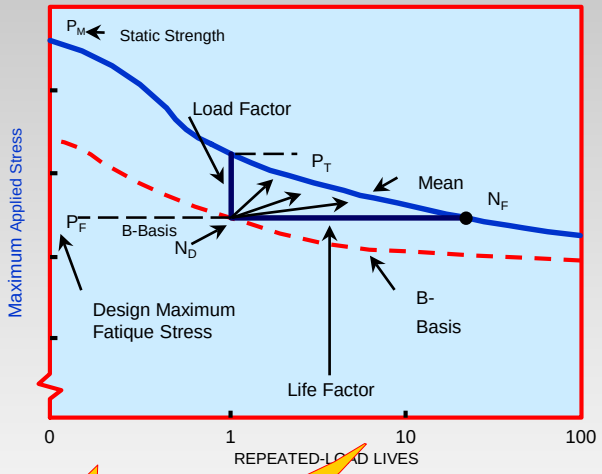
Damage Tolerance Considerations in Composite Aircraft Structure



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National Resource Specialist (Retired)
Advanced Composite Materials

Damage Tolerance

Safety-of-Flight composite aircraft structure should be designed damage tolerant

The damage tolerance evaluation should:

- Include anticipated manufacturing and service related defects/damage
- Demonstrate a “B” - Basis (or “A” - Basis, as appropriate) repeated-load life, inspection interval, etc.
- Include the considerations contained in FAA Advisory Circulars (AC) 20-107A, Composite Aircraft Structure, and 25.571-1C, Damage-Tolerance and Fatigue Evaluation of Structure

Damage Tolerance Evaluation

Damage Tolerance

The damage tolerance evaluation of structure

(under the typical load and environmental spectra expected in service) is intended to ensure, that should fatigue, intrinsic/discrete damage, large area manufacturing flaws, or severe accidental damage occur within the operational life of the aircraft, the remaining structure will withstand reasonable loads without failure or excessive structural deformation until the damage is detected.

Included are considerations historically associated with fail-safe design.

Damage Tolerance

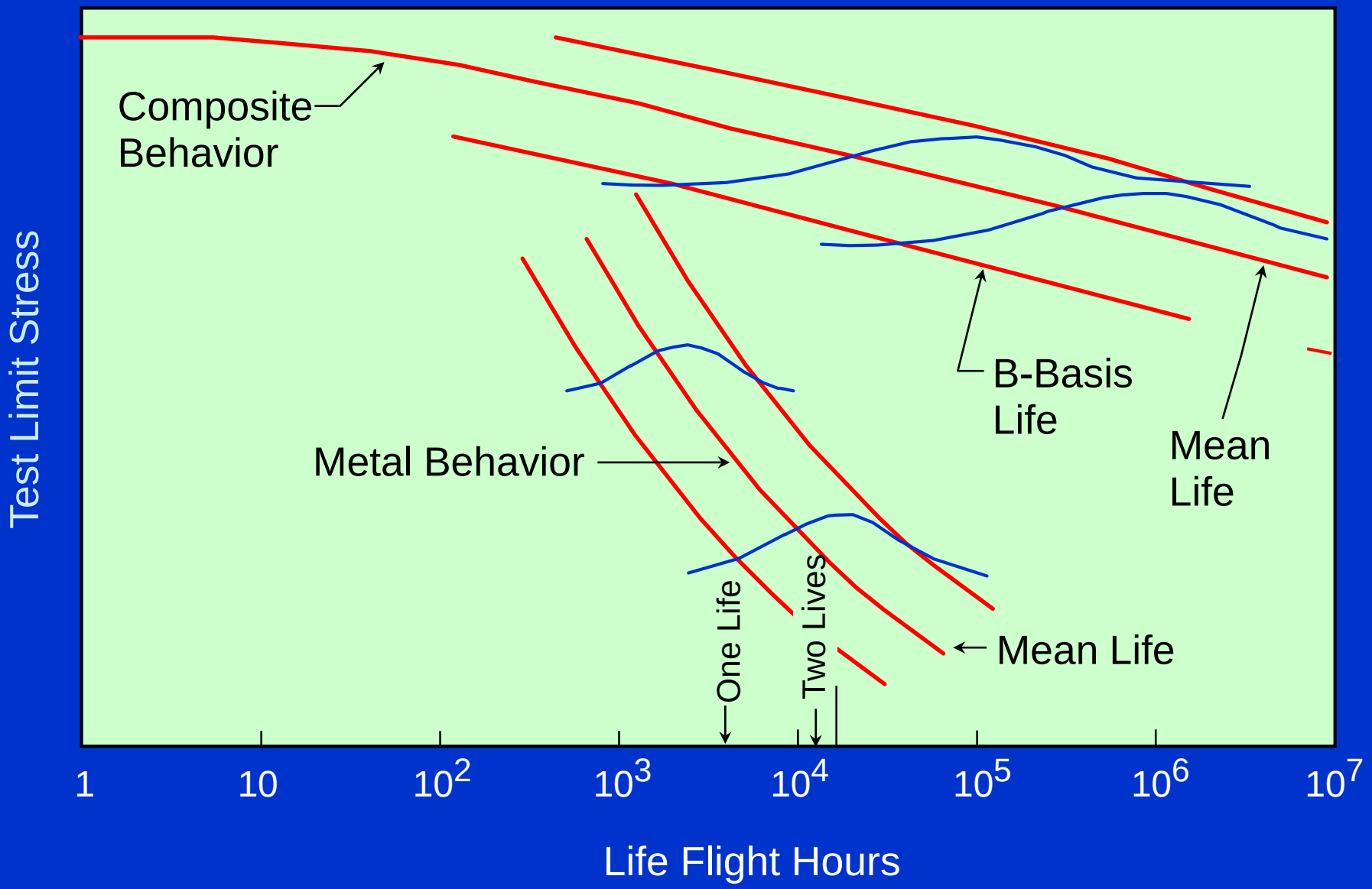
Damage Tolerance Design and Verification Criteria
-- Composite Aircraft Structure --

- Identify principal structural elements
- Establish probable types and locations of defect/damage
- Establish extent of initially detectable defect/damage
- Evaluate repeated-load sensitivity of principal structural elements
- Determine extent of damage for residual strength assessment
- Characterize defect/damage growth
- Validate residual strength
- Determine inspection intervals
- Include damage at multiple sites, where appropriate
- Include effects of temperature and humidity
- Evaluate capability of aircraft structure to sustain immediately obvious damage

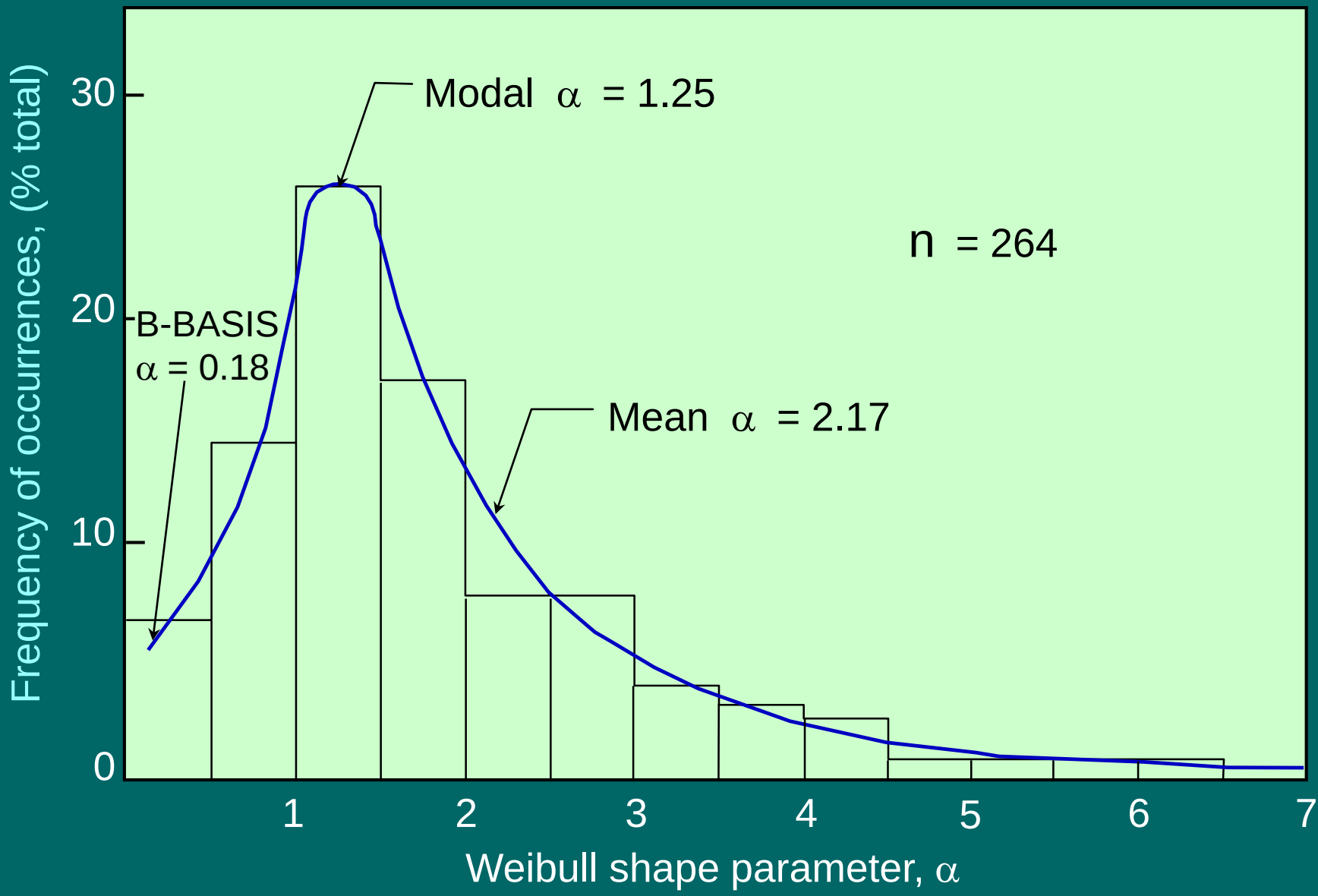
Damage Tolerance Considerations

- **Defect/Damage Growth Validation**
- **Residual Strength Validation**

Repeated-Load Response Comparison



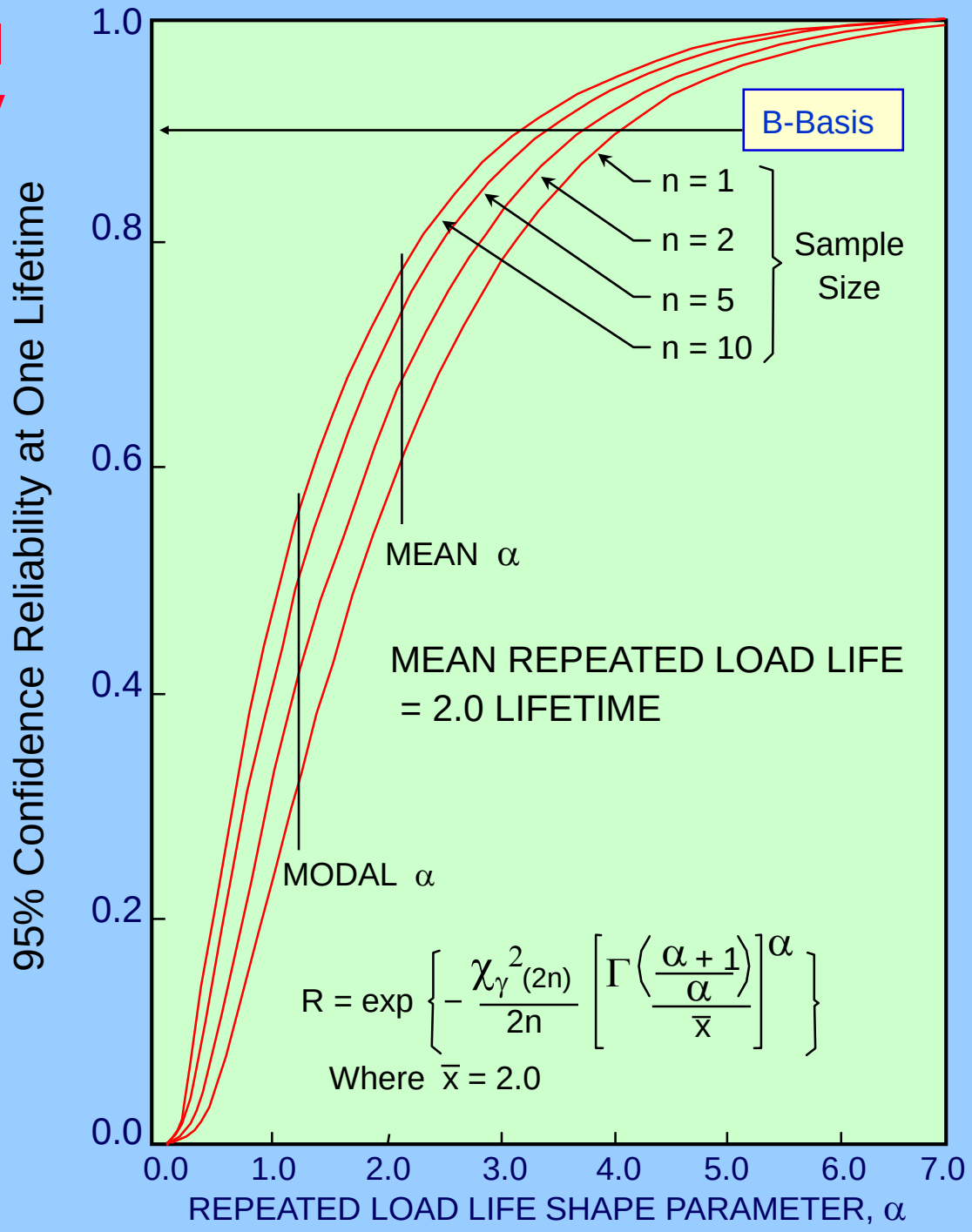
Repeated-Load Life Scatter Distribution



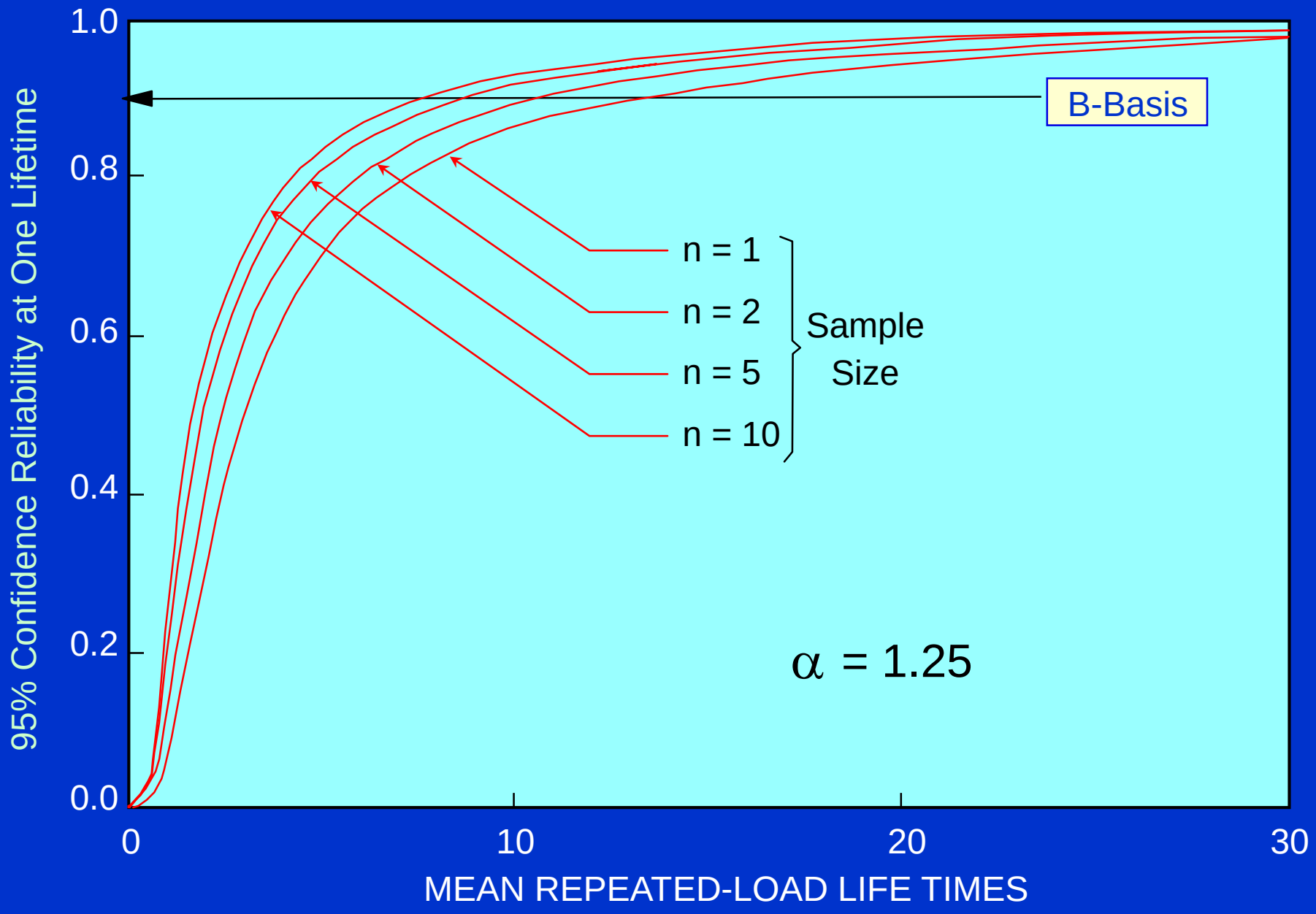
Variability

Material	Static Strength α	Repeated-Load Life α_L
Aluminum	35	7.5
Carbon/ Epoxy	20	1.25

Structural Reliability



Structural Reliability

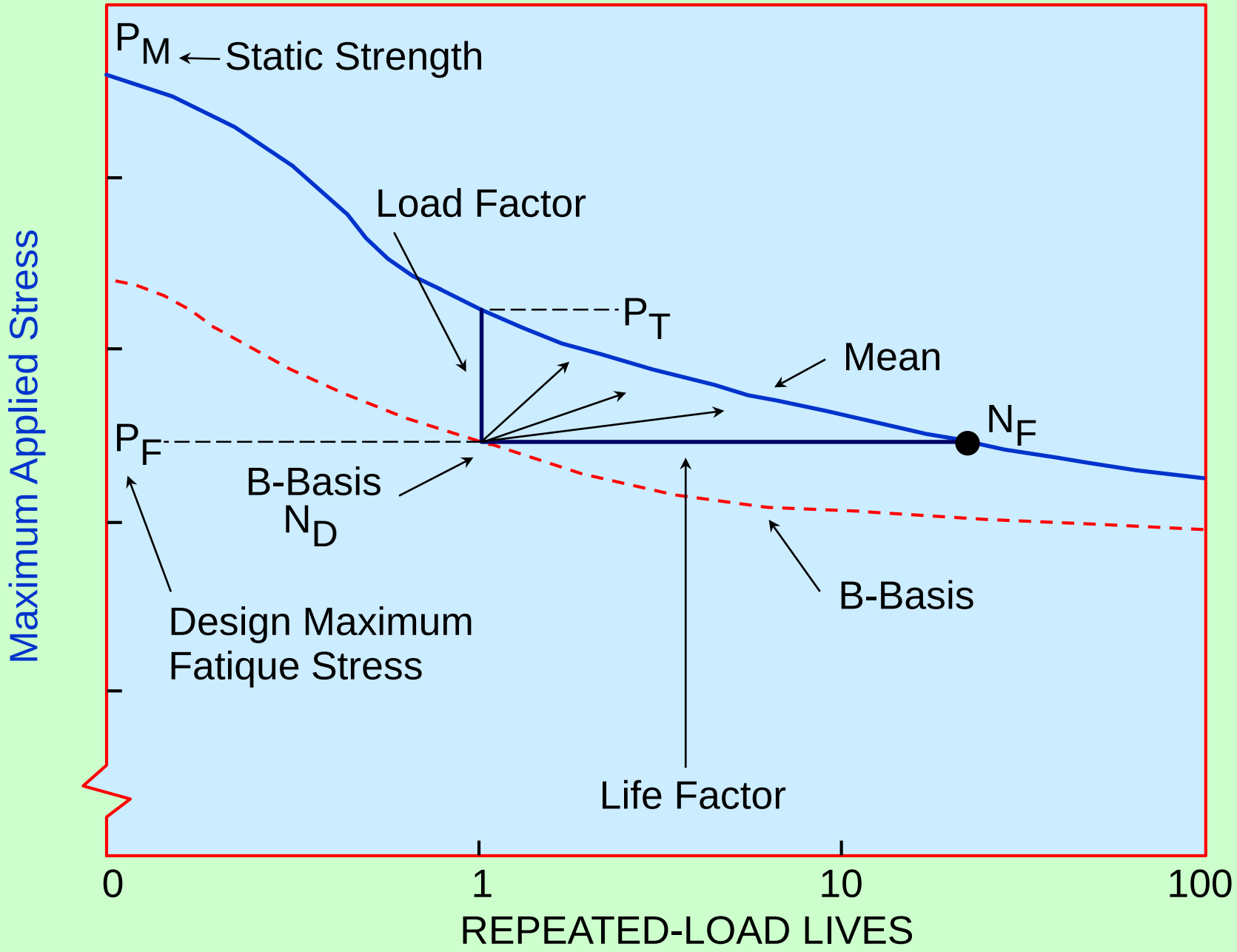


AC 20-107A: Composite Aircraft Structure

Section 7 (a)(2)

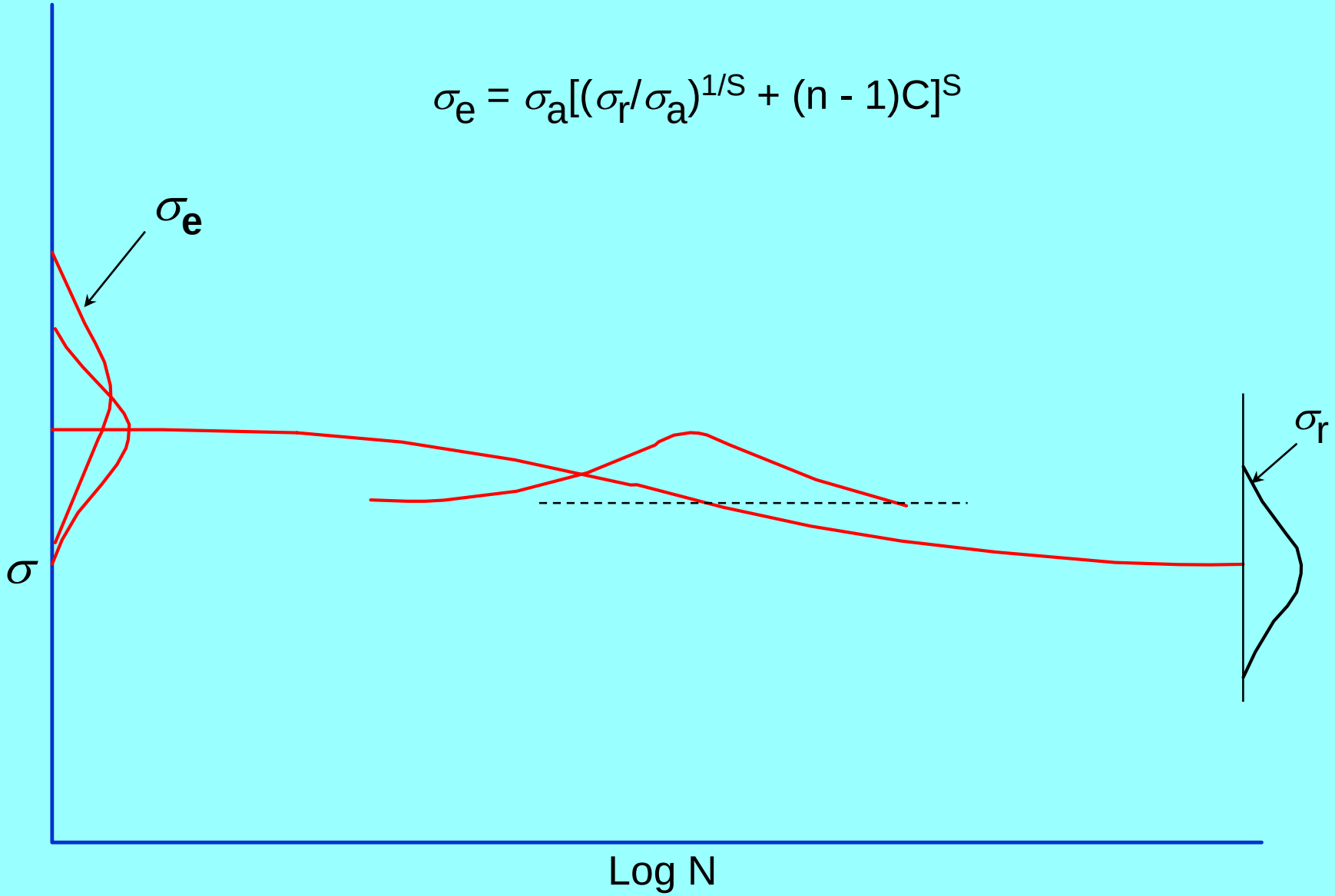
"…….Should be statistically significant, and may be determined by load and/or life considerations."

Load Enhancement Factor Approach



Sendeckyj Equivalent Strength Model

$$\sigma_e = \sigma_a[(\sigma_r/\sigma_a)^{1/S} + (n - 1)C]^S$$



Mathematical Relationships

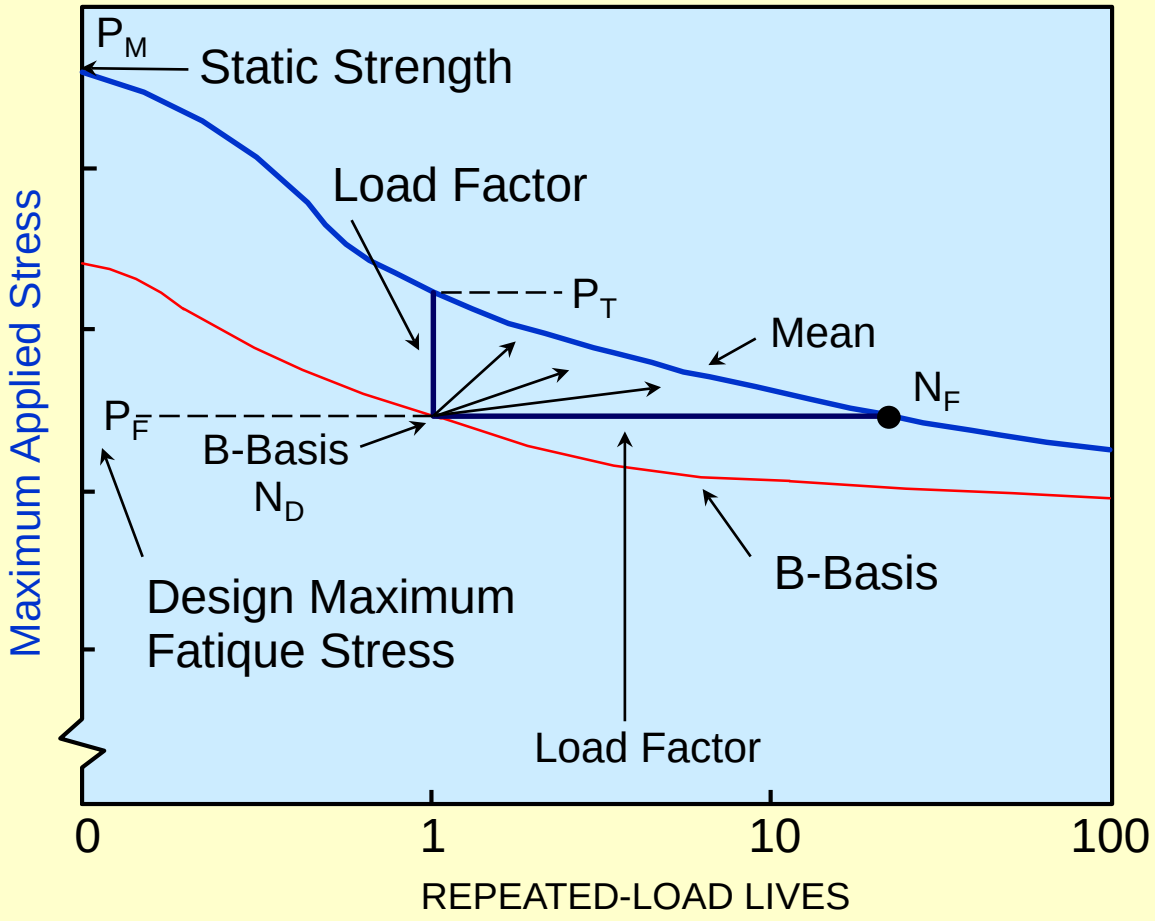
Load Enhancement Factor:

$$F = \frac{\mu\,\Gamma\left(\frac{\alpha_R + 1}{\alpha_R}\right)}{\left[\frac{-\ln(p)}{\chi_\gamma^2(2n)/2n}\right]^{1/\alpha_R}}$$

When:

$$\mu = \frac{\left[\Gamma\left(\frac{\alpha_L + 1}{\alpha_L}\right)\right]^{\alpha_L / \alpha_R}}{\Gamma\left(\frac{\alpha_R + 1}{\alpha_R}\right)}$$

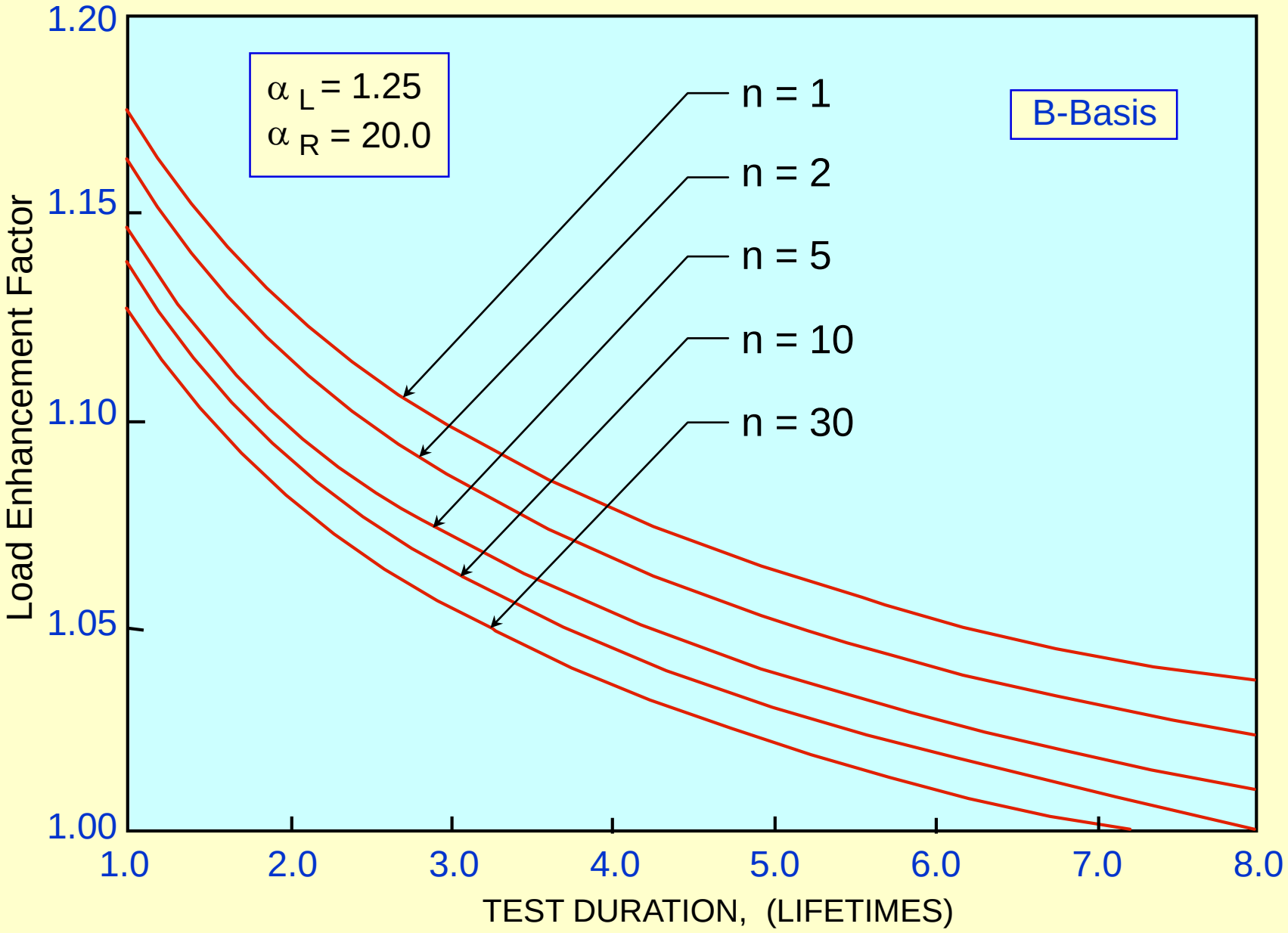
$$\text{and } p = \exp\left[\ln(\mathbf{l})N^{\alpha_L}\right]$$



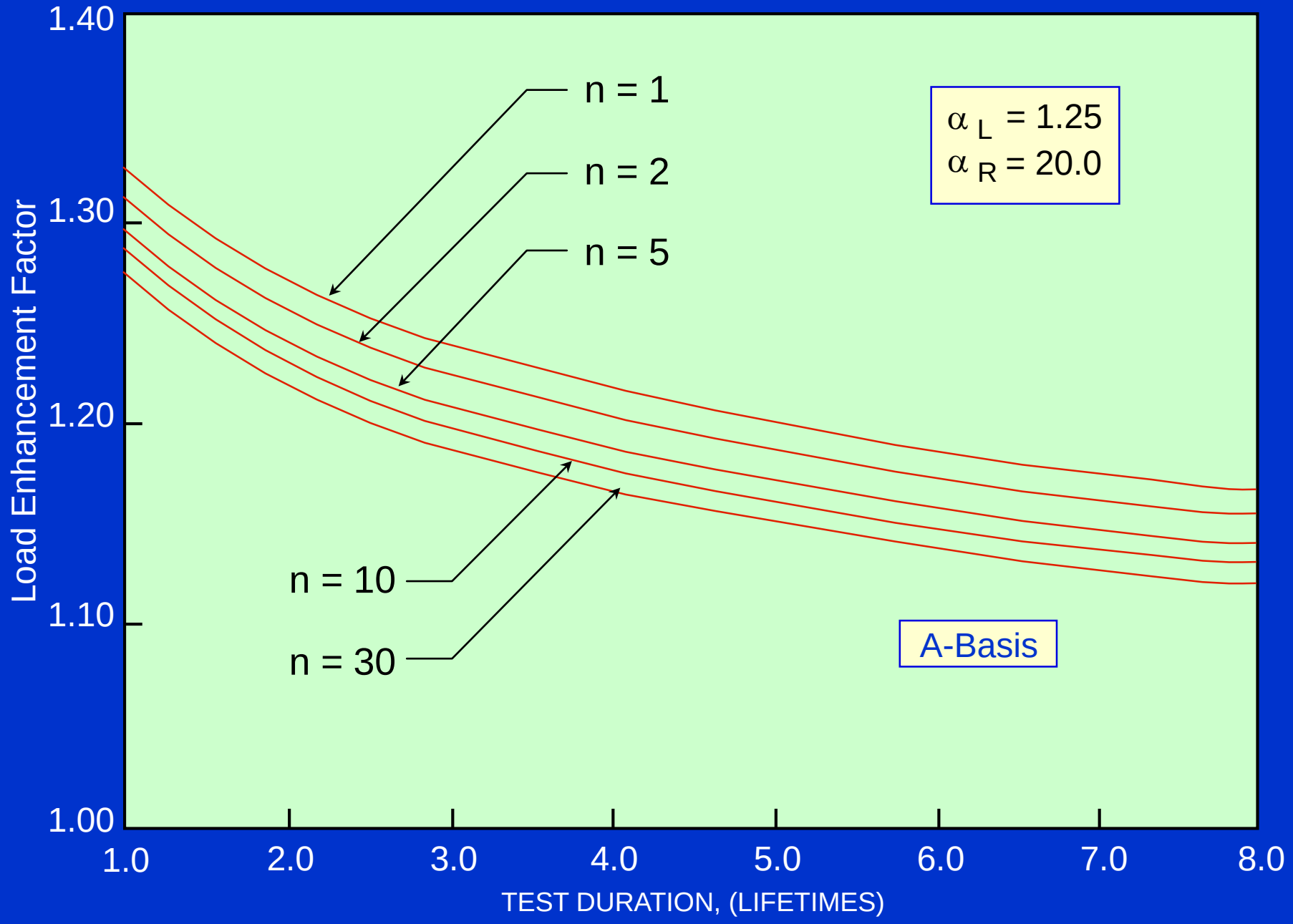
Repeated-Load Life Factor:

$$N_F = \frac{\Gamma\left(\frac{\alpha_L + 1}{\alpha_L}\right)}{\left[\frac{-\ln(0.9)}{\chi_\gamma^2(2n)/2n}\right]^{1/\alpha_L}}$$

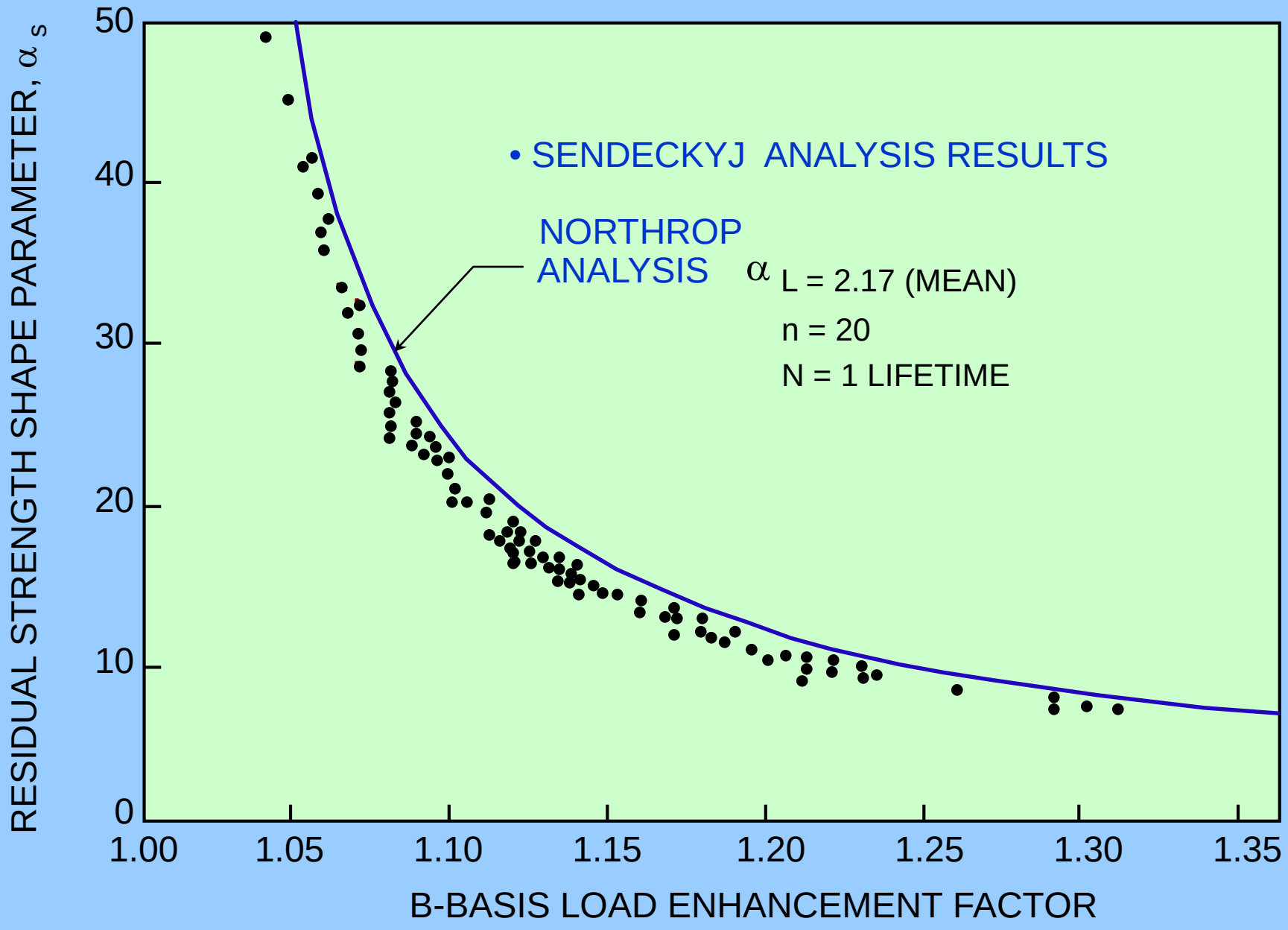
Load Enhancement and Life Factors



Load Enhancement and Life Factors



Load Enhancement Factor Comparison



Damage Tolerance Considerations

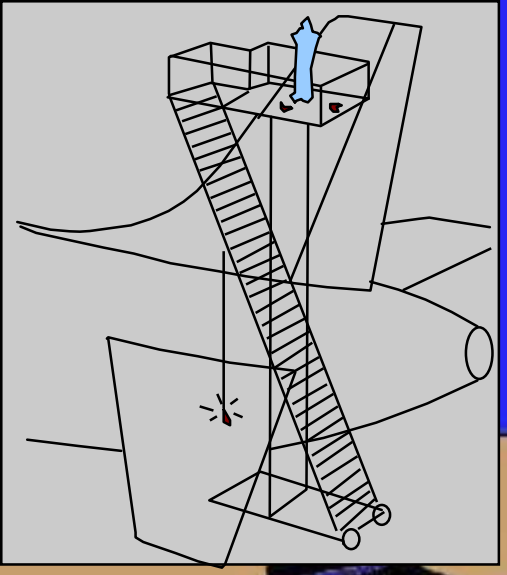
- Defect/Damage Growth Validation
- Residual Strength Validation

Residual Strength Assessments

Considerations should include:

- **Damage extent identified during the damage characterization process**
- **Large area manufacturing defects, e.g., understrength bonds**
- **Severe accidental damage**

Impact Damage Sources

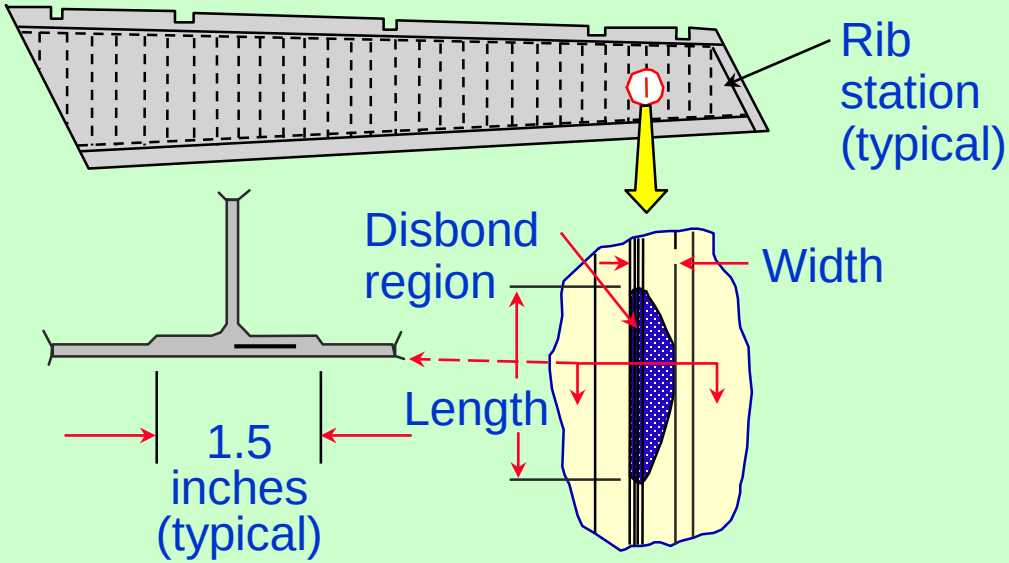


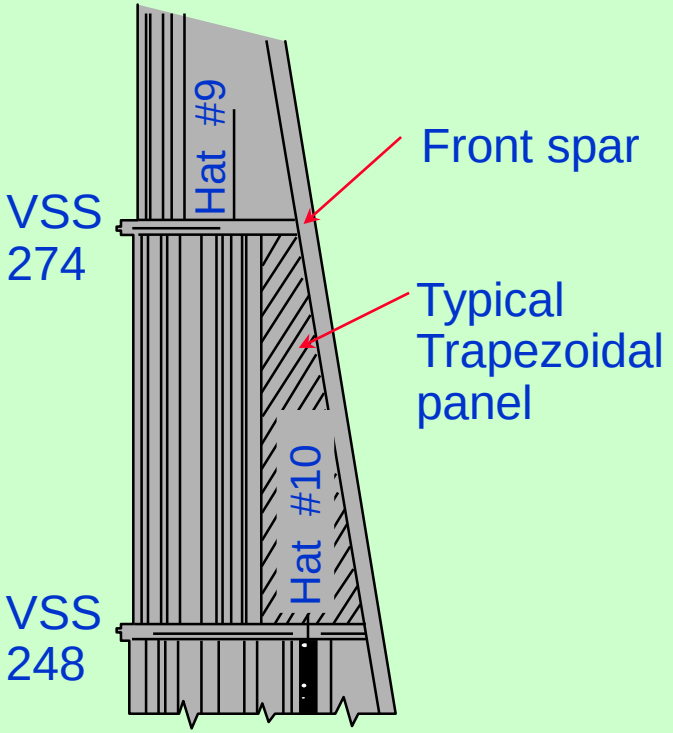
Residual Strength Assessments

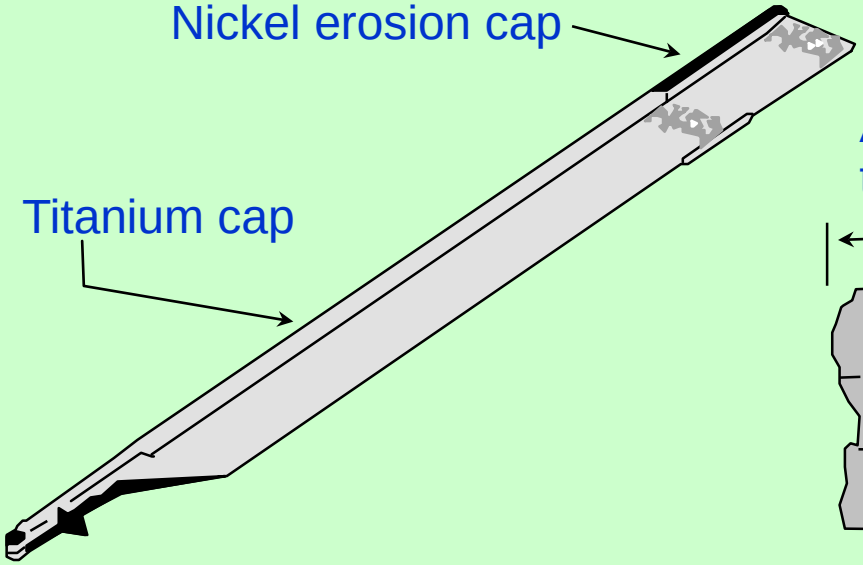
Considerations should include:

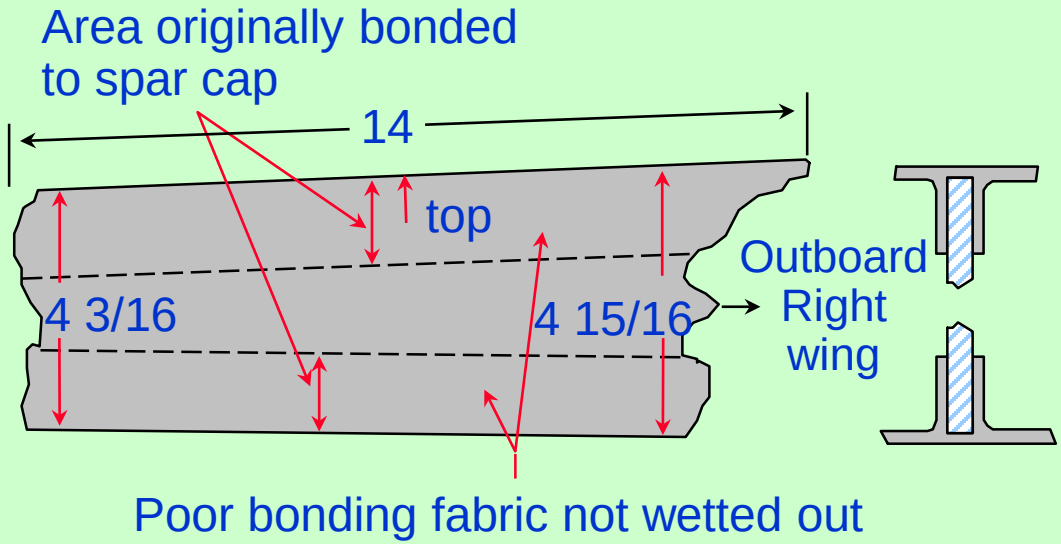
- Damage extent identified during the damage characterization process
- **Large area manufacturing defects, e.g., understrength bonds**
- Severe accidental damage

Case Histories









FAR 23.573 (a)(5) Damage Tolerance and Fatigue Evaluation of Structure

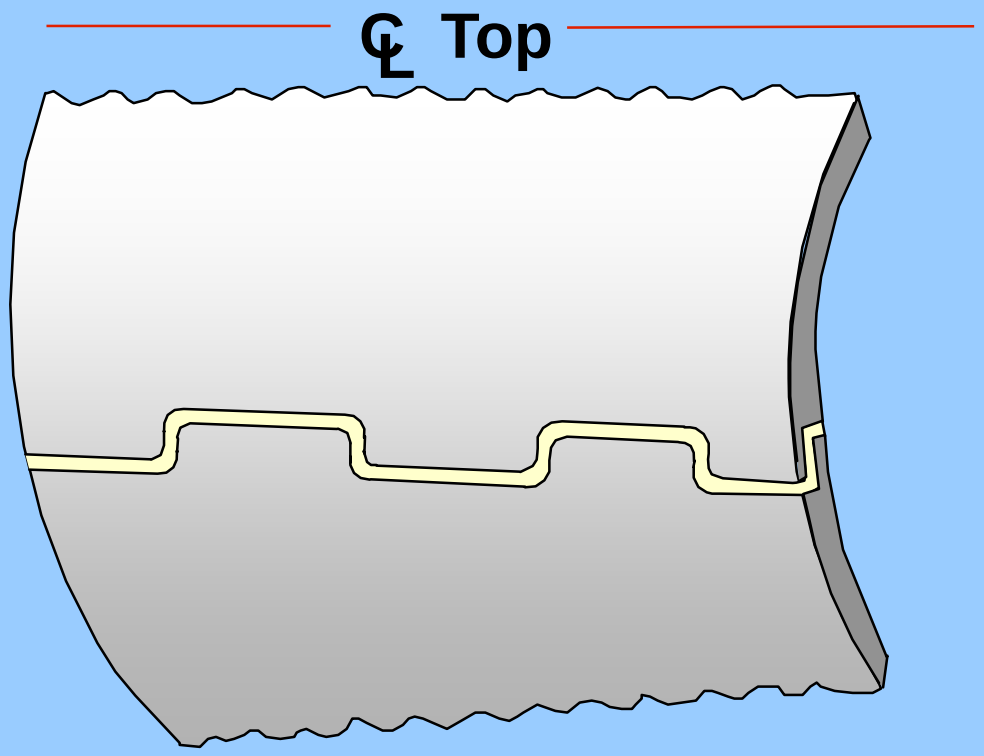
"In any bonded joint, the failure of which would result in catastrophic lost of the airplane, the limit load capacity must be substantiated by one of the following methods"

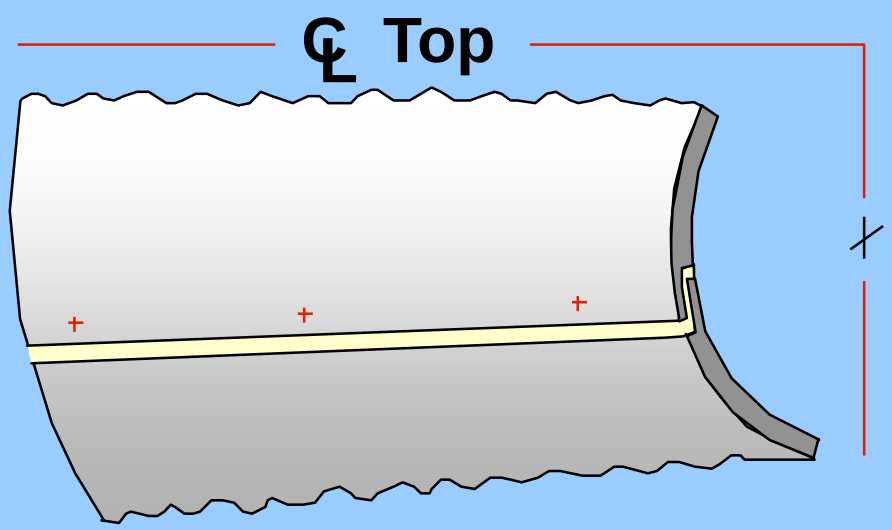
(i) The maximum disbonds of each bonded joint consistent with the capability to withstand the loads in paragraph (a) (3) of this section must be determined by analysis, tests, or both. Disbonds of each bonded joint greater than this must be prevented by design features; or;

(ii) Proof testing must be conducted on each production article that will apply the critical limit design load to each critical bonded joint; or

(iii) Repeatable and reliable non-destructive inspection techniques must be established that ensure the strength of each joint."

Design Features





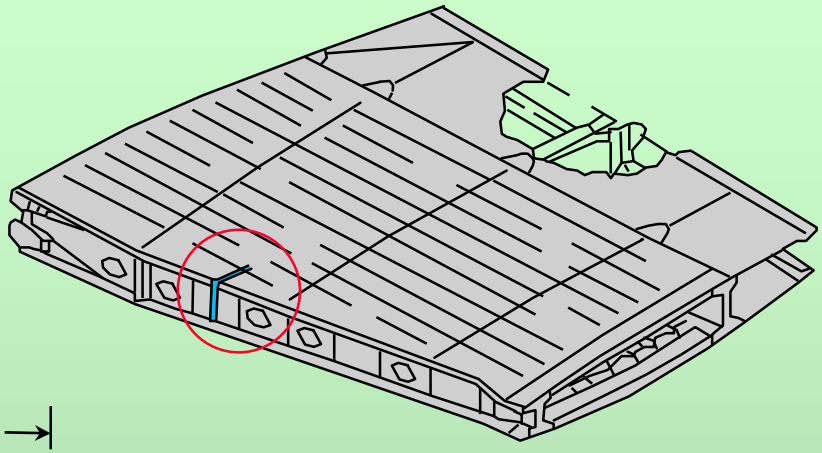
Residual Strength Assessments

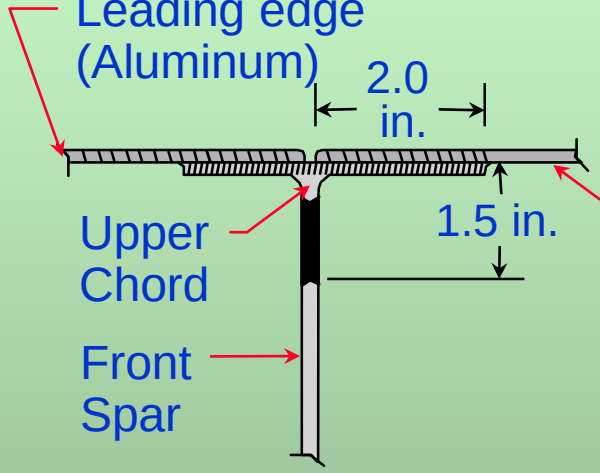
Considerations should include:

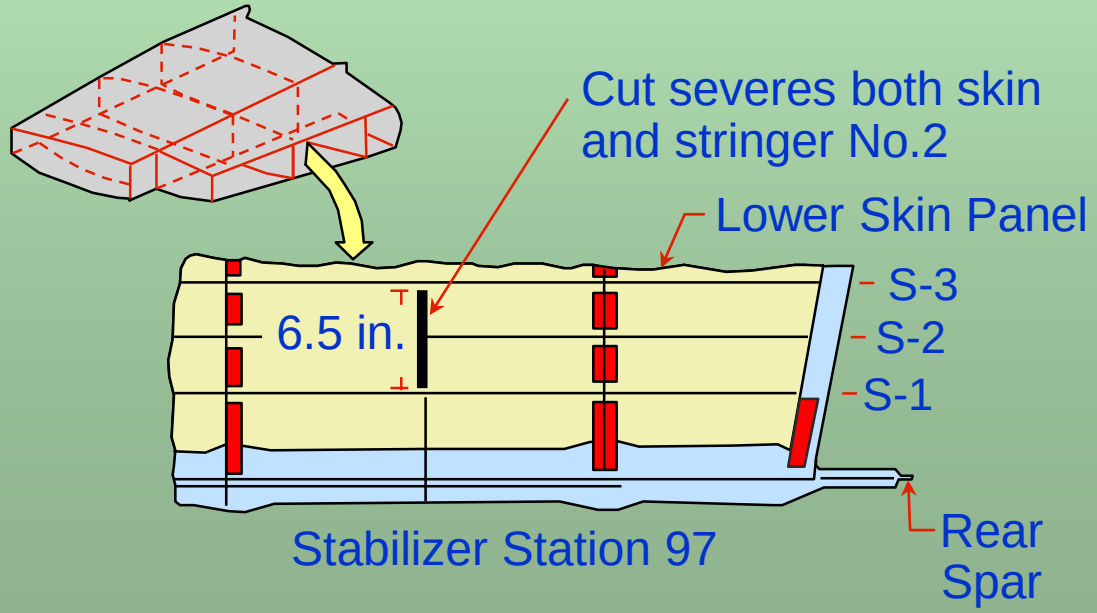
- Damage extent identified during the damage characterization process
- Large area manufacturing defects, e.g., understrength bonds
- Severe accidental damage

Severe Accidental Damage

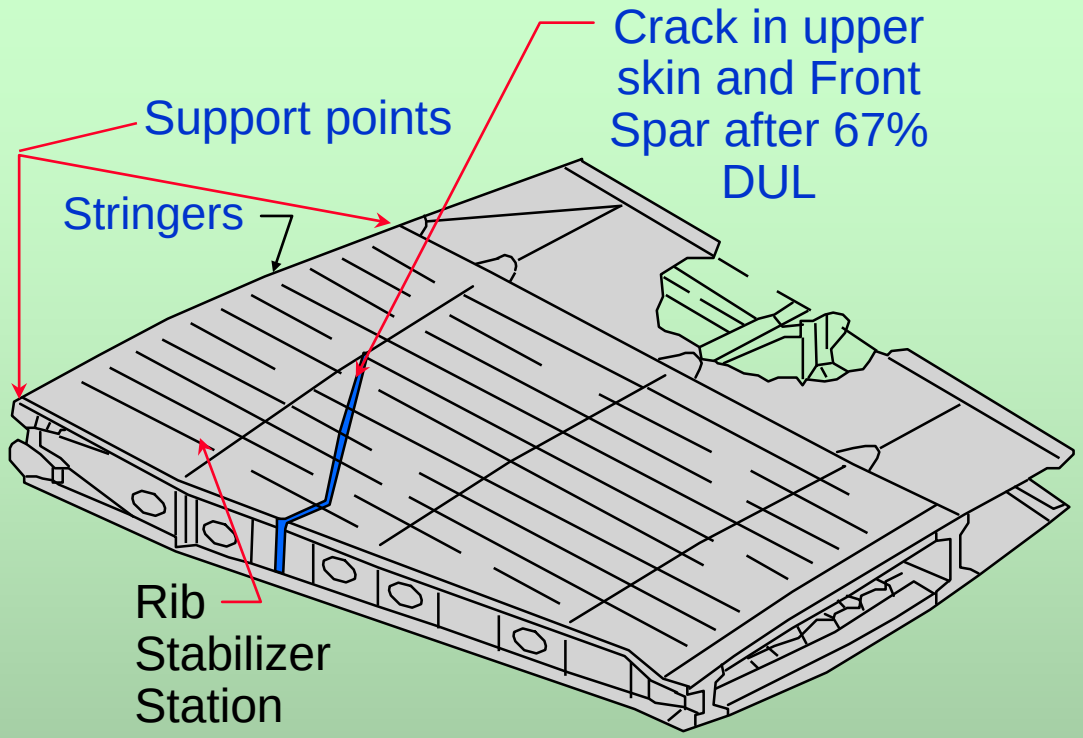
Section through front spar showing area of cut (shaded)

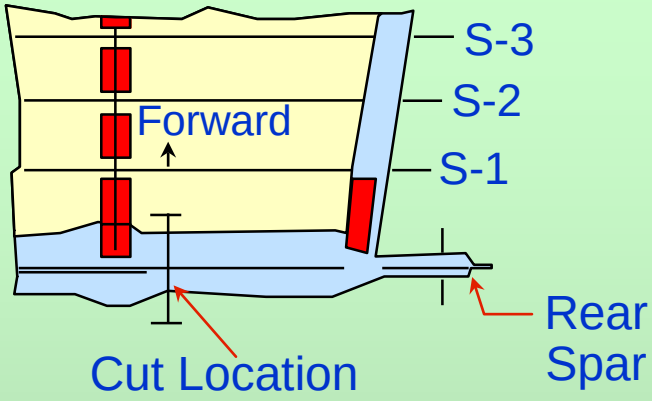


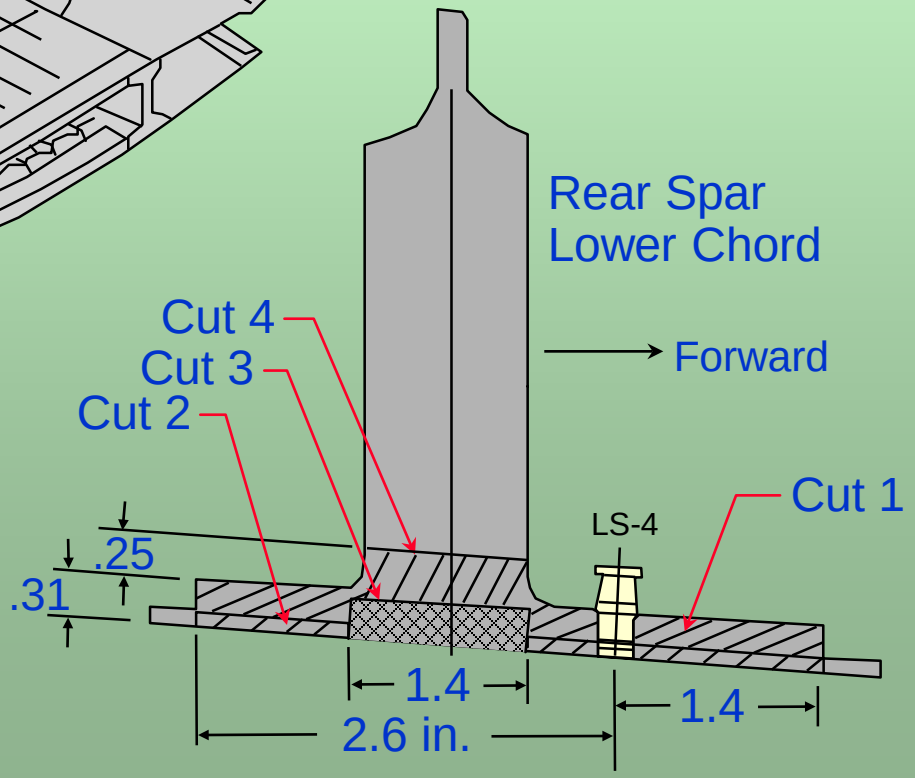




Severe Accidental Damage (Cont'd)







Accident/Incident Report

19.9	C46	HK-3468	Avesca	Bogota	Non-Scheduled Freight	11	Crew Pass Others	11 0 0	0 0 8	0 0 0	Destroyed

About one minute after take-off the crew declared an emergency and stated that they would be returning to the airport. However, the aircraft failed to reach the runway, crashed and burst into flames. All eleven on board were killed and eight persons on the ground were injured.

22.9	B737	G-MONM	Monarch	Luton	Non-Scheduled Passenger	152	Crew Pass	0 0	0 0	7 145	Substantial

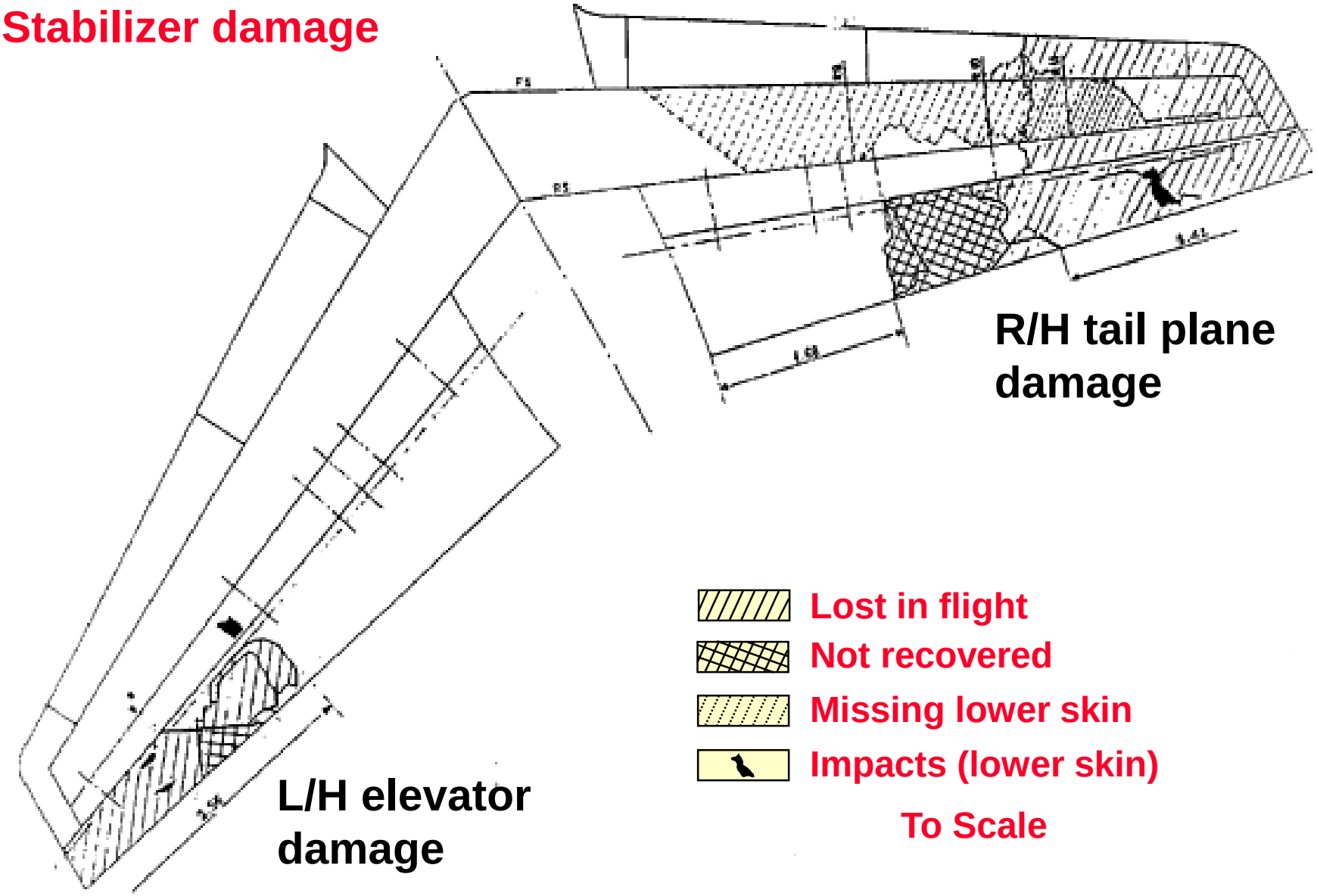
As the aircraft accelerated for take-off some loose concrete blocks were dislodged from the runway and struck the tailplane. The crew were unaware of the incident until arrival when approximately 18 holes were were found in the underside of the right horizontal stabilizer, the largest measuring about 18” X 6”

22.9	Fokker F27	XY-ADZ	Myanma Airways	Yangon	Scheduled Passenger	45	Crew Pass	0 0	0 0	4 41	Substantial

The aircraft ran off runway on to soft ground during landing. The nose landing gear collapsed and both engines suffered ingestion damage.

General explanation of the incident

Stabilizer damage



R/H tail plane damage

L/H elevator damage

Lost in flight

Not recovered

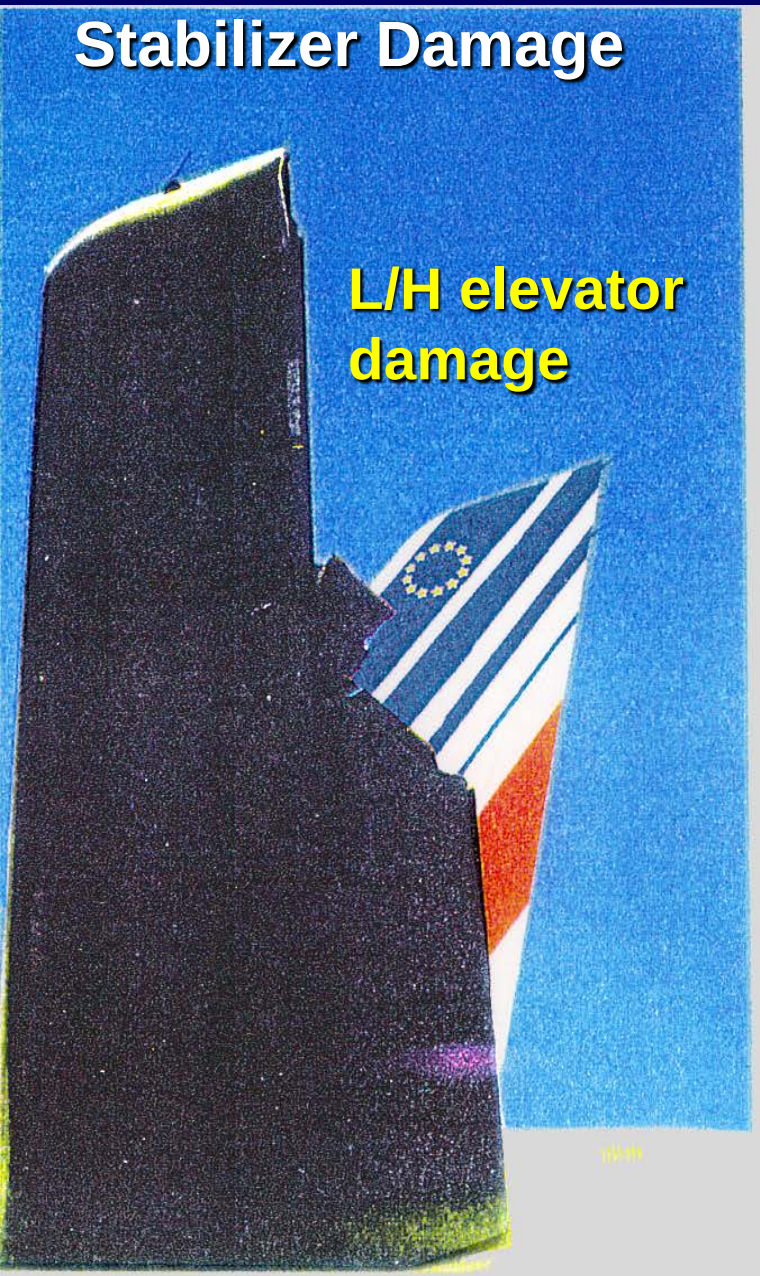
Missing lower skin

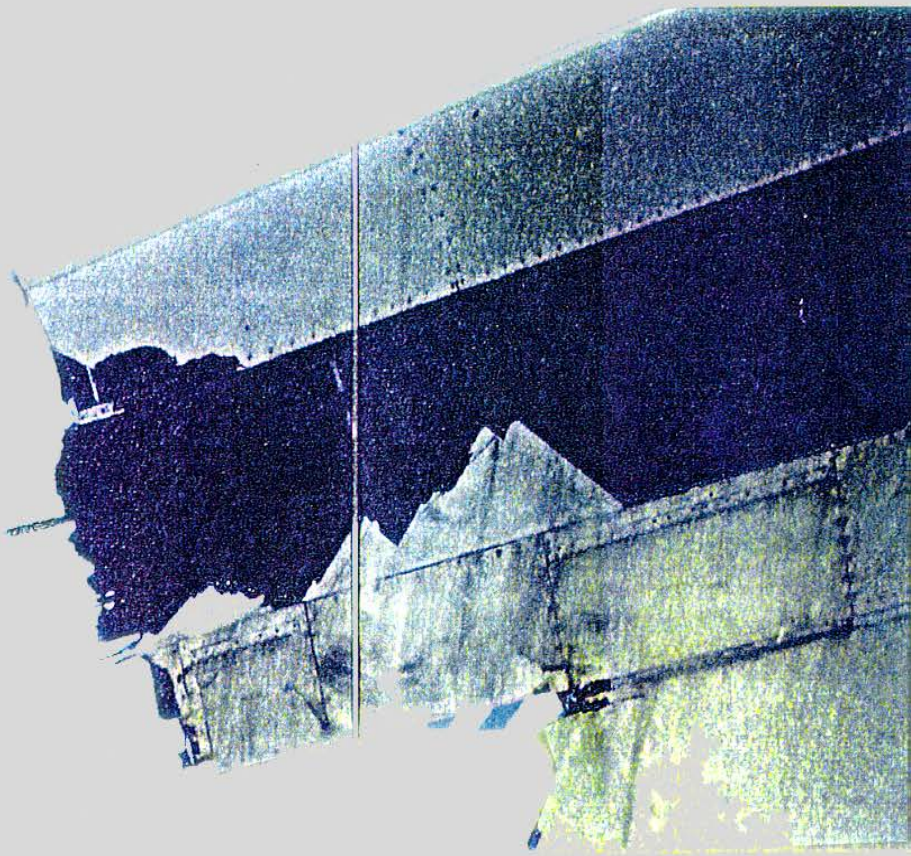
Impacts (lower skin)

To Scale

General Explanation of the Incident

Stabilizer Damage

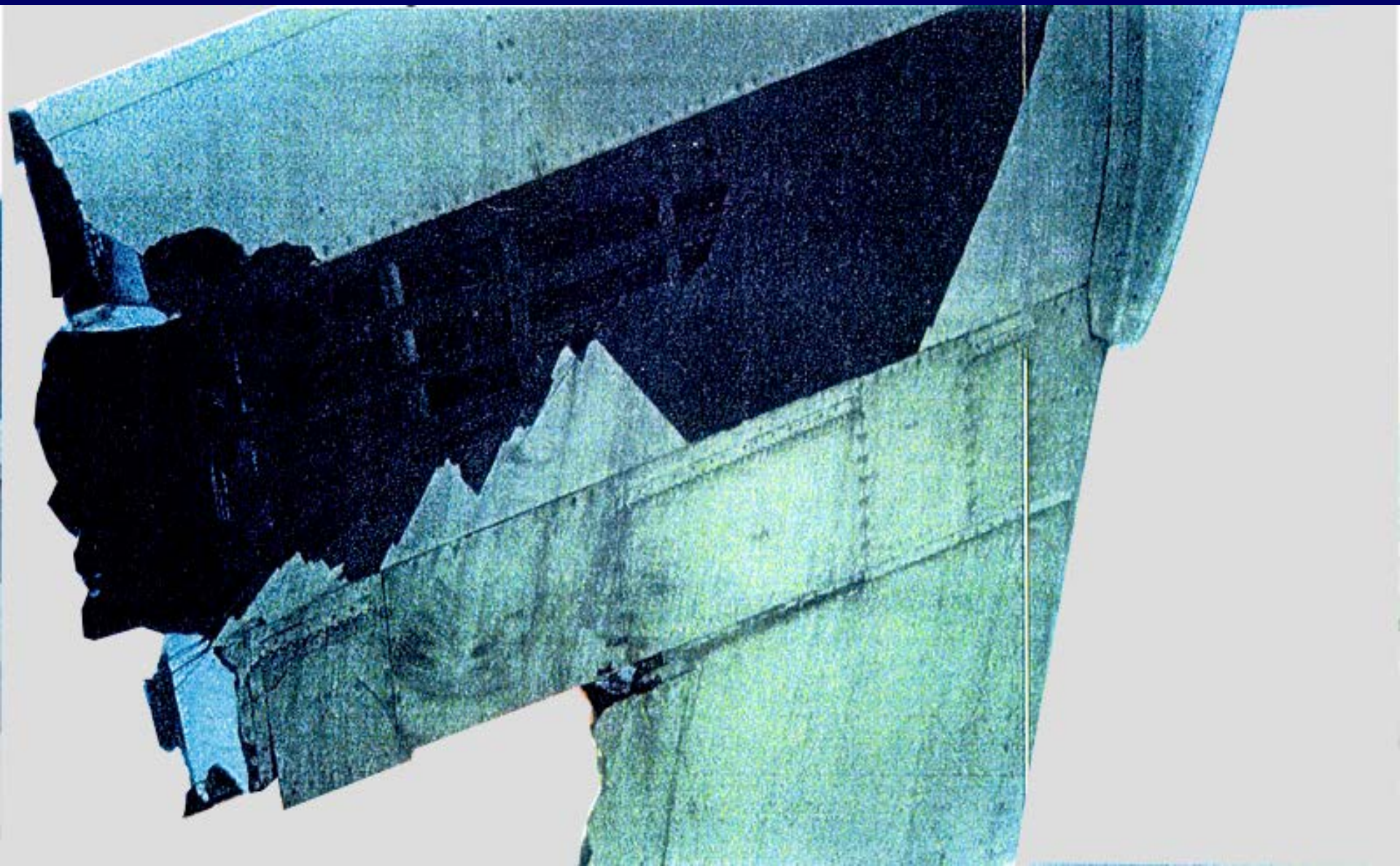




R/H tail plane
damage

General Explanation of the Incident

Stabilizer Damage



General Explanation of the Incident

Stop Way Damage

Summary

The damage tolerance requirements of FAR Parts 23.573, 25.571, 27.571 [together with AC 27-1A, Section 788 (g)(6)], 29.571 [together with AC 29-2B, Section 788 (g)(6)], and the guidance material in Section 7(a) of AC 20-107A should be reviewed during preparation of the structural substantiation program. AC 25.571-1A should also be reviewed as many of the principles and objectives contained therein are independent of materials of consideration and may prove useful in developing a damage tolerance evaluation program.

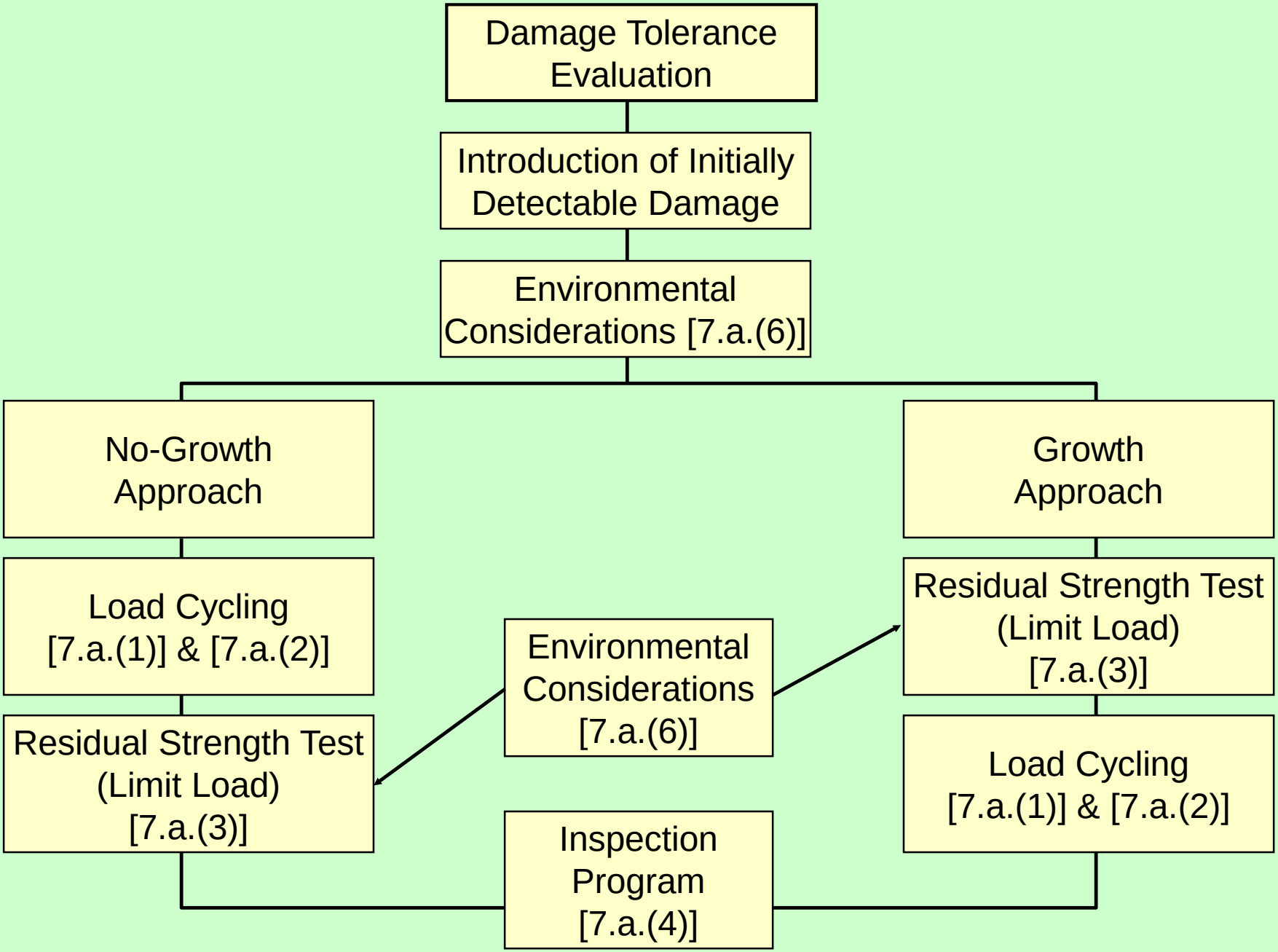
- **Unless the ultimate strength of each bonded joint critical to safe flight is reliably substantiated by a nondestructive inspection technique, the limit load capability of each of these bonded joints should be substantiated by either of the following methods or by a combination thereof:**

  (1) The maximum disbond of each critical bonded joint that will carry limit load should be established by test, analysis, or both. Disbonds of each bonded joint greater than this should be prevented by design features.

  (2) Each critical bonded joint of each production article should be proof tested to its critical limit load.

Damage Tolerance (Cont'd)

- Severe accidental damage (fail-safe) assessments, should be made, I.e., severing principle structural elements or portions of principle structural elements and showing that the remaining structure can sustain limit load.
- The inspection intervals established in accordance with the guidance material in AC 20-107A Section 7 (a)(4) should take into account that the damage may be missed during scheduled inspections.
- Load spectra, load truncation methods, and all other major aspects of the damage tolerance evaluation should be documented in test proposals and submitted to the FAA for approval.
- A "B" - basis repeated-load demonstration should be conducted on safety-of-flight redundant structure and may be conducted on single load path structure that has been shown to possess fail safe capability, I.e., the structure has been shown to be able to sustain limit load after failure of a significant portion of the single load path element.
- Hail stone impacts should be included in hazard analyses considerations.


Damage Tolerance Evaluation
Introduction of Initially Detectable Damage
Environmental Considerations [7.a.(6)]
No-Growth Approach
Growth Approach
Load Cycling [7.a.(1)] & [7.a.(2)]
Residual Strength Test (Limit Load) [7.a.(3)]
Environmental Considerations [7.a.(6)]
Residual Strength Test (Limit Load) [7.a.(3)]
Load Cycling [7.a.(1)] & [7.a.(2)]
Inspection Program [7.a.(4)]