The Joint Matriculation Board 'A' Level Examination in Engineering Science.

The development of new examination procedures in Applied Science and Technology.

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An A-level in Engineering Science is seen as a qualification for university entrance that provides an alternative to an A-level in Physics. Its syllabus is believed to offer a more suitable basis for engineering courses in higher education than the traditional physics syllabus but still provides a good foundation for further work in physics and the other sciences. Compared to the traditional J.M.B. physics examination, more emphasis is placed on the candidate's ability to apply his knowledge in unfamiliar situations; there are fewer questions in the cognitive areas of knowledge and comprehension, a greater proportion in the higher areas. Most important is the emphasis placed on course work, some of which, assessed by teachers and moderated by external examiners, contributes towards the overall assessment.

The Board of Examiners concerned with Engineering Science are aided by a development officer appointed by the J.M.B. Schools Council Project Technology gave financial support during the first two years of this appointment and Deryck Kelly, the Project's Science Co-ordinator for three years and now Director of the Engineering Science Textbook Writing Unit at Loughborough University, played and is continuing to play a notable part in the development of the examination in Engineering Science. The A-level examination was first sat by candidates from five schools in 1969; in 1972 there should be just over 200 candidates from 40 schools.

The syllabus sprang from the same dissatisfaction with traditional school science, with its emphasis on the recall of facts, definition and descriptions of standard experiments, as did the Nuffield science courses.

However those responsible for this syllabus see many of the short-comings of the traditional syllabus as deriving from the nature of natural science itself which they consider to be essentially analytical and lacking in creative potential: "science is concerned with understanding of nature as it exists" state the Notes for Guidance issued to teachers of Engineering Science, a rather narrow view with which many scientists would quarrel. In contrast "the engineering scientist is concerned with the utilisation of natural resources in the pursuit of human aims", a process considered to present more opportunity for creative work.

The most original feature of the syllabus is the importance given to the laboratory work which the student carries out during the course and for whose guidance the Board provides a set of notes considerably larger and more detailed than that which has usually accompanied science syllabuses in the past.

There are three types of course work:

a. *Controlled Assignments,* short undertakings which are closely controlled by the teacher;

b. *Experimental Investigations,* longer undertakings in which the candidate is given the opportunity to exercise considerable discretion within the general terms of the investigation;

c. *Projects,* major undertakings in which candidates are encouraged to exercise the greatest possible freedom in planning and carrying out the investigation.

The aim of this work is to enable a candidate to develop certain practical techniques, and, more importantly, his abilities in analysis and synthesis and his originality. This aim is developed in the Notes for Guidance into a set of objectives.

Each candidate is assessed by his teacher on three experimental investigations and his project. The teacher completes a booklet which asks a series of questions such as: "has the candidate discussed alternative solution to problems arising during the course of the investigation?" To each the teacher has to reply "yes" or "no" and support an affirmative answer by reference to the page in the candidate's report or in his laboratory diary on which there is evidence to justify the answer. The assessment booklets and the candidates reports are submitted to one of four moderators whose purpose is to achieve uniformity of standard between the assessments of the different schools.

The moderator has previously approved the project plans of the candidates and indeed, in the case of schools entering candidates for the first time, visited them to discuss these with candidates and their teachers. Before he will approve a project, the moderator has to be satisfied that it has a well-defined aim and one that is likely to be achieved in about 50 hours. The moderator will also visit a school after he has moderated the school assessments to discuss these with the candidates and their teachers; however the assessments of teachers who are submitting candidates for a second or third time usually need so little adjustment by the moderators that these visits are likely to be discontinued.

The course work assessment is intended to have a strong influence on the course work and the questions asked in the assessment booklet are directly related to the course objectives; for this reason candidates are encouraged to consult the booklet at intervals during the course. The range of projects undertaken is very wide. Three examples are:

An investigation of the properties of air bearings;

The application of photocells to door opening devises;

Method study of an egg farm.

There is no doubt that many candidates enjoy their course work and, as well as achieving a high proportion of the objectives, derive benefits of a more personal kind from it.

The Board gives less guidance for the theoretical part of the course. Although the bulk of the syllabus could be found in a traditional physics syllabus, it is arranged differently to emphasise different aims. For example, one aim is that the candidates should appreciate the analogies which exist between the treatments of certain phenomena; in order to help them achieve this aim diffusion (flow of water), thermal conduction (flow of heat) and electric current (flow of charge) are grouped under the heading of Transport Phenomena.

Because the course has little concern with the processes of science, with how scientific principles are established, its syllabus might appear didactic compared with a new syllabus in the natural sciences; however it is pre-eminently concerned with how the principles of science can be applied, with the processes of technology epitomised as the process of design.

The examinations are at first sight similar to others which have been developed in the last few years: Paper I contains 40 fixed-response questions and a comprehension test, Paper II, nine short questions from which six must be attempted and six longer questions from which three must be attempted. However Paper I in addition contains a design question, a project-planning exercise similar to that undertaken as part of the course work and a question involving the economic aspects of technology. Also the questions in Paper II demand less pure recall than the traditional J.M.B. Physics Paper II and are much more concerned with the application for principles in new situations.

The problems facing Engineering Science derive from its unusual position: the demands it makes on teachers and students are much more than those expected of a new syllabus and equivalent to those of a curriculum development project such as the Nuffield A-level Physics but its resources are very much less than those of the curriculum project. To meet a request from schools, a set of text books was produced hurriedly by the Board; more recently a textbook writing unit, funded by the Schools Council, has been established at Loughborough University and is producing a set that will meet the aims of the course more fully.

Another problem, less easy to solve, is caused by some schools regarding Engineering Science as a somewhat less demanding alternative to physics and so suitable for weaker candidates perhaps to be taken in conjunction with A-level Mechanical Drawing and Metal work. In fact the course is more demanding than traditional J.M.B. Physics. At present Engineering Science is often taught in a school to small groups of less able pupils while traditional physics is taught to a larger group of more able pupils. In such a school its viability is doubtful and the growth of numbers taking the examination is likely to be slow. Nevertheless it has an advantage not shared by most curriculum development projects, whose teams are disbanded after three years or so: it continues to develop every year with the continued feedback achieved through the course work moderators enabling the Board and the schools to solve the initial problems together. Thus although progress may be slow there is no doubt that a very worthwhile syllabus is being developed.

The summer 1971 papers for the J.M.B. Engineering Science Advanced Examinations (Paper 1 section B and C) which illustrate D. A. Tawney's article are reproduced here by kind permission of the Board © J.M.B. (Paper 1 Section A (Objective Test) and Paper 2 are not reproduced).

Joint Matriculation Board

General Certificate of Education

Engineering Science Advanced Paper I Sections B and C

Section B Comprehension Test

Read carefully the passage on the enclosed sheet. Answer as many of the following questions as your can.

If you experience difficulty with a particular question proceed to the next question. You are advised that marks will be awarded for a good standard of English.

1 Name two methods currently in use to
   (a) contain oil slicks:
   (b) collect the oil

2 What is the main contention of the article?

3 State three factors which can contribute to the bodily movement of oil on the sea. Give in each case the expected magnitude of the effect.

4 What is meant in paragraph 7 by "a second order effect of the wave field"?

5 Sketch a labelled diagram representing a physical boom designed for oil slick containment.

6 Describe in your own words how a pneumatic boom produces a condition of oil stand-off from the boom.

7 What physical principles are utilised in deriving the expression for the plume velocity of the pneumatic boom?

8 Give a reasoned argument which describes the variation of velocity of plume surface current shown on Fig. 2.

9 In undertaking the experiment noted in paragraph 13, which physical quantities will be varied?

10 State why you would expect the experimental results plotted on Fig. 3 to yield a straight line of slope 3/2.

11 In para.15 an experiment is described to check the validity of equation 5. Describe the experiment and give the reasoning for its design.

12 If a pneumatic boom is designed with a power capacity of 70 kW m^{-1} what type of current effects are likely to be overcome?

Containment and Collection Devices for Oil Slicks

1 Present containment devices for oil slicks consist of two main types: physical booms or barriers and pneumatic booms. A typical physical boom might consist of a buoyant cylinder 0.3 m in diameter, to which is attached a fabric curtain 0.5 m deep, and which is weighted down by a chain sewn in its lower edge. It is supposed that the combination of buoyant cylinder and chain tends to hold the curtain vertical in the sea, thereby producing a barrier which prevents the spread of oil.

2 A pneumatic boom consists of a submerged pipe which is perforated with small holes. When compressed air is supplied to the pipe, a large number of fine bubbles are created and the resultant air-water mixture, having a density slightly less than the surrounding water, rises, creating a vertical current. At the surface the vertical current splits into two horizontal currents on opposite sides of the boom and moving away from it. It is this surface current which is used to prevent the tendency of the oil to spread.

3 There are also two main types of collection device, the roller and the towed or pushed boom. As the roller moves over the surface of the sea it collects the oilwhich sticksto it; the oil is lifted out of the water as the roller rotates, and is scraped off into a collector. If a vee-shaped boom is pushed into an oil slick, the oil tends to pile up in the notch of the vee, where it may be collected.

4 It is a common observation of the *Torrey Canyon* and *Santa Barbara* disasters that none of these devices worked in the open sea. It is the thesis of this paper that the devices failed because they were not designed to operate in the actual environment of the sea.

5 The main environmental conditions which must be taken into account are the effects of wind, waves and current.

6 A typical wind speed, of 12 m s^{-1} generates a surface current of approximately 0.4 m s^{-1} (i.e. about 3% of the wind speed); oil on a calm sea will be moved by this effect.

7 Even without a wind, a particle subject to wave action has a mean drift velocity in addition to the wave motion. This is a second order effect of the wave field and may typically be of the order of 0.3 m s^{-1}. Wind and wave effects can combine together, therefore, to generate surface currents in excess of 0.3 m s^{-1}.

8 Acting in combination with wind and wave effects are tidal currents, which can have velocities from 0.25 m s^{-1} to 1.2 m s^{-1}.

9 It therefore follows that oil spilled on the surface of the sea could be transported with velocities appreciably greater than 0.3 m s^{-1}. It is the purpose of containment devices to combat this tendency of the oil to spread due to wind, waves and tidal currents, and also to combat the effects of density difference and surface tension, which tend to cause the oil to spread even on still water.

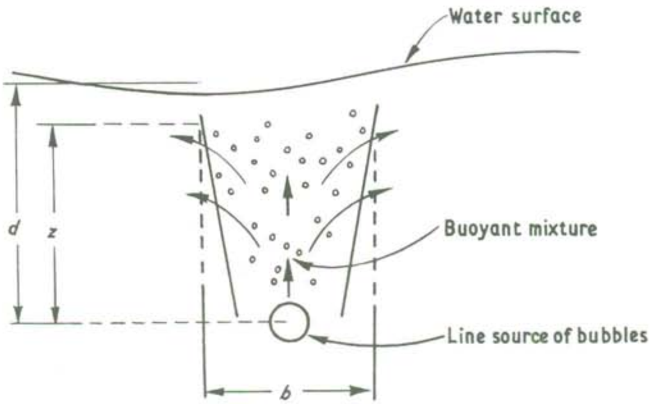


FIGURE 1

The Pneumatic Boom

10 Consider a pipe, located at a depth d below the water surface and supplied with compressed air which flows out of small holes drilled in the pipe. The bubbles formed create a buoyant air and water mixture (Fig. 1).

11 At some height z above the pipe the buoyant mixture has a width b and rises with a velocity v. Let δ be the volume of bubbles in unit volume of mixture at the height z. If air flows out of the pipe at a rate of $V\ m^3\ s^{-1}$ per metre of pipe, and it is assumed that the volume of bubbles per unit volume of mixture is small, then using the fact that the mass of air within the plume must be conserved

$$V \approx vb\delta. \tag{1}$$

The buoyancy acting to accelerate the plume upwards at a height z is $\rho b\delta g$, where ρ is the density of water and g is the acceleration due to gravity. Consideration of momentum in the plume then suggests that

$$v \approx \left(g\frac{Vz}{b}\right)^{1/3}. \tag{2}$$

b will be a function of z and in rough water may depend on wave action, but for a given value of z it is anticipated that the variation of v is dominated by V and hence v remains proportional to the cube root of the volume rate of flow.

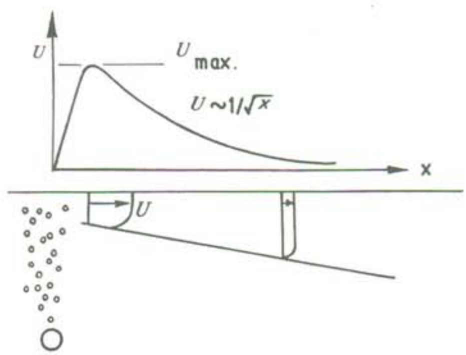


FIGURE 2

12 In still water when the buoyant plume reaches the surface, it divides into two horizontal jets. Let x be the horizontal distance from the pipe (Fig. 2). Experiment and theory suggest that the depth of the surface current is proportional to x. Since momentum is conserved, it can be shown that

$$U^2 x \approx \mathrm{d}(gV)^{2/3} \tag{3}$$

where U is the magnitude of the surface current.

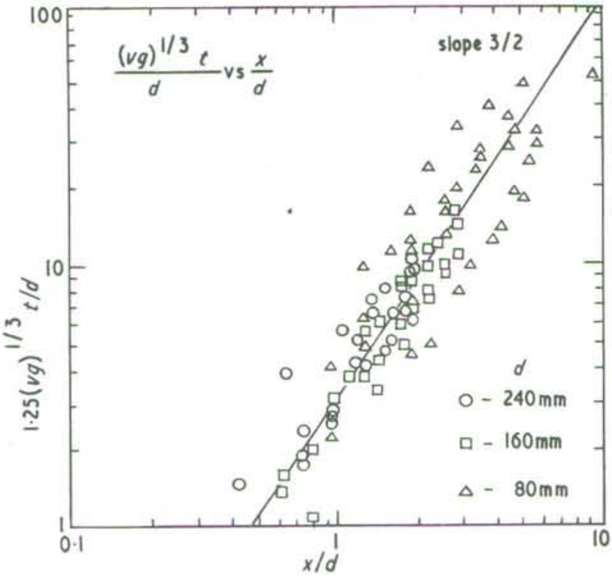


FIGURE 3

13 In an experiment to check equation (3) small wood chips were released at $x = 0$ above the pneumatic boom, and the resulting position of the particles as a function of time was recorded. From the theory we expect the particle position $x(t)$ is given by

$$\frac{(gV)^{1/3}t}{\mathrm{d}} \approx \left(\frac{x}{\mathrm{d}}\right)^{3/2} \tag{4}$$

Fig. 3 shows the experimental data which do in fact agree with equation (4).

14 Let us suppose that in a wave field, the surface current generated by a pneumatic boom is substantially the same as it is in still water. However, if the oil is drifting towards the boom with a velocity U_D, the surface current generated by the boom must be strong enough to stop the oil a distance from the boom, for otherwise the motion of the wave field will carry a particle across the boom. Increasing V, the volume rate of flow, increases the stand-off distance of the oil, x_s. According to the above assumptions, x_s is the distance at which $U = U_D$ and equation (3), derived for still water, gives

$$\frac{x_s}{\mathrm{d}} \approx \frac{(gV)^{2/3}}{U_D^2}. \tag{5}$$

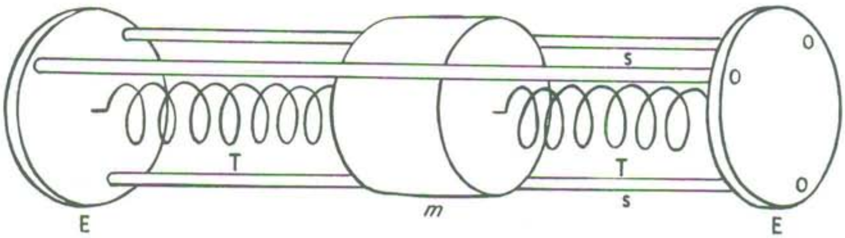
15 A further laboratory experiment was carried out to check these assumptions in which U_D was the drift velocity due to the wave field alone, no wind or tidal currents being present. The oil was simulated by small wood chips. The results were found to be in fair agreement with the theory.

16 Using the experimentally confirmed theory and evaluating the contents of proportionality from the experimental data, the power required to hold an oil slick can be estimated. A reasonable estimate gives 2·5 kW m^{-1} of boom, supposing the boom is 3·5 m below the surface and operates in 1·2 m high waves. In the absence of wind the boom will leak oil whenever the tidal flow is greater than 0·15 m s^{-1}. To stop a tidal current of = 0·7 m s^{-1} would require about 70 kW m^{-1} of boom—an excessive amount of power. The pneumatic boom in its present form is limited by the power available.

Section C Project Design

This question forms a project planning exercise similar to that undertaken as part of the Course Work requirement. Credit will be given for depth of thought, consideration of practicable alternatives where relevant, and for clear statements of reasons for decisions and choices. You are advised to spend approximately 30 minutes on Section (iii).

Introduction



In designing an accelerometer for use in a car it is decided to employ the principle illustrated in the figure. A mass m is constrained to move in one line only by a support system s; m is attached to one or both of the end plates E by one or two tension springs T (the arrangement sketched in the figure has been adopted for clarity only). If the accelerometer is accelerated longitudinally with a magnitude of f m s^{-2} the mass m will exert a reaction force $-mf$ on the springs and will undergo a displacement x metres relative to the end plates given by $x = -kmf$.

The constant k will be determined by the arrangement and stiffness of the springs. (It has been assumed that frictional forces between m and the supports are small enough to be neglected.)

A school project is to be developed on the detailed design and manufacture of a system to measure the displacement of the mass m.

Question

Carry out the following initial planning exercises:

(i) List in order of descending importance the desirable properties to be possessed by the measuring system. Explain briefly the importance of each property.

(ii) Outline briefly two possible methods which could be used to measure the displacement of the mass and list the advantages and disadvantages of both. Select the method you consider to be more suitable. State the reasons for your selection.

(iii) Design experiments to test the selected measuring device with respect to the **two** most important properties listed in Section (i). Describe, with the aid of sketches, the important aspects of the procedure to be adopted, the measurements you would take and your treatment of the measurements.

(iv) Assuming that 50 hours (excluding construction time) are available for the project, draw up a timetable of operations for the design, production and testing of the device.