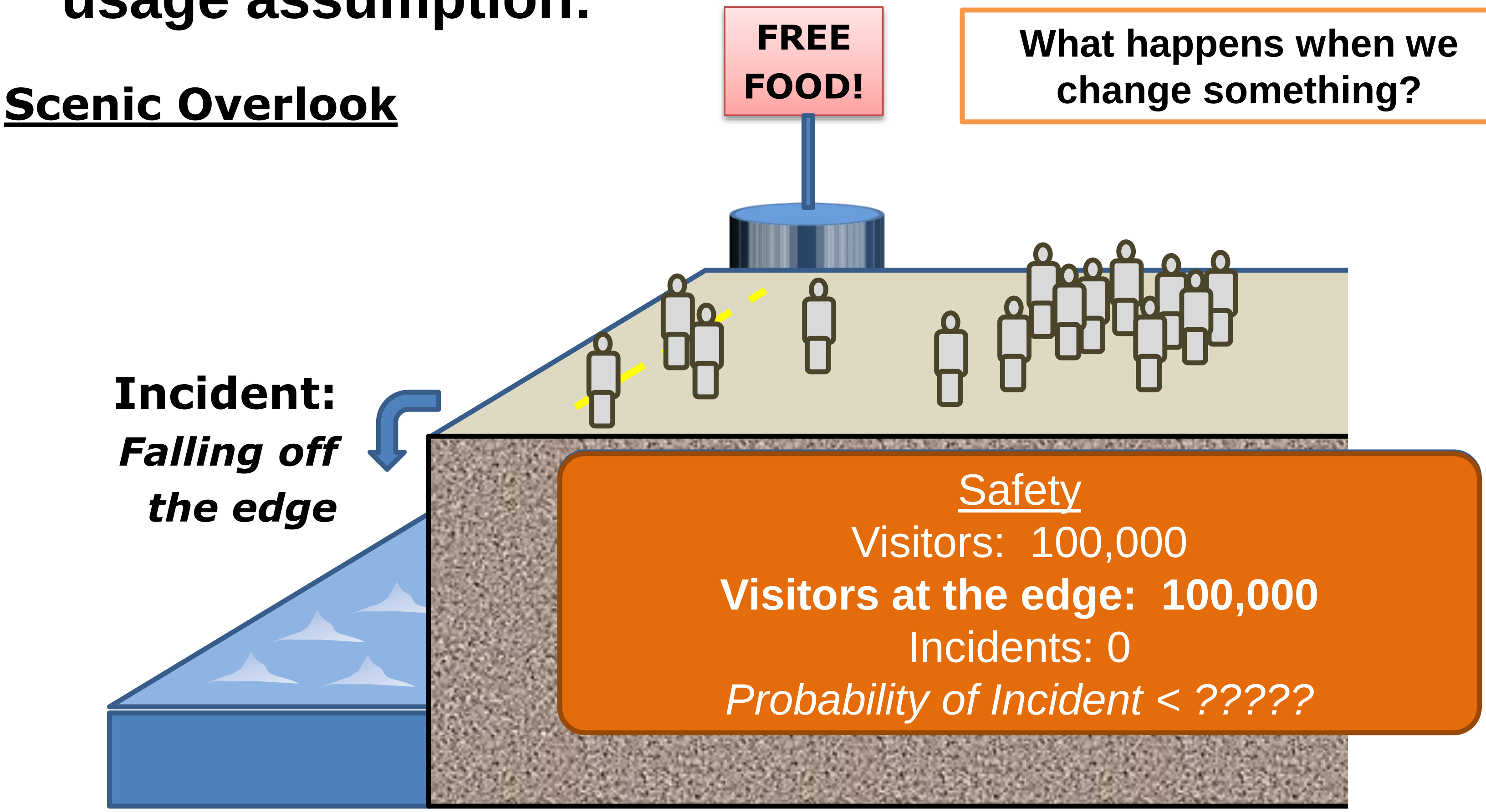
The Problem with Credit

- Some of current safety comes from conservative usage assumption



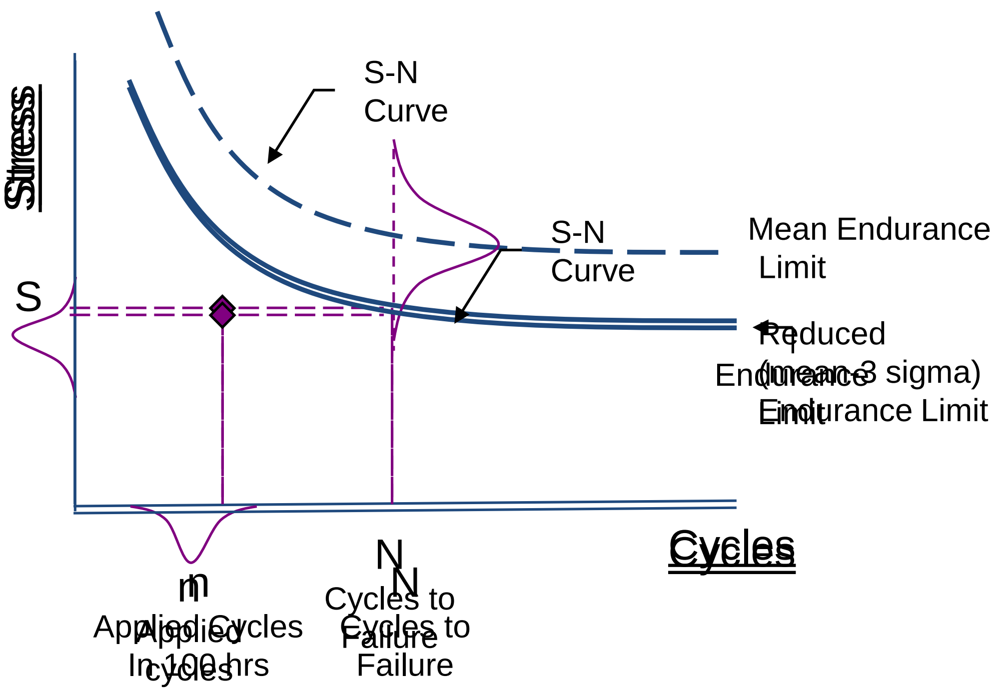
Analogy

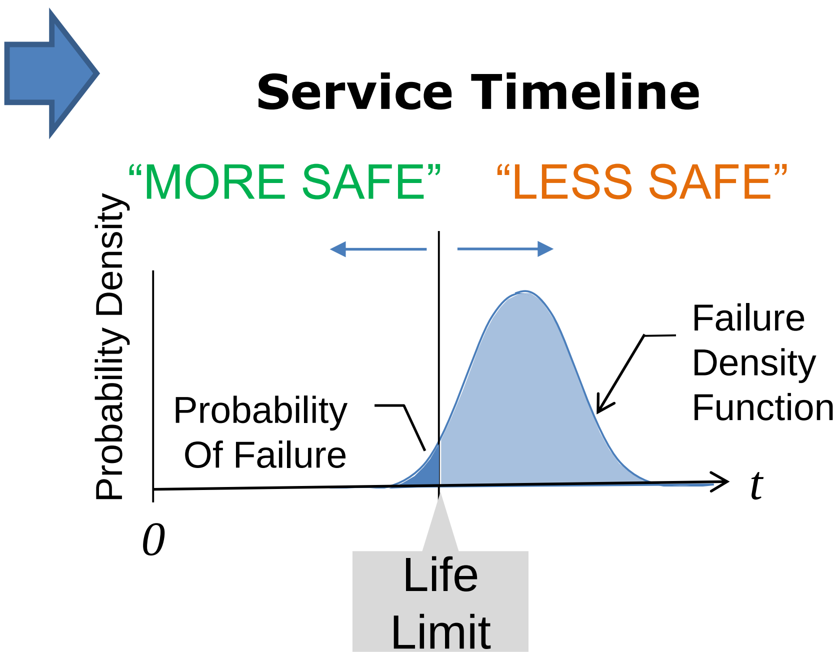
- **Some of current safety comes from conservative usage assumption:**



Structural Reliability

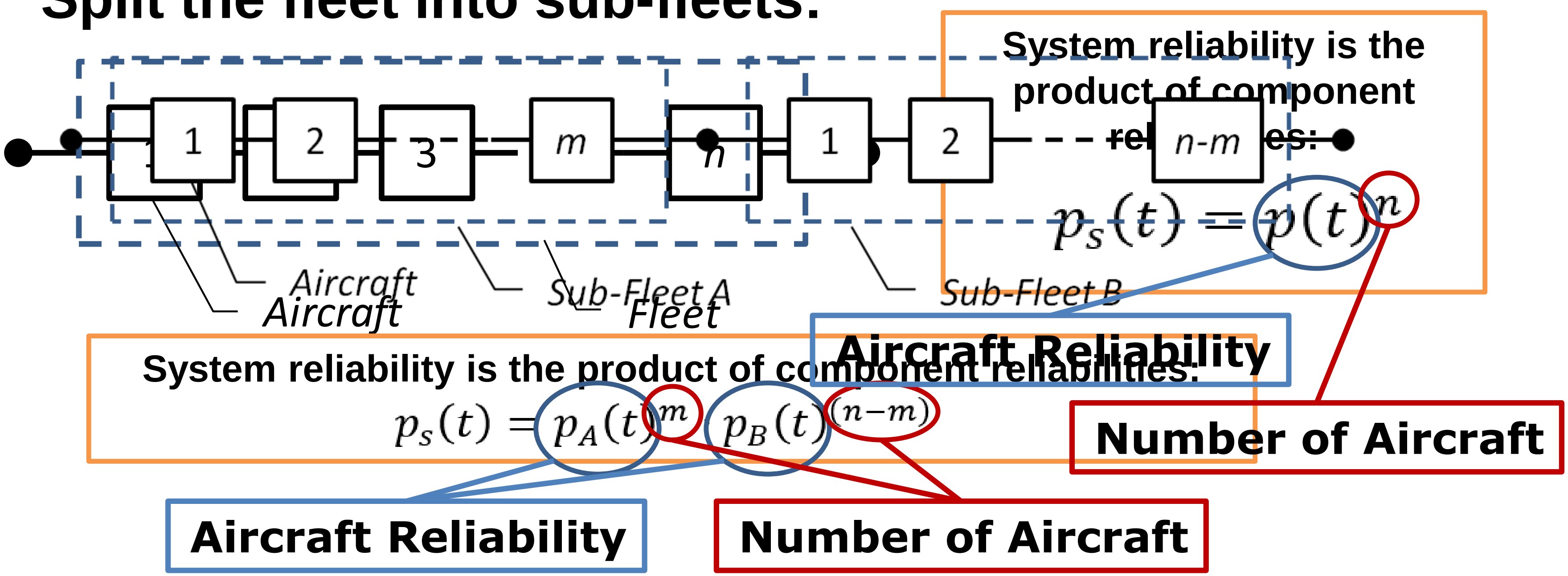
- **Probabilistic reality of fatigue**
  - Strength, load, usage have distributions
- **Result – failure density functions**
- **→ Q: How to determine impact of credit of safety?**





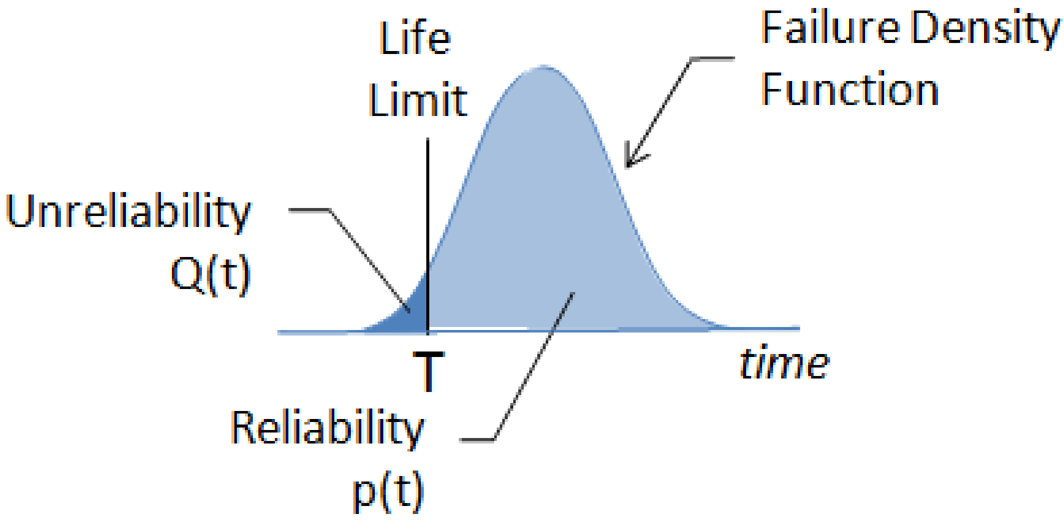
Proposed Solution – System Reliability Method

- One means to quantify the impact of credit is to look at the fleet as a system
- System reliability methods – already used in non-structural qualification
- Model the aircraft fleet as a serial system:
- Split the fleet into sub-fleets:



As Easier Way to Visualize System Reliability

- **Unreliability and Reliability**



- **Mathematical simplification of fleet reliability**
  - For very small unreliability, the unreliability of a system is the sum of the unreliability of its components.

$$p_s(t) = p(t)^n = \left(1 - Q(t)\right)^n \approx 1 - n \cdot Q(t) \;\; for\; Q(t) \ll 1$$

$$\therefore n \cdot Q(t) \approx 1 - p_s(t) = Q_S(t)$$

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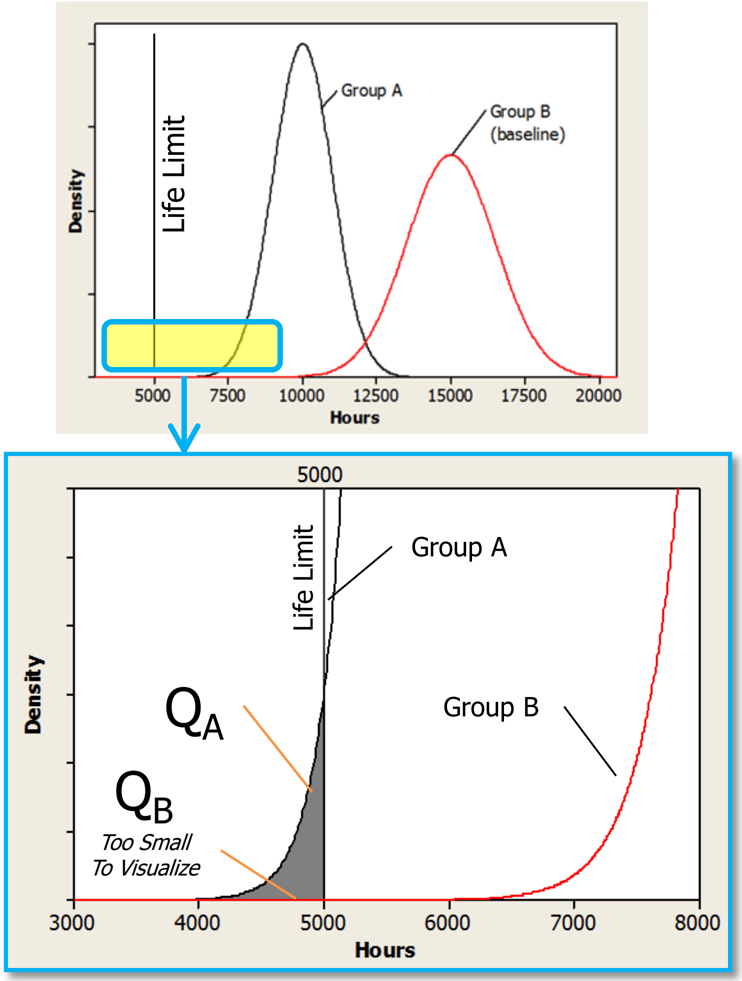
Simple Example - Baseline

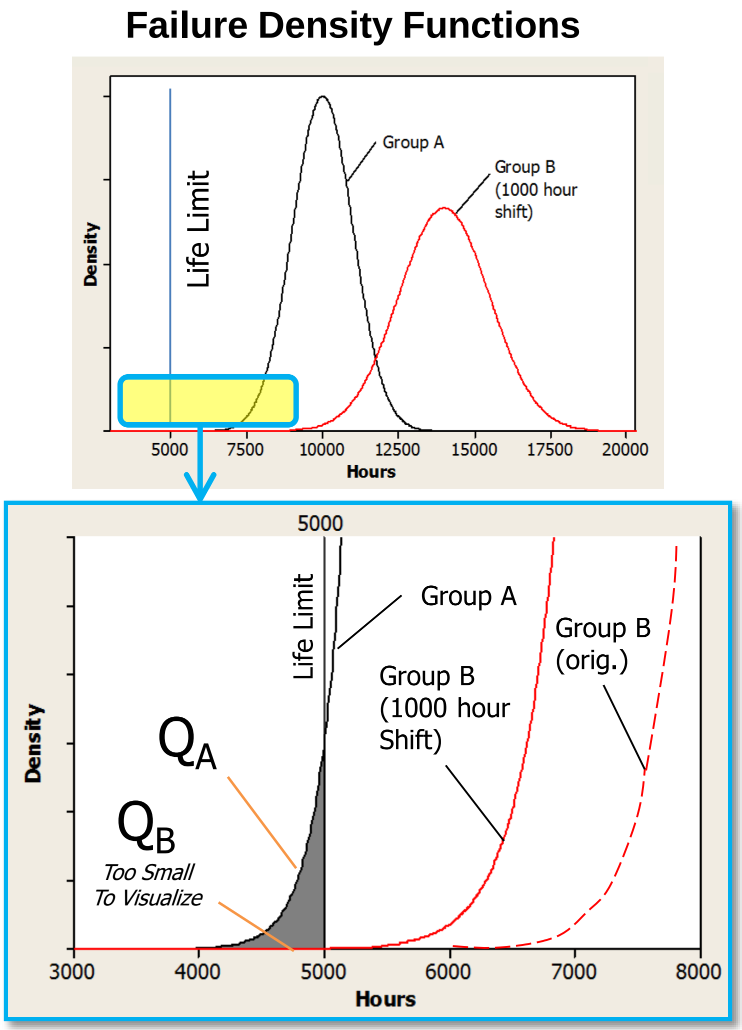
- **Assumptions:**
  - Life limit already established.
  - Failure density functions known:
    - Group A: severe usage
    - Group B: mild (benign) usage
  - Fleet breakdown:
    - Group A – 25 aircraft
    - Group B – 75 aircraft
- **Fleet unreliability:**
  - 7.2×10^{-6}
- **<u>Group A drives the fleet unreliability</u>**

Failure Density Functions



Simple Example – with credit

- **Apply usage credit of <u>1000 hours</u> to all aircraft in Group B**
  - Group B – 75 aircraft
- **Conclusions:**
  - Group A still drives fleet unreliability
  - Fleet unreliability increased by only 1%.
- **Easy to evaluate sensitivity to credit amount, fleet breakdown**



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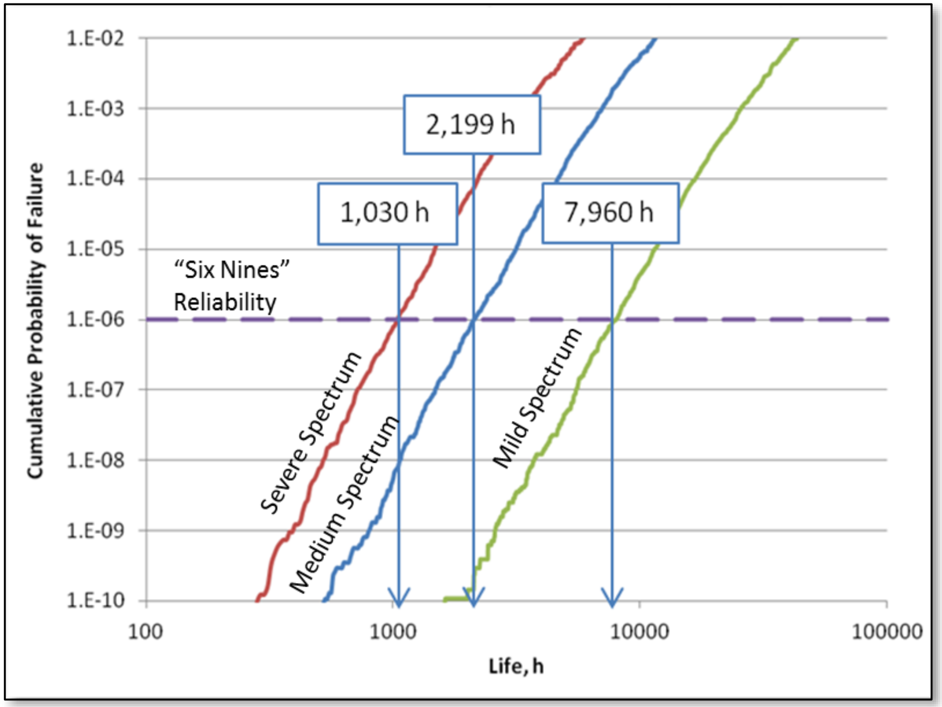
Reference Problem*

- **Given**
  - Distributions of strength, load
  - Deterministic usage spectra – severe, medium, mild usage
- **Solutions for reliability vs. retirement life match published values**

Bell Solutions from Monte Carlo Simulations with Importance Sampling

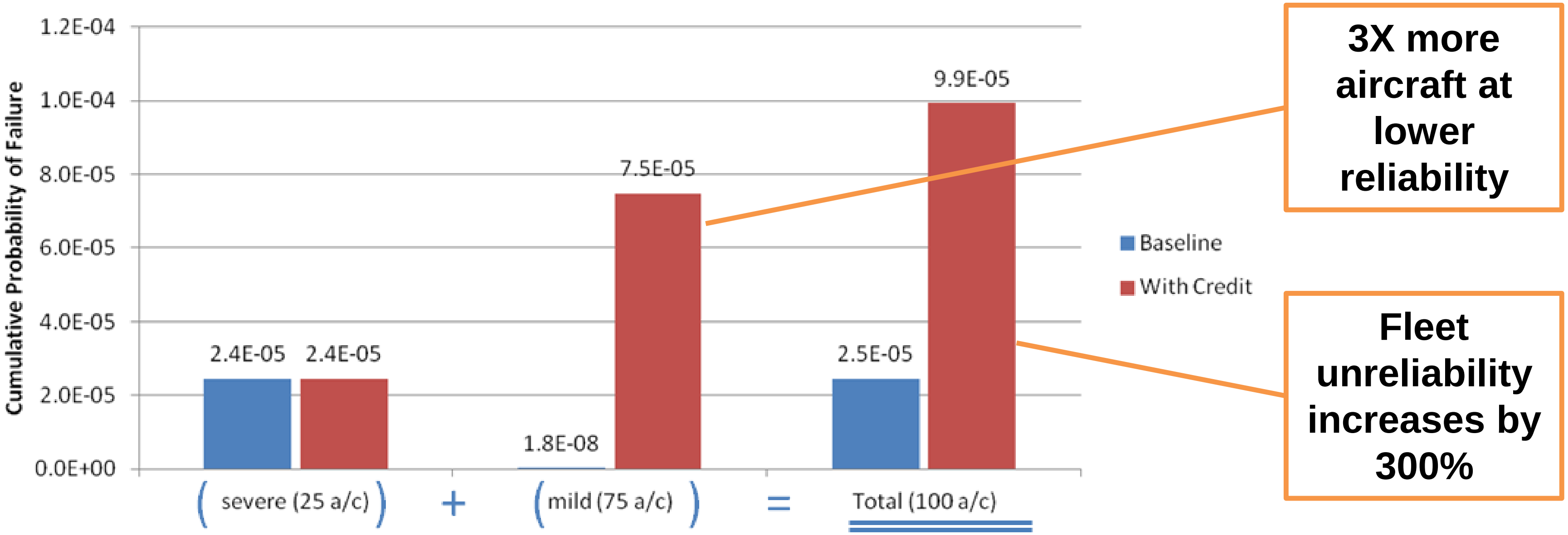
(1,000 simulations)



- *AHS International – Fatigue and Damage Tolerance Subcommittee – Structural Reliability Round Robin Problem – "Round 1" (2006)*

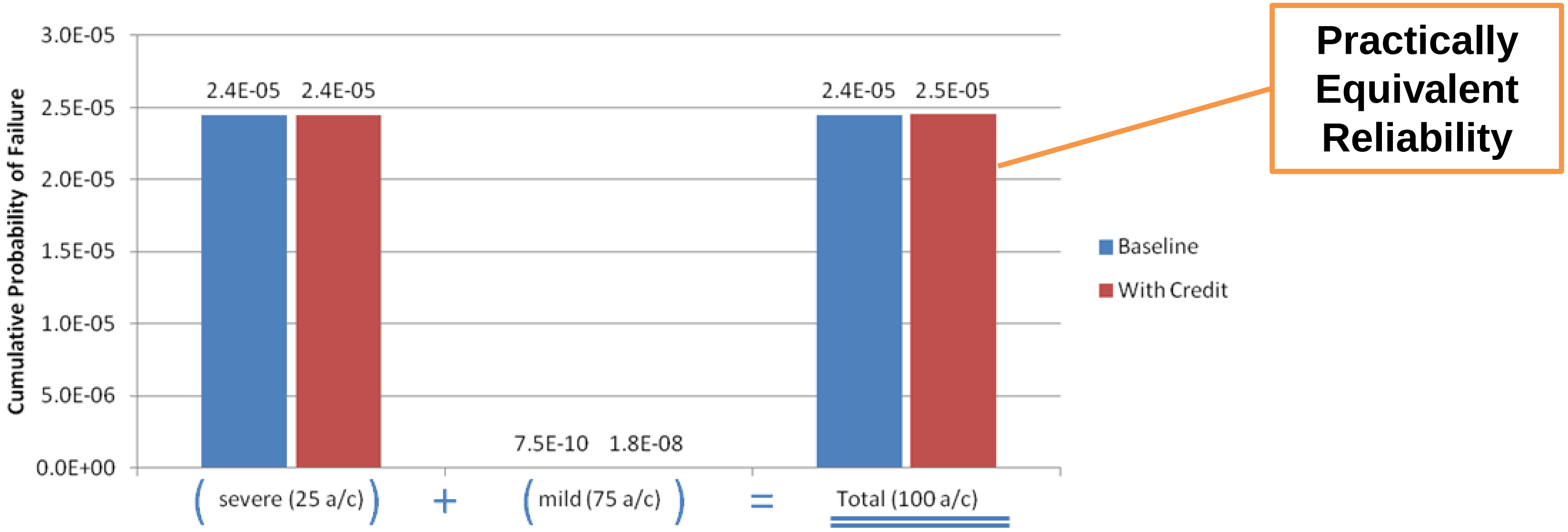
Simple Example using Reference Problem

- **Life Limit: 1,030 hours**
  - based on "severe" usage – "six nines" reliability
- **Fleet Makeup:**
  - Severe usage (exclusive): 25 aircraft
  - Mild usage (exclusive): 75 aircraft
- **Fleet Unreliability (probability of failure)**
- **Credit Option 1: set mild aircraft reliability to "six nines"**
  - *7,960 hour life = credit of 6,930 hours*



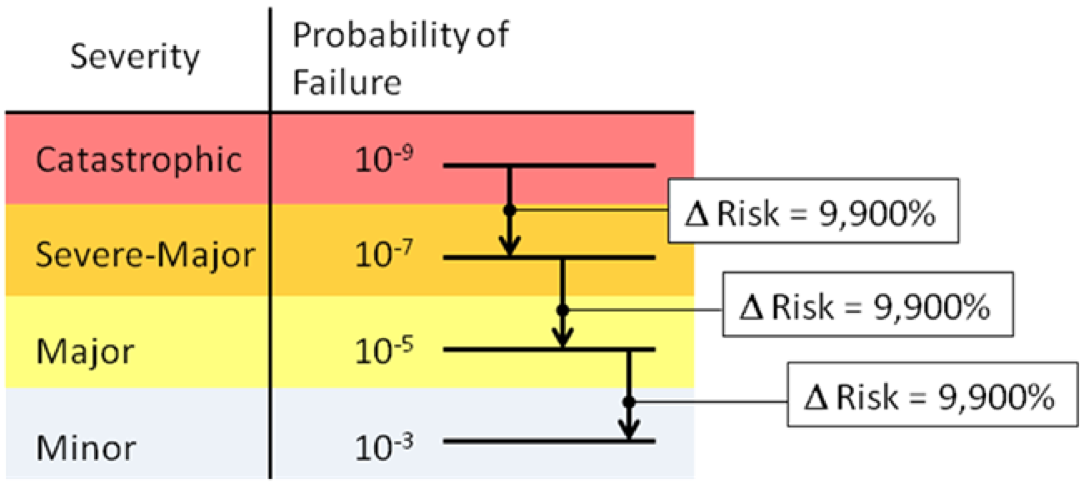
Reference Problem – Using New Method

- **Iterate using system reliability method to reach 1% increase in fleet unreliability**
  - Result: *2,130 hour life = credit of 1,100 hours*
- **Unreliability of the mild sub-fleet increases significantly…**
- ***But not enough to significantly impact total fleet***



What is the Right Threshold?

- **System Safety certification methods use levels of risk (change in unreliability)**
- **Example: changing from "Catastrophic" Severity (10^{-9}) to "Severe-Major" (10^{-7}):**
  - $\Delta\, Risk = \frac{(New - Current)}{Current} = \frac{(10^{-7} - 10^{-9})}{10^{-9}}(100\%) = 9900\%$



Since a 1% change is 5 orders of magnitude smaller than smallest recognized step, it is practically equivalent

Managing Total Aircraft Risk

- **Total risk budget split between:**
  – Risk Budget
  – "Risk Reserve"
- **Risk budget includes risk allocations for each component**

Aircraft-Level ΔRisk Threshold **1.0%**	
Allocations:	
ΔRisk Budget: **0.5%**	ΔRisk Reserve: **0.5%**

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Conclusions

- **To safely apply usage credit to life-limited components, we must understand how usage contributes to the current fleet reliability**
- **System reliability methods can be used to quantify this contribution**
- **In cases where a portion of the fleet drives the majority of the risk, it may be possible to apply credit to the remaining aircraft with almost no impact to the fleet reliability**
- **A reasonable risk threshold and a “risk reserve” can ensure that such an approach can be tolerant of changes in usage, other unknowns.**

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