WHEN TRUST MATTERS

Overview of current processes and future developments in composites certification

A wind turbine industry perspective

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Summary

About DNV

About the Presenter

The Type Certification Process

The Present:

Safe Life – Load and Resistance Factor Design

Reliability

The Future:

Damage Tolerance

A global assurance and risk management company

159	~13,000	~100,000	100+	5%+
years	employees	customers	countries	of revenue in R&D

Ship and offshore classification and advisory

Energy advisory, certification, verification, inspection and monitoring

Software, cyber security, platforms and digital solutions

Management system certification, supply chain and product assurance

DNV

About the Presenter

1996 – 2000 – PhD in Composite Materials at Bath University

1999 – 2008 – Aeromechanics and Design at Westland Helicopters

2008 – 2010 – Product Development at Vestas Wind: Wind Turbines

2010 – 2012 – Blade Design at Nordic Windpower: Wind Turbines

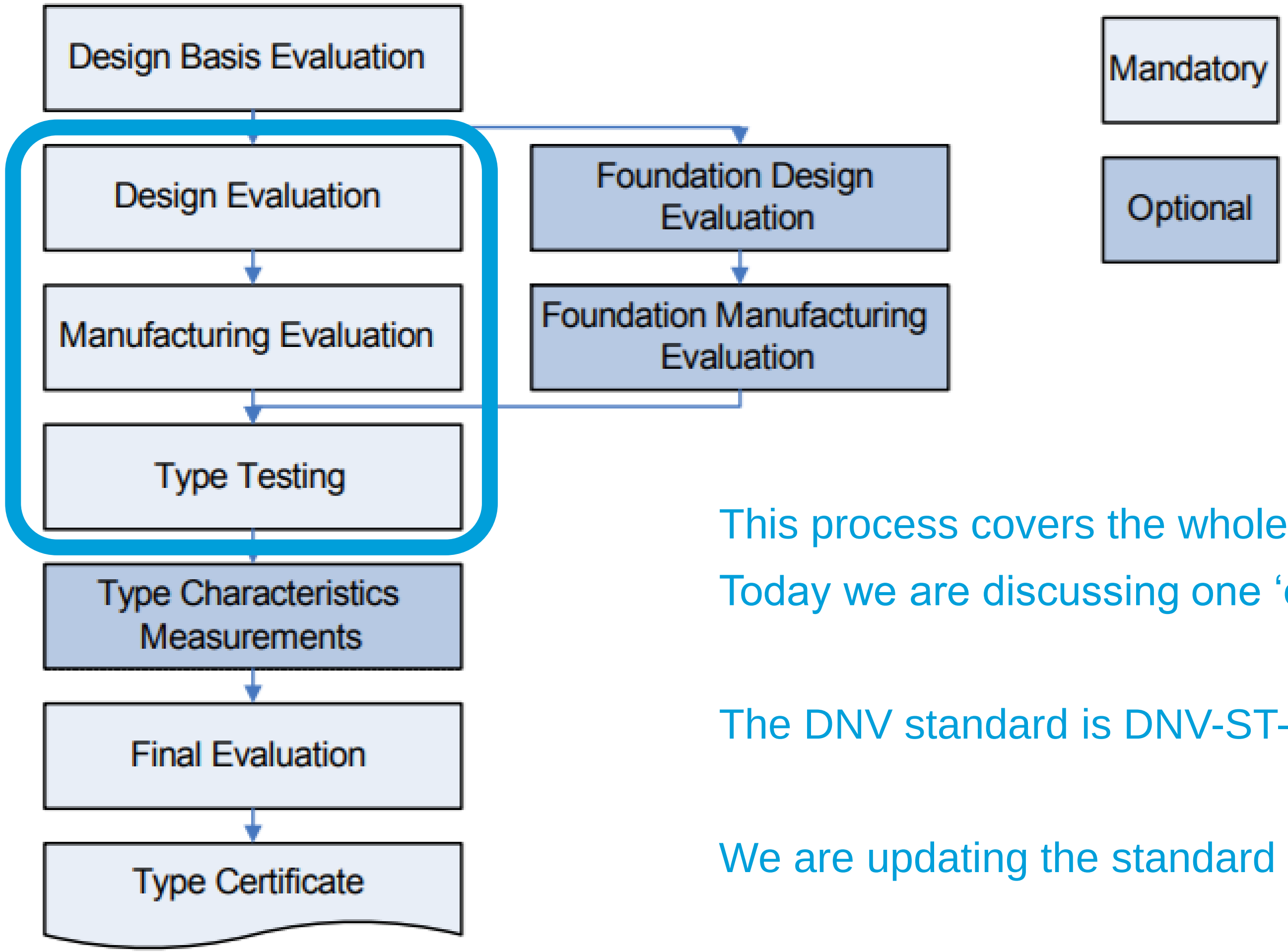
2012 – 2018 – Composites Consultant at Atkins: Aerospace, Defence, Renewables, Infrastructure

July 2018 – Now: Renewables Certification at DNV A/S

October 2018 - 2021: Visiting Professor at UWE

Type Certification Process

Accredited by:



This process covers the whole turbine.

Today we are discussing one ‘component’ - the blade.

The DNV standard is DNV-ST-0376.

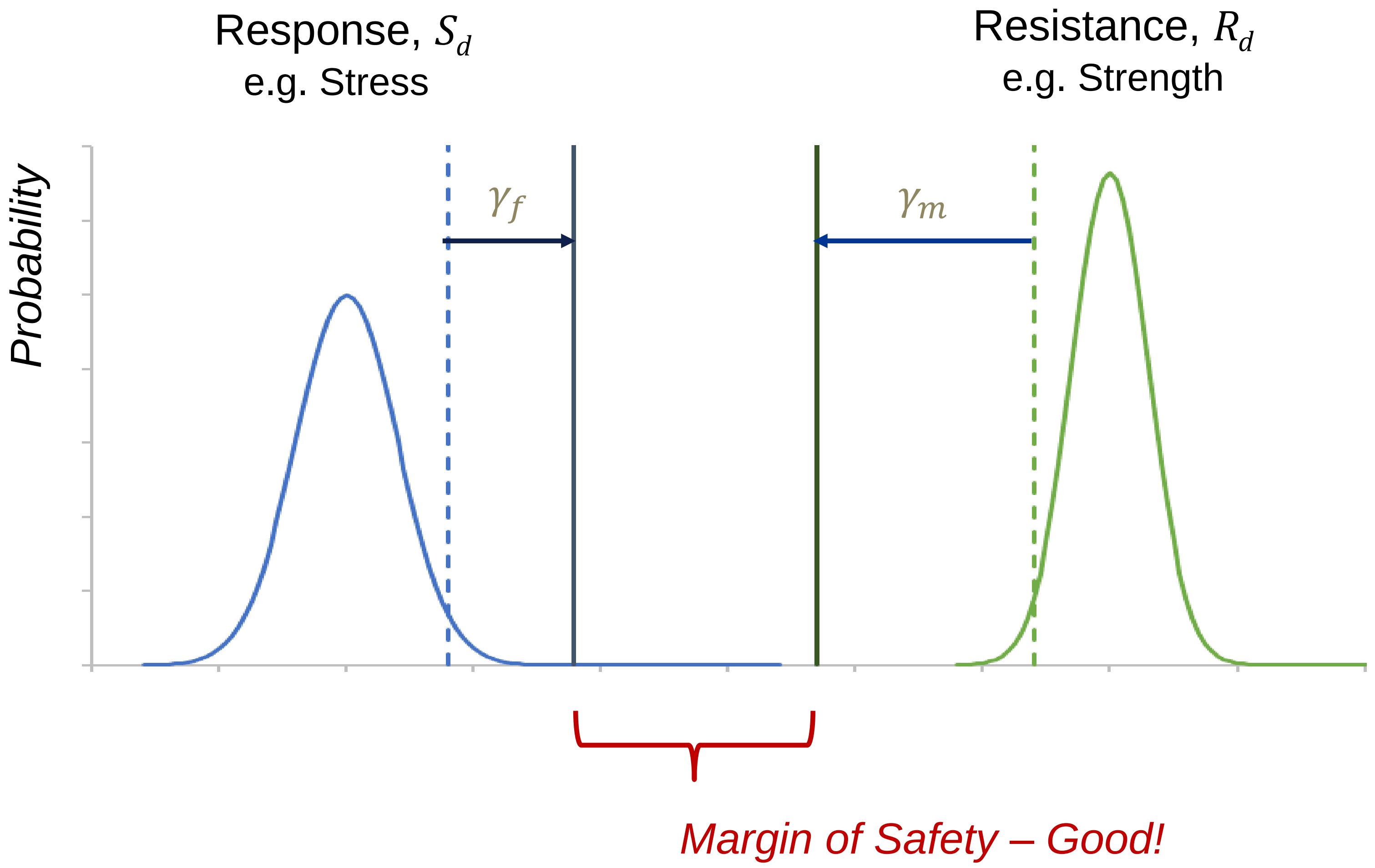
We are updating the standard now. Release date: October 23.

Present Requirements

Design Evaluation – Mandatory Failure Modes

- Blade-tower strike (SLS)
- Laminate fibre failure (ULS and FLS)
- Buckling instability (ULS)
- Bonded joint failure (ULS and FLS)
- Inter-fibre failure (SLS)

Design Evaluation - Load and Resistance Factor Approach



$$S_d(\gamma_f, F_k) \leq \frac{R_d}{\gamma_m}$$

Target: $P_f \sim 10^{-4}$

Design Evaluation – Partial Material Safety Factors

$$\gamma_m = \gamma_{m0} \times \gamma_{mc} \times \gamma_{m1} \times \gamma_{m2} \times \gamma_{m3} \times \gamma_{m4} \times \gamma_{m5}$$

$$S_d \leq \frac{R_d}{\gamma_m}$$

γ_m – the safety factor.

R_d – the design value (e.g. material strength from coupon testing)

S_d - the structural response under factored design loads (e.g. material stress or strain)

γ_{m0}	Base factor applied to analyses
γ_{mc}	Criticality of failure mode
γ_{m1}	Irreversible long-term degradation
γ_{m2}	Reversible temperature effects
γ_{m3}	Manufacturing effects
γ_{m4}	Accuracy of analysis methods
γ_{m5}	Accuracy of load assumptions
γ_m	**Total**

Manufacturing Effects

		Min.	Max.
Base factor	γ_{m0}	1.20	1.20
Criticality of failure mode	γ_{mc}	1.08	1.08
Environmental degradation	γ_{m1}	1.10	1.20
Reversable temperature effects	γ_{m2}	1.00	1.00
Manufacturing effects	γ_{m3}	1.00	1.30
Accuracy of analysis methods	γ_{m4}	1.00	1.25
Accuracy of load assumptions	γ_{m5a}	1.00	1.30
	γ_{m5b}	1.00	1.20
Total	γ_m	**1.43**	**3.94**
		(1.35)	

this factor accounts for uncertainty in manufacturing variation…

…which could be

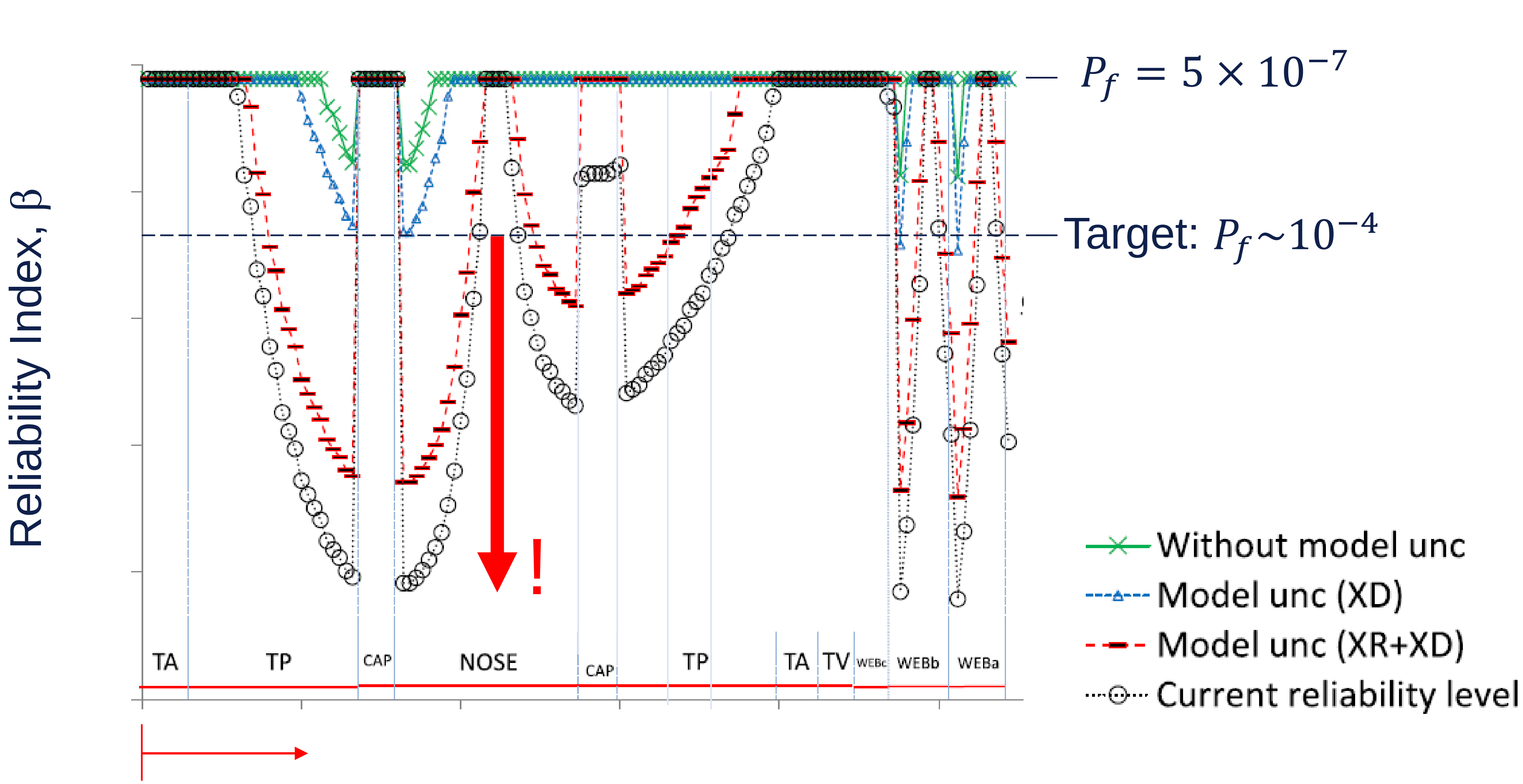
- Variation in fabric placement
- Variation in fibre angle
- Wrinkles
- Air entrapment in laminates
- Variation in fibre/resin ratio
- Contamination in resin
- Variation in mix ratio of resin
- Variation in mix ratio of glue
- Variation in degree of cure
- Contamination in bonding
- Surface preparation
- Variation in bond thickness
- Variation in bond width
- Variation of moisture in core
- Variation in cure shrinkage
- Variation in thermal shrinkage

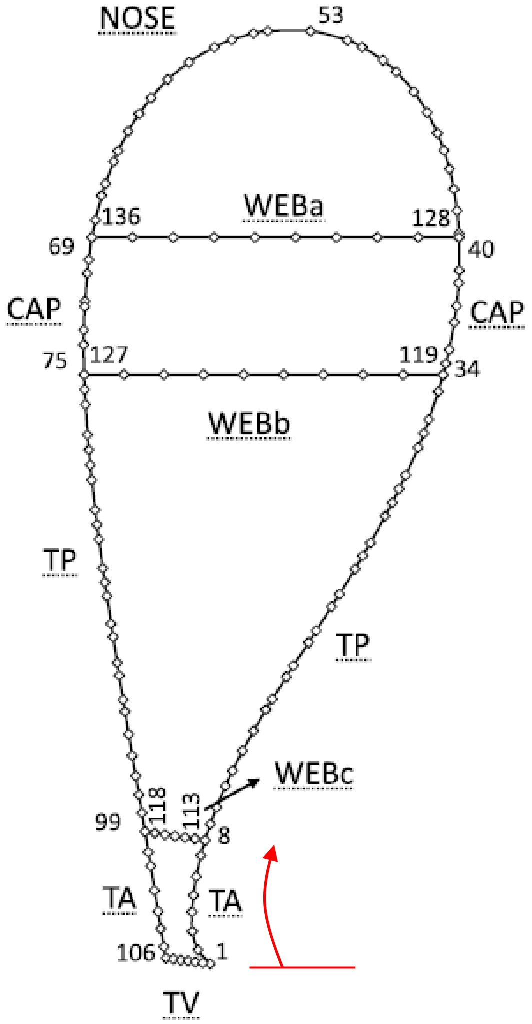
Design Evaluation – “Semi” Probabilistic Design Approach

		Min.	Max.
Base factor	γ_{m0}	1.20	1.20
Criticality of failure mode	γ_{mc}	1.08	1.08
Environmental degradation	γ_{m1}	1.10	1.20
Reversable temperature effects	γ_{m2}	1.00	1.00
Manufacturing effects	γ_{m3}	1.00	1.30
Accuracy of analysis methods	γ_{m4}	1.00	1.25
Accuracy of load assumptions	γ_{m5a}	1.00	1.30
	γ_{m5b}	1.00	1.20
Total	γ_m	**1.43**	**3.94**

These factors are based on engineering judgement and experience. They are uncalibrated.

Reliability





'Effect of uncertainty sources on the reliability level of wind turbine rotor blades', Konstantinos Bacharoudis, Wind Energy 2018 : 21 : 1029-1045

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Evolution.

Not Revolution!

1981

V15 (Vestas)
15m diameter
55kW
Units sold = 975

MOD-2 (NASA/Boeing)
91m diameter
2MW
Units sold = 3

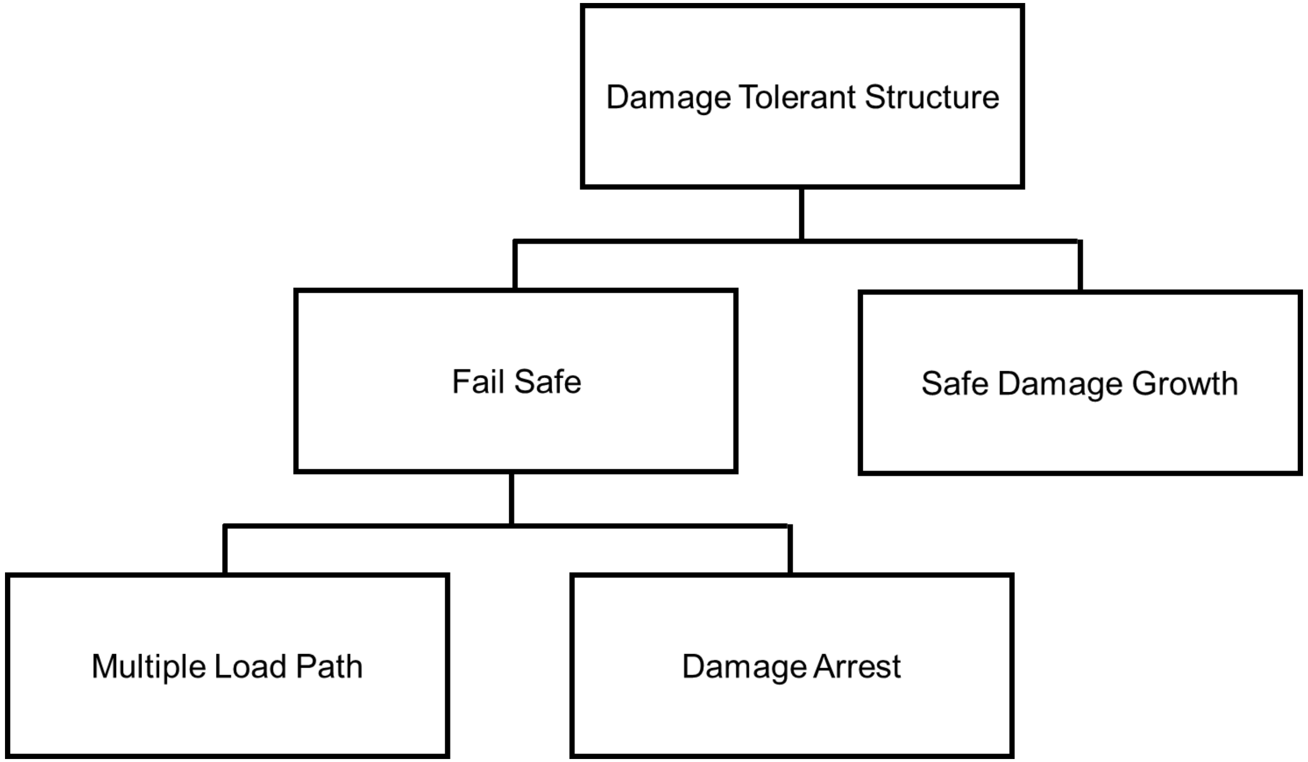
But today wind turbines are really, really big!

the consequence of defects and damage are higher and so we need to modernise certification to stay relevant to todays industry.

Future Requirements

Damage Tolerance - Definition

We recommend a definition of damage tolerance:

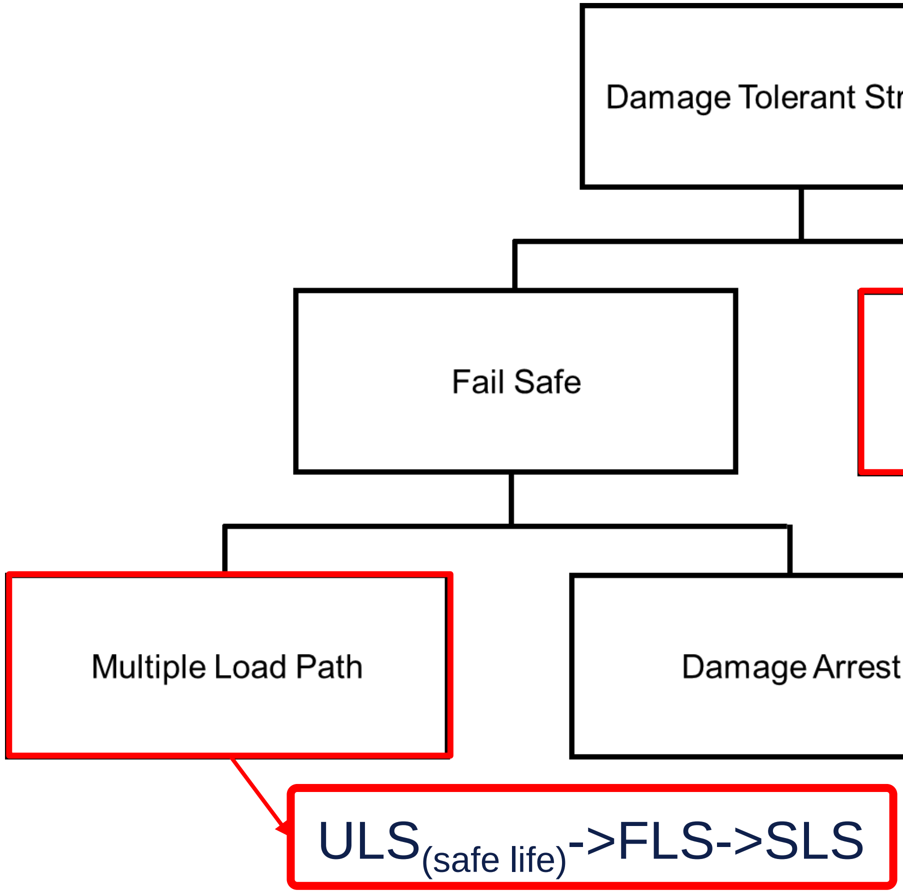


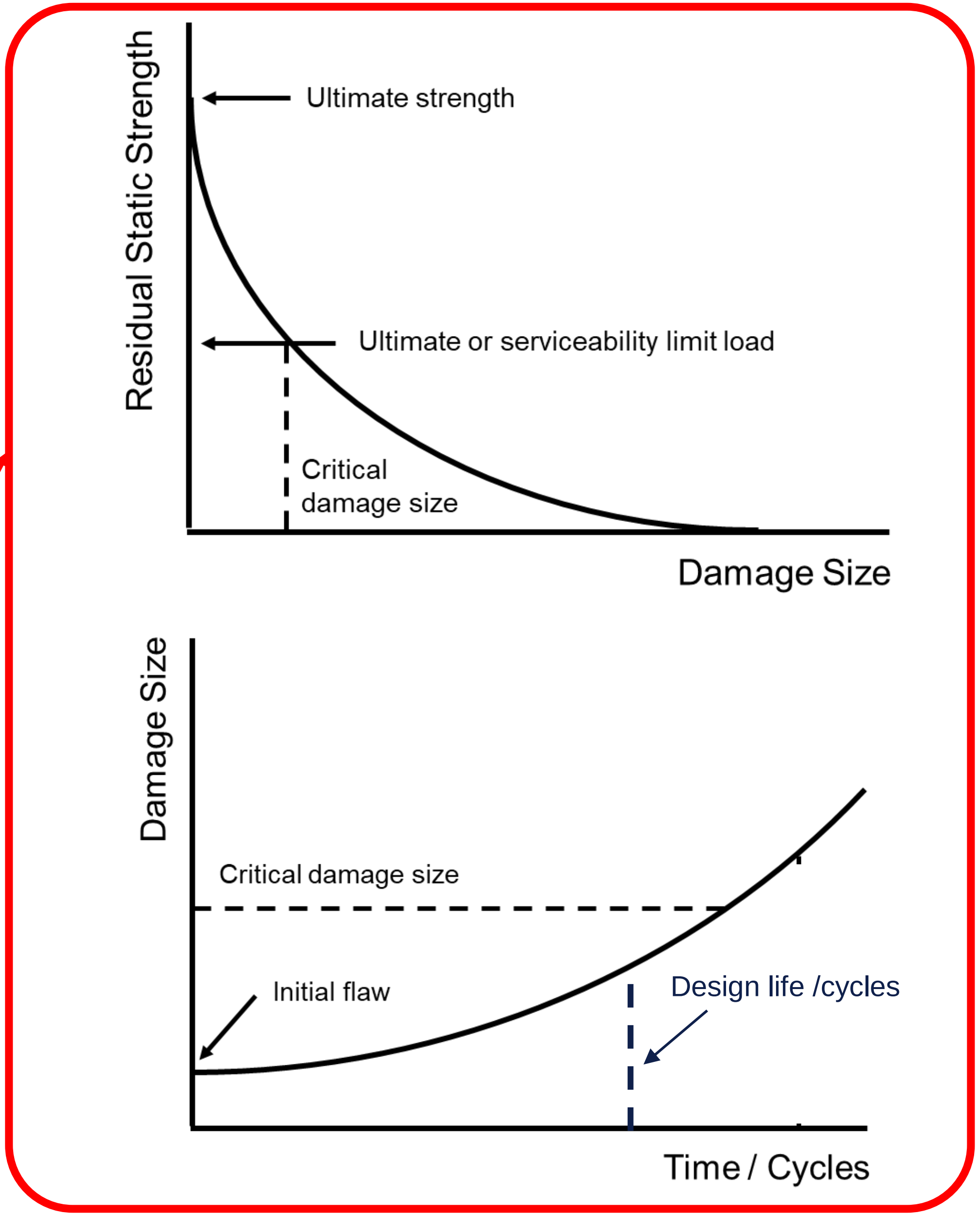
'Safe-Life and Damage-Tolerant Design Approaches for Helicopter Structures', Harold K. Reddick Jr., Applied Technology Laboratory, Army Research and Technology Laboratories (AVRADCOM)

'Damage Tolerance Evaluation of Fiber Reinforced Composite Tail Rotor Blades', Elif Ahci, 30th European Rotorcraft Forum

Damage Tolerance - Definition

We recommend a definition of damage tolerance:





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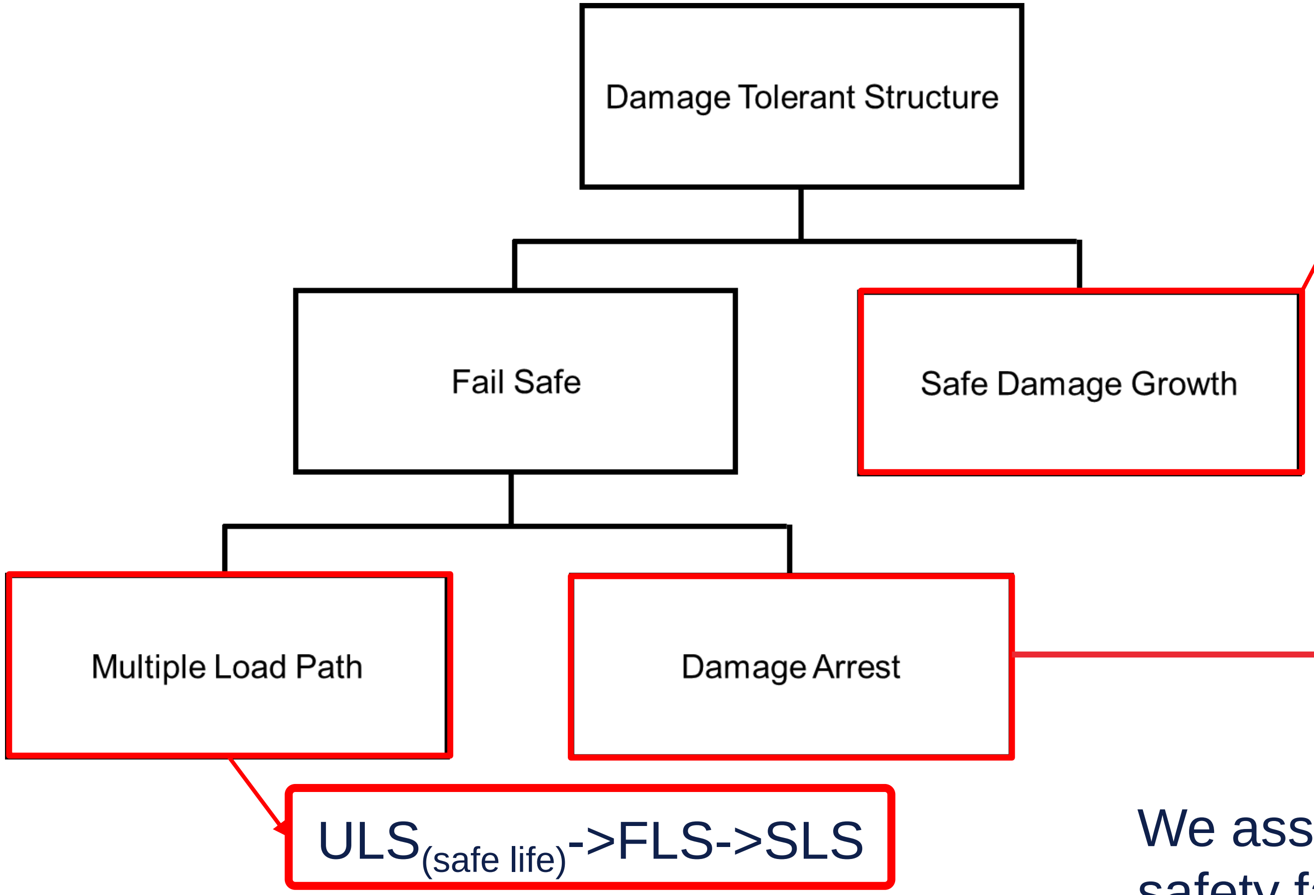
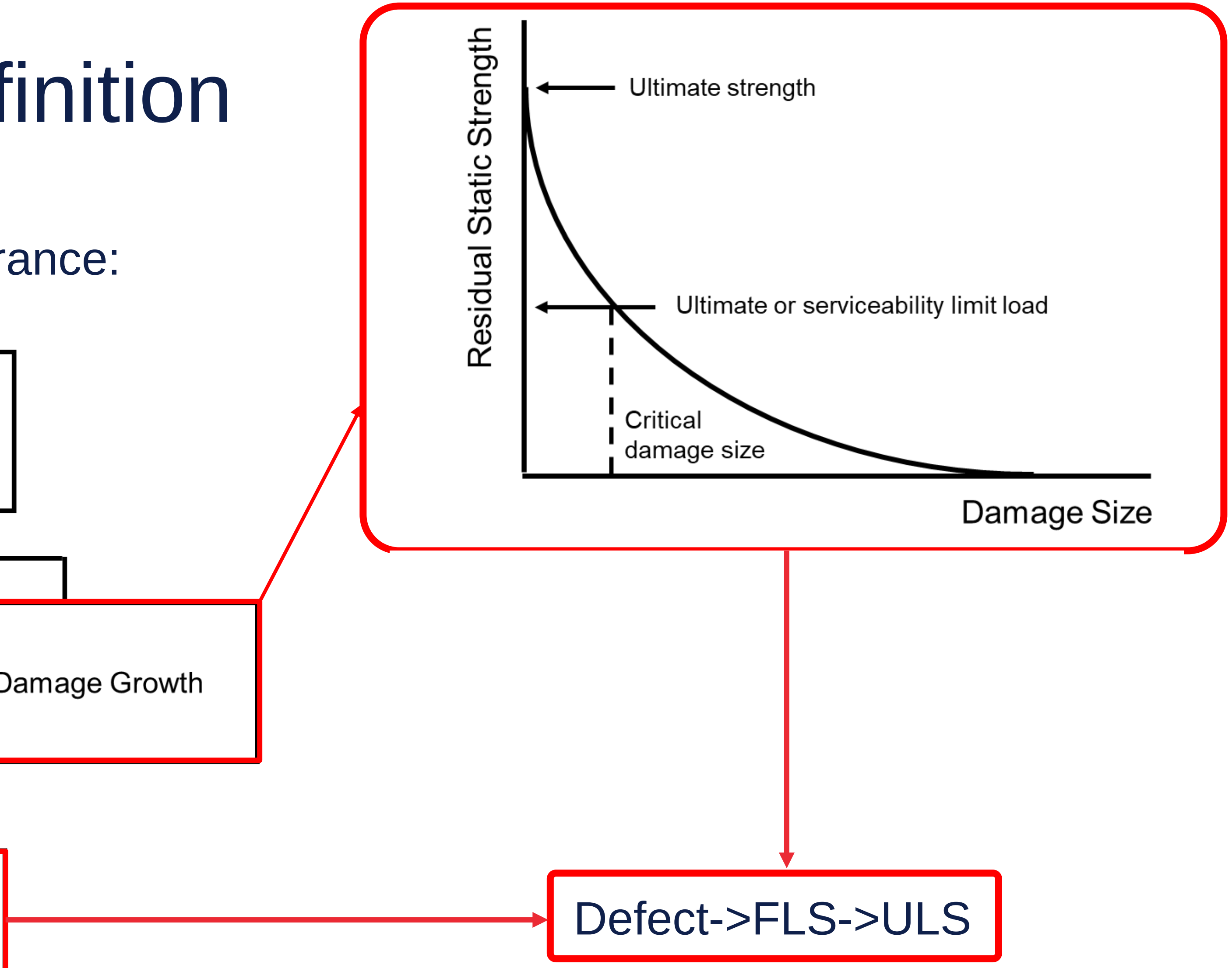
Damage Tolerance - Definition

We recommend a definition of damage tolerance:





We assume the same uncalibrated partial safety factors as for safe life analyses.

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Damage Tolerance – Accepted Methods of Assessment

Damage Type	Numerical Analysis	Sub-Structure Testing	Note
Fibre Failure		Acceptable	Numerical analyses = fracture mechanics Sub-structure test = define characteristic values
Inter-fibre Failure		Acceptable	
Interlaminar Failure / Delamination	Acceptable	Acceptable	
Adhesive Failure	Acceptable	Acceptable	
Core Failure		Acceptable	
Facesheet Debonding	Acceptable	Acceptable	

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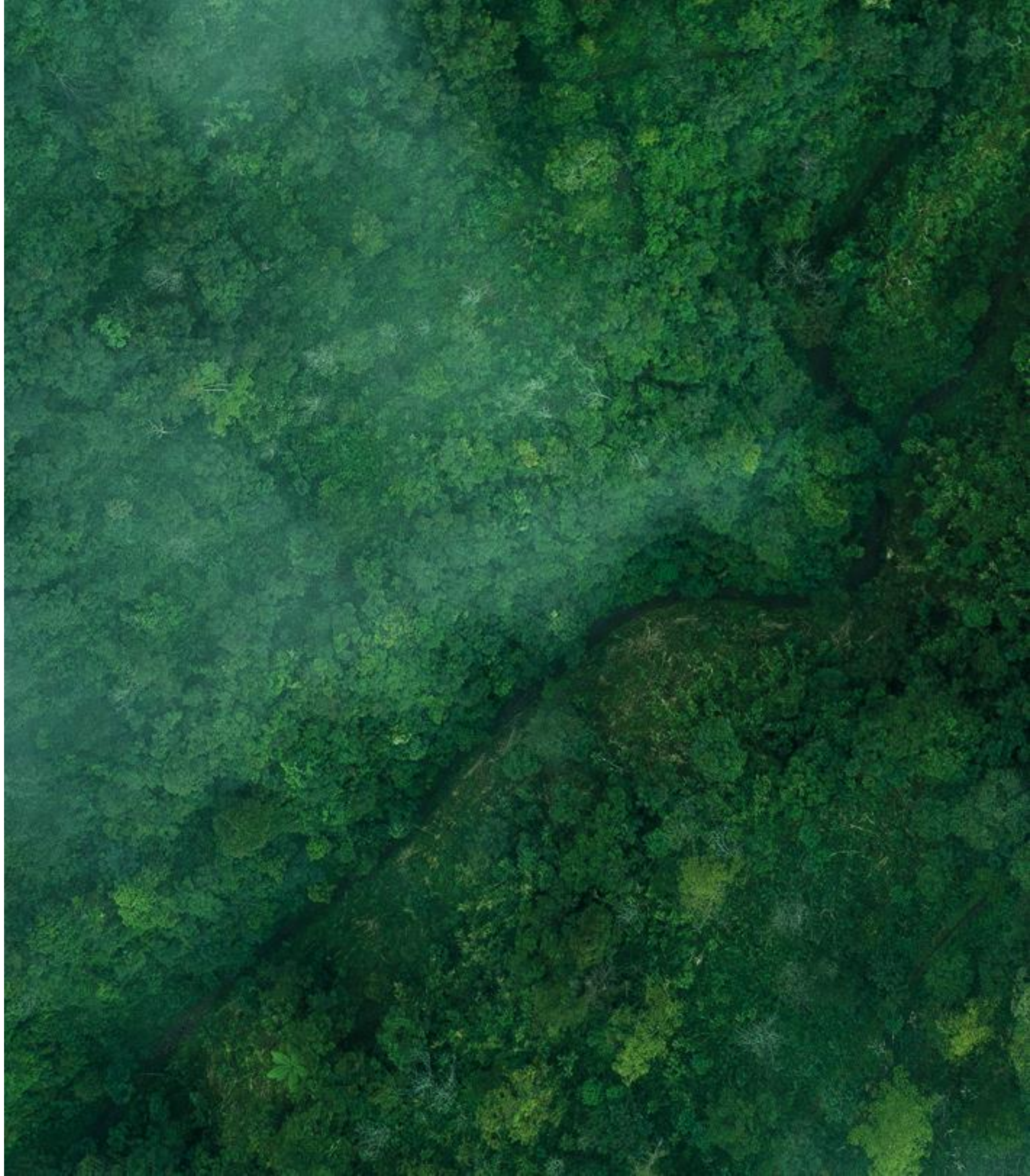
2 takeaways....

2 takeaways…..

1. The current partial material safety factors are based on engineering judgement and experience. They are uncalibrated, and work has shown that they are insufficient in producing the required target reliability.

2. We will use the same uncalibrated partial material factors for new damage tolerance assessment.

We could be happy for collaborative projects to better define these factors for future updates to the standard, DNV-ST-0376.



Any questions?

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