ARIKETAK

1. GAIA: Haizea baliabide gisa

① $D = 12m$ Urteko energia produkzioa?

$u = 8 m/s$

$\eta = 0'4$

$\rho = 1'2 kg/m^3$

$$\frac{P}{A} = \frac{1}{2} \eta \rho v^3 = \frac{1}{2} \cdot 0'4 \cdot 1'2 \cdot 8^3 = 122'88 \; W/m^2$$

Urtean $\Rightarrow 122'88 \times 365'25 \text{ egun} \times 24 h = 1'076 \cdot 10^6 \; Wh/m^2$

Atalera kontuan badugu:

$$P = 1'076 \cdot 10^6 \cdot \frac{\pi \, 12^2}{4} = 121'74 \cdot 10^6 \; Wh$$

$$\boxed{P_{urtean} = 121'74 \; MWh}$$

② $D = 40 m$ a) Errotazio abiadura? (Ω [bira/min])

$P = 700 kW$ Punta-abiadura ratioa $\lambda = 0'5$

$u = 14 m/s$

$V = \omega R \Rightarrow u = \Omega \cdot R$

Punta abiadura u_{punta}:

$$\lambda = \frac{\text{Punta abi.}}{\text{Haizearen abi.}} \Rightarrow u_{punta} = \lambda \cdot u_{haize} = 0'5 \cdot 14 = 7 m/s$$

$$\Omega = \frac{u_{punta}}{R} = \frac{7}{20} = 0'35 \, rad/s \cdot \frac{60}{2\pi} = \boxed{3'342 \text{ bira/min} = \Omega}$$

b) Puntako abiadura. (u_{punta})

$$\boxed{u_{punta} = 7 m/s}$$

c) $\Omega = 1800$ bira/min

Transmizio erlazioa? (t)

$$t = \frac{\Omega_2}{\Omega_1} = \frac{1800}{3'342} = \boxed{538'56 = t}$$

d) Turbinaren efizientzia totala? (η_T)

$$Pot = 1/2 \, \eta_T \, \rho \, A u^3 \cdot \boxed{C_p} \rightarrow \text{betz}$$

$$700 \cdot 10^3 = 1/2 \cdot \eta_T \cdot 1'2 \cdot \frac{\pi \, 40^2}{4} \cdot 14^3 \cdot 0'59$$

$$\eta_T = 0'5734$$

$$\boxed{\eta_T = \% \, 57'34}$$

③ $h_2 = 40m$ Zuhaitzekin:

$h_1 = 10m$

$u_1 = 5 m/s$

u_2?

$z_0 = 0'1$ zuhaitzekin

$z_0 = 0'01$ zuhaitz gabe

$$\frac{u_2}{\ln\left(\frac{h_2}{z_0}\right)} = \frac{u_1}{\ln\left(\frac{h_1}{z_0}\right)} \Rightarrow \frac{u_2}{\ln\left(\frac{40}{0'1}\right)} = \frac{5}{\ln\left(\frac{10}{0'1}\right)} \rightarrow \boxed{u_2 = 6'505 m/s}$$

Zuhaitz gabe:

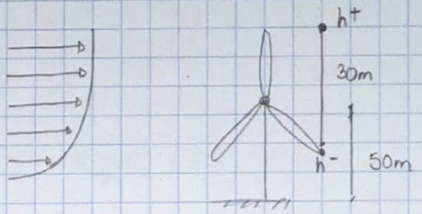
$$\frac{u_2}{\ln\left(\frac{h_2}{z_0}\right)} = \frac{u_1}{\ln\left(\frac{h_1}{z_0}\right)} = \frac{u_2}{\ln\left(\frac{40}{0'01}\right)} = \frac{5}{\ln\left(\frac{10}{0'01}\right)} \rightarrow \boxed{u_2 = 6 m/s}$$

? ④ $d = 30m$ Errotorearen goiko partean eta behekoan eskuragarriden energiaren erlazioa topatu.

$h = 50m$

$\alpha = 0'2$

Lokoefizientedo potentzia



$$\frac{P(h^+)}{P(h^-)}$$

$h^+ = 50 + 15 = 65m$

$h^- = 50 - 15 = 35m$

$\cancel{\left(\frac{h^+}{h^-}\right)^{\alpha} = \left(\frac{65}{35}\right)^{0'2}} = 1'13$ goikoan

Beraz, % 13 gehiago sortzen da

$$\frac{P^+}{P^-} = \frac{\cancel{1/2}\ \cancel{\rho}\ \cancel{A} u^3}{\cancel{1/2}\ \cancel{\rho}\ \cancel{A} u^3} = \left(\frac{h^+}{h^-}\right)^{\alpha \cdot 3} = \left(\frac{65}{35}\right)^{0'2 \cdot 3} = 1'45 \Rightarrow \boxed{\%\ 45} \text{ gehiago sortzen da}$$

⑤ $P = 100\,kW$

$u = 7'5\,m/s$

$c_p = 16/27$

$\eta = 1$

$D?$

$$P = 1/2\ \eta\ \rho\ A u^3 c_p$$

$$100 \cdot 10^3 = 1/2 \cdot 1 \cdot 1'2\ \frac{\pi D^2}{4} \cdot 7'5^3\ 16/27$$

$$\boxed{D = 24'13m}$$

⑥ $c = 6\,m/s$

$k = 1'8$

Weibull

a) Batazbesteko abiadura:

$$\bar{u} = c\,\Gamma\left(1 + \frac{1}{k}\right) = 6\,\Gamma\left(1 + \frac{1}{1'8}\right) = 6\,\Gamma\ 1'5 = 6 \cdot 0'889 = \boxed{5'335\,m/s = \bar{u}}$$

b) Zenbat ordutan $u = 6'5 - 7'5\,m/s$ artekoa

$$6'5 \leq \bar{u} \leq 7'5$$

$$F(7'5) - F(6'5) = 1 - e^{-(x/c)^k} - \left(1 - e^{-(x/c)^k}\right) = 1 - e^{-(7'5/6)^{1'8}} - \left(1 - e^{-(6'5/6)^{1'8}}\right)$$

$$= 0'09$$

$$\text{Urtean} = 0'09 \cdot 365'25 \cdot 24 = \boxed{794'73 \text{ ordu/urtean}}$$

c) Zenbat ordu 16m/s baino handiagoekin

$u \geq 16$ $\quad 1 - F(16) = 1 - \left(1 - e^{-(16/6)^{1'8}}\right) = 1 - 0'99 = 0'002896$

$$\text{Urtean} = 0'002896 \cdot 365'25 \cdot 24 = \boxed{25'38 \text{ ordu/urtean}}$$

⑥2 $\bar{u} = 6 m/s$

Rayleigh $k=2$

a) 9'5 eta 10'5 m/s artean zenbat ordu urtean?

$$\bar{u} = c\,\Gamma\left(1+\frac{1}{k}\right) = c\,\Gamma\left(1+\frac{1}{2}\right) = c\,\Gamma\,1'5$$

$$6 = c \cdot 0'88622693$$

$$c = 6'77 m/s$$

$9'5 \leq u \leq 10'5$ $$F(10'5) - F(9'5) = 1 - e^{-(10'5/6'77)^2} - \left(1 - e^{-(9'5/6'77)^2}\right) = 0'049$$

$$\text{Urtean} = 0'049 \cdot 365'25 \cdot 24 = \boxed{432'68 \text{ ordu/urte}}$$

b) 16m/s gainetik

$u \geq 16$ $$1 - F(16) = 1 - \left(1 - e^{-(16/6'77)^2}\right) = 1 - 0'996 = 0'00375$$

$$\text{Urtean} = 365'25 \cdot 24 \cdot 0'00375 = \boxed{32'88 \text{ ordu/urtean}}$$

⑦ Energia produkzioa urtean

$D = 12m$

$\bar{u} = 8m/s$

Rayleigh $k=2$

$$\overline{u^3} \neq u^3$$

$$\bar{u} = c\,\Gamma\left(1+\frac{1}{2}\right) \Rightarrow 8 = c \cdot 0'88$$

$$c = 9'027 m/s$$

$$\overline{u^3} = c^3\,\Gamma\left(1+\frac{3}{k}\right)$$

$$\overline{u^3} = 9'027^3\,\Gamma\left(1+\frac{3}{2}\right) = 9'027^3\left[1'5\,\Gamma\,1'5\right] = 9'027^3 \cdot 1'5 \cdot 0'8862$$

$$\Gamma(r+1) = r\,\Gamma\,r$$

$$\overline{u^3} = 977'837 m/s$$

$$P = 1/2\,\eta\,\rho\,A\,\overline{u^3} = 1/2 \cdot 1 \cdot 1'2 \cdot \frac{\pi\,12^2}{4} \cdot 977'837 = 66354'455 W$$

$$P_{urte} = 66354'45 \cdot 365'25 \cdot 24 = 581'663 \cdot 10^6 Wh/urte$$

$$\boxed{P_{urte} = 581'663 MWh/urte}$$

? ⑧ $$CF = 0'87\,\bar{u} + \frac{P_R}{D^2}$$

Ariketa gehigarriak:

① Kalkulatu zenbat ordu funtzionatzen duen tipikoki haize errota batek potentzia nominalean urtean.

$365 \text{ egun} \times 24h \times \frac{20-30}{100} \simeq 1752 - 2628 \text{ ordu} \rightarrow \simeq 2000 \text{ ordu}$

② Frogatu EPE 800-1500 dela CF eta PE kontuan hartuta

$EPE = CF \cdot PE \cdot 365'25 \cdot 24 = PE \cdot (1752 - 2628)$

③ 20 urteko bizitza duen makina batek, zenbat kWh sortuko du 3m-ko diametroa izanda?

Diametroa jakin gabe: $EPE \times (1752 - 2628) \times 20$

Diametroa jakinda: $1/2 \, \eta \, \rho \, A \, u^3 \times (1752 - 2628) \times 20$

$1/2 \cdot 0'4 \cdot 1'2 \cdot \frac{\pi \, 3^2}{4} \cdot u^3 \times 2000 \times 20$

2. GAIA: Turbina eolikoen aerodinamika

① u = 26'8 m/s

m = 10' = α

R = 4'57 m

z = 0'61 m

m = 45'36 kg

T = 21'2

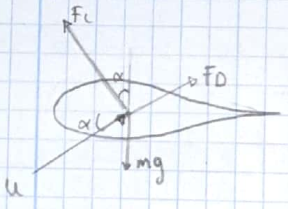
a) Palen abiadura drag gabe?

$$\rho = \frac{P}{R'T} = \frac{1'013 \cdot 10^5 \text{ Pa}}{287\,(273+21'2)} = 1'19973 \text{ kg/m}^3$$

$$F_L = 1/2\ C_L\ u^2\ \rho A$$

$$C_L = 2\pi \sin\alpha = 2\pi \sin 10 = 1'091$$

$$A = R\, z = 4'57 \cdot 0'61 = 2'7877$$



$$\cos\alpha = \frac{mg}{F_L} \Rightarrow F_L = \frac{45'36 \cdot 9'8}{\cos 10} = 455'033$$

$$F_L = 1/2\ C_L\ u^2\ \rho A$$

$$455'03 = 1/2 \cdot 1'091 \cdot u^2 \cdot 1'19973 \cdot 2'7877$$

$$\boxed{u = 15'79 \text{ m/s}}$$

b) 26'8 m/s hegan urten. Azelerazioa horizontala?

$$\frac{C_D}{C_L} = 0'03 \qquad C_L = 2\pi \sin\alpha = 2\pi \sin 10 = 1'091$$

$$\frac{C_D}{C_L} = 0'03 \Rightarrow C_D = 0'03 \cdot 1'091 = 0'03273$$

$$F_x \Rightarrow -F_L + F_D = -(1/2\, C_L\, \rho\, u^2 A \sin\alpha) + (1/2\, C_D\, \rho\, u^2 A \cos\alpha)$$

$$= -(1/2 \cdot 1'091 \cdot 1'19973 \cdot 26'8^2 \cdot 2'7877 \sin 10 + 1/2 \cdot 0'03273 \cdot 1'19973\ 26'8^2\ 2'7077 \cos 10$$

$$\begin{cases} F_x = -188'83 \text{ N}, \text{ berat ezkerrera mugituko da} \\ F = m \cdot a = 45'36 \cdot a \end{cases}$$

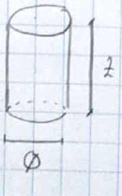
$$-188'83 = 45'36 \cdot a$$

$$\boxed{a = -4'163 \text{ m/s}^2}$$

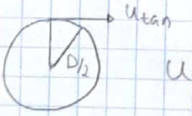
② Ø = 0'75 m

z = 7'5 m

w = 60 bira/min



a) Zirkulazioa zilindroaren inguruan



$$u_{tan} = R \cdot w = \frac{D}{2} \cdot w\, \frac{2\pi}{60} = \frac{D w \pi}{60}$$

$$\Gamma = \int_0^{2\pi} u_{tan}\, D/2\, d\theta = \frac{D^2 w \pi}{120} \int_0^{2\pi} d\theta = \frac{D^2 w \pi^2}{60} = \frac{0'75^2 \cdot 60 \cdot \pi^2}{60} =$$

$$\boxed{\Gamma = 5'55 \text{ m/s}}$$

?? **b)** Liftaren adierazpidea (F_L) altuera unitateko, u-ren, ω-ren eta D-ren menpe

$$\Gamma = \rho\, u \cdot \pi^2 \frac{D^2 \omega}{60}$$

c) $u = 10\ m/s$ F_L? $F_L = 1'2 \cdot 10 \cdot \pi^2 \cdot \frac{0'75^2 \cdot 60}{60} = 66'62\ N$

③ $T = 0\ °C$

$\nu = 1'33 \cdot 10^{-5}\ m^2/s$

Reynolds?

① $Re = \frac{vc}{\nu} = \frac{16'14 \cdot 1'41}{1'33 \cdot 10^{-5}} = 1'711 \cdot 10^6$

② $Re = \frac{vc}{\nu} = \frac{75'08 \cdot 0'35}{1'33 \cdot 10^{-5}} = 1'975 \cdot 10^6$

④a) $\varphi, \theta_P, \theta_T$ eta c $r/R = 0'45$ tik $r/R = 0'55$ $\lambda r = \lambda$ puntan $r/R = 0'5$ erabiliko dugu

$C_d = 0$

$a' = 0$ $\lambda_r = \lambda \cdot r/R = 7 \cdot 0'5 = 3'5$

$\lambda = 7$ $tg\,\varphi = \frac{1-a}{\lambda_r (1-a')}$ edo $\varphi = atan\left(\frac{2}{3\lambda}\right) = atan\left(\frac{2}{3 \cdot 3'5}\right) = \boxed{10'78 = \varphi}$

$B = 3$ $c = \frac{8\pi r \sin\varphi}{3 B C_L \lambda_r} = \frac{8\ \pi (0'5 \cdot 5) \sin 10'78}{3 \cdot 3 \cdot 1 \cdot 3'5} = \boxed{0'3731 = c}$

$R = 5$ $\theta_p = \varphi - \alpha = 10'78 - 7 = \boxed{3'78° = \theta_p}$

$C_L = 1'0$ $\theta_T = \theta_p - \theta_{p,0} = 3'78 - \left(atan\left(\underset{\lambda=7}{\frac{2}{3 \cdot \lambda}}\right) - 7\right) = \boxed{5'34° = \theta_T}$

C_D/C_L min

$\alpha = 7$

b) $C_d/C_L = 0'02$ $u_{rel}, dF_{L1}, dF_{D1}, dF_{N1}, dF_{T1}, dQ_1$ $dr = R/10 = 5/10 = 0'5$

$u = 10\ m/s$

$u_{rel} = \frac{u(1-a)}{\sin\varphi} = \frac{10(1 - 1/3)}{\sin 10'78} = \boxed{35'64\ m/s = u_{rel}}$

$a = 1/3$

$a' = 0$ $dF_{L1} = 1/2\ C_L\ \rho\, u_{rel}^2 \cdot c\ dr = 1/2 \cdot 1 \cdot 1'24 \cdot 35'64^2 \cdot 0'3731\ \frac{5}{10} = \boxed{146'9\ N = dF_L}$

$\rho = 1'24\ kg/m^3$

$\boxed{dF_{D1}} = 1/2\ C_D\ \rho\, u_{rel}^2\ c\ dr = 1/2 \cdot (0'02 \cdot 1) \cdot 1'24 \cdot 35'64^2\ 0'37\ \frac{5}{10} = \boxed{2'94N}$

$dF_N = dF_L \cos\varphi + dF_D \sin\varphi = 146'9 \cos 10'78 + 2'94 \sin 10'78 = \boxed{144'85N = dF_N}$

$dF_T = dF_L \sin\varphi - dF_D \cos\varphi = 146'9 \sin 10'78 - 2'94 \cos 10'78 = \boxed{24'587N = dF_T}$

$dQ = B\, r\, dF_T = 3 \cdot (0'5 \cdot 5) \cdot 24'587 = \boxed{184'408\ N = dQ}$

?? **c)**

3. GAIA: Mekanika eta dinamika

① 60 bira/min

$I_b = 13558\ kgm^2$

a) E_z gelditu aurretik? Zenbat energia xurgatu balautatean?

	Newton	Solido zurruna
masa	$m_1 V_1 = m_2 V_2$	$J_1 \Omega_1 = J_2 \Omega_2$
indarra	$F = m \cdot a$	$\varphi = J \alpha$ (momentua) biratzen dagoelako
E_z	$E_z = 1/2\ m V^2$	$E_t = 1/2\ J \Omega^2$
Potentzia	$P = F\ V$	$P = \varphi \cdot \Omega$

kasu honetan, biratzen dagoenez, $I_b \Rightarrow J$ Inertzia momentu AXIALA

$$E_z = 1/2\ J \Omega^2 = 1/2 \cdot 13558\ kgm^2 \left(60\ \frac{2\pi}{60}\right)^2 rad/s^2 = 267624'2\ J$$

Turbina guztiz gelditzen bada, energia guztia xurgatzen du.

$$\boxed{E_z = E_{xurg} = 267'6242\ kJ}$$

b) $m = 27\ kg$

$c_p = 0'46\ kJ/kg\ ^\circ C$

ΔT ?

$$Q = m\ c_p\ \Delta T \Rightarrow 267'6242 = 27 \cdot 0'46 \cdot \Delta T$$

$$\boxed{\Delta T = 21'55\ ^\circ C}$$

② I_b palanka $= 4'2 \cdot 10^6\ kgm^2 = J$

$P = 1500\ kW$

$\omega = \Omega = 20$ bira/min

$$\begin{cases} \Omega = \Omega_0 + \alpha_0 t \\ \alpha = \alpha_0 \end{cases} \longrightarrow \begin{matrix} \Omega_0 = 20 \text{ bira/min} \\ \Omega = 40 \text{ bira/min} \end{matrix}$$

$$P = \varphi \cdot \Omega \Rightarrow 1500 \cdot 1000 = \varphi \cdot 20\ \frac{2\pi}{60}$$

$$\varphi = 716197'25\ J$$

$$\varphi = J \alpha \Rightarrow 716197'25 = 4'2 \cdot 10^6 \cdot \alpha$$

$$\alpha = 0'17052\ rad/s^2$$ azeleratzea

$$\Omega = \Omega_0 + \alpha t \Rightarrow (40 - 20)\ \frac{2\pi}{60} = 0'17052\ t$$

$$\boxed{t = 12'28 s}$$

Beste modu bat:

$$P = [J/s] = E_t/t \to \Delta t = \Delta E_t / P$$

$$E_{z_1} = 1/2\ J \Omega_1^2 = 1/2\ 4'2 \cdot 10^6 \left(20\ \frac{2\pi}{60}\right)^2 = 9211630'774\ J$$

$$E_{t_2} = 1/2\ J \Omega_2^2 = 1/2\ 4'2\ 10^6 \left(40\ \frac{2\pi}{60}\right)^2 = 36846523'1\ J$$

$$\Delta t = \frac{\Delta E_t}{P} = \frac{36846523'1 - 9211630'774}{1500 \cdot 1000} = \boxed{18'423 s = \Delta t}$$

③ $m = 1500 kg$

$P_n = 275 KW$

$\Omega = 60$ bira/min

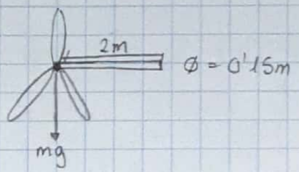
$\varnothing = 0'15 m$

Altzairuzkoa

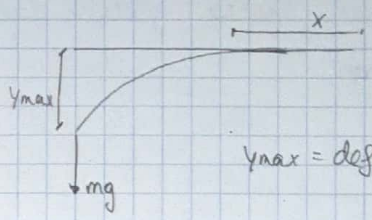
$L = 2m$

$E = 210GPa$

a) Zenbat okertzen da errotorearen eta ardatzaren kargengatik?



Makurdura ardatzean:



ymax = deflexioa, makurdura max

$$y_{max} = \frac{\overset{\to P = m \cdot g}{W} L^3}{3 E I_b}$$

$$I_b = \frac{\pi d^4}{64} = \frac{\pi\, 0'15^4}{64} = 2'4 \cdot 10^{-5} kg m^2$$

$$y_{max} = \frac{(1500 \cdot 9'8) \cdot 2^3}{3 \cdot 210 \cdot 10^9 \quad 2'4 \cdot 10^{-5}} = 7'511 \cdot 10^{-3} m = y_{max}$$

$$\boxed{y_{max} = 7'511 mm}$$

b) Zenbat bihurtzen da (tortsioz)? Esfortzu mozteilea?

φ = bihurdura angelua

$$\varphi = \frac{\varphi\, L}{G\, J}$$

φ = Indar parea → $\begin{cases} P = \varphi \cdot \Omega \\ \varphi = S \cdot \alpha \end{cases}$

L = ardatzaren luzeera

G = zurruntasun modulua = $\frac{E}{2(1+\mu)}$

J = Inertzi momentu axiala = $\frac{\pi d^4}{32}$

· E = 210GPa Altzairua

· $\mu = 0'3$ Poissonen konstante

$$\varphi = \frac{\varphi L}{G J} = \frac{\left(\frac{275 \cdot 1000}{60\,(2\pi/60)}\right) \cdot 2}{\left(\frac{210 \cdot 10^9}{2(1+0'3)}\right)\left(\frac{\pi\, 0'15^4}{32}\right)} = 0'022 \text{ rad} \quad \frac{180}{\pi} = \boxed{1'25° = \varphi}$$

$$\tau_{max} = \frac{\varphi_0 \cdot R}{J} = \frac{\frac{275 \cdot 1000}{60\,(2\pi/60)} \cdot \frac{0'15}{2}}{\frac{\pi\, 0'15^4}{32}} = 66046401'2 \text{ Pa}$$

$$\boxed{\tau_{max} = 66'05 MPa}$$

④ $z = 24'38m$

$T = 26'69kN$

$P_n = 250 kW$

$u = 44'7 m/s$

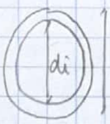
$T = 71'62 kN$

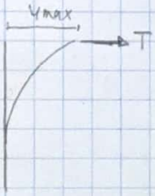
a) Altzairuz

$\varnothing = 1'22m$

$e = 0'0254$

ymax?





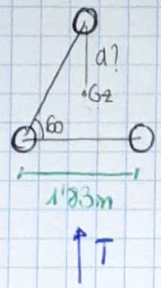
$$y_{max} = \frac{T \cdot L^3}{3 E\, I_b}$$

$$I_b = \frac{\pi d^4}{64} = \frac{\pi\,(1'22^4 - (1'22 - 0'0254)^4)}{64} = 0'0087$$

$$P_b \Rightarrow \quad y_{max} = \frac{26'69 \cdot 10^3\, 24'38^3}{3 \cdot 210 \cdot 10^9 \cdot 0'008} = 0'0696 m \Rightarrow \boxed{y_{max} = 70mm}$$

$$\text{HuraKan} \Rightarrow y_{max} = \frac{71'62 \cdot 10^3\, 24'38^3}{3 \cdot 210 \cdot 10^9 \cdot 0'008} = 0'1876m \Rightarrow \boxed{y_{max} = 187'7mm}$$

b) Dorreak 3 hanka dituela suposatut : y.max ?

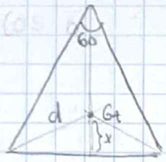


$\varnothing_e = 0'152m$

$\varnothing_i = 0'127m$

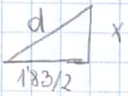
Oraungoan Inertzia momentua Steiner bidez kalkulatu behar da

$$I_m = \frac{\pi d^4}{64} = \frac{\pi(0'52^4 - 0'127^4)}{64} = 13'43277 \cdot 10^{-6} \, kgm^2$$



$$\sin 60 = \frac{h}{1'83} \rightarrow h = 1'58m$$

$$x = h/3 = 1'58/3 = 0'528m$$



$$d = \sqrt{0'528^2 + (1'83/2)^2} = 1'056m$$

$$I_t = \Sigma I + A_i \cdot d_{G_t}^2 = 3\left(I + \frac{\pi(\varnothing_e - \varnothing_i)^2}{4} \cdot d_{G_t}^2\right)$$

$$I_t = 3\left(13'43277 \cdot 10^{-6} + \frac{\pi(0'152 - 0'127)^2}{4} \cdot 1'056^2\right) = 1'68 \cdot 10^{-3} \, kgm^2$$

Handiagoa atera behar da ?!

$$y_{max} = \frac{26'69 \cdot 10^3 \cdot 24'38^3}{3 \cdot 210^9 \cdot 0'0018} = 0'36$$

⑤ $f = 1 Hz$

$\beta = 10°$

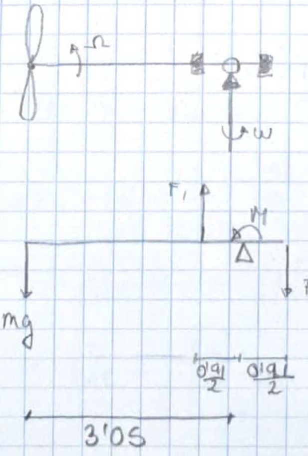
$J = 13558 \, kgm^2$

$m = 1459 \, kg$

$L = 3'05m$

$d = 0'91m$

a) Euste indarra yawing gabe!



yawin gabe $w = 0$

$\Sigma F = 0 \Rightarrow F_1 - F_2 - mg = F_1 - F_2 - 1459 \cdot 9'8 = 0$

$\Sigma M = 0 \Rightarrow 9'8 \cdot 1459 \cdot 3'05 - F_1 \frac{0'91}{2} - F_2 \frac{0'91}{2} = 0$

$$\boxed{\begin{array}{l} F_1 = 55071'64N \\ F_2 = 40773'44N \end{array}}$$

b) yawing badago :

$$MG = I \, \Omega \, w = 13558 \cdot \overset{Hz}{1} \cdot 2\pi \cdot 10 \frac{\pi}{180} = 14\,868'01 Nm$$

$$FG = \frac{MG}{3} = \frac{14868'01}{3} = 4956 \, N$$

$\Sigma F \Rightarrow -(1459\cdot 9'8 + 4956) + F_1 - F_2 = 0$

$\Sigma M \Rightarrow (1459\cdot 9'8 + 4956)\cdot 3'05 - 0'91/2\, F_1 - 0'91/2\, F_2 = 0$

$$\boxed{\begin{array}{l} F_1 = 74160'4\,N \\ F_2 = 54906'207N \end{array}}$$

⑥ $\varnothing = 38'1m$

$c = 1m$

$f = 1'67$

$\Omega = 50$ bira/min

$f_2 = 1'92\,Hz$

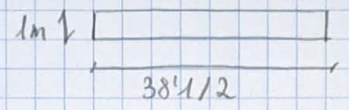
$O_p = 1'8^{\circ}$

$u = 8m/s$

$\rho = 1'225kg/m^3$

$m = 898\,kg$

Zurruntasuna, I_b eta offseta



Perfil simplifikatua

$$z = \frac{w_R^2 - w_{nR}^2}{\Omega^2} = \frac{(1'92\cdot 2\pi)^2 - (1'67\cdot 2\pi)^2}{\left(50\,\frac{2\pi}{60}\right)^2} = \boxed{1'2924 = z}$$

$$\text{Offset}: e = \frac{2(z-1)}{3+2(z-1)} = \frac{2(1'2924-1)}{3+2(1'2924-1)} = \boxed{0'1631 = e}$$

Inertzia momentua: mugitzen dagoen zatiarena

$$\boxed{I_b} = m_b\,\frac{R^2}{3}\,(1-e)^3 = 898\,\frac{(38'1/2)^2}{3}\,(1-0'1631)^3 = \boxed{63666'95\,kgm^2}$$

k_b : malgutasun elastikotasuna

$$w_{nR} = \sqrt{k_b/I_b} \rightarrow k_b = w_{nR}^2\cdot I_b = (2\pi\, 1'67)^2\cdot 63666'95 = 7\cdot 10^6\,\frac{kgm^2}{s}$$

$$\boxed{k_b = 7\,MNm}$$

→ Zenbat denbora pasatu behar da palak erresonantzian sartzeko?

$B = 3$ pala

$P = 400\,kW$

$w_R = 4f$

$w_{nR} = 10'49 rad/s$

$I_b = 3\cdot 63666'95 =$

$w_R^2 = w_{nR}^2 + \Omega^2 \rightarrow \Omega = \sqrt{(4\cdot 2\pi)^2 - 10'49^2} = 22'84\,rad/s$

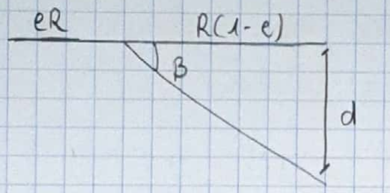
$$\varphi = \frac{P}{\Omega_0} = \frac{400\cdot 10^3}{50\,\frac{2\pi}{60}} = 76394'37\,rad/s$$

$$\alpha = \frac{\varphi}{I} = \frac{76394'37}{3\cdot 63666'95} = 0'4\,rad/s^2$$

$$\Omega = \Omega_0 + \alpha t \rightarrow 22'84 = 50\,\frac{2\pi}{60} + 0'4\,t$$

$$\boxed{t = 44s}$$

⑦ Aurkitu flaping angelua



$$\beta = \frac{\gamma A}{2K}$$

$$\gamma = \rho \, C_{L_\alpha} \, c \, \frac{R^4}{I_b}$$

↳ Lift koefizientea α-rekiko $\left(\frac{dC_L}{d\alpha}\right) \simeq 2\pi$

$$A = \frac{\Omega}{3} - \frac{\theta_p}{4}$$

$$\Lambda = \frac{u(1-a)}{\Omega R}$$

$$K = 1 + \varepsilon + \frac{k_\beta}{I_b \Omega^2}$$

↳ $\varepsilon = \frac{3+e}{2(1-e)}$

$$I_b = m_b \, {}^{R^2}/_{3} \, (1-e)^3$$

Aurreko ariketako datuak hartuz:

$$\gamma = \rho \, C_{L_\alpha} \, c \, \frac{R^4}{I_b} = 1'225 \cdot 2\pi \cdot 1 \, \frac{(38'1/2)^4}{63666'95} = 15'92 \text{ rad}$$

$$\Omega = \frac{u(1-a)}{\Omega R} = \frac{8(1-1/3)}{50 \, \frac{2\pi}{60} \, \frac{38'1}{2}} = 0'054$$

$$A = \frac{\Lambda}{3} - \frac{\theta_o}{4} = \frac{0'054}{3} - \frac{1'8 \, \frac{\pi}{180}}{4} = 9'969 \cdot 10^{-3}$$

$$K = 1 + \frac{3+e}{2(1-e)} + \frac{k_\beta}{I_b \Omega^2} = 1 + \frac{3+0'1631}{2(1-0'1631)} + \frac{7 \cdot 10^6}{63666'95 \left(50 \, \frac{2\pi}{60}\right)^2} = 6'9$$

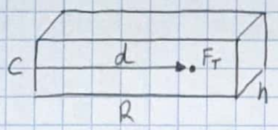
$$\beta_o = \frac{\gamma A}{2K} = \frac{15'92 \cdot 9'969 \cdot 10^{-3}}{2 \cdot 6'9} = 0'0115 \text{ rad} \, \frac{180}{\pi} \Rightarrow \boxed{\beta_o = 0'66^\circ}$$

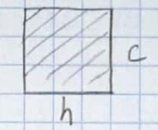
Ariketa anitzak

③ Tentsio maximoa tamainarekiko independentea dela frogatu:

Pala homologoa eta laukizuzena

$\hookrightarrow$ eskalan proportzionalki handitzen / txikitzen da.





Apurtuko den sekzioa

$I_0 = \frac{ch^3}{12}$

Makurdura momentua: $MF = F_T \cdot d$

- $F_T = C_T \frac{1}{2} \rho A u^2$ → Pala guztietan

  Pala batean nahi duguna:

  $F_T = \frac{1}{B} C_T \, 1/2 \, \rho \, (\pi R^2) \, u^2$

- $d = \frac{2R}{3}$

Palaren dimentzioa denez guk behar duguna, beste balio guztiak kte. betala hartuko ditugu:

ρ, u kte

Inportatzen zaizkigun balioak R, c eta h dira.

Tentsioa $= \sigma = \frac{Mh}{I}$

- $M \propto R^3$
- $I \propto ch^3$

Beraz,

$$\sigma = \frac{R^3 h}{c h^3} = \frac{R^3}{ch^2}$$

Adibidez:

$$(R, c, h) \xrightarrow{\text{Eskala} \times 2} (2R, 2c, 2h)$$

$$\frac{R^3}{ch^2} \longrightarrow \frac{(2R)^3}{2c\,(2h)^2} = \cancel{\frac{2^3}{2\,2^2}} \, \frac{R^3}{ch^2}$$

Ikus dezakegu berdina dela, beraz tentsioa ktc mantenduko da palaren tamaina handitu edo txikitu arren

④ Zurruntasuna

Zurruntasuna:

$R = E \cdot I$

↳ Elastikotasuna konstante

$R = I = \frac{ch^3}{12}$

$R \propto c h^3$

× 2 eskala ⟶ $(2R, 2c, 2h) = 16 c h^3$

× S eskala ⟶ $s^4 c h^3$

①

$u = 15 m/s$

$h = 40m$

$D = 40m$

$T = 14s$

$$U_{gust} = 6'4 \left(\frac{\sigma_x}{1 + 0'1 (D/21)} \right)$$

• σ_x desbidatio estandarra

$$u(T) = \begin{cases} u - 0'37 \, U_{gust} \sin \left(\frac{3\pi t}{T} \right) \left[1 - \cos \left(\frac{2\pi t}{T} \right) \right. & \text{for } 0 \leq t \leq T \\ u & \text{for } t < 0 \text{ and } 0 > T \end{cases}$$

→ abiadura errotorearen erdian, sartzen dena

$\sigma_x = I_{ref} (0'75 \, U_{hub} + 5'6)$

↳ turbulentzien intentsitatea

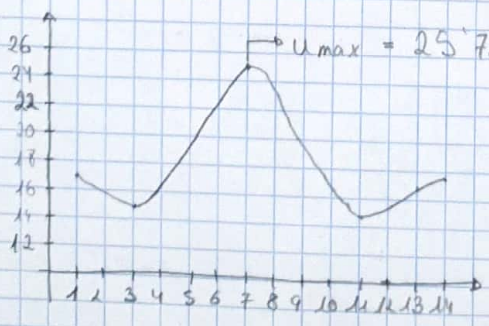
• Taulan begiratu

A	I_{ref}	0'16	Turbulentzia handia ✓
B	I_{ref}	0'14	Turbulentzia ertaina
C	I_{ref}	0'12	Turbulentzia txikia

$\sigma_x = I_{ref} (0'75 \, U_{hub} + 5'6) = 0'16 (0'75 \cdot 15 + 5'6) = 2'696$

$$U_{gust} = 6'4 \left(\frac{\sigma_x}{1 + 0'1 (D/21)} \right) = 6'4 \left(\frac{2'696}{1 + 0'1 (40/21)} \right) = \boxed{14'493 m/s = U_{gust}}$$

Grafikoa egiteko denbora desberdinak hartu eta ordezkatu



Grafikoan esker ikus dezakegu $t_1 = 4'66s$-an 15 m/s baino altuagoa den abiadura dugula, eta $t_2 = 9'34$ denean, berriz jaisten da 15 m/s baino txikiagoak izanda. Beraz:

Haize boladen denbora tartea: $\boxed{t = 4'68 s}$

Lortutako abiadura pikoa: $\boxed{U_{max} = 25'72 m/s}$
)

transmitizio enenclimondua CF (sistema globalarenal)

② 16 urteko datuak

Topatu 50 eta 100 urtetan espero duren u_{max}

Liburuan formulak bilatu

$$F(U_e) = \exp\left(-\exp\left(\frac{-(U_e-\mu)}{\beta}\right)\right)$$ → Gumbel-en distribution

- U_e = abiadura maximoa periodo jakin batean
- $\beta = \left(\frac{\sigma_e\sqrt{6}}{\pi}\right)$
- $\mu = \bar{U}_e - 0'577\,\beta$
- $\bar{U}_e$ = the mean of a set of extreme values
- σ_e = the standard deviation of that set
- Desbiderapen tipikoa : $\sigma = \sqrt{\frac{\Sigma(\bar{U}_m-\bar{U})^2}{N}}$
  - Batez besteko abiadura : 18'66 m/s

$\sigma = 2'3711$

$$\beta = \left(\frac{\sigma\sqrt{6}}{\pi}\right) = \left(\frac{2'3711\sqrt{6}}{\pi}\right) = 1'8487$$

$$\mu = \bar{U}_e - 0'577\beta = 18'6625 - 0'577 \cdot 1'8487 = 17'5958$$

50. urtetan

$$1 - F(U_e) = \frac{1}{50} \rightarrow F(U_e) = 0'98$$

$$0'98 = \exp\left(-\exp\left(\frac{-(U_e-17'595)}{\beta}\right)\right) \rightarrow \boxed{U_e = 24'75\ m/s}$$

100 urtetan

$$1 - F_e(U_e) = \frac{1}{100} \rightarrow F(U_e) = 0'99$$

$$0'99 = \exp\left(-\exp\left(\frac{-(U_e-17'595)}{1'8487}\right)\right) \rightarrow \boxed{U_e = 26'1 m/s}$$

⑥ $t = 10 \, min$ a) $\varepsilon = 0'0002 m$ Batez-besteko abiadura!

$u = 8'5 \, m/s$ $h = 80m$

$h = 10m$

$d = 104m$

$$\frac{u(z)}{u(z_r)} = \frac{\ln(z/z_0)}{\ln(z/z_0)}$$

$$\frac{u(z)}{8'5} = \frac{\ln(80/0'0002)}{\ln(10/0'0002}$$

$$\boxed{u(z) = 10'13 \, m/s}$$

b) A_c 0'018 Batez-besteko abiadura?

C_D 0'0015

$h = 80m$

$u' = u \, c_D^{1/2}$

$$u' = u \, c_D^{1/2} = 8'5 \cdot 0'0015^{1/2} = 0'35 \, m/s$$

$$z_0 = A_c \frac{(u')^2}{g} = 0'018 \, \frac{0'35^2}{9'8} = 2 \cdot 10^{-4} m$$

$$u(z) = \frac{u'}{k} \cdot \ln\left(\frac{z}{z_0}\right) = \frac{0'33}{0'4} \ln \frac{10}{2 \cdot 10^{-4}} = 8'93 \, m/s$$

$$u(80) = u(10) \frac{\ln(80/2 \cdot 10^{-4})}{\ln(10/2 \cdot 10^{-4})} = \boxed{10'13 m/s = u(80)}$$

c) $h = 20m$

$z = 3m$

$T = 9s$

$h = 80$

$$L_p = \overset{\text{peak periodo}}{\text{wave lenght}} = \frac{g \, t^2}{2\pi} \sqrt{\tanh \frac{4\pi^2 d}{t^2 g}} = \frac{9'8 \, 9^2}{2\pi} \sqrt{\tanh \frac{4\pi^2 \, 20}{9^2 \, 9'8}} = 110'09m$$

$$\frac{z_0}{H_s} = 1200 \left(\frac{H_s}{L_p}\right)^{4'5} = 1200 \left(\frac{3}{110'09}\right)^{4'5} \cdot 3 = 3'3 \cdot 10^{-4} m/s$$

$$u(10) = \frac{u'}{k} \ln\left(\frac{z}{z_0}\right) = \frac{0'33}{0'4} \ln\left(\frac{10}{3'3 \cdot 10^{-4}}\right) = 8'52 m/s$$

$$u(80) = 8'52 \, \frac{\ln(80/3'3 \cdot 10^{-4})}{\ln(10/3'3 \cdot 10^{-4})} = \boxed{10'24 m/s = u(80}$$

⑧ $\varnothing_e = 90m$

$\varnothing_{mon} = 4m$

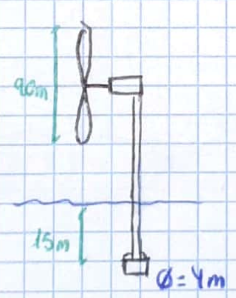
$z = 15m$

$u = 12 m/s$

$h = 2m$

$\lambda = 100m$

$c_D = 1'5$



Sasoko duen indar maximoa?

- Haizeagatiko indarra
- Olatu frenteen indar inertziala
- Olatuen arrastre indarra

a) $F_H = 1/2 \, \rho \, A \, u^2 \, C_T$

Errotorearekiko bultzada koefizientea (c_T) Betz-en potentzia koefizienteari dagokio

$$a = 1/3 \; ; \; C_T = 4a(1-a) = 8/9$$

$$F_H = 1/2 \; 1'2 \cdot \pi^2 \, 45^2 \cdot 12^2 \cdot 8/9 = \boxed{488'58 kN = F_H}$$

b) $F_I = \rho_w \, g \, \frac{C_M \, \pi \, D^2}{4} \, \zeta \tanh[k \cdot d]$

Airy-ren ereduari jarraituz $k = \frac{2\pi}{L_p} \equiv$ uhin zenbakia

Inertzia koefizientea $C_M = 2$

$\zeta = 1 \equiv$ anplitudea $= \frac{\cancel{H}}{2} = \frac{2}{2} = 1$ $\quad H_s \rightarrow$ olatuen altuera

$d \equiv$ sakonera

$$F_I = 1000 \cdot 9'8 \, \frac{2 \, \pi \, 4^2}{4} \, 1 \, \tanh\left[\frac{2\pi}{100} \cdot 15\right] = \boxed{181'365 kN = F_I}$$

c) $F_D = \rho g C_D \frac{D}{2} \, \S \left[1/2 + \frac{k \cdot d}{\sinh(2kd)} \right]$ zilindro bat izanda $C_D = 1'5$

$F_D = 1000 \cdot 9'8 \quad 1'5 \quad \frac{4}{2} \cdot 1 \left[\frac{1}{2} + \frac{2\pi \, 15}{100 \sinh\left(\frac{2\pi}{100} \cdot 15\right)} \right] = \boxed{23'3124kN = F_D}$

Indarren batura

$F_T = F_H + F_D + F_I = \boxed{693'25kN = F_T}$

⑨ 2000 biztanleen   Potentzia nominala?

Kontsumoa pertsonako   Kontsumo totala: $Q = 2000 \cdot 100 \, l/s = 0'0023 \, m^3/s$

$H = 100m$

Bernoulli:

$CF = 0'25$

$$\frac{P_1}{\gamma} + z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$

$\eta_{ponpa} = 0'80$

$Hm = 100m$

$P_{ponpa} = \rho g \, Hm \, Q / \eta_p = 1000 \cdot 9'8 \cdot 1000 \cdot 0'0023/0'8 = 2'8175 \, kW$

$P_{ponpa} = P_{turbina}$

$P_{nom} = P_{tur}/CF = 2'8175/0'25 = \boxed{11'27 \, kW = P_n}$

⑩ $n = 2000$ biztanleen

$Q = 100 \, l/egun$

$\rho_{its} = 1020 \, kg/m^3$

$T = 20°C$

gazitasuna $S = 38$

$CF = 0'25$

$\eta_{sis} = 0'2$

Kontsumo totala $Q = \frac{Q_p \cdot n}{3600 \cdot 24} = 0'0023 m^3/s$

Ura gazitzeko presioa: bi modu daude presio osmotikoa kalkulatzeko

1) Maxwell-en liburua 48'9 orr.

$P_\pi (T = 20°C, \rho = 1020 \, kg/m^3) = 2'7 \, MPa$

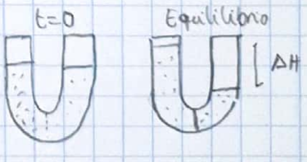
2) Formula erabiliz:

$P_\pi = i \cdot S \cdot \rho \cdot R \cdot T/M$

- i: Van't Hoff-en konstantea = 1'8 [-]
- R: gas nobleen konstantea = 8'31447 $m^3 \, Pa/mol \cdot K$
- M: gatzaren pisu molekularra

$P_\pi = 1'8 \cdot 38 \cdot 1020 \cdot 8'31447 \quad 293/58'5 = 2'9054 \, MPa$

Potentzia:



$P_{sis} = Q \cdot P_\pi = 0'0023 \cdot 2'9054 \cdot 10^6 = 6'68 \, kW$

$P_{erre} = P_{sis}/\eta = 6'68/0'2 = 33'4121 \, kW$

$P_{tur} = \frac{P_{erre}}{CF} = \frac{33412'1}{0'25} = \boxed{133'6484 kW = P_{tur}}$

Betz zenbakia aplikatu nahi bada:

$P_{turb} = C_p \cdot P_{ins} \Rightarrow P_{ins} = \frac{133'6484}{0'59} = 226'523 kW$

Azalpena:

Gatza membrana semi-permeable batetik pasatzeko behar den presioari presio osmotikoa deritzo. Membranak, ur garbia eta itsasoko ura banatzen ditu eta bien artean dagoen altuera diferentzia (ΔH) presio osmotikoaren ondorioz gertatzen da. Presio hau aplikatuz, ura gezatzen da.

⑲ $P_n = 500kW$

$\varnothing = 40m$

$\Omega = 40 bira/min$

$u = 12 m/s$

$B = 3$

Zarata estimatu

$V = R \cdot \Omega = 20 \cdot 40 \frac{2\pi}{60} = 83'77 m/s$

1) $L_{wA} = 10 \log P_{wT} + 50 = 10 \log 500 \cdot 10^3 + 50 = \boxed{L_{wA} = 106'99 dB}$

2) $L_{wA} = 22 \log D + 72 = 22 \log 40 + 72 = L_{wA} = \boxed{107'24 dB}$

3) $L_{wA} = 50 \log V + 10 \log D - 4 = 50 \log 83'77 + 10 \log 40 - 4 = \boxed{L_{wA} = 108'175 dB}$

11. ariketa

a) DATUAK:

- n=2000 bizilagun
- Kontsumoa pertsonako $E_{pertsonako}$ = 8KWh / egun
- Tangaren tamaina:
  - Diametroa D = 30 m
  - Altuera h = 5
- Tangaren kota H = 70 m

Hustutze denbora?

PROZEDURA:

Potentzia kontsumo totala: $Pot_{total} = n \cdot Pot_{pertsonako} = 2000 \cdot 8 \frac{kW \cdot h}{egun} \cdot \frac{1\, egun}{24\, h} = 666{,}66 kW$

Tangaren bolumen totala: $V_{tanga} = pi \cdot \frac{D^2}{4} \cdot h = 3534.29\ m^3$

Turbinak emandako potentzia: $Pot_{turbina} = Q \cdot p \cdot g \cdot H = \frac{3534.29}{t} \cdot 1000 \cdot 9.8 \cdot 70 = \frac{2424522940}{t}$

Jakinik $Q = \frac{V}{t}$ dela

Kontuan izanik turbina kontsumoa asetzeko erabiliko dela: $Pot_{total} = Pot_{turbina}$

Hortik denbora atera dezakegu beraz $t = \frac{2424522940}{666666} = 3636.82\ s = 1.01\ h$

b) DATUAK

- Turbinaren ezaugarriak:
  - CF = 0.25
  - Errendimendua (Suposatutakoa) = 0.7
  - CP (Suposatutakoa) = 0.59
- Ponparen ezaugarriak:
  - Errendimendua = 0.8
- Haizearen abiadura U = 8 m/s
- Betetze denbora: t = 3636.82 s

Betetze denbora?

PROZEDURA

$$\text{Haizea } (Pot_{haiz}) \overset{CP}{\Rightarrow} \text{Haize turbina } (Pot_{nom}) \overset{CF}{\Rightarrow} \text{H. turbina } (Pot_{turb})$$
$$\xRightarrow{\eta_{turb}} \text{H. turbina } (Pot_{erab}) \overset{1}{\Rightarrow} \text{Ponpa } (Pot_{trans}) \xRightarrow{\eta_{ponpa}} \text{Ponpa } (Pot_{ponpa})$$

Haize turbinaren potentzia nominala: $Pot_{nom} = \frac{1}{2} \cdot p \cdot A \cdot U^3$

Ponparen potentzia nominala: $Pot_{ponpa} = p \cdot g \cdot Q \cdot H = 666654.8\ W$

Emaria: $Q = \frac{V}{t} = 0.9718\ m^3/s$

Altuera: H = 70 m

Beraz, haizearen potentzia lortzeko ponparen potentziatik abiatuta:

$$Pot_{haizea} = \frac{Pot_{ponpa}}{\eta_{ponpa} \cdot \eta_{turbina} \cdot CF \cdot Cp} = 8070881.356\ W = 8.1\ MW$$

Beraz, : $Pot_{haizea} = \frac{1}{2} \cdot p \cdot A \cdot U^3 = \frac{1}{2} \cdot p \cdot pi \cdot \frac{D^2}{4} \cdot U^3$ $\qquad D = 6.3357\ m$

FORMULAZIOA:

1. GAIA: HAIZEA BALIABIDE BEZELA

○POTENTZIA:

$$\begin{cases} P=F\cdot v \\ P=\underset{\substack{\uparrow \\ \text{parea}}}{T}\cdot \underset{\text{↳ abiadura angeluarra}}{\omega} \end{cases}$$

$$E_z = \frac{1}{2}\cdot m\cdot U^2 = \frac{1}{2}\cdot J\cdot \Omega^2$$

$$P = \frac{dE_t}{dt} = \frac{1}{2}\cdot \dot{m}\cdot U^2 = \frac{1}{2}\cdot\rho\cdot A\cdot U^3$$

↳ Fluxu masikoa $= \dot{m} = \rho\cdot Q = \rho\cdot U\cdot A$

- PE: POTENTZIA ESPEZIFIKOA:

$$\frac{P}{A}=\frac{1}{2}\cdot\underset{\text{↳ 0,4 inguru}}{\eta}\cdot\rho\cdot U^3 \quad \left(\frac{P}{A}\simeq 0{,}4\text{–}0{,}5\,\text{kW/m}^2 \text{ inguru}\right)$$

- TURBINAREN EFIZIENTZIA TOTALA:

$$P=\frac{1}{2}\cdot\eta_T\cdot\rho\cdot A\cdot U^3\cdot \underset{\text{↳ Betz}=0{,}59\text{ (ideala)}}{c_P}$$

○WEIBULL:

Denboran zehar zein frakzio U-ren azpitik

C = eskala = b.b. abiadura

K = forma parametroa

- PROBABILITATE DENTSITATEA:

$$\bar{U} = \int_0^\infty U\cdot f(U)\,dU = C\,\Gamma\Big(\underbrace{1+\frac{1}{K}}_{\text{1-2 artean}}\Big) \rightarrow \Gamma 2\uparrow \rightarrow (x-1)\Gamma(x-1)$$

*

- FUNTZIO AKUMULATUA:

$$F(U) = 1-e^{-(U/C)^K}$$

- DESBIDERAKETA ESTANDARRA:

$$\sigma^2 = C\,\Gamma\left(1+\frac{2}{K}\right) - U^2$$

$$\sigma^2 = \frac{1}{N-1}\cdot\sum_{i=1}^{N}(U_1-\bar{U})^2$$

$$K = \left(\frac{\sigma}{\bar{U}}\right)^{-1{,}086}$$

- URTEKO ENERGIA PRODUKZIOA:

$$P = C_p\cdot\eta_T\cdot\frac{1}{2}\,\rho\,A\,\Big(\underbrace{C^3\,\Gamma\Big(1+\frac{3}{K}\Big)}_{\bar{U}^3 = \text{batez besteko abiadura}}\Big)\cdot\text{orduak}$$

* Rayleigh → K=2

FORMULA GEHIGARRIAK:

- $\lambda = \frac{\text{puntako-abiadura}}{\text{haizearen abiadura}}$
  - $\lambda \simeq 1$ Makina motelak
  - $\lambda \simeq 5-8$ Makina azkarrak

- ERROTAZIO ABIADURA = $\Omega = \frac{\text{Punta abiadura}}{\text{Erradioa}}$ [rad/s]

$U = \omega \cdot R \rightarrow U_{punta} = \Omega \cdot R$

- TRANSMISIO ERLAZIOA = $t = \frac{S}{E} = \frac{\Omega_1}{\Omega_2}$

- LEGE POTENTZIALA = $\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha}$ → potentzia koef.

- LEGE LOGARITMIKOA = $\frac{U_2}{U_1} = \frac{\ln(h_2/z_0)}{\ln(h_1/z_0)}$

Zuhaitzekin: $z_0 = 0{,}1$

Zuhaitz gabe: $z_0 = 0{,}01$

Puntu altuan: z

Puntu baxuan: z_r

$z_0 = A_c \cdot \frac{(u')^2}{g}$

$U(z) = \frac{u'}{K} \cdot \ln\left(\frac{z}{z_0}\right)$

- ERRENDIMENTUA:

$\eta_T = C_{pmax} \cdot \eta_m \cdot \eta_e = 0{,}59 \cdot 0{,}9 \cdot 0{,}9 \simeq 0{,}4$

→ elektrikoa: sorgailua

→ mekanikoa: ardatza

→ Betz aerodinamikoa.

Ez du kontuan hartzen:

- Zorratz birakaria.
- Pala kopuru infinitua.
- F drag $U_2 = U_3$.

3. GAIA: MEKANIKA ETA DINAMIKA

FORMULAK

○ OINARRIZKO FORMULAK:

	Newton	Solido Zurruna
Masa	$m_1 \cdot u_1 = m_2 \cdot u_2$	$J_1 \cdot \Omega_1 = J_2 \cdot \Omega_2$
Indarra	$F = m \cdot a$	$Q = J \cdot \alpha$
Ez	$Ez = \frac{1}{2} m \cdot u^2$	$Ez = 1/2 \cdot J \cdot \Omega^2$
Potentzia	$P = F \cdot u$	$P = Q \cdot \Omega$

Q = Indar-parea

J = Inertzia-momentu polarra

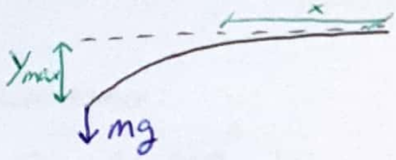
Ω = abiadura angeluarra (bira/min)

$Q = m \cdot cp \cdot \boxed{\Delta T}$ → Balaztatzean zenbat berotzen zen jakiteko.

○ ARDATZA OKERTU:

$$Y_{max} = \frac{\overset{T\ (bulkada)\ edo}{W} \cdot L^3}{3 \cdot E \cdot I_b} \ [m]$$

- $W = p = mg$ (bertikalean badago bulkada egongo da T)
- L = ardatzaren luzera
- E = elastikotasuna (Altzairua 210 GPA($\cdot 10^9$))
- I_b = inertzia momentua ($I_b = \frac{\pi \cdot d^4}{64}$)

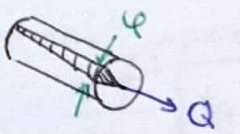


○ BIHORDURA (tortsioa):

$$\varphi = \frac{Q_p \cdot L}{G \cdot J} \ [rad]$$

- Q: indar parea $\begin{cases} P = \varphi \cdot \Omega \\ \varphi = J \cdot \alpha \end{cases}$
- L: ardatzaren luzera
- G: Zurruntasun modulua: $G = \frac{E}{2(1+\mu)}$
- J: inertzia momentu axiala: $J = \frac{\pi \cdot d^4}{32}$

- μ: Poissonen Ktea 0,3
- E: elastikot. (210 GPa)



○ ESFORTZU MOZTAILEA:

$$Z_{max} = \frac{Q_p \cdot R}{J} \ [Pa]$$

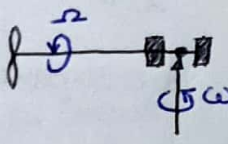
- Q: Indar parea
- R: erradioa
- J: inertzia momentu axiala

○ EUSTE INDARRA: Yawing badago → $\omega \neq 0$

$$MG = I \cdot \Omega \cdot \omega \ [Nm]$$

Momentu giroskopikoa

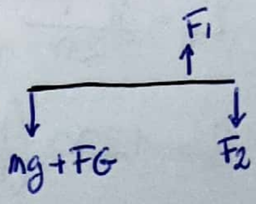
- $I = J$ = inertzia momentua
- $\omega = F \cdot 2 \cdot \pi$ [rad/s]
  ↳ frekuentzia [Hz]



$$FG = \frac{MG}{L} \ [N]$$

Indar giroskopikoa

- $\Omega = \alpha \cdot \frac{\pi}{180}$ [°]



- ZURRUNTASUNA:

$$Z = \frac{\overset{2\pi}{\dot{\omega}}_{R}^{2} - \overset{2\pi}{\dot{\omega}}_{NR}^{2}}{\Omega^{2}} \ [-]$$

$$Z = E \cdot I_b$$

- ω_{NR}: geldirik dagoen maiztasun naturalaren arabera
- ω_R: abian dagoen maiztasunaren arabera
- Ω [rad/s]

- OFFset-a:

$$e = \frac{2(Z-1)}{3+2(Z-1)} \ [-]$$

- INERTZIA MOMENTUA: mugitzen den zatiarena

$$I_b = m_b \cdot \frac{R^2}{3} (1-e)^3 \ [Kg\,m^3]$$

- Malgukiaren elastikotasuna: K_β

$$\omega_{NR} = \sqrt{\frac{K_\beta}{I_b}} \longrightarrow K_\beta = \omega_{NR}^{2} \cdot I_b \ [Kg\,m^2/s = Nm]$$

↳ mugitzen den zatiaren inertzia momentua

- FLAPPING ANGELUA:

$$\beta = \frac{\gamma \cdot A}{2 \cdot K}$$

- $\gamma = \rho \cdot C_{L,\alpha} \cdot C \dfrac{R^4}{I_b}$

↳ lift koef. α-rekin $\frac{dC_L}{d\alpha} \simeq 2\pi$

- $A = \dfrac{\Omega}{3} - \dfrac{\theta_p}{4}$

$$\Lambda = \frac{4(1-a)}{\Omega \cdot R}$$

- $K = 1 + \varepsilon + \dfrac{K_b}{I_b \cdot \Omega^2}$

$$\varepsilon = \frac{3+e}{2(1-e)}$$

- SOLIDOTASUNA:

$$\sigma = \frac{B\,c}{2 \cdot \pi \cdot r} = \frac{\text{palaren azalera}}{\text{barreiatutako perimetroa}}$$

Aero sorgailu batean zenbat solido dagoen.

$$L_p = \frac{g \cdot T^2}{2\pi} \sqrt{tgh \cdot \frac{4\pi^2 d}{T^2 \cdot g}} \ [m]$$

- T=periodoa
- d =sakonera

$$Z_0 = 1200 \cdot \left(\frac{H_s}{L_p}\right)^{4,5} \cdot H_s$$

- Hs =datuen altuera

ARIKETA GEHIGARRIAK FORMULAK

- **DESBIDERAZIO ESTANDARRA:**

Abiadura errotorearen erdian

$$\sigma_x = I_{rel}\,(0{,}75\,U_{hub} + 5{,}6)$$

Turbulentziaren intentsitatea

- **GUMBEL-en DISTRIBUZIOA:**

$$F(U_e) = \exp\left(-\exp\left(\frac{-(U_e-\mu)}{\beta}\right)\right)$$

$1 - F(U_e) = 0{,}98$ edo beste bat

- U_e = abiadura maximoa periodo jakin batean
- $\beta = \frac{\sigma_e\sqrt{6}}{\pi}$
- $\mu = \bar{U}_e - 0{,}577\beta$
- $\bar{U}_e$ = la media de un conjunto de valores extremos
- σ_e = la desviación estandar de ese conjunto
- Desbiderapen tipikoa: $\sigma = \sqrt{\frac{\Sigma(\bar{U}_m - \bar{U})^2}{N}}$

- **CHARNOCK:**

$$z_0 = A_c \cdot \frac{U_m^2}{g}$$

$$U(z) = \frac{U_m}{\kappa} \cdot \ln\left(\frac{z}{z_0}\right)$$

0,4 Ktea

- **OLATUAK:**

periodoa ≈ 9, Kantaurin

$$L = \frac{g \cdot T^2}{2\pi}\sqrt{tgh\left(\frac{4\pi^2 \cdot d}{T^2 g}\right)}$$

sakonera

L ≈ 100m

$$\frac{z_0}{H_s} = 1200\left(\frac{H_s}{L}\right)^{4,5}$$

olatuen altuera

uhin luzera

- **INDARRAK:**
  - Haizeagatiko indarra:

$$F_H = \frac{1}{2} \cdot \rho \cdot A \cdot U^2 \cdot C_T \qquad C_T = 4a(1-a)$$

C_T = Errotorearekiko bulkada [N]

  - Olatu frenteen indar inertziala:

$$F_I = \rho \cdot \omega \cdot g \cdot \frac{C_M \cdot \pi \cdot D^2}{4}\,\xi\, tgh(K \cdot d)$$

- $K = \frac{2\pi}{L_P}$ = uhin zenbakia
- ξ = anplitudea = $\frac{H_s}{2}$
- C_M = inertzia koef.

  - Olatuen arrastre indarra:

$$F_D = \rho \cdot g \cdot C_D \cdot \frac{D}{2}\,\xi\left[\frac{1}{2} \cdot \frac{K \cdot d}{\sinh(2K\alpha)}\right]$$

- Zilindro bat izanda $C_D = 1{,}5$

- ZARATA ESTIMATU:
  - Potentziarekin:

$$L_w = 10 \cdot \log P_{WT} + 50$$

  - Diametroarekin:

$$L_w = 22 \log D + 72$$

  - Punta abiadurarekin:

$$L_w = 50 \log V + 10 \log D - 4$$

$$\cdot V = R \cdot \Omega = 20 \cdot 40 \frac{2\pi}{60} = 83{,}77 m/s$$

ARIKETAK:

1. GAIA: Haizea Baliabide gisa:

① $D=12m$
$u=8m/s$
$\eta=0.4$
$\rho=1,2Kg/m^3$

Urteko energia produkzioa?

- Azalera kontuan hartu gabe:

$$\frac{P}{A}=\frac{1}{2}\cdot\rho\cdot\eta\cdot u^3=\frac{1}{2}\cdot1,2\cdot0,4\cdot8^3=122,88\ W/m^2$$

$$\text{Urtean}\rightarrow \underset{W/m^2}{122,88}\cdot\underset{egun}{365,25}\cdot\underset{h}{24}=1,0771\cdot10^6\ Wh/m^2$$

- Azalera kontuan hartuta:

$$P=1,0771\cdot10^6\cdot\frac{\pi\cdot12^2}{4}=121,824\cdot10^6\ Wh$$

$$P_{urtean}=\underline{121,824\ MWh}$$

②

$D=40m$
$P=700KW$
$u=14m/s$

a) Errotazio abiadura?

Punta-abiadura ratioa: $\lambda=0,5$

$$\Omega=\frac{\text{Punta abiadura}}{\text{Erradioa}}$$

Punta-abiadura (U_{punta}):

$$\lambda=\frac{\text{Punta-abiadura}}{u}\longrightarrow U_{punta}=\lambda\cdot u=0,5\cdot14=7\ m/s$$

$$\Omega=\frac{7\ m/s}{20m}=0,35\ rad/s\cdot\frac{60}{2\pi}=\underline{3,342\ bira/min}$$

b) Puntako abiadura? $\underline{U_{punta}=7m/s}$

c) $\Omega=1800\ bira/min\rightarrow$ transmisio erlazioa (t)?

$$t=\frac{\Omega_1}{\Omega_2}=\frac{1800}{3,342}=\underline{538,56}$$

d) η_T?

$$P_{TOT}=\frac{1}{2}\cdot\eta_T\cdot\rho\cdot A\cdot u^3\cdot c_p\rightarrow\text{beta}$$

$$700\cdot10^3=\frac{1}{2}\cdot\eta_T\cdot1,2\cdot\frac{\pi\cdot40}{4}\cdot14^3\cdot0,59$$

$$\underline{\eta_T=\%57,34}$$

③ U_2?

$h_2 = 40m = z_2$
$h_1 = 10m = z_1$
$U_1 = 5m/s$

$z_0 = 0{,}1$ Zuhaitzekin
$z_0 = 0{,}01$ Zuhaitz gabe

Zuhaitzekin:

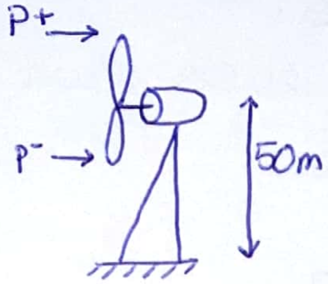
$$\frac{U_2}{U_1} = \frac{\ln(h_2/z_0)}{\ln(h_1/z_0)} \longrightarrow \frac{U_2}{5} = \frac{\ln(40/0{,}1)}{\ln(10/0{,}1)} \Rightarrow U_2 = 6{,}5\ m/s$$

Zuhaitzik gabe:

$$\frac{U_2}{5} = \frac{\ln(40/0{,}01)}{\ln(10/0{,}01)} \longrightarrow U_2 = 6\ m/s$$

④

D=30m
h=50m
$\alpha = 0{,}2$
↳ Perfil bertikalaren lege esponentziala



$$\frac{P(65m)}{P(45m)} = \frac{1/2 \cdot 1{,}22 \cdot \pi \cdot 15^2 \cdot U(65)^3}{1/2 \cdot 1{,}22\,\pi \cdot 15^2 \cdot U(35)^3} = $$

$$= \frac{U(65)^3}{U(35)^3} = 1{,}13^3 = 1{,}45$$

%45 aldiz potentzia gehiago

POTENTZIA

$$\left(\frac{h^+}{h^-}\right)^{\alpha} = \left(\frac{65}{35}\right)^{0{,}2} = 1{,}13 \rightarrow \%13 \text{ gehiago}$$

INDARRA

⑤

P= 100KW
U=7,5m/s
Cp=16/27
n=1

D?

$P = 1/2\, n \cdot \rho \cdot A\, U^3 cp$

$$100 = 1/2 \cdot 1 \cdot 1{,}2 \cdot \frac{\pi \cdot D^2}{4} \cdot 7{,}5^3 \cdot \frac{16}{27} \longrightarrow D = 29{,}13m$$

6.1.

Weibull:
$c=6m/s$
$K=1,8$

a, Bataz besteko abiadura:

$$\bar{u}=c\Gamma\left(1+\frac{1}{K}\right)=6\Gamma\left(1+\frac{1}{1,8}\right)=6\Gamma 1,\hat{5}=6\cdot 0,809=5,335 m/s$$

b, Zenbat ordutan $u=6,5-7,5 m/s$ artean?

$6,5\leq u\leq 7,5$

$$F(7,5)-F(6,5)=1-e^{-(x/c)^K}-\left(1-e^{-(x/c)^K}\right)=1-e^{-(7,5/6)^{1,8}}-\left(1-e^{-(6,5/6)^{1,8}}\right)$$

$$=0,09$$

Urtean $=0,09\cdot 365,25\cdot 24=794,73$ ordu/urtean

c, Zenbat ordu $u\leq 16m/s$?

$u\geq 16\quad 1-F(16)=1(1-e^{-(16/6)^{1,8}})=1-0,99=0,002896$

Urtean $=0,002896\cdot 365,25\cdot 24=35,38$ ordu/urte

6.2.

$\bar{u}=6m/s$
Rayleigh → $K=2$

a, Zenbat ordu 9,5 eta 10,5 m/s artean?

$$\bar{u}=c\cdot\Gamma\left(1-\frac{1}{K}\right)=c\Gamma\left(1+\frac{1}{2}\right)=c\Gamma 1,5$$

$6=c\cdot 0,88622693$

$c=6,77 m/s$

$$9,5\leq u\leq 10,5\rightarrow F(10,5)-F(9,5)=1-e^{-(10,5/6,77)^2}-\left(1-e^{-(9,5/6,77)^2}\right)$$

$$=0,049$$

Urtean $=0,049\cdot 365,25\cdot 24=432,68$ ordu/urte

b, Zenbat ordu $u\leq 16m/s$?

$$1-F(16)=1-\left(1-e^{-(16/6,77)^2}\right)=1-0,996=0,00375$$

Urtean $=0,00375\cdot 365,25\cdot 24=32,88$ ordu/urte.

⑦

$D = 12m$
$\bar{u} = 8 m/s$
Rayleigh → $K=2$

Energia produkzioa urtean?

$$\bar{u}^3 \neq u^3$$

$$\bar{u} = c\,\Gamma\left(1+\frac{1}{2}\right) \longrightarrow 8 = C \cdot 0{,}88$$

$$\hookrightarrow C = 9{,}027\, m/s$$

$$\bar{u}^3 = c^3\,\Gamma\left(1+\frac{3}{K}\right)$$

$$\bar{u}^3 = 9{,}027^3\,\Gamma\left(1+\frac{3}{2}\right) = 9{,}027^3\left(1{,}5\,\Gamma 1{,}5\right) =$$

$$\hookrightarrow \Gamma(r+1) = r\,\Gamma r$$

$$= 9{,}027^3 \cdot 1{,}5 \cdot 0{,}8862 = 977{,}837\, m/s$$

$$P = 1/2 \cdot n \cdot \rho \cdot A \cdot \bar{u}^3 = \frac{1}{2} \cdot 1 \cdot 1{,}2 \cdot \frac{\pi \cdot 12^2}{4} \cdot 977{,}837 = 66354{,}455 W$$

$$P_{urte} = 66354{,}455 \cdot 365{,}25 \cdot 24 = 581{,}663 \cdot 10^6\ Wh/urte$$

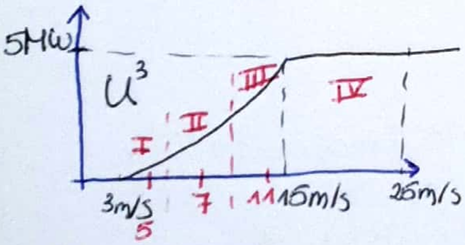
$$P_{urte} = 581{,}663\ MWh/urte$$

EXTRAALAIN:

5MW $D = 120m$ $\rho_0 = 1{,}2 Kg/m^3$ $K = 2$ $C = 7m/s$

$$\bar{P}^{goi}_{lim} = \frac{1}{2} \cdot 1{,}2 \cdot 0{,}59 \cdot \pi \cdot 60^2 \cdot 0{,}59 \cdot 7^3\,\Gamma\left(1+3/2\right) = 1{,}83 \cdot 10^6 W = 1{,}8 MW$$

$$AEP^{goi}_{lim} = 1{,}8 \cdot 365{,}25 \cdot 24 \simeq 16\ GWh$$



	(m/s) TARTEA	P	Zenbat ordu	Energia (KW·h)
I	3-7	P(5) 150	4070	$610 \cdot 10^3$
II	7-11	P(7) 1050	2500	$2625 \cdot 10^3$
III	11-15	P(11) 3300	650	$2145 \cdot 10^3$
IV	15-25	5000	90	$450 \cdot 10^3$

AEP = 5,8 GWh

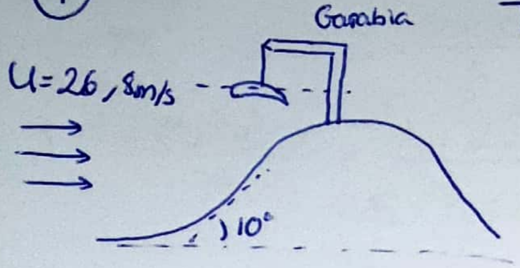
$$P = a u^3 + b$$

$$\left.\begin{matrix} 5000 = a \cdot 15^3 + b \\ 0 = a \cdot 3^3 + b \end{matrix}\right\} \begin{matrix} a = 1{,}5 \\ b = -40 \end{matrix}$$

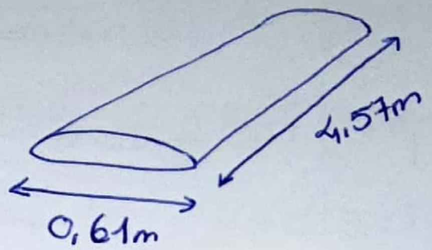
$$P = 1{,}5\, u^3 - 40$$

2. GAIA: Turbina Eolikoen Aerodinamika

①



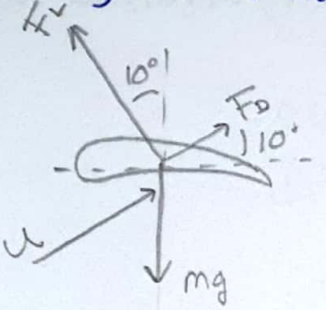
T = 21,2°



C = Ktea = 0,6m

$m = 45{,}36 \text{kg}$

a, Ze u hartuko da drag indarrik ez badago?



$\alpha_1 = 10° \longrightarrow C_L = 2 \cdot \pi \cdot \sin 10 = 1{,}091$

$$\rho = \frac{P}{R' T} = \frac{1{,}013 \cdot 10^5 \text{ Pa}}{287(273+21{,}2)} = 1{,}19973 \text{ kg/m}^3$$

$$F_L = \frac{1}{2} \cdot C_L \cdot u^2 \cdot \rho \cdot A =$$

$A = R \cdot c = 4{,}57 \cdot 0{,}61 = 2{,}7877$

$$\cos\alpha = \frac{mg}{F_L} \longrightarrow F_L = \frac{45{,}36 \cdot 9{,}8}{\cos 10} = 455{,}033$$

$$455{,}033 = \frac{1}{2} \cdot 1{,}091 \cdot u^2 \cdot 1{,}19973 \cdot 2{,}7877$$

$$u = 15{,}79 \text{ m/s}$$

b, 26,8 m/s hegan irten. Azelerazio horizontala?

$\frac{C_D}{C_L} = 0{,}03 \longrightarrow C_D = 0{,}03273$

$$F_x = -F_L + F_D = -\left(\frac{1}{2} \cdot C_L \, \rho \cdot A \cdot u^2 \sin 10\right) + \left(\frac{1}{2} \cdot C_L \, \rho \cdot A \cdot u^2 \cdot \cos 10\right)$$

$$= -\left(\frac{1}{2} \cdot 1{,}091 \cdot 1{,}1997 \cdot 2{,}78 \cdot 26{,}8^2 \cdot \sin 10\right) + \left(\frac{1}{2} \cdot 0{,}03273 \cdot 1{,}1997 \cdot 2{,}78 \cdot 26{,}8^2 \cdot \cos 10\right)$$

$= -188{,}83 \text{ N}$ beraz ezkerrera mugituko da.

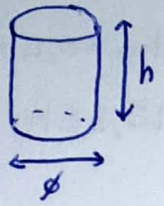
$F_x = m \cdot a$

$-188{,}83 = 45{,}36 \cdot a$

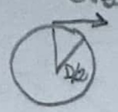
$$a = -4{,}163 \text{ m/s}^2$$

②

D - 0,75m
$h = 7,5m$
$\omega = 60$ bira/min



a, Topatu zirkulazioa zilindroaren inguruan:



$$U_{tan} = \omega \cdot r = 60 \cdot \frac{2\pi}{60} \cdot \frac{0,75}{2} = 2,356 \, m/s$$

$$\Gamma = \int_0^{2\pi} U_{tan} \frac{D}{2} \, d\theta = \frac{D^2 \omega \pi}{120} \int_0^{2\pi} d\theta = \frac{D^2 \omega \pi^2}{60} = \frac{0,75^2 \cdot 60 \cdot \pi^2}{60}$$

$$\Gamma = 5,55 m/s$$

b, Liftaren adierazpidea (F_L) altuera unitateko, U-ren, ω-ren eta D-ren mende.

c, $U = 10 m/s \rightarrow F_L$?

$$F_L = 1,2 \cdot 10 \cdot \pi^2 \cdot \frac{0,75^2 \cdot 60}{60} = 66,62 N$$

③

T=0°C
$\nu = 1,33 \cdot 10^{-5} m^2/s$

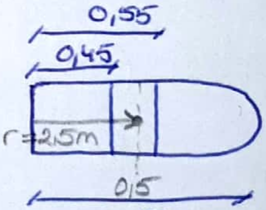
Reynolds?

① $Re = \frac{V \cdot c}{\nu} = \frac{16,14 \cdot 1,41}{1,33 \cdot 10^{-5}} = 1,711 \cdot 10^6$

② $Re = \frac{V \cdot c}{\nu} = \frac{75,08 \cdot 0,35}{1,33 \cdot 10^{-5}} = 1,975 \cdot 10^6$

④ a, $\varphi, \theta_P, \theta_T$ eta c r/R=0,45tik r/R=0,55era:
→ partzio-erdatikoa

$C_d = 0$
$a' = 0$
$\lambda = 7$
$B = 3$
$R = 5$
$C_L = 1$
C_d/C_L min
$\alpha = 7$



Gradutan → $\varphi = \text{arctg}\left(\frac{2}{3\lambda_r}\right) = 10,8°$

$$\lambda_r = \frac{\Omega \cdot r}{U} = \boxed{\frac{\Omega \cdot R}{U}}_{=\lambda} \cdot \frac{r}{R} = 7 \cdot \frac{2,5}{5} = 3,5$$

$$\theta_p = \varphi - \alpha_{opt} = 10,8 - 7 = 3,8°$$

puntuak $\begin{cases} \varphi_0 = \text{arctg}\left(\frac{2}{3 \cdot 7}\right) = 5,4° \\ \theta_{p,0} = \varphi_0 - \alpha = 5,4 - 7 = -1,6° \end{cases}$

$$\theta_T = \theta_P - \theta_{p,0} = 3,8 - (-1,6) = 5,4°$$

$$c = \frac{8\pi \cdot r \cdot \sin\varphi}{3 \cdot B \cdot C_L \cdot \lambda_r} = \frac{8 \cdot \pi \cdot 2,5 \cdot \sin 10,8}{3 \cdot 3 \cdot 1 \cdot 3,5} = 0,3738 m$$

b)

$C_d/C_L = 0{,}02$ lehenengo elementuan

$U = 10 m/s$

$a = 1/3$

$a' = 0$

$\rho = 1{,}24 Kg/m^3$

$U_{rel}, dF_L, dF_D, dF_N, dF_t, dQ$. eta dP?

$$U_{rel} = \frac{\overset{10}{U}(1-1/3)}{\sin 10{,}8} = 35{,}6 m/s$$

$R/N = 5/10 = 0{,}5$

$$dF_L = \frac{1}{2}\cdot\rho\cdot C_L\cdot U_{rel}^2\cdot C\cdot dr = \frac{1}{2}\cdot 1{,}24\cdot 1\cdot 35{,}6^2\cdot 0{,}37\cdot 0{,}5 = \underline{145 N}$$

$$dF_D = 0{,}02\cdot dF_L = \underline{2{,}9 N}$$

$$dF_N = F_D\cdot\sin\varphi + F_L\cdot\cos\varphi = 2{,}9\cdot\sin 10{,}8 + 145\cdot\cos 10{,}8 = \underline{144 N}$$

$$dF_t = F_L\cdot\sin\varphi - F_D\cdot\cos\varphi = \underline{24 N}$$

$$dQ = dF_t\cdot r = 24\cdot 2{,}5 = \underline{60 N\cdot m}$$

$$dP = dQ\cdot\Omega = 60\cdot 14 = \underline{840 m}$$

3. GAIA: Mekanika eta Dinamika

①

$\omega = 60$ bira/min

$I_b = 13558\ Kgm^2$

a, Zein da errotorearen energia zinetiko geratu baina lehen? Zenbat energia xurgatu du balaztak?

Kasu honetan, biratzen ari denez, $I_b \Rightarrow J$ Inertzia momentu AXIALA

$$E_z = \frac{1}{2} \cdot J \cdot \Omega^2 = \frac{1}{2} \cdot 13558\ Kg\,m^2 \left(60 \cdot \frac{2\pi}{60}\right)^2 [rad/s^2] = 267624,2\ J$$

Turbina guztiz gelditzen bada energia guztia xurgatzen du.

$$E_z = E_{xurg} = 267,6242\ KJ$$

b, $m = 27 Kg$ $c_p = 0,46\ KJ/Kg°C$ Zenbat igoko da tenperatura?

$Q = E_{xurg} = 267,6242$ $Q = m \cdot c_p \cdot \Delta T$

$267,6242 = 27 \cdot 0,46 \cdot \Delta T \rightarrow \Delta T = 21,55\ °C$

②

$J = 4,2 \cdot 10^6\ Kgm^2$

$P = 1500\ KW$

$\omega = \Omega = 20$ bira/min

Zenbat denbora ω bikoizteko?

Sare-elektrikoak huts, balaztak huts.

$$P = \frac{\Delta E_z}{t} = \frac{\left(\frac{1}{2} \cdot 4,2 \cdot 10^6 \cdot \left(\frac{2\pi}{60} \cdot 40\right)^2\right) - \left(\frac{1}{2} \cdot 4,2 \cdot 10^6 \left(\frac{2\pi}{60} \cdot 20\right)^2\right)}{t} = 1500 \cdot 10^3$$

$t = 18,42s$

EDO

$\Omega_0 = 20$ bira/min

$\Omega = 2\Omega_0 = 40$ bira/min

$$P = Q \cdot \Omega \rightarrow 1.500 \cdot 10^3 = Q \cdot 20 \cdot \frac{2\pi}{60}$$

$$Q = 716197,25\ J$$

$$Q = J \cdot \alpha \rightarrow 716197,25 = 4,2 \cdot 10^6 \cdot \alpha$$

$\alpha = 0,17052\ rad/s^2$ (azelerazioa)

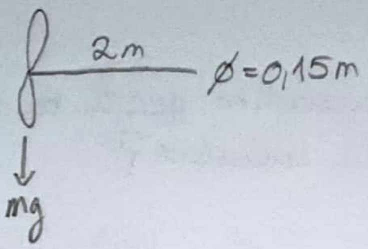
$$\Omega = \Omega_0 + \alpha t \rightarrow (40 - 20) \cdot \frac{2\pi}{60} = 0,17052 \cdot t$$

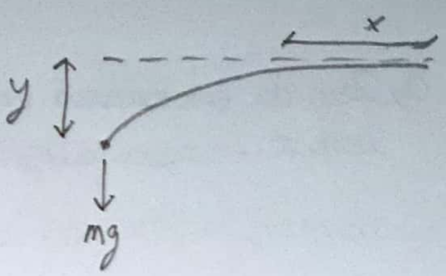
$$t = 12,28s$$

③

$m=1500 Kg$
$P=275 KW$
$\omega = 60$ bira/min
$\varnothing = 0,15m$
Altzairuzkoa
$L=2m$
$E=210GPa$

a, Zenbat okertzen da?

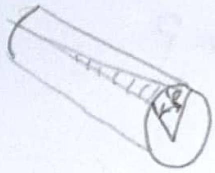




$$Y_{max} = \frac{\omega \cdot L^3}{3 \cdot E \cdot I_b} \qquad I_b = \frac{\pi \cdot 0,15^2}{64} = 2,4 \cdot 10^{-5} Kg m^3$$

$$Y_{max} = \frac{(1500 \cdot 9,8) \cdot 2^3}{3 \cdot 210 \cdot 10^9 \cdot 2,4 \cdot 10^{-5}} = 7,511 \cdot 10^{-3} m = 7,511 mm$$

b, Zenbat bihurtzen da? Esfortzu moztailea?



φ_1 = bihurdura angelua $E = 210GPa$ $\mu = 0,3$ $J = \frac{\pi \cdot d^4}{32}$

$$\varphi_1 = \frac{Q \cdot L}{G \cdot J} \qquad G = \frac{E}{2(1-\mu)} \qquad Q = \frac{P}{\Omega}$$

$$\varphi = \frac{\left(\frac{275 \cdot 10^3}{60 \cdot \frac{2\pi}{60}}\right) \cdot 2}{\left(\frac{210 \cdot 10^9}{2(1-0,3)}\right) \cdot \left(\frac{\pi \cdot 0,15^4}{32}\right)} = 0,022 \, rad \cdot \frac{180}{\pi} = 1,25° = \varphi$$

$$\tau_{max} = \frac{Q_P \cdot R}{J} = \frac{\left(\frac{275 \cdot 10^3}{60 \, (2\pi/60)}\right) \frac{0,15}{2}}{\pi \cdot 0,15^4/32} = 66646401,2 Pa = 66,05 MPa$$

④

$z = 24,38m$
$T = 26,69 KN$
$P = 250 KW$
$u = 44,7 m/s$
$T = 71,62 KN$

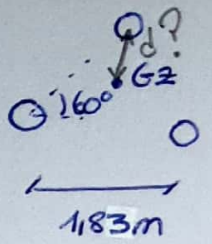
a, Altzairua y_{max}?
$\varnothing = 1,22m$
$e = 0,0254m$ $\varnothing_{kanpo} - \varnothing_{barne}$

$$I_b = \frac{\pi \cdot d^4}{64} = \frac{\pi (1,22^4 - (1,22-0,0254)^4)}{64} = 0,0087$$

Potentzia nominalean: $$y_{max} = \frac{26,69 \cdot 10^3 \cdot 24,38^3}{3 \cdot 210 \cdot 10^9 \cdot 0,0087} = 0,0696m \rightarrow y_{max} = 70mm$$

Hurakanean: $$y_{max} = \frac{71,62 \cdot 10^3 \cdot 24,38^3}{3 \cdot 210 \cdot 10^9 \cdot 0,0087} = 0,1876m \rightarrow y_{max} = 187,7mm$$

b, Dorreak 3hanka dituela suposatuz y_{max}?

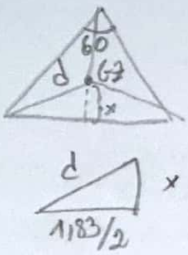


$\varnothing_e = 0,152m$

$\varnothing_i = 0,127m$

Oraingoan nertzia momentua Steiner bidez kalkulatu behar da.

$$I_m = \frac{\pi \cdot d^4}{64} = \frac{\pi(0,152^4 - 0,127^4)}{64} = 13,43277 \cdot 10^{-6}\ Kgm^2$$



$$\sin 60 = \frac{h}{1,83} \rightarrow h = 1,58m$$

$$x = \frac{h}{3} = 1,58/3 = 0,528m$$

$$d = \sqrt{0,528^2 + (1,83/2)^2} = 1,056m$$

$$I_T = \Sigma\, I + A_i \cdot d_{Gz}^2 = 3\left(I + \frac{\pi(\varnothing_e - \varnothing_i)^2}{4} \cdot d_{Gz}^2\right)$$

$$I_T = 3\left(13,43277 \cdot 10^{-6} + \frac{\pi(0,152^4 - 0,127^4)}{4} \cdot 1,056^2\right) = 1,68 \cdot 10^{-3}\ Kgm^2$$

$$Y_{max} = \frac{26,69 \cdot 10^3 \cdot 24,38^3}{3 \cdot 210^9 \cdot 0,0016} = 0,36\ mm$$

⑤

$F = 1Hz$

$\beta = 10°$

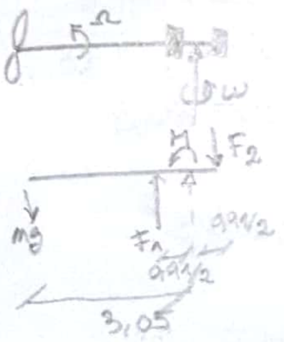
$J = 13558\ Kgm^2$

$m = 1459 Kg$

$L = 3,05m$

$\varnothing = 0,91m$

a, Zeintzuk dira euste indarrak? (Yawing gabe)



Yawing ez → ω=0

$$\Sigma F = 0 \quad F_1 - F_2 - mg = F_1 - F_2 - 1459 \cdot 9,8 = 0$$

$$\Sigma M = 0 \quad 3,05 \cdot 1459 \cdot 9,8 - \frac{F_1 \cdot 0,91}{2} - F_2 \cdot \frac{0,91}{2} = 0$$

$$\boxed{\begin{matrix} F_1 = 55071,64N \\ F_2 = 40773,44N \end{matrix}}$$

b, Yawing badago?

$$MG = I \cdot \Omega \cdot \omega = 13558 \cdot \overset{Hz}{1} \cdot 2\pi \cdot 10 \cdot \frac{\pi}{180} = 14868,01\ Nm$$

$$FG = \frac{MG}{3} = \frac{14868,01}{3} = 4956N$$

$$\Sigma F \rightarrow -(1459 \cdot 9,8 + 4956) + F_1 - F_2 = 0$$

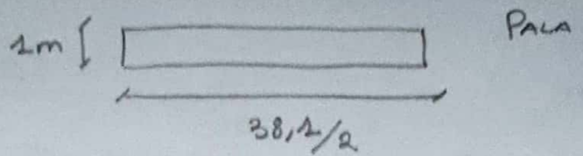
$$\Sigma M \rightarrow (1459\ 9,8 + 4956) \cdot 3,05 - \frac{0,91}{2} F_1 - \frac{0,91}{2} F_2 = 0$$

$$\boxed{\begin{matrix} F_1 = 74160,4N \\ F_2 = 54906,207N \end{matrix}}$$

⑥

$D = 38{,}1m$
$C = 1m$
$F_1 = 1{,}67Hz$
$\omega = 50\,bira/min$
$F = 1{,}92Hz$
$\theta_p = 1{,}8°$
$U = 8m/s$
$\rho = 1{,}225\,Kg/m^3$
$m = 898\,Kg$

Zurruntasuna, I_b eta OFFseta?



$$z = \frac{\omega_R^2 - \omega_{NR}^2}{\Omega^2} = \frac{(1{,}92\cdot 2\pi)^2 - (1{,}67\cdot 2\pi)^2}{\left(50\,\frac{2\pi}{60}\right)^2} = 1{,}2924$$

Offset:

$$e = \frac{2(z-1)}{3+2(z-1)} = \frac{2(1{,}2924-1)}{3+2(1{,}2924-1)} = 0{,}1631$$

Inertzia momentua: mugitzen ari den zatia

$$I_b = m_b \cdot \frac{R^2}{3}(1-e)^3 = 898\,\frac{\left(\frac{38{,}1}{2}\right)^2}{3}\cdot(1-0{,}1631)^3 = 63666{,}95\,Kgm^2$$

K_b: malgukiaren elastikotasuna:

$$\omega_{NR} = \sqrt{\frac{K_\beta}{I_b}} \longrightarrow K_\beta = \omega_{NR}^2 \cdot I_b = (1{,}67\,2\pi)^2\cdot 63666{,}95$$
$$= 7\cdot 10^6\,Kgm^2/s = 7MNm$$

Zenbat denbora behar da pala erresonantzian sartzeko?

$B = 3$ pala
$P = 400\,KW$
$\omega_R = 4F$
$\omega_{NR} = 10{,}49\,rad/s$

$$I_b = 3\cdot 63666{,}95 = 191000{,}85\,Kgm^3$$

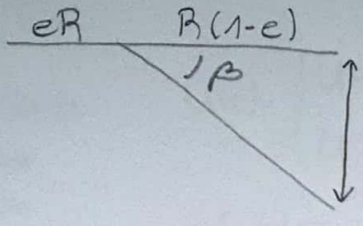
$$\omega_R^2 = \omega_{NR}^2 + \Omega^2 \rightarrow \Omega = \sqrt{(4\cdot 2\pi)^2 - 10{,}49^2} = 22{,}84\,rad/s$$

$$\varphi = \frac{P}{\Omega_0} = \frac{400\cdot 10^3}{50\cdot\frac{2\pi}{60}} = 76394{,}37\,rad/s$$

$$\alpha = \frac{\varphi}{J} = \frac{76394{,}37}{191000{,}85} = 0{,}4\,rad/s^2$$

$$\Omega = \Omega_0 + \alpha t \longrightarrow 22{,}84 = 50\cdot\frac{2\pi}{60} + 0{,}4\cdot t$$
$$\hookrightarrow t = 44s$$

⑦ Aurkitu flapping angelua.



$$\beta = \frac{\gamma A}{2K} \qquad \gamma = \rho \cdot C_{L\alpha} \cdot C \frac{R^4}{I_b}$$

↳ lift koef. α-rekiko $\frac{dC_L}{d\alpha} \approx 2\pi$

$$A = \frac{\Omega}{3} - \frac{\theta_p}{4}$$

$$\Lambda = \frac{4(1-a)}{\Omega R}$$

$$K = 1 + \varepsilon + \frac{K_b}{I_b \cdot \Omega^2}$$

↳ $\varepsilon = \frac{3+e}{2(1-e)}$

$$I_b = m_b \cdot \frac{R^2}{3} \cdot (1-e)^3$$

Aurreko datuekin:

$$\gamma = 1{,}225 \cdot 2\pi \cdot 1 \, \frac{(38{,}1/2)^4}{63666{,}95} = 15{,}92 \text{ rad}$$

$$\Omega = \frac{8(1+1/3)}{50\frac{2\pi}{60} \cdot \frac{38{,}1}{2}} = 0{,}054$$

$$A = \frac{0{,}054}{3} - \frac{1{,}8 \cdot \pi/180}{4} = 9{,}969 \cdot 10^{-3}$$

$$K = 1 + \frac{3 + 0{,}1631}{2(1-0{,}1631)} + \frac{7 \cdot 10^6}{63666{,}95(50\frac{2\pi}{60})^2} = 6{,}9$$

$$\beta_0 = \frac{15{,}92 \cdot 9{,}969 \cdot 10^{-3}}{2 \cdot 6{,}9} = 0{,}0115 \text{ rad} \, \frac{180}{\pi} \longrightarrow \underline{\underline{\beta_0 = 0{,}66°}}$$

PROBLEMA ANITZAK:

①

$U = 15 m/s$

$h = 40 m$

$D = 40 m$

$T = 14 s$

$$U(t) = \begin{cases} U - 0{,}37 U_{gust50} \sin(3\pi t/T)\,[1-\cos(2\pi t/T)] & 0 \le t \le T \\ U & t<0 \text{ eta } t>T \end{cases}$$

$$U_{gust50} = 6{,}4\left(\frac{\sigma_x}{1+0{,}1(D/21)}\right)$$ • σ_x desbiazio estandarra.

↝ abiadura errotorearen erdian

$$\sigma_x = I_{ref}\,(0{,}75\,U_{hub} + 5{,}6)$$

↳ Turbulentziaren intentsitatea

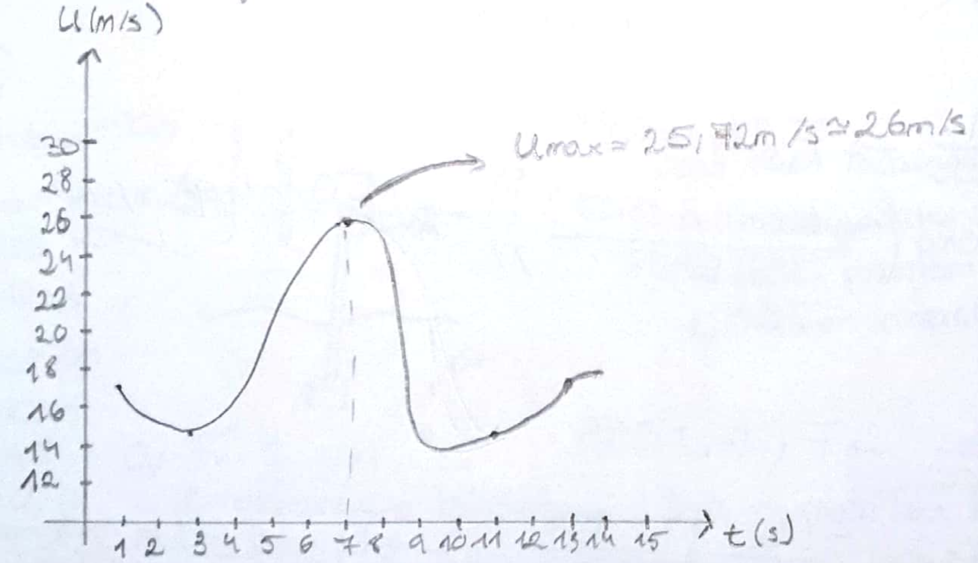
• TAULAN BEGIRATU:

A	I_{ref}	0,16	Turbulentzia handia ✓
B	I_{ref}	0,14	" ertaina
C	I_{ref}	0,12	" txikia

$$\sigma_x = 0{,}16\,(0{,}75 \cdot 15 + 5{,}6) = 2{,}696$$

$$U_{gust50} = 6{,}4\left(\frac{2{,}696}{1+0{,}1(40/21)}\right) = \underline{14{,}493 m/s}$$

GRAFIKOKI egiteko: denbora desberdinak hartu eta ordezkatu ($U(t)$)



Grafikoari esker ikus dezakegu $t_1 = 4{,}66 s$-an 15 m/s baino altuagoa den abiadura dugula, eta $t_2 = 9{,}84$ denean, berriz jeisten dela 15 m/s baino txikiagora. Beraz:

Haize boladen denbora tartea: $t = 4{,}68 s$

Lortutako abiadura pikoa: $\underline{U_{max} = 25{,}72 m/s}$

② 16 urteko datuak   exp = e°

Topatu 50 eta 100 urtetan espero diren Umax:

Liburuan formulak begiratu

$$F(U_e) = \exp\left(-\exp\left(\frac{-(U_e-\mu)}{\beta}\right)\right)$$ → Gumbel-en distribuzioa.

- U_e = abiadura maximoa periodo jakin batean
- $\beta = \left(\frac{\sigma_e\sqrt{6}}{\pi}\right)$
- $\mu = \bar{U}_e - 0{,}577\beta$
- $\bar{U}_e$ = the mean of a set of extreme values (la media de un conjunto ...]
- σ_e = the standard deviation of that set (la desviacion estandar de ese conjunto)
- Desbiderapen tipikoa: $\sigma = \sqrt{\frac{\Sigma(\bar{U}_m - \bar{U})^2}{N}}$
  - Batez besteko abiadura: 18,66 m/s

$\sigma = 2{,}3711$

$\beta = \left(\frac{2{,}3711\sqrt{6}}{\pi}\right) = 1{,}8487$

$\mu = \bar{U}_e - 0{,}577\beta = 18{,}66 - 0{,}577 \cdot 1{,}8487 = 17{,}5958$

50. URTETAN:

$1 - F(U_e) = \frac{1}{50} \rightarrow F(U_e) = 0{,}98$

$0{,}98 = \exp\left(-\exp\left(-\frac{(U_e - 17{,}5958)}{1{,}8487}\right)\right) \rightarrow U_e = 24{,}75\,m/s$

100. URTETAN:

$1 - F(U_e) = \frac{1}{100} \rightarrow F(U_e) = 0{,}99$

$0{,}99 = \exp\left(-\exp\left(-\frac{(U_e - 17{,}5958)}{1{,}8487}\right)\right) \rightarrow U_e = 26{,}1\,m/s$

⑥

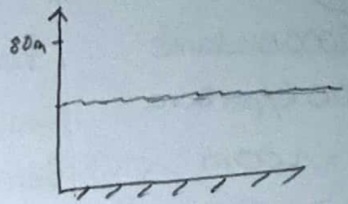
$t=10min$
$U=8{,}5m/s$
$h=10m$
$d=10Km$

a) $\varepsilon=0{,}0002m$ $\quad U(80m)$?

$$\frac{U(z)}{U(z_r)}=\frac{\ln(h/z_0)}{\ln(h/z_0)}\rightarrow\frac{U(z)}{8{,}5}=\frac{\ln(80/0{,}0002)}{\ln(10/0{,}0002)}\rightarrow U(80)=10{,}13m/s$$

b) $A_c=0{,}018$ $\quad C_{D,10}=0{,}0015$ $\quad h=80m$ $\quad U'=U\cdot C_{D_{10}}^{1/2}$

Charnock



$$U'=8{,}5\cdot 0{,}0015^{1/2}=0{,}35m/s$$

$$z_0=A_c\cdot\frac{(U')^2}{g}=0{,}018\cdot\frac{(0{,}35)^2}{9{,}8}=2\cdot10^{-4}m$$

$$U(z)=\frac{U'}{K}\cdot\ln\left(\frac{z}{z_0}\right)=\frac{0{,}33}{0{,}4}\cdot\ln\frac{10}{2\cdot10^{-4}}=8{,}93m/s$$

$$U(80)=U(10)\cdot\frac{\ln(80/2\cdot10^{-4})}{\ln(10/2\cdot10^{-4})}=10{,}18m/s$$

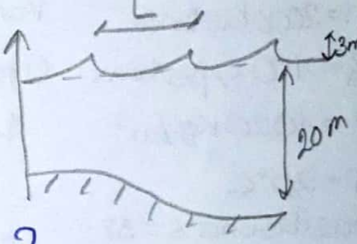
c) $h=20m$ sakon $\quad z=3m$ (uhinaren altuera) $\quad T=9s$ $\quad U(80)$?

$$L_p=\text{peak periodo wave lenght}=\frac{g\,t^2}{2\pi}\cdot\sqrt{tgh\,\frac{4\cdot\pi^2 d}{t^2 g}}=\frac{9{,}8\cdot9^2}{2\pi}\sqrt{tgh\,\frac{4\pi^2\,20}{9^2\,9{,}8}}=110{,}09m$$

$$\frac{z_0}{H_s}=1200\left(\frac{H_s}{H_p}\right)^{4{,}5}=1200\left(\frac{3}{110{,}09}\right)^{4{,}5}\cdot3=3{,}3\cdot10^{-4}m/s$$

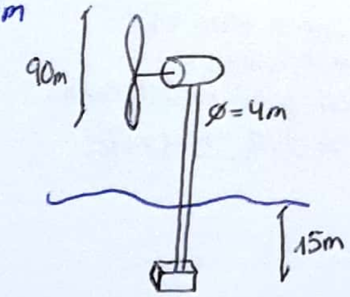
$$U(10)=\frac{U'}{K}\cdot\ln\left(\frac{z}{z_0}\right)=\frac{0{,}33}{0{,}4}=\ln\left(\frac{10}{3{,}3\cdot10^{-4}}\right)=8{,}52m/s$$

$$U(80)=8{,}52\cdot\frac{\ln(80/3{,}3\cdot10^{-4})}{\ln(10/3{,}3\cdot10^{-4})}=10{,}24m/s$$



⑧

$D_{errotorea}=90m$
$D_{dorrea}=4m$
$z=15m$
$U=12m/s$
$h_{olatua}=2m$
$\lambda=100m$
$C_D=1{,}5$
$CM=2$
Inertzia Koef.



Jaso duen indar maximoa?

a) Haizeagatiko indarra.
b) Olatu frenteen indar inertziala.
c) Olatuen arrastre indarra.

a) $F_H=\frac{1}{2}\cdot\rho\cdot A\cdot U^2\cdot C_T$

Errotorearekiko bulkada (C_T) Betz-en potentzia Koefizienteari dagokio.

$a=1/3$; $\quad C_T=4a(1-a)=8/9$ $\qquad F_H=\frac{1}{2}\cdot1{,}2\cdot\pi^2\cdot45^2\cdot12^2\cdot\frac{8}{9}=488{,}58KN=F_H$

b) $F_I=\rho\cdot w\cdot g\,\frac{CM\cdot\pi\cdot D^2}{4}\,\zeta\,tgh[K\cdot d]$

Aury-ren ereduari jarraituz $\quad K=\frac{2\pi}{L_p}\equiv$ Uhin zenbakia

Inertzia Koef $CM=2$

$\zeta=1\equiv$ anplitudea $=\frac{H_s}{2}=\frac{2}{2}=1$ $\quad\rightarrow$ Olatuaren altuera

$d=$ sakonera

$$F_I=1000\cdot9{,}8\cdot\frac{2\cdot\pi\cdot4^2}{4}\cdot1\cdot tgh\left[\frac{2\pi}{100}\cdot15\right]=181{,}365KN=F_I$$

c) $F_D = \rho \cdot g \cdot C_D \cdot \frac{D}{2} \{ \left[\frac{1}{2} + \frac{K \cdot d}{\sinh(2K\alpha)}\right]$ Zilindro bat izanda $C_D = 1{,}5$

$F_D = 1000 \cdot 9{,}8 \cdot 1{,}5 \cdot \frac{4}{2} \cdot 1 \left[\frac{1}{2} + \frac{2\pi \cdot 15}{100 \sinh(\frac{2\pi}{100} \cdot 15)}\right] = 23{,}314 KN = F_D$

GUZTIEN BATURA:

$F_T = F_H + F_D + F_I = 693{,}25 KN$

⑨

2000 biztanle

100 l/pertsona

h = 100m

CF = 0,25

$\eta_{ponpa} = 0{,}8$

Potentzia nominala?

Kontsumo totala: $Q = 2000 \cdot 100 = 0{,}023 m^3/s$

Bernoulli: $\frac{P_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ $H_m = 100m$

$P_{ponpa} = \rho \cdot g \cdot H_m \cdot Q/\eta_p = 1000 \cdot 9{,}8 \cdot 100 \cdot \frac{0{,}023}{0{,}8} = 2{,}8175 KW$

$P_{ponpa} = P_{turbina}$

$P_{nom} = P_{turb}/_{CF} = 2{,}8175/0{,}25 = 11{,}27 KW$

⑩

n = 2000 biztanle

Q = 100 l/pertsona

$\rho = 1020 Kg/m^3$

T = 20°C

Gazitasuna s = 38

CF = 0,25

$\eta_{sistema} = 0{,}2$

Kontsumo totala: $Q = \frac{Q_p \cdot n}{3600 \cdot 24} = 0{,}0023 m^3/s$

Ura gesatzeko presioa: bi modu daude presio asmotikoa kalkulatzeko.

1) Manwell-en liburua.

$P_\pi (T = 20°C, \rho = 1020 Kg/m^3) = 2{,}7 MPa$

2) Formula erabiliz:

$P_\pi = i \cdot S \cdot \rho \cdot R \cdot T/M$

- i = Van't Hoffen Ktea = 1,8
- R = 8,31447 m³Pa/molK
- M = gatzaren pisu molekularra.

$P_\pi = 1{,}8 \cdot 38 \cdot 1020 \cdot 8{,}31447 \cdot 293/58{,}5 = 2{,}9054 MPa$

Potentzia:

$P_{sistema} = Q \cdot P_\pi = 0{,}0023 \cdot 2{,}9054 \cdot 10^6 = 6{,}68 KW$

$P_{erre} = P_{sis}/\eta = 6{,}68/0{,}2 = 33{,}4121 KW$

$P_{turb} = \frac{P_{erre}}{CF} = \frac{33{,}4121}{0{,}25} = 133{,}6484 KW$

Betz zenbakia aplikatu nahi bada:

$P_{turb} = C_p \cdot P_{ins} \rightarrow P_{inst} = \frac{133{,}6484}{0{,}59} = 226{,}523 KW$

⑲

$P_N = 500KW$

$D = 40m$

$\Omega = 40$ bira/min

$U = 12m/s$

$B = 3$

Zarata estimatu:

$V = R \cdot \Omega = 20 \cdot 40 \frac{2\pi}{60} = 83{,}77 m/s$

Potentziarekin

1) $L_{WA} = 10 \log \cdot P_{WT} + 50 = 10 \log 500 \, 10^{3} + 50 = L_{WA} = \underline{106{,}99 dB}$

Diametroarekin

2) $L_{WA} = 22 \log D + 72 = 22 \cdot \log 40 + 72 = L_{WA} = \underline{107{,}24 dB}$

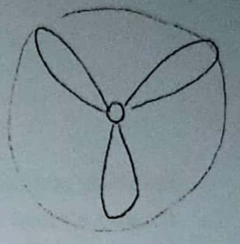
3) $L_{WA} = 50 \log V + 10 \log D - 4 = 50 \log 83{,}77 + 10 \log 40 - 4 = L_{WA} = \underline{108{,}175 dB}$

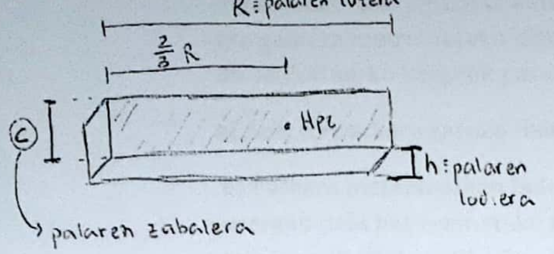
Punta abiadurarekin.

3. ariketa

$$\underset{\swarrow \text{Aerodinamiko}}{M_{A,F}}^{\uparrow \text{Flektorea}} = \frac{1}{B} \cdot \left(\underbrace{\frac{2}{3} \cdot R}_{\nearrow \text{presio zentroaren posizioa} = H_{PZ}} \right) \cdot \left(\underbrace{\boxed{C_T}}_{\nearrow \text{Bultzada koef.}} \cdot \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot u^2 \right)$$

$$C_T = \frac{T}{\frac{1}{2} \underbrace{\boxed{\pi \cdot R^2}}_{\to A \to} \cdot u^2}$$





STRESS AERODINAMIKOA:

$$\sigma_{A,F} = \frac{M_{A,F} \cdot c \ (m^4)}{I \ (m^4)} \longrightarrow \left(I = \frac{R^3 \cdot c}{12} \right)$$

Pala luzeago bat errazago apurtu?

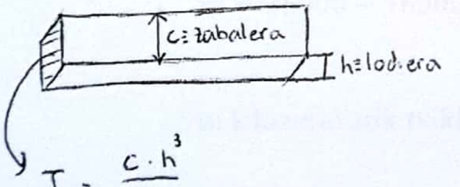
$$\frac{\sigma_{A,F\,1}}{\sigma_{A,F\,2}} = \frac{\dfrac{R_1^3 \cdot c}{R_1^3 \cdot c/12}}{\dfrac{R_2^2 \cdot c}{R_2^3 \cdot c/12}} = 1 \longrightarrow$$

Argi ikusten denez, stress aerodinamikoa ez da distantziaren menpe egongo

4. ariketa

$$\text{Okerdura zurruntasuna} = \frac{\text{Momentua}}{\text{Deflexio unitatea}} = \overset{\nearrow \text{Elastikotasun modulua} \to \text{Materialaren arabera}}{\boxed{E}} \cdot I$$

Sinplifikatzeko pala laukizuzen bat hartu:



$$I = \frac{c \cdot h^3}{12}$$

Antzekotasun geometrikoa:

$2 \cdot R \to 2 \cdot c,\ 2 \cdot h \to$ Beraz $\to I_{berria} = 16 \cdot I$

↳ Hau kontuan hartuta, okerdura zurruntasuna:

$$E \cdot I \underset{\hookrightarrow \text{proportzionala}}{\propto} R^4$$

Konklusioz: Pala zenbat eta handiagoa izan, orduan eta zurrunagoa izango da.
ASKOZ ZURRUNAGOA.

4) Ikerketa batek determinatu duenez korda maximoa pala batean honela adieraz daiteke: c = 0.0005 L2 + 0.024 L + 1.4, non L palaren luzera den. Eta palen masa kilotan honela doa, m = 9.034 L2 – 340 L + 6300. Kamioiak hauek eramateko 5.5 metroko lekua dauka bidean zehar eta gainera metro bateko distantzia laga behar luke ertzetatik. Gainera, bideko zubietan ezin da 36 000 kg-ko kargatik pasa. Kamioiak hutsik 16 000 kg pisatzen ditu.

a) Zein da parkera garraia daitekeen palarik handiena bi irizpideak kontuan izanda?

b) Parkera iristeko azken bidea txarra eta estua da. Bidearen kurbatura erradio minimoa, r, L luzerako pala bat eramateko nahikoa izango dena, bidearen zabalera w izaki honela emana dator: r = [(L/2)2 – w2] / 2w. Zein da bidearen kurbatura erradio minimoa aurreko atalean aukeratutako palarentzat bidearen zabalerak 8 m baditu?

a)

Kordaren luzera → $c = 0.0005L^2 + 0.024L + 1.4$

Palaren masa → $m = 9.034L^2 - 340L + 6300$

Bideak 5,5m-ko zabalera duenez, eta segurtasunagatik alboetan 1m utzi behar denez :

Palaren korda maximoa → c = 5,5-2 = 3,5m

- $c = 3.5 = 0.0005L^2 + 0.024L + 1.4$ → $\boxed{\mathbf{L = 45.11m}}$

Kamioiak 16.000 kg-ko pisua eta zubiak 36000kg-ko pisu maximoa jasan dezakeenez:

Gure palak izan dezakeen masa maximoa → $m = 36000 - 16000$

- $m = 36000 - 16000 = 9.034L^2 - 340L + 6300$ → **L = 62,1 m**

Bi L luzeretatik txikiena hartuko dugu bi baldintzak betetzen dituelako

L = 45,11 m

b)

Zabalera → w = 8m
Palaren Luzera → L = 45,11m

$$r = \frac{\left[\left(\frac{L}{2}\right)^2 - w^2\right]}{2w} = \frac{\left[\left(\frac{45{,}11}{2}\right)^2 - 8^2\right]}{2*8} = 27m \text{ -ko erradio minimoa}$$

11. ariketa

a) DATUAK:

- n=2000 bizilagun
- Kontsumoa pertsonako $E_{pertsonako}$ = 8KWh / egun
- Tangaren tamaina:
    - Diametroa D = 30 m
    - Altuera h = 5
- Tangaren kota H = 70 m

Hustutze denbora?

PROZEDURA:

Potentzia kontsumo totala: $Pot_{total} = n \cdot Pot_{pertsonako} = 2000 \cdot 8\frac{kW \cdot h}{egun} \cdot \frac{1\ egun}{24\ h} = 666{,}66kW$

Tangaren bolumen totala: $V_{tanga} = pi \cdot \frac{D^2}{4} \cdot h = 3534.29\ m^3$

Turbinak emandako potentzia: $Pot_{turbina} = Q \cdot p \cdot g \cdot H = \frac{3534.29}{t} \cdot 1000 \cdot 9.8 \cdot 70 = \frac{2424522940}{t}$

Jakinik $Q = \frac{V}{t}$ dela

Kontuan izanik turbina kontsumoa asetzeko erabiliko dela: $Pot_{total} = Pot_{turbina}$

Hortik denbora atera dezakegu beraz $t = \frac{2424522940}{666666} = 3636.82\ s = 1.01\ h$

b) DATUAK

- Turbinaren ezaugarriak:
    - CF = 0.25
    - Errendimendua (Suposatutakoa) = 0.7
    - CP (Suposatutakoa) = 0.59
- Ponparen ezaugarriak:
    - Errendimendua = 0.8
- Haizearen abiadura U = 8 m/s
- Betetze denbora: t = 3636.82 s

Betetze denbora?

PROZEDURA

$$\text{Haizea } (Pot_{haiz}) \overset{CP}{\Rightarrow} \text{Haize turbina } (Pot_{nom}) \overset{CF}{\Rightarrow} \text{H. turbina } (Pot_{turb})$$
$$\xRightarrow{\eta_{turb}} \text{H. turbina } (Pot_{erab}) \overset{1}{\Rightarrow} \text{Ponpa } (Pot_{trans}) \xRightarrow{\eta_{ponpa}} \text{Ponpa } (Pot_{ponpa})$$

Haize turbinaren potentzia nominala: $Pot_{nom} = \frac{1}{2} \cdot p \cdot A \cdot U^3$

Ponparen potentzia nominala: $Pot_{ponpa} = p \cdot g \cdot Q \cdot H = 666654.8\ W$

Emaria: $Q = \frac{V}{t} = 0.9718\ m^3/s$

Altuera: H = 70 m

Beraz, haizearen potentzia lortzeko ponparen potentziatik abiatuta:

$$Pot_{haizea} = \frac{Pot_{ponpa}}{\eta_{ponpa} \cdot \eta_{turbina} \cdot CF \cdot Cp} = 8070881.356\ W = 8.1\ MW$$

Beraz, : $Pot_{haizea} = \frac{1}{2} \cdot p \cdot A \cdot U^3 = \frac{1}{2} \cdot p \cdot pi \cdot \frac{D^2}{4} \cdot U^3$ $\quad D = 6.3357\ m$

19.Ariketa:

Hiru palako turbina baten zarata estimatu.

- $B = 3$ palako turbina
- $Pot_{Nominala} = 500\ [kW] = 500 \cdot 10^3\ [W] = P_{Wind_{Turbine}}$
- $D_{Errotorea} = 40\ [m]$
- Errotorearen abiadura errotazionala: $\Omega = 40\ [rpm]$
- Haizearen abiadura: $u = 12\ [m/s]$
- Soinuaren potentzia maila: $L_{W_A}\ [dB]$
- Puntako abiadura: $\mathrm{v}_{Tip}\ [m/s]$

1.klasea:

Mota honetako modeloak soinuaren potentzia maila totalaren estimazio sinple bat egiten dute haize turbina baten parametro basikoen funtzioan (adibidez: errotorearen diametroa, potentzia eta haizearen abiadura).

1.klaseko modeloen soinuaren potentzia maila estimatzeko hurrengo ekuazio enpirikoak erabiltzen dira:

$$(12.9) \quad L_{W_A} = 10 \cdot \log_{10}(P_{W_T}) + 50$$

$$(12.10) \quad L_{W_A} = 22 \cdot \log_{10}(D) + 72$$

$$(12.11)\ Metodo\ zehatzena\text{:}\ L_{W_A} = 50 \cdot \log_{10}(\mathrm{v}_{Tip}) + 10 \cdot \log_{10}(D) - 4$$

$$\mathrm{v}_{Tip} = \frac{D_{Errotorea}}{2} \cdot \Omega = \frac{40\ [m]}{2} \cdot 40\ [rpm] \cdot \frac{2\pi\ [rad]}{1\ [bira]} \cdot \frac{60\ [s]}{1\ [min]} = \frac{\mathbf{80}}{\mathbf{3}} \cdot \boldsymbol{\pi}\ [\boldsymbol{m/s}]$$

$$(12.9) \quad L_{W_A} = 10 \cdot \log_{10}(500 \cdot 10^3) + 50 = 106.99\ [dB]$$

$$(12.10) \quad L_{W_A} = 22 \cdot \log_{10}(40) + 72 = 107.24\ [dB]$$

$$(12.11) \quad L_{W_A} = 50 \cdot \log_{10}\left(\frac{80}{3} \cdot \pi\right) + 10 \cdot \log_{10}(40) - 4 = \mathbf{108.17}\ [dB]$$

12.4 *Taula*:

Onartutako zarataren limite baliokidea soinuaren presio mailarekiko. $L_{eq}\ [dB(A)]$: Herrialde Europarretan (Gipe, 1995)

Herrialdea	Komertziala	Mistoa	Egoitza-gunea	Baserria
Danimarka			40	45
Alemania:				
egunez	65	60	55	50
gauez	50	45	40	35
Holanda:				
egunez		50	45	40
gauez		40	35	30

20.Ariketa:

- $R = 100\ [m] \rightarrow L_P = 60\ [dB]$

R: Turbinaren fokutik (puntu infinitesimala) leku batera dagoen distantzia da $[m]$-tan.

L_P: Soinuaren presio maila da eta $[dB]$-tan neurtzen da.

L_{W_A}: Soinuaren potentzia maila $[dB]$-tan.

α: Frekuentziaren araberako soinuaren absortzio koefizientea.

Orokorrean $\alpha = 0.005\ [dB(A)/m]$ dela suposatuko dugu ariketa baten enuntziatuak kontrakoa esaten ez badu (α _tenperaturaren funtzioan aldatzen da_).

Zeintzuk dira zarata maila hauek 300, 500 eta 1000 metrora?

- Modelo hemisferikoa (soinu-iturria lurretik gertu dagoenean aplikatzen da, adibidez minieolikan):

  Esferaerdi baten azalera: $A_{Esferaerdi} = 2\pi R^2$

  $$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R \qquad (12.14)$$

- Modelo esferikoa (soinu-iturria lurretik urrun dagoenean, hots, altuera handi batean dagoenean aplikatzen da. Adibidez: turbinak mendietan daudenean, parke eolikoetan...):

  Esfera baten azalera: $A_{Esfera} = 4\pi R^2$

  $$L_P = L_W - 10 \cdot \log_{10}(4\pi R^2) - \alpha \cdot R \qquad (???)$$

  Soinu-iturri baten fokuaren ALTUERA ↑↑↑ → ZARATA ↓↓↓

Oharra:

Metodo hemisferikoaren eta esferikoaren emaitzen artean ezberdintasun txikia dago, baina planteatzen den kasuaren arabera bata edo bestea erabiltzen da.

a) $\mathrm{R} = 100\ [\mathrm{m}]$; $\mathrm{L_P} = 60\ [\mathrm{dB}]$

$$L_W = L_P + 10 \cdot \log_{10}(2\pi R^2) + \alpha \cdot R \rightarrow$$

$$\rightarrow L_W = 60 + 10 \cdot \log_{10}(2\pi \cdot 100^2) + 0.005 \cdot 100 = 108.48\ [dB]$$

b) $\mathrm{R} = 300\ [\mathrm{m}]$

$$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R \rightarrow$$

$$\rightarrow L_P = 108.48 - 10 \cdot \log_{10}(2\pi \cdot 300^2) - 0.005 \cdot 300 = 49.46\ [dB]$$

c) $\mathrm{R} = 500\ [\mathrm{m}]$

$$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R \rightarrow$$

$$\rightarrow L_P = 108.48 - 10 \cdot \log_{10}(2\pi \cdot 500^2) - 0.005 \cdot 500 = 44.02\ [dB]$$

d) $R = 1000\ [m]$

$$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R \rightarrow$$

$$\rightarrow L_P = 108.48 - 10 \cdot \log_{10}(2\pi \cdot 1000^2) - 0.005 \cdot 1000 = 35.5\ [dB]$$

21.Ariketa:

Lehenengo kasu berean, distantzia berdinetara, zarata maila zein izango da halako 2, 5 eta 10 turbina ipiniz gero?

Intuitiboena da puntu batean turbinak izan ohi diren soinu-iturri kopurua bikoizten badugu soinu energiaren igorpena bikoiztuko dela pentsatzea.

Baina dezibelioen eskala logaritmikoa denez soinu presio mailaren gehikuntzarako aplikatu behar dugun erlazioa hurrengoa da:

$$(12.13) \qquad L_{Total} = 10 \cdot \log_{10}\left(\sum_{i=1}^{N} 10^{L_i/10}\right)$$

Erlazio hau N soinu-iturri kopuru batentzako orokortu daiteke.

L_{Total}: Foku batean ipinitako soinu-iturri kopuru baten soinuaren presio mailaren gehikuntza (eskala logaritmikoan) totala da eta $[dB]$-tan neurtzen da.

<u>Formula hau aplikatzerakoan kontuan hartu beharreko irizpideak:</u>

- Puntu batean balio berdineko bi presio maila gehitzen baditugu soinuaren presio mailaren balio totala haurreko presio mailaren balioa (L_1 edo L_2) + $3\ [dB]$ izango da.

- Bi soinu-iturriren (balio berdinekoak edo ezberdinekoak, berdin du) arteko kenketaren balio absolutua "$|L_1 - L_2|$" $> 15\ [dB]$ bada, orduan soinu-iturri horietako balio baxuenaren gehikuntza mespretxagarria da. Ala ere, kontuan hartu behar dugu soinu iturri asko jartzen baditugu, azkenean soinu iturri horien gehikuntza ez dela izango hain mespretxagarria.

- Foku batean L_P berdina duten “n” soinu-iturri izatetik “2·n” soinu-iturri izatera pasatzen bagara, orduan ahurreko $L_{P_{Totala}}$-ri 3 $[dB]$ gehitzen zaizkio emaitza berria lortzeko. Hori horrela da hurrengo kalkulua betetzen delako:

$$10 \cdot \log_{10}(2) = 3$$

Ondorioz:

$$L_{total_1} = 10 \cdot \log_{10}\left(\sum_{i=1}^{N} 10^{L_i/10} \cdot n\right) \rightarrow$$

$$\rightarrow L_{total_2} = 10 \cdot \log_{10}\left(\sum_{i=1}^{N} 10^{L_i/10} \cdot 2 \cdot n\right) =$$

$$= 10 \cdot \log_{10}\left(\sum_{i=1}^{N} 10^{L_i/10} \cdot n\right) + 10 \cdot \log_{10}(2) = L_{total_1} + 3$$

- $R = 100[m]$ eta $L_P = 60\ [dB]$:

  a) 2 turbina eta L_P berdinak: ($L_{Total} \approx L_0 + 3\ [dB] \cdot (n-1)$ aldiz; kasu honetan n = 2 turbina eta $|L_1 - L_2| = 0 < 15\ [dB]$; $L_0 = L_1 = L_2$)

$$L_{Totala} = L_0 + 3 \cdot (2-1) \approx 60 + 3 \cdot 1 = 63\ [dB]$$

  b) 5 turbina eta L_P berdinak: (kasu honetan n = 5 turbina → $n - 1 = 4$ aldiz, ~~$L_{Totala} \approx L_0 + 3\ [dB] \cdot (n-1)$~~ $\leftrightarrow |L_1 - L_2 - L_3 - L_4 - L_5| = 180 > 15\ [dB]$!!

  Adibidez: ($L_1 = L_2 = L_3 = L_4 = \cdots = L_n$)

- $|L_1 - L_2| = |60 - 60| = 0 < 15\ [dB] \rightarrow\ L_{Total_0} \approx L_0 + 3\ [dB] \cdot (n-1)$

- $|L_1 - L_2 - L_3| = |60 - 60 - 60| = 60 > 15\ [dB] \rightarrow L_{Total_0} \approx L_{Total_1}$

- $|L_1 - L_2 - L_3 - L_4| = |60 - 60 - 60 - 60| = 120 > 15\ [dB] \rightarrow$

  $\rightarrow L_{Total_0} \neq L_{Total_2} \leftrightarrow L_{Total_0} = 63.01\ [dB] \neq 66.02\ [dB] = L_{Total_2}$

- $|L_1 - L_2 - L_3 - L_4 - \cdots - L_n|$; non $L_{Totala_n} \sim L_{Totala_{n-1}}$ baina $L_{Totala_n} \ggg L_{Totala_1}$

Ondorioz, n > 2 turbina ditugunean formula zuzenean aplikatu behar dugu:

$$L_{Totala} = 10 \cdot \log_{10}(10^{60/10} + 10^{60/10} + 10^{60/10} + 10^{60/10} + 10^{60/10})$$

$$L_{Totala} = 10 \cdot \log_{10}(10^{60/10} \cdot 5) = 66.99\ [dB]$$

c) 10 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{60/10} \cdot 10) = 70\ [dB]$$

- $R = 300[m]$ eta $L_P = 49.46\ [dB]$:

  a) 2 turbina eta L_P berdinak: ($L_{Total} \approx L_0 + 3\ [dB] \cdot (n-1)$ aldiz; kasu honetan n = 2 turbina eta $|L_1 - L_2| = 0 < 15\ [dB]$; $L_0 = L_1 = L_2$)

$$L_{Totala} = L_0 + 3 \cdot (2-1) \approx 49.46 + 3 \cdot 1 = 52.46\ [dB]$$

  b) 5 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{49.46/10} \cdot 5) = 56.45\ [dB]$$

  c) 10 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{49.46/10} \cdot 10) = 59.46\ [dB]$$

- $R = 500[m]$ eta $L_P = 44.02\ [dB]$:

  a) 2 turbina eta L_P berdinak: ($L_{Total} \approx L_0 + 3\ [dB] \cdot (n-1)$ aldiz; kasu honetan n = 2 turbina eta $|L_1 - L_2| = 0 < 15\ [dB]$; $L_0 = L_1 = L_2$)

$$L_{Totala} = L_0 + 3 \cdot (2-1) \approx 44.02 + 3 \cdot 1 = 47.02\ [dB]$$

  b) 5 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{44.02/10} \cdot 5) = \mathbf{51.01}\ [dB]$$

c) 10 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{44.02/10} \cdot 10) = \mathbf{54.02}\ [dB]$$

- $R = 1000[m]$ eta $L_P = 35.5\ [dB]$:

a) 2 turbina eta L_P berdinak: ($L_{Total} \approx L_0 + 3\ [dB] \cdot (n-1)$ aldiz; kasu honetan n = 2 turbina eta $|L_1 - L_2| = 0 < 15\ [dB]$; $L_0 = L_1 = L_2$)

$$L_{Totala} = L_0 + 3 \cdot (2-1) \approx 35.5 + 3 \cdot 1 = \mathbf{38.5}\ [dB]$$

b) 5 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{35.5/10} \cdot 5) = \mathbf{45.49}\ [dB]$$

c) 10 turbina eta L_P berdinak:

$$L_{Totala} = 10 \cdot \log_{10}(10^{35.5/10} \cdot 10) = \mathbf{48.5}\ [dB]$$

22.Ariketa:

$L_W = 105\ [dB]$ igortzen dituzten 2 turbina $R_1 = 200\ [m]$ eta $R_2 = 240\ [m]$; $\alpha = 0.005\ [dB/m]$ badira, zenbat izango da $L_{P_{Totala}}$?

Eredu hemisferikoa aplikatuz ariketa hau ebatzi dugu:

$$L_{P_1} = L_W - 10 \cdot \log_{10}(2\pi R_1^2) - \alpha \cdot R_1$$

$$\boldsymbol{L_{P_1}} = 105 - 10 \cdot \log_{10}(2\pi \cdot 200^2) - 0.005 \cdot 200 = 49.997\ \ [dB] \approx \mathbf{50\ [dB]}$$

$$L_{P_2} = L_W - 10 \cdot \log_{10}(2\pi R_2^2) - \alpha \cdot R_2$$

$$\boldsymbol{L_{P_2}} = 105 - 10 \cdot \log_{10}(2\pi \cdot 240^2) - 0.005 \cdot 240 = \mathbf{48.21[dB]}$$

$$L_{P_{Totala}} = 10 \cdot \log_{10}(10^{L_{P_1}/10} + 10^{L_{P_2}/10}) = 10 \cdot \log_{10}\left(10^{50/10} + 10^{48.21/10}\right)$$

$$L_{P_{Totala}} = 52.21\ [dB]$$

23.Ariketa:

Aerosorgailu batek $102\ [dB]$*-ko zarata sortzen du eta haizearen abiadura* $u = 8\ [m/s]$ *da.*

Marraztu zarata presio maila VS distantzia zarataren hedapen eredu hemisferikoa eta esferikoa erabiliz.

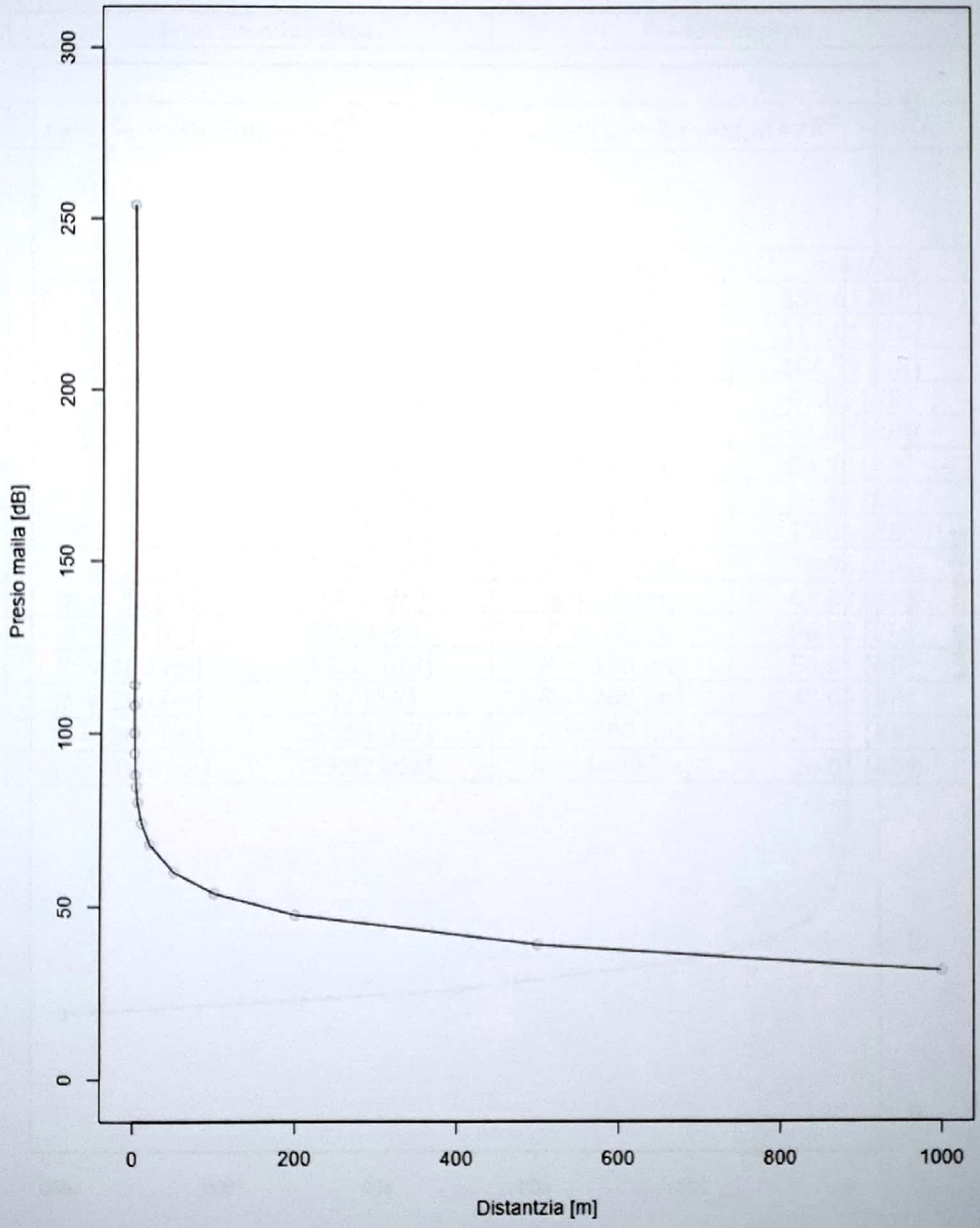
Egin hau zarata absortzio koefizientea (α) = 0.0025; 0.005; 0.01 izanik.

- $\alpha = 0.0025\ [dB/m]$ denean ($u = 8\ [m/s]; L_w = 102\ [dB]$):

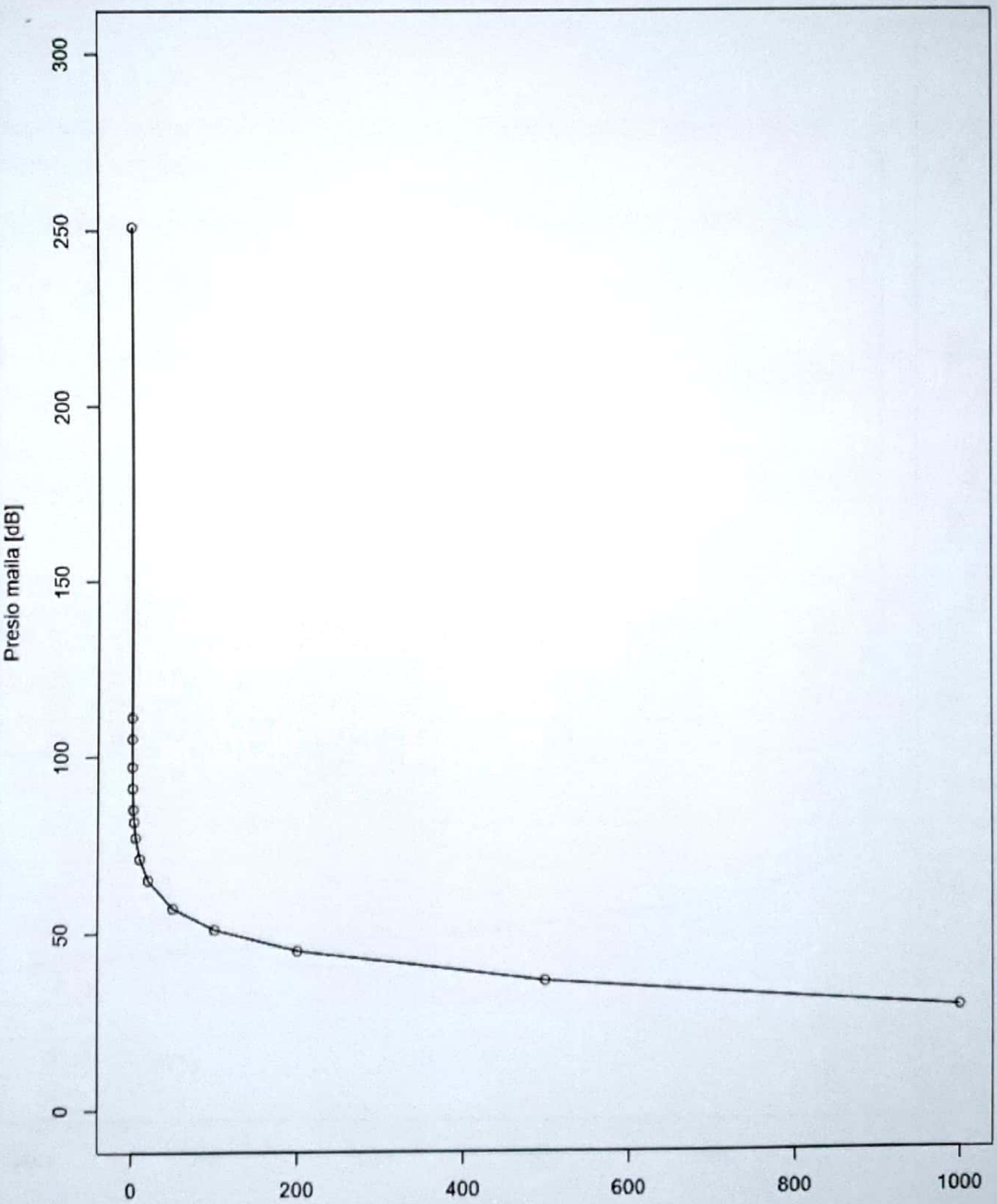
Eredu hemisferikoa:	Eredu esferikoa:
$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R$	$L_P = L_W - 10 \cdot \log_{10}(4\pi R^2) - \alpha \cdot R$

$R = 0\ [m]$	$\infty\ [dB]$	$R = 0\ [m]$	$\infty\ [dB]$
$R = 1 \cdot 10^{-8}\ [m]$	$254.02\ [dB]$	$R = 1 \cdot 10^{-8}\ [m]$	$251.01\ [dB]$
$R = 0.1\ [m]$	$114.02\ [dB]$	$R = 0.1\ [m]$	$111.01\ [dB]$
$R = 0.2\ [m]$	$108.04\ [dB]$	$R = 0.2\ [m]$	$104.99\ [dB]$
$R = 0.5\ [m]$	$100.04\ [dB]$	$R = 0.5\ [m]$	$97.03\ [dB]$
$R = 1\ [m]$	$94.01\ [dB]$	$R = 1\ [m]$	$91.01\ [dB]$
$R = 2\ [m]$	$87.99\ [dB]$	$R = 2\ [m]$	$84.98\ [dB]$
$R = 3\ [m]$	$84.47\ [dB]$	$R = 3\ [m]$	$81.46\ [dB]$
$R = 5\ [m]$	$80.03\ [dB]$	$R = 5\ [m]$	$77.02\ [dB]$
$R = 10\ [m]$	$73.99\ [dB]$	$R = 10\ [m]$	$70.98\ [dB]$
$R = 20\ [m]$	$67.95\ [dB]$	$R = 20\ [m]$	$64.94\ [dB]$
$R = 50\ [m]$	$59.91[dB]$	$R = 50\ [m]$	$56.9\ [dB]$
$R = 100\ [m]$	$53.77\ [dB]$	$R = 100\ [m]$	$50.76\ [dB]$
$R = 200\ [m]$	$47.5\ [dB]$	$R = 200\ [m]$	$44.49\ [dB]$
$R = 500\ [m]$	$38.9\ [dB]$	$R = 500\ [m]$	$35.78\ [dB]$
$R = 1000\ [m]$	$31.52\ [dB]$	$R = 1000\ [m]$	$28.51\ [dB]$

- Eredu hemisferikoa:



- Eredu esferikoa:



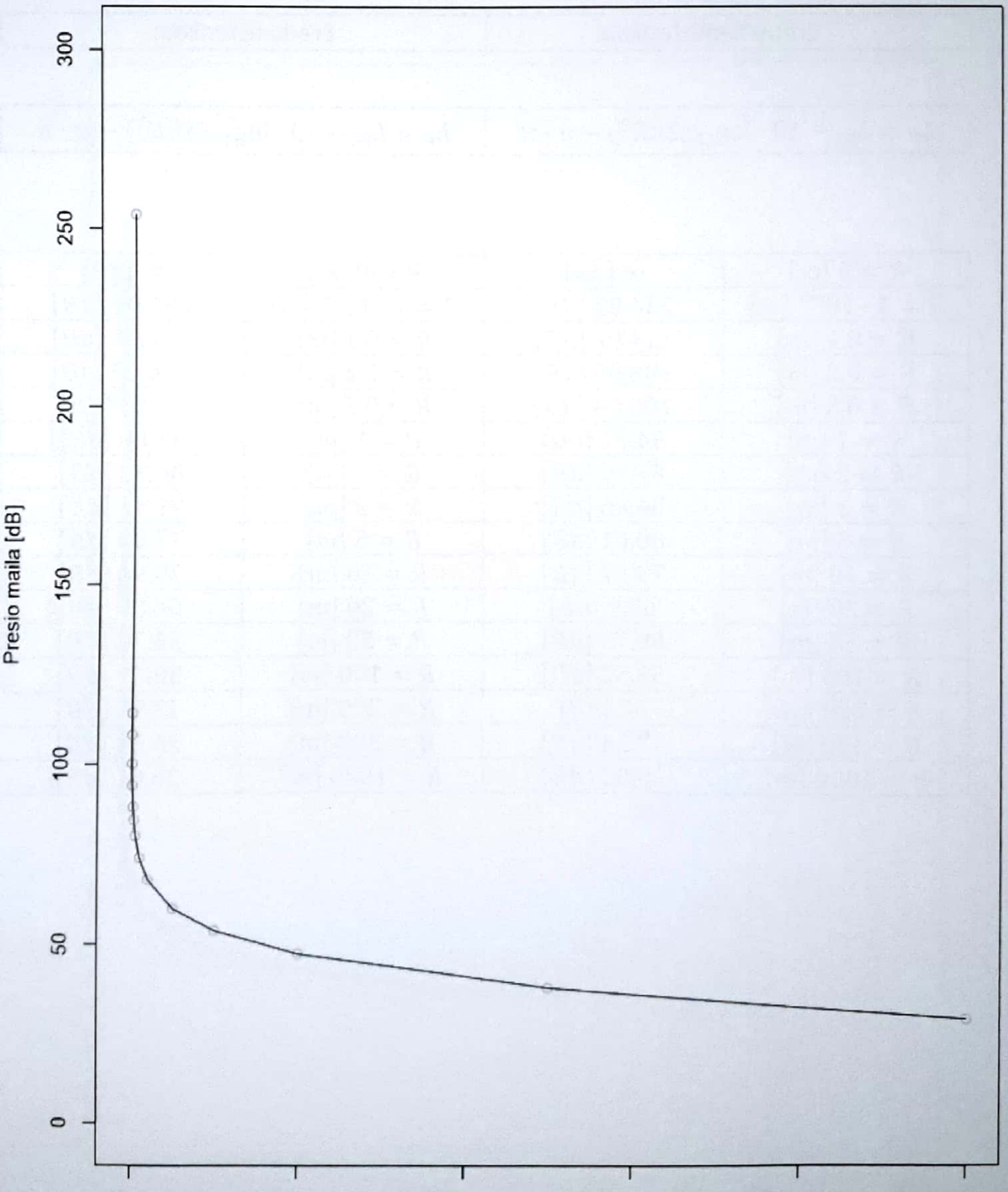
- $\alpha = 0.005\ [dB/m]$ denean ($u = 8\ [m/s]; L_w = 102\ [dB]$):

Eredu hemisferikoa:	Eredu esferikoa:

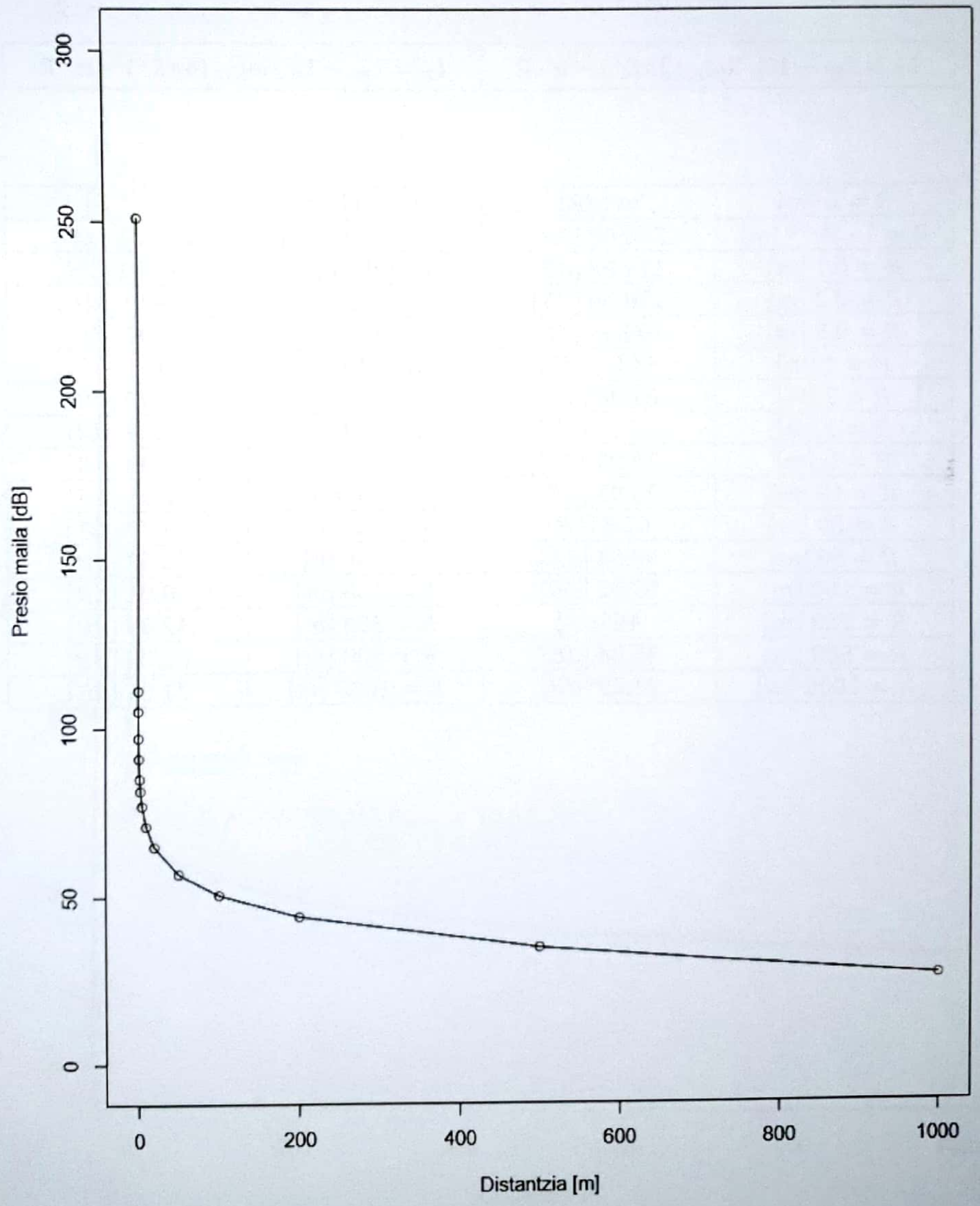
$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R$	$L_P = L_W - 10 \cdot \log_{10}(4\pi R^2) - \alpha \cdot R$

$R = 0\ [m]$	$\infty\ [dB]$	$R = 0\ [m]$	$\infty\ [dB]$
$R = 1 \cdot 10^{-8}\ [m]$	$254.02\ [dB]$	$R = 1 \cdot 10^{-8}\ [m]$	$251.01\ [dB]$
$R = 0.1\ [m]$	$114.02\ [dB]$	$R = 0.1\ [m]$	$111.01\ [dB]$
$R = 0.2\ [m]$	$108.00\ [dB]$	$R = 0.2\ [m]$	$104.99\ [dB]$
$R = 0.5\ [m]$	$100.04\ [dB]$	$R = 0.5\ [m]$	$97.03\ [dB]$
$R = 1\ [m]$	$94.01\ [dB]$	$R = 1\ [m]$	$91.00\ [dB]$
$R = 2\ [m]$	$87.99\ [dB]$	$R = 2\ [m]$	$84.98\ [dB]$
$R = 3\ [m]$	$84.46\ [dB]$	$R = 3\ [m]$	$81.45\ [dB]$
$R = 5\ [m]$	$80.01\ [dB]$	$R = 5\ [m]$	$77.00\ [dB]$
$R = 10\ [m]$	$73.97\ [dB]$	$R = 10\ [m]$	$70.96\ [dB]$
$R = 20\ [m]$	$67.9\ [dB]$	$R = 20\ [m]$	$64.89\ [dB]$
$R = 50\ [m]$	$59.79\ [dB]$	$R = 50\ [m]$	$56.78\ [dB]$
$R = 100\ [m]$	$53.52\ [dB]$	$R = 100\ [m]$	$50.51\ [dB]$
$R = 200\ [m]$	$47\ [dB]$	$R = 200\ [m]$	$43.99\ [dB]$
$R = 500\ [m]$	$37.54\ [dB]$	$R = 500\ [m]$	$34.53\ [dB]$
$R = 1000\ [m]$	$29.02\ [dB]$	$R = 1000\ [m]$	$26.01\ [dB]$

- Eredu hemisferikoa:



- Eredu esferikoa:



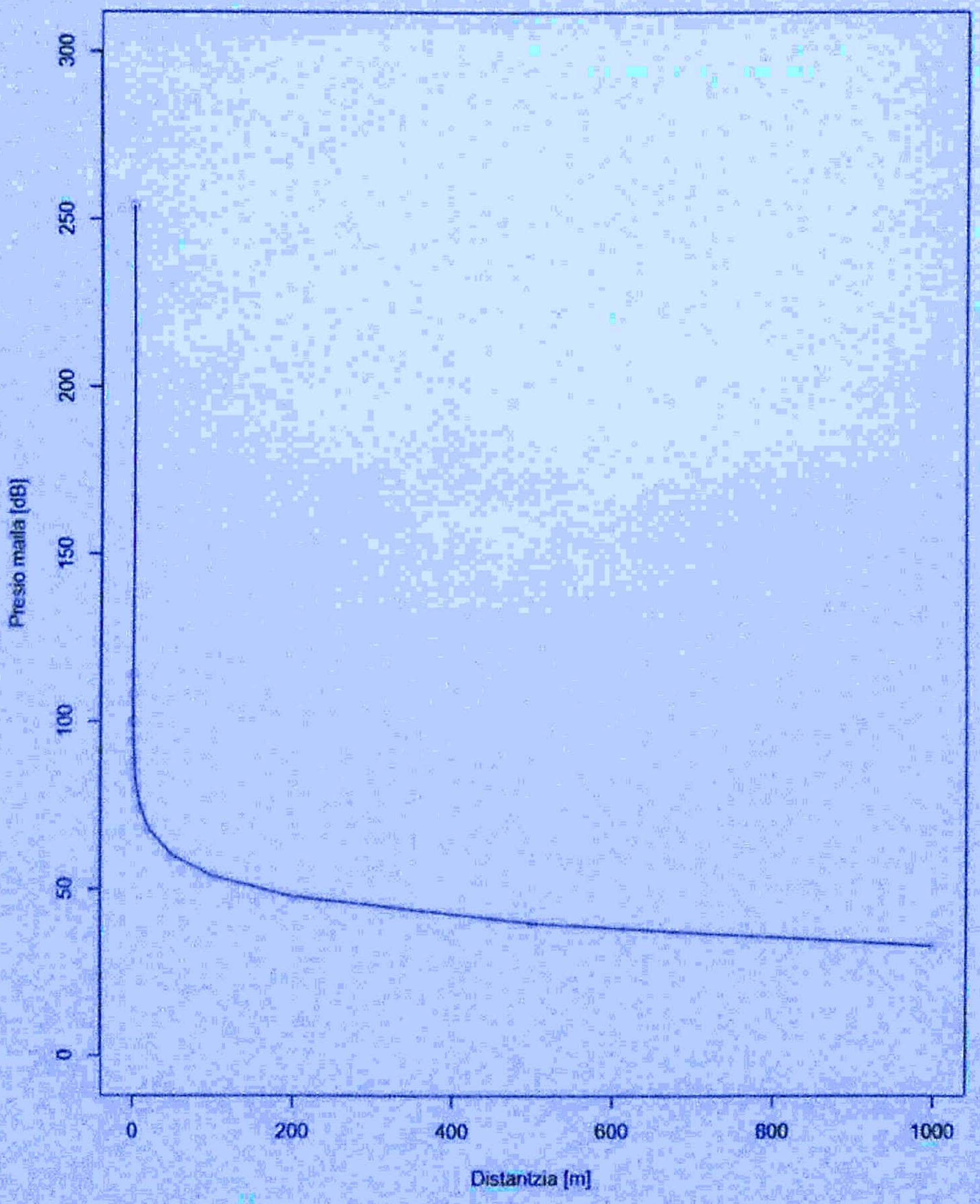
- $\alpha = 0.01\ [dB/m]$ denean ($u = 8\ [m/s]; L_w = 102\ [dB]$):

Eredu hemisferikoa:	Eredu esferikoa:

$L_P = L_W - 10 \cdot \log_{10}(2\pi R^2) - \alpha \cdot R$	$L_P = L_W - 10 \cdot \log_{10}(4\pi R^2) - \alpha \cdot R$

$R = 0\ [m]$	$\infty\ [dB]$	$R = 0\ [m]$	$\infty\ [dB]$
$R = 1 \cdot 10^{-8}\ [m]$	$254.02\ [dB]$	$R = 1 \cdot 10^{-8}\ [m]$	$251.01\ [dB]$
$R = 0.1\ [m]$	$114.02\ [dB]$	$R = 0.1\ [m]$	$111.01\ [dB]$
$R = 0.2\ [m]$	$108.00\ [dB]$	$R = 0.2\ [m]$	$104.99\ [dB]$
$R = 0.5\ [m]$	$100.03\ [dB]$	$R = 0.5\ [m]$	$97.02\ [dB]$
$R = 1\ [m]$	$94.01\ [dB]$	$R = 1\ [m]$	$91\ [dB]$
$R = 2\ [m]$	$87.98\ [dB]$	$R = 2\ [m]$	$84.97\ [dB]$
$R = 3\ [m]$	$84.45\ [dB]$	$R = 3\ [m]$	$81.44\ [dB]$
$R = 5\ [m]$	$79.99\ [dB]$	$R = 5\ [m]$	$76.98\ [dB]$
$R = 10\ [m]$	$73.92\ [dB]$	$R = 10\ [m]$	$70.91\ [dB]$
$R = 20\ [m]$	$67.8\ [dB]$	$R = 20\ [m]$	$64.79\ [dB]$
$R = 50\ [m]$	$59.54\ [dB]$	$R = 50\ [m]$	$56.53\ [dB]$
$R = 100\ [m]$	$53.02\ [dB]$	$R = 100\ [m]$	$50.01\ [dB]$
$R = 200\ [m]$	$46\ [dB]$	$R = 200\ [m]$	$42.99\ [dB]$
$R = 500\ [m]$	$35.04\ [dB]$	$R = 500\ [m]$	$32.03\ [dB]$
$R = 1000\ [m]$	$24.02\ [dB]$	$R = 1000\ [m]$	$21.01\ [dB]$

- Eredu hemisferikoa:



- Eredu esferikoa: