RELIABILITY OF TIDAL STREAM TURBINES AND THEIR COMPONENTS

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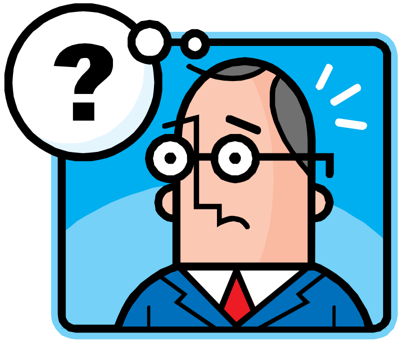
MAIN CHALLENGE

- Extraction of kinetic energy from tidal streams is a new technology
- No historical data on failures of tidal stream turbines

How can reliability be assessed in such situation?



POSSIBLE APPROACHES

1) Direct use of data on failure rates of similar parts from other industries (e.g., NPRD-95, OREDA, Windstats) – T. Delorm & P. Tavner, Durham University)

2) Modification of the base failure rate to conditions of tidal stream turbines by using “influence” multiplying factors

3) Direct probabilistic analysis of the turbine subsystem/component

4) Testing of subsystem/component – P. Thies, G. Smith & L. Johanning, University of Exeter

MODIFICATION OF BASE FAILURE RATE – BAYESIAN APPROACH

$$\lambda = \lambda_B C_m \prod_j C_j$$

$$\left.\begin{array}{l} \lambda_B \text{ – base failure rate for component} \\ C_j \text{ – influence factors} \\ C_m \text{ – factor representing model uncertainty} \end{array}\right\} \text{random variables}$$

$$\Downarrow$$

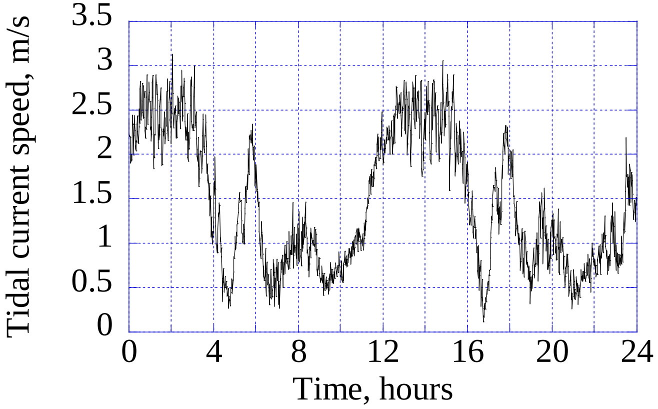
Prior distribution of failure rate, $\pi_0(\lambda)$

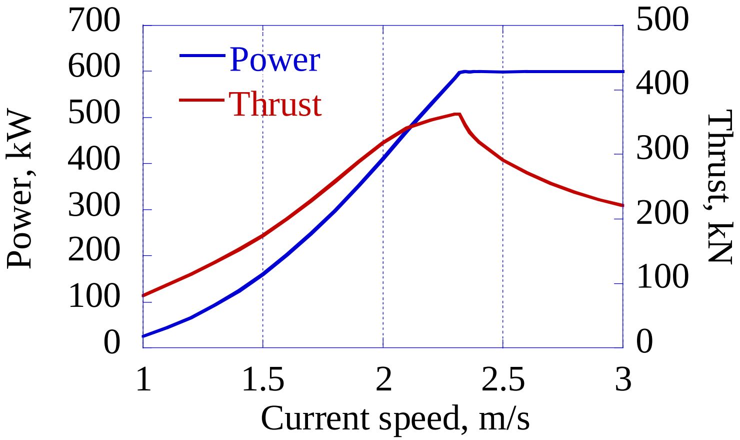
$$\Downarrow$$

New information – number of failures, n, over time T

Posterior distribution $\pi(\lambda) = \frac{1}{c}\pi_0(\lambda)L(n \mid \lambda)$

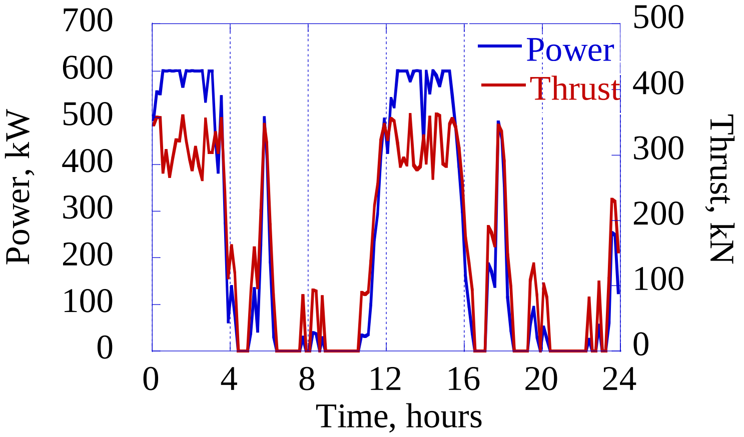
EXAMPLE: Estimation of failure rate of main bearing of tidal turbine drive train





Turbine parameters:

- Horizontal axis
- Single indirect drive train
- Power = 600 kW
- Rated current speed = 2.4 m/s
- Rotor diameter = 16 m
- Pitch-controlled blades



Prior distribution of failure rate

Random variable	Mean	COV	Distribution
Basic failure rate, λ_B	$0.14/L_{10}$	0.20	Lognormal
Operating temperature, t_0	60°C	0.20	Beta on (20°C, 100°C)
Percentage of water in lubricant	0.2%	0.20	Beta on (0.01%, 1.0%)
Service condition factor, C_F	1.1	0.05	Beta on (1., 1.4)
Factor for model uncertainty, C_m	1	0.1 - strong 0.5 - medium 1.0 - weak	Lognormal

$$\lambda = \lambda_B C_v C_C C_t C_{SF} C_m$$

Using Monte Carlo simulation

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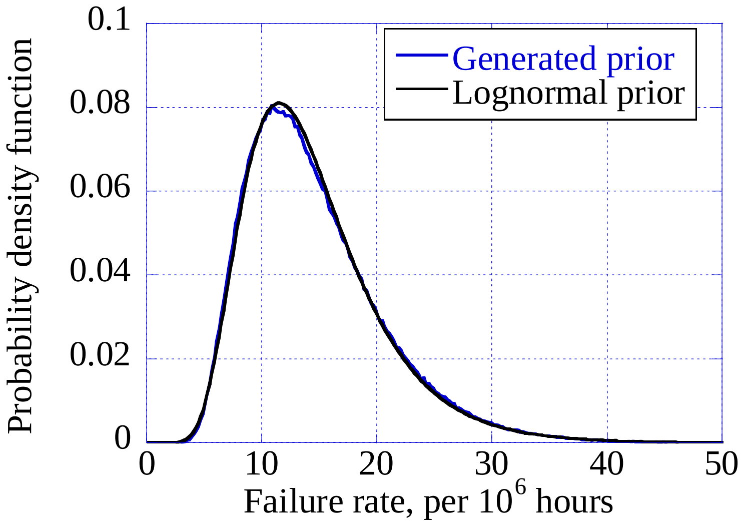


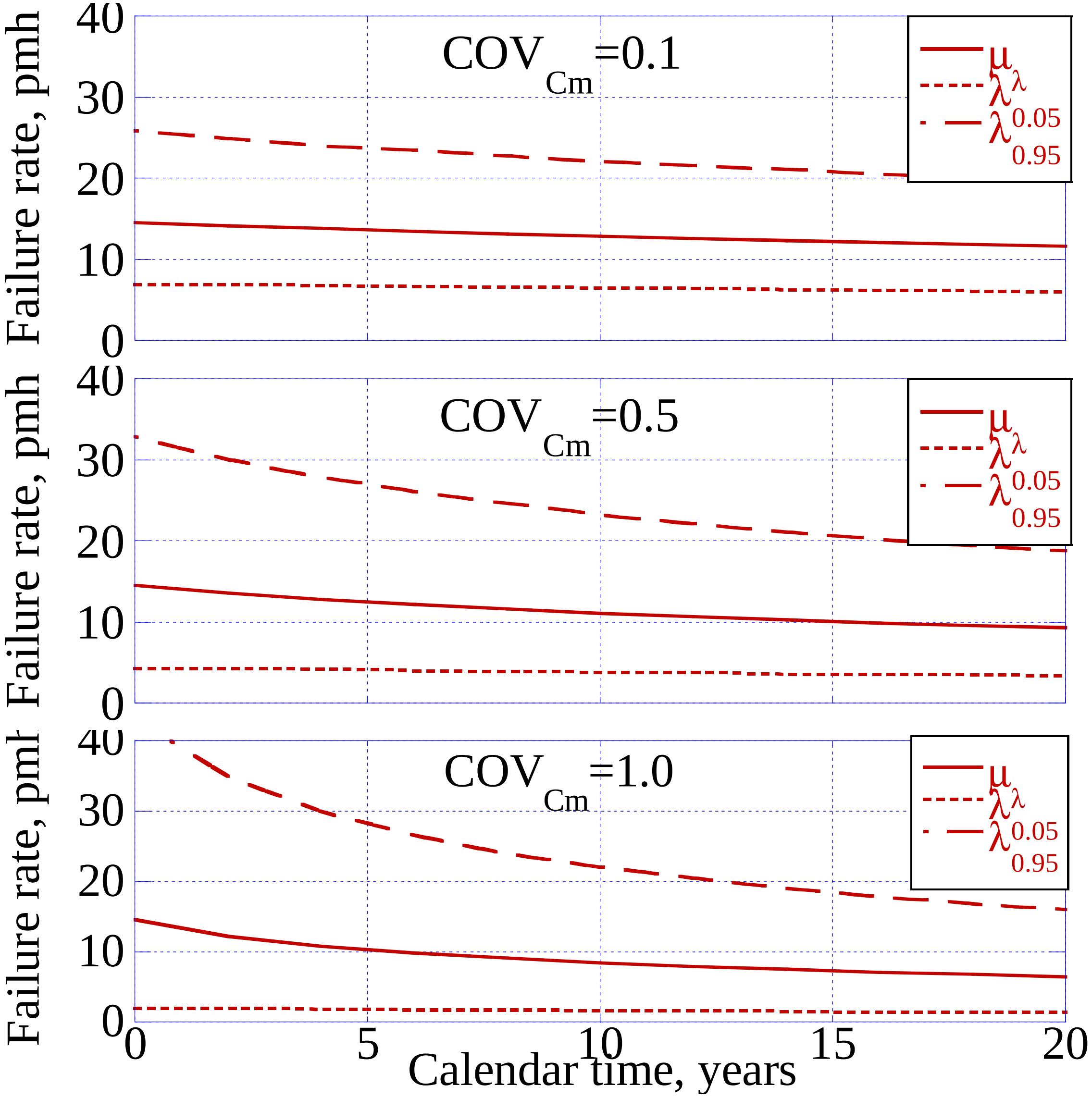
Posterior distribution of failure rate

After one calendar year of operation

COV_{Cm}	n (failures)	μ_{λ} (pmh)	COV_{λ}	$\lambda_{0.05}$ (pmh)	$\lambda_{0.95}$ (pmh)
0.1	prior distribution				
	-	14.6	0.41	6.9	25.9
	posterior distribution				
	0	14.4	0.41	7.0	25.3
	1	16.8	0.41	8.1	29.7
	2	19.5	0.41	9.5	34.5
0.5	prior distribution				
	-	14.6	0.67	4.3	32.9
	posterior distribution				
	0	14.1	0.65	4.4	31.5
	1	20.0	0.65	6.3	44.7
	2	28.4	0.64	9.0	62.7
1.0	prior distribution				
	-	14.6	1.16	2.0	43.1
	posterior distribution				
	0	13.2	1.06	2.0	38.7
	1	27.9	0.98	4.6	78.9
	2	54.8	0.89	9.9	148.4

Posterior distribution of failure rate

After 20 calendar years of failure-free operation



DIRECT PROBABILISTIC ANALYSIS

Probability of failure of a structural component

$$P_f = \Pr\left[G(\mathbf{x}) \leq 0\right]$$

$G(\mathbf{x})$ – limit state function

$G(\mathbf{x}) \leq 0$ – failure of the component

$\mathbf{x}$ – vector of basic random variables

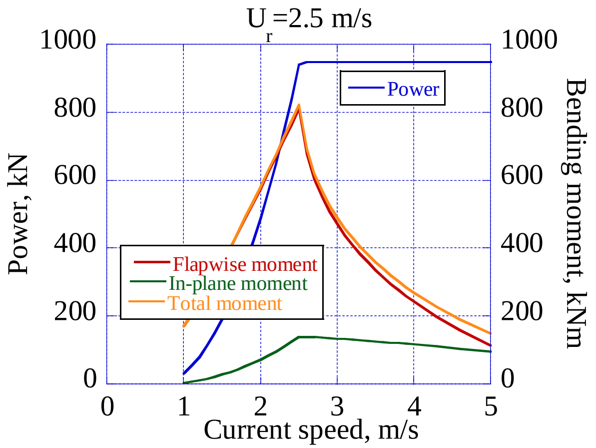
Reliability index: $\beta = -\Phi^{-1}(P_f)$

For decision making: $P_f \leq P_{f,T}$ or $\beta \geq \beta_T$

According to ISO 2394 “General principles on reliability for structures”:

$\beta_T = 2.3 \div 3.1$ (or $P_{f,T} = 1\times10^{-3} \div 1\times10^{-2}$)

EXAMPLE: Reliability analysis of blades of tidal stream turbine



Turbine parameters:

- Horizontal axis
- Single indirect drive train
- Rated current speed U_r = 2.0 or 2.5 m/s
- Rotational speed = 13 rpm or 14 rpm
- Three-bladed rotor, diameter = 18 m
- Pitch-controlled blades (NREL S814)

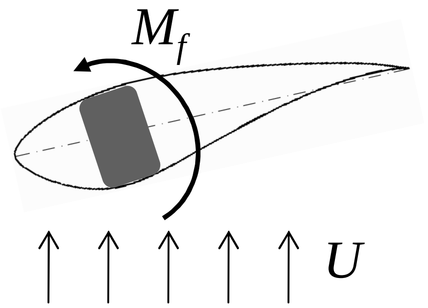
For constant pitch angle at rated speed

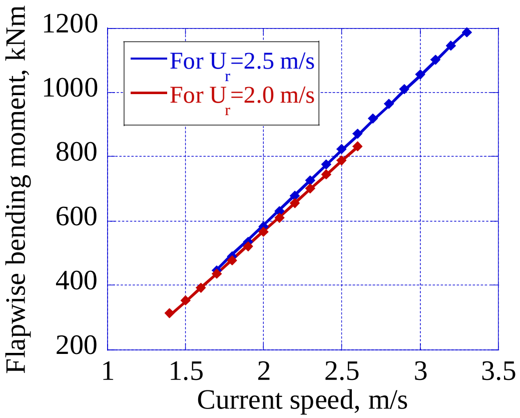
U_r= 2.0 m/s:

$M_f = 438U - 306$ (kNm)

U_r= 2.5 m/s:

$M_f = 464U - 338$ (kNm)





Results of reliability analysis

Limit state function:

$$G = f_t - \frac{M_f}{Z} = f_t - \frac{C_m\left[A\left(U_r + \Delta U\right) - B\right]}{Z}$$

Z – section modulus of the spar

f_t – tensile strength of the blade spar material: lognormal, COV = 0.10

ΔU – current speed fluctuations: beta on ($-0.3U_r$, $0.3U_r$), mean = 0

C_m – factor representing model uncertainty: normal, mean =1, COV=0.15

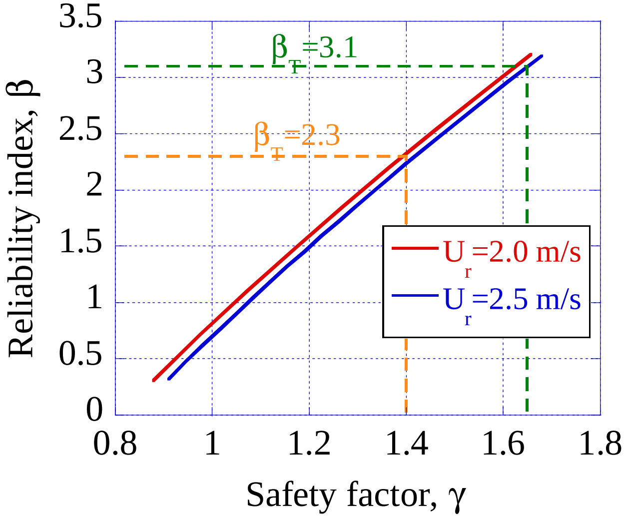
Ultimate limit state design: $R_d \geq S_d$

$$R_d = \frac{f_{t,k}}{\gamma_m}; \quad S_d = \gamma_f \frac{M_f}{Z}$$

Safety factor: $\gamma = \gamma_f \gamma_m = \frac{f_{t,k}}{M_f / Z}$

β_T=2.3: γ_m=1.1; γ_f=1.3

β_T=3.1: γ_m=1.1; γ_f=1.5



SUMMARY

- To be used for reliability assessment of tidal stream turbines available generic failure data need to be adjusted
- Method for estimation of failure rates of mechanical components in new applications using generic failure data and new information from observing performance of the components in operating devices has been presented
- Direct probabilistic analysis can be used for reliability assessment of structural components of tidal stream turbines
- Partial safety factors for design of rotor blades in tidal stream turbines have been derived using structural reliability analysis