First period of examinations
Summer semester 2020 / September

Study Course: _________ **(Use abbreviation ME or IE or SE respectively)**

Module Title: **27101 Fluid Mechanics B.Sc. (Prof. Gebel)**

Family Name: ____________________

First Name: ____________________

Student No.: ____________________

I hereby confirm in lieu of an oath that I am the person who was admitted to this examination. Further, I confirm that the submitted work is my own and was prepared without the use of any unauthorised aides or materials*. I am fully aware of the legal consequences of making a false declaration.

Date: 23.09.2020 **Signature:** ______________________________

* The following aides and materials are permitted:

- Non-programmable pocket calculator
- Geometrical tools
- All my lectures slides and exercises available on Moodle
- Your personal handwritten notes

According to the “Regulations to offset academic adversities caused by the coronavirus epidemic (SARS-CoV-2)” you are permitted to withdraw from the examination before submission. It is mandatory that you sign the following statement in case you wish to withdraw and that you submit the front pages as necessary proof. No signature means that the examination will be graded.

I hereby wish to withdraw from this examination.

Date: 23.09.2020 **Signature:** ______________________________

Register No.: ____________

Examination form: Written exam

Points: 84

Duration: 120 Minutes

Check that the document contains 6 problems.

All calculations and sketches can be made on your own paper sheets. Tablets or comparable devices are not permitted. **Each sheet must contain your name, your student number and your signature. Prepare <u>one</u> document in the end. Moodle does not accept two or more documents to be submitted.**

Please write legibly. Thank you very much and good luck.

	Q1	Q2	Q3	Q4	Q5	Q6	Written exam	Practical Training	Total
Max. Points	14	14	14	14	14	14	84	16	100
Achieved									
							$\geq$ **42** **Yes | No**	**Grade**	

Graded by		Checked by

Final Grade

Regular grading key.	
Adjusted grading key. (Please add the adjusted grading key to the exam-results)	X

Register No.: ____________

Question 1 … Question Session **Points: 14**

<u>There is only one correct answer for each question. Use a consistent format for your answer, for instance Q1.1.A or Q1.3.C</u>

1. What happens if the flow of water within a horizontal tube changes from laminar to turbulent?

   A. The pressure losses remain constant.
   B. The pressure losses will increase.
   C. The pressure losses will decrease.

2. Consider laminar flow of water under steady-state conditions. What happens if the diameter of a horizontal tube smoothly increases?

   A. The pressure will decrease and the velocity will increase.
   B. Pressure and velocity remain constant.
   C. Pressure and velocity will decrease.
   D. The pressure will increase and the velocity will decrease.

   $P_1 - P_2 = \Delta P_{Losses}$

   $\lambda = \frac{64}{Re} = \frac{64\eta}{\rho v d\uparrow}\downarrow \Rightarrow \Delta P_{Loss}\downarrow$

   $\Rightarrow P_2\uparrow$

3. Consider laminar flow of air under steady-state conditions through a horizontal tube. What happens if the temperature of the air decreases due to cooling of the tube?

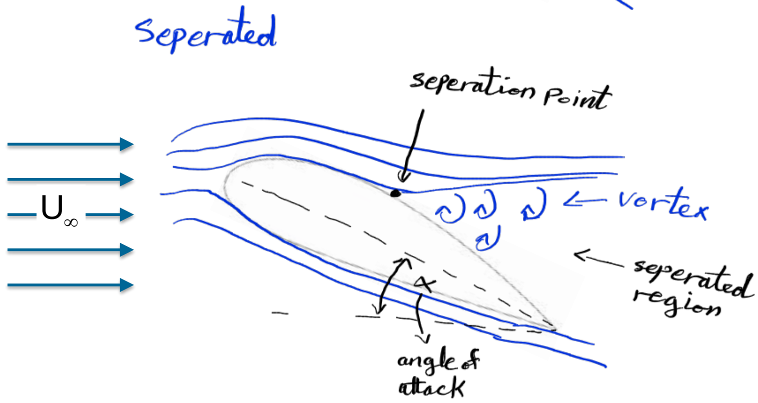
   $T\downarrow \Rightarrow \eta\downarrow \Rightarrow \lambda\downarrow \Rightarrow \Delta P_{Loss}\downarrow$

   A. The pressure losses will increase.
   B. The pressure losses will decrease.
   C. The pressure remains constant.

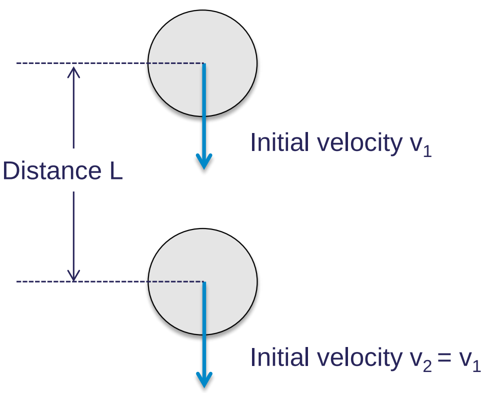
4. Plaice are bottom-living flatfish similar to flounder. At rest they constitute low, rounded humps on smooth, sandy bottoms. What happens if the current passing over the fish becomes stronger, i.e. higher flow velocity?

   A. The flatfish is pressed on the ground.
   B. The flatfish is lifted up into the current.
   C. The flatfish remains quiescent.

5. Sketch the streamlines over an airfoil at a large angle of attack for both attached flow and separated flow.



6. What happens if two 5-cm-diameter spheres are falling one after another through air at an initial vertical distance of 10 cm?



A. The distance L remains constant.

B. The distance L becomes smaller. because the upper sphere will have less drag

C. The distance L becomes bigger.

7. A Pitot-static probe … (pressure difference)

A. … is a measurement instrument used to measure gage pressure.

B. … is a measurement instrument used to measure fluid flow velocity.

C. … is a measurement instrument used to measure total pressure.

8. Within the International System of Units (SI = Système Internationale) Power P has the well-known unit Watt [W]. Applying the M-L-T (Mass-Length-Time) system Power P has the following dimensions:

$W = J/s = Nm/s$
$Kg \cdot m^2/s^3$

A. $M^1 \cdot L^2 \cdot T^{-3}$
B. $M^1 \cdot L^1 \cdot T^{-2}$
C. $M^1 \cdot L^{-2} \cdot T^{-3}$

9. Determine the force acting on the 150-mm-diameter headlight of an automotive traveling at 120 km/h. Assume an air density of 1.23 $^{kg}/_{m^3}$.

A. $F = 12.1$ N

$F_D = C_D \frac{\rho}{2} v^2 \cdot \frac{\pi}{4} d^2$

B. $F = 6.05$ N
C. $F = 24.2$ N

10. Consider a car moving at a velocity of 60 km/h. What happens to the drag force if the car accelerates to 120 km/h?

becomes 4 times bigger because v^2

A. The drag force remains constant.
B. The drag force at 120 km/h is twice the drag at 60 km/h.
C. The drag force at 120 km/h is eight times bigger than the drag at 60 km/h.
D. No correct answer is given.

Register No.: ____________

Question 2 … Power demand of a pump **Points: 14**

A 75%-efficient pump delivers 0.1 m³/s of water from a big, open reservoir to a device at an elevation of 50 m above the reservoir. The gage pressure, which must be provided by the pump at the entrance to the device is 180 kPa.

Determine the necessary power input to the pump if the loss coefficient is 5.6.

Given:

Density of water: $\rho = 1{,}000\,\dfrac{\text{kg}}{\text{m}^3}$

Diameter of the pipe: d = 80 mm

Loss coefficient for minor losses: $\zeta = 5.6$

Friction within the pipe: negligible, i.e. $\lambda \approx 0$

Solution:

$P = 210\,\text{kW}$

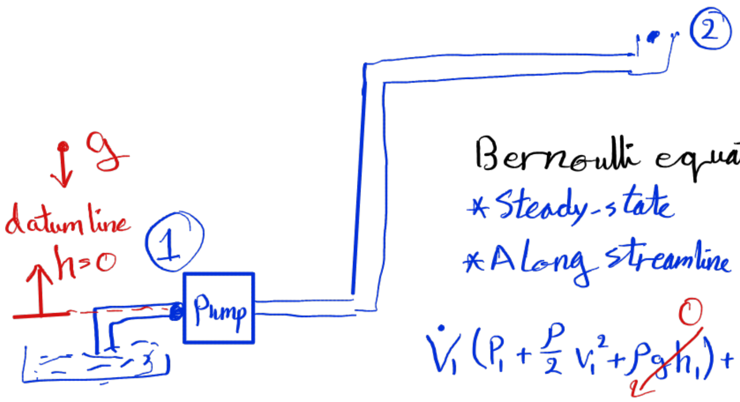
Continuity equation $\dot{m}_{in} = \dot{m}_{out}$

$\cancel{\rho} V_1 \cancel{A_1} = \cancel{\rho} V_2 \cancel{A_2}$

$A_1 = A_2 \Rightarrow V_1 = V_2$

$$V_1 = V_2 = \frac{\dot{V}_1}{A_1} = \frac{0.1\,m^3/s}{\frac{\pi}{4}(0.08\,m)^2} \approx 19.9\,m/s$$

$$\dot{V}_1 = \dot{V}_2 = \dot{V} = 0.1\,m^3/s$$



Bernoulli equation;

* Steady-state
* ρ = cons.
* Along streamline
* No viscous forces

$$\dot{V}_1\left(P_1 + \frac{\rho}{2}V_1^2 + \cancel{\rho g h_1}^{\,0}\right) + P_{Pump} = \dot{V}_2\left(\cancel{P_2}^{\,P_{atm}} + \frac{\rho}{2}V_2^2 + \rho g h_2 + \Delta P_{Losses}\right)$$

$$P_{Pump} = \dot{V}\left(-P_1 + \rho g h_2 + \frac{\rho}{2}\cancel{(V_2^2 - V_1^2)}^{\,0} + \zeta \cdot \rho \frac{V^2}{2}\right)$$

$P_{Pump} \approx 189.244\,KW$

Question 3 … Viscosity   Points: 14 (6+8)

Q3.1

A velocity distribution in a 5-cm-diameter pipe is measured as

$$u(r) = A \cdot (1 - \frac{r^2}{r_0^2})$$

$$\tau = \eta \cdot \frac{du}{dr}$$

where $r = 0$ represents the centreline of the tube
and $r = r_0$ is the radius of the pipe.

Calculate the shear stress at the wall if water at 25°C is flowing through the pipe.

Given:

Constant A $A = 9\,\frac{m}{s}$

Viscosity of water as function of temperature

Temperature	Viscosity
[°C]	[mPas]
10	1.3080
20	1.0020
30	0.7978
40	0.6531
50	0.5471
60	0.4668
70	0.4044
80	0.3550
90	0.3150
100	0.2822

η	T
1.0020	20
η_{25}	25
0.7978	30

$$\eta_{25} = \frac{1.0020 - 0.7978}{20 - 30}(25 - 30) + 0.7978$$

$$\eta_{25} = 0.8999\ \frac{mN}{m^2} \cdot s$$

$$\frac{du}{dr} = A \cdot \frac{d(1 - \frac{r^2}{r_0^2})}{dr} = A\left(-2\frac{r}{r_0^2}\right)$$

$$\tau_{center} = \eta_{25} \cdot A\left(-2\frac{0}{r_0^2}\right) = 0$$

$$\tau|_{r=r_0} = \eta_{25} \cdot A\left(-2\frac{\cancel{r_0}}{r_0^{\cancel{2}}}\right) = 9\times10^{-4}\frac{N}{m^2}\cdot s\ (9\,\frac{m}{s})\left(-2\,\frac{1}{0.025\,m}\right)$$

$$= -0.648$$

The direction of the shear

<u>Solution:</u>

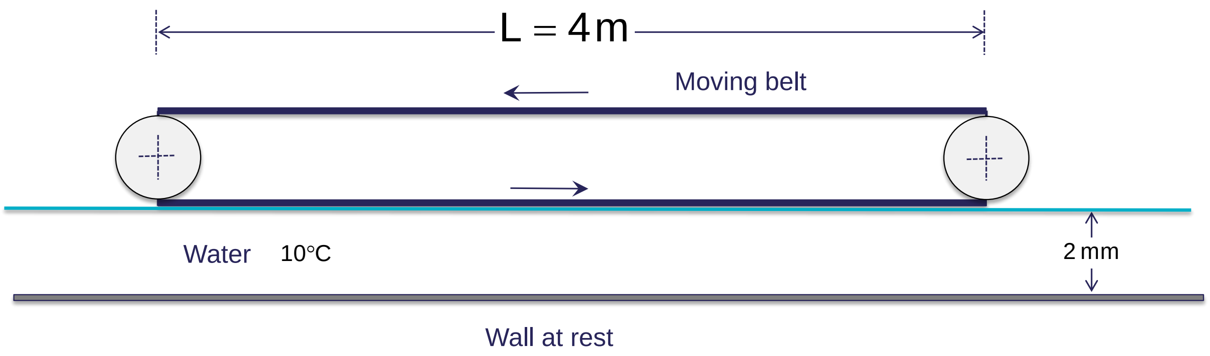
$$\tau = 0.648\,\frac{N}{m^2}$$

Register No.: ____________

Q3.2

A 60-cm-wide belt moves at 10 m/s over the water surface as shown in the figure.

The belt is touching the surface with its complete area. $\eta_{10} = 1.3080 \times 10^{-3}$ Pa.s



Calculate the power required to drive the belt.

Assume a linear velocity profile in the 10°C water.

Given:

Viscosity of water as function of temperature (see **Q3.1**)

<u>Solution:</u>

$P = 157$ W

Register No.: ____________

Question 4 … Hydraulic power generation **Points: 14**

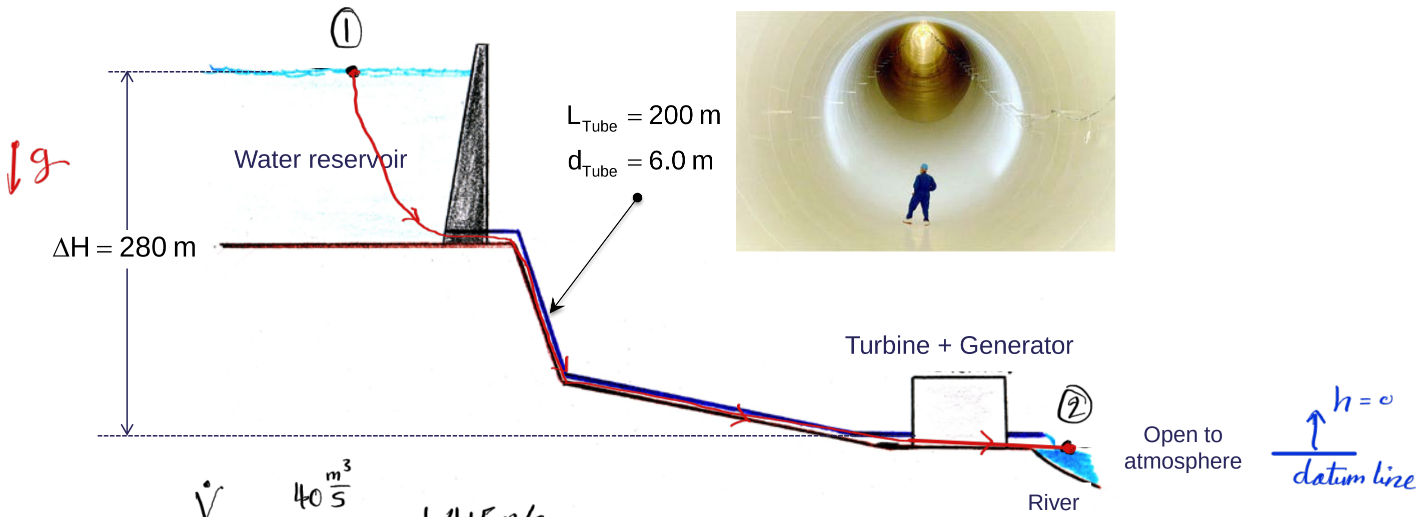
The *Vianden Pumped Storage Plant* owned by Société Electrique de l'Our and RWE is located just north of Vianden in Diekirch District, Luxembourg. The power plant uses the pumped-storage hydroelectric method to generate electricity and serves as a peaking power plant. At present 11 pump-turbine units are installed bringing the plant's electricity generating capacity to more than 1,000 megawatts. The plant generates an average of 1,650 gigawatt-hours annually.

$P_{out} = 10^3\,MW$

$1650\,GW\cdot h/year$

Calculate the mechanical power generation of a **single** turbine under the following operating conditions:

Difference in height	$\Delta H = 280\,m$
Volume flow	$\dot{V} = 40\,\frac{m^3}{s}$
Density of water	$\rho = 1{,}000\,\frac{kg}{m^3}$
Viscosity @ 10°C	$\eta = 1.308\times10^{-3}\,\frac{Ns}{m^2}$
Length of the tube between reservoir and turbine	$L_{Tube} = 200\,m$
Diameter of the tube	$d_{Tube} = 6.0\,m$
Roughness of the tube	$e = 0.1\,mm$
Loss coefficient for minor losses	$\zeta = 20$



$$V = \frac{\dot{V}}{A} = \frac{40\,\frac{m^3}{s}}{\frac{\pi}{4}(6\,m)^2} = 1.415\,m/s$$

Bernoulli equations:
* ρ = cons.
* Along streamline
* steady-state
* There are losses

open to atm

$$\dot{V}\left(\cancel{p_1} + \frac{\rho}{2}\cancel{v_1^2} + \rho g h_1\right) = \dot{V}\left(\cancel{p_2} + \frac{\rho}{2}\cancel{v_2^2} + \rho g h_2 + \Delta p_{Losses}\right) + P_{Tur} \Rightarrow P_{Turbine} = \dot{V}\rho g(h_1 - h_2) - \Delta p_{Losses}$$

Continuity equation: $\dot{m}_{in} = \dot{m}_{out} \Rightarrow \cancel{\rho} v_1 A_1 = \cancel{\rho} v_2 A_2 \Rightarrow d_{tube} = cons. \Rightarrow v = cons.$

Register No.: ____________

For the determination of the the friction coefficient λ you can either use the Swamme-Jain equation, which is valid for fully turbulent flow or the Moody diagram.

$$\boxed{P_{Tur} = \dot{V} \rho g \Delta H - \lambda \frac{L}{d} \frac{\rho}{2} v^2}$$

Option 1

$$\lambda = 1.325 \cdot \left[ln\left(\frac{\varepsilon/d}{3.7} + 5.75\left(\frac{1}{Re}\right)^{0.9}\right)\right]^{-2}$$

$$Re = \frac{\rho v d}{\eta} = \frac{10^3 \frac{kg}{m^3}(1.415 \frac{m}{s})(6\,m)}{1.308 \times 10^{-3} \frac{Ns}{m^2}} = 6.5 \times 10^6$$

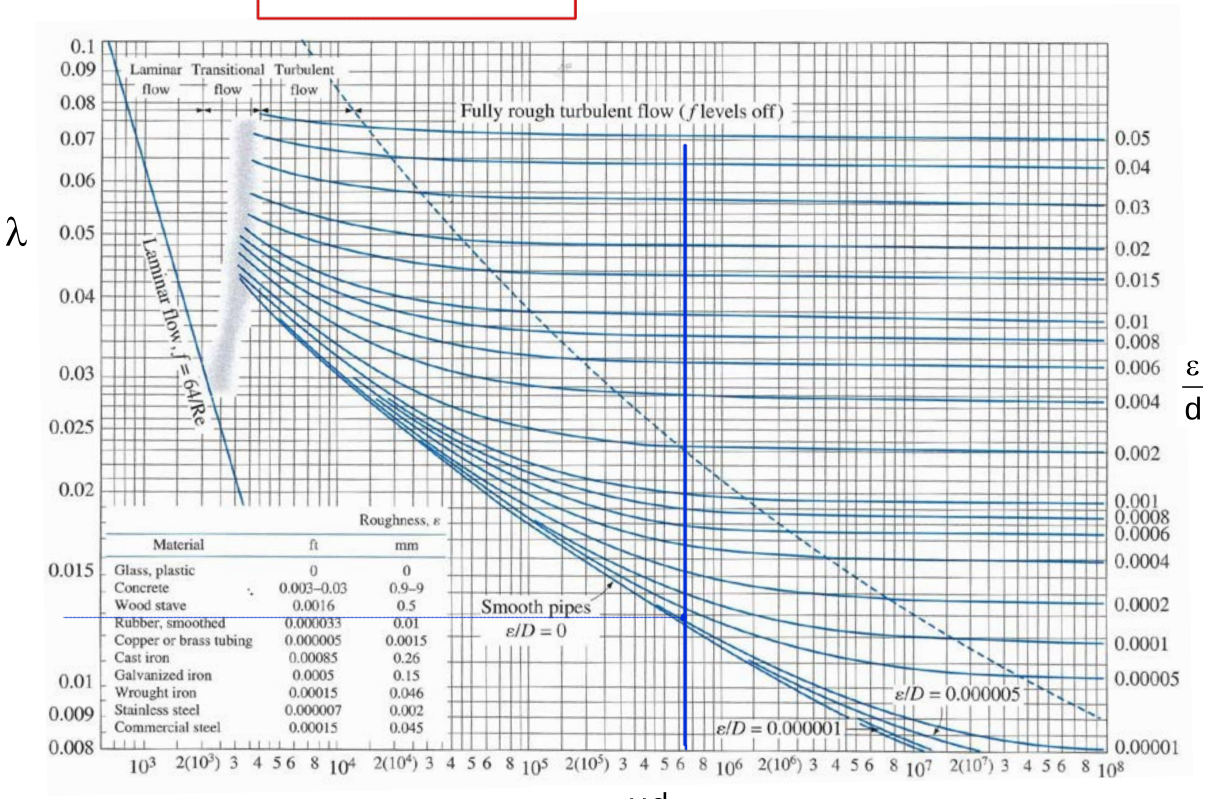
$$\frac{e}{d} = \frac{0.1\,mm}{6000\,mm} = 1.67 \times 10^{-5}$$

from Moody diagram $\lambda = 0.0129$

Option 2

$P_{Tur} = 109871569.7\ W$

$$\boxed{P = 109.9\ MW}$$



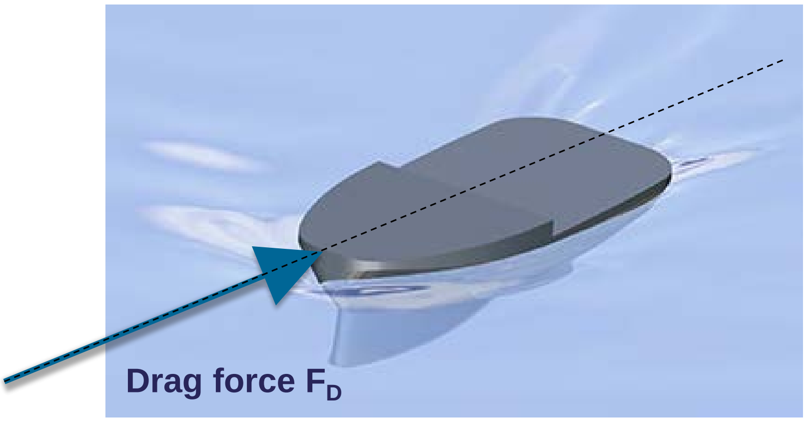
$$Re = \frac{\rho v d}{\eta}$$

Solution:

$P = 109\ MW$

Question 5 … Dimensional analysis **Points: 14**

The drag force acting on a ship's hull is considered to be a function of the fluid density ρ , the viscosity η, gravity g, ship velocity v, and a characteristic length l.



$n - m = 6 - 3 = 3$ $\quad \Pi_1 = f(\Pi_2, \Pi_3)$

a) Use an appropriate method to determine a set of suitable dimensionless numbers, i.e. π-terms, to describe the function

$$F_D = f(\rho, \eta, g, v, l)$$

$\Pi_1 = \frac{F_D}{\rho v^2 d^2}$ $\quad \frac{\cancel{kg}\,\cancel{m}}{\cancel{s^2}} \frac{\cancel{m^3}}{\cancel{kg}} \frac{\cancel{s^2}}{\cancel{m^2}} \cdot \frac{1}{\cancel{m^2}} = 1$

$\Pi_2 = \frac{\eta}{\rho v L}$ $\quad \frac{F_D}{\rho v^2 d^2} = f\left(\frac{\rho v l}{\eta}, \frac{g d}{v^2}\right)$

$\Pi_3 = \frac{g d}{v^2}$

b) Which commonly known dimensionless numbers have you detected?

c) The detected dimensionless numbers represent the ratio of different forces. Please express the dimensionless numbers in terms of forces.

b) Π_2 is Renoulds number

$\Pi_2 = \frac{\rho v l}{\eta} = \frac{\text{Inerial force}}{\text{Viscous force}}$

$\Pi_1 = \frac{F_D}{\rho v^2 d^2} = \frac{\text{Drag force}}{\text{Inerial force}}$

$\Pi_3 = \frac{g d}{v^2} = \frac{\text{gravitional force}}{\text{Inerial force}}$

Question 6 … Wind energy **Points: 14**

The torque of a windmill can be generated by rotating blades with a certain speed.

a) Assuming the wind is moving from left to right, indicate the direction of rotation of the windmill shown in the picture. Is it clockwise or counter clockwise?

b) Provide a velocity polygon and a schematic representation of the different forces, i.e. magnitude and direction, acting on the blade at a certain radius.

Use a ruler (!!!) to draw the velocity polygons.

Indicate torque and drag clearly.

c) Why should the blades be twisted from the root to the tip? Use three velocity polygons at different radii for your explanations.

End of exam