Probabilistic design with focus on blades

Sandia Blades Workshop 12-14 May 2008

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Contents

- Introduction: why do we use probabilistic design?
  - Public safety
  - Economic reasons
- Method
  - Example
  - Selected results
- Future work

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Public safety

(click image to play video)

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Public safety

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Which failure probability is allowed?

- *Failure is not an option.*
  - Gene Kranz, during the (movie of the) rescue of the Apollo 13, 1969.

- *Failure is an option, we just don't want it to happen very often.*
  - Dick Veldkamp, 2006.

- How often may be set by:
  - public safety considerations
  - economic considerations

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Public safety: small failure probability required

- Guidelines/standards: design for $p = 10^{-5}$ per year (component); even lower values may be required.

- Can we prove that we achieve this with statistics?

- Dutch Handbook for Risk Assessment of Wind Turbines
  - $p = 6.3\times10^{-4}$ (expected value, wind turbine)
  - $p = 8.4\times10^{-4}$ (95% reliability, wind turbine)

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Are new blades safer?

- A new blade has annual failure probability $p_{fail} = p$
- Probability of having $n = 0$ failures after N years:

$$P_0 = P(n=0) = (1-p)^N$$

- P_o is "amount of luck". Allow maximum amount of luck, then:

$$p \leq 1 - P_0^{1/N}$$

- Example: N = 5000 wind turbine years without failure, $P_o = 0.05$, then p < 6.0×10^{-4}

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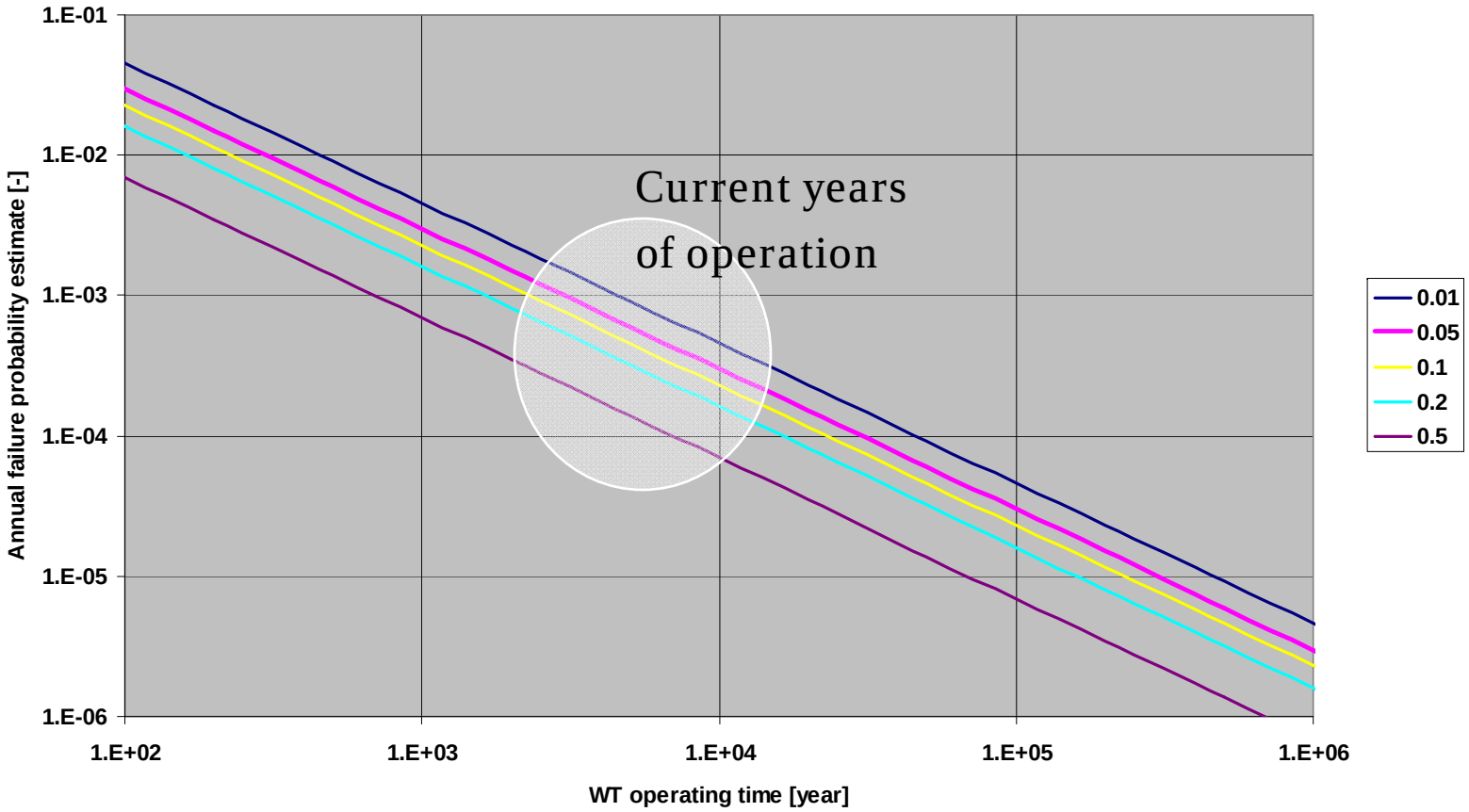
Are new blades safer?



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Why probabilistic methods?

- Low annual failure probability demanded.

- We cannot prove with data from actual turbines that blades have a failure probability at the design level of $p = 10^{-5}$ (300,000 turbine years needed)

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Economic reasons for probabilistic design

- Competition with other energy sources
- Competition with our colleague manufacturers
- Hence: blades must be just strong enough (and no stronger)

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Economic reasons

Cost [Euro ct/kWh]	Wind	Conventional
Generation	4-7	4
External (environment)	0	1-15
Financing (economic life)	3-6 (10 years)	0 (40 years)
TOTAL	7-13	5-19

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Why probabilistic methods?

- We cannot prove with statistical data from actual turbines that blades have a failure probability at the design level of $p = 10^{-5}$ (300,000 turbine years needed)

- Economic considerations.

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Design method

$$\frac{R}{\gamma_m} \geq \gamma_f S$$

- How large γ_f and γ_m must be is determined by probabilistic considerations: which failure probability is allowed?
- Failure probablity found by examining the limit state function $Z(\underline{x}) = R(\underline{x}) - S(\underline{x})$ as function of γ_f and γ_m

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Limit state function $Z(\underline{x}) = R(\underline{x}) - S(x)$

- Resistance R depends on:
  - Fatigue strength
    - Test probe fatigue strength
    - Stress factor (reduction of strength due to sequence effects)
  - Manufacturing tolerances
  - Accuracy of design methods
  - ...

- Load S depends on:
  - Wind climate (speed, turbulence, shear)
  - Wave climate
  - Controller settings
  - ...

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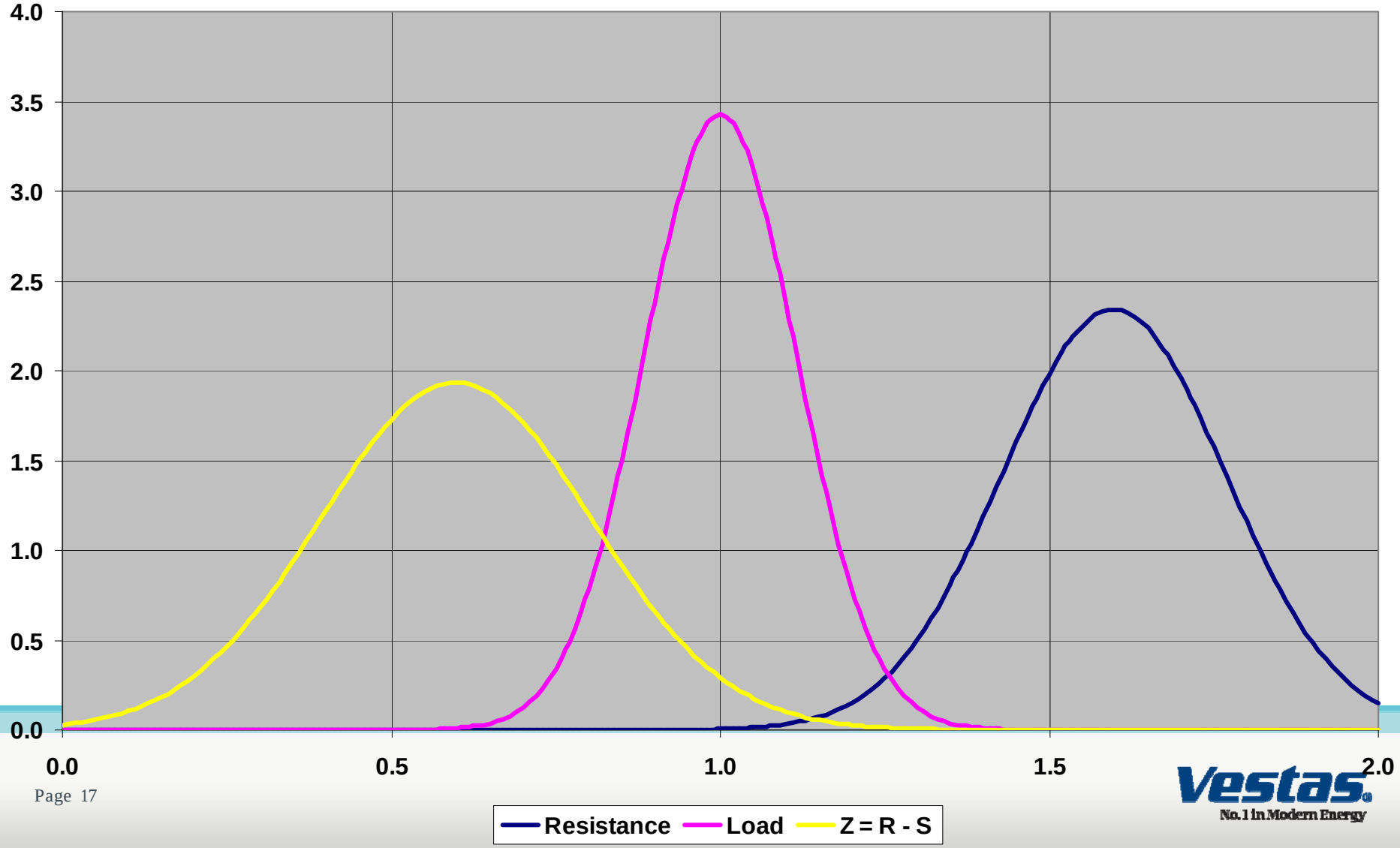
Probabilistic design: variation in $Z(\underline{x}) = R(\underline{x}) - S(\underline{x})$



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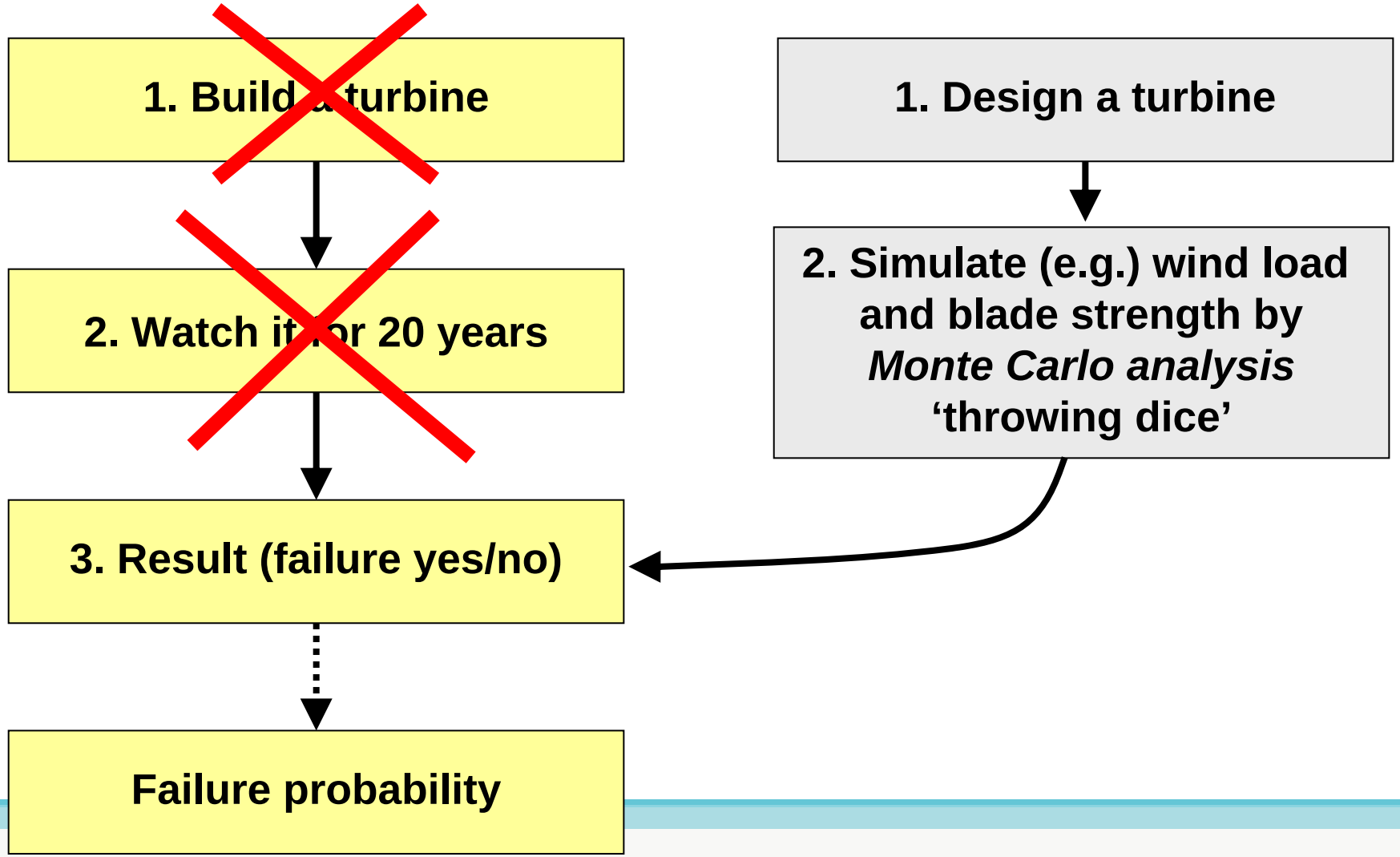
Monte Carlo: 100.000 experiments



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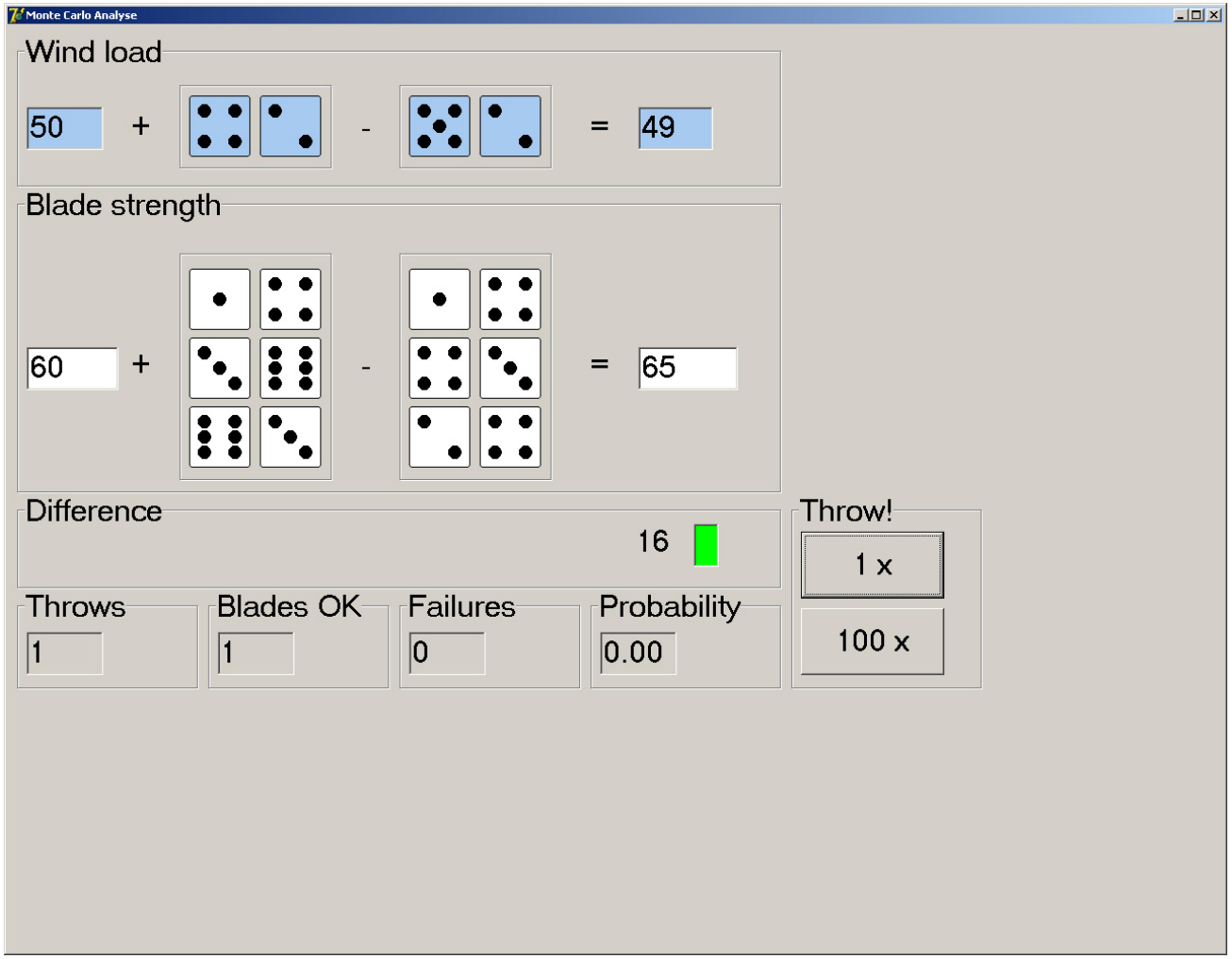
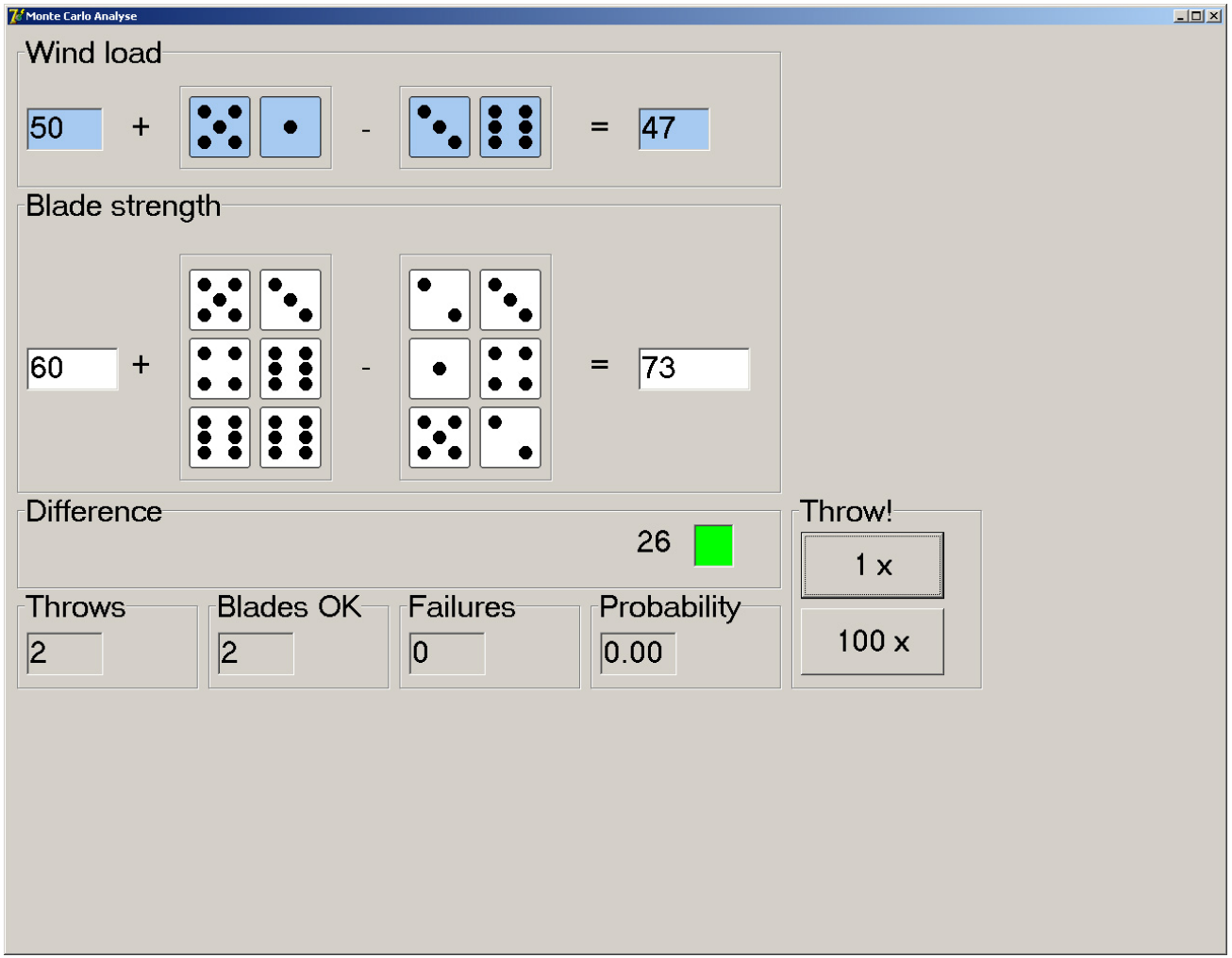
Demo Monte Carlo method



Demo Monte Carlo method



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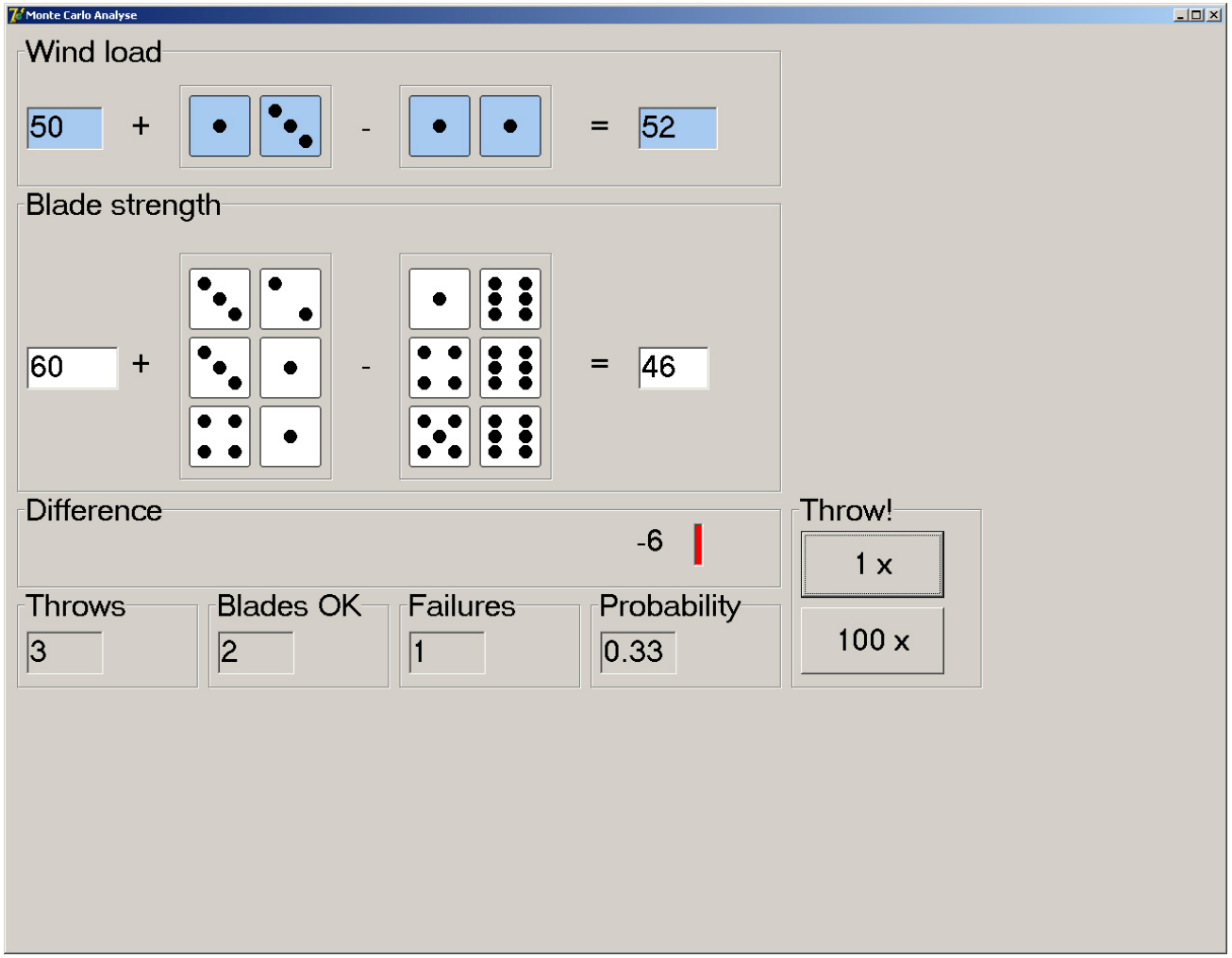

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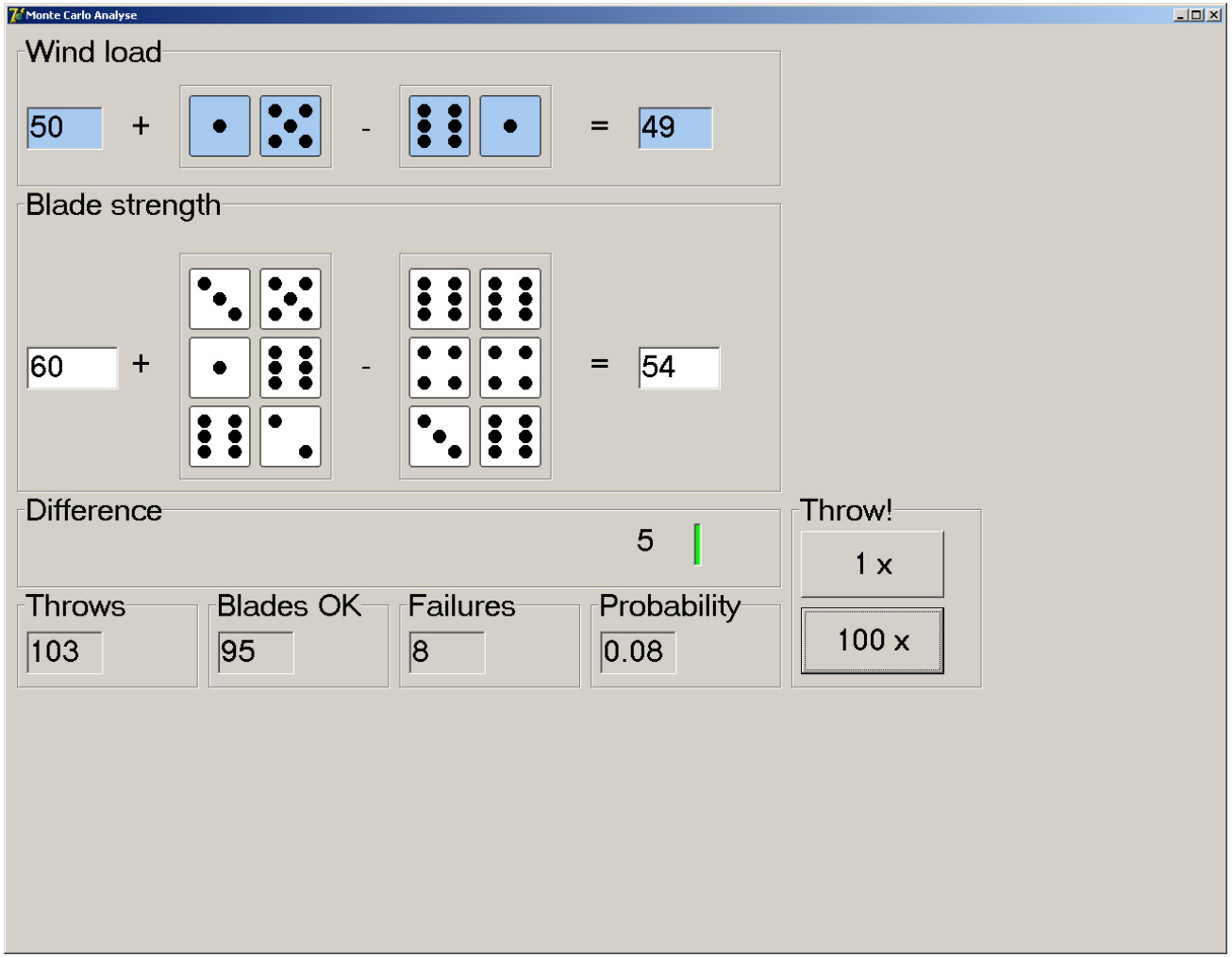

Example: base case

- NM92/2750-70 Pitch Regulated Variable Speed
- IEC II design for and IEC class II site
- Wind speed: $U_{design} = U_{site} = 8.5$ m/s at hub height
- Turbulence intensity: $I_{design} = 18\%$, $I_{site} = 16\% + 2\%$ for windfarm wakes
- Wind spectrum shape: Mann's $\Gamma_{design} = 3.9$ (Kaimal), $\Gamma_{site} = 3$
- Total safety $\gamma = \gamma_f \gamma_m = 1.5$

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Annual failure probabilities found

- Edge moment: $p_1 = 4.5\times10^{-6}$
- Flap moment: $p_1 = 5.4\times10^{-5}$
- Handbook: $p_1 = 6.3\times10^{-4}$

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Explanation of difference

- Turbines are better now
- Extreme failures are not considered
- Lightning strike is not considered
- Optimism in estimation of distribution

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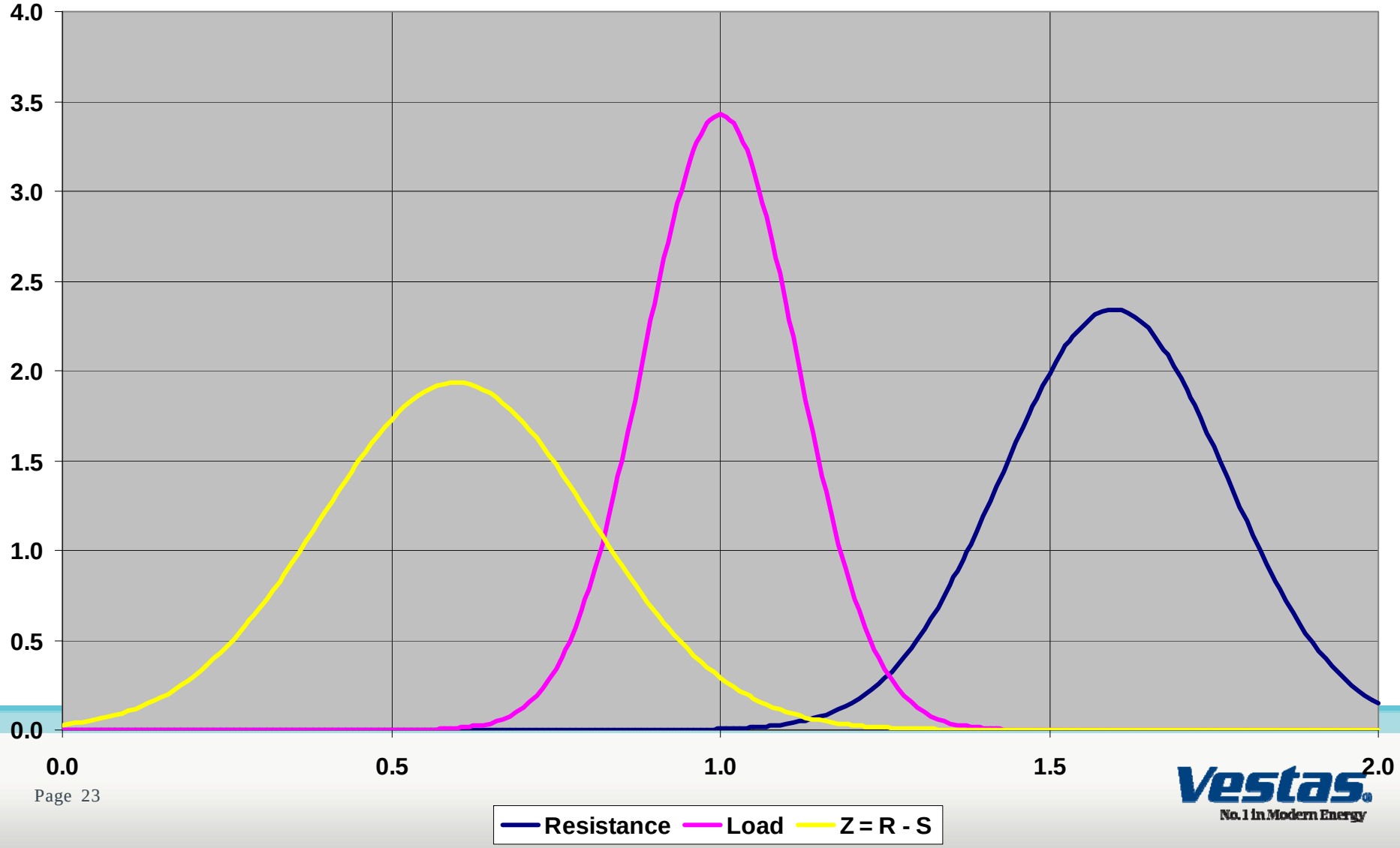
Probabilistic design: variation in $Z(\underline{x}) = R(\underline{x}) - S(\underline{x})$



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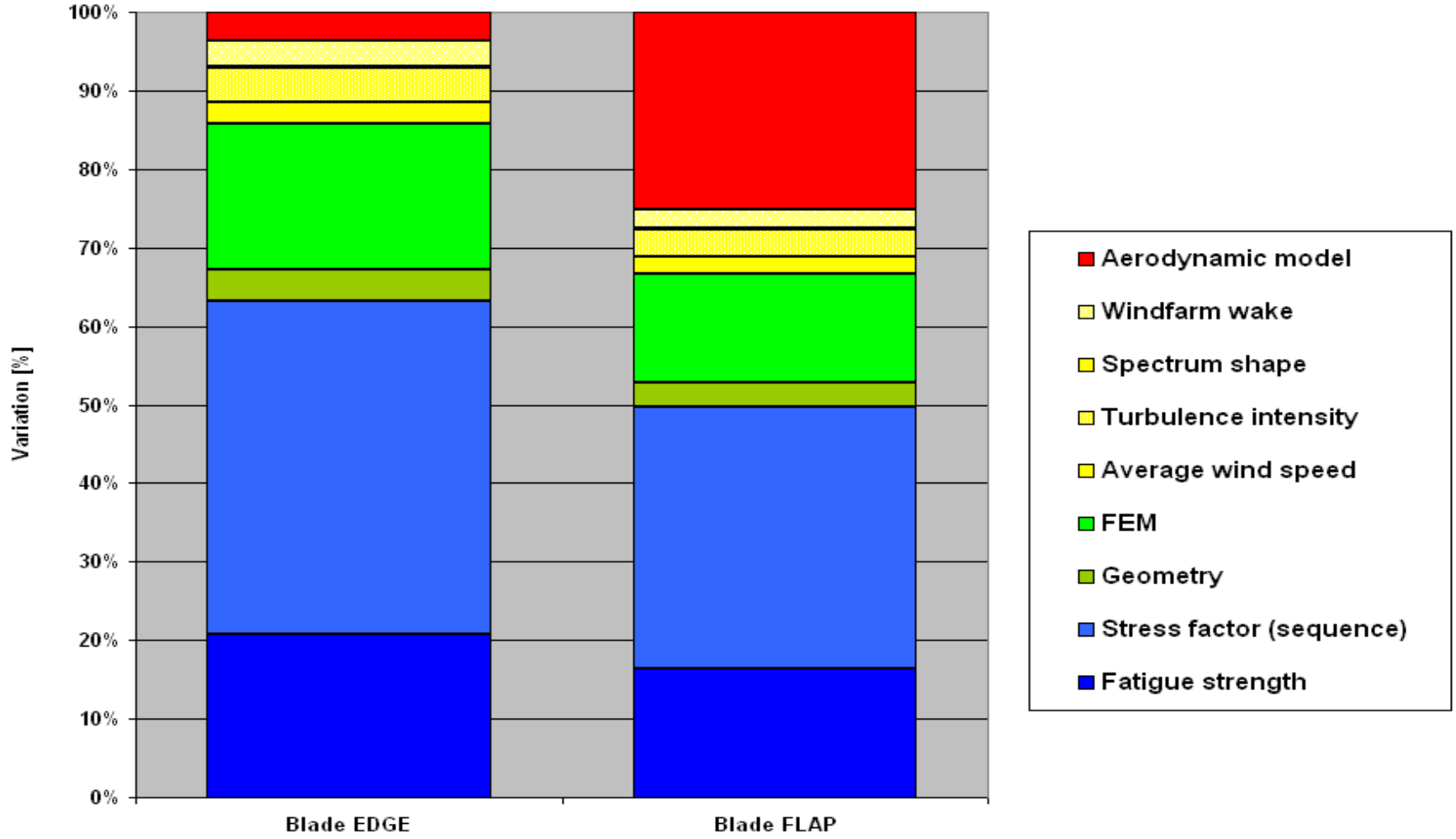
Distribution of variation in limit state function $Z(\underline{x})$



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Required safety factor for target $p_1 = 10^{-4}$ per year

Parameter **known exactly**	Edge moment	Flap moment
None	1.33	1.45
Aerodynamic model	1.33	1.34
FEM	1.27	1.40
Stress factor (load sequence)	1.18	1.33
Test probe fatigue strength	1.26	1.39

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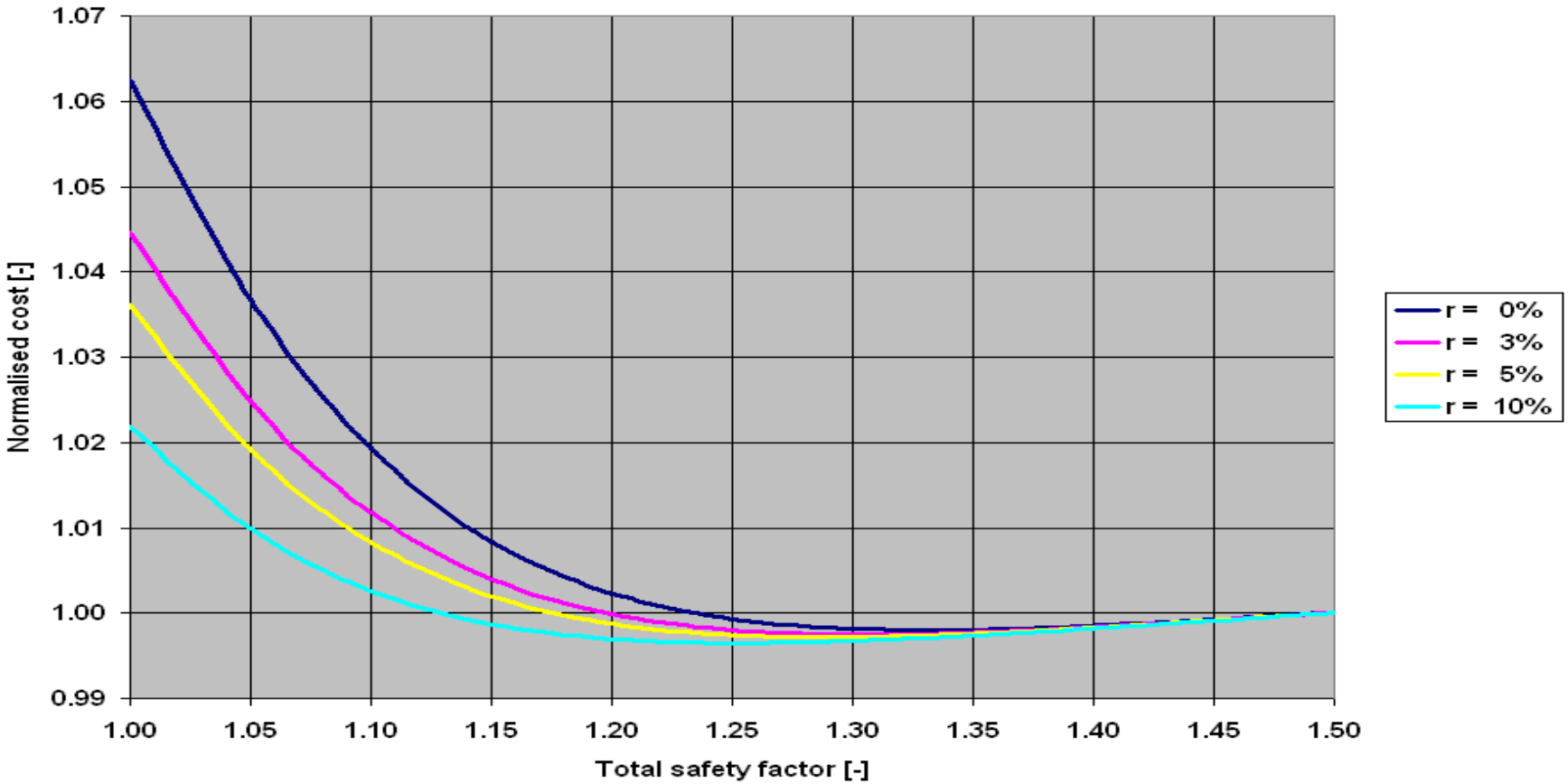
Economic optimum: interest rate



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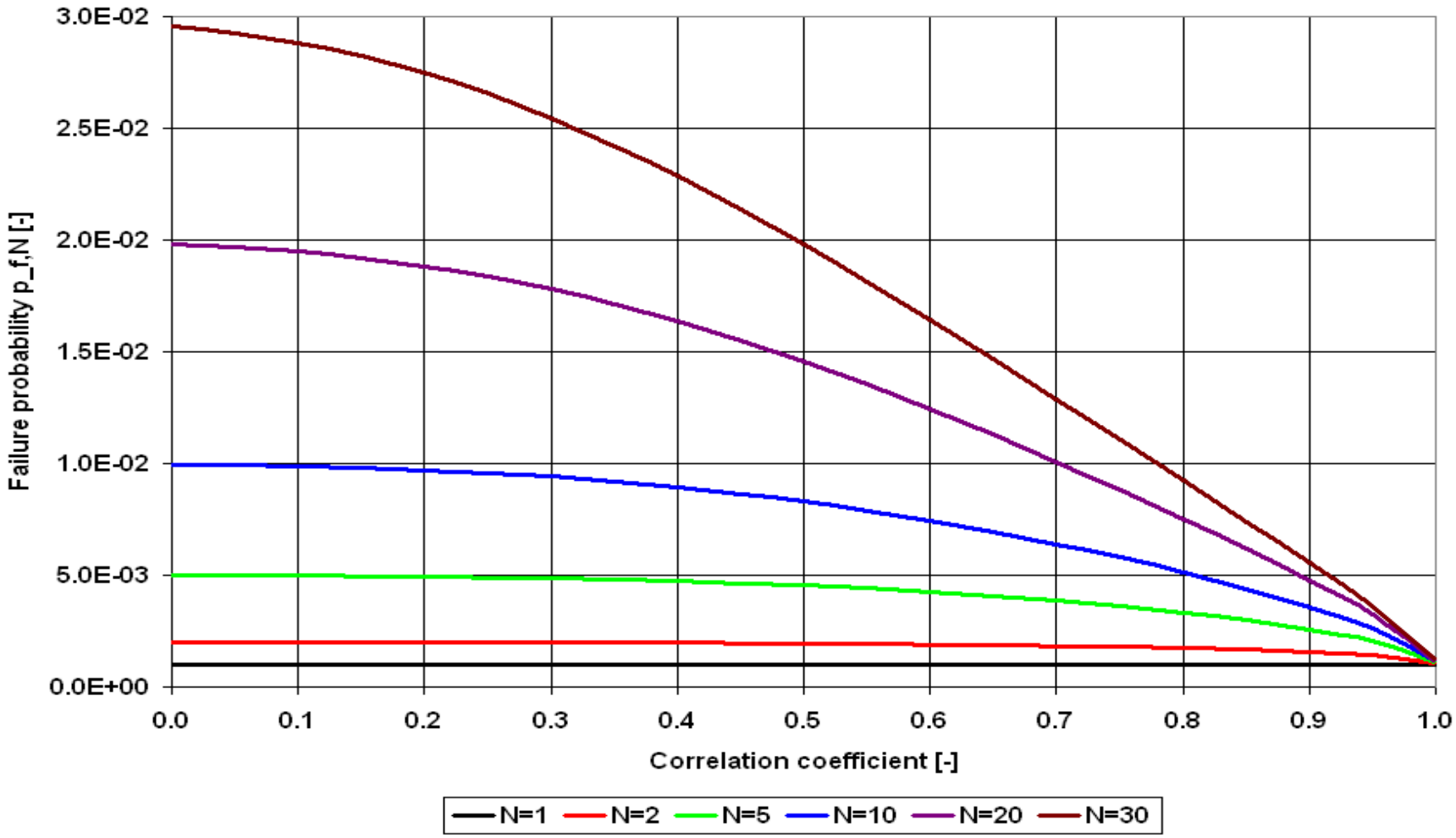
Multiple failure locations



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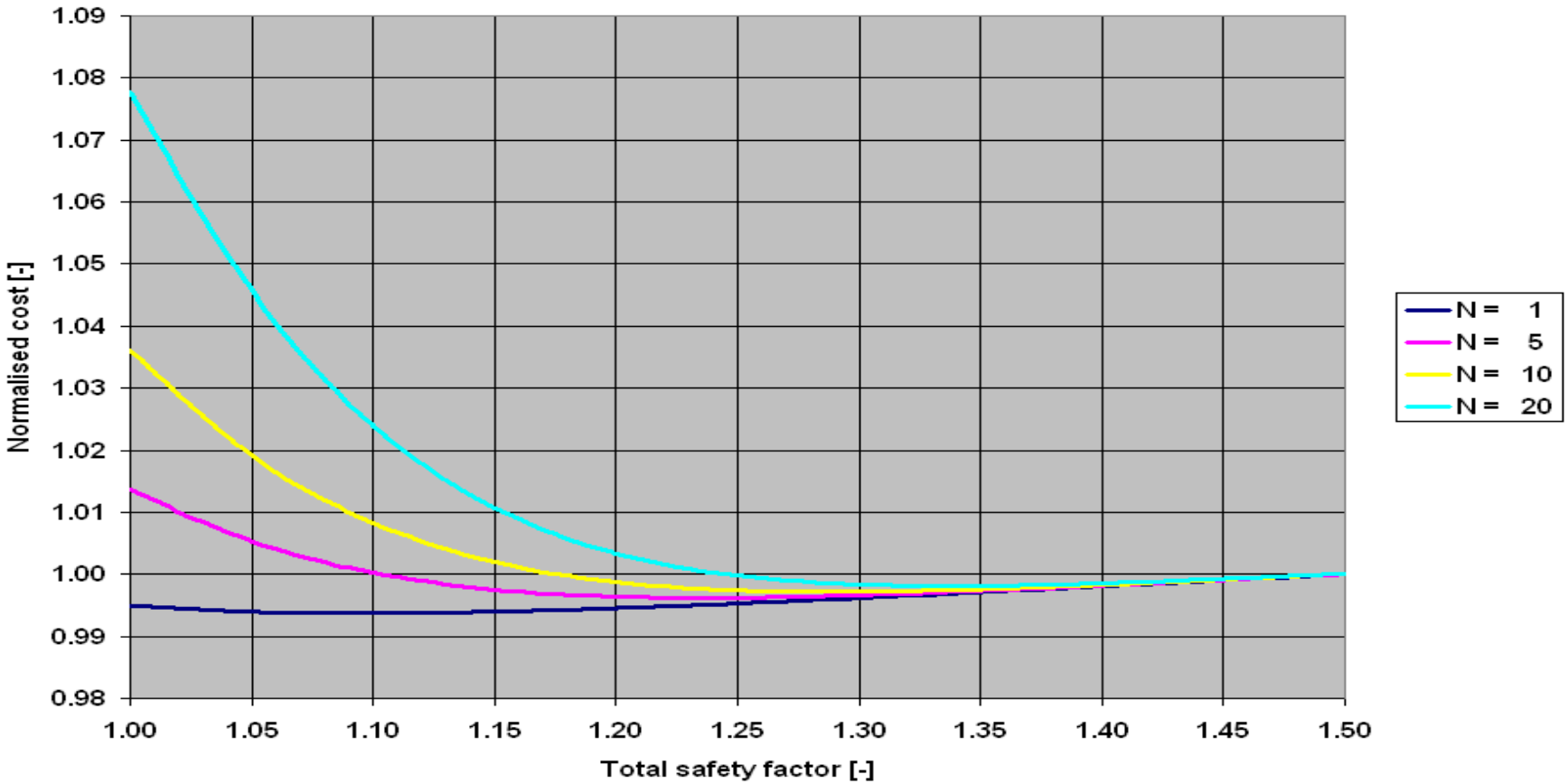
Economic optimum: number of failure locations



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Future work

- Common failure database?
- Fatigue testing and modeling
- Aerodynamic research
- More insight into FEM: blind FEM testing, stochastic FEM?

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Details?

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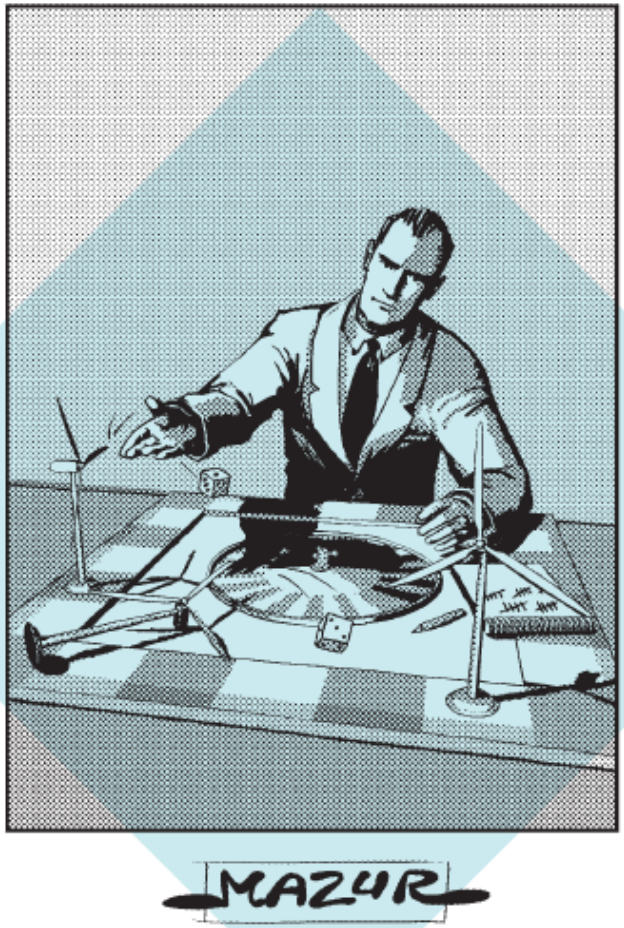
Details:

Chances in Wind Energy

A Probabilistic Approach to Wind Turbine Fatigue Design



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