THE CHOICE AND DESIGN OF LABORATORY EQUIPMENT IN THE TEACHING OF FLUID MECHANICS

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ABSTRACT

The purposes of laboratory work in the teaching of Fluid Mechanics are reviewed, and the success with which common apparatus fulfils these purposes is discussed.

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The equipment in any laboratory represents the ideas and hopes of those in charge, and fluid mechanics laboratories are no exception. Thus many designs and sizes of equipment are observed, and it is the purpose of this paper to stimulate thought on the most suitable purpose and sizes of equipment.

Experimental work in Fluid Mechanics is given to students for two basic reasons:

1. To demonstrate the principles of the art.

2. To give experience in important techniques or to work with equipment of great practical importance.

In many laboratories it may also be necessary to provide equipment which is readily adaptable for post-graduate students or teaching staff to carry out research; or to provide equipment to be used for industrial or governmental standardization testing. These secondary purposes, though often important, may very well produce equipment poorly adapted for undergraduate work.

It is obvious that all experiments involve a mixture of the above two reasons. It is not so obvious that an experiment primarily intended to demonstrate a principle can be made tedious and obscure to a student if the technique used is lengthy and complicated; or that an experiment primarily intended to familiarise students with important apparatus can miss the point if the principles involved are spurious or uncertainly shown.

In an apparatus designed for the first purpose above, it is essential that the principles involved are shown to be undeniably correct and that no experimental coefficients are introduced to make observation fit theory. A fine example of inefficient apparatus in this respect is a Pelton wheel, which does not develop the torque expected by a momentum analysis; many teachers will remember students who refer to 'lost momentum, or who use a coefficient to 'explain' the momentum theorem.

Since time is (or should be) most precious to students working for a degree, laboratory experiments and apparatus should be designed to reduce to a minimum the interval between readings, or time required for flows to 'settle down'. In general this implies

small size of equipment - a principle which will gladden the hearts of university administrators. A further argument for fairly small equipment is that it allows the possibility of duplicate sets, thus allowing more of a large class of students to do experiments at an appropriate time of their course. However, carrying this policy too far can introduce unwanted scale effects, making the clear demonstration of the principles involved far less certain. More importantly, when training engineers, very small scale equipment fails to create an impression of engineering practice and design; students are subjected to a 'physics laboratory' scale of equipment and they fail to absorb the problems of design and manufacture of engineering scale apparatus.

Other factors affecting the size and scale of equipment are the need to economise in technician manpower and the need to allow easy cleaning. The former is another argument for small equipment, with easily fixed modifications and fittings, and the latter is an argument for pipes, channels and ducts to be large enough to allow a man's hand, arm or body (as the case may be) to enter for cleaning purposes. Thus glass-sided channels 3 inches wide do not accept a man's hand, and are unnecessarily difficult to clean and to work in; 4 inches is a better width.

The great principles of fluid mechanics demonstrable to undergraduates can be gathered under the headings

1. Visualization of Flow
2. Continuity
3. Momentum
4. Energy
5. Shear Flow

It is curious to reflect upon the success with which each of these principles has attracted well-designed equipment. Energy relations (both in compressible and incompressible flows) and shear flows seem to be easily and efficiently catered for. There is a wide variety of pipe, channel, 'Venturi' and 'orifice' apparatus available which adequately show the validity of the Bernoulli or energy equations. Pipe friction rigs are also easy to arrange, although there is a lack of an arrangement wherein the effect of relative roughness is clearly shown - this is probably much more important to teach than the usual tests on smooth pipes. Flow Visualization apparatus, after some neglect in the past, now seems to be accepted as an essential in laboratory courses. The Ahlborn method (dust particles on a water stream) is simple and has many advantages; smoke in a wind tunnel, though undoubtedly giving smaller equipment, requires more preparation time and is probably more expensive. Hele-Shaw tanks attract many who delight in potential flow problems yet are difficult to explain adequately to students with poorer mathematical equipment. Continuity of flow is an easy concept for many to grasp, but its application in a physical sense to engineering problems is largely in the field of measurement of flow: it is difficult to divorce this aspect from purely technological aspects of standard tests.

It is in the case of the Momentum Theory that most difficult problems arise on laboratory equipment. The classic apparatus (which gives an undeniably accurate confirmation of the Momentum Theory) is the constant pressure jet of water striking a plane surface. This is a dull and unexciting experiment for the student partly because there are few direct applications of such jet impacts, and partly because there are few interesting auxiliary observations to be made. Measurements in a boundary layer on a flat surface, or in the wake of a two-dimensional object may also be used,but these involve a sensitive force balance in a wind or water tunnel. These balances are expensive, and not usually found in teaching laboratories and a cheaper, robust design is clearly necessary. It is important to ensure that the supports in the tunnel cause no unexplained secondary drag effects, and that an undue amount of plotting of velocity profiles is not called for. The hydraulic jump in an oepn channel is of course a good example of the momentum theory but the necessary introduction of the critical depth is an undesirable complication for comparatively junior students (who should be impressed with the validity of the theorem at an early stage). A better experiment in an open channel or flume is to immerse a grid or screen, to measure the change of depth and the load on the screen: care is necessary here to ensure that the retarding force is diffused fully into the stream.

Turning now to apparatus intended to give experience with important techniques and equipment, it is clear that turbines and pumps have pride of place in many laboratories. As demonstrations of principles they are of small value, since few, if any, of the hydraulic measurements can be satisfactorily predicted by simple theories, and experimental coefficients or efficiencies must be applied. The usual tests carried out on turbines have little content of Fluid Mechanics, since they are largely a matter of measuring the horsepower output of a shaft and the flow in a pipe, and it is difficult to show in a rotating system the details of the fluid movements. A similar criticism can be made of typical pump experiments, which essentially culminate in a series of performance curves at different speeds. A working knowledge of such curves is however of much more practical value to a young engineer than

the corresponding work on a turbine, since a great majority of men must deal with a pump at some stage in their career but few will deal with a turbine. It therefore appears that money spent on a range of pumps is better value than that spent on turbines.

Students are of course introduced to many techniques which appear in experiments designed to demonstrate principles. A rather more elaborate experiment bringing out an important technique is the pressure plotting of a 2-dimensional body in a fluid stream, integrating the force components to find the form drag. Taken in conjunction with a flow visualization demonstration a far clearer idea can be made of the resultant flow pattern, but an economy of student effort might be made if the tedious plotting (at which typical students are very slow) can be reduced, perhaps by using a multiple tube manometer. Calibrations of instruments (weirs, orifices, venturi meters etc) give useful introductions to the advantages of non-dimensional parameters but it is difficult to make these experiments give convincing demonstrations of dynamical similarity. Over the range of variables possible in an undergraduate experiment, few non-dimensional parameters show a distinct anomaly or discontinuity that can be repeated at different scales; there is a tendency (in Reynolds' Number experiments for example) either for changes of the parameter to have little or no effect on the dependent variables, or for the experiment itself to demand a skill and time not available to students. A really conclusive experiment to show a distinct, obvious and measurable change of flow pattern with a change of scale would be very desirable. It is not good enough merely to change the viscosity (which can be done easily over several orders of magnitude).

As Hunter-Rouse has pointed out, the influence of the flow pattern governs the magnitude of measurable parameters in fluid flows. An awareness of the pattern is therefore quite essential by all students in carrying out their experimental work. In too many laboratories there is insufficient attention paid to flow visualization for students, and their understanding of problems is thereby reduced. Transparent windows and dye injection equipment should be available in all equipment, together with an adequate number of visualization tanks for 2-dimensional models; and students must be encouraged by every means at our disposal to sketch and anlyse the patterns so observed. Well designed equipment too enables improvements to be suggested and carried out to the flow, and so impress still further the experimental method in engineering science on our students.