EXTERNAL FLOW TEST PROBLEMS

Introduction
The non-proprietary tests used to validate INSTED® analysis of external flow are presented in this section. The tests for Tube Banks are presented in a different section. You may need to consult the original sources of the various test problems in order to assess the accuracy of INSTED® predictions in more detail. These sources are given, as are a few notes to aid you in your comparison exercise. Some diagnostic results reported in the sources are presented here and compared with INSTED® predictions. You will be expected to have simulated some of these test problems before you attempt to solve more realistic engineering problems.

Test Problem 1: Flat Plate

- **Problem Statement:**

Water flows with a freestream velocity of U = 1.5 m/s and a freestream temperature of T_f = 80°C past a flat surface of total length L = 10 cm and maintained at a temperature T_s = 40°C. Using the results obtained from the solution of the differential formulation for the boundary layer

(a) Find the thickness of the velocity boundary layer and the thermal boundary layer at a location x = 5 cm from the leading edge.
(b) Find, per unit meter of depth in to the paper, the total drag force and heat flow on one side of the surface. Use the properties of water evaluated at the mean of the surface and freestream temperatures.

- **Source:**

Alan J. Chapman. 1987. Fundamentals of Heat Transfer. Macmillan Publishing Co. New York. Page 268.

- **Comments**

- Use online unit conversion to convert units from °C to K.
- Use thermophysical property values given in the source (ρ = 98.3 kg/m^3, μ = 0.466776 X 10^{-3} Ns/m^2, k = 0.6507 W/m K, Pr = 3.0)
- Diagnostic results from source are compared below with INSTED predictions. Below, δ, δ_t, and Re are the boundary layer thickness (hydrodynamic and thermal) and the Reynolds number, and F_D, Nu, q', and h are the average drag force per unit depth, Nusselt numer, heat transfer rate per unit depth, and the heat transfer coefficient.

- **Comparison for L = 5 cm**

Variable	Chapman	INSTED®	Difference
Re	1.58 x 10^5	2.58 x 10^5	< 1%
δ (cm)	0.0629	0.0629	< 1%
δ_t (cm)	0.0436	0.0436 cm	< 1%

- **Comparison for L = 10 cm**

Variable	Chapman	INSTED®	Difference
Re	3.159 x 10^5	3.159 x 10^5	< 1%
Nu	538	538	< 1%
F_D (N/m)	0.26	0.261	< 1%
h (W/m^{2}K)	3500	3503	< 1%
q' (W/m)	1.4 x 10^4	-1.4 x 10^4	< 1%

- Name of data file: CHAPMAN.268

Test Problem 2: Cylinder in Cross Flow

➢ **Problem Statement:**

Atmospheric-pressure air flows with a freestream velocity and temperature of $U_\infty = 10$ m/s, $T_\infty = 25^oC$ normal to a circular cylinder of diameter $D = 1.25$ cm, and maintained with a surface temperature of T_s = 125^{o}C.

(a) Estimate the average surface heat transfer coefficient h using Zhkauskas correlation.
(b) Repeat the calculation using Churchill and Berstein's formula and compare the results.

➢ **Source:**

Alan J. Chapman. 1987. Fundamentals of Heat Transfer. Macmillan Publishing Co. New York. Page 268.

➢ **Comments**

- Use online unit conversion to convert units from ^{o}C to K.
- Flow over a circular cylinder is considered.
- Use thermophysical property values given in the source. Absolute viscosity is taken from Thaerocomp's database. (ρ = 1.00116 kg/m^3, μ = 0.207327 X 10^{-4} Ns/m^2, k = 0.029057 W/m K, Pr =0.707)
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- Diagnostic results from source are compared below with INSTED® predictions. In the 'Difference' column, INSTED® results are compare with the results in Chapman that used the Churchill and Bernstein (C & B) formula.

Variable	**Chapman (Zhukauskas)**	**Chapman (C&B)**	**INSTED®**	**Difference**
Re	6124	6124	6036	1.5%
Nu	43	41	40.7	< 1%
h (W/m^{2}K)	102	97	96.2	< 1%

♦ Name of data file: CHAPMAN.348

Test Problem 6-10: Impingement Flows

➢ **Problem Statement:**

The next five test problems are provided for users to confirm that their versions of INSTED® is working as expected. The test problems are those that have been hand-checked for accuracy of INSTED®, vis-à-vis the model equations discretized in INSTED® for impingement flow analysis. The agreement between the exact solutions of the model equations and INSTED® predictions are exact to five significant rigures. With the input data, which are contained in the distribution disks, you should be able to reproduce the results. The five tests are respectively for:

(1) Single round nozzle
(2) Array of round nozzles - aligned
(3) Array of round nozzles - staggered
(4) Single slot nozzle
(5) Array of slot nozzles

➢ **Test Problem 6 - Single round nozzle**

Name of data file: IMPINGE1.000

- **Test Problem 7 - Array of round nozzles (aligned)**

The input data for test problem 7 are the same as those for test problems 6, with the understanding that item 6 in the menu now refers to the separation between nozzle centers.
Name of data file: IMPINGE2.000

- **Test Problem 8- Array of round nozzles (staggered)**

The input data for test problem 8 are the same as those for test problems 7, except that the separation between nozzle centers (item 6 in the input data menu) is 4.0 m.
Name of data file: IMPINGE3.000

- **Test Problem 9 - Single slot nozzle**

Name of data file: IMPINGE4.000

- **Test Problem 10 - Array of slot nozzles**

Name of data file: IMPINGE5.000