EDUCATION, TASKS AND OUTLOOK OF THE ENGINEER

Inaugural Lecture
of the Professor of Engineering
delivered at the College
on 16 February 1950
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ACCORDING to the Charter of the Institution of Civil Engineers, engineering is defined as 'the Art of Directing the Great Sources of Power in Nature for the Use and Convenience of Man' and though, perhaps, this may be an inadequate definition it is, at least, one which leaves no doubt that in the minds of those who framed it engineering was conceived not as an exact science but as something personal and creative. And, indeed, this was no new idea. If we turn, for instance, to the pages of Samuel Johnson's *Rasselas*, written many years before the Institution of Civil Engineers was founded, we find the following passage:

> Among the *artists* that had been allured into the Happy Valley, to labour for the accommodation and pleasure of its inhabitants, was a man eminent for his knowledge of the mechanic powers, who had contrived many engines both of use and recreation.

But the grandiloquence of Dr. Johnson must not blind us to the fact that the practice of applied mechanics has too often been regarded in the past as one of the less worthy activities of mankind. To the Greeks the grimy figures seen dimly through the smoke of the workshop or the smithy had seemed an affront to the physical perfection which was their ideal, and, though civil engineering had played no small part in the development of the Roman empire, with the collapse of that empire men's desire to press natural forces and natural materials into their service waned, and the old ideas of distrust and dislike of experiment took a firm hold of the minds of intelligent men and did not relax their grip for more than a thousand years.

The great burst of engineering activity which marked the Industrial Revolution brought about an almost complete reorientation of views regarding the profession of the engineer and his importance to society. In Great Britain, especially, the achievements of the engineers during the period between the middle of the eighteenth and the middle of the nineteenth centuries had brought the names of Watt, Rennie, Smeaton, Telford, Stephenson, and many others constantly before the public, and it became evident to the more far-sighted that the new and complex problems thrown up by the age of steam would require for their solution men who had had a wider and more scientific training than practical experience alone could provide; and attempts were made, at first in an uncertain and rather timid fashion, to supplement such experience with a grounding in the mathematical and physical sciences.

Higher engineering education in this country is just about as old as the railways, for it was in 1828, the year before the famous Rainhill Trials, that University College, London, was founded, one of its professors being appointed to a Chair of Engineering, the first to be instituted in these islands. However, various difficulties delayed the opening of the Engineering School at University College until 1841 and it is, in fact, King's College, London, which has the honour of having given the first properly organized university course in this field, beginning in October 1838. A little later, in 1840, a royal commission recommended the first appointment to the Regius Chair of Civil Engineering and Mechanics at Glasgow, but the wisdom of creating such chairs was, at that time, doubted by many, both within the academic and the engineering professions.

The significant change brought about in 1850 by the establishment on a proper basis of the great principle of the Conservation of Energy led to the conviction, slow to develop but nevertheless profound, that engineering, like medicine partly a science and partly an art, was deserving of a place among university subjects of study. Within a century there have grown up more than a score of engineering schools in the British universities and these schools, our own not least among them, have shown their vigour by flourishing and expanding even at times when the fortunes of the nation have been at a low ebb.

In these post-war years when the great question of industrial efficiency is so often on the public mind, it is natural that the training of engineers has become a controversial subject, and that reformers, in their haste to adopt ideas which have been successful in other places and, perhaps, under different circumstances, are sometimes eager to abandon piecemeal the lessons of a hundred years of trial and error. It is not my intention to argue these debatable questions, but rather to discuss as judicially as I can a few of those aspects of engineering training, education, and research which seem to me to have a special importance today.

During the past hundred years the education of engineers has undergone a process of steady development and improvement, and this process has led away from the old belief in the paramount importance of practical training and towards a system in which a planned scientific foundation is considered to be the ideal basis upon which the future superstructure of technical, economic, and managerial experience will be erected. This does not mean that an academic training alone is sufficient; it means that the old, rather haphazard ways of gaining experience in the factory are being superseded by carefully planned courses which are aimed at providing the apprentice engineer with the greatest amount of insight into industrial methods in the minimum period of time, so that he may be transferred to a responsible post as soon as possible.

It cannot be denied that doubts are sometimes expressed as to whether the modern system is preferable to the old one. If it is certain that the training of an engineer must nowadays be a blend of the academic and the practical, the proportion of each ingredient in the mixture is a matter of controversy. In the days when engineering was looked upon mainly as an art, a theoretical training was thought by some of the older school to be something of a waste of time, and a long apprenticeship, in which a considerable period was spent in acquiring a degree of manual skill with various tools, was looked upon as essential. Whilst the modern method makes it a quicker process for the graduate to be transformed into a qualified engineer, it may be that the older system, although in its early stages often damaging to a trainee's self-esteem, produced the type of engineer who was more conscious of workshop problems and better informed as to the potentialities of men and machines. I think it would not be unfair to say that the newer system is well matched, on the whole, to a mass-production era in which the need for specialists is an over-riding consideration; but, where adaptability and vision founded on wide experience are required, as they will be in the highest posts, the older scheme might produce the better man.

The shift in emphasis from practical to theoretical training has been accelerated in recent years. The immediate cause is the need for more applied research, with its accompanying requirement of more research workers. Quoting first from the Percy Report on Higher Technological Education published in 1945, we find '. . . that the position of Great Britain as a leading industrial nation is being endangered by a failure to secure the fullest

possible application of Science to Industry' and this pronouncement is reinforced by the Advisory Council on Scientific Policy, whose statement, presented to Parliament in 1948, declares that '. . . a return to prosperity can only be achieved if we are able in the future, as in the past, to lead the world not only in the discovery but in the application of scientific knowledge'. Both reports stress the shortage of qualified engineers and other technologists to apply the results of research to development, and it is the opinion of the authors of the second that current *fundamental* research is unlikely to have any early influence on productivity, and for prompt results the more effective application of scientific knowledge already available is likely to prove more fruitful.

In a certain sense, the conclusions referred to above mark the end of an era in scientific opinion. Gone are the days of the rather contemptuous snobbery which viewed work in pure science as always of much higher intellectual quality than applied research, and there has been a return to the opinion of Francis Bacon, who held that 'the legitimate goal of the sciences is the endowment of human life with new inventions and riches'. It has at last become evident that the work of the applied scientist is in a very real sense complementary to that of the fundamental research worker, and that both must tackle problems requiring the same diligence, skill, and tenacity of purpose for their solution.

I do not mean to suggest that there should be a sort of moratorium in pure science whilst the applied scientists make up leeway. The only effect of such a course, in the long run, would be to bring all scientific development to a full stop. The point has been well put by Professor Peter Kapitza, the renowned Russian physicist:

> We, however, are often apt to judge scientific achievements only by their practical results and consequently it appears as if

the person who picked the apple had done the main job, while in actual fact the apple was created by the person who planted the tree.

The modern tendency towards *collective* investigation must be emphasized. We cannot expect, in the future, that great names in scientific research will appear as frequently as in the past. Then, the apples of scientific discovery were thick upon the tree, but now the lower, and perhaps the best-covered branches have been denuded of their fruits and the picking of those higher up becomes a task of increasing difficulty. Many of the problems facing the applied scientist today are of such complexity and of such inherent difficulty that they can only be solved by the united efforts of a number of individuals, and this new orientation of science towards team work rather than individual effort marks the beginning of a new era in scientific development.

A technical education in engineering, whether or not ultimately directed towards research, must rest upon a foundation of mathematics. No subject is so revered by its disciples, none so cordially disliked by those whose early training in it has been imperfect, or who are unsympathetic to its precise and rather cold-blooded discipline. The eloquent complaint of Thomas Grey still finds an echo in many hearts:

> Must I pore upon Mathematics? Alas, I cannot see in too much light, I am no eagle. It is very possible that two and two make four but I would not give four farthings to demonstrate this ever so clearly; and if these be the profits of life give me the amusements of it!

This defeatist attitude must have no place among the thoughts of the modern engineer. If we no longer agree with Roger Bacon that 'Mathematics alone can purge the intellect and fit the student for the acquirement of all

knowledge', we must admit that the real explanation of experimentally established facts, and the limits beyond which experiment is unprofitable, are only to be discovered and expressed in mathematical terms. The standard required by the applied scientist is, in general, not an exalted one, but it is essential that he should be able to employ with confidence the rather low-brow mathematics—what has been called the 'tin-opening variety'—which suffices for the vast majority of practical problems.

For those more intricate puzzles sometimes encountered in present-day research, the elegant and formal solution, deriving from classical methods of attack, very often cannot be achieved, and new methods, for example the Moment Distribution method of Hardy Cross and the Relaxation methods of Southwell, have scored spectacular successes. A comparatively recent aid is the development of mechanical and electrical analysers and computers which greatly shorten the time and ease the labour necessary for a solution, and with the help of such machines complex problems which, literally, could not be solved in a lifetime by ordinary methods, can now be disposed of in a few minutes. It was recently reported that engineers at the University of California are building a so-called 'Electronic Brain' which, in addition to computing, will, it is claimed, translate foreign languages.

To sum up, one might perhaps say that those whose responsibility it is to teach engineering mathematics should realize that though it may be a dull and pedestrian activity to the professional mathematician it is a most potent weapon in the armoury of the engineering scientist, whose future professional competence may be endangered if this weapon never acquires an edge. At the same time, one might remind the young engineer that whilst it may be true that Abraham de Moivre, the famous French mathematician, habitually slept for twenty hours out of the twenty-four his example should not be followed by students of more ordinary ability.

Although the importance of the technical and practical education of the applied scientist is now generally realized, too little attention has been given to problems of training for management in industry and elsewhere. It is a commonplace to assert that this country needs today an ample supply of men and women possessing that elusive quality known as 'leadership'—that is, leadership in its best sense, suggesting example and persuasion rather than discipline and compulsion; and it is much to be regretted that there is an unhappy unanimity amongst those best qualified to judge that science graduates often fail in the acid test of personal responsibility and shrink from undertaking those tasks in which human relationships are all-important. Hazlitt, in a well-known essay, compared the man of the world with a chameleon and the scientist with an armadillo, observing that the typical man of the world takes his cue from his surroundings and quickly becomes at home in any company whilst the scientific man is often awkward and shy, retiring behind an impenetrable armour of aloofness. The almost traditional inarticulateness of the scientist is certainly connected with the fact that his training is concerned with the study of inarticulate objects, with things rather than with people; and thus he is often at a disadvantage in conversation and debate. Education in science or technology has produced many people who are most expert in attacking and overcoming technical problems but who shrink from the great human problems which industry presents.

Those responsible for the training of young engineers are not unmindful of these dangers. During the recent centenary celebrations of the Institution of Mechanical Engineers an important pronouncement was made, which

stated '. . . that the engineering degree curriculum . . . should leave freedom for individual development in academic, technical, and social directions', Sir Charles Inglis, for many years head of the Engineering Department at Cambridge, in his Presidential Address to the Institution of Civil Engineers, put in a plea for leavening an engineering education with a small measure of the humanities, and pointed out that exclusive concentration on the materialistic and scientific aspects of his profession tends to produce in a student a certain narrowness which subsequent experience may never wholly rectify.

The applied scientist of the coming era will not only be concerned with the development of new processes and new machines; much of his effort will be devoted to a study of the problems of the worker in the factory or on the building site, and for this reason the tendency towards early specialization which has followed from the increasing complexity and ever-expanding volume of all branches of science should, in my view, be resisted. This is difficult at a time when there is an urgent need for more research workers and when the young graduate is often expected to have an up-to-the-minute knowledge of the latest developments in a particular subject, but it is not to be overlooked that many science students will join the management staffs of business and manufacturing firms, or will become teachers, or will enter the Administrative Civil Service, and such students undoubtedly require a wider training than does the professional scientist. The fear that some modern systems of scientific education may tend to produce a mass of narrow specialists for the sake of a comparatively few workers in a narrow field is spreading and will, I believe, eventually produce corrective action along broader and less materialistic lines.

Let us now leave these problems of education, training, and human relations, with the reflection that a significant part of this great complex of activities known as engineering still defies scientific analysis. Much remains imprecise, governed by causes no more than partly understood, by factors nebulous and imponderable. At every point engineering is concerned with the interaction between men and things and, in spite of the march of science, is and will remain partly an art, a proper sphere of activity for those interested in people as well as machines.

PRESENT TASKS OF THE ENGINEER

I turn now to a discussion of a few of those questions which concern directly both the practising engineer and the community at large. To select from the whole vast field of engineering activity is no easy matter, but there are three types of problems which are of special interest and importance today; namely, problems connected with the maintenance of the world's food-supply, problems related to industrial and domestic power, and problems concerned with travel and communications.

Food-supply

In spite of the evident difficulties in restocking our national larder many people seem to think that the post-war shortage of food is purely a short-time phenomenon, a condition which will inevitably cure itself in the course of a few years and which is due, in some way, to the dislocation of the normal means of production and exchange.

Such a belief entirely ignores the stupendous growth of world population. Two hundred years ago the population of the world was increasing at the rate of about 2 millions per year; today the annual rate of increase is

nearly 20 millions, and in the last 10 years the number of people to be fed has grown by 150 millions, in spite of wholesale slaughter by bombardment and concentration camp. According to Lord Boyd Orr, it is estimated that, taking account of the anticipated increase in population, world food production must be doubled in the next 25 years to provide a bare sufficiency for the people of all the countries. But the land on which this food is to be produced is no longer as fertile as it was. Soil exhaustion and soil erosion have affected vast areas in America, South Africa, and elsewhere, and the results of wasteful exploitation have led to the loss, for many years to come, of tens of millions of acres.

The picture presented by these facts is indeed a gloomy one, but fortunately they do not tell the whole story. Before the advent of the colonists, the vast area of the North American continent barely sufficed to maintain the small Red Indian population, whereas now a population more than twenty times as great finds it possible to export a great surplus of food as the result of scientific husbandry. Some authorities declare—though others disagree—that the world's reserves of virgin soil have nearly been reduced to vanishing-point, but even if this is so it is certain that more food could be produced on the present acreage. As A. N. Whitehead has pointed out, a successful organism modifies its environment; in a crowded world man must do the same if he is to survive.

The farmer already owes much to the engineer, and in the future co-operation between the two professions will become closer. In recent years great strides have been made in substituting mechanical power for the muscular effort of draught animals. As the steam-engine developed it was natural that it should be employed for agriculture and the system of cable ploughing, employing wire ropes and a stationary engine and steam-boiler, became widely used, at least where large fields were concerned. The relative clumsiness of the steam traction-engine, and its requirements for fuel and water, militated against its popularity and it was not until the internal-combustion-engined tractor was developed that the need for an independent transportable power unit on the farm was met.

The modern motor-tractor has transformed agricultural methods. Its efficiency as a haulage unit, its capacity for saving labour and time, and its relatively low cost are such that there has been an enormous increase in the number of tractors employed by farmers. According to recent statistics, in 1939 there were 13 horses to every tractor on British farms; today the proportion is only about 2 to 1 and there are upwards of 300,000 tractors at work in England and Wales. If the number of tractors employed on a given area be taken as the criterion Great Britain now has the most highly mechanized farming industry in the world, with the one exception of New Zealand.

The processes of reaping and harvesting of the crops have for a long time been dependent on the efforts of the engineer. In 1783 the London Society for Encouragement of Arts offered a gold medal for 'inventing a machine to answer the purpose of mowing or reaping wheat, barley, oats or beans', but no medal was awarded, none of the entries apparently being of sufficient merit. A little later, in the first quarter of the nineteenth century, several British patents were taken out for mechanical mowing devices, and in 1834 McCormick patented in the United States his first reaping machine. If the seven essential elements of his design had already appeared in previous British patents, he still deserves the highest praise for having produced the first practical solution, and, though the appearance of it was such as to excite wonder and even derision—*The Times* referred to it as a 'cross between a chariot, a wheelbarrow, and a flying machine'—its success has been phenomenal, and by its use and that of similar devices, the saving in time and effort in harvesting has been enormous. For instance, in 1880 it took 20 man-hours to harvest an acre of wheat, in 1934–6 the average time was 6·1 man-hours only, and, since then, the period has doubtless been still further shortened. Figures such as these demonstrate the contribution which mechanization has made towards food production. It is a contribution which can be maintained and increased if engineers are given the opportunity to design and to manufacture the plant which is needed to guarantee our future food-supply. Much of the land remaining for cultivation is admittedly 'marginal' and on such land orthodox methods of farming are not worth while. To make it productive by devising machines, dams, irrigation works and so forth is an engineering problem, a problem which can—and must—be solved if Malthus's prophecy is finally to be disproved.

Power

One of the most potent influences retarding the economic recovery of these islands is the shortage of industrial electric power, which prevents us from equalling the higher degree of mechanization of American factories with which our own must compete.

Present-day demands for industrial power have come at a time when there has been an astonishing rise in the consumption of electricity in the home. Between 1927 and 1946 the industrial load was quadrupled; during the same period domestic consumption increased twelvefold, partly, no doubt, as the result of pre-war propaganda campaigns to popularize electricity. This enormous domestic load has proved a serious embarrassment to industry in its efforts to equal American productivity, which, per head of working population, was estimated before the war to be twice as high as in Great Britain and has since improved on its pre-war standard.

The gap between European and transatlantic industrial efficiency can only be closed by building more thermal power stations generating electricity from heat energy in fuel; and by the fuller utilization of water-power resources.

Water-power cannot, in this country, produce a very large proportion of the total amount of electricity required—well over 98 per cent. still comes from steam—and the greater part of the load must fall on the thermal stations, for which coal is the primary source of energy. According to the first report of the British Electricity Authority, British thermal power stations consumed during 1948–9 over 28 million tons of coal and coke, and it must be one of the most urgent tasks of the engineer to increase the efficiency of generation in order to reduce as far as possible the heavy demand for fuel. During the last quarter-century there have been noteworthy improvements in power-generating plant, resulting in a great reduction in fuel consumption per unit generated, but the law of diminishing returns does not hold out much hope for a steadily continued improvement along similar lines.

In spite of the best efforts of applied science, an evil alliance between the laws of thermodynamics and those governing the strengths of materials at high temperatures has so far prevented more than about one-third of the available heat in a lump of coal from being transformed into electrical energy. Actually, considering all the power-stations in the country, the average efficiency of generation is still nearer one-fifth than one-third, and to make matters worse, getting rid of the waste heat represented by this inefficiency is no easy matter, often requiring the

construction of huge, expensive, and ugly cooling towers. These eyesores may be dispensed with altogether, and a considerable overall saving in fuel obtained if what has been known as 'district heating' can be adopted. By district heating we mean a system in which the waste heat from the power-station is employed in the form of hot water, to warm dwellings in the vicinity. The adoption of such a scheme requires that the necessary piping be laid underground, and the capital cost of this can only be justified in the case of a new housing estate or, better still, a new town. Such plans are only feasible in special cases, and the absolute necessity for reducing fuel consumption requires expedients of more general application.

At the present time the greater part of the 200 million tons of coal per annum which are mined in Great Britain is consumed most wastefully, the average efficiency of utilization being much less than 20 per cent. The biggest offender is the open domestic grate, which probably wastes nine-tenths of the heat with which it is supplied, and which burns per year in aggregate about 40 million tons of coal. The inefficient extraction of the potential heat of coal is leading to an appalling wastage of power, and when it is remembered that raw coal is a fertile source of chemical products this misuse of our resources ought not to be tolerated. It has been contended that if coal were considered as a primary chemical and if the utilization of electricity, gas, and transport were regarded as a single undertaking, in, say, twenty years the same amount of power, heat, and light could be gained from about 120 million tons of coal as are now obtained from 200 million tons. To do this would require a stricter control over our fuel resources than has up till now been considered desirable, and would, no doubt, involve large capital expenditure, but the ultimate advantages might be tremendous. The lesson to be learned is that our coal resources are wasting assets, and these assets are still being squandered.

It ought not to be expected that an engineer should prophesy when atomic energy will become available as a large-scale competitor to coal. At the present time there is no evidence to suggest that atomic power generation will be an economic proposition for several years to come, but there is every hope that eventually the problems involved in building atomic piles delivering large quantities of power will be solved. Those qualified to express opinions in these matters suggest that within ten or twenty or thirty years there may be a few atomic power stations whose output will be comparable to medium-sized steam stations, but whose capital cost will be much greater. Perhaps these prophets are being too cautious—perhaps not, but in either case it is certain that the great bulk of the world's power for some years to come will be dependent on conventional fuels, whose efficient utilization involves problems of engineering, economic, and political importance.

Travel and Communications

The modern engineer tends to divide the subject of transport into two sections, the first comprising travel by land and sea, the second by air alone. The reason for this division is the fact that the methods of travel we employ on land and sea are now firmly established and the limitations they impose are clearly understood, a compromise solution of their problems having been arrived at as a result of experience in the past. Technical questions associated with the construction of ships, railways, roads, and road vehicles now for the most part cause little argument, and in many cases the improvements we can expect will be due rather to better organization and administration than to advances in scientific knowledge.

Speedier and more comfortable travel by road and rail will owe less to the engineer than to the central authority which can provide the finance necessary for improved highways and bridges, for more comfortable railway coaches and more powerful locomotives, and the position today is such that, on the railways at least, we find it most difficult to attain the standards of half a century ago, let alone to improve upon them. For example, in 1888 the time required for a railway journey from London to Edinburgh was reduced to eight hours; seven years later a train ran from London to Aberdeen at an average speed of over 63 miles per hour. Such speeds were exceptional, it is true, but they indicate that the normal limits of performance along conventional lines were probably reached years ago, and future improvements are so closely linked with economic factors that the engineering aspects are of secondary importance. The design of ships, though perhaps less stereotyped than that of trains and road vehicles, does not now offer much scope for novelty, the inexorable laws of economics having established a kind of stranglehold on the fertile imagination of the engineer, and having dictated, for instance, the limits of size for a vessel of a given class, limits which can only be ignored in very special cases.

It may be objected that the recent development of the gas-turbine engine must have a profound effect on transport, but, as regards land and sea travel there seems no good reason why this should be so. Even if, for instance, gas-turbine locomotives supersede the conventional steam-engine as the chief power unit for our railways, very much higher speeds are hardly to be expected as a result—the chief gain should be in fuel economy, and this alone might not be enough unless it were coupled with a reliability not far short of that of the steam locomotive, which may sometimes run a quarter of a million miles between major overhauls. The position as regards ship propulsion is not dissimilar; here again the gas-turbine has certain special advantages, particularly on the score of compactness, but it is unlikely to produce revolutionary changes in ship design, except perhaps where war vessels are concerned.

Let us now turn to aerial transport where the picture is somewhat different. The progress made by civil aviation in the last twenty-five years is such that commercial flying can no longer be said to be in its infancy, yet it cannot be claimed to have reached maturity, and aircraft design has certainly not yet been stabilized. Since the war, British designers have been concerned with a number of types of very large aircraft, and, whilst the engineering problems involved in the design and construction of such giant machines are of great interest and importance to the technician, it is their financial implications which force themselves upon the attention of all. Recent statements indicate that the development cost of a new air liner amounts to about £40 sterling per lb. of gross aircraft weight, so that for a medium-sized air liner weighing about 50 tons the actual cost to be borne before production can begin amounts to over £4 millions. In America it has been stated that the sale of 400 of certain types of civil aircraft needs to be assured before contractors can recover their initial outlay.

Figures like these give little grounds for hope that the aircraft industry and the State Air Corporations will ever be self-supporting. Perhaps the right view to take is to consider civil air transport to be an activity whose political, diplomatic, and strategic importance outweighs its purely commercial aspects and for which subsidies must be paid in any country where flying is bound up with national prestige and national defence.

Flying as a means of communication is synonymous

with speed and in the thirty years which have elapsed since the end of the First World War aeronautical engineers have seemed bent on proving that problems of time and distance only exist as a challenge to be met and to be overcome. In 1919 the first flight from England to Australia took nearly a month; now the journey only requires about four days, and specially designed aircraft have, on both sides of the Atlantic, exceeded the speed of sound. The development of high-speed rockets—not true aeroplanes—has even opened up the possibilities of interplanetary communication, and though the time has not yet come when, with Puck in *Midsummer Night's Dream*, we can boast: 'I'll put a girdle round about the earth in forty minutes', who knows when even this may be possible?

The excitement of high speed must not blind us to the fact that there is room for differences of opinion regarding certain trends in aircraft development and utilization. For trans-ocean flying in large machines the tendency to fly at great heights at very high speeds is no doubt justified, but for shorter journeys between cities in the same continent one may ask whether the pre-war standard of about 200 miles per hour is not fast enough for most purposes. Like ships, aeroplanes are subject to a law which decrees that the attainment of high speeds requires a supply of power approximately in proportion to the cube of speed, so that a given aeroplane travelling at 400 miles per hour must use something like eight times as much power as the same machine flying at the same height at half that speed. This great increase in power involves a serious rise in fuel consumption, and in a world where the demands for fuel are never satisfied, the wisdom of burning it up in this manner is at least open to question.

Much still remains to be done to make high-speed flying a safe means of transport. The periods of greatest potential danger in any flight occur when taking-off and when landing, and, broadly speaking, the faster an aeroplane flies the greater become the speeds at which these two difficult operations occur, and the smaller the margin for errors in judgement by the pilot. Is it too much to hope that the airliners of the future, instead of needing mile-long runways of thick concrete—not easily to be found when an emergency arises—may, perhaps by an extension of the helicopter principle, be able to raise themselves gently from the earth, or slowly descend with a degree of safety as yet unattained?

THE OUTLOOK FOR THE FUTURE

We have now dealt with a few of the more important problems which lie on the engineer's immediate horizon, and we have mentioned the necessity for a great expansion and development of applied science if material prosperity is to be regained. Let us now attempt to take a longer view and look into the future in the forming of which this expansion must play its part.

It has to be admitted that the pursuit of applied science on a grand scale cannot be undertaken without incurring grave risks, chief among which is the risk that in striving after technical efficiency human values may be neglected or forgotten. As the applications of science become more numerous the powers wielded by a central authority grow more widespread and, in countries where the respect for liberty is less deeply rooted than in our own, more difficult to shake off. It is customary to suppose that no greater danger can threaten humanity than modern scientific warfare, but—as recently pointed out by Aldous Huxley and others—however dire the effects of atomic bombs, bacterial warfare, and the rest, a war still represents a conflict of ideas and for that conflict to be possible more ideas than one must be in the field. Unless the

dangers are realized in good time, it may eventually be possible, by an abuse of the powers which applied science confers, for a small group to impose its will on a country, a continent, or even on the whole of mankind and the chances of the unorganized majority of deposing such a group would certainly be doubtful.

Bertrand Russell, in his Reith Lectures, has made the point that a balance between the liberties of the individual and the powers of the State is a necessary condition of modern civilization; when the balance is disturbed in one direction the result is anarchy, when it is disturbed in the opposite sense the result is dictatorship and slavery. In recent times and in certain foreign countries the tilt towards totalitarianism has been unmistakable, and many of the latest triumphs of applied science—and many of those to be expected in the future—cannot but increase the unbalance.

No small part of the obligation to reverse the present trend lies on the shoulders of the applied scientists, whose work has done so much to bring it into being. Huxley's suggested remedy of splitting states and nations into smaller, self-supporting groups does not seem practicable at a time when suspicion and fear are so widespread; a more hopeful solution may be the proposal that scientific men should take a broader view of their duties and that, through the deliberations of some world organization of science, only those scientific projects which are agreed to be to the general benefit of mankind and not to its detriment shall receive encouragement and support. These are great days for applied science, but great opportunities carry great responsibilities—

> . . . if the pilot slumber at the helm,
> the very wind that wafts us
> towards the port
> may dash us on the shelves. . . .

All this is not a plea that scientists ought, by right and virtue of their training, to have a greater share in parliamentary government. It is a suggestion that a body qualified to speak for the great mass of world scientific opinion, actuated by disinterested motives, and organized, perhaps, on similar lines to the Parliamentary and Scientific Committee now existing in this country, could not fail to have a good influence on affairs.

Perhaps before it could be made effective, the education of scientists would have to be much modified, so that they would all understand that in human affairs efficiency is not always the same thing as wisdom. In any event, the modern tendency towards larger and larger organizations, bigger and bigger power groups, will remind the scientist that on grounds of efficiency alone the size of an organism cannot increase indefinitely. The dinosaurs died out because they grew too large; it is certain that the advent of a world-wide dictatorship, based on the powers of applied science, would result in the death of freedom and would substitute for the rich and varied pattern of human life the drab uniformity of the ant-hill.

The problem is one of vast difficulty and it is easy to pour scorn on any suggested solution; nevertheless, the stakes are very high—on the one hand, the possibility of peace, freedom, and the elevation of the human spirit; on the other, to use Toynbee's striking phrase, 'a world fast bound in misery and iron'.

Philosophical Implications

A survey of the education, tasks, and outlook of the engineer cannot close without attempting to indicate the nature of the lessons which seem to be contained in the story of the development of engineering up to the present, and which must determine its outlook for the future. After slow and uncertain beginnings and a long period

during which its practitioners were counted as being of very little worth, engineering, by virtue of the wealth and power it conferred upon an industrial nation, found itself during the last century and the early part of this one suddenly elevated to a position of paramount importance among the arts and sciences. The achievements of applied mechanics and applied electricity during the Victorian era filled the common man with astonishment and a kind of awe—in those days there was magic in the electric telegraph and in the steamship; engineering seemed to offer the possibility of a fuller, freer life and an unrestricted development of the world's resources; the very power and size of man-made machines seemed to some to spell the end of drudgery and to others the potency of mechanized weapons suggested that war had become impossible because it would be too destructive.

It was not surprising that the prevailing attitude affected men of science. Their success in designing and fabricating machines to fulfil various tasks led them to attempt to describe the phenomena of nature in terms of machinery. The molecules and atoms from which matter was made were supposed to be subject to pushes and pulls produced by forces applied in familiar ways, and the universe itself was likened to a gigantic machine the purpose of which was not understood but which, perhaps, would one day be revealed by the genius of the engineer-scientist. It was typical of the times that the German physicist von Helmholtz should declare that 'the ultimate purpose of all science was to resolve itself into mechanics' and that Lord Kelvin should confess that 'he could understand nothing of which he could not make a model'.

With the birth of the twentieth century there came into being new theories which were destined to turn science along a different path and to shatter these mechanistic pictures of the physical world. The engineer-scientist, accustomed to represent physical phenomena in the same terms which sufficed for the description of man-made machines, was deposed from his position at the head of the scientific hierarchy and certain of the laws he had supposed to be of universal application were found to be merely of local significance. But what is more surprising is the fact that it is not only in the world of science where the engineer has had to take a humbler place. The wonders of engineering no longer impress men as they used to do; familiarity, perhaps, has bred contempt, and the most spectacular achievements of mechanical science are taken almost for granted, although the pace of development is as fast as ever. Perhaps this lessening of respect has occurred partly because we live in a mechanical age—but, perhaps, it is also connected with the fact that the two greatest wars in history have employed machines to destroy on an unprecedented scale. People are realizing that the mechanical arts and sciences by themselves offer no easy way out of the world's difficulties, that machines can hold out no guarantee of happiness, progress, and security, that the pursuit of applied science does not necessarily lead to universal enlightenment.

Engineers themselves have not been slow to learn these lessons, and in learning them have gained some of that humility which is necessary as a corrective to scientific arrogance. The solution of every engineering problem is a compromise; engineering lays no claim to exact precision; 'tolerance' is a common engineering term. These are principles which every engineer applies to his work—may one not hope that they may find wider acceptance in the world at large?

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