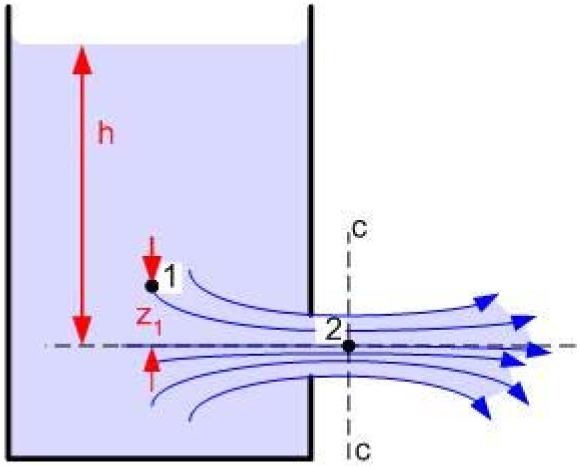
Laboratory Handbook

Mechanical Engineering Courses

School of EPS



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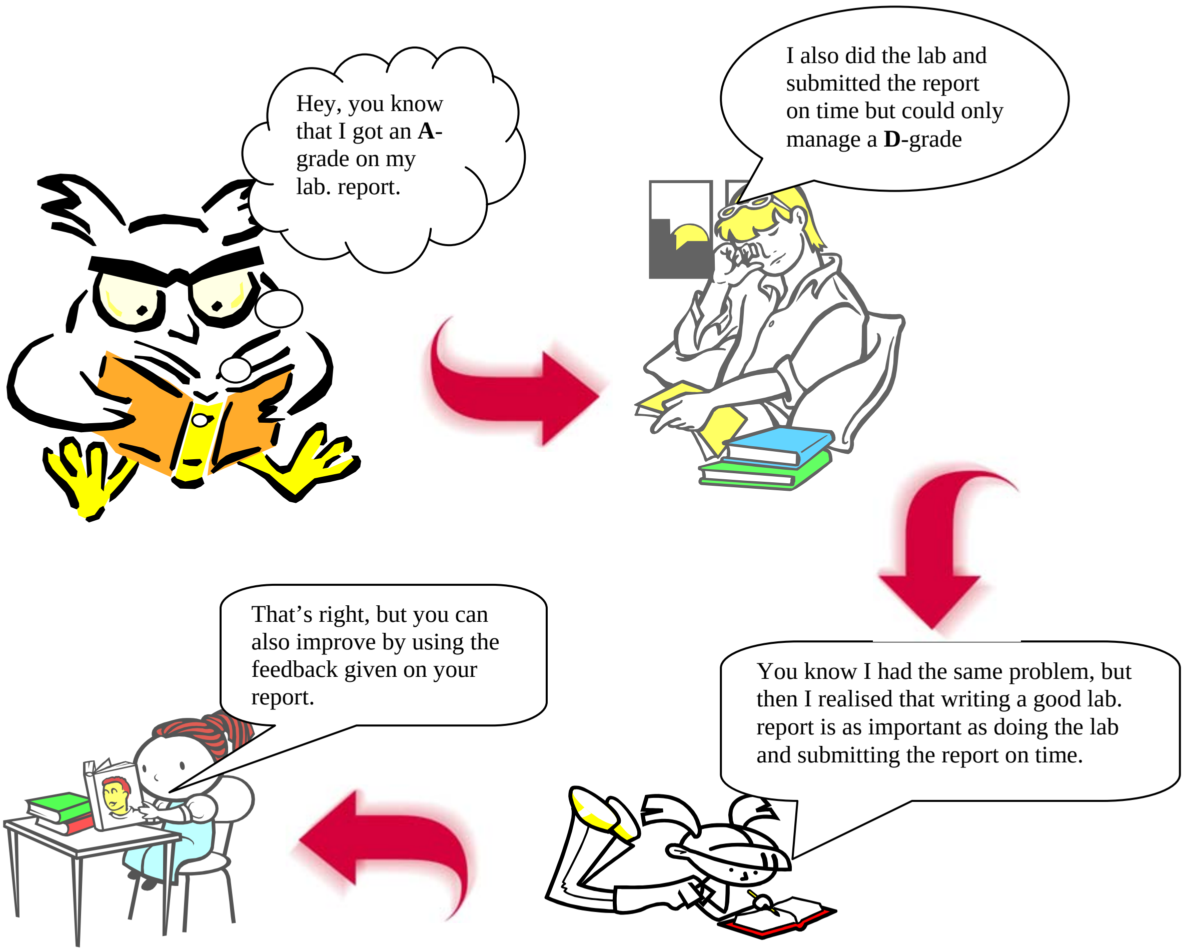

Hey, you know that I got an **A**-grade on my lab. report.
I also did the lab and submitted the report on time but could only manage a **D**-grade
You know I had the same problem, but then I realised that writing a good lab. report is as important as doing the lab and submitting the report on time.
That's right, but you can also improve by using the feedback given on your report.

Contents Page

1 Introduction

Professional engineers without good presentation skills, not only have problems convincing potential employers about their true potential, but also in coping with their job requirements. Technical report writing is an important presentation skill that enables engineers to communicate their assessment of the feasibility, design, performance and outcome of engineering processes to their peers and in some cases the general public. It is therefore critical that students currently studying for an engineering degree should develop these skills. Understanding and applying the skill of technical report writing is an essential part of the professional development process.

This handbook is aimed at these developing engineers to provide some insight to the process of writing good technical reports. It also indicates the management infrastructure which relates to the process of conducting and submitting laboratory work within the mechanical engineering discipline at Heriot-Watt University.

2 Essential Skills for Writing a Laboratory Report

You may have been writing reports and essays as part of the academic development and assessment at your school or college. Technical report writing is however different in many respects e.g. technical reports provide specific information in terms of the procedures, results, analysis and conclusions of an engineering process. The process of writing a good lab report is therefore as important as performing and analysing results. It is often observed that students after performing the experiment leave the writing of report to the last minute which does not give them the opportunity to go through the iterative process of improving the report.

Your report should provide a consistent chain of events to the point that someone with a basic knowledge of the subject area should be able to follow your thoughts. It is very likely that the person marking your report was not observing your specific experiment. It is therefore good practice to read your report from the perspective of your audience. Your report therefore should be written to clearly demonstrate the following requirements:

- What is it that you did in the laboratory?
- How did you do it e.g. equipment and procedure you followed? Was this a suitable equipment and procedure for the task at hand? Why or why not?
- How did you analyse your results and using which formulae? What are the strengths and limitations of your data for analysis and why was a certain formulae used?
- Did you present the results in a manner which gives a clear picture of the outcome of your experiment? Why did you choose to present the results in the form of a single or multiple graphs or tables or vice versa?
- What constituted the error?
- Did you justify your conclusions on the basis of your results and discussion?

The following presentation slides are designed to help you develop the essential skills of technical report writing and are based upon the experience of a number of academics and students to indicate the best practice. It is anticipated that as your style of technical report writing develops over the years; you will be able to apply this knowledge to write consultancy reports, research papers or communicate with general public through newspaper articles after accessing the requirements of your readers.

How to write a good laboratory report

(The principles here also apply to final year project, dissertations, etc…)

"The aim of your report writing style should be to present your work in the best possible manner"

This Presentation covers:

- Why laboratory work and why lab reports
- Before the start of the session
- During the session: what to do to make it efficient
- Right after the session
- How to write a lab report without jeopardising your study time
- Submitting you lab report
- Feedback

WHY BOTHER?

- Laboratory work is highly underestimated by undergraduate students: you think this is another 'tick in the box' to pass the module
- Lab work allows you to put into practice your "boring" lectures. It is entirely up to you to make the most of them!
- HWU Mech Eng degree accredited by IMechE = lab work is COMPULSORY
- Hands-on experience is one of the most important set of skills sought by employers
- Writing skills = communication = money !!

BEFORE THE SESSION

- Bring your calculator and other useful tools (e.g. graph paper, reference books, etc)
- Information about the lab and, sometimes, the lab sheet will be placed on VISION for you to read before the session. Review the theory given in lectures, when possible.
- Plan your writing up task and do not leave it for the last minute!
- Make note of submission deadlines

DURING THE SESSION

- Make sure your attendance is recorded and double-check the submission deadline
- Be aware of the safety issues
- Take readings as accurately as possible during the experiment and do preliminary calculations before leaving the lab
- Take notes during the lab and do not simply rely on your memory!
- Make sure that you have all the data and background information about the experiment before you leave the lab

RIGHT AFTER THE SESSION

- Draft the main points of your lab report: observations, initial discussion on the results, identify the underpinning principles of your experimental procedure and prepare a literature survey schedule
- Do this ASAP, when it is still fresh in your mind
- 'Lab report express'

HOW TO WRITE A LAB REPORT

- This is something you must do, so stop delaying the task
- Accept this is part of your professional life: you will have to do it if you want to work as an engineer
- As any other skill, the more you practise, the better you get at it! And also the easier the task is

Report Structure

- Summary or Abstract
- Table of Contents
- Introduction
- Theory
- Apparatus
- Procedure
- Results
- Discussion
- Conclusions
- References

Suggested sections in your report.

They don't need to appear in this order, if it does not fit your purpose.

Adapt when required.

SUMMARY OR ABSTRACT

- First impression: this is your chance to get the reader interested in your work. It should be concise and informative.
- Use a good opening statement,
  - *"The steel tested during this experiment was very strong"* should be written as
  - *"The steel alloy had a high Young's modulus (220 GPa) and UTS (1000MPa) making it suitable for high stress applications"*
- Write it at the end, as it should be a summary of the theory, the apparatus, the results and the discussion.

INTRODUCTION

- Explain what you did and why you did it (cover the aims and objectives of your work)
- Provide Engineering background to your work and explain why is it needed, e.g. applications of your work, real life applications, etc.

THEORY

- Which formulae are you going to use?
- What are the limitations of these formulae?
- Demonstrate that you have done further reading on the subject
- Use the recommended books and module syllabus as a guide (do not use internet sources, as they are not reliable). Reference this sources
- Contextualise the experiment: real life situations where these phenomena happen. Give examples

APPARATUS

- Describe the apparatus and experimental rig with a very good schematic diagram (when possible, drawn using proper software)
- You must label all parts and provide the details of individual parts (e.g. accuracy, range for the Vernier calliper, for the thermocouple, etc.)

PROCEDURE

- Do not simply repeat (or copy & paste) what is already on the lab sheet !
- Explain what you actually did
- Note any observation that you made during the experimental session
  - e.g. *"the surface where the tripod was sitting was not completely flat, therefore, this could have misled the readings"*, etc

RESULTS

- Calculations of results should be clear. If there are repeated calculations provide a general method on this section or in an appendix
- Include errors (e.g. *value ± 0.005mm*)
- Present results in a tabulated or graphical form. In some cases, both might be included
- Be careful about the units and symbols

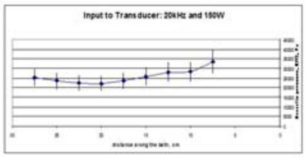
RESULTS

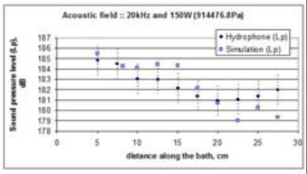
- Compare and asses experimental results vs. theoretical results
  - How are the theoretical results obtained?
    - Present full calculations in the appendix, or a sample in the report.
  - Errors?
- Which are the main sources of error? Why? Explain how to improve this experiment

Error Analysis

$$I = \frac{b \cdot h^3}{12}$$

- Systematic (cumulative) and human errors
- Intrinsic errors
  - e.g. errors in measurement:
    - Second moment of inertia
- Error bars: use them in your graphs to show the level of uncertainty





DISCUSSION

- After the *Results* section, this is the most important section
- Explain what results you were expecting e.g. from theoretical calculations, and how they differ from your experimental observations.
- Do the results make sense? What do they mean? Rational judgement
- How precisely have you met the aims and objectives?

DISCUSSION

- What constituted the error? Which were the source of errors?
- Explain any unusual things during the experiment e.g. equipment malfunction and what steps did you take to avoid it? Do not blame the equipment for your unexplained results.
- Check-list: If a marking scheme has been made available by your lecturer, make sure you cover all the sections as indicated

CONCLUSIONS

- They must be listed in the order of priority or report structure
- Statements must be supported by a comparison between theoretical and experimental results
- How can things be improved?
- How to perform the data acquisition more effectively, more precisely?
- How to measure accurately?
- Do not include personal feelings
  - *e.g. I think this lab was a success as it allowed me to become familiar with the tensile testing techniques…*

REFERENCES

Put them by placing their number in brackets e.g. [1], [2] or as footnotes. Follow academic styles of referencing, some examples:

Journal Reference

[1] Cole, S. J., & Sayles, R. S. "A numerical model for the contact of layered elastic bodies with real rough surfaces", Transactions of ASME, Vol **114**, pp 334-340 (1992).

Book Reference

[2] Powlaski, L. "The science and engineering of thermal spray coatings", John Wiley and Sons, ISBN-0-471-95253-2, (1995).

Internet Reference

[3] MIT OpenCourseWare, Strength of Materials: http://dspace.mit.edu/html/1721.1/35906/LectureNotes/index.htm (Accessed on 9 March 2008)

ACADEMIC LANGUAGE

- Your report will be read by your lecturer, your tutor, your boss, your client, … people who require a level of grammar, language, a piece of work free of typos written academically

e.g.
- Block was very heavy…. ×

"The block weighed 10 kg….." ✓

- Material did not appear to be strong… ×

"Yield was reached at a stress of 200 MPa…" ✓

- Sample had the wrong shape or dimensions… ×

"The sample was 13.5 mm in diameter, 0.1 mm smaller than the standard dimensions….." ✓

ACADEMIC LANGUAGE (cont.)

- Reports must be written in passive third person (Do not use I, WE, THEY or YOU)
  - *e.g. "The equipment was calibrated using a specimen of known dimensions…" instead of "I checked the equipment…"*
- Verbs you will use at some point to demonstrate your subject mastery:
  - Procedure and theoretical background: Formulate and test hypotheses, Design, asses the benefits of, identify, test, avoid systematic errors, expect data to behave, initiate,
  - Data collection or retrieval: Assemble data, observe, record, apply strategies, identify trends, solve problems on-site,
  - Discussion: Evaluate data, compare, demonstrate, contextualise, analyse, solve (a) problem, critically review, synthesise, design and evolve novel solutions,

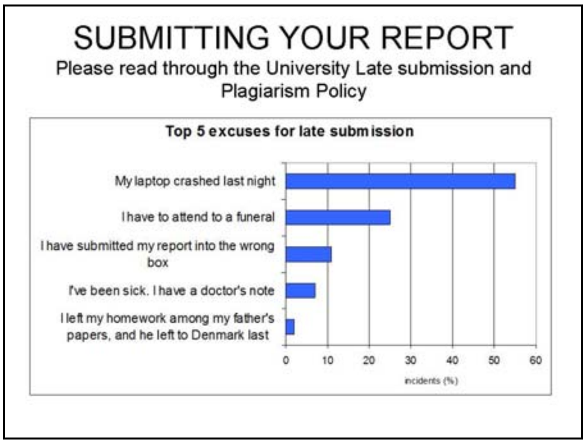
ACADEMIC LANGUAGE (cont.)

	# words	verb[1]	mode[1]	refs
Abstract or Summary	~150	Present tense	Passive/Active voice	+
Introduction	~400	Present/Past tense	Passive/Active voice	++
Theoretical	variable	Present tense	Passive voice	+++
Set-up	<300	Past tense	Passive voice	+
Results	variable	Present/Past tense	Passive/Active voice	nil
Discussion	~600	Present tense	Passive/Active voice	++
Conclusion	~100	Present/Past tense	Passive/Active voice	+

[1]Adapted from Swales and Feak (2004, p.223) by Smith K., Writing your dissertation – the structure – presentation, EDU (2007)

AFTER YOU FINISH

- Make sure you proof-read the report before you submit it
- Avoid spelling mistakes. Use the spellchecker
- Text is justified and Figures, Tables and Equations have a caption
- Submit on time
- Attend any feedback session: they are an investment ! Ask if you don't understand your feedback
  - Final year project, dissertations
  - Future career



3 Laboratories Associated with Teaching Modules

As part of the academic assessment process at Heriot-Watt University, students in various mechanical engineering courses are required to do a range of laboratories relating to four mainstream subject areas of Thermodynamics, Fluid Mechanics, Dynamics and Mechanics of Materials. There are also some specific laboratories which are offered outside mechanical engineering discipline e.g. in electrical engineering for robotics students. The number of laboratories each student is required to do in a specific year depends not only on the course but also on the modules chosen. **Table 1** summarises the laboratory requirements for all students in Years 1 to 3 registered for mechanical engineering modules. In years 2 and 3, you are expected to attend one laboratory per semester for each of the four mainstream subject areas, e.g. there are three thermodynamics laboratories listed in Year 2 in Table 1, you are expected to do one of these laboratories in semester 1 and the other in Semester 2. The choice of the laboratory will depend upon the grouping schedule for the specific module. Laboratory descriptors for individual laboratories in specific years can be seen in **Appendix A** to **C** of this handbook.

Table 1, Summary of laboratories associated with mechanical engineering modules[1]

Year / Subject (Module)	**Year 1**	**Year 2**	**Year 3**
Thermodynamics	Temperature Measurement **(B57VA1)**	1) Boys Calorimeter 2) Marcet Boiler 3) Spark Ignition (Petrol) Engine Test **(B58EE1, B58EF2)**	1) Heat Loss from Pipes 2) Forced Convection (in a Cross Flow Heat Exchanger) **(B59EI1, B59EJ2)**
Fluid Mechanics	Hydrostatics **(B57VA1)**	1) Orifice Plate 2) Pipe Friction **(B58EE1, B58EF2)**	1) The Centrifugal Pump 2) Francis Turbine 3) Pelton Wheel **(B59EI1, B59EJ2)**
Dynamics	Fly Wheel **(B57VA1)**	1) Wheel and Axle Acceleration 2) Trifilar Suspension **(B58EC1, B58ED2)**	1) One Degree of Freedom Vibration Experiment - Free & Forced Response 2) Design and Construction of a Dynamic Vibration Absorber 3) Two Degree of Freedom Forced Vibration - Shear Building Model **(B59EG1, B59EH2)**
Mechanics of Materials	Strain Measurement in Thin Plate **(B57VA1)**	1) Cantilever beam 2) Torsion Lab (**B58EC1, B58ED2)**	1) Finite Element Modelling 2) Design Assignment **(B59EG1, B59EH2)** *(These form part of continuous assessment)*

[1] Some new dynamics are being proposed at the moment for Y3 so some information may change for this lab in Semester 2.

4 Timing of Laboratories

Praxis (B57VA1) laboratories in year 1 will start in week 2 of the semester; all other laboratories in year 2 and 3 will start in week 9 and finish by week 12 of each semester. The module responsible person or the person responsible for the laboratories will schedule the experiments in the four mainstream subject areas. This grouping list will be available by week 8 of each semester. Please note that the timetable followed in weeks 1 to 8 of each semester may not be applicable in these four laboratory weeks as extra laboratory sessions may be required. All of these extra sessions will however be indicated in the grouping schedule.

5 Submission of Laboratories – *New Changes about Laboratory Sheets and laboratory Reports*

5.1 First Year labs – Praxis Module

You are required to submit the laboratory report through vision or as instructed by the laboratory responsible person within ten days of the date of your laboratory.

5.2 Second Year labs – Engineering Science Modules

The structure of laboratory work has changed for year 2 from previous practices. You will be asked to submit a LABORATORY SHEET before you finish your experiment. Specimen of laboratory sheets are included in Appendix B of this handbook, along with the description of the laboratory. This will allow you sufficient time to read through the information, familiarise with the questions asked in the laboratory sheet and more importantly prepare in advance for the laboratory. Each laboratory sheets will be worth 5% of the module mark.

You are only required to submit one LABORATORY REPORT per module in each semester. This is to allow you more time to write a comprehensive report. The report which you will need to submit will be clearly marked on the laboratory schedule e.g. as part of the B58EE1 module you will perform two laboratories (one in fluid mechanics and other in thermodynamics). You will submit the laboratory sheet for each of these laboratories before you leave the laboratory session. The Laboratory Sheet will be marked and returned to you with feedback a week after you complete the laboratory. Please use this feedback when writing the Laboratory Report. You will only be required to submit the laboratory report on one of these laboratories (either Fluid Mechanics or Thermodynamics as indicated on the laboratory schedule). These reports will be worth 10% of the module mark.

5.3 Third Year labs – Engineering Science Modules

There is no mechanics of materials laboratory work in 3rd year as this aspect of learning is integrated within the individual projects (e.g. Finite Element Project) for that subject area. Hence for the B59EG1 and B59EH2 modules you will only perform one dynamics laboratory per semester**.** The laboratory sheets for these dynamics laboratories are appended with this handbook. You are required to follow the instructions of laboratory responsible person about the use of these laboratory sheets.

For the B59EI1 and B59EJ2 modules you will be asked to submit a LABORATORY SHEET before you finish your experiment or the next day through VISION as instructed by the laboratory responsible person. Specimen of laboratory sheets are included in Appendix C of this handbook, along with the description of the laboratory. This will allow you sufficient time to read through the information, familiarise with the questions asked in the laboratory sheet and more importantly prepare in advance for the laboratory. Each laboratory sheets will be worth 5% of the module mark.

You are only required to submit one LABORATORY REPORT per module in each semester instead of two which was the practice in previous years. This is to allow you more time to write a comprehensive report. The report which you will need to submit will be clearly marked on the laboratory schedule e.g. as part of the B59EI1 module you will perform two laboratories (one in fluid mechanics and other in thermodynamics). You will submit the laboratory sheet for each of these laboratories before you leave the group on the day you perform a particular laboratory or as instructed by the laboratory responsible person. The Laboratory Sheet will be marked and returned to you with feedback a week after you complete the laboratory. Please use this feedback when writing the Laboratory Report. You will only be required to submit the laboratory report on one of these laboratories (either Fluid Mechanics or Thermodynamics as indicated on the laboratory schedule). These reports will be worth 10% of the module mark.

5.3 When to Submit Laboratory Reports?

Unless otherwise stated by your laboratory instructor, laboratory reports must be submitted within ten days of performing a specific laboratory in the first semester. For the second semester, laboratories done in weeks 9 and 10 must be submitted before Easter break (week 12)[2] and laboratories done in weeks 11 and 12 must be submitted on the first Monday following the Easter break (Week 13). This is designed to allow you a bit more time over the Easter break to do your report. Reports should have a laboratory cover sheet at the front of your report. These reports will generally be submitted electronically as instructed by the laboratory instructor through VISION. In some cases you may be asked to submit the laboratory report in the boxes provided in the crush area of the James Nasmyth Building, however your laboratory instructor may indicate an alternative submission method for the specific laboratory. These boxes will be checked by the mechanical engineering staff and after stamping the submission date, they will be passed to the instructor for assessment.

5.4 Late Submission Policy

The University has now issued clear guidelines on the late submission policy. **Table 2** indicates the proportion of marks you will loose each day for late submission. Further details of the policy can be seen in **Appendix D** of this handbook.

Table 2, Late submission of coursework and dissertations

Penalties incurred

Deadline (any time of day) — **Day submitted (after deadline)**

	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Monday	-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%					
Tuesday		-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%				
Wednesday			-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%			
Thursday				-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%		
Friday					-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%	

If, after deducting the penalty, the mark is less than zero, then no mark is awarded

EXAMPLE OF HOW PENALTIES WOULD BE DEDUCTED FROM COURSEWORK THAT CONSTITUTES ONE ELEMENT OF A MODULE MARK

Examination 70%; Coursework 30%

Coursework submitted 3 days late and incurs a penalty of 15%

Assessment Type	Original Mark	Penalty	Penalty Calculation	Final Mark (per assessment)	Final Contributory Mark
Coursework	67%	15%	*67-15 = 52*	52%	16% *(rounded up)*
Examination	58%	n/a	n/a	58%	41%
TOTAL MODULE MARK	61%				**57%**

6 Policy on Plagiarism

Full details of the university plagiarism policy can be seen in **Appendix E**. They can also be accessed via the link: http://www.hw.ac.uk/registry/resources/PlagiarismGuide.pdf. According to the university guidelines, "*Plagiarism involves the act of taking the ideas, writings or inventions of another person and using these as if they were one's own, whether intentionally or not. Plagiarism occurs where there is no acknowledgement that the writings or ideas belong to or have come from another source*".

Students must pay particular attention to the following examples of common plagiarism mistakes made by other students when reflecting on their own work:

[2] This generally will mean that you submit one laboratory report out of two before the Easter break. However, if you are grouped such that you have done more than two laboratories in weeks 9 and 10, then you should only submit one report before Easter break and the remaining one after the Easter break in week 13 (Monday).

• *“I thought it would be okay as long as I included the source in my bibliography” [without indicating a quotation had been used in the text]*

• *“I made lots of notes for my essay and couldn't remember where I found the information”*

• *“I thought it would be okay to use material that I had purchased online”*

• *“I thought it would be okay to copy the text if I changed some of the words into my own”*

• *“I thought that plagiarism only applied to essays, I didn't know that it also applies to oral presentations/group projects etc”*

• *“I thought it would be okay just to use my tutor's notes”*

• *“I didn't think that you needed to reference material found on the web”*

• *“I left it too late and just didn't have time to reference my sources”*

7 Feedback on Laboratory Reports

You will be given electronic feedback for most of your reports. In some cases, where the submission of the laboratory is in the form of hard copy as opposed to electronic submission, comments will be written on the report. The feedback on the laboratory sheets will be given the following week in the form of written comments.

Providing feedback on submitted coursework help students improve the quality of their work in future reports. During the first year, specific feedback may therefore be sought through your mentors before submitting your first laboratory report. After the submission of your report, specific feedback relating your report will be included in the form of written comments. It is important that you should take these written comments on board when reflecting on the strengths and weaknesses of your report. If you are not clear about certain aspects of the comments made on your report, you are advised to contact the person responsible for the specific laboratory for clarification. In some cases relating to first semester laboratories, an instructor may choose to hold open feedback session(s) where specific feedback can be sought. Some trials of automated feedback are also underway where feedback on your report may be available in electronic form via VISION.

APPENDIX A

Year 1 Module Descriptors

Module **B57VA –Praxis**	Year **1**
Subject **Thermodynamics**	Semester **1**
Laboratory Title **Temperature Measurement**	

Objective
The object of this laboratory exercise is to calibrate a digital thermocouple against a mercury thermometer (analogue) reference.

Theory
A thermocouple works on the basis of the thermoelectric effect or the Seebeck effect, named after Thomas Johann Seebeck who discovered it in 1821. It was found that a voltage (or potential difference) existed from one end of a conductor to the other which is proportional to the temperature difference between each end as follows:

$$V_{1\to 2} \propto \left(T_1 - T_2\right)$$

The constant of proportionality (S) is known as the Seebeck coefficient and is a material property of the conductor; it is also known as the thermoelectric power of the material:

$$V_{1\to 2} = S \times \left(T_1 - T_2\right)$$

When two dissimilar metals are joined such as in a thermocouple, a voltage is generated in the circuit that is proportional to temperature difference between the junction and the leads according to the following equation:

$$V \propto \left(T_{junction} - T_{leads}\right)$$

If the temperature of the leads is constant and equal to the ambient air temperature then the voltage is directly proportional to the junction temperature.

The sensitivity of a measurement technique is defined as follows:

$$\text{Sensitivity} = \frac{\text{Change in Reading}}{\text{Change in Quantity Measured}}$$

Equipment
A K-type thermocouple consists of a copper wire joined with a constantan wire. The leads of the thermocouples are connected to a signal amplifier that amplifies the voltage generated at the junction by a factor of 10, 50, 100 and 1000 (depending on the setting). The output from the amplifier is acquired by a Data Acquisition System.

A constant temperature water bath will be used to set temperature points for the calibration of the thermocouple. The bath includes a heating element, a thermostat and a circulation pump that work together to ensure the water is held at a constant set temperature.

A pre-calibrated mercury thermometer will be used as a reference temperature measurement.

Procedure
1. Define the temperature range and temperature increments at which you will calibrate your thermocouple
2. Set the temperature of the bath to the lowest temperature

3. Record the voltage from the thermocouple and reference temperature from the mercury thermometer
4. Increase the temperature of the bath by your pre-defined increment
5. Repeat steps 3 and 4 until you have reached the upper temperature within range
6. If you have sufficient time this can be repeated as the water bath cools
7. Plot the reference temperature against the recorded voltage and fit a linear regression curve to the data.

Report

Discuss your results with reference to theory. Can you quantify the uncertainty of the measurement technique i.e. how far do individual data points vary from the regression curve?

If the ambient temperature in the lab were to change significantly, how would this affect your result? How could you mitigate against this?

Compare thermocouple temperature measurement to other measurements techniques (fluid filled thermometers, infra-red thermal imaging and liquid crystal thermography etc.) on the basis of sensitivity and temporal and spatial resolution etc.

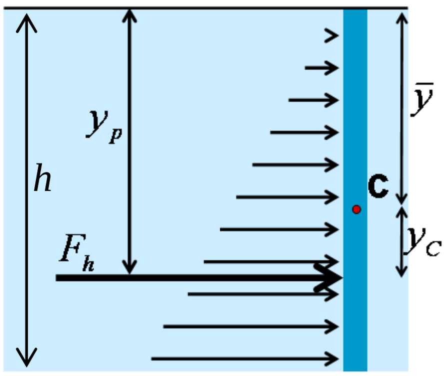
Reference

Dataforth Corporation Application Notes - available on VISION

Module **B57VA –Praxis**	Year **1**
Subject **Fluid Mechanics**	Semester **1**
Laboratory Title **Hydrostatics**	

Objective
To measure the hydrostatic force on a partially submerged vertical surface and compare them to their theoretical equivalents.

Theory
A submerged body will experience a hydrostatic force due to the weight of the fluid above it as indicated in the figure below



$$F_h = \rho g \bar{y} A$$

The magnitude of the resultant force (F_h) is the product of the pressure at the centroid ($\rho g \bar{y}$) and the surface area (A). The line of action of this force (y_p) is at a distance (y_c) below the centroid ($\bar{y}$). For a vertical surface, it can be shown that:

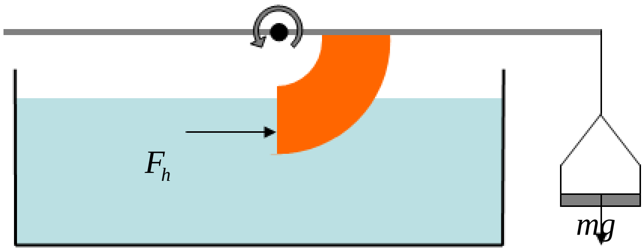
$$\bar{y} = \frac{h}{2} \qquad y_c = \frac{h}{6} \qquad y_p = \bar{y} + y_c$$

Therefore:

$$y_p = \frac{2h}{3}$$

Equipment
As indicted in the diagram below a partially submerged dam wall is connected to cross-beam that pivots on fulcrum above a water tank. The cross-beam also extends a distance perpendicular to the dam surface. This lever arm can be loaded with different weights; thus creating an effective balance with the hydrostatic load.

The tanks is also instrumented with a pointer to determine the level of the fluid in the tank. A spirit level will indicated when the balance is level



Procedure

1. Adjust the weight balance until the cross-beam is level
2. Add weights to the weight tray and increase the level of the water until both the cross-beam is balanced again.
3. Increase the weight in the tray in similar small increments and note the corresponding water level required to rebalance the cross-bream each time.

Report

Plot the weight applied in the tray against the depth of water in the tank.

Calculate the hydrostatic force for each test by equating clockwise and anticlockwise moments about the fulcrum. Show details of one sample calculation.

Compare the theoretical hydrostatic force to the measured force and comment on your results.

Reference

Mechanics of Fluids, B. S. Massey, (Van Nostrand)

Module **B57VA –Praxis**	Year **1**
Subject **Dynamics**	Semester **1**
Laboratory Title **Fly Wheel**	

Objective: To predict the time taken for a falling weight to accelerate a flywheel using the appropriate equations of motion.

Introduction:
A flywheel is a large rotating disc acting as a mechanical store of kinetic energy, like a mechanical battery. When compared to a chemical battery, it has a significantly longer life span. One common example is in the automotive vehicle, where a flywheel coupled to the clutch is used to regulate the speed and also ensure smooth motion when acceleration is not applied by converting the stored energy into rotational action. In order to maximise the efficiency of a flywheel, the energy-to-mass ratio requires to be optimised.

Can you identify other examples of flywheel application? Highlight two examples and briefly explain their purpose, advantages and disadvantages. Include this in your report in the introduction.

Theory:

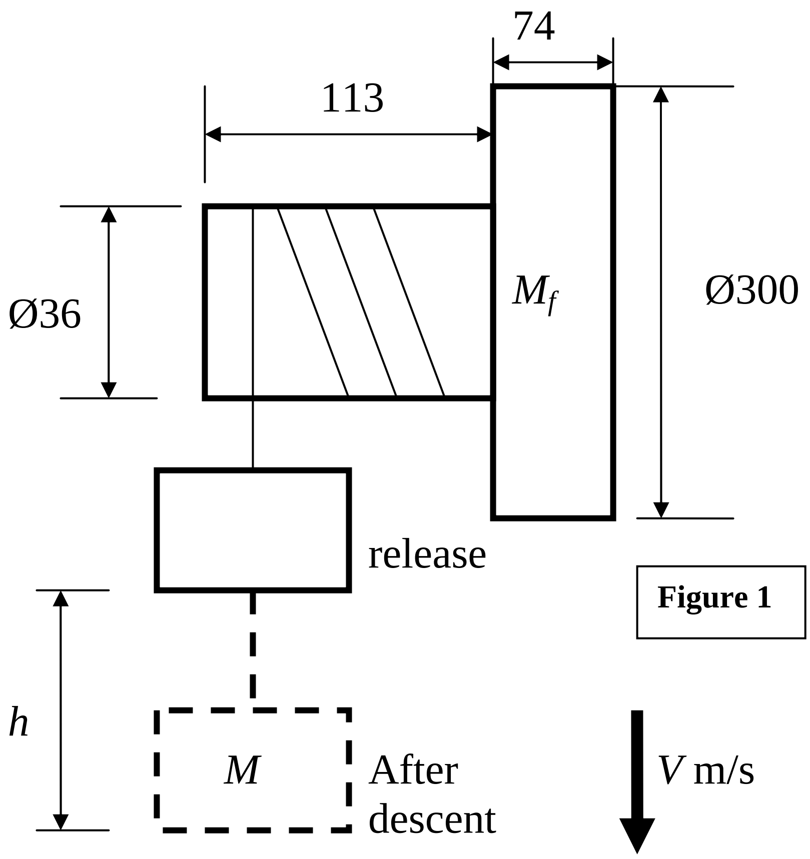


Figure 1

All dimensions in Figure 1 are in mm.

Considering the forces acting on the descending mass and Newton's 2nd law of motion,

$$Mg - T = Ma \qquad (1)$$

For the flywheel the tension, T provides an acceleration torque for the flywheel,

$$Tr = I\alpha \qquad (2)$$

Where $I = \frac{1}{2} M_f R^2$

Note: I is the polar moment of inertia for the flywheel and α is the angular acceleration.

Assuming that the string does not stretch then

$$a = \alpha r \qquad (3)$$

Substitute equations 2 and 3 into 1 to obtain:

$$Mg - \frac{Ia}{r^2} = Ma$$

$$\therefore a = \frac{g}{1 + \frac{I}{Mr^2}} \qquad (4)$$

Assuming the acceleration *a* is constant from release, time taken can be predicted for a specific fall *s*. Derive an expression for time *t* and show the full derivation in your report.

Note:

M_f is the mass of the flywheel (kg)

M is the mass of the falling weight (kg)

R is the radius of the flywheel (m)

r is the radius of the shaft (m)

Density of the flywheel and shaft is 7830kgm^{-3}.

Experiment:

A flywheel and a shaft as shown in Figure 1, has a string attached to the shaft and to a base unit (hanger) of mass 504g. Using four measured distances *h*, measure the time taken for the mass for these distances and compared them against the calculated time. Present your data in a table.

Discussions:

1. Comparing the experimental and calculated values, what is the percentage error between the two for each distance? Plot t^2 versus *s* for experimental and calculated values on the same graph for comparison and comment on the linearity and the difference between the two lines.

2. Identify and explain any source of error (the derived expression for time).

3. Conclude on the experiment.

Module **B57VA –Praxis**	Year **1**
Subject **Mechanics of Materials**	Semester **1**
Laboratory Title **Strain Measurement in Thin Plate**	

Objective

The objectives of this experiment are to:

- Measure axial and lateral strain in a thin plate
- Valuate the approximate value of Young's modulus and Poisson's ratio from the strain measurements

Background

To design a structure which ensures the necessary strength while keeping the harmony between safety and economics, it is significant to know the stress borne by each material part. However, at the present scientific level, there is no technology which enables direct measurement and judgment of stress. So, the strain on the surface is measured in order to know the internal stress.

Theory

If an object receives an external force from the top, it internally generates a repelling force to maintain the original shape. The repelling force (*F*) divided by the cross-sectional area (*A*) of the object is called **stress**.

$$\sigma = F/A . \quad (1)$$

When a bar is pulled, it elongates by ΔL , and thus it lengthens to L (original length) + ΔL (change in length). While lengthening, the pulled bar becomes thinner from its original diameter D to $D - \Delta D$. The ratio of this elongation: ΔL to the original length L , is called **axial strain**

$$\varepsilon_{axial} = \Delta L/L , \quad (2)$$

Similarly, the **lateral strain** is

$$\varepsilon_{lateral} = -\Delta D/D . \quad (3)$$

The ratio between lateral and axial strains is called **Poisson's ratio**, which is expressed in ν :

$$\nu = -\varepsilon_{lateral}/\varepsilon_{axial} . \quad (4)$$

The proportional constant between stress and axial strain is called **Young's modulus**, the value of which depends on the materials.

$$E = \sigma/\varepsilon_{axial} . \quad (5)$$

Strain measurement in engineering materials is generally difficult especially if attempted via the route of physical measurement of changes in dimensions. The problem can however be easily resolved by the use of a device called "**strain gauge**". Strain gauge (**Figure 1**)[(a)] is simply a grid of fine metal wire (approximately 0.025 mm in diameter) or a metal foil, bonded to a non-conducting substrate. This strain gauge is tightly bounded to a measuring object so that the sensing element may elongate or contract according to the strain borne by the measuring object. When bearing mechanical elongation or contraction, most metals undergo a change in electric resistance. The strain gauge applies this principle to strain measurement through the resistance change. The ratio of the change in resistance per unit original resistance ($\Delta R/R$) can than be related to the ratio of change in length per unit original length or strain ($\varepsilon = \Delta L/L$) in the metal wire by a conversion factor called "**Gauge Factor**" represented here by "G", i.e.

$$G = (\Delta R/R)/(\Delta L/L) \quad (6)$$

[(a)] Ref: www.sensorland.com

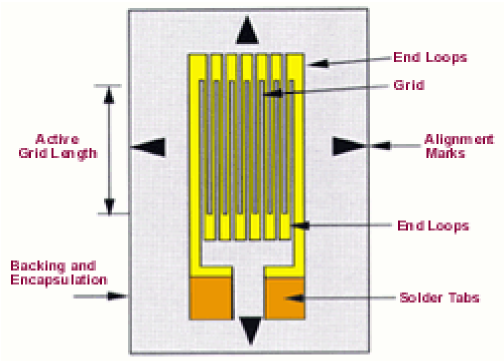


Figure 1. Schematic of a strain gauge

Generally, the value of gauge factor is around 2.1. Exact value of gauge factor, which is typical of the gauge type, can usually be obtained from strain gauge manufacturer(s). However, the change in resistance (ΔR), just like the change in length (ΔL) of the strain gauge is very small. It is therefore essential to evaluate this change in resistance in terms of the changes in voltage, amplified via an electrical circuit. For this, Wheatstone bridge is generally used. Wheatstone bridge consists of four resistors which are mounted in a configuration shown in **Figure 2**, such that the change in resistance (ΔR) of the resistors changes the output voltage (V_{out}), for any given value of input voltage (V_{in}).

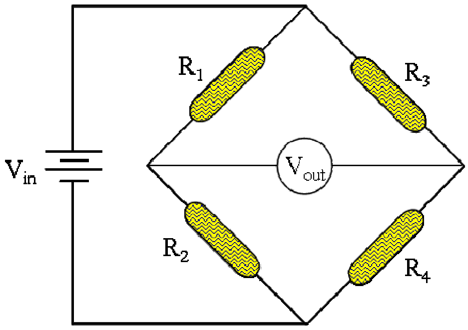


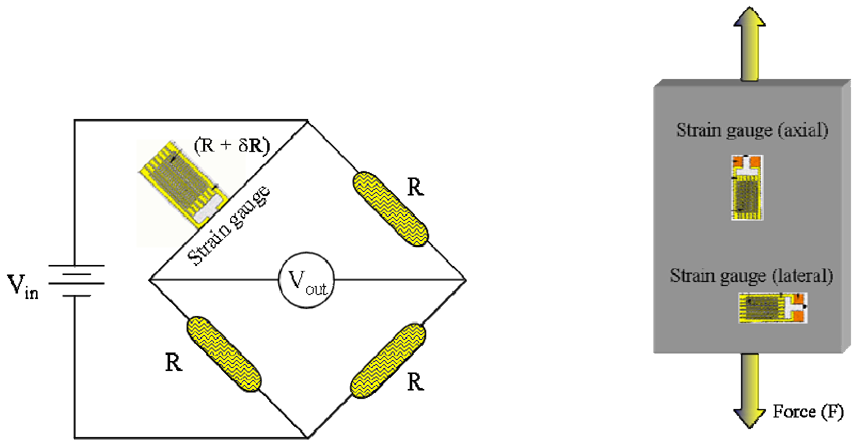
Figure 2. Wheatstone bridge circuit

When Wheatstone bridge is completely balanced by variable resistors i.e. resistors R_1, R_2, R_3 and R_4 satisfy the condition $R_1/R_2 = R_3/R_4$, it can be proved that $V_{out} = 0$. Any change in the resistance of R_1, R_2, R_3 or R_4 will thus cause the out put voltage to alter from zero i.e. for the conditions $R_1/R_2 \neq R_3/R_4$. This change in output voltage with resistance is thus used to measure strain.

In this experiment, we have two strain gauges and thus two separate bridge circuits will be used, which will be identical in configuration. However, as we are interested in measuring the change in resistance (in terms of output voltage) of only one resistor (i.e. strain gauge) in our bridge, we can set all other resistors in Wheatstone bridge circuit to have the same resistance value, as the initial resistance of strain gauge. Hence, if the resistance of strain gauge (which can be measured by multimeter) is R, then in our bridge circuit, we can have $R = R_1 = R_2 = R_3 = R_4$, and the resulting circuit can be schematically represented as **Figure 3(a)**. This resistance R for the strain gauge(s) used in this experiment was measured as 120 Ohm. This configuration of Wheatstone bridge circuit is called **quarter configuration**, as only one of the four resistors (i.e. strain gauge) is the variable resistor in our quarter configuration circuit.

There are prefabricated Wheatstone bridge circuits available in the lab, which measure strain for a given gauge factor. However, these prefabricated Wheatstone bridge circuits are calibrated for a **quarter bridge circuit** which amplify the actual value of the strain by an approximate factor of four since only one resistor is variable type. Therefore, the strain can than be measured directly in the specimen, using the relation:

$$\varepsilon = 4V_{out}/(V_{in}G)\,. \tag{7}$$



(a) (b)

Figure 3. Quarter configuration of Wheatstone bridge circuit (a); Schematic diagram of strain gauge arrangement (b)

Experimental Test Procedure

Having had the knowledge of measuring strain in a given specimen using a linear strain gauge (described above), the experiment involves measuring the strain in axial (ε_{axial}) and lateral ($\varepsilon_{lateral}$) directions in a thin plate, with axial direction represented as the direction of load axis (**Figure 3b**). A plate of dimensions length (l) = 280 mm, width (w) = 215 mm and thickness (t) = 6mm is to be pulled in tension using a tensometer, which is essentially a hydraulic press, capable of inserting tensile or compressive loads. Two[(d)] strain gauges, one aligned to measure the axial, and the other lateral strain, are already attached to the plate. Typical procedure (see also **Table 1**) can be summarised as follows:

- The plate is to be pulled in tension with an initial load of 1kN to take the slackness out of the system (bolts etc.).
- The strain gauge readings are then set to zero. This means that the strain caused by the initial load is neglected and thus the corresponding value of load to be neglected from the total load readings on the tensometer.
- The load is then increased in intervals of 5kN, up to a total value of 25 kN (note that in these conditions the final tensometer reading will be 26kN to compensate the initial 1kN load).
- The strain at each value of load is then measured from the quarter bridge circuit.
- Calculations of Poisson's ratio and Young's modulus.

  Poisson's ratio: $-\varepsilon_{lateral} / \varepsilon_{axial}$

  Young's modulus: $F/(wt\varepsilon_{axial})$

Load case	Applied Load (F)	Axial Strain (ε_{axial})	Lateral Strain ($\varepsilon_{lateral}$)	Estimated Poisson's ratio $\nu = -(\varepsilon_{lateral})/(\varepsilon_{axial})$	Axial Stress ($\sigma = F/w \times t$)	Estimated Young's Modulus ($E = \sigma/(\varepsilon_{axial})$)
I						
II						
III						
IV						
V						

Table 1. Typical calculation procedure

The report should comprise of detailed experimental procedure, experimental results, discussion and conclusions. Discussion should include accuracy of results, various sources of error during the experiment, and suggestions about improving the accuracy of results. Note; ***use correct units!***

[(d)] A third gauge attached to the plate at +45° to the lateral gauge should be neglected for this experiment.

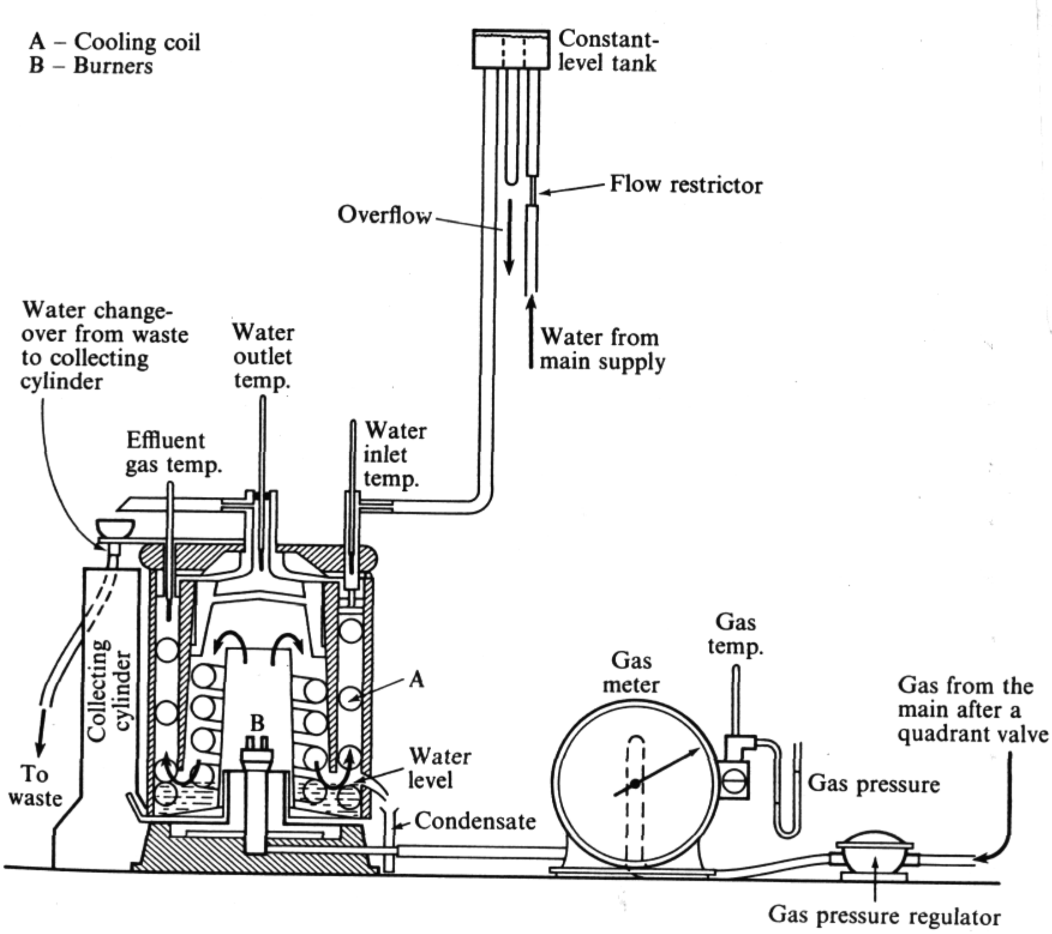
APPENDIX B

Year 2 Module Descriptors

Module (s) **B58EE, B58EF–Mech. Eng. Sci. 5, 6**	Year **2**
Subject **Thermodynamics**	Semester (s) **1 and 2**
Laboratory Title **The Boys' Gas Calorimeter**	

Objective
To determine the higher and lower calorific values of natural gas. (HCV and LCV). Sometimes referred to as the gross calorific value and the net calorific value.

Background



Boys' Calorimeter

Definition of Calorific Value (Ref 1 p221)
The calorific value of a fuel may be defined as the energy transferred as heat to the surroundings (e.g. cooling water) per unit quantity of fuel when it is burned at constant pressure, the combustion products being at the same temperature as the reactants (fuel and air). If the H_2O in the products is condensed then the Higher or Gross calorific value (HCV) is determined, if the H_2O in the products remains in the vapour phase (or corrections are made to this effect) then the Lower or Net calorific value (LCV) is determined.

During the lab and subsequent analysis

A. Carry out the experiment and calculate the results. Take measurements of important temperatures, pressures and volume flow rates (necessary to calculate the calorific values) at the initial gas flow rate. You should check that the results are repeatable.

B. Discuss the following points:-
   a. The comparison between your measurement of calorific values using the low and high gas flow rate and the quoted value in the reference material.
   b. Is it correct to use the latent heat of steam at 25^{o}C in calculating the lower calorific value?
   c. The relative merits of the use of HCV and LCV in power plant thermal efficiency definition.

References

1. Eastop, T.D. and McConkey, A., Applied Thermodynamics for Engineering Technologists

Boys' Calorimeter – Results

Test No		**Ambient Temp**		**^{o}C**
Parameter	**Value**	**Units**	**Value (SI)**	**Units**
Gas				
Volume of gas				
Gauge Pressure				
Absolute Pressure				
Inlet Temperature				
Exhaust Temperature				
Elapsed time				
Corrected Volume (15^{o}C 1bar)				
Volume flow/sec (15^{o}C 1bar)				
Cooling Water				
Volume of coolant				
Elapsed time				
Mass collected				
Mass flow/sec				
Temp. in				
Temp. out				
Specific heat capacity				
Heat transferred/sec				
Condensate				
Volume collected				
Elapsed Time				
Mass collected				
Mass collected/sec				
Latent heat				
Mass/sec x Specific Latent				

Heat				
HCV				
LCV				

Ensure consistent units are used

Calculations

The Higher Calorific value may be calculated from:

Volume of fuel used (at 1bar 15^oC) x HCV
= (mass of cooling water) x (specific heat capacity) x temperature rise of water)

Where the volume of the fuel used and the mass of water are measured over the same time interval (e.g. 1 second)

The Lower Calorific value may be calculated from:

(HCV-LCV) x Volume of fuel = Mass of condensate collected x Latent heat of H_2O

Where the volume of the fuel used and the mass of condensate are measured over the same time interval (e.g. 1 second)

The Latent heat of H_2O at a temperature of 25^oC should be use. This may be determined from tables.

Laboratory Sheet for the Experiment

The Boys' Gas Calorimeter

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

How can you calculate the higher calorific values (HCV) and lower calorific values (LCV)?

Is it correct to use the latent heat of steam at 25 °C in calculating the lower calorific value? Why?

What are the relative merits of the use of HCV and LCV in power plant thermal efficiency definition?

Are the calorific values from your measurement using the low and high gas flow rate different with the quoted value in the reference material? Why?

What can you conclude from this lab exercise? Can the experiment set-up be used to measure the HCV/LCV of other fuels? Why?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

Module (s) **B58EE, B58EF–Mech. Eng. Sci. 5, 6**	Year **2**
Subject **Thermodynamics**	Semester (s) **1 and 2**
Laboratory Title **Marcet Boiler Experiment**	

Objective

To study the relationship between the saturation pressure and temperature of water/steam in the range 0 – 14 bar (gauge) and to study the change in temperature of a body when being heated or cooled.

Safety

The apparatus is a pressure vessel. The pressure must not exceed 14 Bar (gauge)!

Background

1) In order to carry out a heat transfer experiment simultaneously with measurement of vapour pressure, it is required that the rates of heating and cooling of the pressure vessel, the rate of energy addition by the heater and the ambient temperature are recorded.

2) Study the following derivation of a simplified 1st Law (energy) equation relating the temperature of the boiler to time as it is heated and cooled.

Assumptions

i. The temperature is uniform throughout the boiler. Thus the outside surface temperature of the boiler is the same as the steam temperature, *T*.

ii. Newton's Law of cooling applies – the rate of heat transfer from the surface is proportional to the surface area, A_s, and to the temperature difference between the boiler surface and the surroundings ($T- T_{\alpha}$).

Thus,

$$\frac{dQ_t}{dt} = \alpha A_s \left(T - T_\alpha\right)$$

where α (kW/m2K) is called the **heat transfer coefficient** for heat transfer between the boiler surface and the surroundings. By Newton's law of cooling it is assumed constant.

The 1st law balance for the boiler at time t (secs) is

$$\frac{dQ}{dt} = \frac{dQ_t}{dt}$$ + Rate of change of internal energy of the boiler and contents.

Therefore,

$$\frac{dQ}{dt} = \frac{dQ_t}{dt} + MC\frac{dT}{dt}$$

Where MC (kJ/ K) is the heat capacity of the boiler which in this simplified development is assumed constant.

So, **when being heated**,

$$\frac{dQ}{dt} = \alpha\, A_s\, (T - T_\alpha) + MC\frac{dT}{dt}_{heating} \qquad (1)$$

and **when cooling**,

$$0 = \alpha\, A_s\, (T - T_\alpha) + MC\frac{dT}{dt}_{cooling} \qquad (2)$$

At a value of T_1 on the lot of the measured heating curve and at a value T_2 on the cooling curve, the respective slopes,

$$\frac{dT}{dt}_{cooling} \quad \text{and} \quad \frac{dT}{dt}_{heating}$$

are determined by construction. The value of *dQ/dt* may be calculated from tabulated measurements of electrical energy consumption (kWh) versus time (hrs), or from a direct reading of a Wattmeter. Hence, the values of the products □ A_s and *MC* can be calculated by simultaneous solution of (1) and (2).

Remember – gauge pressures should be converted to absolute values.

During the lab and subsequent analysis

A. Sketch the apparatus

B. Carry out the experiment and calculate the results.

C. Plot p versus T for both heating and cooling on a graph. Also plot p versus T using published values (ref 1) comment on this graph.

D. Plot graphs of measured T versus time and calculate the products A_s and MC. Hence calculate T_{max}, and the time t for the boiler to cool from the maximum temperature achieved in the test to 10 ^oC above ambient temperature and comment on the values obtained.

E. Derive, from (1) and (2),

    a. An expression for the maximum temperature T_{max}, the boiler would reach if heating were to continue at the rate *dQ/dt* (kW).

    b. The time, t it would take for the boiler to cool 100^{o}C, to 10^{o}C above ambient temperature. (This requires solution of the differential equation (2)).

Reference

Thermodynamic and Transport Properties of Fluids, Rogers G.F.C and Mayhew Y.R., 5th edition, “Steam Tables”

Laboratory Sheet for the Experiment

Marcet Boiler

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

How can you calculate the values of the products αA_s and MC

Why is it necessary to expel the air from the apparatus at start of experiment?

Applying 1st law of thermodynamics, explain the energy balance at T = Tmax in this experiment:

How does the published data of P versus T compare to measured data of P versus T for both heating and cooling? Why are they different?

Can you list some examples of industrial application of the liquid and vapour behaviour observed through the experiment?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

Module (s) **B58EE, B58EF–Mech. Eng. Sci. 5, 6**	Year **2**
Subject **Thermodynamics**	Semester (s) **1 and 2**
Laboratory Title **Spark Ignition (Petrol) Engine Test**	

Introduction
Spark ignition reciprocating internal combustion engines are widely used in automobiles (the petrol engine) and as small industrial units. Industrial engines typically run on lpg , as do some automobile engines.

Automobile engines operate over a wide range of conditions of speed and torque. In order to characterise an engine it is necessary to construct a performance map. Such a map may show brake thermal efficiency or brake specific fuel consumption (BSFC) as a function of speed and torque. The information provided in a performance map can be used in conjunction with the characteristics of the load (e.g. the power vs speed and the mass of a car) to determine appropriate gear ratios.

Objective
1. To become familiar with the equipment and measurements taken when testing an internal combustion engine.
2. To investigate the variation of Thermal Efficiency and BSFC with torque (or power) when operating at constant speed
3. To carry out an energy balance for the engine.

Apparatus
The apparatus comprises a Volkswagen 999cm^3 4 cylinder petrol engine with a compression ratio of 10.5:1 driving an eddy current brake. The engine and load are controlled and monitored remotely.
The engine is shown in figures 1 and 2.. Students should annotate the figures to show the following:

1.
2. Brake
3. Fuel Tank
4. Cooling Water Heat Exchanger
5. Exhaust Silencer
6. Battery
7. Power Electric Cabinet
8. Circuit Breakers
9. Emergency Stop
10. Signal Conditioning Electronics
11. PLC (Programmable Logic Controller)
12. Air intake

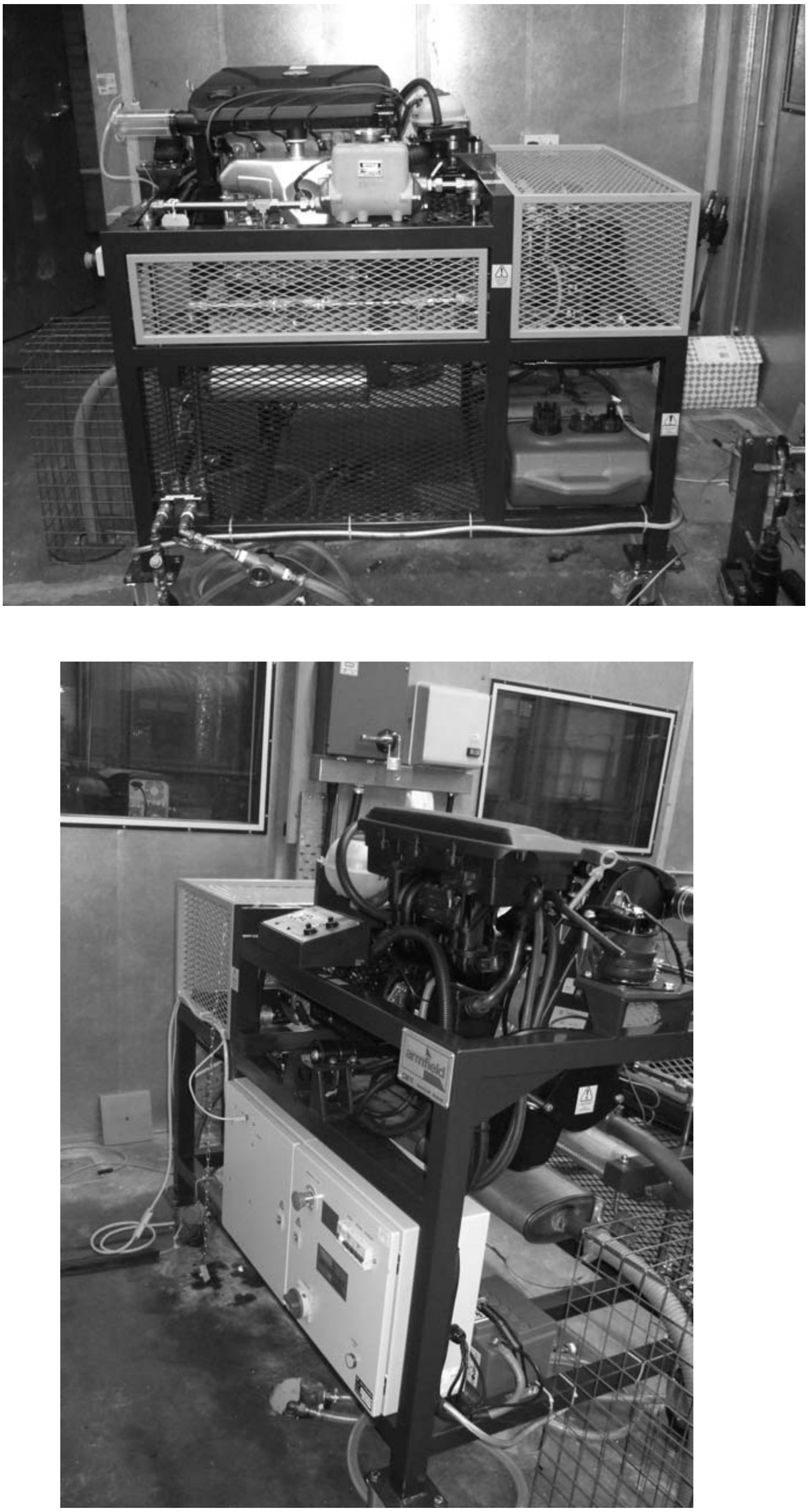


Figure 1. Engine test bed

All instruments are connected to a PC based data logger and parameters are displayed on a mimic diagram as shown in Figure 2.

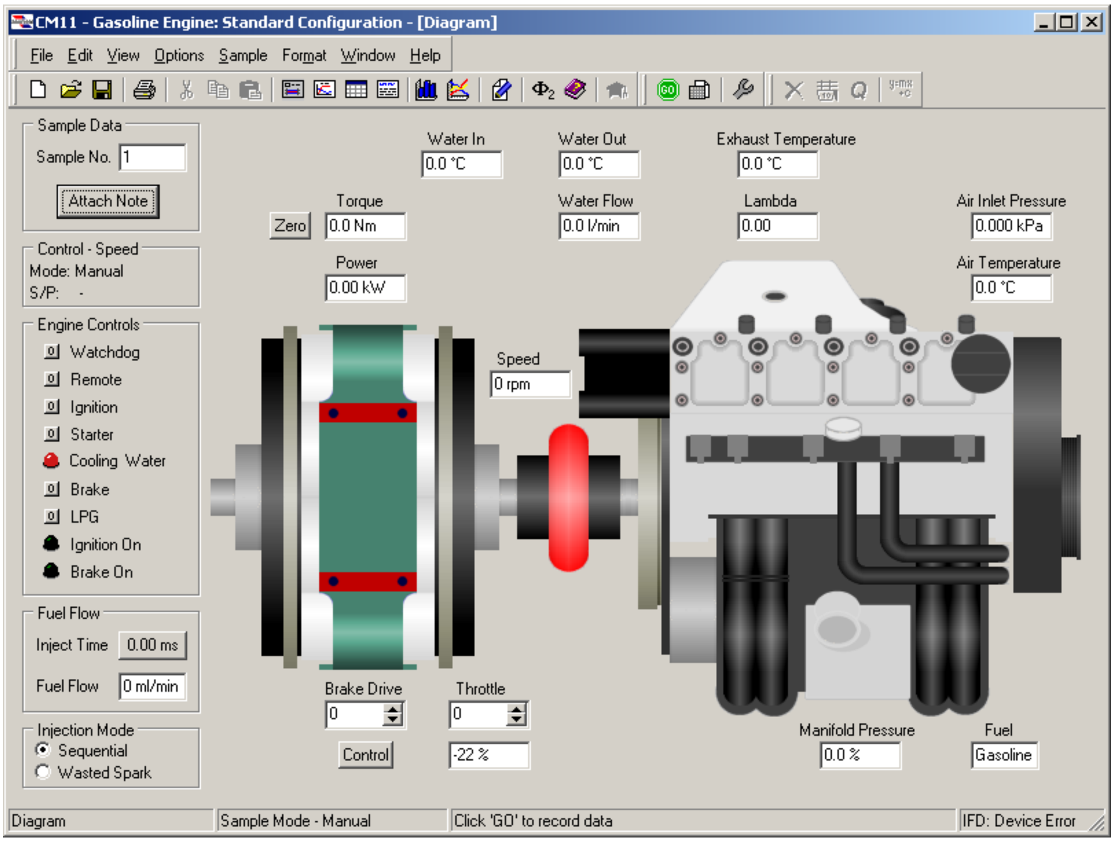


Figure 2 Mimic diagram

Further data may also be extracted from the MOTEC engine management unit using a separate DOS based program.

Test Method

1. Ensure power supply to engine is on
2. Start PC(s)
3. Run Armfield CM11 Gasoline Engine software package. Choose “Standard configuration”
4. Set cooling water flow to approximately 8//min
5. Switch on exhaust extractor and engine cell ceiling fan.
6. Zero torque measurement
7. Set Fuel Flow Calculator to “Wasted Spark”
8. Load MOTEC program and return to Armfield Mimic
9. Press ***remote***
10. Press ***Ignition*** (Green light should illuminate on mimic, red light on ***engine*** PLC)
11. In MOTEC window select ***Calibration/Diagnostic*** then ***View*** then ***Main*** (Note MOTEC is DOS program – it requires keyboard input not mouse!)
12. **Set throttle to zero**
13. Press ***Starter***
14. Run engine for 10 minutes or until Lambda sensor reads ~1
15. Open throttle and adjust speed to 3000rpm (Note throttle control is non-linear and has a lag – therefore open slowly and pause after small increment
16. Insert EPW from MOTEC software into fuel flow calculator
17. Sample data when engine is running steadily
18. Press ***Brake on***
19. Press ***Control***
20. Set speed to 3000rpm

21. Set to automatic control
22. Open throttle by 5-10% and record data when engine is running steadily at each condition. (Remember to insert EPW from MOTEC software into fuel flow calculator.)
23. repeat 22 until throttle is fully opened.
24. Slowly close throttle do not allow engine speed to fall below 2800rpm until load falls below 10%, then reduce further until load is zero.
25. Switch of brake and control to manual
26. When load is removed, allow engine to run at tickover speed for 5 minutes.
27. **If the engine speed increases above 5000rpm immediately close throttle – if this does not result in a reduction in speed switch ignition off. If this fails to slow engine and speed may reach 5500rpm supervisor should press emergency stop.**

Analysis

You will be provided with an Excel file containing most of the data required for analysis. You should satisfy yourself that you understand the theory used in determining the derived data in the spreadsheet.

Add the following columns:

(Note: Check that the units are consistent, and convert as necessary)

1. Fuel mass flow rate kg/s

$$\dot{m}_F = \dot{V}_F\,(m^3/s) \times \rho_F\,(kg/m^3) \text{ kg/s}$$

2. Air fuel ratio (kg/kg)

$$AFR = \frac{\dot{V}_a\,(\mathrm{m^3/s}) \times \rho_a\,(\mathrm{kg/m^3})}{\dot{V}_F\,(\mathrm{m^3/s}) \times \rho_F\,(\mathrm{kg/m^3})}$$

3. Brake specific fuel consumption (kg/kWhr)

$$BSFC = \frac{\dot{V}_F\,(\mathrm{m^3/s}) \times \rho_F\,(\mathrm{kg/m^3}) \times 3600(\mathrm{sec/hr})}{P_b\left(\mathrm{kwhr/hr}\right)} \text{ kg/kwhr}$$

4. Power to exhaust gases kW

$$\dot{m}_a = \dot{V}_a\,(\mathrm{m^3/s}) \times \rho_a\,(\mathrm{kg/m^3}) \text{ kg/s}$$

$$P_E = c_{pe}\,(\mathrm{kJ/kgK}) \times \left(\dot{m}_a + \dot{m}_F\right)(\mathrm{kg/s}) \times \left(t_{ex} - t_{amb}\right)(\mathrm{K}) \text{ kW}$$

5. Power to coolant kW

$$\dot{m}_{cw} = \dot{V}_{cw}\,(m^3/s) \times \rho_w\,(kg/m^3) \text{ kg/s}$$

$$P_c = c_{pw}\,(\mathrm{kJ/kgK}) \times \dot{m}_{cw}\,(\mathrm{kg/s}) \times \left(t_{c,out} - t_{c.in}\right)(\mathrm{K}) \text{ kW}$$

6. Power supplied in fuel kW

$$P_F = \dot{m}_F\,(kg/s) \times CV_F\,(kJ/kg) \text{ kW}$$

7. Brake thermal efficiency

$$\eta_{brake} = \frac{P_b}{P_F} \times 100\%$$

Nomenclature

AFR	Air fuel ratio	kg/kg
$\dot{V}_a$	Air volume flow	m^3/s
ρ_a	Density of air	kg/m^3
$\dot{m}_a$	Air mass flow rate	kg/s
$\dot{m}_F$	Fuel mass flow rate	kg/s
$\dot{V}_F$	Fuel volume flow	m^3/s
ρ_F	Density of fuel	kg/m^3
$\dot{m}_{cw}$	Mass flow rate of coolant	kg/s
$\dot{V}_{cw}$	Volume flow rate of coolant	m^3/s
ρ_w	Density of water	kg/m^3
BSFC	Brake specific fuel consumption	kg/kwhr
c_{pe}	Specific heat capacity of exhaust	kJ/kgK
c_{pw}	Specific heat capacity of coolant	kJ/kgK
CV_F	Calorific value of fuel	kJ/kg
P_b	Brake power output	kW
P_c	Power to coolant	kW
P_E	Power to exhaust	kW
P_F	Power input from fuel	kW
t_{amb}	Air inlet temperature	^oC
$t_{c,in}$	Temperature of coolant in	^oC
$t_{c,out}$	Temperature of coolant out	^oC
t_{ex}	Temperature of exhaust	^oC
η_{brake}	Brake thermal efficiency	

Report

Students should observe and note the test conditions; in particular they should note any deviations from the test procedure, or malfunction of the apparatus.

Show sample calculations for the terms listed in 1-7 above.

Include Figure 1 appropriately annotated.

The report should include graphs of the following parameters against torque for each engine speed tested.

1. Brake thermal efficiency
2. Brake specific fuel consumption
3. Air-fuel ratio
4. P_b, P_e, P_{cw} and P_F and $(P_b+P_e+P_{cw})$
5. Exhaust Temperature

Graphs of volumetric efficiency and torque against throttle position should also be included.
Comment on the values obtained and the form of the resulting plots.

Module (s) **B58EE, B58EF–Mech. Eng. Sci. 5, 6**	Year **2**
Subject **Fluid Mechanics**	Semester (s) **1 and 2**
Laboratory Title **Orifice Plate**	

Objective
The method of operation of an Orifice Plate as means of measuring volume flow rate is investigated. The Bernoulli Equation will be used to relate the pressure drop across the orifice to the volume flow rate through the orifice.

Theory
As indicated in figure 1 liquid issues from the orifice as a free jet. Fluid approaching the orifice converges and the streamlines continue to converge beyond the orifice to the vena contracta, and then diverge.

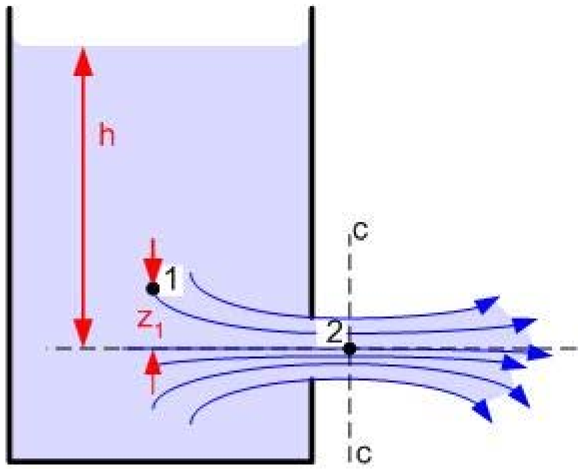


Figure 1: Schematic of Test Rig

The Bernoulli Equation (1) represents energy conservation within an incompressible fluid flow and therefore can be used to relate velocity of the flow through the orifice to the pressure within the tank.

$$P + \frac{1}{2}\rho U^2 + \rho g h = const \qquad (1)$$

Equipment
As indicated in figure 1 the rig consists of a large water tank with a replaceable orifice plate (*D = 3.1; 6.0mm*) in one of the walls. The level of the water is kept constant throughout testing and the flow rate can be measured using a graduated cylinder and a stop-watch.

Procedure
1. For a least 3 tank water levels (or pressure heads) measure the volume flow rate through the orifice.
2. Repeat for two different orifice diameters.
3. Starting with the Bernoulli Equation (1) show that the theoretical volume flow rate can be calculated from the pressure head in the water tank:

$$Q_{th} = A\sqrt{2gh} \qquad (2)$$

4. Plot the measured volume flow rate against the theoretical flow rate and determine the equation of the best fit linear to the data.
5. Determine the loss coefficient, C_d and compare with reported values in textbooks or published research.

Reference

"Mechanics of Fluids", B. S. Massey

Laboratory Sheet for the Experiment

Orifice Plate

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

Starting with the Bernoulli Equation, show how the volume flow rate from an orifice is calculated:

From your experimental settings, can you calculate* the theoretical volume flow rate?

From your experimental results, can you calculate* the actual/measured flow rate?

How does the theory compare to experiment? Why is it different?

How do your findings compare to literature**?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations
**Some reference books are available from the demonstrator

Module (s) **B58EE, B58EF–Mech. Eng. Sci. 5, 6**	Year **2**
Subject **Fluid Mechanics**	Semester (s) **1 and 2**
Laboratory Title **Pipe Friction**	

Objective
The pressure drop in a pipe flow due to surface roughness is to be investigated for a wide range of flow rates that account for laminar, transitional and fully turbulent conditions.

Theory
The Reynolds number (1) is a dimensionless number which represents the ratio of inertial forces to viscous forces within a fluid flow. The Reynolds number for pipe flow is calculated using the pipe diameter (*D*) as the length parameter. When inertial forces dominate the flow is turbulent and similarly when viscous forced dominate the flow is laminar. Therefore there exists a critical Reynolds number where the flow transitions from laminar to turbulent. For a pipe flow this transitional Reynolds number is approximately equal to 2000.

$$\mathrm{Re} = \frac{\rho U D}{\mu} \qquad (1)$$

Pressure drop (Δp) over a length of pipe (l) is a function of average fluid velocity in the pipe. In the laminar flow range, the pressure drop per unit length is directly proportional to the velocity:

$$\frac{\Delta p}{l} \propto U \qquad (2)$$

At higher Reynolds numbers an abrupt increase in the pressure drop is observed in the transitional range where it is impossible to define a simple relationship between pressure drop and velocity. At higher Reynolds numbers again, where the flow in the pipe is fully turbulent the relationship becomes exponential such that:

$$\frac{\Delta p}{l} \propto U^2 \qquad (3)$$

Equipment
Water is pumped through a long (2*m*) stainless steel pipe (internal diameter, *D* = 6.0*mm*) which has two pressure tappings. These tappings are connected to opposite ends of a differential manometer which indicates the pressure drop due to pipe friction between the two points.

Procedure
1. Measure the pressure drop for an extensive range of pipe flow rates. Measure the volume flow rate using a graduated cylinder and a stopwatch.
2. For each test, calculate the Reynolds number (*Re*) and the head loss due to friction:

$$h_f = \frac{\Delta p}{\rho g} \qquad (4)$$

3. Hence determine the friction factor (*f*) from the Darcy-Weisbach equation:

$$h_f = \frac{4fl}{D}\left(\frac{U^2}{2g}\right) \qquad (5)$$

4. Plot the friction factor, *f* against Reynolds number, *Re* on a log-log scale for all flow rates.
5. Determine the critical or transitional Reynolds number. Comment on your results by comparing with theory and the Moody diagram on the next page.

Reference
“Mechanics of Fluids”, B. S. Massey

Laboratory Sheet for the Experiment

Pipe Friction

.

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

How can you predict if the pipe flow is laminar or turbulent?

What is the difference between laminar and turbulent Flow; will it affect pressure drop?

Calculate* the pressure head loss due to friction:

Calculate* the friction factor for the pipe flow:

Are your results consistent with the Moody Diagram**? How do they compare?

From your results can you make recommendations to reduce pipe friction losses in a system?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations

**A Moody Diagram and some reference books are available from the demonstrator

Module (s) **B58EC, B58ED–Mech. Eng. Sci. 3, 4**	Year **2**
Subject **Dynamics**	Semester (s) **1 and 2**
Laboratory Title **Wheel and Axle Acceleration**	

Objective: To predict the time taken for a wheel to roll on its axle, down a slope using energy methods

Theory:
Energy Method

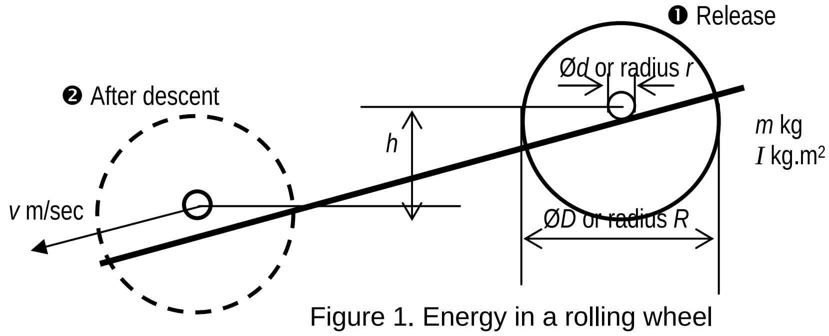


Figure 1. Energy in a rolling wheel

Referring to Figure 1 when the wheel is released from rest and subsequently rolls down the slope, it accelerates and hence gains energy. Now for a rolling wheel the kinetic energy has two components, translational due to the bodily movement of the mass centre down the slope and rotational due to the wheel spin. Now the source of this energy is the loss in potential energy as the wheel moves down the slope. If it is reasonable to assume that friction effects are insignificant then no energy is lost. Thus the loss in potential energy becomes a gain in kinetic energy.

Hence,

Loss in potential energy = mgh, is equal to the (1)
Gain in kinetic energy = $0.5mv^2 + 0.5I\omega^2$ (2)

where v = velocity of the mass centre down slope (m/sec)
ω = angular velocity of wheel (rad/sec)
= v/r, r is the axle radius when rolling
I = Polar moment of inertia = $mR^2/2$

Applying conservation of energy, equate equations 1 and 2 to derive an expression for the velocity v at the bottom of the slope. Using the linear equations of motion, find the expression for time t. Show these derivations in your report.

Experiment:
Using the measured distances (100mm to 500mm, intervals of 100mm) travelled by the wheel and the expressions i.e. (1) velocity at bottom of slope and (2) acceleration down the slope, calculate the time taken for the wheel to roll down the slope. Compare the calculated values with the experimental data

Discussions:
Plot a graph of time t^2 vs distance s for calculated and experimental data. Explain the discrepancies between calculated values and experimental data. Discuss and quantify sources of errors.

Laboratory Sheet for the Experiment

Wheel and Axle Acceleration

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

Applying conservation of energy, show how the time of rolling wheel is calculated:

From your experiment, can you calculate* the theoretical time of rolling wheel?

From your experimental results, can you calculate* the actual/measured time?

How does the theory compare to experiment? Why is it different?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations
**Some reference books are available from the demonstrator

Module (s) **B58EC, B58ED–Mech. Eng. Sci. 3, 4**	Year **2**
Subject **Dynamics**	Semester (s) **1 and 2**
Laboratory Title **Trifilar Suspension**	

Objective:

To calculate the polar moment of inertia of an assembly and using the result to predict the periodic time of a trifilar suspension of the assembly.

Theory:

The moment of inertia of a solid object is obtained by integrating the second moment of mass about a particular axis. The general formula for inertia is:

$$I_g = mk^2$$

where I_g = inertia in *kg.m*^{2} about the mass centre
m = mass in *kg*
k = radius of gyration about mass centre in *m.*

In order to calculate the inertia of an assembly, the local inertia I_g needs to be increased by an amount mh^2.

where m = local mass in *kg*
h = the distance between parallel axis passing through the local mass centre and the mass centre for the overall assembly.

The Parallel Axis Theory has to be applied to every component of the assembly. Thus

$$I = \sum \left(I_g + mh^2 \right)$$

The polar moments of inertia for some standard solids are:

Cylindrical solid	$I_0 = \dfrac{mr^2}{2}$
Circular tube	$I_{tube} = \dfrac{m}{2}\left(r_o^2 + r_i^2\right)$
Square hollow section	$I_{sq.section} = \dfrac{m}{6}\left(a_o^2 + a_i^2\right)$

An assembly of three solid masses on a circular platform is suspended from three chains to form a trifilar suspension. For small oscillations about a vertical axis, the periodic time is related to the Moment of Inertia.

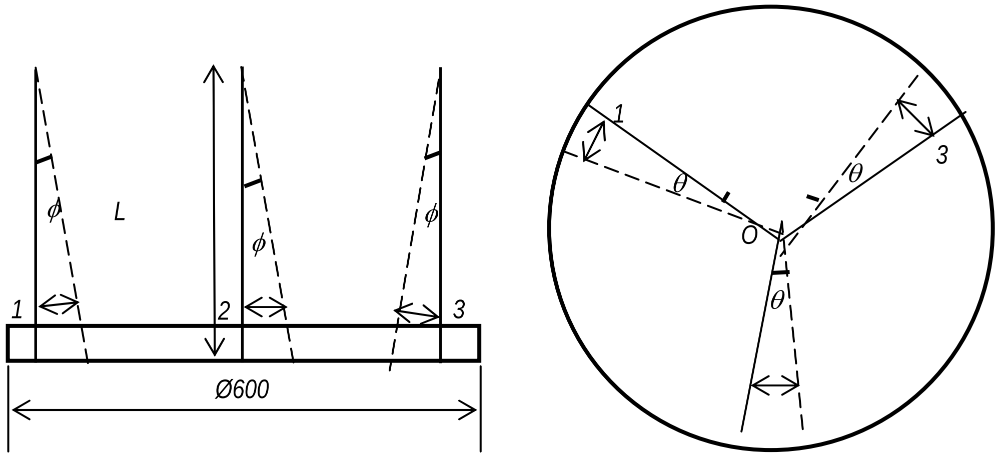


Figure 1. Trifilar suspension

From Figure 1, the equation of motion is:

$$I\frac{d^2\theta}{dt^2}+\frac{mgR^2}{L}\theta=0 \qquad (1)$$

Comparing this to the standard equation (2nd order differential equation) for Simple Harmonic Motion (SHM),

$$\frac{d^2y}{dx^2}+\omega^2x=0 \qquad (2)$$

the frequency ω in radians/sec and the period T in seconds can be calculated by:

$$\omega=\sqrt{\frac{mgR^2}{LI}} \qquad (3)$$

and

$$T=2\pi\sqrt{\frac{LI}{mgR^2}} \qquad (4)$$

Assuming the general solution for the equation (1) is $\theta=\theta\sin(\omega t)$, solve the differential equation (1) to obtain equation (3) and use frequency $\omega=2\pi f$ to obtain equation (4). Show the derivation in your report.

Experiment:

A circular plywood platform, as shown in Figure 2, has three solid masses located as shown with reference to the centre of the platform. Using a spreadsheet or otherwise devise a tabular method for calculating the polar moment of inertia of the platform alone and the assembly.

Measure the length of the chains supporting the platform.

In your case, use apparatus A or the alternative B, and the three radii to be used are:

R_1 = ___________ mm for hollow square section;

R_2 = ___________ mm for cylinder;

R_3 = ___________ mm for the circular tube.

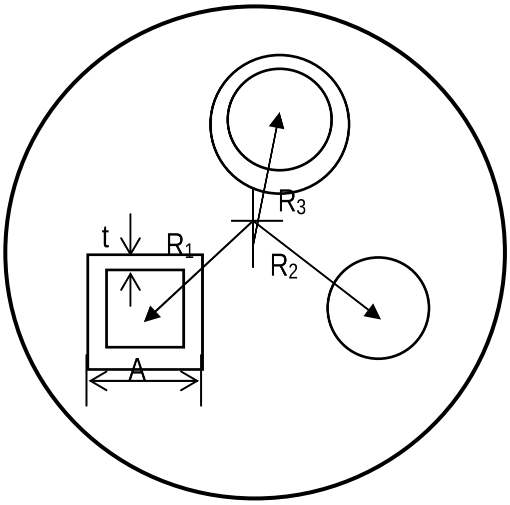


Figure 2. Assembly details

Using the result of your calculation of inertia to predict the periodic time of the SHM for both the platform and the assembly.

Assemble the masses on the platform as specified above and obtain an experimental value for the period. Repeat the experiment for the platform alone.

Compare calculated values and experimental data, and explain the discrepancies. Discuss and quantify sources of errors.

Discussions:
Compare the experimental time and calculated time t from equation 4. Determine the %error and identify and explain the sources of error.

Plot a graph of time vs $\sqrt{\frac{I}{m}}$ for experimental and calculate data. Comment on the linearity of the graphs.

Apparatus Data:

Set A			Set B	
	Mass (kg)	Dimensions (mm)	Mass (kg)	Dimensions (mm)
Circular platform	2.0	Ø 600	2.7	Ø 600
Cylinder	6.82	Ø126	5.6	Ø129
Tube	2.196	78 I/D, 98 O/D	1.29	87 I/D, 102 O/D
Square Section	2.503	A=100 t=6	2.37	A=100 t=6.5

Density of mild steel, $\rho_{steel} = 7{,}800 kg/m^3$.

Laboratory Sheet for the Experiment

Trifilar Suspension

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

Applying simple harmonic motion, show how the time of rolling wheel is calculated:

From your experiment, can you calculate* the theoretical period of trifilar suspension?

From your experimental results, can you calculate* the actual/measured period?

How does the theory compare to experiment? Why is it different?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

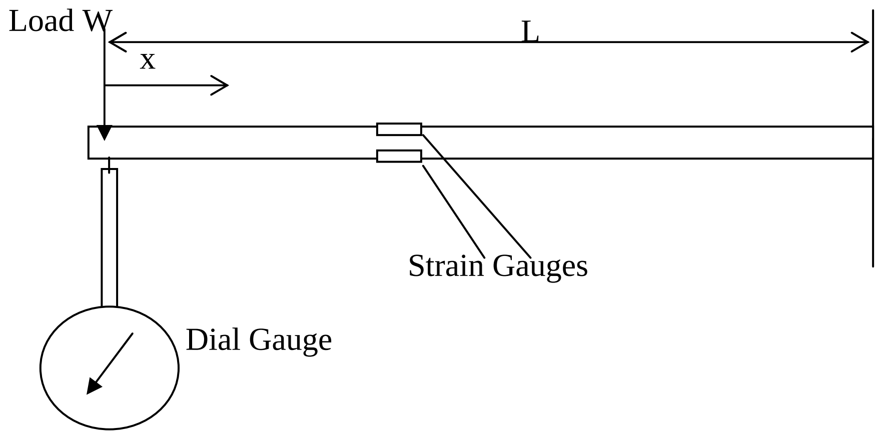
*Show sample calculations
**Some reference books are available from the demonstrator

Module (s) **B58EC, B58ED–Mech. Eng. Sci. 3, 4**	Year **2**
Subject **Mechanics of Materials**	Semester (s) **1 and 2**
Laboratory Title **Cantilever beam**	

Objective
To investigate the relationships between load, bending moment, stress and strain, slope and deflection in a cantilever beam.
Venue and Time
Location: Mechanical Engineering workshop area.
Time: Please refer to the timetable and group numbers.

Equipment

- 1 Bench.
- 2 G clamps to fix beam to bench.
- 1 Aluminium cantilever beam (E ≈ 70GPa), with strain gauges top and bottom. The beam will be marked at 50 mm intervals on both top and bottom surfaces.
- 1 Strain gauge bridge amplifier with digital readout in microstrain.



Note: The bridge amplifier readings is the difference in strain between the top and bottom surfaces of the beam.

- 1 Hanger with weights for loading beam.
- 1 Dial gauge, on long retort stand.
  Note: dial gauge may read in imperial or metric units – check which you've got.

Before you start,

- Note the serial number of your beam (#1, #2, ...)
- Measure the beam thickness and width.
- Measure the distance from the strain gauge to the end of the bench (the built-in end of the cantilever).

Procedure

1. Clamp one end of the beam to the edge of the bench using the G clamps so that your cantilever is 500 mm long. Place the weight hanger over the free end of the cantilever. Position the dial gauge to measure the beam deflection near the free end of the cantilever. Weight the end with at least 8 different loads, and for each loading record the strain and the deflection due to the applied load. Plot graphs of strain vs. load and deflection vs. load on separate sheets of graph paper *before going on the next part*.

2. Clamp the beam further along, so that your cantilever is around 400 mm long—the strain gauges must not be within 50 mm of the clamped section. Load the end, and for each loading

record strain and deflection. Plot these results in the same graphs as your previous results (one graph for strain, a separate graph for deflection). Before continuing to the next section, calculate the strain and deflection predicted by theory and compare with your results (see attached for theory).

3. Clamp the beam in the vice again so that your cantilever is at least 500 mm long. Weight the end with 2 different loads (e.g. 500g and 1000g), and measure the end deflection for zero load and each of the two loads. *There is no need to record strain for these measurements.* Repeat this process, shifting the position of the dial gauge 50 mm each time so that you measure deflection for at least 5 points along the beam. Plot your results – the beam deflection against position along the beam i.e. the deflected shape of the beam – on a single set of axes and compare against theory.

Reporting
The lab report shall contact abstract, introduction, apparatus, theory, method, results, discussion, and conclusions. For theoretical background, you must demonstrate that you have done some relevant background reading on the subject under study for this experiment. You must present the underpinning equations of the principles demonstrated in this lab.

Your report should summarise the relationships between deflection and load, and, strain and load for a cantilever beam – using the various experimental data obtained to illustrate the form of the relationship. In particular, you should comment on the errors between theory and experiment. What are the potential error sources? (Questions to ask yourself are: whether the Young's modulus value given is accurate for this sample of aluminium, how maximum stress and deflection in a cantilever beam scale with the length, breadth, and thickness of the beam and therefore what effect a small error in measurements of these values would have). The report should then assess how your measurements agree with theoretical predictions, and provide credible explanations for any departures from theory.

For bonus marks take your data from the 3rd experiment and obtain the gradient of deflection against position along the beam for each of the two data sets. Plot these gradients against position in a separate graph. Plot the theoretical curve on this graph in order to compare your results with theory.

Please indicate on your report the date on which you did the experiment and the other members of the group you shared the apparatus with.

Laboratory Sheet for the Experiment

Cantilever Beam

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

Using experimental data, can you summarise the relationships between deflection and load for a cantilever beam?

Using experimental data, can you summarise the relationships between strain and load for a cantilever beam?

Could you comment on the errors between theory and experiment if any? What are the potential error sources?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations
**Some reference books are available from the demonstrator

Module (s) **B58EC, B58ED–Mech. Eng. Sci. 3, 4**	Year **2**
Subject **Mechanics of Materials**	Semester (s) **1 and 2**
Laboratory Title **Torsion Laboratory**	

Laboratory handout and laboratory sheet will be available in week 8 of semester

APPENDIX C

Year 3 Module Descriptors

Module (s) **B59EI, B59EJ–Mech. Eng. Sci. 9, 10**	Year **3**
Subject **Thermodynamics**	Semester (s) **1 and 2**
Laboratory Title **Heat Loss from Pipes**	

Objective

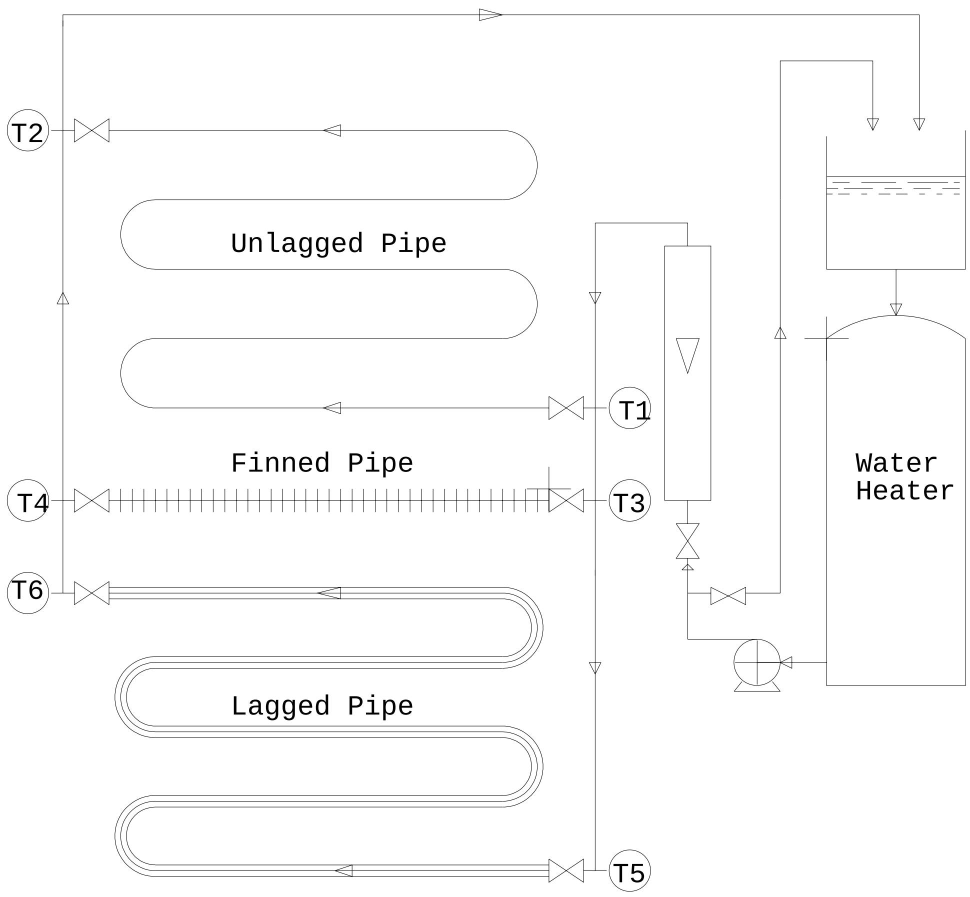
To find the heat loss, by natural convection, from various pipes by experiment and theoretical calculations. Available are sections of unlagged, lagged and finned pipe.

The results obtained in practice and by theory can be then compared as well as the differences in heat loss from the various pipes.

Context

Heat is always lost from hot surfaces in a cold environment (heat is also gained by a cold surface in a hot environment). This experiment investigates the amount of heat lost from a tube with a bare surface, an insulated surface and a finned surface. The finned surface is designed to improve heat loss (for example the condenser or evaporator in a heat pump) and the insulated surface is designed to reduce heat loss (for example lagging on the pipes and devices in a steam power plant).

Diagram



Basic Theory

From the experiment, when it is in steady state, the heat loss from each pipe section can be calculated from simple calorimetry.

Rate of heat Loss, $\dot{Q} = \dot{m}c_p\left(T_{in} - T_{out}\right)$

Where $\dot{m}$ = Mass flowrate of water, kg/s
c_p = Specific heat capacity of water, J/kgK
T = Water temperature K

This heat loss can also be calculated from theory by finding the heat loss by natural convection from the surface of the pipe, plus the heat loss by radiation from the pipe.

In its simplest form heat loss by convection, $\dot{Q}_c = \alpha_c A \Delta T$

α_c	Heat transfer coefficient for natural convection for horizontal pipes	$1.18\left(\Delta T / d\right)^{\frac{1}{4}}$	$W/m^2.K$
d	Outside pipe diameter		m
A	Surface area for heat transfer		m^2
ΔT	Temperature difference	$T_{avge} - T_{amb}$	K
T_{avge}	Average of inlet and outlet temperatures	$\left(T_{in} + T_{out}\right)/2$	K
T_{amb}	Ambient Temperature		K

and heat loss by radiation, $\dot{Q}_r = eA\sigma\left(T_{avg}^4 - T_a^4\right) = \alpha_r A \Delta T$

α_r	Heat transfer coefficient for radiation	$\frac{\sigma.e}{\left(T_{avge} - T_{amb}\right)}.\left(T_{avge}^4 - T_{amb}^4\right) = \left(T_{avge}^2 + T_{amb}^2\right)\left(T_{avge} + T_{amb}\right)$	$W/m^2.K$
σ	Stefan-Boltzmann constant		$W/K^4.m^2$
e	Emmissivity		-

Note: T <u>must be</u> in absolute units, i.e. K

Therefore the Theoretical Heat Loss, $Q_t = Q_c + Q_r$

This theory however can only be applied with reasonable accuracy to the unlagged pipe. Complications arise with the finned and lagged pipes.

With the lagged and finned pipe, full theoretical calculation of the heat loss is beyond the scope of this experiment at present

Method

Initially, the apparatus will be switched on with a low water flow going through the unlagged pipe only, with the thermostat set to 60^oC. When steady state has been reached (steady state being assumed when two sets of readings 5 minutes apart are identical), note the inlet and outlet water temperatures, water flowrate and ambient temperature. Repeat the experiment for each pipe configuration.

Increase the water flow rate (some multiple of the original flow rate). Leave to reach a steady state and note the temperatures and flow rate.

In summary you have to do 2 sets of runs. Each run consists of steady state conditions for each of the three pipe systems.

- Set 1 – High temp and low flow rate
- Set 2 – High hemp and high flow rate

Some points for discussion

Before outlining some possible points to discuss it is worth remembering that temperature difference is the main driving force behind any transfer of heat.

Below are some discussion topics, *they are by no means exhaustive.*

- The effect of flow rate on heat loss in unlagged pipe. What is changing, how will it affect heat transfer?
- You are measuring small temperature differences of inlet and outlet water flow. What is the accuracy of temperature measuring instrument, how could this affect your calculations?

Data

Pipe Material	Copper
Pipe O.D's	1.27×10^{-2} m
Pipe I.D's	0.91×10^{-2} m
Pipe lengths	to be measured
Fin diameter	to be measured
No. of fins	to be counted
Lagging thickness	to be measured
Lagging O.D.	to be measured
Emissivity of Copper	0.78
Emissivity of lagging	0.9
Stefan-Boltzmann Constant	5.6688×10^{-8} $W/K^4.m^2$
Specific Heat of water	4.18 kJ/kg.K
Thermal Conductivity of lagging	1.9×10^{-2} BTU/hr.ft.^oR

Laboratory Sheet for the Experiment

Heat Loss from Pipes

Mechanical Engineering Science 9

Name: **Registration No.:**

Briefly summarise in your own words the purpose of this laboratory.

For the plain tube, conduct a heat balance (heat loss by fluid = heat gain by the environment) and comment on the outcome for both flow rates.

For a constant flow rate, are the heat loss from each pipe as you would expect? Comment

For the finned tube, what design features of the fins do you think are critical for heat transfer?

Is it possible to quote and "efficiency" for this thermodynamic process?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

This sheet is to be returned through Vision within one week of conducting the laboratory

Module (s) **B59EI1, B59EJ–Mech. Eng. Sci. 9, 10**	Year **3**
Subject **Thermodynamics**	Semester (s) **1 and 2**
Laboratory Title **Forced Convection** (in a Cross Flow Heat Exchanger)	

Introduction

This experiment can be used to investigate heat transfer associated with flow past cylindrical tubes either in isolation or in banks of various configurations. Flow patterns upstream and downstream of a bank of tubes can also be investigated.

There is an operator's manual available for this experiment in which there is a full description of all variables that can be investigated.

Context

In semester 1 there has been mention of heat exchangers in a number of power cycles: the *feed heating* in steam power plant regeneration and the *regenerator* in the gas power plant. The majority of heat exchangers use banks of pipes. Pipes have many advantages both in terms of strength (internal and external pressure) and manufacture. This experiment allows students to investigate the heat transfer characteristics of air flow across a single tube.

In semester 2, the subject of heat transfer is investigated further including the theoretical determination of the heat transfer coefficient from first principles for different geometries.

In the fourth year, the second thermodynamics module investigates the design of heat exchangers.

Objective

To determine the heat transfer characteristics of a cylinder under cross flow conditions when the cylinder is isolated.

Description

Figure 1 shows the test section which can contain a bank of 18 removable Perspex rods. Any rod can be interchanged with a test rod which consists of a copper cylinder containing a copper - constant thermocouple. The heat flow rate from the test rod is found by heating the cylinder in an electrical heater, placing it in the desired position in the test section and measuring the cooling rate using a chart recorder connected to the thermocouple.

Theory

Considering the heat lost by forced convection form the test rod. The amount of heat transferred is given by

$$\dot{Q} = \alpha A\left(T - T_a\right) \text{..(1)}$$

where $\dot{Q}$ = rate of heat transfer, W
α = film heat transfer coefficient, W/m^2K
A = area for heat transfer, m^2
T = temperature of the copper rod, ^oC or K
T_a = temperature of air, ^oC or K

so, in any period of time, *d*t, then the fall in temperature, *d*T, will be given as :-

$$-\dot{Q}dt = m\,c_p\,dT \text{ ....(2)}$$

where m = mass of copper rod, kg
c_p = specific heat of the copper rod, J/kgK

Eliminating Q from (1) and (2) then

$$\frac{-dT}{T-T_a} = \frac{\alpha A}{m\,c_p}dt$$

since T_a is constant, $dT=d(T-T_a)$

Integrating gives:

$$\ln\left(T-T_a\right) = -\frac{\alpha A}{m\,c_p}t + C_1$$

at t = 0, T=T_o, hence C_1 = ln(T-T_o), hence:

$$\ln\left(T-T_a\right) = -\frac{\alpha A}{m C_p}t + \ln\left(T_0 - T_a\right)$$

Or

$$\ln\left(\frac{T-T_a}{T_0-T_a}\right) = -\frac{\alpha\,A}{m\,c_P}t$$

Therefore a plot of $ln((T-T_a)/(T_{max}-T_a))$ against t should give a straight line of gradient $-\alpha A/m\,c_p$ from which the heat transfer coefficient, α, can be found.

To find the velocity of air passing the rod, first the velocity upstream must be found.

From basic fluid flow theory

$\Delta P = \rho.v^2/2$ in the air stream

and $\Delta P = \rho.g.h$ in the measuring manometer

therefore

$$\frac{\rho_a.v^2}{2} = \rho_w.g.h \text{ ....(3)}$$

where ρ_a = density of air
ρ_w = density of fluid in manometer
v = mean velocity of air
h = head in manometer

Therefore measuring the air temperature and air pressure the density can be found,

$$\rho_a = \frac{P_a}{RT_a}$$

Where R=289 J/kg K. $v^2 = \dfrac{2\rho_w g\,h}{\rho_a}$

if ρ_w is taken as 1000 kg/m^3 and h is measured in m, then $v = 140.1\sqrt{\dfrac{h}{\rho_a}}$

however the velocity, u, used in heat transfer calculations is normally based on the minimum flow area.

Therefore with the single rod - $u = \dfrac{10v}{9}$, since

Practical forced convection heat transfer relationships are often expressed in the dimensionless form

$$Nu = C.Re^n.Pr^m$$

However for gases, Pr is virtually constant, therefore

$$Nu = K.Re^n$$

Typical *K* and *n* values are (for Pr ≅ 0.7)

Re	K	n
3 - 35	**0.795**	**0.384**
35 - 5000	**0.583**	**0.471**
5000 – 50 000	**0.148**	**0.633**
50 000 – 230 000	**0.0208**	**0.814**

Method (part a – Figure 1)

Remove all rods from the test section and plug the all holes except one from each side where the test rod will be inserted.

After heating the rod for approximately 10 minutes (i.e) until the chart recorder reaches maximum deflection; place it in position (a) (see figure 1) and record the temperature - time curve using the chart recorder. Do this for, at least, 6 different air flow rates by adjusting the orifice slide on the air outlet from between 10% and fully open. After initial heating of the test rod, reheating times between runs can be reduced to a few minutes as there will still be a significant amount of residual heat in the rod.

Data Surface area of copper cylinder = 0.00404 m^2
Mass of copper cylinder = 0.1093 kg
Specific heat of copper = 0.38 kJ/kg.K

For a Copper/Constantan thermocouple, 0.041 mV is equivalent to 1°C over the range of temperatures expected in this experiment.

Width of working section = 125 mm
Height of working section = 125 mm
Diameter of rod = 12.5 mm

Nu = Nusselt Number, $\dfrac{\alpha d}{k}$

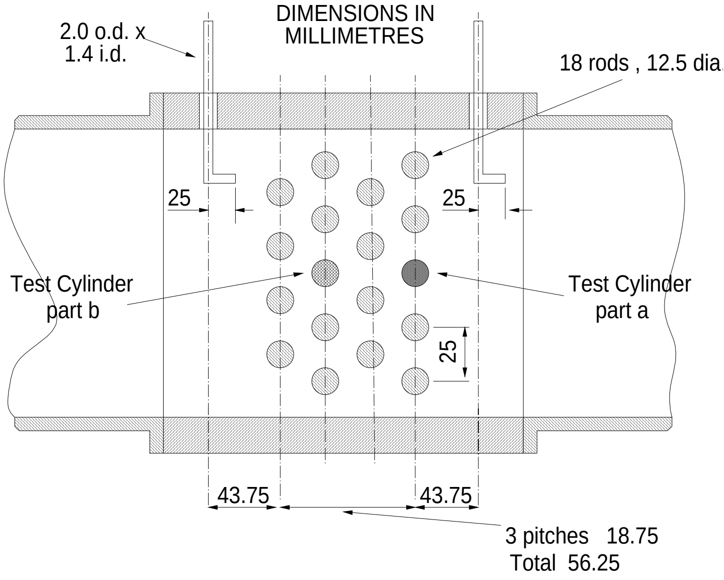
Re = Reynold's Number, $\dfrac{\rho_a . v . d}{\mu}$

Pr = Prandtl Number, $\dfrac{C_p . \mu}{k}$

where *d* = diameter of rod, m
k = thermal conductivity of air, W/mK
μ = viscosity of the air, kg/ms

Properties of air

T	μ	k	ρ (at 1 atm)
275	1.725	2.428	1.284
300	1.846	2.624	1.177
	x 10^{-5} (kg/ms)	x 10^{-5} (kW/mK)	kg/m^3



DIMENSIONS IN
MILLIMETRES
2.0 o.d. x
1.4 i.d.
18 rods , 12.5 dia
25
25
Test Cylinder
part b
Test Cylinder
part a
25
43.75
43.75
3 pitches 18.75
Total 56.25

Figure 1

Laboratory Sheet for the Experiment

Forced Convection (in a Cross Flow Heat Exchanger)

Mechanical Engineering Science 9

Name: **Registration No.:**

Briefly summarise in your own words the purpose of this laboratory.

For one airflow, compare the actual heat transfer coefficient measure in the experiment with the theoretical value and comment on the result

What can be deduced about heat transfer coefficient and air flow rate?

What effect would having a tube bundle have on the heat transfer from each tube in the bundle?

How would an increase in tube diameter effect the heat transfer?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

This sheet is to be returned through Vision within one week of conducting the laboratory

Module (s) **B59EI, B59EJ–Mech. Eng. Sci. 9, 10**	Year **3**
Subject **Fluid Mechanics**	Semester (s) **1 and 2**
Laboratory Title **The Centrifugal pump**	

Experiment:

The Centrifugal pump is a machine used to convert shaft power to pressure energy and is used to drive fluids through fluid circuits or pipe systems. The Centrifugal pump is a rotodynamic machine. There is a link between the flow rate through the pump and the pressure gained by the flowing fluid. The purpose of this experimental programme is to obtain the pump characteristics showing the relationship between the pressure rise across the pump and the flow rate through it and the efficiency of this process.

The pump can be run as two speeds. For each speed several flow rates through the pump needs to be set so that the pressure rise across it and the power consumed by it can be measured.

The flow rate is obtained from the rotameter. The height is read off the meter and converted to a flow rate on the chart provided.

The pressure rise across the pump is measured on the differential pressure gauge.

The electrical power to the pump is obtained from the measured voltage and current and using

$$P_s = VI$$

The fluid power is obtained from

$$P_F = Q\Delta p$$

And the efficiency from

$$\eta = \frac{P_F}{P_E}$$

Analysis
The analysis should contain at least the following parts:-

For both speeds:
The maximum operating efficiency
The specific speed of the machine

Report
One laboratory report should be produced in the standard format by each person.

Laboratory Sheet for the Experiment

The Centrifugal Pump

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

How can you calculate maximum fluid power for this experiment?

From your experimental setup what will be the operating efficiency of the Turbine?

Can you estimate maximum specific speed of the machine?

How can you improve the maximum operating efficiency?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

Module (s) **B59EI, B59EJ–Mech. Eng. Sci. 9, 10**	Year **3**
Subject **Fluid Mechanics**	Semester (s) **1 and 2**
Laboratory Title **The Pelton Wheel**	

Experiment:
The Pelton Wheel is a machine used to convert pressure energy to shaft power, which could be used to drive an electric generator. The Pelton Wheel consists of a number of blades, sometimes called buckets, that are struck by a fluid jet to create rotational motion. The purpose of this experimental programme is to obtain power output data in terms of rotational speed for a fixed inlet condition. This relationship should be compared on a graph with the experimental data obtained showing where the maximum efficiency should occur.

The upstream pressure of the water approaching the wheel is set using the Bourdon gauge. A value of 40psi is typical. The velocity of the water jet approaching the wheel can be found from

$$U = \sqrt{\frac{2P}{\rho_w}}$$

The flow rate should be set using the venturi meter. A flow corresponding to 18 inches of Mercury on the differential manometer is reasonable. The pressure drop across the venturi meter can be found from

$$\Delta p = (\rho_m - \rho_w) gh$$

And the flow through the venture from

$$Q = C_v \sqrt{\frac{2\Delta p}{\rho_w}} A_t \left[1 - \left(\frac{A_t}{A} \right)^2 \right]^{-1}$$

The venturi meter has an upstream diameter of 76.2 mm, a throat diameter of 41 mm and a velocity coefficient of 0.921.

The rotational speed can be altered by adding mass to the band break, 1 kg at a time is typical. NB: The weight hanger has a mass of 1.9 kg. The tension in the band break is the difference between the applied weights and the spring balance. The break torque can be found from

$$T = (W - S) R_B$$

The wheel radius is 0.168 m. The rotational speed can be measured by the rev counter. The output power can be found from

$$P = T\omega$$

Analysis
The analysis should contain at least the following parts:-

A derivation of the Pelton Wheel relationship

$$\eta = 2 \frac{\omega R}{U} \left(1 - \frac{\omega R}{U} \right) (1 - \cos\theta)$$

The blade radius is 0.124 m and the blade angle is about 165^{o}.

Report
One laboratory report should be produced in the standard format by each person.

Laboratory Sheet for the Experiment

The Pelton Wheel

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

How can you calculate maximum flow through the venture from this experiment?

From your experimental setup what will be the maximum output power?

Can you estimate maximum pressure drop across the venture meter?

Give some recommendations to improve maximum obtainable power from the Wheel?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

Module (s) **B59EI, B59EJ–Mech. Eng. Sci. 9, 10**	Year **3**
Subject **Fluid Mechanics**	Semester (s) **1 and 2**
Laboratory Title **The Francis Turbine**	

Experiment:
The Francis Turbine is a machine used to convert pressure energy to shaft power, which could be used to drive an electric generator. The Francis Turbine is a reaction turbine. It consists of a stationary vane that guides the fluid into a rotor. As the fluid moves through the turbine there is an interaction between the fluid pressure and velocity as the machine, which runs full of fluid, generates power. The purpose of this experimental programme is to obtain power output data in terms of rotational speed for a fixed load and hence to deduce the maximum efficiency of the machine.

The load on the machine should be set. The load carrier has a mass of 1.9 kg, a further 15 kg should be added. The flow rate to the machine should be altered so that the inlet pressure changes. For inlet pressures between 10 and 20 psi, the change should be 1psi, otherwise it should be 2 psi. The maximum pressure should not exceed 47psi. At every inlet pressure setting, readings should be taken of the volume flow rate through the machine, the exit pressure, the angular velocity and the force on the spring balance.

The flow rate should is obtained from the venturi meter. The pressure drop across the venturi meter can be found from

$$\Delta p = (\rho_m - \rho_w) g h$$

And the flow through the venture from

$$Q = C_v \sqrt{\frac{2\Delta p}{\rho_w}} A_t \left[1 - \left(\frac{A_t}{A} \right)^2 \right]^{-1/2}$$

The venturi meter has an upstream diameter of 102 mm, a throat diameter of 66.7 mm and the velocity coefficient is 0.92.

The tension in the band break is the difference between the applied weights and the spring balance. The break torque can be found from

$$T = (W - S) R_B$$

The wheel radius is 0.179 m. The rotational speed can be measured by the tachometer. The output power can be found from

$$P = T\omega$$

Analysis
The analysis should contain at least the following parts:-

The maximum operating efficiency
The specific speed of the machine

Report
One laboratory report should be produced in the standard format by each person.

Laboratory Sheet for the Experiment

The Francis Turbine

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

How can you predict the pressure drop across the venturimeter?

From your experimental setup what will be the operating efficiency of the Turbine?

Can you estimate maximum possible operating efficiency from this experiment?

From your experimental results give some recommendations for improving operating efficiency.

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

Module (s) **B59EG, B59EH–Mech. Eng. Sci. 7, 8**	Year **3**
Subject **Dynamics**	Semester (s) **1 and 2**
Laboratory Title **One Degree of Freedom Vibration Experiment - Free & Forced Response**	

1. **Introduction**
   In this experiment a beam is pivoted at one end and is supported by a spring and a viscous damper placed along its length as shown in figure 1. The system is excited by an electric motor driving a pair of unbalanced discs. The linear displacement of the end of the beam is measured by an L.V.D.T. and the rotational speed of the unbalanced discs is obtained from a magnetic sensor. The aim of the experiment is to determine the mass moment of inertia of the assembly about the pivot, the value of the spring constant, K, and the rate of the viscous damper C. These experimental values will be validated finally by a simple frequency response test.

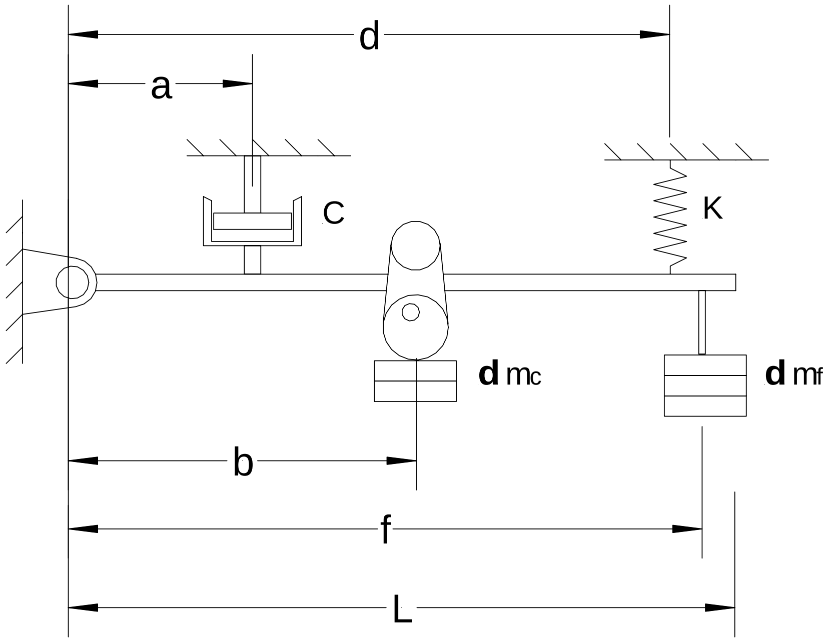


Figure 1 Sketch of Apparatus

2. Theoretical Considerations 1

The equation of motion for this system is:

$$I_o\ddot{\theta} + Ca^2\dot{\theta} + Kd^2\theta = me\omega^2 b\sin\omega t \qquad (1)$$

where I_o is the mass moment of inertia of the assembly about the pivot
C is the damper rate
K is the spring stiffness
m is the unbalance mass
e is the eccentricity of the unbalance mass
θ is the angular displacement of the beam.

All other symbols are defined in figure 1

(Note:
Your report should show how this equation is obtained.)

The system natural frequency of this system may be defined from equation (1) as:

$$\omega_n^2 = \frac{Kd^2}{I_o} \qquad (2)$$

and

$$\omega_n = 2\pi f_n = \frac{2\pi}{T_n} \qquad (3)$$

where f_n is the natural frequency in Hz and T_n is the natural period of oscillation. Then

$$\frac{4\pi^2}{T_n^2} = \frac{Kd^2}{I_o}$$

whence

$$T_n^2 = \frac{4\pi^2}{Kd^2} I_o \qquad (4)$$

The mass moment of inertia of the assembly about the pivot may be considered to be the sum of the mass moment of inertia of the beam, the mass moment of inertia of the fittings (treated as point masses) and the mass moment of inertia of any additional masses at the end of the beam (also point masses) about the pivot. i.e.

$$I_o = \frac{M_{beam} L^2}{3} + M_{drive} b^2 + \delta m_f f^2 \qquad (5)$$

The first two terms in equation (4) are constant and may be called I_{ass}:

$$I_{ass} = \frac{M_{beam} L^2}{3} + M_{drive} b^2$$

Then

$$I_o = I_{ass} + \delta m_f f^2 \qquad (6)$$

Substitution of equation (6) into equation (4) results in

$$T_n^2 = \frac{4\pi^2}{Kd^2}\left[I_{ass} + \delta m_f f^2\right] = \frac{4\pi^2 f^2}{Kd^2}\delta m_f + \frac{4\pi^2}{Kd^2} I_{ass} \qquad (7)$$

Questions:

If a graph of T_n^2 vs δm were to be plotted, what shape would it be?

How could you use this information to extract the spring stiffness *K* and the mass moment of inertia of the assembly I_{ass} from the graph?

3. Experiment 1

Determine the system natural frequency, and hence the natural period T_n, for a range of masses δm_f attached to the beam at location f by adjusting the speed of the drive until a resonant condition is observed. Plot a graph of T_n^2 vs δm_f and hence estimate the value of *K* and of I_{ass}. Check your value of I_{ass} from your knowledge of the mass of the rod and its fittings. Assume that the rod is made of mild steel with a density of 7850 kg/m^3.

4. Theoretical Considerations 2

The damping ratio ζ may be determined by several techniques. In this laboratory the logarithmic decrement method will be used to obtain an estimate of the damping.

4.1 Logarithmic Decrement

The logarithmic decrement technique is illustrated by figure 2 and theoretical notes on how it is developed are available in the third year course notes or in the course text book (W.T. Thomson)

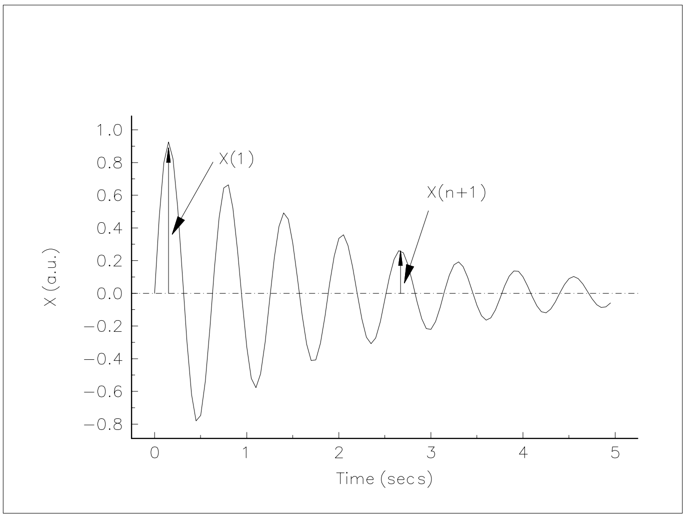


Figure 2

The damping ratio is obtained from measurements of *x(1)* and *x(n+1)* followed by substitution into:

$$Ln\left(\frac{x(1)}{x(n+1)}\right) = \frac{2\pi\zeta n}{\sqrt{1-\zeta^2}} \qquad (8)$$

4.1.1 Experiment 2

Use the apparatus provided to generate a ring-down curve similar to figure 2 and hence obtain an estimate of the damping ratio ζ using equation (8) and hence determine the damper rate *C*.

6. Validation

6.1 Experiment 3

With arbitrary loads (suggested by the lab supervisor) placed at positions b and f calculate the damped natural frequency of the system ($\omega_d = \omega_n\sqrt{1-\zeta^2}$). Use the apparatus provided to verify your calculated value.

B5.9EG1/EI2 Lab Marking Scheme – 1 degree of freedom

Item	Marks	Awarded
Proper derivation of equations of motion	3	
Description of apparatus	1	
Description of experiment, how to perform measurements resulting in a straight line graph, theoretical derivation of this	3	
Results	3	
Experimental and theoretical Estimates of Io, Do they agree? Estimates of stiffness *k* , damping ratio ζ and damping constant *C*	2	
Error analysis	2	
Use of experimental system model to confirm final resonant test	2	
Discussion, reasons for errors etc., why is final test so accurate?	4	
Total	20	

Laboratory Sheet for the Experiment

One Degree of Freedom

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

Indicate briefly how you would find the spring stiffness & moment of inertia from your graph

What are your experimentally determined values of stiffness and moment of inertia?

By how much does the theoretical inertia differ from the experimental value? Why?

What value of damping ratio did you obtain? What are the limitations of the log-decrement technique as applied in the lab and how would you overcome them?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations
**Appropriate reference books have been suggested in the lecture course

Module (s) **B59EG, B59EH–Mech. Eng. Sci. 7, 8**	Year **3**
Subject **Dynamics**	Semester (s) **1 and 2**
Laboratory Title **Design and Construction of a Dynamic Vibration Absorber**	

1) Introduction
In this experiment a vibration absorber will be designed to reduce the pitch vibration of the balancing rig to zero when it is excited at its natural frequency in pitch. It will be necessary to develop a mathematical model of the system to which end a knowledge of the system mass, inertia and stiffness properties will be required.

2) Mass and stiffness properties
To obtain the mass and stiffness properties experimentally the following procedure should be followed. Adjust the speed of the driving wheel until a resonant condition in heave (vertical motion) is observed and measure the associated frequency f_{n1} using the HP frequency analyser. Add a known mass δm to the frame using the weight carrier and repeat the above procedure measuring a new resonant frequency f_{n2}. Then because there are four springs, theory gives:

$$\omega_{n1} = 2\pi f_{n1} = \sqrt{\frac{4K}{M}} \qquad (1)$$

Where K is the (unknown) spring stiffness and M is the (unknown) frame mass

And
$$\omega_{n2} = 2\pi f_{n2} = \sqrt{\frac{4K}{M + \delta m}} \qquad (2)$$

From (1)

$$4\pi^2 f_{n1}^2 M = 4K$$

Substitute in (2)

$$2\pi f_{n2} = \sqrt{\frac{4\pi^2 f_{n1}^2 M}{M + \delta m}} = 2\pi f_{n1}\sqrt{\frac{M}{M + \delta m}}$$

Thus

$$f_{n2} = f_{n1}\sqrt{\frac{M}{M + \delta m}} \qquad (3)$$

Equation (3) can be solved for M and substitution into either (1) or (2) leads to an estimate of K.

3) Pitch frequency measurement and mass moment of inertia estimation
In this case we need to know the mass moment of inertia about the pitch axis of the apparatus. Carefully adjust the speed of the driving wheel until a resonant condition about an axis parallel to the driving wheel axis is observed. This is motion about the pitch axis. Note the approximate location of the pitch axis. Using the frequency analyser measure the frequency of pitch oscillations f_{np} and note the setting on the speed controller device. Theory tells us that:

$$\omega_{np} = 2\pi f_{np} = \sqrt{\frac{2K}{I_P}} \qquad (4)$$

Where I_P is the mass moment of inertia of the apparatus about the pitch axis which can be obtained from a solution of equation (4).

4) Check on the mass moment of inertia estimates
In order to give confidence in our calculations so far it is useful to estimate the mass moment of inertia of the apparatus from physical measurements of its dimensions. Measure the

dimensions of the angle iron frame upon which the apparatus is based and assuming a density ρ of 7850 kg/m^3 calculate the mass of the frame, M_f. Subtract this mass from that measured in part 2 to obtain the mass of the motor and driving wheel combined, M_{md} and assume that this is equally located on either side of the pitch axis observed in part (3). If it is assumed that the pitch axis passes through the centre of gravity of the frame, the mass moment of inertia about this axis may be approximated from:

$$I_P = \frac{M_f L^2}{12} + \frac{M_{md}}{2} b^2 + \frac{M_{md}}{2} b^2 = \frac{M_f L^2}{12} + M_{md} b^2$$

Where L is the length of the frame and b is half the distance between the axis of the motor and the axis of the driving wheel. Compare this value with that obtained in part 3

5) Design of the dynamic absorber

The vibration absorber will be designed to absorb vibrations at the natural frequency in pitch which you measured in part 3. Referring to the book by W.T.Thomson, "Vibration theory with applications" show that this means that the natural frequency of the absorber standing alone must be the same as the frequency which you are trying to absorb. Your report should show this.

The absorber will be constructed from the two steel rules attached to the underside of the apparatus to act as the spring elements of the absorber and from the mass carriers as its mass elements. From your notes in term 1 you will see that the stiffness of a cantilever beam may be approximated by:

$$k_b = \frac{3EI}{l^3}$$ where E is Young's modulus for the cantilever =207 GN/m^2, I is the second moment of area of the cantilever cross section and l is the length of the cantilever from its root to the added mass. Also from the notes we have an expression for the natural frequency of a mass on a light beam:

$$\omega_n = \sqrt{\frac{3EI}{M_a l^3}}$$ where M_a is the added mass.

Thus our vibration absorber design requires:

$$\omega_{np} = \sqrt{\frac{3EI}{M_a l^3}} . \qquad (5)$$

Measure the dimensions of the cantilever beam and calculate the second moment of area of its cross section. Then select a combination of M_a and l which solves equation (5) with the restriction that the value of M_a shall be no greater than 2% of the overall mass of the apparatus which you determined in section 2.

6) Install the absorber and tune it until the optimum response is obtained

7) Points for discussion in your report

a) Explain any differences between the predicted absorber performance and those required for optimum performance.
b) Is symmetry of the absorber locations important? Explain.
c) What is the effect of de-tuning?
d) What are the advantages and disadvantages of using a device such as this to remove unwanted vibrations?

B5.9EG1/EI2 Lab Marking Scheme – Vibration Absorber

Item	Marks	Awarded
Proper derivation of equations of motion showing how absorber works	3	
Description of apparatus	1	
Description of experiment.	4	

Estimation of strut length (*l*) strut second moment of area (*I*) and mass (M_a) of absorber	3	
Results including reduction in db(V) of vibration	3	
Error analysis	2	
Discussion, reasons for errors etc.	4	
Total	20	

Laboratory Sheet for the Experiment

Vibration Absorber

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

Summarise the values of mass, moment of inertia and spring stiffness found. Suggest how you could check these values through a rough estimation.

What were the heave and pitch natural frequencies you measured?

What absorber length and mass did you choose? Why?

Explain any differences between expected absorber performance and that which was observed.

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations
**Appropriate reference books have been suggested in the lectures.

Module (s) **B59EG, B59EH–Mech. Eng. Sci. 7, 8**	Year **3**
Subject **Dynamics**	Semester (s) **1 and 2**
Laboratory Title **Two Degree of Freedom Forced Vibration - Shear Building Model**	

1 Introduction

In this experiment a two storey steel framed structure is modelled as a two degree of freedom system. Framed structures have a number of degrees of freedom, each one being associated with a distinct frequency and associated vibration mode shape. The relative importance of each of these is determined by the frequency content of any external excitation (earthquakes, traffic, internal machinery etc.) which is present at the location of the structure. Usually the design is such that only a small number of vibration modes of the structure are important. Consequently a simple two-degree of freedom model, such as that illustrated in figure 1, demonstrates many of the significant features of such a structure.

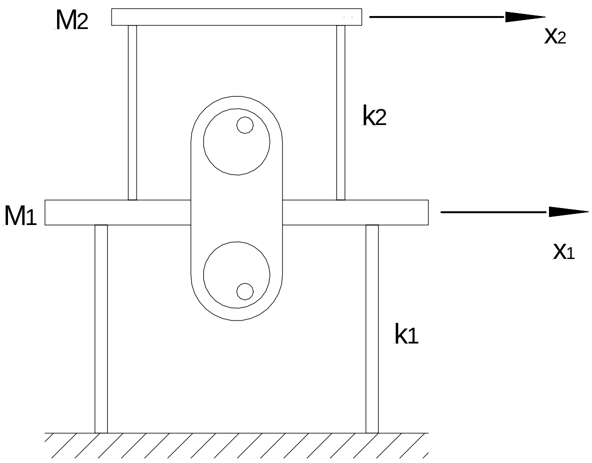


Figure 1 Shear Building Model

2 Theoretical considerations

By drawing free body diagrams for each of the masses M_1 and M_2 and applying Newton's second law to each of the masses it is possible to obtain the equations of motion for each mass.

$$\begin{aligned} M_1\ddot{x}_1 + k_1x_1 - k_2(x_2 - x_1) &= me\omega^2 \sin\omega t \\ M_2\ddot{x}_2 + k_2(x_2 - x_1) &= 0 \end{aligned} \qquad (1)$$

If only the natural frequencies and mode shapes for this system are of interest it is necessary simply to consider the equations of motion for free vibrations in which case the left hand side of the first of equations (1) may be set to zero. If the free vibration response is assumed to be sinusoidal such that

$$x_1 = X_1 \sin\omega t \qquad x_2 = X_2 \sin\omega t$$

which gives

$$\ddot{x}_{1,2} = -\omega^2 X_{1,2} \sin\omega t = -\omega^2 x_{1,2}$$

Then the frequency equation for this system may be found by evaluating the determinant of the equations of motion to be

$$M_1M_2\omega^4 - [k_1M_2 + k_2(M_1 + M_2)]\omega^2 + k_1k_2 = 0 \qquad (2)$$

Equation (2) is a quartic in ω but with no odd powers of ω. It can be solved by making the substitution $\lambda = \omega^2$ to produce a quadratic in λ which will yield the two natural frequencies of the system.

Note

The theoretical section of your report should show how equations (1) and (2) are obtained. As a guide you may wish to study (but not copy because it gives a slightly different system as an example) the course textbook, Theory of Vibration with Applications (ref Chap 5 in 4th edition)

3 Practical considerations

In order to use equation (2) in this experiment a knowledge of the spring stiffnesses and the system masses is required

4 Experiment 1

Estimate the masses M_1 and M_2 assuming that the plates are manufactured from mild steel of density 7850 kg/m^3. Include in the value of M_1 an allowance for the motor and motor base plate (written on these elements)

5 Experiment 2

Use the apparatus provided to obtain a load/deflection curve for both the upper and lower set of struts. Hence determine the spring stiffness for both sets of struts. For a single strut of the type used in this experiment which is assumed to be built-in at both ends the theoretical stiffness is

$$k = \frac{12EI}{L^3}$$

where E = 209 x 10^9 N/m^2 and I is the second moment of area of the strut section. Calculate the theoretical stiffnesses and account for any differences between these values and your experimental values. Note that in each case the theoretical stiffness for each storey should be greater than the corresponding experimental values. Explain this last remark.

6 Experiment 3

Use the apparatus provided to determine the system natural frequencies. This is most easily achieved by adjusting the speed of the motor until a resonant condition is observed at which point the motor speed (in rev/min) should noted. (Remember that there are two such conditions). At each resonant condition note and comment on the oscilloscope traces paying particular attention to their phasing.

7 Experiment 4

Using your estimates of masses M_1 and M_2 obtained in experiment 1 and the *experimental* values of stiffness obtained from experiment 2, solve equation (1) to determine the theoretical values of natural frequencies. Compare these values with the experimental values obtained from experiment 3. Why are the theoretical values so different from the experimental values?

B5.9EG1/EI2 Lab Marking Scheme – 2 degree of freedom

Item	Marks	Awarded
Proper derivation of equations of motion	3	
Description of apparatus	1	
Description of experiment, how to perform measurements resulting in straight line graphs.	4	
Results. Do measured and calculated natural frequencies agree?	3	
Experimental and theoretical estimates of strut stiffnesses, do they agree? Estimated values of masses.	3	
Error analysis	2	
Discussion, reasons for errors etc.	4	
Total	20	

Laboratory Sheet for the Experiment

Two Degree of Freedom

Name: **Registration No.:**

Why is this lab exercise useful; where can the results be used in engineering design/industry?

1.

2.

3.

What were the experimental spring stiffnesses? How did these compare with theoretical values? Why do they differ from theory?

Using experimental values for system parameters what are the calculated natural frequencies?

What are the experimental natural frequencies? Why do they differ from calculated values?

What are the two largest sources of error which you encountered in this experiment?

What can you conclude from this lab exercise? How do your findings relate to engineering design?

Please note that this experimental report summary is not a substitute for full and comprehensive laboratory experiment notes which will be used for full data analysis and reporting.

*Show sample calculations
**Appropriate reference books have been suggested in the lectures.

Module (s) **B59EG, B59EH–Mech. Eng. Sci. 7, 8**	Year **3**
Subject **Mechanics of Materials**	Semester (s) **1 and 2**
Laboratory Title **Finite Element Modelling and Design Exercise**	

These labs form a part of the continuously assessed part of the module in the form of a project and hence there is no separate laboratory in this subject. Two main themes of these projects are:

1) Finite Element Modelling

2) Design of Engineering Components involving thermal or creep effects and/or composite materials.

APPENDIX D

Submission Policy

HERIOT WATT UNIVERSITY

Policy on Submission of Coursework and Dissertations

There shall be a date set for the submission of all coursework and dissertations, and a penalty shall be awarded for late submission.

This policy is intended to ensure equity and fairness for all students and to ensure that feedback to students provided in a timely manner does not benefit students who make late submissions.

A separate set of procedures on how the Policy is expected to be implemented are provided.

POLICY

Approved for implementation by Mechanical Engineering Teaching Group 6th August 2008

PROCEDURES FOR LATE SUBMISSION OF COURSEWORK AND DISSERTATIONS

1. **Background**

1.1 It is apparent that Schools within the University are deploying various practices in the procedures for the late submission of coursework/ dissertations. Therefore the Undergraduate Studies Committee and the Postgraduate Studies Committee recommend that a common framework for all Schools should be introduced for all taught undergraduate and postgraduate students that allows for flexibility at a local level, but which highlights good practice in maintaining consistent standards and ensuring equity of treatment.

1.2 Coursework refers to work carried out by a student which constitutes or contributes towards his or her overall grade for a module but which is assessed separately from written examinations.

2. **Proposed Policy for dealing with late Submission of Coursework/ Dissertations**

2.1 Coursework/dissertations for undergraduate and postgraduate courses submitted late without prior agreement, or good cause where prior agreement could not be obtained, will have marks deducted. Standard procedures will be applied across the University and these will be communicated clearly and in advance to all students through verbal communication and student handbooks. The procedures, including the required date, time and form of submission, should also be provided for relevant coursework. However, flexibility should be permitted at a local level for extenuating circumstances.

The date and time of submissions will be acknowledged by timestamp on receipt. Students should be advised to retain copies of receipts where relevant, including those acknowledging electronic submission.

2.2 Coursework/dissertations submitted late (as defined in 2.1) will normally have a penalty of 5 percentage points deducted for each day (up to a maximum of seven days, including weekends) from the total coursework/dissertation mark available. No grade should be awarded until the final mark is known.

Coursework/dissertations submitted after seven days after the set deadline will be awarded zero percentage points of the coursework/dissertation mark available (see example attached at Appendix 3).

Where a School considers a submission to represent a small proportion of the overall module assessment, then coursework submissions may be required within a shorter period of time. In this case the maximum period during which penalties may be applied may be reduced and the penalty may be increased if details are clearly communicated in advance to students.

Extensions to coursework/dissertation submission dates

2.3 Students who have serious concerns about meeting coursework/dissertation submission dates should consult the Module Leader or dissertation coordinator as appropriate as soon as possible and normally at least one week prior to the submission date, unless there are exceptional circumstances which make this impossible.

2.4 Any extension to the submission deadline for a particular student must be approved by the Module Leader or other designated person and the reason for the extension must be recorded.

Where the submission represents a substantial proportion of the overall module assessment, Schools should use a 'Request for Extension to Coursework/Dissertation Submission Date in Extenuating Circumstances' Form (see Appendix 2) where there are extenuating circumstances and a request for an extension is being sought. The Form should be completed and submitted to the Module Leader for approval, together with any medical certificates or other supporting documentation. Students should obtain a receipt from the relevant School, and keep a copy of their assessed work, the Form and all supporting documentation. Schools should ensure that late submissions are recorded. Schools should clearly communicate to students in advance examples of what they consider could be acceptable 'extenuating circumstances' through verbal communication and information contained in student handbooks (see Appendix 1).

2.5 Retrospective applications for extension will not normally be approved.

2.6 All approved extensions should be reviewed at the appropriate Module Board of Examiners along with any medical certificates and supporting documentation. The Board will have the option to reinstate the full mark or to reduce the standard penalty in the light of circumstances. Those students who were granted extensions or who submitted late without an extension should not be notified of their marks/grades until after the meeting of the Board.

Appendix 1

Examples of Acceptable Reasons for Requesting an Extension to Coursework/Dissertation Submission Dates

The following is given as a guide to students and staff on the types of reasons considered acceptable or unacceptable for the purposes of requesting and approving extensions to coursework/dissertation deadlines.

Acceptable reasons:

- significant medical problems
- significant problems of a personal nature (e.g. family emergency)
- compassionate grounds (e.g. family bereavement)
- major computer problems (e.g. failure of university IT systems, such as network or server failure)

N.B. In all cases students must provide suitable documentary evidence to support their request for an extension.

Unacceptable reasons:

- minor computer problems (e.g. lost or damaged files, printer breakdown)
- unverifiable travel difficulties
- running out of time
- other assignments due
- temporary lack of availability of key resources required for the completion of the work

N.B. It is the student's responsibility to ensure that s/he plans and manages their workload such that they are able to complete and submit coursework and dissertations by the deadline set.

Appendix 2

HERIOT WATT UNIVERSITY

REQUEST FOR EXTENSION TO COURSEWORK/DISSERTATION SUBMISSION DATE IN EXTENUATING CIRCUMSTANCES

Section 1– to be completed by the Student and forwarded to the Module Leader	
Name of Student	
Registration No.	
Course Currently Registered for	
Module Title/Dissertation	
Module Code	
Original Submission Date	
Reason for Late Submission ***(If you have a medical certificate, YOU DO NOT HAVE TO GIVE DETAILS UNLESS YOU WISH TO PROVIDE MORE INFORMATION – simply state "medical certificate provided" and attach the original)***	
Signature of Student	
Date	

Section 2 – to be completed by the Module Leader		
a. Period of submission may not be extended	Signed:	Dated:
b. Period of submission may be extended. Period for submission to be extended until:	Signed: New submission date:	Dated:
Signature of Tutor NAME (in capital letters) Date	Signed: Printed:	Dated:

Please read the following guidelines before completing the Form.
Please note that extension dates are not granted lightly.

1. In the interests of fairness to other students, you are expected to have a genuine reason for requesting an extension to the coursework/dissertation submission date.
2. Your request should be made and given approval prior to the original submission date.
3. In the case of illness, you must provide written evidence from an appropriate medical practitioner and enclose this.
4. In other circumstances, you should discuss your case with either the Module Leader, Course Director or your Mentor. However, you will still be required to provide appropriate written evidence in support of your request.
5. When you have completed Section 1 of the Form, you should pass the Form to the Module Leader who will sign the Form, and return it to you indicating whether or not an extension has been granted. A copy of the Form will be placed in your file.
6. If you are granted an extension, you must attach a copy of the signed Form to your coursework/dissertation when you hand it in on or before the new submission date.
7. For the revised submission date, the normal penalties for late submission will apply:
   a) if submitted after the due date, 5 percentage points deducted daily from the total mark available for the submission (up to a maximum of seven days after submission date)
   b) if submitted after seven days, zero percentage points of the total mark available for the submission will be awarded.

For further information and an application form, please refer to the Policy on Submission of Coursework and Dissertations: http://www.hw.ac.uk/home/dir/70/student-policy-and-documents

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Appendix 3

LATE SUBMISSION OF COURSEWORK AND DISSERTATIONS

Penalties incurred

Deadline (any time of day) — **Day submitted (after deadline)**

Deadline	Tues	Wed	Thurs	Fri	Sat	Sun	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Monday	-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%					
Tuesday		-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%				
Wednesday			-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%			
Thursday				-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%		
Friday					-5%	-10%	-15%	-20%	-25%	-30%	-35%	-100%	

If, after deducting the penalty, the mark is less than zero, then no mark is awarded

EXAMPLE OF HOW PENALTIES WOULD BE DEDUCTED FROM COURSEWORK THAT CONSTITUTES ONE ELEMENT OF A MODULE MARK

<u>Examination 70%; Coursework 30%</u>

Coursework submitted 3 days late and incurs a penalty of 15%

Assessment Type	Original Mark	Penalty	Penalty Calculation	Final Mark (per assessment)	Final Contributory Mark
Coursework	67%	15%	*67-15 = 52*	52%	16% *(rounded up)*
Examination	58%	n/a	n/a	58%	41%
TOTAL MODULE MARK	61%				**57%**

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Appendix E

Plagiarism Policy

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STUDENT GUIDE TO PLAGIARISM [1]

Plagiarism is intellectual theft and is a major offence which the University takes seriously in all cases. Students must therefore avoid committing acts of plagiarism by following these guidelines and speaking to academic staff if they are uncertain about what plagiarism means. Those who are found to have plagiarised will be subject to the University's disciplinary procedures, which may result in penalties ranging from the deduction of credits and modules already achieved by students to compulsory termination of studies. Students are advised to refer to Regulation 50 at http://www.hw.ac.uk/ordinances/regulations.pdf and to the Guidelines for Staff and Students on Discipline at http://www.hw.ac.uk/registry/Discipline.php for further details of how the University deals with all acts of plagiarism.

1. Introduction

1.1. This guide is intended to provide students at Heriot-Watt University with a clear definition of plagiarism and examples of how to avoid it.

1.2. The guide may also be of use to members of staff who seek to advise students on the various issues outlined below.

2. Definition

2.1. Plagiarism involves the act of taking the ideas, writings or inventions of another person and using these as if they were one's own, whether intentionally or not. Plagiarism occurs where there is no acknowledgement that the writings or ideas belong to or have come from another source.

2.2. Most academic writing involves building on the work of others and this is acceptable as long as their contribution is identified and fully acknowledged. It is not wrong in itself to use the ideas, writings or inventions of others, provided that whoever does so is honest about acknowledging the source of that information. Many aspects of plagiarism can be simply avoided through proper referencing. However, plagiarism extends beyond minor errors in referencing the work of others and also includes the reproduction of an entire paper or passage of work or of the ideas and views contained in such pieces of work.

3. Good Practice

3.1. Academic work is almost always drawn from other published information supplemented by the writer's own ideas, results or findings. Thus drawing from other work is entirely acceptable, but it is unacceptable not to acknowledge such work. Conventions or methods for making acknowledgements can vary slightly from subject to subject, and students should seek the advice of staff in their own School/Institute about ways of doing this. Generally, referencing systems fall into the Harvard (where the text citation is by author and date) and numeric (where the text citation is by using a number). Both systems refer readers to a list at the end of the piece of work where sufficient information is provided to enable the reader to locate the source for themselves.

3.2. When a student undertakes a piece of work that involves drawing on the writings or ideas of others, they must ensure that they acknowledge each contribution in the following manner:

[1] The author acknowledges the following sources of information used in preparing this guide to Plagiarism:
"Plagiarism – A Good Practice Guide", Carroll, J and Appleton, J (2001) and various extracts from Student/Course Handbooks 2004/2005, Schools and Institutes at Heriot-Watt University

- **Citations**: when a direct quotation, a figure, a general idea or other piece of information is taken from another source, the work and its source must be acknowledged and identified where it occurs in the text;

- **Quotations**: inverted commas must always be used to identify direct quotations, and the source of the quotation must be cited;

- **References**: the full details of all references and other sources must be listed in a section at the end of any piece of work, such as an essay, together with the full publication details. This is normally referred to as a "List of References" and it must include details of any and all sources of information that the student has referred to in producing their work. (This is slightly different to a Bibliography, which may also contain references and sources which, although not directly referred to in your work, you consulted in producing your work).

3.3. Students may wish to refer to the following examples which illustrate the basic principles of plagiarism and how students might avoid it in their work by using some very simple techniques:

3.3.1. Example 1: A Clear Case of Plagiarism

Examine the following example in which a student has simply inserted a passage of text (*in italics)* into their work directly from a book they have read:

> University and college managers should consider implementing strategic frameworks if they wish to embrace good management standards. *One of the key problems in setting a strategic framework for a college or university is that the individual institution has both positive and negative constraints placed upon its freedom of action.* Managers are employed to resolve these issues effectively.

This is an example of bad practice as the student makes no attempt to distinguish the passage they have inserted from their own work. Thus, this constitutes a clear case of plagiarism. Simply changing a few key words in such a passage of text (e.g. replace '*problems*' with '*difficulties*') does not make it the student's work and it is still considered to be an act of plagiarism.

3.3.2. Common Mistakes

Students may also find the following examples[2] of common plagiarism mistakes made by other students useful when reflecting on their own work:

- "I thought it would be okay as long as I included the source in my bibliography" [without indicating a quotation had been used in the text]
- "I made lots of notes for my essay and couldn't remember where I found the information"
- "I thought it would be okay to use material that I had purchased online"
- "I thought it would be okay to copy the text if I changed some of the words into my own"
- "I thought that plagiarism only applied to essays, I didn't know that it also applies to oral presentations/group projects etc"
- "I thought it would be okay just to use my tutor's notes"
- "I didn't think that you needed to reference material found on the web"
- "I left it too late and just didn't have time to reference my sources"

None of the above are acceptable reasons for failing to acknowledge the use of others' work and thereby constitute plagiarism.

3.4. What follows are examples of the measures that students should employ in order to correctly cite the words, thought or ideas of others that have influenced their work:

3.4.1. Example 2: Quoting the work of others

If a student wishes to cite a passage of text in order to support their own work, the correct way of doing so is to use quotation marks (e.g. " ") to show that the passage is someone else's work, as follows:

[2] Extract from 'Plagiarism at the University of Essex' advice copyrighted and published by the Learning, Teaching and Quality Unit at the University of Essex (http://www.essex.ac.uk/plagiarism/pages/about.htm), reproduced with kind permission.

> *"One of the key problems in setting a strategic framework for a college or university is that the individual institution has both positive and negative constraints placed upon its freedom of action".*

3.4.2. Example 3: Referencing the work of others

In addition to using quotation marks as above, students must also use a text citation. If the work being cited is a book, page numbers would also normally be required. Thus, using the Harvard system for a book:

> *"One of the key problems in setting a strategic framework for a college or university is that the individual institution has both positive and negative constraints placed upon its freedom of action" (Jones, 2001, p121).*

The same reference could also be made to a book using the numeric system:

> *"One of the key problems in setting a strategic framework for a college or university is that the individual institution has both positive and negative constraints placed upon its freedom of action" (Ref.1, p121).*

More often, a piece of work will have multiple references and this serves to show an examiner that the student is drawing from a number of sources. For example, articles by Brown and by Smith may be cited as follows in the Harvard system

"It has been asserted that Higher Education in the United Kingdom continued to be poorly funded during the 1980's [Brown, 1991], *whereas more modern writers* [Smith, 2002] *argue that the HE sector actually received, in real terms, more funding during this period than the thirty year period immediately preceding it".*

or as follows using the numeric system:

"It has been asserted that Higher Education in the United Kingdom continued to be poorly funded during the 1980's [Ref 1], *whereas more modern writers* [Ref 2] *argue that the HE sector actually received, in real terms, more funding during this period than the thirty year period immediately preceding it".*

3.4.3. Example 4: Use of reference lists

Whichever system is used, a list must be included at the end, which allows the reader to locate the works cited for themselves. The Internet is also an increasingly popular source of information for students and details must again be provided. You should adhere to the following guidelines in all cases where you reference the work of others:

If the source is a book, the required information is as follows:

- Author's name(s)
- Year of Publication
- Title of Book
- Place of Publication
- Publishers Name
- All Page Numbers cited
- Edition (if more than one, e.g. 3rd edition, 2001)

If the source is an article in a journal or periodical, the required information is as follows:

- Author's name(s)
- Year of Publication
- Title of Journal
- Volume and part number
- Page numbers for the article

If the source is from the Internet, the required information is as follows:

- Author's or Institution's name ("Anon", if not known)
- Title of Document
- Date last accessed by student
- Full URL (e.g. http://www.lib.utk.edu /instruction/plagiarism/)
- Affiliation of author, if given (e.g. University of Tennessee)

The way in which the information is organised can vary, and there are some types of work (for example edited volumes and conference proceedings) where the required information is slightly different. Essentially, though, it is your responsibility to make it clear where you are citing references within your work and what the source is within your reference list. **Failure to do so is an act of plagiarism.**

3.5. Students are encouraged to use a style of acknowledgement that is appropriate to their own academic discipline and should seek advice from their mentor, course leader or other appropriate member of academic staff. There are also many reference sources available in the University Library which will provide useful guidance on referencing styles.

4. Managing Plagiarism

4.1. Students, supervisors and institutions have a joint role in ensuring that plagiarism is avoided in all areas of academic activity. Each role is outlined below as follows:

How you can ensure that you avoid plagiarism in your work:

- Take responsibility for applying the above principles of best practice and integrity within all of your work
- Be aware that your written work will be checked for plagiarism and that all incidents of plagiarism, if found, are likely to result in severe disciplinary action by the University. The standard penalty is to annul all assessments taken in the same diet of examinations (for details please refer to Regulation 50 at http://www.hw.ac.uk/ordinances/regulations.pdf and to the Guidelines for Staff and Students on Discipline at http://www.hw.ac.uk/registry/Discipline.php).

How your School/Institute will help you to avoid plagiarism:

- Highlight written guidance on how you can avoid plagiarism and provide you with supplementary, verbal guidance wherever appropriate
- Regularly check student work to ensure that plagiarism has not taken place. This may involve both manual and electronic methods of checking. A number of plagiarism detection packages are in use at Heriot-Watt University, one example being the Joint Information Systems Committee (JISC) "TurnItIn" plagiarism detection software. See https://submit.ac.uk/static_jisc/ac_uk_index.html for more information on how this software package works.
- Alert you to the procedures that will apply should you be found to have committed or be suspected of having committed an act of plagiarism and explain how further action will be taken in accordance with University policy and procedures.

How the University will endeavour to reduce student plagiarism:

- Provide clear written guidance on what constitutes plagiarism and how to avoid it directly to your School/Institute and to you
- Alert you and staff in your School/Institute to the penalties employed when dealing with plagiarism cases
- Take steps to ensure that a consistent approach is applied when dealing with cases of suspected plagiarism across the institution
- Take the issue of academic dishonesty very seriously and routinely investigate cases where students have plagiarised and apply appropriate penalties in all proven cases.