Problem 1 (9 Points)

A ship loaded by a container is in a closed lock (condition „1“). Subsequently, the container drops into the water. At condition „2“ the container „C“ (volume $V_C$, density $\rho_C$) is on the ground of the lock, i.e., there is no container on the ship.

\begin{align*}
\Delta H &= \ \text{change of the height of the water surface} \\
\text{Given:} & \quad A, \ \rho_w, \ \rho_C \quad \text{with} \ \rho_C > \rho_w, \ \ V_C \\
\text{Parts b) and c) can be solved independently from a).} \\
\end{align*}

In the following, the ship has left the lock and the water has been pumped down completely (condition „3“). A blimp with a rigid surface (volume $V_Z$, structure mass $m_Z$, gas mass $m_G$) is to be used to transport the container.

b) What altitude does the blimp carrying container reach in an isothermal ($T_0 = \text{const.}$) atmosphere?

Due to a crack in the surface of the blimp a perfect pressure balance with the atmosphere occurs.

c) How does the altitude change qualitatively (increase, decrease, remain constant) assuming the interior pressure of the blimp before the surface cracked to be smaller than $p_i < p(z_{\text{max}})$. Give reasons for your answer.

Given for b) and c):
\begin{align*}
g, \quad V_Z, \quad V_C << V_Z, \quad m_G, \quad m_Z, \quad m_C, \quad p_a, \quad T_0, \quad R_L \\
\end{align*}

Hint:
- Check the measurement units and signs of your results!
Problem 1

a) Force balance between the weight of the container and a virtual lifting body:

\[ F_{A,AK} = G_C \]

\[ \rho_W g A \Delta H_{AK} = \rho_C g V_C \]

\[ \Rightarrow \Delta H_{AK} = \frac{\rho_C V_C}{\rho_W A} \]

Without container there is less displacement of the ship, i.e., the water level \( \Delta H_{AK} \) sinks. At condition "2" water is displaced by the volume of the container, which leads to a reduced decrease of the water level \( \Delta H_C \).

\[ \Delta H = \Delta H_C - \Delta H_{AK} = \frac{V_C}{A} - \frac{\rho_C V_C}{\rho_W A} \]

\[ \Rightarrow \Delta H = \frac{V_C}{A} \left( 1 - \frac{\rho_C}{\rho_W} \right) < 0 \]

Since \( \rho_C > \rho_W \), the water level is lower for the ship without container.

b) max. height:

\[ \sum F = 0 \]

\[ F_A - F_G - F_Z - F_C = 0 \]

\[ \rho_L g V_Z = (m_G + m_Z + m_C)g \]

\[ \Rightarrow \rho_L = \frac{m_G + m_Z + m_C}{V_Z} \]

scale height relation (general): \( \rho_L(z) = \rho_0 e^{-\frac{gz}{R_L T_0}} \)

\[ \rho_0 e^{-\frac{gz_{max}}{R_L T_0}} = \frac{m_G + m_Z + m_C}{V_Z} \]

\[ \Rightarrow -\frac{g z_{max}}{R_L T_0} = \ln \left( \frac{m_G + m_Z + m_C}{V_Z \rho_0} \right) \]

perfect gas law: \( p_a = \rho_0 R_L T_0 \)

\[ z_{max} = \frac{R_L T_0}{g} \ln \left( \frac{V_Z p_a}{R_L T_0 (m_G + m_Z + m_C)} \right) \left[ \frac{J}{kgK} \frac{s^2}{m^2} \right] \ln \left( m^3 \frac{kg}{m^3 \cdot kg} \right) = [m] \]

c) \( p_i < p(z_{max}) \rightarrow m_G \) increases \( \rightarrow z_{max} \) decreases
Problem 2  (9 Points)

Two water jets merge at an angle $\alpha + \beta$. A horizontal jet develops impinging upon a vertical plate. At the plate the jet is inviscidly deflected into two identical jets.

![Diagram of two water jets merging]

a) Determine the angle $\beta$.

In the following the angle $\beta$ is assumed to be given.

b) Determine the cross section $A_3$ and the velocity $v_3$.

In the following, the cross section $A_3$ and the velocity $v_3$ are assumed to be given.

c) Determine the mass flux $\dot{m}$ of one of the deflected jets.

d) Determine the anchoring force $F$.

Given:

$A_1$, $A_2$, $v_1$, $v_2$, $\alpha$, $\rho$

Hint:

- Check the measurement units and signs of your results!
Problem 2

a) momentum equation in the y-direction:
\[ \rho v_1^2 \sin \beta A_1 - \rho v_2^2 \sin \beta A_2 = 0 \]
\[ \sin \beta = \frac{A_2 v_2^2}{A_1 v_1^2} \sin \alpha \]
\[ \beta = \arcsin \left[ \frac{A_2 (v_2/v_1)^2 \sin \alpha}{A_1} \right] \]

b) momentum equation in the x-direction:
\[ -\rho v_1^2 A_1 \cos \beta - \rho v_2^2 A_2 \cos \alpha + \rho v_3^2 A_3 = 0 \]
\[ \Rightarrow A_3 v_3^2 = A_1 v_1^2 \cos \beta + A_2 v_2^2 \cos \alpha \quad (1) \]
Continuity eqn.:
\[ v_1 A_1 + v_2 A_2 = v_3 A_3 \quad (2) \]
(2) in (1):
\[ \Rightarrow v_3 = \frac{A_1 v_1^2 \cos \beta + A_2 v_2^2 \cos \alpha}{v_1 A_1 + v_2 A_2} \]
\[ \Rightarrow A_3 = \frac{(v_1 A_1 + v_2 A_2)^2}{A_1 v_1^2 \cos \beta + A_2 v_2^2 \cos \alpha} \]

c) massflux \( \dot{m} = \rho A_4 v_4 \)
Continuity eqn.: \( A_4 = \frac{1}{2} A_3 \) from symmetry
Bernoulli: \( v_4 = v_3 \)
\[ \Rightarrow \dot{m} = \frac{1}{2} \rho A_3 v_3 \]

d) Momentum in x-direction: \( \frac{dF}{dt} = \rho v_3^2 A_3 = \sum F_x \)
\[ \Rightarrow F = \rho v_3^2 A_3 \]
Problem 3 (12 Points)

The flow of a Bingham fluid (density $\rho$, viscosity $\eta$) between two parallel infinite plates (distance $2b$) is considered. The flow is fully developed and there is no pressure gradient in the $x$-direction $dp/dx = 0$.

a) Sketch the balance of the forces per unit area for an element and determine the differential equation of the velocity distribution in the region $a \leq y \leq b$.

b) State the corresponding boundary conditions.

c) Determine the distance $a$.

In the following, the distance $a$ is assumed to be given.

d) Determine the velocity distribution $u(y)$ in the region $0 \leq y \leq b$.

e) Sketch the time-averaged velocity profile in a laminar and a turbulent pipe flow. If there is any, explain the difference between the profiles and give the reasons for the variation of the distributions.

Given:

$b$, $\rho$, $\eta$, $\tau_0$, $g$, $dp/dx = 0$

Hint:

• Flow rule of a Bingham fluid:

$$|\tau| \geq \tau_0 : \tau = \begin{cases} -\eta\frac{du}{dy} + \tau_0 & \text{für } \frac{du}{dy} < 0 \\ -\eta\frac{du}{dy} - \tau_0 & \text{für } \frac{du}{dy} > 0 \end{cases}$$

Hint:

• Check the measurement units and signs of your results!
Problem 3

a) force balance:

\[
\left( \tau - \left( \tau + \frac{d\tau}{dy} \right) \right) \ dx + \rho g \ dx \ dy = 0
\]

\[
\frac{d\tau}{dy} = \rho g \quad ; \quad \tau = -\eta \ \frac{du}{dy} + \tau_0
\]

\[
\frac{d^2 u}{dy^2} = -\frac{\rho g}{\eta} \left[ \frac{m}{s \ m^2} \right] = \left[ \frac{kg \ ms}{m^3 \ s^2 \ kg} \right] = \left[ \frac{1}{ms} \right]
\]

b) 1. \( u(y = b) = 0 \)
   2. \( \tau(y = a) = \tau_0 \) i.e., \( \frac{du}{dy}|_{y=a} = 0 \)

c) For the solid inner part \( (y \leq a) \) the uniform movement needs an equilibrium between the weight (per length \( dx \) and width) and the shear stresses at the outer boundaries:

\[
\tau_0 = \rho g a \quad \Rightarrow \quad a = \frac{\tau_0}{\rho g} \left[ \frac{kg \ m^3 \ s^2}{s^2 \ m^2 \ kg \ m} \right] = [m]
\]

d) \( y \geq a \):

\[
\frac{du}{dy} = -\frac{\rho g}{\eta} y + C_1
\]

\[
u = -\frac{\rho g}{2\eta} y^2 + C_1 y + C_2
\]

introduce B.C. \( \Rightarrow C_1 = \frac{\rho g a}{\eta} \), \( C_2 = \frac{\rho g b^2}{2\eta} - C_1 b \)

\[
a \leq y \leq b : \quad u(y) = \frac{\rho g}{2\eta} (b^2 - y^2) - \frac{\rho g a}{\eta} (b - y) = \frac{\rho g}{2\eta} [(b-a)^2 - (y-a)^2]
\]

\[
0 \leq y \leq a : \quad u = \frac{\rho g}{2\eta} (b^2 - a^2) - \frac{\rho g a}{\eta} (b - a) = \frac{\rho g}{2\eta} (b-a)^2
\]

Units of \( u(y) \) and \( u \) are:

\[
\left[ \frac{kg \ m \ ms}{m^3 \ s^2 \ kg \ m} \right] = \left[ \frac{m}{s} \right]
\]

e) Laminar (left) and time-averaged turbulent (right) velocity profile.

Unlike the laminar profile the turbulent is bulky or full, since the momentum exchange in the radial direction is larger.
Problem 4  (11 Points)

A light house (diameter $D$, height $H$) in a flow field at freestream velocity $u_\infty$ is considered. On the leeward side a Kármán vortex street develops. The shedding frequency of the vortices is denoted by $f$. To determine the wind force $F_W$ onto the tower windtunnel experiments will be performed.

a) Determine the dimensionless parameter(s) of the problem by Buckingham’s $\pi$ theorem and express the resulting parameters by conventional parameters of fluid mechanics.

Given for a): All necessary reference values

The experiments shall be performed in a so-called cryo tunnel at low temperature conditions ($p_{\text{model}} = p_0$, $T_{\text{model}} < T_{\text{real}}$) using a model scale 1:10. The fluid in the cryo tunnel is a perfect gas ($R_{\text{model}} = R_{\text{real}}$, $\gamma = 1.4$). The viscosity of air and of the test gas is given by:

$$\eta(T) = \eta_0 \left( \frac{T}{T_0} \right)^{0.72}, \quad \text{with} \quad \eta_0 = \eta_{0,\text{real}} = \eta_{0,\text{model}}$$

b) Determine the ratio of frequencies of the separating vortices $\frac{f_{\text{model}}}{f_{\text{real}}}$.

c) In the experiment compressibility effects in the model should be neglected. Determine the maximum wind velocity where this condition is valid.

Given for b) and c):

$$\frac{D_{\text{real}}}{D_{\text{model}}} = 10, \ T_0, \ T_{\text{model}}, \ R_{\text{real}}, \ \gamma$$

Hint for b):
Assume ambient conditions at the real light house ($T_{\text{real}} = T_0$, $p_{\text{real}} = p_0$). Hint:
- Check the measurement units and signs of your results!
Problem 4

a) system variables: η, ρ, H, D, F_W, f, u_∞ with

\[ \eta = \left[ \frac{kg}{m \cdot s} \right], \quad \rho = \left[ \frac{kg}{m^3} \right], \quad H = [m], \quad D = [m], \]
\[ F_W = \left[ \frac{kg m}{s^2} \right], \quad f = \left[ \frac{1}{s} \right], \quad u_\infty = \left[ \frac{m}{s} \right], \]

⇒ 7 physical quantities, 3 basic dimensions → 4 dimensionless parameters
choose 3 recurring variables, e.g.: ρ, u_∞, D

\[ K_1 = \eta \cdot u_\infty^{\alpha_1} \cdot \rho^{\beta_1} \cdot D^{\gamma_1} \]
\[ kg : 1 + 0 + \beta_1 + 0 = 0 \Rightarrow \beta_1 = -1 \]
\[ m : -1 + \alpha_1 - 3\beta_1 + \gamma_1 = 0 \Rightarrow \gamma_1 = -1 \]
\[ s : -1 - \alpha_1 + 0 + 0 = 0 \Rightarrow \alpha_1 = -1 \]
\[ \Rightarrow K_1 = \frac{\eta}{\rho u_\infty D} = \frac{1}{Re} \]

\[ K_2 = F_W \cdot u_\infty^{\alpha_2} \cdot \rho^{\beta_2} \cdot D^{\gamma_2} \]
\[ kg : 1 + 0 + \beta_2 + 0 = 0 \Rightarrow \beta_2 = -1 \]
\[ m : 1 + \alpha_2 - 3\beta_2 + \gamma_2 = 0 \Rightarrow \gamma_2 = -2 \]
\[ s : -2 - \alpha_2 + 0 + 0 = 0 \Rightarrow \alpha_2 = -2 \]
\[ \Rightarrow K_2 = \frac{F_W}{\rho u_\infty^2 D^2} = \bar{c}_w \]

\[ K_3 = H \cdot u_\infty^{\alpha_3} \cdot \rho^{\beta_3} \cdot D^{\gamma_3} \]
\[ kg : 0 + 0 + \beta_3 + 0 = 0 \Rightarrow \beta_3 = 0 \]
\[ m : 1 + \alpha_3 + 0 + \gamma_1 = 0 \Rightarrow \gamma_3 = -1 \]
\[ s : 0 - \alpha_3 + 0 + 0 = 0 \Rightarrow \alpha_3 = 0 \]
\[ K_3 = \frac{H}{D} = \text{geometry parameter} \]

\[ K_4 = f \cdot u_\infty^{\alpha_4} \cdot \rho^{\beta_4} \cdot D^{\gamma_4} \]
\[ kg : 0 + 0 + \beta_4 + 0 = 0 \Rightarrow \beta_4 = 0 \]
\[ m : 0 + \alpha_4 - 3\beta_4 + \gamma_4 = 0 \Rightarrow \gamma_4 = 1 \]
\[ s : -1 - \alpha_4 + 0 + 0 = 0 \Rightarrow \alpha_4 = -1 \]
\[ \Rightarrow K_4 = \frac{f D}{u_\infty} = Sr \]

Alternatively: system variables: η, ρ, H, D, F_W, f, u_∞, T, R with additional

\[ T = [K], \quad R = \left[ \frac{m^2}{s^2 K} \right] \]
⇒ nine physical quantities, 4 basic dimensions \( \rightarrow 5 \) dimensionless parameters
choose 4 recurring variables, z.B.: \( \rho, u_\infty, D, T \)
The former 4 parameters are still valid since \( [K] \) only in \( T \) and \( R \). One additional parameter
\[
K_5 = R \cdot u_\infty^{\alpha_5} \cdot \rho^{\beta_5} \cdot D^{\gamma_5} \cdot T^{\delta_5}
\]
\( kg : 0 + 0 + \beta_5 + 0 + 0 = 0 \Rightarrow \beta_5 = 0 \)
\( m : 2 + \alpha_5 - 3\beta_5 + \gamma_5 + 0 = 0 \Rightarrow \gamma_5 = 0 \)
\( s : -2 - \alpha_5 + 0 + 0 + 0 = 0 \Rightarrow \alpha_5 = -2 \)
\( T : -1 + 0 + 0 + 0 + \delta_5 = 0 \Rightarrow \delta_5 = 1 \)
\[\Rightarrow K_5 = \frac{RT}{u_\infty^2} = \frac{\gamma RT}{\gamma u_\infty^2} = \frac{1}{\gamma M^2} \]

b) \( Re_{\text{real}} = Re_{\text{model}} \Rightarrow \frac{u_{\infty\text{model}}}{u_{\infty\text{real}}} = \frac{\eta_{\text{model}}}{\eta_{\text{real}}} \frac{\rho_{\text{real}}}{\rho_{\text{model}}} \frac{D_{\text{real}}}{D_{\text{model}}} = \left( \frac{T_{\text{model}}}{T_{\text{real}}} \right)^{1,72} \frac{D_{\text{real}}}{D_{\text{model}}} \]

with \( \frac{\eta_{\text{model}}}{\eta_{\text{real}}} = \left( \frac{T_{\text{model}}}{T_{\text{real}}} \right)^{0,72} \)
perfect gas \( \frac{P}{\rho} = RT \Rightarrow \frac{\rho_{\text{real}}}{\rho_{\text{model}}} = \frac{T_{\text{model}}}{T_{\text{real}}} \), since \( R_{\text{real}} = R_{\text{model}} \) and \( p_{\text{model}} = p_0 = p_{\text{real}} \).
\( Sr_{\text{real}} = Sr_{\text{model}} \Rightarrow \frac{f_{\text{model}}}{f_{\text{real}}} = \frac{D_{\text{real}}}{D_{\text{model}}} \frac{u_{\infty\text{model}}}{u_{\infty\text{real}}} = \left( \frac{D_{\text{real}}}{D_{\text{model}}} \right)^2 \left( \frac{T_{\text{model}}}{T_{\text{real}}} \right)^{1,72} = 100 \left( \frac{T_{\text{model}}}{T_0} \right)^{1,72} \)

c) Condition: \( M_{\text{model}} \leq 0.3 \)
\[\Rightarrow M_{\text{model}} = \frac{u_{\infty\text{model}}}{\sqrt{\gamma R_{\text{model}}} T_{\text{model}}} = \frac{u_{\infty\text{model}}}{u_{\infty\text{real}}} \frac{u_{\infty\text{real}}}{\sqrt{\gamma R_{\text{real}}} T_{\text{model}}} \]
\[= 10 \left( \frac{T_{\text{model}}}{T_0} \right)^{1,72} \frac{u_{\infty\text{real}}}{\sqrt{\gamma R_{\text{real}}} T_{\text{model}}} \leq 0.3 \]
\[\Rightarrow u_{\infty\text{real, max}} = 0.03 \left( \frac{T_0}{T_{\text{model}}} \right)^{1,72} \sqrt{\gamma R_{\text{real}}} T_{\text{model}} \]
Problem 5 (8 Points)

The plane flow field of two tornados of equally strength is to be investigated by the potential theory. The distance of the tornados is $k$.

a) Determine the complex potential function $F(z)$ using the elementary functions. State the sign of the constants.

b) Are any stagnation points in the flow field? Justify your answer without any computation.

c) Sketch the streamline pattern and mark prospective stagnation points and prospective streamlines absorbed in the stagnation points.

d) Determine the velocity component in the $x$-direction $u_{ind}$ induced by tornado 1 in the center of tornado 2 ($x = k, y = 0$). How will the distance of the tornados change as a function of time?

Given:

$k$, all necessary constants in the elementary functions

**elementary functions:**

parallel flow: $F(z) = (u_\infty - iv_\infty)z$

potential vortex: $F(z) = \frac{-i\Gamma}{2\pi}\ln z$

source/sink: $F(z) = \frac{E}{2\pi}\ln z$

stagnation point flow: $F(z) = az^2$

dipole: $F(z) = \frac{M}{2\pi z}$

**Hint:**

• Check the measurement units and signs of your results!
Problem 5

a) $F(z)$ consists of 2 potential vortices and 2 sinks:
\[
F(z) = -\frac{i\Gamma}{2\pi} \ln z - \frac{E}{2\pi} \ln z - \frac{i\Gamma}{2\pi} \ln(z - k) - \frac{E}{2\pi} \ln(z - k)
\]
$\Gamma > 0$, $E > 0$

b) 2 vortices of likewise strength and rotational direction. There must be a stagnation point on the centerline between the vortices at $x = \frac{k}{2}$ (symmetry).

c) Sketch: Stagnation streamlines are bold

\[\text{Diagram showing stagnation streamlines.}\]

d) contribution of vortex 1 to the flowfield:
\[
F_1(z) = -\frac{i\Gamma}{2\pi} \ln z - \frac{E}{2\pi} \ln z
\]
\[
\overline{w_1} = u_1 - iv_1 = \frac{dF_1}{dz} = -\frac{i\Gamma + E}{2\pi} \frac{x - iy}{x^2 + y^2}
\]
\[\Rightarrow\quad u_{ind,1 \rightarrow 2} = u_1(x = k, y = 0) = \frac{-E}{2\pi} \frac{x}{x^2 + y^2} \bigg|_{x=k,y=0} - \frac{\Gamma y}{2\pi(x^2 + y^2)} \bigg|_{x=k,y=0}
\]
\[= -\frac{E}{2\pi k} < 0\]

Tornado 1 induces a negative velocity in the $x$-direction at the center of tornado 2. Vice versa tornado 2 induces a positive velocity in the $x$-direction in the center of tornado 1. Therefore, the distance of the tornados will decrease in time.
A laminar incompressible boundary layer over a flat plate under zero angle of attack (width $B$) is considered. Via equidistantly distributed holes the volume flux $\dot{V}$ is sucked off at constant velocity over the length $L$. The velocity profile in $x$-direction in the boundary layer is approximated by the polynomial ansatz

$$\frac{u(y)}{u_a} = a_0 + a_1 \left( \frac{y}{\delta} \right) + a_2 \left( \frac{y}{\delta} \right)^2.$$ 

a) To determine the coefficients, state the 3 boundary conditions that uniquely describe the problem.

b) Determine the coefficients $a_0$, $a_1$, and $a_2$ of the velocity profile for this boundary layer flow.

c) The plate is used as a lower wall plate in a wind tunnel having a diverging cross section such that the boundary layer separates in point $x_{ab}$. Determine the velocity profile of the boundary layer at the separation point as a function of the given quantities.

d) Is it possible by to measure the stagnation pressure inside the boundary layer by a Pitot tube? Give reasons for your answer!

**Given:** $\dot{V}$, $B$, $L$, $\eta$, $\rho$, $u_a(x_{ab})$, $\delta(x_{ab})$

**Hint:**
- $x$-momentum equation of the boundary-layer equations for 2 dimensional steady state flow:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = - \frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\eta \partial^2 u}{\rho \partial y^2}$$

**Hint:**
- Check the measurement units and signs of your results!
Problem 6

a) Boundary conditions:

(i) \( y = 0 \Rightarrow u = 0 \) (no-slip)

(ii) \( y = \delta \Rightarrow u = u_a \) (boundary layer edge)

(iii) \( y = 0 \) : x-momentum at \( y = 0 \):

\[
v(y = 0) \left. \frac{\partial u}{\partial y} \right|_{y=0} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\eta}{\rho} \left. \frac{\partial^2 u}{\partial y^2} \right|_{y=0}
\]

with \( v(y = 0) = -\frac{\dot{V}}{LB} \) and \( \frac{\partial p}{\partial x} = 0 \) (flat plate without pressure gradient):

\[
-\frac{\dot{V}}{LB} \left. \frac{\partial u}{\partial y} \right|_{y=0} = \frac{\eta}{\rho} \left. \frac{\partial^2 u}{\partial y^2} \right|_{y=0}
\]

b) coefficients:

using (i): \( a_0 = 0 \)

using (ii): \( a_1 + a_2 = 1 \)

using (iii) and \( \left. \frac{\partial u}{\partial y} \right|_{y=0} = u_a \frac{a_1}{\delta} \) and \( \left. \frac{\partial^2 u}{\partial y^2} \right|_{y=0} = 2a_2 u_a \frac{a_1}{\delta^2} \):

\[
-\frac{\dot{V}}{LB} \frac{a_1 u_a}{\delta} = \frac{2\eta a_2 u_a}{\rho \delta^2} \Rightarrow a_2 = -\frac{\dot{V} \rho \delta}{2LB \eta} a_1
\]

\[
\Leftrightarrow 1 - a_1 = -\frac{\dot{V} \rho \delta}{2LB \eta} a_1 \Rightarrow a_1 = \frac{1}{1 - \frac{\dot{V} \rho \delta}{2LB \eta}}, \quad a_2 = 1 - a_1 = 1 - \frac{1}{1 - \frac{\dot{V} \rho \delta}{2LB \eta}}
\]

\[
\Rightarrow \frac{u}{u_a} = \frac{1}{1 - \frac{\dot{V} \rho \delta}{2LB \eta}} \left( \frac{y}{\delta} \right) + \left( 1 - \frac{1}{1 - \frac{\dot{V} \rho \delta}{2LB \eta}} \right) \left( \frac{y}{\delta} \right)^2
\]

c) Profile at the separation point \( x_{ab} \) for the given profile:

BCs (i) and (ii) are still valid \( \Rightarrow a_0 = 0, \quad a_1 + a_2 = 1 \)

BC (iii) is now the separation condition: \( \tau(y = 0) = 0 \Leftrightarrow \left. \frac{\partial u}{\partial y} \right|_{y=0} = 0 \)

\( \Rightarrow a_1 = 0 \) therefore: \( a_2 = 1 - a_1 = 1 \)

Velocity profile: \( u = u_a(x_{ab}) \left( \frac{y}{\delta(x_{ab})} \right)^2 \)

d) No. The Pitot tube must be outside the boundary layer to measure the stagnation pressure since due to friction the stagnation pressure varies. That is, although the static pressure is constant normal to the wall the stagnation pressure decreases due to the decreased velocity.