Homework 5

Homework due Mar 19, 2021 23:14 CDT Past due

Due Date

Friday, 3/19 at 11:59 PM ET *(3/20 at 03:59 UTC)*

Directions:

1. Answer each of the homework problems listed below.
2. Click the **Click here to open Gradescope button** below to access Gradescope.
3. Follow the prompts to submit your PDF to the assignment **HW 5**.

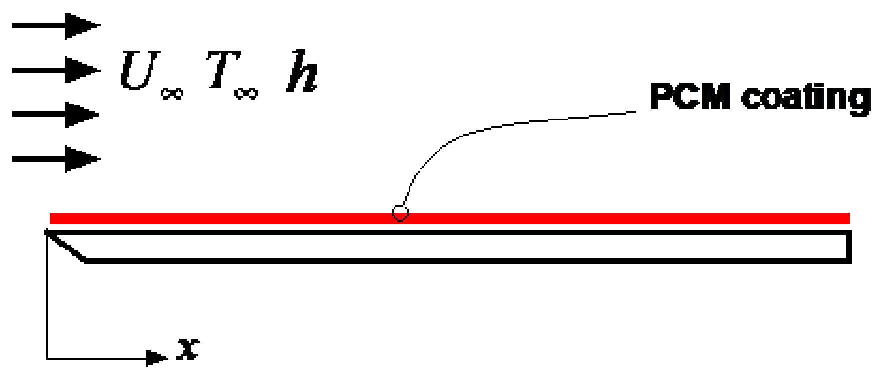
   Refer to the *Submitting Assignments With Gradescope* section of this course if you need a reminder of how to submit your assignment in Gradescope.

Homework Information and Guidelines:

1. Each student must turn in their own homework assignment and complete their own calculations, coding, etc. independently.
   - However, we encourage you to use most available resources including other textbooks, information from similar courses online, discussions with class and lab mates, office hours, etc. with the exception of using old solutions to the exact problems to complete the assignment.
   - Cite all your sources including discussions with colleagues and online websites. For example, if you and a friend compare answers or work together on a problem indicate this at the end of the problem. As an example, you might have a list like this at the end of each problem: "Resources used: [1] Fourier, J.B.J., *La Theorie Analytique de la Chaleur*, F. Didot, 1822. [2] Discussion with Joseph Fourier. [3] Wikipedia: Heat Flux, https://en.wikipedia.org/wiki/Heat_flux."
   - If we find papers with identical answers and approaches that do not indicate collaboration in the resource list, this is a violation of the academic honesty policy. Similarly, if your solutions match resources available online, this is a violation of the academic honesty policy.
2. Homework will be collected via Gradescope and is due at 11:59 PM ET. A grace period of 15 minutes is allowed in case of issues during the upload. Beyond that no late homework is accepted.
3. You may submit handwritten solutions or type up your solutions. We encourage you to use computer programs of your choice to solve problems, and some problems will require computational solutions. Recall "sketch" indicates you can draw something by hand, while "plot" indicates you should quantitatively calculate the curves and will likely use a computer program to create the graph. If "sketching" a curve, make sure trends, boundary conditions, etc. are clear.

Problem 1

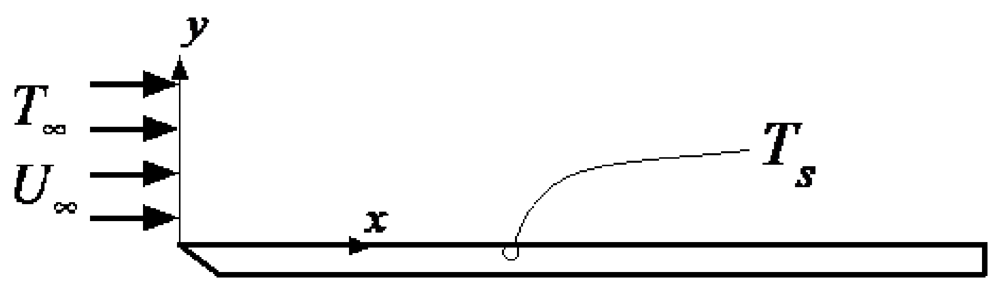
Consider a wing of a space shuttle re-entering earth atmosphere. Due to substantial viscous heating during the re-entry, the wing needs to be protected from over-heating. In order to reduce the heat transfer rate to the wing, a thin layer of phase change material (PCM) is coated on the wing. The PCM sublimates (i.e., change phase from solid to gas at a temperature T_s) with latent heat of L_s and provides cooling effect. This situation can be approximated to a flat plate (length = *l* and width = *w*) with PCM coating, which is exposed to a hot air flow at temperature T_∞, velocity U_∞, and convective heat transfer coefficient, h, as shown below. The thickness of the coating, δ, is very slowly decreasing while the PCM is sublimating, and you can assume the heat transfer coefficient is constant and uniform. Determine the total heat transfer rate applied to the plate according to the following steps.



- a) Draw your control volume (or surface) and clearly define relevant heat transfer rates around it. Also, list any assumptions made.
- b) Apply energy balance to formulate an equation to determine the heat transfer rate applied to the plate.

Problem 2

Consider a flow of extremely low Prandtl number fluid over an isothermal plate as shown below. Thermal properties of the fluid including kinematic viscosity ν, density ρ, specific heat C_p, and thermal conductivity k are given. Using the integral approach, find the local Nusselt number according to the following steps.



- a) Determine the temperature profile as a second order polynomial function of y and thermal boundary layer thickness δ. Clearly list the boundary conditions for the temperature to determine the coefficients.
- b) Using the temperature profile from Part (a) with the integral energy equation, determine the thermal boundary thickness as a function of x and other given parameters. If you make any assumption, clearly state here.
- c) Determine local Nusselt number as a function of Reynolds number and Prandtl number.

Problem 3

Consider a steady constant property turbulent flow over a flat plate. The flow has been tripped so that the boundary layer was fully turbulent from the leading edge of the plate. In this boundary layer, the velocity and temperature profiles can be approximated as follows:

$$\frac{u}{u_\infty} = \left(\frac{y}{\delta}\right)^{1/7} \quad \frac{T-T_\infty}{T_s-T_\infty} = 1 - \left(\frac{y}{\delta_t}\right)^{1/7}$$

An experimental measurement of the shear stress is found that wall shear stress is related to the momentum boundary layer thickness as:

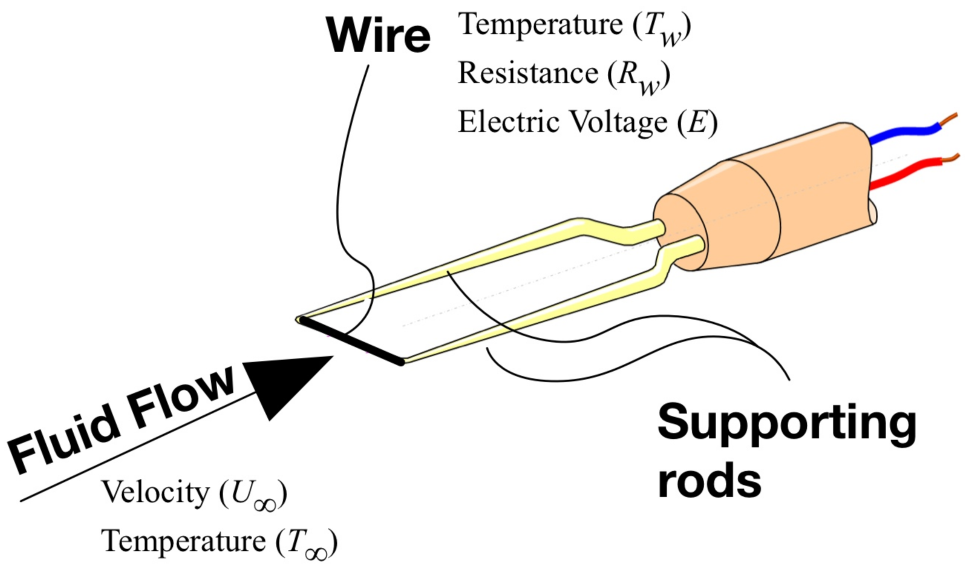
$$\tau_s = 0.0228\rho u_\infty^2 \left(\frac{u_\infty \delta}{\nu}\right)^{-1/4}$$

- a) Using the integral approach, determine the momentum boundary layer thickness as a function of x.

- b) Using the energy integral equation, find the local and average Nusselt number.

Problem 4

Consider a hot-wire anemometer as shown below. The anemometer is to measure the velocity of fluid flow by analyzing heat transfer around a wire whose diameter is *D*, length is *L* and temperature is maintained at a constant temperature T_w. During operation, electric voltage (*E*) is applied to the wire, whose resistance is R_w, so that the heat is generated and dissipated to the fluid whose kinematic viscosity and thermal conductivity are ν and k_f respectively. A feedback control circuit is employed to adjust the electric voltage to maintain the wire temperature at a given operating temperature. Design conditions pertain to an airstream at T_∞ = 20°C and 1 ≤ U_∞ ≤ 50 m/s with a wire temperature of T_w = 100 °C. Answer the following questions.



- a) Formulate the relation between the electric voltage (*E*) and the flow velocity (U_∞) by performing energy balance analysis around the wire using given symbols and relevant empirical correlations in the Equation sheet. You may neglect the conduction heat loss through the supporting rods.
- b) If the conduction loss through the supporting rod becomes not negligible and reaches 10% of the heat generated along the wire, explain whether the value of measured velocity over-predict or under-predict the true flow velocity (U_∞). Your explanation should be based on the energy balance analysis around the wire.

Gradescope (External resource) (100.0 points possible)

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Piazza

Post your questions/comments about Homework 5 to the *HW5* discussion forum in Piazza below (optional).

Piazza (External resource)

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