Windenergienutzung Formelsammlung

Noise

Addition of sound ~~pressure~~ power levels

$$L_W = 10 \log\left(\frac{W}{W_{ref}}\right) \quad [dB]$$

$$L_{W,total} = 10 \log\left(\frac{\sum_{i=1}^{N} W_i}{W_{ref}}\right) = 10 \log\left(\sum_{i=1}^{N} 10^{0,1 L_{W,i}}\right) \quad [dB]$$

W ≙ Sound power [Watts]
W_{ref} ≙ Reference [Watts]; $W_{ref,air} = 10^{-12}$ Watts

Sound ~~power~~ pressure level of a wind turbine at the receiver

$$L_{pA} = L_{WA} - \left[20 \log\left(\frac{R}{R_{ref}}\right) + 11\right] + K + \overbrace{A}^{=\alpha \cdot R} \quad [dBA]$$

L_{WA} ≙ A-Weighted sound power level of the source
R ≙ Distance source-receiver
R_{ref} ≙ R_0, reference distance, usually 1m
K ≙ Adjustment for tonality (K_T) and impulsiveness (K_I)
A ≙ Attenuation occuring during propagation from source to receiver

Sound Level

$$L = 20 \log\left(\frac{p_{measured}}{p_{ref}}\right)$$

At 0dB, there is only $p_{ref} = 2 \cdot 10^{-5}\,Pa = 20\,\mu Pa$

Reliability

~~Reliability~~

~~$P_r(T \geq t) = R(t) = 1-F(t) = \int_0^t f(x)\,dx$~~

~~$f(x)$ ≙ time-to-failure probability density function~~

Cumulative distribution function (describes the probability of failure)

$$P_r(\underbrace{T}_{\text{use-time}} \leq t) = F(t) = 1 - R(t) = \int_0^t f(x)\,dx$$

$f(x)$ ≙ Time-to-failure probability density function

Reliability

$$P_r(T > t) = R(t) = 1 - F(t) = \int_t^{\infty} f(x)\,dx$$

Failure Rate

$$\lambda(t) = \frac{f(t)}{R(t)}$$; $F(t) \cdot n$ = numbers of failed systems

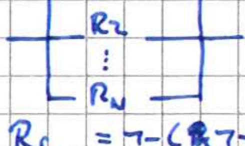
Mean time between failure

$$MTBF = \lambda^{-1}$$

$$R(t) = \exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$$

– R_1 — R_2 — ··· — R_N –

$$R_S = R_1 \cdot R_2 \cdots R_N$$



$$R_S = 1 - (1-R_1)(1-R_2)\cdots(1-R_N)$$

Lidar

Frequency of the emitted light

$f = \frac{c}{\lambda}$ $c \mathrel{\hat{=}}$ Speed of light

Power factor

$Pf = \frac{P}{\sqrt{P^2 + Q^2}}$

Windenergienutzung Formelsammlung

Energy yield calculation

Barometric formula

$$\rho(h_1) = \rho(h_0) \cdot \exp\left(-\frac{\Delta h}{h_s}\right)$$

$h_s \hat{=}$ scale height $\hat{=}$ 7800 m

Weibull probability density function

$$f(x) = \frac{k}{A}\left(\frac{x}{A}\right)^{k-1} \exp\left(-\left(\frac{x}{A}\right)^k\right)$$

$A \hat{=} \frac{2}{\sqrt{\pi}} V_m \hat{=}$ scale parameter
$k \hat{=}$ form parameter (mean windspeed distribution at $k=2$)

Power output

$$PO = \underset{\text{kW}}{P} \cdot \underset{\text{m/s}}{f(x)} \cdot 365 \cdot 24 / 1000 \quad [\text{MWh}]$$

$$P = \frac{1}{2}\rho A V^3 c_p \quad [\text{kW}]$$

Operation at partial load

$$P_{100m} = P_{ref} \frac{\rho_{100m}}{\rho_{ref}}$$

Wind field reconstruction

$$\begin{bmatrix} V_{LOS,1} \\ V_{LOS,2} \end{bmatrix} = \begin{bmatrix} x_1/L_1 & y_1/L_1 \\ x_2/L_2 & y_2/L_2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix}$$

$$V_{hor} = \sqrt{u^2 + v^2}$$

$$\alpha = \tan^{-1}\left(\frac{v}{u}\right) \quad \text{(wind direction)}$$

Extreme wind distribution

Gumbel distribution function

$$F(x) = \exp\left(-\exp\left[-\left(\frac{x-\mu}{\sigma}\right)\right]\right)$$

Probability of exceedance, Return period T

P_e lassen sich austauschen

$$P_e = \frac{1}{T} \quad ; \quad P_e = P(X > x) = 1 - F(x) \quad ; \quad P_e = \frac{\text{rank}(x)}{N+1}$$

Gumbel probability paper

$$-\ln(-\ln(F(x))) = -\ln\left(-\ln\left(\exp\left(-\left[\frac{x-\mu}{\sigma}\right]\right)\right)\right) = \frac{x-\mu}{\sigma} = \underbrace{\frac{1}{\sigma}}_{\text{slope}} x - \frac{\mu}{\sigma}$$

Windenergienutzung Formelsammlung

Extreme wind distribution

Method of moments ($1 - P_e = F(v)$)

$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i$ (arithmetic mean)

$Var(x) = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2$ (Variance) $\left[\frac{m^2}{s^2}\right]$

$\sigma = \sqrt{Var(x)} \cdot \frac{\sqrt{6}}{\pi}$ (scale parameter) $\left[\frac{m}{s}\right]$

$\mu = \bar{x} - \sigma \cdot \gamma$ (Location parameter) Schnitt mit x-Achse $\left[\frac{m}{s}\right]$

$\gamma = 0{,}5772$ (Euler-Mascheroni-constant)

Method of least squares ($1 - P_e = F(v)$)

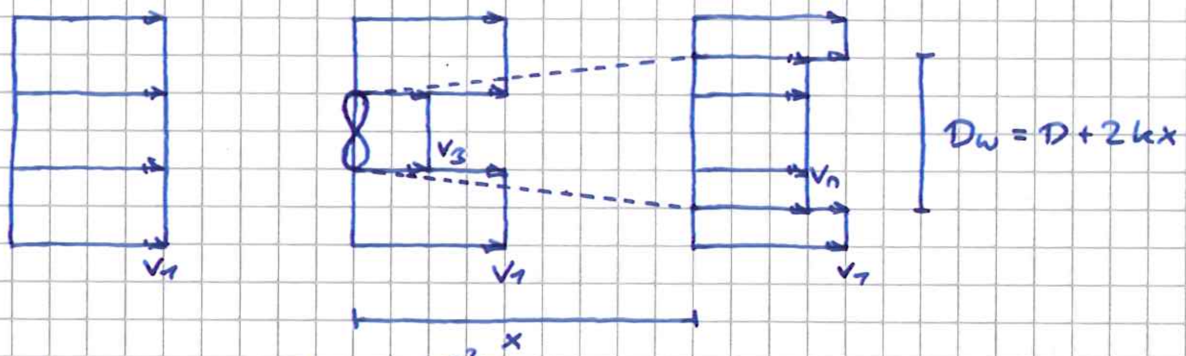
$\sigma = \left(N \cdot \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2\right) : \left(N \cdot \sum_{i=1}^{N} (\hat{y}_i x_i) - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} \hat{y}_i\right)$

$\hat{y}_i = -\ln\left(-\ln\left(\frac{i}{N+1}\right)\right)$

$\mu = \frac{1}{N} \sum_{i=1}^{N} x_i - \frac{\sigma}{N} \sum_{i=1}^{N} \hat{y}_i$

Wake

Jensen Wake model

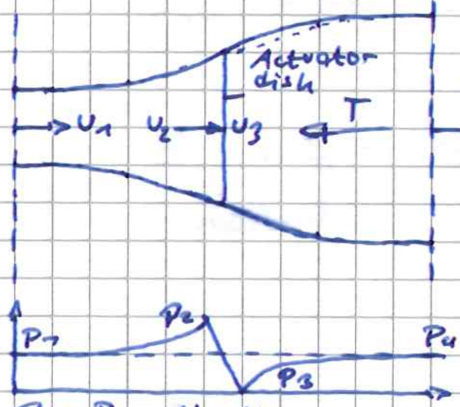


$V_n = V_1 + (V_3 - V_1) \frac{D^2}{D_w^2}$

$D_w = D + 2kx$

$V_3 / V_1 = \sqrt{1 - C_t}$

Steam turbine theory



$P_1 = P_4 \quad U_2 = U_3$

$T = A \frac{\rho}{2} (U_1^2 - U_4^2)$ (Conservation of linear momentum)

$T = \dot{m} (U_1 - U_4)$

$T = A (P_2 - P_3)$

$C_t = \frac{T}{\frac{1}{2} \rho U_1^2 A_2}$ (Thrust coefficient)

$P_1 + \frac{\rho}{2} U_1^2 = P_2 + \frac{\rho}{2} U_2^2$ (Bernoulli)

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Q1

1)

2) $\begin{bmatrix} V_{los,1} \\ V_{los,2} \end{bmatrix} = \overbrace{\begin{bmatrix} x_1/L_1 & y_1/L_1 \\ x_2/L_2 & y_2/L_2 \end{bmatrix}}^{A} \begin{bmatrix} u \\ v \end{bmatrix}$

$L_1 = \sqrt{x_1^2 + y_1^2} = 64{,}03\,m$

$L_2 = \quad " \quad " \quad = 64{,}03\,m$

$V_{hor} = \sqrt{u^2 + v^2} = 10{,}5\,\frac{m}{s}$ I

$\alpha = \tan^{-1}\left(\frac{v}{u}\right) = 7{,}2°$ II

3) $L_1 = L_2 = 89{,}44\,m$

Q2

$L = 20\log\left(\frac{P_{measured}}{P_{ref}}\right) \overset{!}{=} 1\,dB$

a)

Q3

1) $\sigma = \sqrt{var(x)} \cdot \frac{\sqrt{6}}{\pi}$

$\mu = \bar{x} - \sigma \cdot \gamma$

2) $P_e = \frac{1}{T} = \frac{1}{260}$

$1 - F(x) = P_e \rightarrow x = V_{max,\,5\,years}$

Q4

1) ~~[illegible]~~

$T = A\left(\frac{\rho}{2}(U_1^2 - U_4^2)\right) \overset{!}{=} 0{,}8$

Pressure with barometric formula → lets assume $\rho = 1{,}225\,\frac{kg}{m^3}$

2)

Wind II Übung 2 (keine Übung 1?)

Aufgabe 1

a)
$A_{ref} = \frac{2}{\sqrt{\pi}} V_m = 7{,}899 \frac{m}{s}$

$A_{-5\%} = \frac{2}{\sqrt{\pi}} (V_m \cdot 0{,}95) = 7{,}504 \frac{m}{s}$

b)
$V = 1 \frac{m}{s}$ $P = 0\,kW$ $f(v) = 0{,}01154$ Power output $= 0\,MWh$

$V = 2 \frac{m}{s}$ $P = 3\,kW$ $f(v) = 0{,}06013$ Power output $= 1{,}58\,MWh$

$AEP_{ref} = 9635\,MWh$

Same thing for $A_{-5\%}$ $AEP_{-5\%} = 8911\,MWh$

c)
~~Meh~~ $AEP_{ref}/AEP_{-5\%} = 1{,}081 \rightarrow 8{,}1\%$ variation

Aufgabe 2

a)
$P_{T1} = 0{,}97 \cdot P \longrightarrow$

	1	2	3	4	5	6	...
V [m/s]							...
P [kW]	0	2,91	46,56	118,4	325	601,4	...

AEP_{ref} berechnen, aber mit neuen Werten für P

$AEP_{T1,-5\%} = 9424\,MWh$

b)
$AEP_{ref}/AEP_{T1,-5\%} = 1{,}022$

Aufgabe 3

a)
$\rho(400m) = \rho(h_0) \cdot \exp\left(-\frac{\Delta h}{h_s}\right) = 1{,}164 \frac{kg}{m^3}$

b)
$P = \frac{1}{2} \rho A V^3 C_p$ $P_{rated} = 2500\,kW$

$\cancel{\frac{1}{2}} \rho_{rated} \cancel{A_{rated}} V_{rated}^3 \cancel{C_p} = \cancel{\frac{1}{2}} \rho_{400} \cancel{A_{400}} V_{400}^3 \cancel{C_p}$ $V_{rated} = 12 \frac{m}{s}$

$V_{rated,400} = 12{,}21 \frac{m}{s}$

c)
Jeden P-Wert mit $P_{400} = \underbrace{\frac{\rho_{400}}{\rho_{ref}}}_{=0{,}95} \cdot P_{ref}$ neu berechnen

d)
$AEP_{400} = 9234 \rightarrow AEP_{400}/AEP_{ref} = 0{,}958$

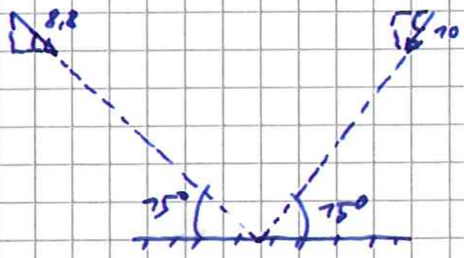
e)
Ratios are not the same, because Air density ~~has~~ only influences the Power output below rated wind speed

Aufgabe 4 Mean wind speed

Wind II Übung 3

1)

$V_{LOS1} = 10 \frac{m}{s}$ $\quad$ $V_{LOS2} = 8,8 \frac{m}{s}$



$L_1 = \sqrt{100^2 + 26,8^2} = 103,5\,m$

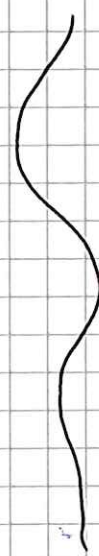
$L_2 = 103,5\,m$

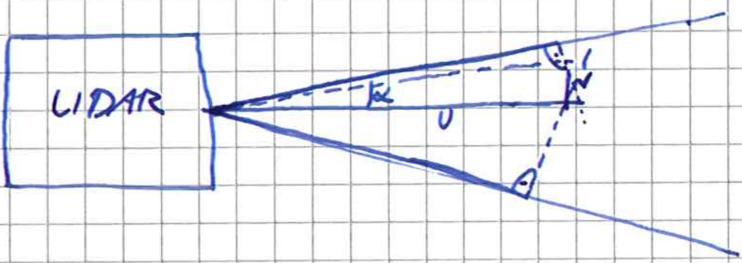
2)

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} x_1/L_1 & y_1/L_1 \\ x_2/L_2 & y_2/L_2 \end{bmatrix}^{-1} \begin{bmatrix} V_{LOS1} \\ V_{LOS2} \end{bmatrix} = \begin{bmatrix} 9,729 \\ 2,312 \end{bmatrix}$$

$V_{hor} = \sqrt{u^2 + v^2} = 10 \frac{m}{s}$

$\alpha = \tan^{-1}\left(\frac{v}{u}\right) = 13,4°$





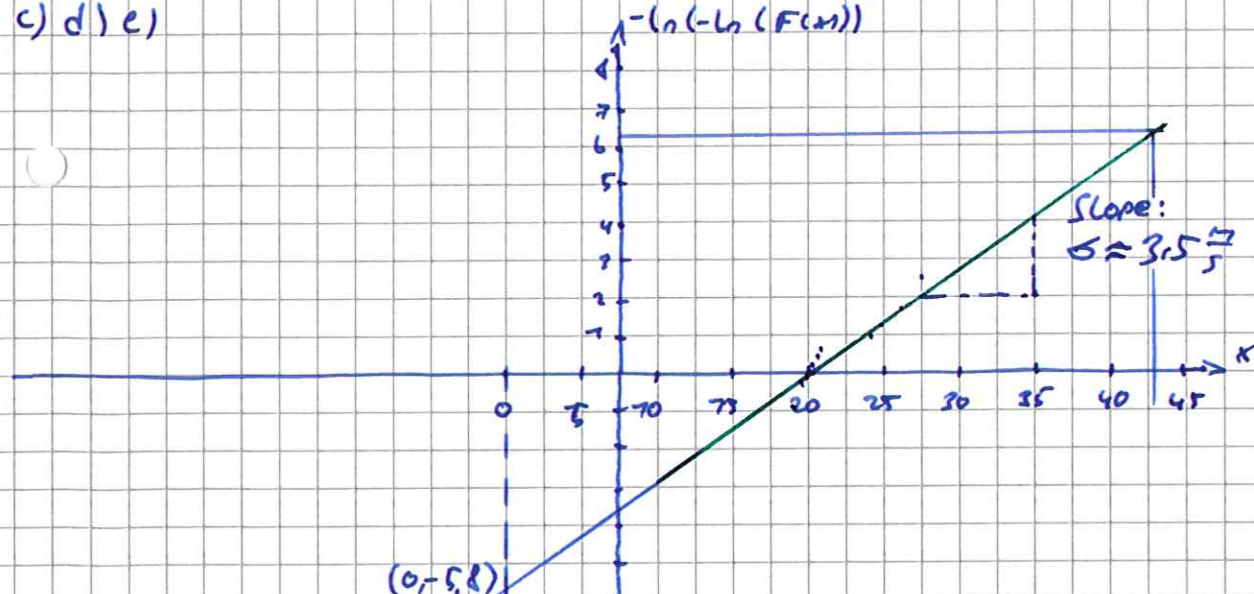
Wind II Übung 4

50-year maximum wind speed mit Gumbel probability paper

a) b)
Sort wind speeds in descending order

i	v_i [m/s]	$\frac{\text{rank}(v)}{N+1} = P_e$	$-\ln(-\ln(1-P_e))$
1	27,6	0,08	2,53
2	26,9	0,15	1,79
3	24,9	0,23	1,34
4	24,6	0,31	1,00
5	22,2	0,38	0,72
6	22,1	0,46	0,48
7	21,8	0,54	0,26
8	21,4	0,62	0,05
9	21	0,69	-0,16
10	20	0,77	-0,38
11	19,7	0,85	-0,63
12	19,5	0,92	-0,94

c) d) e)



$-\frac{\mu}{\sigma} = -5{,}8$

$\mu = 20{,}3\,\frac{m}{s}$

f) $-\ln(-\ln(1-P_e))$ mit $P_e = \frac{1}{12 \cdot 50} \rightarrow 6{,}396 \rightarrow v_{50} \approx 43\,\frac{m}{s}$

50 year maximum wind speed with method of moments

a)

Arithmetic mean $\bar{x} = 22{,}64\ \frac{m}{s} = \bar{v}$

$N = 72$

$Var(V) = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2 \quad = 7{,}5$

$\sigma = \sqrt{Var(V)} \cdot \frac{\sqrt{6}}{\pi} \quad = 2{,}135$

$\mu = \bar{x} - \sigma \cdot \gamma \quad = 21{,}41$

b)

$P_e = \frac{1}{T} \qquad T = 72 \cdot 50$

$F(v) = 1 - P_e \qquad = \exp(-\exp(-(\frac{v-\mu}{\sigma})))$

$v = 35{,}07\ \frac{m}{s}$

50 year maximum wind speed with method of least squares

See solution on Ilias

Wind II Übung 5

Aufgabe 1

a)

Lösen mit Bernoulli

$T = A \cdot \rho/2 \cdot (U_1^2 - U_4^2)$

$P_1 + \frac{\rho}{2} U_1^2 = P_4 + \frac{\rho}{2} U_4^2$

$P_2 + \frac{\rho}{2} U_2^2 = P_3 + \frac{\rho}{2} U_3^2$

ϟ Direkt Position 1 mit 4 in Verbindung gebracht, was wegen Rotor mit Bernoulli nicht geht. Sonst an sich richtiger Ansatz!

$P_1 = P_4 \quad ; \quad U_2 = U_3$

$P_1 = P_1 + \frac{\rho}{2} U_4^2 - \frac{\rho}{2} U_1^2$

$P_2 = P_3 + \frac{\rho}{2} U_3^2 - \frac{\rho}{2} U_2^2$

$P_2 - P_3 = \frac{\rho}{2}(\underbrace{U_3^2 - U_2^2}_{=0}) = \frac{\rho}{2}(U_4^2 - U_1^2)$

$T = A(P_2 - P_3)$ Ab hier mit Musterlösung weiter

b)

$T = \frac{\rho}{2}(U_1^2 \cdot U_4^2) A$

c)

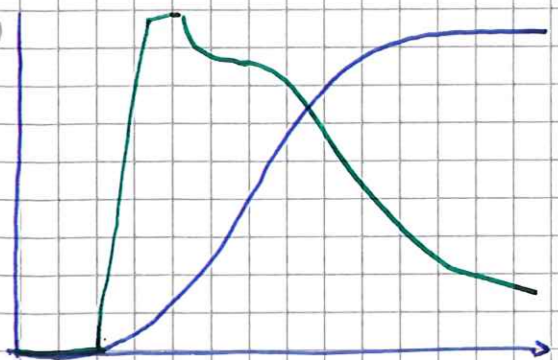
$C_t = \frac{T}{1/2 \, \rho \, U_1^2 \cdot A_2} = \frac{A \, \rho/2 \, (U_1^2 - U_4^2)}{\rho/2 \, U_1^2 A_2} = \frac{U_1^2 - U_4^2}{U_1^2}$

$= 1 - \left(\frac{U_4}{U_1}\right)^2$

$U_4 = U_1 \sqrt{1 - C_t}$

Aufgabe 2

a)



b)

Turbines of the same Type have identical Power curves, so no difference c)

$V_n = V_1 + (V_3 - V_1) \frac{D^2}{D_w}$

$V_1 = \cancel{70}\ 15 \frac{m}{s}$

$\frac{v_3}{v_1} = \sqrt{1 - C_t} = 0,8544 \rightarrow V_3 = 12,82 \frac{m}{s}$

$D_w = D + 2kx = D + 2\ (0,075) \cdot 4D = 1,6D$

$V_n = 14,15 \frac{m}{s}$ kann für jede Geschw. berechnet werden

d)

Wake is larger, therefore k is lower and V_n is slower $\rightarrow$ less power production by the Turbine inside the wake

e)

$k_{offshore} = 0,0\cancel{4}4$

$V_n = 13,15 < 14,15$ bei $V_1 = 15 \frac{m}{s}$

Wind II Übung 6

Aufgabe 1

a)

0dB when pressure is the same as the reference $P = P_{ref} = 20\,\mu Pa$

b)

Yes, if the pressure level is below the reference

-20 dB, if P is ten times smaller than Pref

c)

$$L_W = 10 \log\left(\frac{W}{W_{ref}}\right) \rightarrow W = 10^{L_W/10} \cdot W_{ref}$$

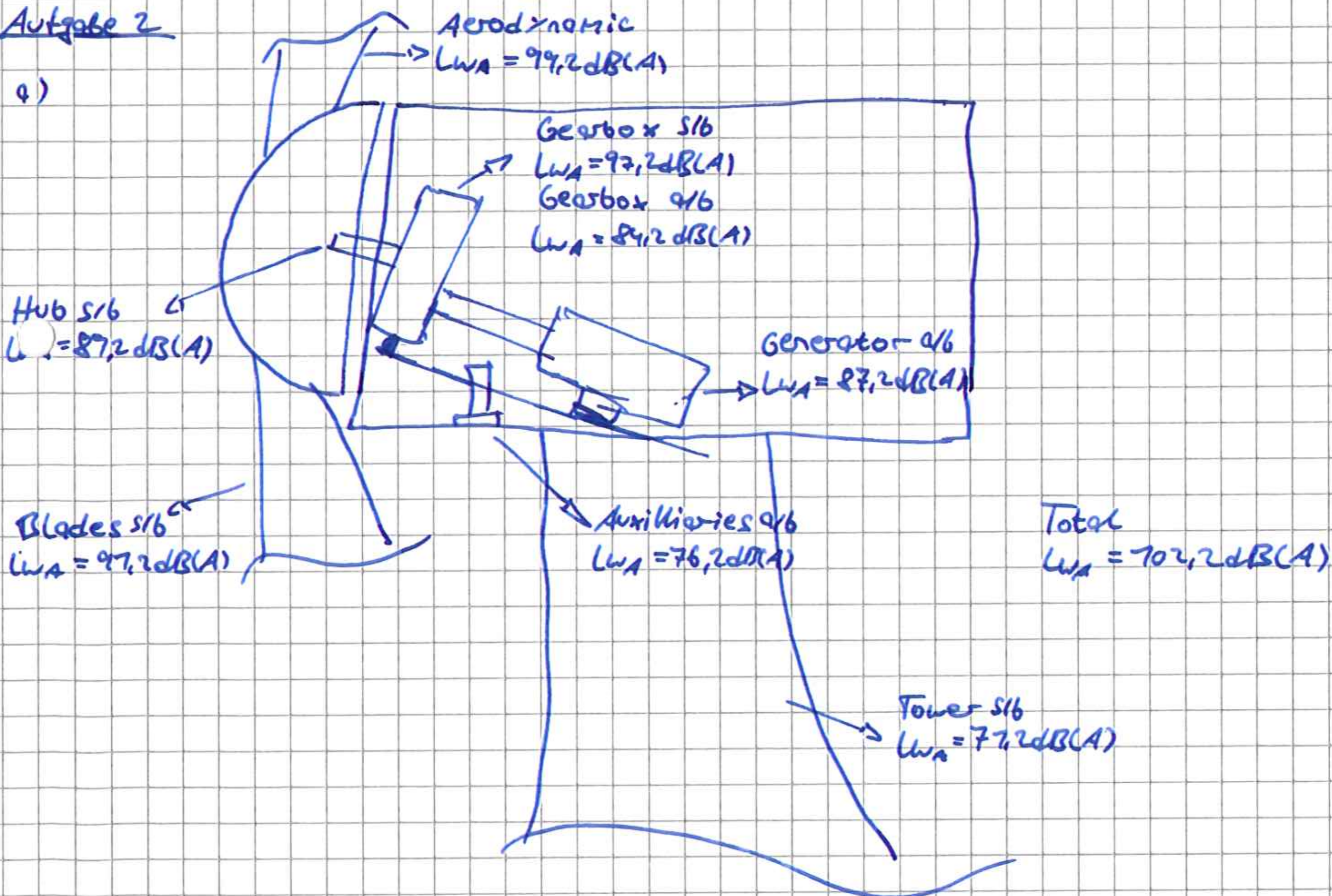
$$W_i = \sum_{i=1}^{N} 10^{\frac{L_{Wi}}{10}} \cdot W_{ref}$$

$$L_{W,total} = 10 \log\left(\frac{\sum_{i=1}^{N} 10^{\frac{L_{Wi}}{10}} W_{ref}}{W_{ref}}\right)$$

$$= 10 \log\left(\sum_{i=1}^{N} 10^{\frac{L_{Wi}}{10}}\right)$$

Aufgabe 2

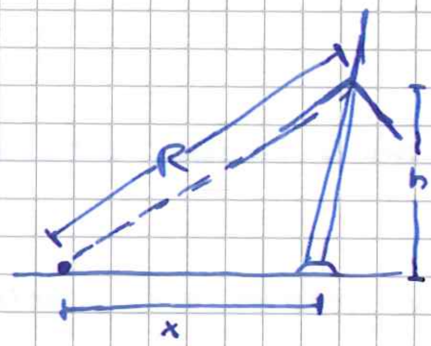
a)



b)

$$L_{W,Total} = 10 \log\left(\sum_{i=1}^{N} 10^{0{,}1 L_{Wi}}\right) = 102{,}2\ dB$$

c)



d)

Wind turbine is quiet enough at about 490 m

e)

$L_{w,total} = 10 \log\left(\sum_{i=1}^{2/4} 10^{0,1 L_{wi}} \right)$

With one turbine : $L_{w\,total} = 102,2$ dB

two : $L_{w\,total} = 105,2$ dB

four : $L_{w\,total} = 108,2$ dB

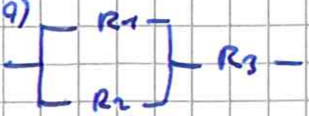
A doubeling of the sound source results in an increase of the sound power level of 3dB ; assumption: sound is emitted at single point, uniform sound propagation

Aufgabe 1

$R_s = 1-(1-R_3)(1-(R_1 \cdot R_2))$

Aufgabe 2

a)

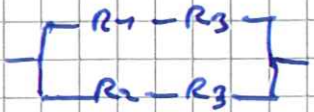


b)

$R_s = (1-(1-R_1)(1-R_2)) \cdot R_3 = 0,9699 \approx 97\%$

c)

Reliability increases to 99,84%, because now there are two independent systems in parallel



Aufgabe 3

a)

$f(t) = \lambda \exp(-\lambda t)$ for $t \geq 0$ $\quad \lambda = \frac{1}{500h}$

$Pr(T \leq t = 200h) = \int_0^{200} f(t)\,dt = 32,97\%$

Probability the motor does not fail before t_1 : 67,03%

b)

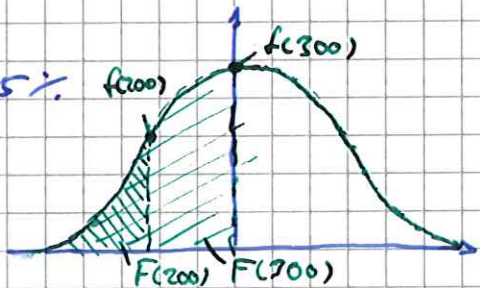
Probability the motor fails before t_2 : 18,13%

$\int_0^{00} f(t)\,dt$

c)

Probability of failure between t_3 and t_4 :

$Pr(t_3 \leq T \leq t_4) = \int_0^{300} f(t)\,dt - \int_0^{200} f(t)\,dt = 12,15\%$



d)

$MTBF = \frac{1}{\lambda} = 500h$

$Pr(T > 500h) = \int_{500}^{\infty} f(x)\,dx = 0,3679 = 36,79\%$

e)

$Pr(T > t) \overset{!}{=} 0,9 \longrightarrow t = 52,68h$

f)

In six months, 5 out of 100 Turbines can break

$$F(t=4320h) = \int_0^{4320} f(x)\,dx \overset{!}{=} 0{,}05$$

$$\lambda = 1{,}1871 \cdot 10^{-5}\ \frac{1}{h}$$

Aufgabe 4

a)

$R_S = 1-(1-R_1 \cdot R_2)(1-R_3) = 89{,}22\%$ (after 200h)

b)

$F(200h) \cdot 100 = 10{,}78$ failures

Notize für Formelsammlung:

Lidar

Frequency of the emitted light: $f = \frac{c}{\lambda}$

Power

~~Reactive power~~ $\cancel{Q = P \cdot \tan(\cos^{-1}(\text{Power factor}))}$

Power factor $= \frac{P}{\sqrt{P^2+Q^2}}$

Windenergienutzung Übungen

Übung 1

(1)

$v_{m,ref} = 7\,\frac{m}{s}$ $\quad k=2 \quad$ $h = 100\,m$

a)

$A_{ref} = \frac{2}{\sqrt{\pi}} v_{m,ref} = 7,899$

$A_{-5\%} = \frac{2}{\sqrt{\pi}} v_{m,ref} \cdot 0,95 = 7,504$

b)

$v\ [\frac{m}{s}]$	$P\ [kW]$	$(f(v))_{ref}$	$(f(v))_{-5\%}$
1	0	0,03754	0,03489
10	2350	0,06454	0,06074
20	2500	0,001054	0,000584
	AEP [MWh]	1352	1251

c)

$\frac{AEP_{-5\%}}{AEP_{ref}} = 0,9246 \rightarrow 92,46\%$

(4) Annual wind speed mean has highest influence upon AEP

(2)

a)

$P_{-5\%} = P_{ref} \cdot 0,97$ below $v_{rated} = 12\,\frac{m}{s}$

$v\ [\frac{m}{s}]$	$P_{-5\%}\ [kW]$
1	0
10	2280
20	2500

b)

$AEP_{-5\%}$ [MWh] 1312

$\frac{AEP_{-5\%}}{AEP_{ref}} = 0,9704 = 97,04\%$

(3)

a)

$\rho(h_1) = \rho(h_0) \cdot \exp\left(\frac{\Delta h}{h_S}\right) = 1,164\ \frac{kg}{m^3}$

~~Übung 2~~

b)

$P_{400} = P_{ref} \frac{\rho_{400}}{\rho_{ref}}$; $P = \frac{1}{2} \rho A v^3 c_p$

$\frac{v_{400}}{v_{ref}} = \sqrt[3]{\frac{P_{400}\, \rho_{ref}}{\rho_{400}\, P_{ref}}} = 1,017$

$v_{rated,400} = 12,21\ \frac{m}{s}$

c)

1 m/s	0 kW
10 m/s	2233 kW
20 m/s	2500 kW

$\frac{AEP_{400}}{AEP_{ref}} = 0,9572$

e) $\frac{\rho_{400}}{\rho_{ref}} = 0,9502$

d) AEP_{400} 1286 MWh

Air density only matters below v_{rated}

Übung 2

(1)

$V_{LOS,1} = 10 \frac{m}{s}$ $\quad V_{LOS,2} = 8,8 \frac{m}{s}$ $\quad V_{vert.} = 0 \frac{m}{s}$

$(x_1 \ y_1) = (100 \ \ 26,8)$

$(x_2 \ y_2) = (100 \ \ -26,8)$

a)

$L_1 = \sqrt{x_1^2 + y_1^2} = 103,5 \ m$

$L_2 = \ '' \ \ '' = 103,5 \ m$

b)

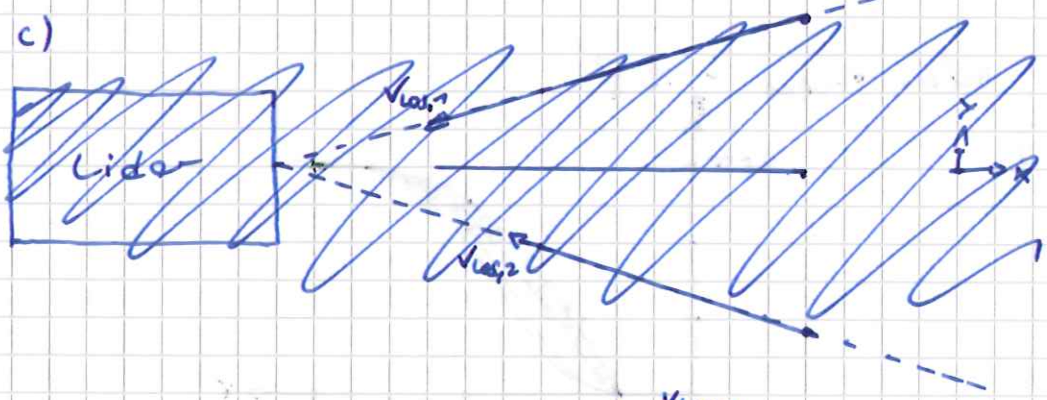
$$\begin{bmatrix} V_{LOS,1} \\ V_{LOS,2} \end{bmatrix} = \begin{bmatrix} x_1/L_1 & y_1/L_1 \\ x_2/L_2 & y_2/L_2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix}$$

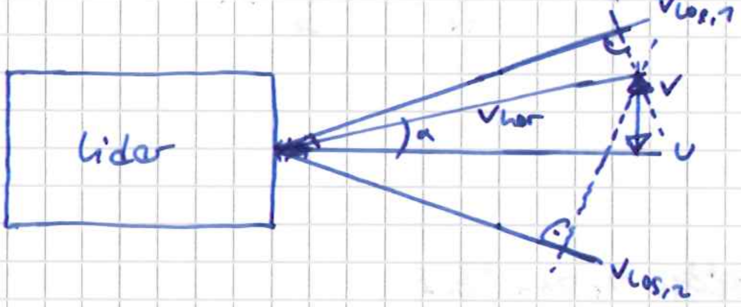
$u = 9,729 \frac{m}{s} \qquad v = 2,317 \frac{m}{s}$

$V_{hor} = \sqrt{u^2 + v^2} = 10 \frac{m}{s}$

$\alpha = \tan^{-1}\left(\frac{v}{u}\right) = 13,40^\circ$

c)





Windenergienutzung Übungen

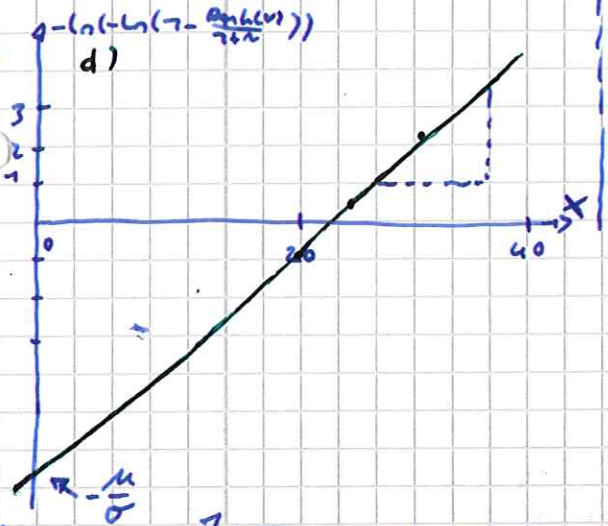
Übung 2

①

a)

~~Monat~~ i	V_{max} i	b) $\frac{rank(v)}{N+1}$	$-\ln(-\ln(1-\frac{rank(v)}{N+1}))$
1	27,6	0,07692	2,525
2	26,9		
3	24,9		
4	24,6		
5	22,2		
6	22,1	0,4615	0,4797
7	21,8		
8	21,4		
9	21,0		
10	20,0		
11	19,7		
12	19,5	0,9231	-0,4412

c)



$(\sigma)^{-1}$ = Slope $= \frac{15,4}{40}$ = 2,6

μ = ~~Intercept~~ $= \sigma \cdot 8,2 = 21,3$

f) $P_e = \frac{1}{(50 \cdot 12)} = 0,001667$

$-\ln(-\ln(1-P_e)) = 6,396$

→ Fitfunktion an dieser Stelle für $v_{50} \approx 38 \frac{m}{s}$ auswerten!

②

a) $\sigma = \sqrt{Var(v)} \cdot \frac{\sqrt{6}}{\pi} = 2,1 \frac{m}{s}$

$\mu = \bar{x} - \sigma \cdot \gamma = 21,4 \frac{m}{s}$

$N = 12$

$\bar{v} = 22,64 \frac{m}{s}$

$Var(v) = \frac{1}{N-1} \sum_i (v_i - \bar{v})^2 = 7,5 \frac{m^2}{s^2}$

b) $1 - P_e \overset{!}{=} F(v_{50}) \longrightarrow v_{50} = 34,83 \frac{m}{s}$

③ a) : Tabelle ① aber umgekehrt

⋮

Alles ausrechnen, dann gleicher Rechenweg wie in ②

Übung 4

1

a)

Conservation of linear momentum:

~~[illegible]~~ $T = \dot{m}(U_1 - U_4)$

$T = \cancel{[illegible]} = \cancel{A}(P_2 - P_3)$

b)

$P_1 + \frac{\rho}{2} U_1^2 = P_2 + \frac{\rho}{2} U_2^2$

$P_3 + \frac{\rho}{2} U_3^2 = P_4 + \frac{\rho}{2} U_4^2$

$(P_1 = P_4)$

$P_4 = P_2 + \frac{\rho}{2} U_2^2 - \frac{\rho}{2} U_1^2$

$P_3 + \frac{\rho}{2} U_3^2 = P_2 + \frac{\rho}{2} U_2^2 - \frac{\rho}{2} U_1^2 + \frac{\rho}{2} U_4^2$

$P_2 - P_3 = \frac{\rho}{2}(U_3^2 - U_2^2 + U_1^2 - U_4^2)$; $(U_2 = U_3)$

$P_2 - P_3 = \frac{\rho}{2}(U_1^2 - U_4^2)$

$T = \cancel{A} \frac{\rho}{2}(U_1^2 - U_4^2)$

c)

$C_t = \frac{T}{\frac{1}{2}\rho U_1^2 A_2} = \frac{A\frac{\rho}{2}(U_1^2 - U_4^2)}{\frac{1}{2}\rho U_1^2 A_2} = \frac{U_1^2 - U_4^2}{U_1^2 A_2}$

$U_4 = + U_1 \sqrt{1 - C_t}$

2

a) Just draw as in solution

b) Same power curve because they are of the same type

c) $V_1 = V_1 + (V_3 - V_1)\frac{D^2}{D_w^2}$

$D_w = D + 2kx = 1{,}6\,D$

$\frac{V_3}{V_1} = \sqrt{1 - C_t}$ ~~[illegible]~~ $\rightarrow$ Fill out table with new Wind Speed

Calculate Power with $P = \frac{1}{2}\rho A v^3 C_p$

$\frac{P_2}{P_1} = \frac{\frac{1}{2}\rho A V_1^3 C_p}{\frac{1}{2}\rho A V_1^3 C_p}$

Windenergienutzung Übungen

Übung 5

1

a) Pressure at 0dB is equal to reference pressure $p_{ref} = 2 \cdot 10^{-5}$ Pa

b) Yes, negative sound level if pressure is below reference pressure

-20 dB would mean pressure 10 times smaller than pref

$L = 20 \log\left(\frac{p}{p_{ref}}\right) = -20\,dB \rightarrow p = \frac{1}{10} p_{ref}$

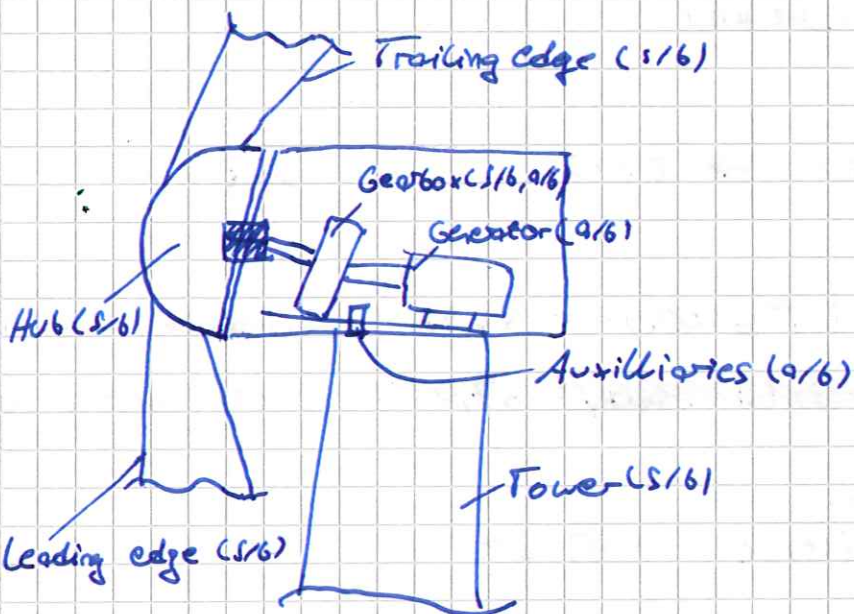
c) $L_{w\,total} = 10 \log\left(\frac{\sum W_i}{W_{ref}}\right)$

$L_W = 10 \log\left(\frac{W}{W_{ref}}\right) \rightarrow W_i = W_{ref} \cdot 10^{\frac{L_{Wi}}{10}}$

$L_{W,total} = 10 \log\left(\sum_i 10^{0,1 L_{Wi}}\right)$ [dB]

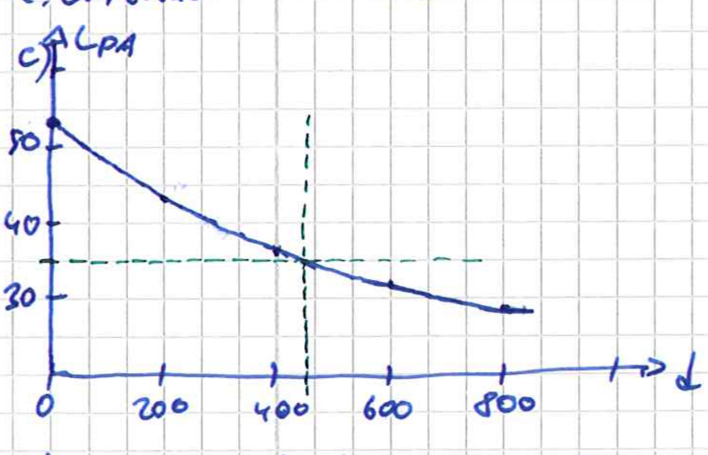
2

a)



b) $L_{W,total} = 102,2\,dB$

c)



d) Village has to be at ca. 450m or farther

e) Sound power +3dB for every doubling of the source

two turbines: 105,2dB four turbines: 108,2 dB

Windenergienutzung Übungen

Übung 7

(1)

$R_s = 1-(1-R_3)(1-(R_1 \cdot R_2))$

(2)

a)

b)

$R_s = (1-(1-R_1)(1-R_2)) \cdot R_3 \quad = 96{,}99\%$

c)

$R_s = 1-(1-R_1R_3)(1-R_2R_3) \quad = 99{,}84\%$

Yes, reliability increases

(3)

$f(t) = \lambda \exp(-\lambda t) \quad$ for $t \geq 0 \qquad \lambda = \frac{1}{500h}$

a)

$\int_0^{200h} f(t)\,dt = P_r(T \leq 200h) = 32{,}97\%$ (Motor does fail)

$1 - P_r(T \leq 200h) = 67{,}03\%$ (Motor has not failed)

b)

$P_r(T \leq 100h) = \int_0^{100h} f(t)\,dt \quad = 18{,}13\%$

c)

$P_r(T \leq 300h) - P_r(T \leq 200h) = 12{,}15\%$

d)

$MTBF = \lambda^{-1} = 500h$

$P_r(T > 500h) = \int_{500h}^{\infty} f(t)\,dt \quad = 36{,}79\%$

e)

$P_r(T > t) \overset{!}{\geq} 0{,}9 \quad \rightarrow t = 52{,}68h$

f)

Number of failed Systems $= \lambda(t) \cdot n \overset{!}{\leq} 5 \quad \rightarrow \lambda = \frac{1}{20a} \cdot \frac{1}{6months}$

$\lambda = \frac{1}{87600h} = 1{,}142 \cdot 10^{-5}\,\frac{1}{h}$

$\int_0^{4380} f(t)\,dt \overset{!}{=} 0{,}05 \rightarrow$

Windenergie Übungen

Übung 7

4

a)

$R_s(t) = \exp(-(\frac{t}{\eta})^{\beta})$

$R_1(t) = 0{,}9999^{t^{1,5}}$ $R_2(t) = 0{,}9996^{t^{1,3}}$ $R_3(t) = 0{,}993^{t^{1,1}}$

$R_s = 89{,}25\,\%$

b)

$F(t) \cdot n$ = number of failed systems = 10,75 systems