Drawing Board Projects

The case for design experiences without three-dimensional realisation.

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In the context of the school curriculum, projects and investigations, as we all know, are now considered indispensible; although I recall being inspired by a certain History master in the late 1940s who set us, as fourth-formers, research exercises on such topics as Jethro Tull, Turnip Townsend, and other agricultural and industrial pioneers of the 18th and 19th centuries. In those days, of course, we still called it "homework", even though the work involved extended field trips into the archives of the public library. Exercises such as these would now be properly termed "investigations", since there is no sense of "projection" into the future or into the production of an original creation or artefact. Since that time, the Project Technology team and others have done much to place technology more widely into the traditional school environment so that, in addition to the analytical study of other peoples efforts, children and students are encouraged to experience the design process for themselves and the exhilaration and inevitable frustrations that are inseparable from it.

The design process, as Deere[1] and others[2] have shown, is the essential core of Technology and any technological project should therefore incorporate a strong element of design; if the prime purpose of an exercise is analysis rather than synthesis, then it might be better described as an investigation.

The JMB syllabus in Engineering Science (A-level)[3] distinguishes between projects and investigations; reports of each are required by the examiners and together they account for up to 20 per cent of the examination marks. A further 13 per cent is allotted to a one-hour written paper on project design (Paper 1, Section C), making 1/3 of the total marks for the examination available for rewarding the student's ability in technological analysis, synthesis, evaluation, and design. Significantly, this examination makes no attempt to assess a student's ability in workshop techniques for, although Engineering Science is probably ideally taught by a partnership of Craft and Science Departments, it must be admitted that in some places it is being handled entirely by the Craft Department and in others completely within the Physics Laboratories. In either event there is much to be said for introducing concentrated design experiences to a class without the obligation actually to manufacture anything beyond a set of drawings or plans; in the case of a Physics specialist attempting to teach the meaning of design in a school where the Craft Department is inconveniently distant or even virtually non-existent, some form of project work which literally never leaves the drawing-board may become a justifiable necessity, although much can be achieved from the use of construction kits. The Craft teacher may also wish to provide experiences in the design of something which cannot be produced in his workshop – such as the plan for a new town or a design for a road or railway locomotive as a logical extension of a smaller-scale construction exercise.

Paper projects, then, have a place in the curriculum of any teacher involved in presenting technological design, whether in the workshop or the laboratory, and can be used to exemplify many of the essential features of the design process. Town-planning offers wide scope for drawing-board projects; as an example, two boys at Bolton School, Lancashire, were able to co-operate with the Borough Engineer in the design of a traffic-free area for the town, which developed into a major project acceptable to the Engineering Science examiners. On a smaller scale, classroom exercises in the design of road junctions, one-way systems, and traffic-signal sequences for optimum traffic flow, form useful teaching units both in the process of design and in the analogous application of physical laws. If motor vehicles in a street are seen as analogs of electrons in a wire, then Kirchoff's law tells us that the number of vehicles entering a junction must equal the number leaving it in the same time period; and Ohm's law suggests that vehicle flow is inversely proportional to the obstructive nature of the street, for a given motive force on the vehicles. The Ministry of Transport booklet on Traffic Engineering Techniques[4] contains much practical information on the organization of traffic surveys and the design of roads and junctions.

Planners' reports on city development also provide valuable source material for paper projects; an outstandingly good example being the Development Proposals report for the new city of Telford, in Shropshire[5, 6]. In Vol. 1. of this report (an excellent piece of technical writing in itself) the fundamental considerations of technological design are clearly stated and the design process presented step by step to the final recommendations. Units selected from the report might be used as raw material for a class design exercise, through which the vital feature of technological design can be presented.

A town-planning project, probably more than any other, highlights the essential feature of any successful design – the need for an optimum balance between the three Rs of design: Requirements, Resources, and Restraints. One may imagine a three-dimensional balance (or a chemical balance with three arms) with one of the Rs in each pan, and each R made up of three components: Social, Economic, and Material. In the case of the Telford site, the fundamental Requirement (a social one) is provision for a population of ¼ million by 1991; housing, community planning, communications, employment, education, and leisure, are other social, economic, and material Requirements. Resources, basically, are 77 km^2 of land – 1/3 now derelict as a consequence of early industry and shallow mining and another 1/3 already built-up but much in need of renewal; whilst Restraints include the need to respect established communities, the instability of ground in many areas, and the fact that the area includes the historically important Coalbrookdale ironworks, where the English industrial revolution began in the early 18th century with the development of a commercial process for manufacturing cast-iron. A class presented with such basic factors as these might then be led through the design process and encouraged to appreciate design factors like the value of conservation areas, the re-use of old railways as cross-town cycle-tracks, and the development of subsidance ponds for sailing and fishing (that is, Restraints incorporated into the plan as Resources), as well as the need for community centres, a town centre, and an adequate communication and transport system. There will also be the need to determine electric, gas, water, and drainage requirements (and the location of processing plants); in fact the scope for technological design experience is almost unlimited, if one accepts Technology in the broad sense of 'design for the benefit of people'. On a smaller scale and nearer home the design of the school timetable usually represents a major design exercise for a senior member of the school staff – rarely a Technologist. Here is a potential project for a small group of senior pupils which actually has to be realized within a given time and with inescapable consequences for the entire school community.

Even in the home or workshop, so-called design often fails to allow for the fact that a machine or process is to be used by real people – and here is yet more scope for paper projects in re-design. Look at the wiring diagram in the driver's handbook of your motor-car; is it comprehensible? Is it set out for the driver's convenience (assuming some elementary technical knowledge) or the designer's? Traditionally it will be set out in the form of a plan view of the vehicle and shows the assembly of colour-coded wires in prefabricated cableforms; what it fails to demonstrate with any clarity is how the electric current flows from the battery to the screenwiper motor, for example, and where the fault might be when it doesn't. A redesign of the diagram, to show current routes and direction (remembering that electron flow is from the battery negative terminal), presents a design exercise calling for the clear and linear thinking that the Technology teacher aims to develop in his students. An example of such a redesigned diagram is given in Pym's "Industrial Society" on page 186[7].

The design of an operating procedure for a machine offers a further scope for analysis of the Requirements, Resources, and Restraints, of the process required.[8]. Neither the machine nor the operation need to be complex; the simple process of making a hole in a piece of metal with a vertical drill offers ample scope for analysis of the skills called for, and the design of a safe procedure for an operator new to the machine.[9] The child's kerb-drill is an example of a job-analysis and the consequent synthesis of a procedure designed to transfer the child from one side of the road to the other with optimum efficiency and complete safety. The same criteria apply to the operation of any machine and a job-analysis project might help to improve both safety and efficiency in the school workshop.

Finally, there is the paper project through which the Craft or Science teacher can offer the experience of a practical design whilst at the same time consolidating an important piece of theory. A practical example may be found in the design of an electric locomotive and its supply system given below; some very basic Physics is needed and the final design offers scope for a model engineering project with suitable scale-factors. This paper-project has been used in school, presented to a first-year sixth-form in the following manner.

Electric Driving Systems

During the 1960s a great advance was made in the technology of railway operation by rebuilding the network linking London with Birmingham and Coventry, Stoke-on-Trent, Crewe, Liverpool, and Manchester, with a 25 kV alternating-current traction system. During the 1970s this system is being extended forward to Glasgow. Many design decisions had to be made in determining the type of power supply required and the specifications of the locomotives to be ordered. Since 1932 all electric railway systems built in Britain had been standardized at either 1500 V DC with an over-head conductor or 750 V DC for third-rail systems, but by the mid-1950s it had become apparent that recent developments, particularly in the design of semi-conductor rectifiers, suggested that a high-voltage AC system would be much cheaper to install and maintain and would enable lighter and more efficient locomotives to be designed.

The following simplified example illustrates some of the design problems facing the engineer in such a situation.

Designing a Railway System

A main-line railway is to be converted to electric traction using an overhead supply to the locomotives, the other connection being through the running wheels to the rails and earth. The trains are to run at speeds up to 160 km h^{-1} (100 mph) and at this speed the wind resistance and friction forces on a train amount to about 54 kN. The maximum accelerating force is required at 10 m s^{-1} and at this speed the total tractive force of the locomotive needs to be about 240 kN. The basic design problem is to determine the number and type of traction motors required in a locomotive and the most suitable supply voltage, AC or DC, for the overhead conductor, whose resistance is assumed to be 1 ohm per km.

1. Power of the Locomotive

Power is defined as energy transferred per second, or watt + joule per second + J s^{-1}. Energy is derived from force x displacement, or joule = N m. Hence power in watt = N m s^{-1} = force x velocity. Therefore at 160 km per hour, when the tractive force is to be 54 kN, the power required = $54 \times 10^3 \times 160 \times 10^3/3600 = 2.4 \times 10^6$ watt. At 10 m s^{-1}, when the tractive force is to be 240 kN, power = $240 \times 10^3 \times 10 = 2.4 \times 10^6$ watt. We may therefore say that under each of the specified conditions the maximum tractive power required is 2.4 MW; this is the total power of the traction motors. One motor of 2.4 MW power would be impractically large, and two of 1.2 MW each would give rise to mounting problems. Four motors each of 600 kW could be more easily carried; one driving each axle of two four-wheel bogies. Six-wheel bogies could be used if required to carry the weight of the locomotive, but the middle axle would probably have insufficient space round it for another motor and so any increase in the number of motors beyond four would lead to more problems that it would solve.

2. Type of Motors and Method of Connection

Traction motors are invariably series-wound, that is the armature coil is in series with the field coil; this arrangement gives a very large starting torque (at zero velocity) and economic running at high speed, when back-emf tends to minimize current in both coils alike. A direct-current motor is always used, since speed control can be effected by the use of series resistors and tappings on the field windings; in an AC motor, speed is determined principally by the supply frequency, which is generally fixed.

Traction motors had reached a well-developed state, through their extensive use on tramcars and early electric railways, by the 1890s; that is, before the electron had been discovered or the nature of electric current really understood. The design of large motors operating on around 600 volt is therefore very advanced and they are commercially available. a 600-volt motor with a nominal power of 600 kW will take a current of about $600 \times 10^3/600 = 1000$ ampere.

The four motors may be connected in series, parallel, or a combination of the two; the possibilities are shown in fig. 1. Arrangement (a) has the disadvantage that if one motor were to burn out or fail, the train would be immobilized unless control gear were supplied to overcome the situation. The series-parallel combination (b) permits the train to continue with one motor out of action, but requires the control gear to handle a larger current than (a). Motors in parallel (c) offer no further advantage for the inconvenience of a larger current still. Series-parallel, then, appears to be the best compromise, requiring a supply of 1200 volt DC at up to 2000 ampere.

3. The Supply System

Let us first assume that 1200 volt is supplied to the overhead cable, from which the locomotive takes a current of 2000 ampere. Assuming the cable to have a resistance of 1 ohm per km, the voltage loss in 1 km of cable = 1×2000 volt, which is clearly impossible with a supply of only 1200 volt. Either the cable must be supplied with power at very frequent intervals or the current must be reduced to bring the voltage loss within tolerable limits. In order to reduce the current for a given power, it is necessary to increase the voltage; but high-voltage traction motors and control gear would lead to expensive insulation problems. On the overhead supply this difficulty is less acute, since the cable is insulated by air except at the suspension points, where large ceramic insulators are quite practicable. We are therefore left with motors requiring 1200 volt DC, at up to 2000 ampere, but with the necessity of supplying the electric energy at much higher voltage in order to obtain a proportionately lower current value in the overhead conductor.

The only efficient way to change voltage without significant energy loss is in a transformer, which only operates with alternating current. The overhead supply must therefore be AC, with the locomotive carrying a transformer and rectifier, and DC control gear and motors.

Let us assume a transformer ratio of, say, 20:1 and test the result by calculation; any ratio could have been chosen, but an excessively large one would lead to an inefficient transformer and a low ratio (say 2:1) would give an insufficiently reduced supply current. It is in making decisions like these that the Engineer or Technologist has to rely on his experience, or at the least on an informed guess, and test the proposed design by calculation and experiment. It is possible, in a well-designed transformer, to achieve over 95 per cent efficiency, and so a 20:1 ratio giving approximately 1200 volt output needs an input of $1200 \times 20 = 24$ kV. Since the output current will be up to 2000 ampere, the input current will be in the region of $2000/20 = 100$ ampere. This current is supplied from the overhead cable whose resistance has been taken as 1 ohm per km; the voltage

Fig. 1

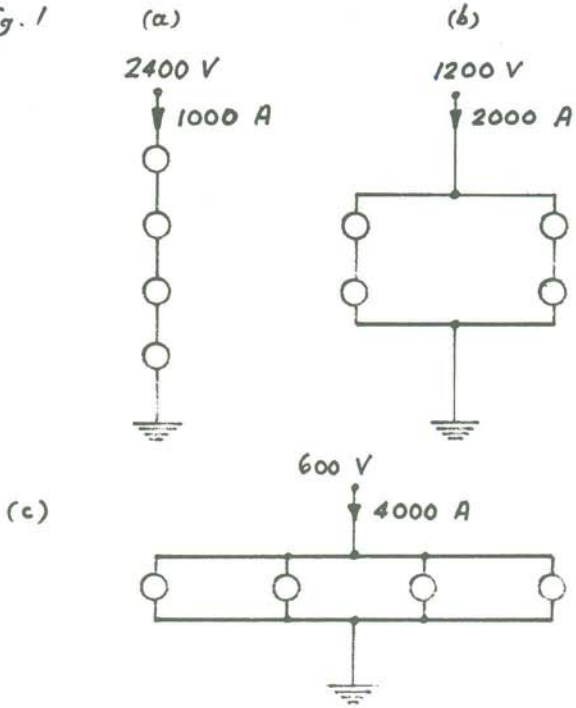
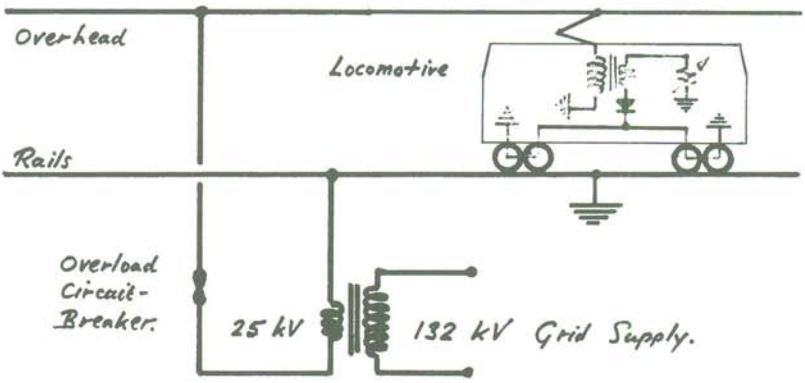

(a)
(b)
2400 V
1000 A
1200 V
2000 A
600 V
(c)
4000 A

Fig. 2


Overhead
Locomotive
Rails
Overload
Circuit-
Breaker.
25 kV
132 kV Grid Supply.

loss in 1 km is therefore 100 x 1 = 100 volt. or 1 kV over 10 km. Hence if the cable were to be supplied with 25 kV AC, then a locomotive 10 km from the supply point will still have 24 kV supplied to its transformer – a loss of only 4 per cent and still adequate to drive the motors at their maximum rated power. In practice the supply points to the overhead cable could be at 20 km intervals; a train would then never be more than 10 km from a supply point. A diagram of this admittedly simplified system is given in fig.2, see also reference[10].

This exercise illustrates some of the processes in an engineering design, where there is no single "right answer" but a range of acceptable solutions; the designer's task is to select the optimum solution from the possible ones. In fact, the railway linking London with the Midlands, Liverpool, and Manchester, is driven by a 25 kV AC system similar in principle to that suggested in the preceding pages.

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