UNIVERSITY OF MICHIGAN-DEARBORN™
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE

Thermal-Fluids Laboratory

- Lab information
- Syllabus
- Lab manual
- Lab Writeup
- Experimentation
- Uncertainties

Lab Information

- Objectives
  - Study principles through experimentation
  - Develop laboratory procedure/safety/skills
  - Apply principles to new problems

- Prerequisites
  - COMP 270 Technical Writing for Engineers
  - ME 325 Thermal Fluid Sciences I
  - ME 349 Instrument and Measurement Systems

Lab Information

- Concurrent or previous enrollment
  - ME 375 Thermal Fluid Sciences II
- Organization
- Text – Lab Manual
- Grading
- Laboratory Reports
- Exam
- Attendance
- Disability Services
- Code of Academic Conduct
- Email Communication

Lab Syllabus

- Six Thermal Fluid Experiments
- Group Projects
  - Assignments
  - Project Report
  - Oral Presentation
- Exam

Lab Manual

- General lab safety
- Instructions
- Lab report guidelines

General Lab Safety

- Know the location of the nearest first aid, fire equipment, phone.
- Emergency guidelines book is available in each laboratory room.
- For immediate emergency assistance dial 911 or 3-5333 and/or contact instructor.
- Sandals and shorts are prohibited in all labs.
- Consult lab manuals for specific instruction and safety rules pertaining to each experiment.
- Wear the appropriate safety equipment i.e., glasses, gloves, etc.
- Do not work on an experiment alone; in case of an accident, the presence of a lab partner next to you is essential.
- Do not attempt to run equipment you do not understand.
- Treat all equipment with care.
- Consult instructor when needed.
- Make sure that equipment is working properly before taking data.
- Follow instructions particular to each experiment.

Additional General Lab Safety

- Do not sit near experiment when running.
- Before running each experiment identify potential hazards.
- Do not work or write on other experimental surfaces. Use only the surrounding tables, or bring a clipboard.
- A pencil, your lab manual, and a calculator are all that is needed while running the experiment. All other belongings leave in 192 ELB at the desks.
- Do not approach the ME shop without instructor permission.
- Do not run any ME shop equipment without technician permission.

Lab Instructions

- The lab sessions will meet in Room 192/188, ELB.
- The students in each group will perform each lab. The class will be divided into several groups during the first lab session. Each student is advised to select lab partners (total of about four/five in each group).
- Each student will have a laboratory manual.
- All that is needed for the lab sessions is a pencil, your lab manual and calculator.

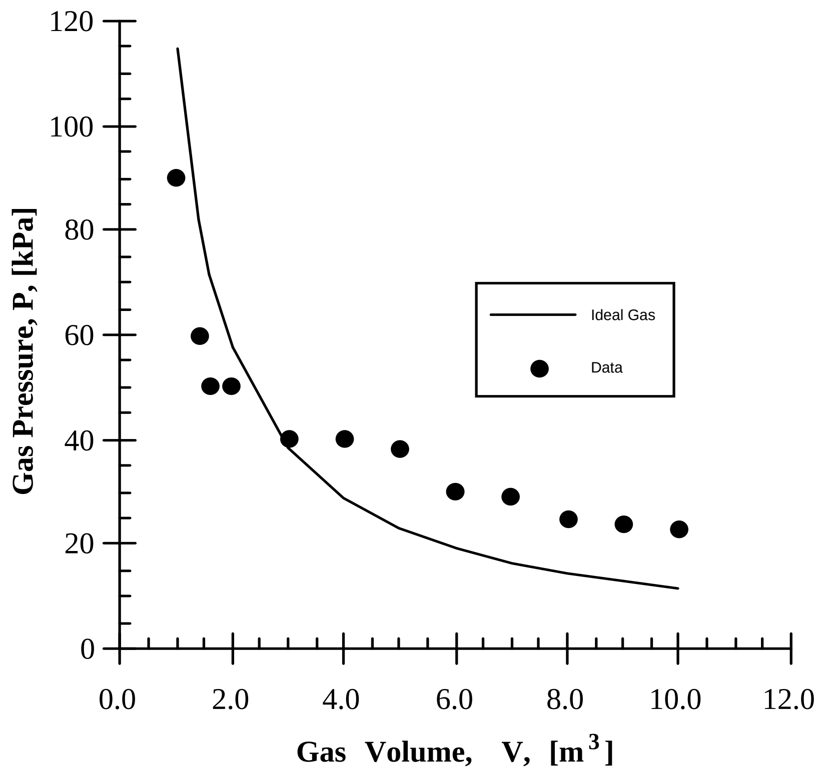
Lab Writeup Guidelines

- Lab Report
  - Each group will submit a formal lab report.
  - All members of a group are expected to contribute equally to the lab report.
  - The instructor will determine the due date.
  - It is necessary to type the lab write-up. Pencil or pen is not allowed in parts listed above. Report must be neat.
  - All reports must be on 8 1/2 x 11" size paper and stapled together in the upper left-hand corner.
  - All tables and graphs should be clearly labeled and appropriate units should be given. Graphs usually require a best-fit curve.
  - Must use 'Rules for Using Units.'
  - Must use 'Rules for Presenting Data.'

Note: Refer to text, "Writing Style and Standards in Undergraduate Reports, 2nd ed.," by S. Jeter and J. Donnell.

Lab Writeup Guidelines

- Example of Figure



Lab Writeup

- Cover page
  - title, name, class, date of experiment, date handed in, honor code, signature
- Abstract
  - Provide on an individual page, a brief summary of what was measured and the most important results and conclusions. This is written last.
- Objectives
  - Discuss exactly what you are trying to show and learn by performing the experiment.
  - Elaborate on how the accomplishments relate to class discussion.
  - This is very important to the reader because he will critically read this report in terms of meeting the prescribed objectives.
- Theory
  - Present any theoretical information that is needed to fulfill the objectives, include important derivations, assumptions, and equations.

Lab Writeup

- Experimental Apparatus
  - Describe the equipment utilized in the experiment.
  - Include a neat sketch of the apparatus with appropriate labels to aid the description.
- Experimental Procedure
  - Describe the procedure used to perform the experiment.
  - This should be general and not a step by step account.
- Discussions of Results
  - Introduce, present, and discuss computed results in a clear and concise form by using tables and graphs.
  - Compare and discuss theoretical expectations with the experimental results.
- Conclusion
  - Discuss how well the experiment accomplished the objectives.
- References
  - List sources by the authors in the order in which they appear in the report.

Lab Writeup

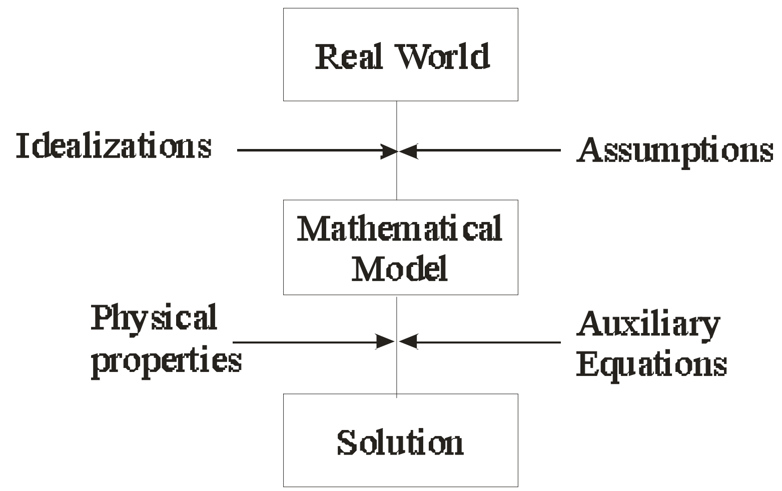
- Appendix
  - Use a cover sheet for the Appendix to separate it from the body of the report.
  - Append sample calculations used to develop the tables and graphs along with the raw data (Xerox copy) from the experiment, and computer programs.
  - Lab Worksheet

Lab Report Grading Policy

• General format of the report (Style, grammar, spelling, etc.)	20%
• Abstract	10%
• Objectives	5%
• Theory and experimental procedure	10%
• Results and discussion	20%
• Calculations	20%
• Conclusions	5%
• Uncertainty analysis	10%

Experimentation

- Demonstrate physical principles
- Define system behavior
  - complex geometry
  - boundary conditions, and/or
  - physical phenomenon
- Validate idealizations and assumptions



Experimentation

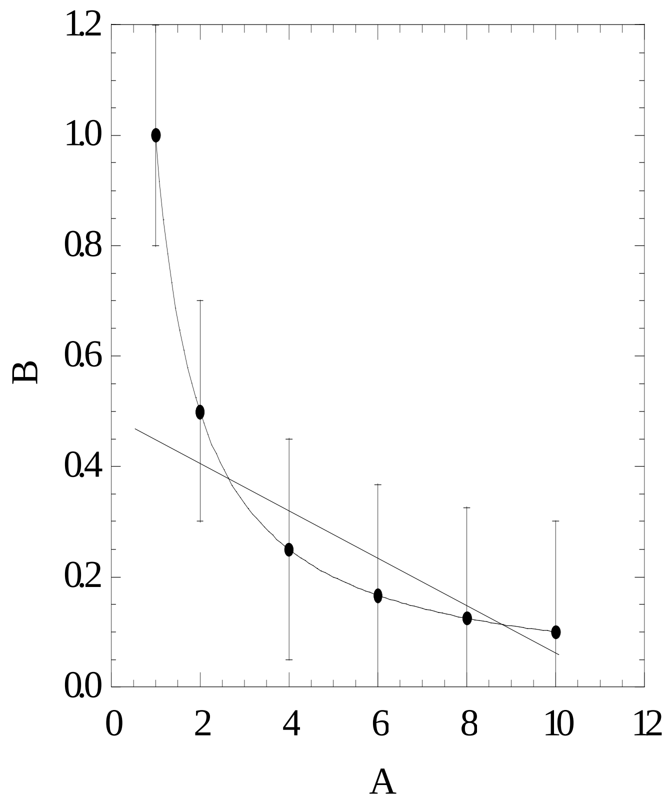
Phases of Experimental Program

- Planning
- Design
- Construction
- Debugging
- Execution
- Data Analysis
- Report Results

* Steps are not always sequential. It is an iterative process

Uncertainty

- How good are the data?
- Which model is better?
- Cannot evaluate until we know how "good" the data are.



Measurement Errors

Total Error = Bias error + Precision error

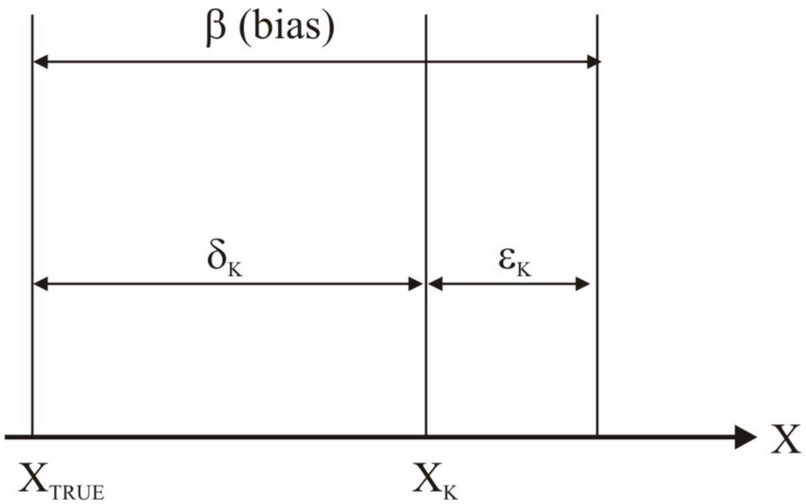
$$\delta = \beta + \varepsilon$$

Bias error - fixed, systematic, constant error which is the same value for all measurements

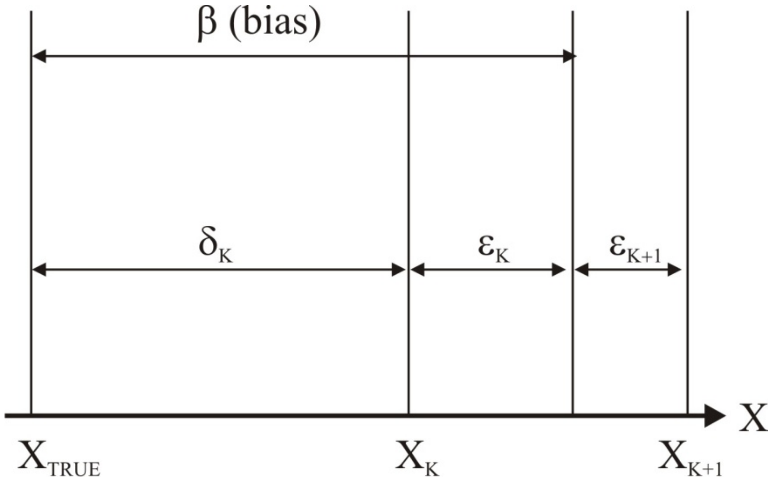
Precision error - random error and is a different value for each measurement.

Measurement Errors

For first measurement

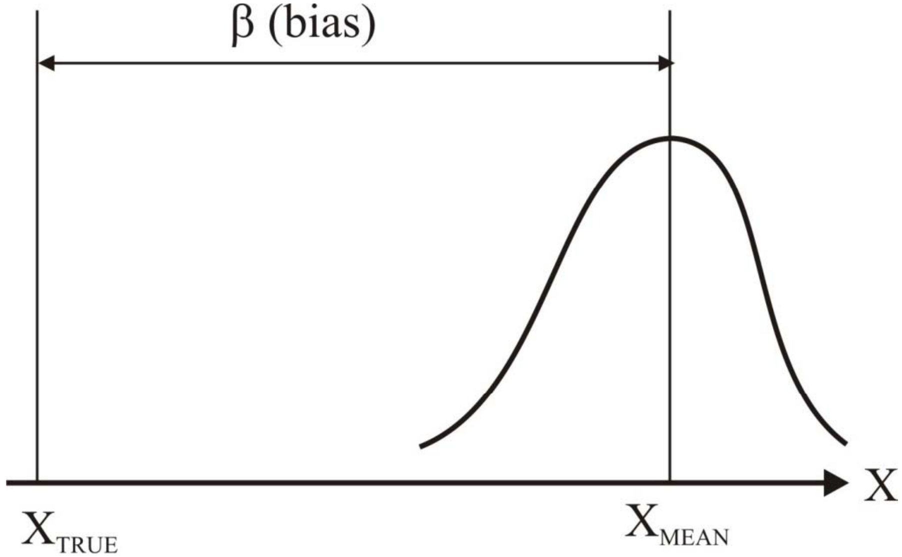


For second measurement



Measurement Errors

For infinite measurements



Measurement Errors

- Minimize bias errors by calibration.
- Eliminate precision errors by statistical methods.
- State ‘goodness’ of data within a range.
  - X±U
  - X is measured value
  - U is uncertainty

Measurement Errors

- First method of uncertainty propagation

$$U_r = \sqrt{\left(\frac{\partial r}{\partial X_1}U_1\right)^2 + \left(\frac{\partial r}{\partial X_2}U_2\right)^2 + \ldots + \left(\frac{\partial r}{\partial X_j}U_j\right)^2}$$

Note: Refer to text, "Writing Style and Standards in Undergraduate Reports, 2nd ed.," by S. Jeter and J. Donnell.

- Second method of uncertainty propagation
  - Addition/subtraction
    - sum the uncertainties
  - Multiplication/division
    - sum the % uncertainties

Uncertainty of Measurements

Given:

$$r = desired\ variable$$
$$X_1, X_2, X_3, \ldots X_j \text{ are variables to be measured directly} \tag{1}$$

The desired reduction equation is

$$r = \left(X_1, X_2, X_3, \ldots X_j\right) \tag{2}$$

Problem: Determine the uncertainty of *r* knowing uncertainty of measurements.

Solution:

Let

1. the data equation be simplified
   $$r = (x, y) \tag{3}$$
2. *r* be continuous and have continuous derivatives.
3. *N* be the number of data points
4. β_x and β_y be the bias errors
5. ε_{xi} and ε_{yi} be the precision errors
6. μ_x and μ_y be the mean values of *x* and *y*

Recall the Taylors series expansion. Its usefulness is to determine the value of a function in the neighborhood *f(a+h, b+k)* of a known value of the function *f(a,b)*.

$$f(a+h,b+k) = f(a,b) + \left(h\frac{\partial}{\partial x} + k\frac{\partial}{\partial y}\right) f(x,y)_{\substack{x=a \\ y=b}} + \ldots \qquad (4)$$

Apply it to biased result $r(\mu_x, \mu_y)$ expanding to the measured result $r_i(x_i,y_i)$.

$$r_i(x_i, y_i) = r_i(\mu_x, \mu_y) + \left[(x_i - \mu_x)\frac{\partial}{\partial x} + (y_i - \mu_y)\frac{\partial}{\partial y}\right] r_i(\mu_x, \mu_y)_{\substack{\mu x \\ \mu y}} + \ldots \qquad (5)$$

If ε is the difference between the measured value and the mean value, then Eq. 5 can be reduced to

$$\varepsilon_{ri} = \varepsilon_{xi}\left.\frac{\partial r}{\partial x}\right|_{\substack{\mu x \\ \mu y}} + \varepsilon_{yi}\left.\frac{\partial r}{\partial y}\right|_{\substack{\mu x \\ \mu y}} \qquad (6)$$

Square and sum the errors for all data points

$$\sum_{i=1}^{N}(\varepsilon_{ri})^2 = \sum_{i=1}^{N}\left[\varepsilon_{xi}\left.\frac{\partial r}{\partial x}\right|_{\substack{\mu x \\ \mu y}} + \varepsilon_{yi}\left.\frac{\partial r}{\partial y}\right|_{\substack{\mu x \\ \mu y}}\right]^2 \qquad (7)$$

Divide by N and take the limit of each term as N approaches infinity.

$$\lim_{N\to\infty}\frac{1}{N}\sum_{i=1}^{N}(\varepsilon_{\text{ri}})^2 = \lim_{N\to\infty}\frac{1}{N}\sum_{i=1}^{N}\left(\frac{\partial r}{\partial x}\right)^2(\varepsilon_{xi})^2 + \lim_{N\to\infty}\frac{1}{N}\sum_{i=1}^{N}2\left(\frac{\partial r}{\partial x}\right)(\varepsilon_{xi})\left(\frac{\partial r}{\partial y}\right)(\varepsilon_{yi}) + \lim_{N\to\infty}\frac{1}{N}\sum_{i=1}^{N}\left(\frac{\partial r}{\partial y}\right)^2(\varepsilon_{yi})^2 \qquad (8)$$

Using the definition of the standard deviation and noting that the covariance is zero, Eq. 8 reduces to

$$U_r = \sqrt{\left(\frac{\partial r}{\partial x}U_x\right)^2 + \left(\frac{\partial r}{\partial x}U_x\right)^2} \qquad (9)$$

where

$$U = \sqrt{\sigma^2} \qquad (10)$$

is the uncertainty. So in general

$$U_r = \sqrt{\left(\frac{\partial r}{\partial X_1}U_1\right)^2 + \left(\frac{\partial r}{\partial X_2}U_2\right)^2 + \ldots + \left(\frac{\partial r}{\partial X_j}U_j\right)^2} \qquad (11)$$

Another Method to Estimate Uncertainty

- Addition/Subtraction – Sum uncertainties

$$
\begin{array}{r}
5 \pm 0.1 \\
\underline{7 \pm 0.3} \\
12 \pm 0.4
\end{array}
$$

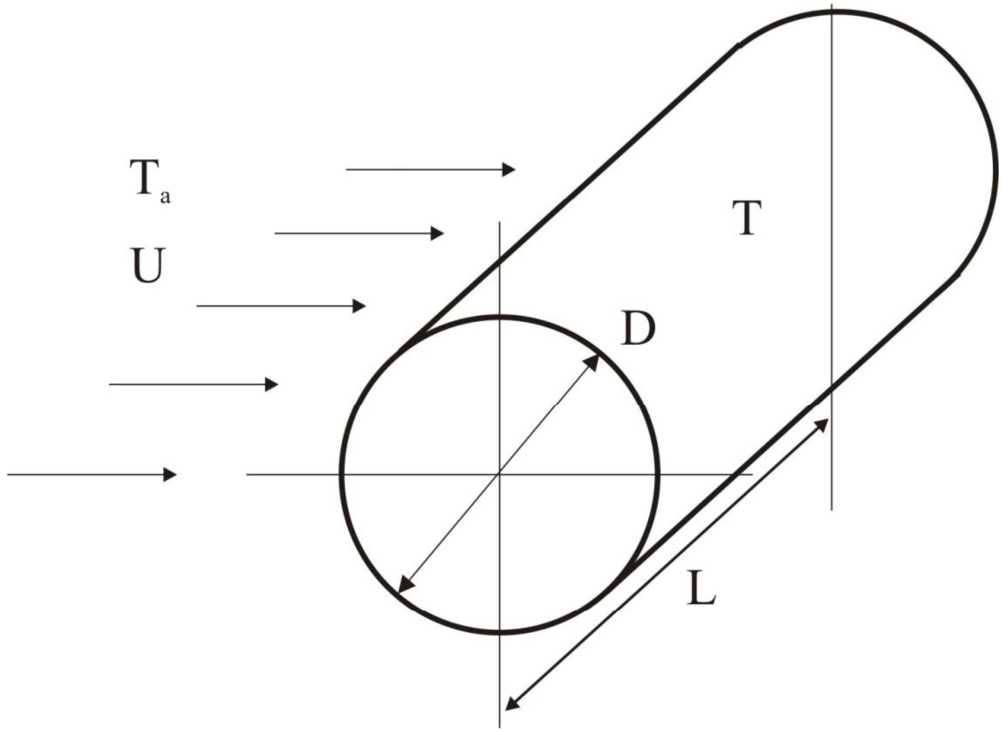
- Multiplication/Division – Sum percentage uncertainties

$$
\begin{aligned}
(5 \pm 0.1)(7 \pm 0.3) &= (5 \pm 2\%)(7 \pm 4.3\%) \\
&= 35 \pm 6.3\% \\
&= 35 \pm 2.2
\end{aligned}
$$

Example

Problem:

Determine relationship of convective heat transfer coefficient between air (1 < V < 100 m/s) and a circular cylinder of finite length.



$$T_a = 25\,C$$

$$T = T_a + 20\,C$$

Example

Proposed Experiment:

- Cylinder to be made of aluminum:

$$c_p = 0.903\ \text{kJ/kg-K}$$
$$L = 0.152\ \text{m}$$
$$D = 0.0254\ \text{m}$$
$$\text{wall thickness} = 1.27\ \text{mm}$$
$$\text{mass} = 0.02\ \text{kg}$$

- Insert resistance heater in cylinder to maintain tube at 45 C by supplying 24 W.

Example

Principle:

- Newton's Law of Cooling

$$\dot{W} = \dot{Q} = h(\pi DL)(T - T_a)$$

$$h = \frac{\dot{W}}{(\pi DL)(T - T_a)}$$

Example

Experimental Uncertainty:

- Given

$$\dot{W} = 24\text{ W} \ \pm 0.5\text{ W}\left(2\%\right)$$
$$D = 0.0254\text{ m} \ \pm 0.000025\text{ m}\left(0.098\%\right)$$
$$L = 0.152\text{ m} \ \pm 0.00025\text{ m}\left(0.16\%\right)$$
$$\Delta T = 20\text{ C} \ \pm 0.25\text{ C}\left(1.3\%\right)$$

- Uncertainty

$$U_h = \sqrt{\left(\frac{\partial h}{\partial \dot{W}} U_{\dot{W}}\right)^2 + \left(\frac{\partial h}{\partial D} U_D\right)^2 + \left(\frac{\partial h}{\partial L} U_L\right)^2 + \left(\frac{\partial h}{\partial \Delta T} U_{\Delta T}\right)^2}$$

Example

$$\frac{\partial h}{\partial \dot{W}} = \frac{1}{(\pi DL)(T - T_a)} \qquad \frac{\partial h}{\partial D} = \frac{-\dot{W}}{(\pi D^2 L)(T - T_a)}$$

$$\frac{\partial h}{\partial L} = \frac{-\dot{W}}{(\pi DL^2)(T - T_a)} \qquad \frac{\partial h}{\partial \Delta T} = \frac{-\dot{W}}{(\pi D^2 L)(T - T_a)^2}$$

$$U_h = \sqrt{\left(\frac{\dot{W}}{(\pi D^2 L)(T - T_a)}\right)^2} \sqrt{\left(\frac{U_{\dot{W}}}{\dot{W}}\right)^2 + \left(\frac{U_D}{D}\right)^2 + \left(\frac{U_L}{L}\right)^2 + \left(\frac{U_{\Delta T}}{\Delta T}\right)^2}$$

$$\frac{U_h}{h} = \sqrt{\left(\frac{U_{\dot{W}}}{\dot{W}}\right)^2 + \left(\frac{U_D}{D}\right)^2 + \left(\frac{U_L}{L}\right)^2 + \left(\frac{U_{\Delta T}}{\Delta T}\right)^2}$$

Example

Experimental Uncertainty:

$$\frac{U_h}{h} = \sqrt{(0.02)^2 + (0.00098)^2 + (0.0016)^2 + (0.013)^2}$$

$$= 0.024$$

$$h = 99 \ \pm \ 2.4 \ \text{W/m}^2\text{-C}$$

Example

Experimental Uncertainty (Another method):

$$h = \frac{24\,\text{W} \ \pm 2\%}{\pi[0.0254\,\text{m} \ \pm 0.098\%][0.152\,\text{m} \ \pm 0.16\%][20\,\text{C} \ \pm 1.3\%]}$$

$$= 99 \ \text{W/m}^2\text{-C} \ \pm \ 3.6\%$$

$$= 99 \ \text{W/m}^2\text{-C} \ \pm \ 3.5 \ \text{W/m}^2\text{-C}$$

Significant Digits

- It is important also to follow the rules of significant digits.
- Refer to ME 379 website for guidelines (Link: Lab Experiment Handouts).