Notes For the First Year Lecture Course:
An Introduction to Fluid Mechanics

School of Civil Engineering, University of Leeds.
CIVE1400 FLUID MECHANICS
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0. Contents of the Module

0.1 Objectives:

- The course will introduce fluid mechanics and establish its relevance in civil engineering.
- Develop the fundamental principles underlying the subject.
- Demonstrate how these are used for the design of simple hydraulic components.

0.2 Consists of:

- Lectures:
  20 Classes presenting the concepts, theory and application.
  Worked examples will also be given to demonstrate how the theory is applied. You will be asked to do some calculations - so **bring a calculator.**
- Assessment:
  1 Exam of 2 hours, worth 80% of the module credits.
  This consists of 6 questions of which you choose 4.

  4 Multiple choice question (MCQ) papers, worth 20% of the module credits.

  Thse will be for 30mins and set during the lectures. The timetable for these MCGs and lectures is shown in the table at the end of this section.
- Laboratories: 2 x 3 hours
  These two laboratory sessions examine how well the theoretical analysis of fluid dynamics describes what we observe in practice.
  During the laboratory you will take measurements and draw various graphs according to the details on the laboratory sheets. These graphs can be compared with those obtained from theoretical analysis.
  You will be expected to draw conclusions as to the validity of the theory based on the results you have obtained and the experimental procedure.
  After you have completed the two laboratories you should have obtained a greater understanding as to how the theory relates to practice, what parameters are important in analysis of fluid and where theoretical predictions and experimental measurements may differ.
  The two laboratories sessions are:

  1. Impact of jets on various shaped surfaces - a jet of water is fired at a target and is deflected in various directions. This is an example of the application of the momentum equation.
  2. The rectangular weir - the weir is used as a flow measuring device. Its accuracy is investigated. This is an example of how the Bernoulli (energy) equation is applied to analyses fluid flow.

  [As you know, these laboratory sessions are **compulsory** course-work. You must attend them. Should you fail to attend either one you will be asked to complete some extra work. This will involve a detailed report and further questions. The simplest strategy is to do the lab.]

- Homework:
  Example sheets: These will be given for each section of the course. Doing these will **greatly** improve your exam mark. They are course work but do not have credits toward the module.
  Lecture notes: Theses should be studied but explain only the basic outline of the necessary concepts and ideas.
  Books: It is very important do some extra reading in this subject. To do the examples you will

definitely need a textbook. Any one of those identified below is adequate and will also be useful for the fluids (and other) modules in higher years - and in work.

- Example classes:
  There will be example classes each week. You may bring any problems/questions you have about the course and example sheets to these classes.

0.3 Specific Elements:

- Introduction
- Fluid Properties
  - Fluids vs. Solids
  - Viscosity
  - Newtonian Fluids
  - Properties of Fluids
- Statics
  - Hydrostatic pressure
  - Manometry / pressure measurement
  - Hydrostatic forces on submerged surfaces
- Dynamics
  - The continuity equation.
  - The Bernoulli Equation.
  - Applications of the Bernoulli equation.
  - The momentum equation.
  - Application of the momentum equation.
- Real Fluids
  - Boundary layer.
  - Laminar flow in pipes.
- Introduction to dimensional analysis
  - Dimensional analysis
  - Similarity

0.4 Books:

Any of the books listed below are more than adequate for this module.

(You will probably not need any more fluid mechanics books on the rest of the Civil Engineering course)

Mechanics of Fluids, Massey B S., Van Nostrand Reinhold.

Fluid Mechanics, Douglas J F, Gasiorek J M, and Swaffield J A, Longman.

Civil Engineering Hydraulics, Featherstone R E and Nalluri C, Blackwell Science.

Hydraulics in Civil and Environmental Engineering, Chadwick A, and Morfett J., E & FN Spon - Chapman & Hall.

0.5 Other Teaching Resources.

There are some extra teaching/learning resources available for you to use that are computer based.

Online Lecture Notes

A more detailed set of lecture notes can be found on the WWW at he following address:

http://www.efm.leeds.ac.uk/cive

You get to this using Netscape from any of the computers in the university.

If you forget this address you can also get to the web pages via Dr Sleigh's web pages linked from the department's main page.

These notes give more information than is found in the lectures. They **do not** replace textbooks. You **must also read at least one of the recommended fluid mechanics books**. The notes may be read online or printed off for personal use.

Online Fluid Mechanics Tutorial

A self-teach package is available on the university computers which gives an introduction fluid mechanics. It is very suited to this course.

This tutorial can be accessed when you have logged on and started *windows*. In the "*Windows Applications*" box there is an icon labelled "*Departmental Software*", choose this, then from the list choose "*Civil Engineering*". Choose "*Fluid Mechanics Tutorial*" from the next list and the tutorial will start. (It is based on Microsoft Excel - but you do not need to know anything about Excel to use it).

The tutorial is designed to be self explanatory - you should follow the instructions that lead you through the exercises. As the first screen will tell you, it is a course designed to supplement other learning so should be treated as such with other work/reading being done at the same time.

There are six sections in the tutorial:

1. Mass conservation
2. Hydrostatics
3. Manometry
4. Bernoulli
5. Viscous flow
6. Darcy's Expression

The top five of these are relevant to this course.

In each section you are taken through the basic concepts, with questions which you must answer (with assistance) before you can carry on to the next section. Worked examples are provided, these are followed by examples that you do online.

This tutorial has received quite favourable response from students in previous years. This method of learning may not be suited to everyone but it is certainly worth trying out.

0.6 Civil Engineering Fluid Mechanics

Why are we studying fluid mechanics on a Civil Engineering course? The provision of adequate water services such as the supply of potable water, drainage, sewerage are essential for the development of industrial society. It is these services which civil engineers provide.

Fluid mechanics is involved in nearly all areas of Civil Engineering either directly or indirectly. Some examples of direct involvement are those where we are concerned with manipulating the fluid:

- Sea and river (flood) defences;
- Water distribution / sewerage (sanitation) networks;
- Hydraulic design of water/sewage treatment works;
- Dams;
- Irrigation;
- Pumps and Turbines;
- Water retaining structures.

And some examples where the primary object is construction - yet analysis of the fluid mechanics is essential:

- Flow of air in / around buildings;
- Bridge piers in rivers;
- Ground-water flow.

Notice how nearly all of these involve water. The following course, although introducing general fluid flow ideas and principles, will demonstrate many of these principles through examples where the fluid is water.

0.7 System of units

As any quantity can be expressed in whatever way you like it is sometimes easy to become confused as to what exactly or how much is being referred to. This is particularly true in the field of fluid mechanics. Over the years many different ways have been used to express the various quantities involved. Even today different countries use different terminology as well as different units for the same thing - they even use the same name for different things e.g. an American pint is 4/5 of a British pint!

To avoid any confusion on this course we will always use the SI (metric) system - which you will already be familiar with. It is essential that all quantities are expressed in the same system or the wrong solutions will results.

Despite this warning you will still find that this is the most common mistake when you attempt example questions.

0.8 The SI System of units

The SI system consists of six **primary** units, from which all quantities may be described. For convenience **secondary** units are used in general practise which are made from combinations of these primary units.

Primary Units

The six **primary** units of the SI system are shown in the table below:

Quantity	**SI Unit**	**Dimension**
length	metre, m	L
mass	kilogram, kg	M
time	second, s	T
temperature	Kelvin, K	θ
current	ampere, *A*	I
luminosity	candela	Cd

In fluid mechanics we are generally only interested in the top four units from this table.

Notice how the term 'Dimension' of a unit has been introduced in this table. This is not a property of the individual units, rather it tells what the unit represents. For example a metre is a length which has a dimension L but also, an inch, a mile or a kilometre are all lengths so have dimension of L.

(The above notation uses the MLT system of dimensions, there are other ways of writing dimensions - we will see more about this in the section of the course on dimensional analysis.)

Derived Units

There are many **derived** units all obtained from combination of the above **primary** units. Those most used are shown in the table below:

Quantity	SI Unit		Dimension
velocity	m/s	ms^{-1}	LT^{-1}
acceleration	m/s^2	ms^{-2}	LT^{-2}
force	N $kg\ m/s^2$	$kg\ ms^{-2}$	$M\ LT^{-2}$
energy (or work)	Joule J N m, $kg\ m^2/s^2$	$kg\ m^2s^{-2}$	ML^2T^{-2}
power	Watt W N m/s $kg\ m^2/s^3$	Nms^{-1} $kg\ m^2s^{-3}$	ML^2T^{-3}
pressure (or stress)	Pascal P, N/m^2, $kg/m/s^2$	Nm^{-2} $kg\ m^{-1}s^{-2}$	$ML^{-1}T^{-2}$
density	kg/m^3	$kg\ m^{-3}$	ML^{-3}
specific weight	N/m^3 $kg/m^2/s^2$	$kg\ m^{-2}s^{-2}$	$ML^{-2}T^{-2}$
relative density	a ratio no units		1 no dimension
viscosity	$N\ s/m^2$ kg/m s	$N\ sm^{-2}$ $kg\ m^{-1}s^{-1}$	$M\ L^{-1}T^{-1}$
surface tension	N/m $kg\ /s^2$	Nm^{-1} $kg\ s^{-2}$	MT^{-2}

The above units should be used at all times. Values in other units should NOT be used without first converting them into the appropriate SI unit. If you do not know what a particular unit means find out, else your guess will probably be wrong.

One very useful tip is to write down the units of any equation you are using. If at the end the units do not match you know you have made a mistake. For example is you have at the end of a calculation,

$$30\ kg/m\ s = 30\ m$$

you have certainly made a mistake - checking the units can often help find the mistake.

More on this subject will be seen later in the section on dimensional analysis and similarity.

0.9 Example: Units

1.

A water company wants to check that it will have sufficient water if there is a prolonged drought in the area. The region it covers is 500 square miles and various different offices have sent in the following consumption figures. There is sufficient information to calculate the amount of water available, but unfortunately it is in several different units.

Of the total area 100 000 acres are rural land and the rest urban. The density of the urban population is 50 per square kilometre. The average toilet cistern is sized 200mm by 15in by 0.3m and on average each person uses this 3 time per day. The density of the rural population is 5 per square mile. Baths are taken twice a week by each person with the average volume of water in the bath being 6 gallons. Local industry uses 1000 m3 per week. Other uses are estimated as 5 gallons per person per day. A US air base in the region has given water use figures of 50 US gallons per person per day.

The average rain fall in 1in per month (28 days). In the urban area all of this goes to the river while in the rural area 10% goes to the river 85% is lost (to the aquifer) and the rest goes to the one reservoir which supplies the region. This reservoir has an average surface area of 500 acres and is at a depth of 10 fathoms. 10% of this volume can be used in a month.

a) What is the total consumption of water per day?

b) If the reservoir was empty and no water could be taken from the river, would there be enough water if available if rain fall was only 10% of average?