Practice Exam Fluid Mechanics

Examiner: apl. Prof. Dr.-Ing. C. Breitsamter

Date of the exam	
Room	
Name, First Name	
Student number	
Signature	

Exam type: Written

Time: 1 hour

This test includes 5 Pages (including cover sheet). A formula collection is issued. Please check the completeness immediately after receiving the test information. Label this cover page with your last name, first name and your student number. Sign this cover sheet. At the end of the test, all worksheets must be submitted.

All tasks are to be answered on the task sheets. Please use the front and back of the sheets. Calculation results are only evaluated with solution path. If partial tasks cannot be solved, make reasonable assumptions for the missing values for further calculation.

Task	1	2a	2b	Sum
Points				
Achieved points				

Notes

The operators used in the exam can be found in the following table. Please consider them when editing the tasks.

name	to mention or identify by name
present	(re-)structure and write down
justify	support a fact or a statement with reasonable arguments
describe	give an accurate account of sth.
show, illustrate	use examples to explain or make clear
explain	describe and define the causes
assess, evaluate	consider in a balanced way the points for and against sth.
interpret	make clear the meaning of sth. and give your own views on it
discuss	investigate or examine by argument; give reasons for and against

Collection of Formulas

Mass conservation for incompressible flows
$$\vec{\nabla} \cdot \vec{u} = 0$$

Navier-Stokes equations
$$\rho(\frac{\partial u_1}{\partial t} + u_1\frac{\partial u_1}{\partial x_1} + u_2\frac{\partial u_1}{\partial x_2} + u_3\frac{\partial u_1}{\partial x_3}) = -\frac{\partial p}{\partial x_1} + \mu(\frac{\partial^2 u_1}{\partial x_1^2} + \frac{\partial^2 u_1}{\partial x_2^2} + \frac{\partial^2 u_1}{\partial x_3^2}) + \rho f_1$$
$$\rho(\frac{\partial u_2}{\partial t} + u_1\frac{\partial u_2}{\partial x_1} + u_2\frac{\partial u_2}{\partial x_2} + u_3\frac{\partial u_2}{\partial x_3}) = -\frac{\partial p}{\partial x_2} + \mu(\frac{\partial^2 u_2}{\partial x_1^2} + \frac{\partial^2 u_2}{\partial x_2^2} + \frac{\partial^2 u_2}{\partial x_3^2}) + \rho f_2$$
$$\rho(\frac{\partial u_3}{\partial t} + u_1\frac{\partial u_3}{\partial x_1} + u_2\frac{\partial u_3}{\partial x_2} + u_3\frac{\partial u_3}{\partial x_3}) = -\frac{\partial p}{\partial x_3} + \mu(\frac{\partial^2 u_3}{\partial x_1^2} + \frac{\partial^2 u_3}{\partial x_2^2} + \frac{\partial^2 u_3}{\partial x_3^2}) + \rho f_3$$

Gas dynamics: Outlet flow
$$\frac{p_0}{p} = (1 + \frac{\gamma - 1}{2}Ma^2)^{\frac{\gamma}{\gamma-1}}$$

Gas dynamics: Perpendicular compression shock
$$\frac{p_2}{P_1} = \frac{2\gamma}{\gamma + 1}Ma_1^2 - \frac{\gamma - 1}{\gamma + 1}$$

1 Short questions

a Describe the physical principle of the formation of friction within a fluid

De: molekularer Impulsaustausch zwischen Fluidelementen unterschiedlicher Geschwindigkeit.

En: molecular momentum exchange between fluid particles of different velocity.

b Consider a gas inside a closed container. Explain the connection between the temperature of the gas and the pressure one can measure at the container walls

De: thermodynamischer Zusammenhang: Zustandsgleichung $p = \rho RT$.

auf molekularer Ebene verursacht die thermische Bewegung der Gasmoleküle Kollisionen mit den Wänden ➔ Druck.

En: thermodynamic correlation: $p = \rho RT$

On molecular level the thermal movement of the particles causes collisions with the walls ➔ pressure.

c Describe the statement of the conservation of momentum considering a fixed volume

De: zeitliche Änderung des Impulses innerhalb eines Kontrollvolumes ist gleich der Resultierenden der auf dieses wirkenden Kräfte.

En: transient variation of momentum within a control volume equals the resultant forces on the control volume.

d Write down the formula of the Bernoulli equation assuming a horizontal flow

$p + \frac{\rho}{2} \cdot U^2 = const.$

e Write down the formula of the Reynolds number

$$Ren = \frac{U \cdot L}{\nu}$$

f What is the meaning of the critical Reynolds number?

De: Umschlag von laminarer zu turbulenter Strömung.

En: Transition of laminar to turbulent flow.

g How is a Couette-Poiseuille flow driven (what acts against the friction)?

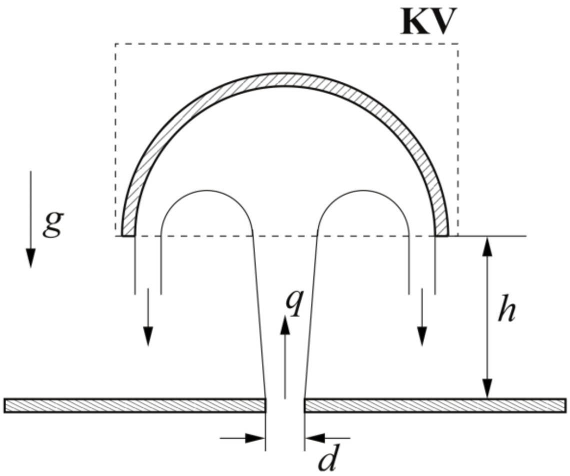
De: Die Couette-Poiseuille-Strömung ist eine Strömung in einem ebenen Kanal, die von einer bewegten Wand und einem Druckgradienten angetrieben wird.

En: The Couette-Poiseuille flow is a flow within an even channel, driven by both a moving wall and a pressure gradient.

2 Calculation tasks

a Free jet

A circular fee jet leaks from a container with the diameter d, the density ρ and the velocity q. In a height h above the container opening the free jet hits axially a hollow hemisphere with the mass m which therefore is hovering ($h = const.$). The flow is stationary, frictionless and ρ is constant.



Given:

$q = 7.0\, m/s$, $\rho = 1000\, kg/m^3$, $d = 0.1m$, $h = 1.0m$, $g = 9.81\, m/s^2$

Note:

The mass of the fluid inside the control volume KV can be neglected, the mass of the free jet outside the control volume cannot be neglected. The cross-section of the redirected flow shows the shape of an annulus. The flow velocities through the container opening and over the boundaries of the control volume are each constant.

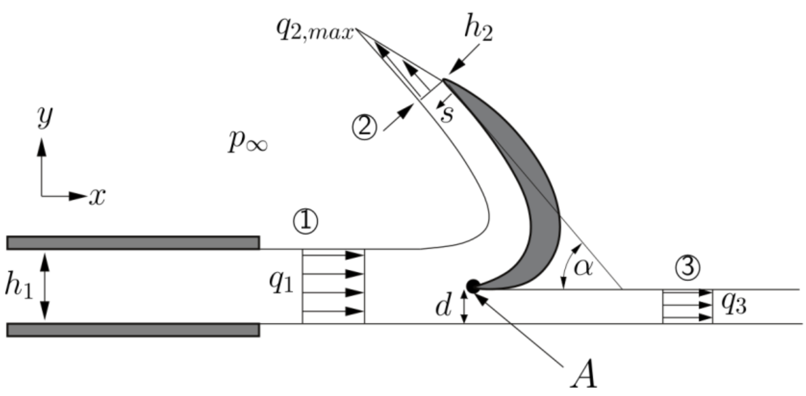
To calculate:

Give a general solution for the mass of the hemisphere dependent on ρ , q, d, h and g. Additionally, calculate the numerical value.

$m = 2\frac{\rho}{g}\sqrt{q^2 - 2gh} \cdot q\frac{\pi}{4}d^2 = 60.754\, kg$

b Thrust reverser

A test bench for aircraft thrust reversers is designed as sketched below. An air jet of constant density rho exhausts as a free jet from a rectangle nozzle of height h_1 and width b with the constant velocity q_1 at the location (1). A guide vane can be translated along the y-direction which separates a portion of the free jet with the height h_2 and width$b$and redirects it (angle α). At the location (2), its velocity profile can be assumed as linear with the values $q_2 = 0$ at the vane wall$s = 0$ and $q_{2,max}$ at the jet surface$s = h_2$. The jet portion (3) has a variable height d at the Point **A** with $0 \leq qd \leq h_1$ and the width b. The velocity of the free jet q_3 is constant over the cross-section at the location (3). The flow is stationary and the influence of the gravity can be neglected. The flow from (1) to (3) can be assumed as without losses.



Given:

$\rho, q_1, h_1, b, \alpha, q_{2,max}, p_\infty$

To calculate:

1) Define the flow velocity q_3 at the location(3).
2) Define the equation of $q_2(s)$ at the location (2) as a function of$s$and in dependency of the unknown h_2.
3) Define the height h_2 at the location (2) in dependency of d.
4) The guide vane is set to a specific position d. Doing so, h_2 and $q_2(s)$ are set as well. Define the vertical and the horizontal component of the force F, necessary to hold the vane in place. Consider h_2 and d as known.

1) $q_3 = q_1$
2) $q_2 = \frac{q_{2,max}}{h_2} s$
3) $h_2 = \frac{2q_1(h_1 - d)}{q_{2,max}}$
4) $F_y = \rho\, b\, \sin\alpha \frac{1}{3}\, q_{2,max}^2\, h_2$