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ELEMENTS OF ENGINEERING
FOR NON-MAJORS

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I hereby recommend that this dissertation prepared under my direction by Larry J. Blake

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ABSTRACT

Man's life on earth has been continually changed and greatly influenced by engineering and will continue to be so. In the increasingly technologically-oriented life of the future, an educated man should be knowledgeable of engineering and other technologies in order to understand his complex society. Elements of this understanding include: a definition of engineering, a history of engineering, engineering problem solution, philosophy of engineering, and engineering influences on society.

In defining engineering, the engineer is first contrasted with the scientist, technician, and other technologists. Engineering is then defined as a profession concerned primarily with the application of a certain body of knowledge, set of skills, and point of view, in the creation of devices, structures and processes used to transform resources into forms which satisfy the needs of society.

It is shown that in the engineer's solution of his problems that neither his problems nor his solutions are neat, simple, or completely satisfying. He must come up with a solution immediately for a problem which is vaguely stated, which has constraints, some of them conflicting, some of them ridiculous, all the while lacking facts or relationships which are unknown and/or unknowable. Although there is no single engineering method of problem solution, it is generalized to include five steps: problem formulation, a relatively broad, detail-free problem definition; problem analysis, a detailed definition of the

problem; search for alternative solutions; determination of optimum solution; and specification of solution.

The philosophy of engineering is shown to be similar in many respects to the pragmatic axiomatic philosophy of science. The engineer has always used unprovable "axioms" upon which to base his theories, or designs and works, rejecting and replacing them when they are proven false. His philosophy differs from others in his view of nature. Other views of nature, such as that of the scientist, are cognitive and seek to understand nature as nature is. The engineer views nature as something not preordained, but which can be altered to his satisfaction for the benefit of man.

The influence of engineering is shown in a brief history of engineering and in descriptions of certain areas of influence. The simplest example is the protection of man from his environment. Others used include: transportation, communications, population growth, urban growth, and standard of living.

The future of man is predicted to be increasingly influenced by technology and a number of examples are given of this influence.

INTRODUCTION

Man's life on earth has been continually changed and greatly influenced by engineering and will continue to be so. The world's engineers have contributed significantly to the shaping of civilization. In every society, the engineer's role has been the development, from the knowledge of his day, of technical applications to meet the practical needs of society: a water wheel to power a mill, an electrical system to light a city, an artificial heart to prolong life. In doing so, he has introduced many changes.

As one travels by jet airplane high above the surface of the earth on a journey which will take hours to travel what once took months, years, or was impossible, he can look down (and up) at the handiwork of engineering which is literally reshaping the face of the earth. Areas which were once desert now bloom with the fruit of life. Rivers which once were rampant have been converted into quiet streams and provide power, water, transportation and recreation. Airports, harbors, highways and railways are signs of man's increased mobility, thanks to engineering. Cities pass below in which people live, work and play, enjoying a healthful standard of living never possible before. In these cities, as well as most of the world, much of the drudgery of life has been alleviated by the development of machines to do the hard, tedious, routine work. Life has been prolonged and suffering relieved by the development of drugs and healthful living.

Engineering has altered man's abilities and capabilities in many ways (Bond 1965). For example, his sensory capabilities have been extended. His vision has been increased by radar, television, radio astronomy, telescopes and the electron microscope and his hearing extended by microphones and amplification techniques. His touch has been aided by instrumentation and control mechanisms such as power steering, power brakes and remote control valves and switches. Even his memory has been assisted by photography, printing, sound tape and video tapes. Similarly, his ability to communicate has been enlarged by printing, radio, television, magnetic tape and telephone. His transportation capability has been increased from foot and animal travel to land, sea, air and space means too numerous to mention.

Engineering has also caused an extension of his intellectual processes in a number of ways. Information processing by computers and other equipment have reduced clerical labor while increasing speed and improving accuracy in business and industry. Computers are also important in problem-solving by permitting calculations for problems otherwise unfeasible and by similarly providing decision-making assistance on major business and military policies and strategies.

He has an increasing amount of energy at his disposal as engineers successively harnessed water, wind, steam, combustion, electrical current, fission and fusion. He has machines which perform the heavy, routine, mechanical aspects of his work, freeing him for other activities.

These are but a few of engineering's influence on man's capabilities and his life.

One writer has asked what it would be like if, by some vast automated whim, all of our machines (one of the groups of engineering end-products) suddenly went on strike (O'Brien 1964). "Our life would grind abruptly, clumsily, comically, tragically, overwhelmingly to a standstill. We would be unable to tell time, wash, shave, cook, open cans, turn on lights, heat the house, mow the lawn, telephone, listen to the radio, watch television, go anyplace or do anything most of us consider worth doing...all of us would be cut off from the world, from the next town, from each other."

Not all of the engineer's devices work entirely for the betterment of man. Traffic accidents involving the automobile, for instance, are a major cause of death and injury in the United States. However, this disastrous effect of the automobile is the fault, principally, of the user, not the device nor the maker.

Confidence in Engineering

Throughout most of history, engineers have been held in high esteem. It is interesting to observe that in most ancient communities the engineer held a position of power and influence (Mantell, Reeder and Stevens 1963). He was normally the adviser of the king, his ministers or his generals. Generally, his genius as a military engineer, assisting in the domination and conquest of others, led to this position. His talent was also evident in the erection of such religious and ruler-glorifying edifices as the pyramids, temples and other monuments.

One Egyptian engineer, Imhotep, designer and builder of the first great pyramid, the Saqqara, even became a god in ancient Egypt.

With the rise of Greek science to a position of eminence and its philosophical attitude exalting mental activity over physical activity, the status of engineering was reduced in the eyes of the intellectual. Although the scientist and the philosopher scoffed at the practicality of the engineer, mankind, in general, continued to appreciate the work of the engineer. Aristotle (384-322 B.C.) for one, exemplified the philosopher's views. Said he: "Only such knowledge as does not make the learner mechanical should form a part of education."

Seneca (4?-65 A.D.), expressing the Roman attitude, was scarcely more charitable. After recording that there had been inventions such as transparent windows and tubes for defusing warmth equally throughout all parts of a building, he observed that, "the inventing of such things is drudgery for the lowest slaves. Philosophy lies deeper. It is not her office to teach men how to use their hands, the object of her lesson is to form the soul".

This attitude of scorn on the part of "intellectuals" toward anything practical continued through the Middle Ages and, although almost completely destroyed by the technological successes of the past two hundred years, is occasionally voiced yet today by some "pure" scientist.

The lack of understanding of and appreciation for engineering evidenced by this attitude and such statements on the part of scientists has led, at some times, to some antipathy between the two groups. Moreover, public assertions in this vein have not added to a general feeling of confidence in engineering. In addition, since the time of the industrial revolution, the work of engineers has sometimes been seen as a threat to the employment of some whose skills are made obsolete. A third factor contributing to a lack of confidence in engineering is an understandable skepticism in the claims of engineers. Scoffers ridiculed the claims of Savory for possible uses of the steam engine, of the future of electricity by Edison, of the possibility of flight by the Wright brothers and others.

In 1786, when Oliver Evans asked the Pennsylvania Legislature for a patent on a horseless, steam-driven carriage, he was advised to stop such fantastic talk if he did not want to be judged insane. When George Westinghouse explained the use of his air brakes for stopping trains to Commodore Cornelius Vanderbilt, the railroad tycoon exclaimed, "Stop a locomotive with wind? I have no time to talk with fools." (Furnas and McCarthy 1966). After his invention in 1905 of the three-element vacuum tube, Lee deForest was actually tried in court for attempting to defraud the public by selling stock in his company. The prosecutor of the court contended that deForest had even claimed that it would be possible to transmit the human voice across the Atlantic Ocean, thereby misleading the public with absurd and impossible claims.

Today, with the rise of engineering and technology to a position of high status and confidence in the public eye, the situation is reversed. From a civilization that was amazed when engineering predictions were fulfilled, now we tend to believe that any prediction will soon be a fact. An announcement of a discovery results in an immediate demand for articles employing the discovery.

Not only is man confident in the eventuality of the predictions of engineering and technology, but he is also confident in using the end products of engineering. He climbs into his automobile and turns on the ignition, confident that the motor will start and is dismayed when this does not happen. He rides in elevators, works in tall buildings, flies in jet airplanes, confident of his safety. He crosses the bridges of our highway system, assured that they will not fall. This confidence is not new, since men climbed high pyramids in Ancient Egypt, crossed bridges built by Romans and attended service in Gothic cathedrals with feelings of absolute safety.

Yet in spite of all of this, man knows very little of the profession which has created these things for him and has so influenced his life.

The Need for Understanding of Engineering

It has often been stated by the humanist and the social scientist that the engineer is an uneducated man in view of the small amounts (in their eyes) of humanities and social sciences which are part of the normal engineering curriculum. They state that, for the engineer to be literate, he must have massive doses of "general" education in order to function as part of society. (Actually, the engineer has many massive doses of general education, formally before college, informally throughout his life.) Yet, when asked how much engineering and technology is needed in other programs of study they find the question completely irrelevant. Moreover, although they may get a smattering of science in grade and high school, little, if any, of the ideas, methods or products of engineering are ever explained to them.

Sir Eric Ashby (1958) answers this, in part, when he states:

> Specialization, for example, is commonly identified with science and technology, and a liberal education is identified with art subjects. It has been forgotten that liberality (as Samuel Alexander wrote) is a spirit of pursuit, not a choice of subject; and no account is taken of the fact that a boy who goes up on the classical side at school and who then takes 'Greats' at Oxford has had the most highly specialized education in Europe and is likely to be innocent of the most elementary knowledge of subjects on which Newton, Faraday, Darwin, and Rutherford spent their lives: whereas by contrast even the meanest engineering graduate has spent eight years or so on history, English, French, and even Latin; he has an inkling of what Shakespeare and Racine and Cicero wrote; he has some rudimentary appreciation of what Erasmus and Martin Luther and Abraham Lincoln did for humanity.

Ashby's comments are particularily meaningful when one considers that not only is our society influenced today to a considerable extent by engineering, but that it will also be increasingly more influenced in the future. How is it possible that a man today can consider himself well-educated and yet be unknowledgeable of engineering and technology? C. P. Snow put it succinctly in discussing the general knowledge of the fields of science and applied science (engineering and technology). In discussing the attitudes of the non-scientist, he states (Snow 1963):

> As with the tone deaf, they don't know what they miss. They give a pitying chuckle at the news of scientists who have never read a major work of English literature. They dismiss them as ignorant specialists. Yet their own ignorance and their own specialization is just as startling. A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who with considerable gusto have been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: 'Have you read a work of Shakespeare's?'

I now believe that if I had asked a simpler question--such as, what do you mean by mass or acceleration, which is the scientific equivalent of saying, 'Can you read?'--not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had.

...I remarked earlier that highly educated members of the non-scientific culture couldn't cope with the simplest concepts of pure science: it is unexpected, but they would be even less happy with applied science. How many educated people know anything about productive industry, old-style or new? What is a machine tool? I once asked a literary party; and they looked shifty. Unless one knows, industrial production is as mysterious as witch-doctoring.

Taking a different approach, Ashby concludes:

A case could be made, therefore, for including technology among the ingredients of a liberal education. But technology in universities could be made to play a far more important part than this; it could become the cement between science and humanism. . . . For technology is inseparable from men and communities. In this respect technology differs from pure science. It is the essence of the scientific method that the human element must be eliminated. Science does not dispense with values but it does eliminate the variability of human response to values. It concerns itself only with phenomena upon which all qualified observers agree. It describes, measures, and classifies in such a way that variation due to human judgment is eliminated. Unlike science, technology concerns the applications of science to the needs of man and society. Therefore technology is inseparable from humanism. The technologist is up to his neck in human problems whether he likes it or not.

Snow expresses his concern for the lack of communication between two cultures because of an eminent crisis he sees for civilization. He states:

It is dangerous to have two cultures which can't or don't communicate. In the time when science is

> determining much of our destiny, that is whether we live or die, it is dangerous in the most practical terms. Scientists can give bad advice, and decision-makers can't know whether it is good or bad. On the other hand, scientists in a divided culture provide a knowledge of some potentialities which is theirs alone. All this makes the political process more complex, and in some ways more dangerous than we should be prepared to tolerate for long, either for the purpose of avoiding disasters, or for fulfilling what is waiting as a challenge to our conscience and good will--a definable social hope. . . . Escaping the dangers of applied science is one thing. Doing the simple and manifest good which applied science has put in our power is another, more difficult, more demanding of human qualities and in the long run far more enriching to us all. It will need energy, self-knowledge, new skills.

It is not only because of the devastating effect of the products of engineering or applied science that we need an understanding of engineering but also because of the promise of a better life which can be predicted based on the technology of the present and that of the future. At the present, engineers can drastically alter the conditions of nature for the betterment of man and will be able to do increasingly more in the future. We presently have the technology and the resources to raise the standard of living of the entire population of the world to that of the most advanced technological society existing. To do this, many more engineers, technologists, technicians and workers must be educated and trained, many more machines built and civil works constructed. But to unleash this benevolent tiger, the leaders and peoples of the world must understand engineering and technology, use them and welcome the better world they can make instead of conceiving of the world as limited and wanting the biggest piece of pie.

Another reason for the need of an understanding of engineering is the increased use of the engineering methods in unrelated fields.

The engineering method combines experience with theory and provides self testing of the critical components. Fortified by the computer it analyzes and attacks situations of ever-increasing complexity, situations that involve whole systems. This is systems engineering which, today, is being applied to economics, politics and people as well as to things.

Engineers have solved many difficult problems of the past. In order to solve the even more difficult ones posed by mass education, urban growth, the war against poverty and building a better world, consideration should be given to applying the methods of engineering to the non-engineering aspects of the problems, the attitude of experimentation and observation, the judicious combination of theory and experience, the evaluation of the feasibility of alternative solutions and the acceptance of today's solution and the improvement of it tomorrow.

It is for these reasons that an understanding of engineering is essential for the non-engineer. Elements of an understanding of engineering include: a definition of engineering, a history of engineering, engineering methods and tools, philosophy of engineering and engineering influences on society.

ENGINEERING, TECHNOLOGY, AND SCIENCE

A SET OF DEFINITIONS

Engineering, as it exists today, is primarily the out-growth of two historical developments. The development with the longest history is that of the gradual evolution of a problem-solving specialist who accepted as his occupation the creation of tools, structures, devices and processes which were to be used for the benefit of man. The other development, which has occurred only during recent history, is the rapid expansion of scientific knowledge and the consequent search for problems that can be solved by a new bit of knowledge.

As seen in a subsequent chapter on the history of engineering, the engineer, throughout most of history, practiced his art with little or no scientific background. Scientific knowledge in a usable form for the engineer was not available until the last 100 or 200 years, yet, throughout history, there were needs of society which had to be satisfied by the engineer whether scientific knowledge existed or not. Bridges, crude as they were, had to be built; buildings constructed; canals dug; water, wind and animal power harnessed; machines devised; road networks constructed; all with the knowledge that existed during the day and age. The early engineers designed their works on the basis of practical experience accumulated by others, their own experience, common sense, experimentation, and inventiveness. In many instances they learned what to do but did not understand the underlying theory.

Thus, in a major difference with today's engineers, their knowledge of the laws of nature was scant. Not that theories were not constructed; but with so many concepts and relationships undiscovered, the theories were usually awkward, inadequate and even naive. But (as has been said) we stand so tall today because we stand on the shoulders of giants and yet we do not know and cannot adequately explain many simple things.

With the development of scientific knowledge during the last two centuries, however, the world of engineering has changed. Scientists have accumulated an immense amount of information regarding the universe. Man's understanding of electro-magnetic phenomenon, the structure of matter, the elements and their relationships, the laws of motion, energy transfer processes and many other aspects of the physical world has increased many times over in this short span of time. During the nineteenth century engineers recognized the potential that scientific knowledge offered in the solution of their problems and began taking advantage of that potential. With this increased utilization of scientific principles in the solution of problems, engineering evolved into what it is today.

However, throughout history, engineers have been involved in the solution of the problems of society's needs, long before any significant body of scientific knowledge was available. The engineer of the present is still addressing to essentially the same problems, but the use of science in the solution of these problems has become so extensive that "application of science" has become a conspicuous characteristic of modern engineering.

It is of value to note, however, that although science has taken their place to some degree, inventiveness, expert judgment, and empirical knowledge are still relied on heavily in the solution of engineering problems.

Technology

Not only in engineering but in other traditionally problem-solving specialties, such as medicine, changes have taken place involving the accummulationof scientific knowledge. In order to make a distinction between the problem-solving specialists and the scientist it is necessary to look at the day-to-day activities and the end product of each profession.

The person whom we call a scientist makes it his primary purpose to explore nature and accumulate scientific knowledge. He does not ordinarily become involved in the application of his findings to practical problems. As the body of scientific knowledge began to accumulate, it was absorbed and utilized by people who were equipped and motivated to apply such knowledge for the satisfaction of society's needs. These problems solvers who are concerned primarily with the application as opposed with the accumulation of scientific knowledge are defined as technologists. The technologist, who functions as a middle man between science and society, for the interpretation and application of scientific knowledge in the solution of society's problems, utilizes both the life sciences and the physical sciences.

In the life sciences a wealth of information exists concerning the processes carried on by living organisms. Bacteriology and physiology, for example, offer much information which can be applied to remedy body ills. The technologist who makes this application is referred to as a physician, and he is a technologist in that he is the applier of a certain body of knowledge to the solution of a group of mankind's problems.

In a similar way, as shown previously, the engineer is a technologist in that he is an applier of the physical sciences (in some cases, biological sciences) to the solution of another group of society's problems. It should be noted, however, that doctors and engineers were solving their respective problems centuries before adequate scientific knowledge was available for them to apply. Although both the physician and engineer have assimilated scientific knowledge into the process of solution, they have always been and still are problem-orientated. Their prime motive is to solve the issue at hand. If they are faced with a situation and there happens to be no scientific knowledge to apply in that particular case, they will still attempt to solve it. (The surgeon does not walk away from a patient on the operating table when he encounters a situation for which science does not tell him what to do next; neither does the engineer refuse to bridge the river, waiting for the ideal material to be developed.) They seek a solution to the problem and, if current scientific knowledge does not cover the situation, will arrive at a solution through experimentation, common sense, empirical knowledge, ingenuity, or perhaps other means. Thus the technologist does not exist solely for the application of science. Rather he exists to solve problems and in so doing, he utilizes scientific knowledge when it is available.

The technologist is not to be confused with the technician, a highly specialized, semi-professional technical assistant to the technologist. In the engineering area, a technician may be a draftsman, cost estimator, time-study specialist, inspector, electronic specialist, operator of complex equipment, computer programmer, etc. In relation to others, the engineering technician occupies a position intermediate between the engineer and the skilled craftsman. In no sense are these relationships to be taken as a hierarchy, but simply a realization that various skills are necessary to do the whole job and that, fortunately, different people have different skills.

Science

Essential to the full understanding of engineering is a clear understanding of the basic difference between science and engineering. Too often, in modern society, the role of these two is misunderstood. Science is a body of knowledge. Specifically, it embraces man's understanding of the structure and behavior of nature, for example, matter, energy and life. Scientists direct their occupational efforts primarily to improving this understanding. They search for useful explanations, classifications, and means of predicting natural phenomena. The primary objective of the scientist is "to know", to discover new facts, develop new theories and learn new truths without concern for the practical application of new knowledge and, in most cases, without any concern for whether or not a practical application even exists (Smith 1952).

Among the activities undertaken by the scientists are: formulation of hypotheses, conducting of experiments, observation of natural phenomena, description of natural phenomena in the language of mathematics, analysis of observation, testing of hypotheses and drawing of conclusions.

If one were to describe the prime objective of the scientist it would be to generate new knowledge.

Engineering

In contrast to the scientist's generation of new knowledge, the engineer's prime objective is the creation of a tangible device, structure or process which is useful to man. Thus, engineering is a profession concerned primarily with creating things. These creations are used to convert material, energy, human and information resources into forms which satisfy the needs of society. These creations must accomplish a given result, specified by quality and quantity, at a minimum cost in personnel, time, material and money. It should be pointed out, however, that there is no unique solution to any engineering problem, but rather a series of alternative solutions from which the engineer, using his knowledge, experience and judgment, selects the most desirable solution.

The engineer is above all a practical man, a pragmatist who shoulders the mundane problems of civilization--and solves them. He gets the job done, efficiently and economically, although he may reach his goal by any one of a variety of paths, using his creative ingenuity to establish a totally new system or to apply an old method in a new and imaginative way.

Many attempts have been made in the last two centuries to define engineering in precise terms. A number of these statements are quoted by Smith (1962). Among them are:

> *Thomas Tredgold (1828):* Engineering is the art of directing the great sources of power in nature for the use and convenience of man.
>
> *A. M. Wellington (1887):* It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain important sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar which any bungler can do with two after a fashion.
>
> *Henry G. Stott (1907):* Engineering is the art of organizing and directing men and controlling the forces and materials of nature for the benefit of the human race.
>
> *Willard A. Smith (1908):* Engineering is the science of economy, of conserving the energy, kinetic and potential, provided and stored up by nature for the use of man. It is the business of engineering to utilize this energy to the best advantage, so that there may be the least possible waste.
>
> *H. P. Gillette (1910):* Engineering is the conscious application of science to the problems of economic production.
>
> *Alfred W. Kiddle (1920):* Engineering is the art or science of utilizing, directing or instructing others in the utilization of the principles, forces, properties and substances of nature in the production, manufacture, construction, operation and use of things . . . or of means, methods, machines, devices and structures. . .
>
> *S. E. Lindsay (1920):* Engineering is the practice of safe and economic application of the scientific laws governing the forces and materials of nature by means of organization, design and construction, for the general benefit of mankind.
>
> *R. E. Hellmund (1929):* Engineering is an activity other than purely manual and physical work which brings about the utilization of the materials and laws of nature for the good of humanity.
>
> *J. A. L. Waddell, Frank W. Skinner, and H. E. Wessman (1933):* Engineering is the science and art of efficient dealing with materials and forces . . . it involves the most economic design and execution . . . assuring, when properly performed the most advantageous combination of accuracy, safety, durability, speed, simplicity, efficiency, and economy possible for the conditions of design and service.

T. J. Hoover and J. C. L. Fish (1941): Engineering is the professional and systematic application of science to the efficient utilization of natural resources to produce wealth.

M. P. O'Brien (1954): The activity characteristic of professional engineering is the design of structures, machines, circuits, or processes, or of combinations of these elements into systems or plants and the analysis and prediction of their performance and costs under specified working conditions.

L. M. K. Boelter (1957): Engineers participate in the activities which make the resources of nature available in a form beneficial to man and provide systems which will perform optimally and economically.

R. S. Smith (1962): Engineering is the professional art of applying science to the optimum conversion of natural resources to the benefit of man.

The Engineers Council for Professional Development defines engineering in the following way:

> "Engineering is the profession in which a knowledge of mathematical and physical sciences gained by study, experience and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the progressive well being of mankind."

The problem with these definitions is that, although they take into account "the application of science", they do not stress the traditional tools of engineering which are as necessary today as they were yesterday where scientific knowledge ceases, those of experimentation, common sense, empirical knowledge, and ingenuity. A more succinct definition might be that: engineering is a profession concerned primarily with the application of a certain body of knowledge, set of skills, and point of view, in the creation of devices, structures and processes used to transform resources to forms which satisfy the needs of society.

It should be noted that, although the above descriptions of the engineer, technologist, technician and scientist are quite distinct, it is possible for a person to perform at different times, each of these functions during the same day. To simplify matters we usually categorize a person by his primary function (or job title), however, this sometimes leads to confusion when a secondary function is more noticeable.

Engineering Specialization

Although engineering can be defined properly in general terms as above, the engineer himself can not encompass the total field of engineering in his study and practice. For instance, it is virtually impossible for an engineer to be competent in designing bridges and television equipment and jet engines and metal refineries and assembly plants. As a consequence, specialization is inevitable. Thus, within the general field of engineering there are the following kinds of engineers:

Aeronautical Engineers: Creators mainly of aircraft and associated systems. This offshoot from Mechanical Engineering has been renamed by some as aerospace engineering (concerned with all travel above the surface of the earth) and astronautical engineering (concerned with flight above the earth's atmosphere).

Chemical Engineers: Creators of media or processes employed primarily in the chemical transformation of materials to more useful forms (for example, crude oil to gasoline). Thus, chemical engineers design processing facilities for the production of plastics, cement, rubber, explosives, paints, etc.

Civil Engineers: Creators mainly of society's major structures and means of constructing them. These creations include highways, bridges, dams, canals, water supply and sewage disposal systems, airports, harbors and many other structures. The designation, Civil Engineer, was originally used in distinction to the Military Engineer.

Electrical Engineers: Creators primarily of the means by which electrical energy is created, transferred and utilized. They design the generators of electricity, transmission networks, communication facilities and many other instruments, appliances and systems.

Industrial Engineers: Creators of the system employed mainly in the physical transformation of materials to more useful forms. Examples of such systems are the automobile plant, the printery, the missile factory, the shipyard and the textile mill. Industrial engineering is an offshot of mechanical engineering with a greater emphasis on the system, both physical and human, and less on the components of the system and the products, as such.

Mechanical Engineers: Creators primarily of the means by which energy is converted to useful mechanical forms and materials are physically converted into useful forms. They design engines, turbines and motors and the mechanisms required to convert the outputs of these devices to a desired form. (The internal combustion engine converts the latent energy in gasoline to the mechanical action of a piston. Then a mechanism consisting of crankshaft, driveshaft, gears and wheels transforms the piston's movement into locomotion.)

Metallurgical Engineers: Creators mainly of media for the extraction and/or processing of metals. Thus, metallurgical engineers are designers of ore refineries and of systems for changing the physical and chemical characteristics of metals (for example, the aluminum extrusion process, the hardening process for steel).

Although there are other branches of engineering (such as Agricultural, Architectural, Geological, Marine, Military and Nuclear), the above seven are the major ones. In addition, each of these seven may be subdivided into numerous sub-branches in response to local needs to yield as many as fifty different specialties. For example, some of the sub-branches of civil engineering are: structural, sanitary, hydraulic, highway, bridge, traffic, soils, foundation, construction, city planning, irrigation, surveying, waterways, harbors, airport and pipeline engineering. Other specialties evolved as physicists became less classical and, at the same time, increasingly more specialized. These engineering specialties include: Engineering Physics, Engineering Mechanics and Engineering Science.

However, regardless of the specialty, the same basic characteristics are identifiable. The same basic skills and same professional point of view are employed in all engineering specialties.

Engineers also specialize within the various disciplines in terms of the stage of the engineering process in which they are involved. These specializations include research, development, design, construction, production, operation and maintenance, data accumulation, sales and management. Thus, for example, an engineer may be a research engineer in astronautics or a design engineer in civil engineering.

The research engineer is very much akin to the scientist in that he investigates basic physical phenomena. He differs in that, whereas the scientist is not interested in applications, the research engineer is constantly concerned with applications. In most engineering organizations research and development are considered a single function. The development engineer occupies a position between research and design. His product is usually a form of a working model which is then designed for economic production. It is the responsibility of the design engineer to take the working model from the development engineer and prepare it for economic production or construction. After the design engineer has completed his plans, specifications and/or working drawings, it is the job of the construction engineer or production engineer to turn the visions of design into reality, the construction engineer if it is a structure, utility, etc., the production engineer if it is a manufactured product. After a piece of equipment or a plant has been designed and produced or constructed, it must still be either operated or maintained and this is the responsibility of the engineer engaged in operation and maintenance. All engineers are engaged in data accumulation although some specialize in this area, in such areas as research, traffic control, surveying and computer operations. A sales engineer is usually engaged by a firm where his knowledge of the technical capabilities and limitations of the firm's product is necessary in order to adequately serve the customer.

Engineers are also becoming more and more involved in management. A recent survey by Columbia University indicated that "forty per cent of industrial management is engineer-trained, replacing both the lawyer and the banker in top industrial posts." (Smith 1962) This is due not only to the increasingly technological complexity of industry but also to the nature of management itself and its adaptability to engineering skills. Management must determine the main purposes of an enterprise and how to use its assets and capabilities in achieving these purposes. Engineers have proven valuable in management positions because of their ability in analyzing the factors involved in a problem, collecting the necessary data, and drawing sound conclusions.

HISTORY OF ENGINEERING

In order to more properly understand the role and influence of engineering in today's world, one should be aware of the role that it has played in history. Many excellent histories of engineering have been written which describe engineering events and the engineers themselves (Armytage 1961, Finch 1951, Forbes 1950, Jenkins 1936, Kirby et al 1956, Lilley 1948, Mumford 1934, and Singer, Holmyord and Hall 1954). For our purposes it will be sufficient to describe the engineering end-product, whether it be machine, prime mover, structure, process, transportation system or instrument of war and leave the engineer anonymous.

It has been said that the history of civilization is the history of engineering. A close examination of man's history and his social life discloses that engineering in some form has been one of the basic means by which civilization has advanced. In particular, of all the factors which have influenced the course of society in the last two hundred years, engineering must be listed as one of the most important. One of the engineering achievements upon which many other advancements have been built has been the harnessing of new sources of non-human power, which followed total reliance on an individual's own power or his slaves, such sources as water, wind, animal, steam, internal combustion, electrical, fission and fusion power. The development of new sources of power and the use of them by engineers has made possible an enormous increase in the productivity of industry and a rising standard of living.

The ages in the history of engineering may be roughly categorized as:

The Agricultural Revolution (6000-3000 B.C.)

The Rise of the Cities (3000-600 B.C.)

Greek and Roman Engineering (600 B.C. - 400 A.D.)

Engineering in the Middle Ages (fifth to sixteenth centuries)

Rise of Modern Science (seventeenth century)

The Industrial Revolution (eighteenth and nineteenth century)

The Technological Revolution (twentieth century)

These periods also roughly approximate significant changes in the life of man which have either increased his ability to control nature or to dominate his neighbors. Engineering, however, did not begin with the agricultural revolution. Pre-historic man throughout the ages gradually adapted to his use many things which occured in nature.

The first engineer may have been the man who purposefully felled a tree across a stream for a bridge. Or, possibly before him, the man who made the tools, such as the ax or knife, which allowed him to fell the tree.

Two of the first engineering devices of long standing use are the lever and the roller. It is interesting to note that when a modern engineer has to move a heavy machine in cramped quarters, he goes right back to his prehistoric counterpart and employs the lever or roller (Smith 1962).

The Agricultural Revolution

Before 6000 B.C. the major task of man was gathering food. He hunted the wild animals, fished in lakes and streams, and harvested edible plants wherever he could find them. His was essentially a nomadic existence, going wherever the food was to be found, starving when it wasn't.

Then about 6000 B.C., probably in Asia Minor or Africa, he gradually began to domesticate animals and to cultivate plants. This change in a way of living, from nomadic to stationary, required the talents of the engineer. They were needed to divert water for irrigation of crops and to build permanent dwellings for the population. It was these engineers who invented the wheel, the brick, harness, the plow, sails for boats, and techniques for recovering copper from its ores. During this period, as it became necessary for man to have at his disposal more power or strength than his own, slavery became the principal source of power and continued to be until the Middle Ages. Although slaves represent individual human power, the control of a number of slaves enlarged the amount of power available to the slave owner.

As agriculture became more efficient, it became possible for men to be released from food production and thus an age of specialization began. Some became priests, others merchants, government officials, soldiers, craftsmen, and still others became the first full-time engineers in a world which gave rise to the growth of cities.

The Rise of the Cities

In the earlier civilizations prior to the rise of cities (before 3000 B.C.), most knowledge was empirical and was handed down from person to person. Shortly after this time man developed a knowledge of elementary computation and mensuration. He also developed a means to pass on this knowledge more efficiently with a written language, using clay tablets and later, papyrus. Thus the engineer developed rules for surveying, measuring, weighing and construction and was able to communicate them more readily.

Another significant influence of the growth of cities on engineering was caused by the increase in wealth, growth of trade and extension of political power which in its turn had been made possible by engineering. Great palaces and temples were built. Monumental tombs were made possible by the great wealth of rulers. The false arch as a structural form was introduced and bridges and canals never before possible were built.

The stone which was required for the temples, tombs and palaces was not always available locally, but had to be transported considerable distances. The increase in trade also required improved transportation. Engineers solved the transportation problems by learning how to build roads, bridges, canals and ships.

Improvements in agriculture demanded better and bigger canals, levees, dams and reservoirs. With the increasing population of the cities more water was required and occasionally tunnels were constructed to bring water from nearby sources. It was not until about 700 B.C. that stone aqueducts were first built to carry water. The engineer also constructed systems to remove surface water from within the city.

Of the earliest civilizations of this era, those in Mesopotamia, little is known of their engineering other than the ruins of cities. The ziggurat, or temple tower, at Ur was apparently about 200 feet by 150 feet by 70 feet tall. It was constructed of sun dried brick and survived some 2000 years. Since brick was the principal building material, the buildings of these peoples were limited in height. The Mesopotamian engineers were the developers of the false arch, as mentioned earlier.

But their major engineering contributions were in the field of hydraulics. The remains of the Marib Dam, which was in use up to the sixth century, A.D., show that it was 650 meters long, had five spillway channels and 14 irrigation channels (Kheirallah 1952). A recently excavated aqueduct, built by the engineers of Sennacherib in the seventh century, B.C., had as its most striking feature a bridge 1,000 feet long, 70 feet wide, and 30 feet high.

Road building was also an achievement of the Mesopotamian engineer. He used cobblestones at first and then bricks and limestone. The longest road of this time is recorded only in history as no archeological traces have been found. It was the Royal Road of Darius, built in the sixth century, B.C., from Sardis in Asia Minor to Susa near the Persian Gulf, over 1500 miles.

But it was the Egyptian engineers who left for posterity some of the most striking structures of this time. Their work was made possible by the tremendous wealth of the Pharaohs, the abundant use of slaves and great quantities of building stone in the ledges of the upper Nile. Time also was of no importance as years were taken on each structure.

The only basic machines which the Egyptians were known to have used were the lever, the inclined plane, the wedge and the wheel (Leach and Beakley 1960). Thus, in hauling blocks weighing 15 tons or more to the height of the pyramids, vast amounts of human labor were used. It is estimated that about 100,000 persons labored twenty years to build the Great Pyramid at Gizeh in the twenty-seventh century, B.C.

The engineers of Egypt were remarkable men. The average length to the side of the Great Pyramid was 756 feet at the base, yet two sides varied from the average as little as one inch, and two of the angles were but three or four minutes in error. It rises to a height of 481 feet (higher than a forty-story building) and is constructed of over two million square limestone blocks averaging 1! tons in weight.

Irrigation was another area which required the work of the engineer. In order to control the Nile and turn its waters, complex systems of dikes, dams, flood-control gates and canals were built.

Although the Mesopotamian and Egyptian engineers were able to use computations and mensuration in constructing their great works they seldom concerned themselves with abstract principles. Prior to the sixth century B.C. there were few general theories of natural phenomena or of mathematics. This advancement came with the Greeks.

Greek and Roman Engineering

One of the greatest glories of Greek civilization was the advancement and development of science to a state that was not significantly improved upon until the Middle Ages. Until Grecian times, almost all knowledge was gained as a result of experimentation. Man had not come to realize that within nature there is order and regularity. Perhaps the greatest glory of Greek science was the discovery of science itself, the discovery that there are general laws in nature which man can come to know (Kirby et al 1956).

However, even with the advances in science, there was very little of its application to engineering in Greek times, or for that matter, until the latter half of nineteenth century. This much time was necessary for science to reach a state of usability for engineering. One of the few exceptions was the applications of Euclidean geometry to surveying.

Greek engineers satisfied themselves with improving and perfecting the technology of the past. The water systems required for their cities were well advanced. One system at Pergamon in Asia Minor had a piped system which had pressures of almost 300 pounds per square inch, several times the usual pressure in American systems (Kirby et al 1956). But it was in construction in stone that the Greeks reached the height of perfection. The Romans continued to build in the Greek manner and, except for adding the true arch and dome, added little else to this form of construction.

The Roman engineers are justly named the foremost engineers of classical antiquity. Although the Romans did little theorizing (there was never a Roman scientist of the first rank), they were skillful at learning and adapting the ideas and practices of others.

In the Roman Empire, one can find a classical example of the interrelationship of engineering and history. Not only did engineering provide means for the conquest of the known world, such means as war machines, good roads, and transport systems, but the political, economic and social needs of the Empire presented new problems which engineers were required to solve. This produced important advances in building construction, water supply, bridges, roads, harbors, ships and mining.

Probably most famous were the highways of Rome. Good roads and with them, good communication, were essential to the expansion, administration, defense and even the daily life of the Empire. At the height of Roman power, there was a system of over 180,000 miles of improved roads and paths throughout the Empire. It should be noted, however, that these roads were not roads in the modern sense. Just as present engineers design roads to suit particular needs, so did Roman engineers. Roads were classified by their width, the two-lane *via* was about eight feet wide, the *actus* was four feet, the *iter* three feet and the *semita*, or footpath, but one foot wide.

Roman engineers are also famous for their aqueducts and bridges, many of which exist today. Probably the most outstanding example is the Pont du Gard, near Nimes, France, which was 150 feet high, over 900 feet long, and carried both an aqueduct and roadway.

To construct and maintain such a system of engineering works required tremendous amounts of power. However, the only form of power available was slave power, and herein may lie a partial answer to the downfall of Rome. During the last years of the Empire, Christianity became prevalent throughout the land and with it the attitude that all men were equal before God. The subsequent freeing of slaves and decreased use of slave power resulted in an attrition of almost the only source of power. Only a few decades before the fall did Roman engineers begin to make limited use of water power.

Engineering in the Middle Ages

As one writer states, "The chief glory of the later Middle Ages was not its cathedrals or its epics or its scholasticism, it was the building for the first time in history of a complex civilization which rested not on the backs of sweating slaves but primarily on non-human power" (White 1962). The christian aversion to the use of slaves and the subsequent search for other sources of power can be considered one of the most important developments in history.

Sources of power developed included horses, water and wind. Although the horse had been used throughout antiquity, it had been a very inefficient source of power because the yoke then used tended to strangle the horse and, also, the unprotected hoof broke easily. With the invention of the horse collar in the ninth century and the use of horseshoes, the horse became an important source of non-human power in agriculture and in the operation of machines.

After its introduction by the Romans, the water wheel steadily gained acceptance and by the eleventh century was busy at numerous mechanical tasks, such as grinding flour, operating saws, making paper, operating bellows, pumping water, and working in breweries and factories (Kirby et al 1956). The first water wheels were of the undershot type, set in the current of a stream to take advantage of the velocity of the current. At some time during this period, an engineer thought to take advantage of the fall of water from a height rather than the speed of running water in a stream. By impounding water and allowing it to flow over the water wheel a much more efficient power source was developed.

Wind became another source of power with the development and widespread use of windmills after the twelfth century. It is reported that in the 1830's Holland alone had 12,000 windmills (Mumford 1934).

The harnessing of water and wind placed at man's disposal many times the amount of power previously available. However, their use was restricted by geographical and meteorological conditions, such as location of streams, stream slope, local weather, rainfall and wind conditions. In the latter case, use is restricted by the normal wind velocity, direction and the total amount of time the wind blows.

Equally as important as the development of power were the inventions of the latter half of the Middle Ages. One writer states that most of the primary inventions came into being during this period (Mumford 1934). These included the mechanical clocks, telescope, cheap paper, print, printing press and the magnetic compass.

In other aspects of engineering, the engineer of the Middle Ages only improved upon that of his predecessors. Many of the world's outstanding masonry structures, mostly cathedrals, castles and bridges, were built during this time.

The Rise of Modern Science

Following the introduction of the primary inventions and the availability of increasing amounts of power, the medieval world changed rapidly. One of the major changes occured in the increased activity in the scientific field. The great scientific advances which began in the seventeenth century were based on the methodology of Greek science. There was, however, a new element in the science of this period which distinguished it from the early sciences, namely experimentation. It was during this time that scientists began to adopt the empirical experimentation that engineers and artisans were already using. Not only did the scientists adopt the experimental attitude from the engineers, but they also began to use the products of engineering, such as pumps, balances, telescopes and microscopes.

Although engineers started to use some of the knowledge of the modern sciences in the seventeenth century it was not until the nineteenth century that the engineers could consistently apply science to achieve advances in some field. Among the scientists whose work was to become important for the engineer of the future were Galileo, Newton, Leibnitz, Boyle, Huygens, Hooke, Torricelli, and Pascal.

In the field of engineering, major advances during the seventeenth century were made in transportation. During this time major advances were made in the construction of canals, docks and harbors. These canals which, prior to the coming of the railroad, were the most important means of providing inland transportation, were constructed in all of Europe, particularly Italy, France, the Netherlands, Sweden, England and Russia. A typical example is the Languedoc Canal from Bordeaux to the Mediterranean, a distance of more than 300 miles across Southern France. This canal rose 200 feet in 24 miles to its summit and then dropped gradually 620 feet to the Mediterranean. There were 100 locks in the canal. It also had a tunnel 500 feet long which was the first in which gunpowder was used extensively for blasting.

It was also during the sixteenth century that the initial rises in technology spearheading the industrial revolution were made. These were associated with the textile industry where advances were made in spinning and weaving. About the beginning of the century a spinning machine was invented which was able to twist yarn into a thread. Shortly thereafter improvements were made in looms which vastly improved the output of woven cloth of all kinds.

The rise of vigorous new nation states in the sixteenth and seventeenth centuries created a political and intellectual environment which became gradually more favorable to the study of science, as national self-interest put a premium on technological innovations. These developments coincided with the discovery of the New World and the consequent competition between nations to increase prestige and prosperity by the acquisition of colonies. The exploitation of the vast resources of the world came to depend upon the perfection of new techniques and processes, demanding the combined talents of the scientist and engineer. Thus, the pursuits of engineering became socially respectable and increasingly influential in western European society.

The Industrial Revolution

Although the engineer had exerted a continuing influence on the course of civilization from pre-historic times, this influence began to accelerate at the beginning of the eighteenth century, during a period called the industrial revolution. During the following two centuries, the engineer and his works were to greatly change society. These changes were brought about by new sources of power, new machines, new techniques, increased transportation and increased communications.

New Sources of Power

At the end of the seventeenth century the only inanimate sources of continuous physical energy were wind and water power. As stated earlier these were available only within narrowly limited areas. At the turn of the century occurred probably the most remarkable of all modern technological achievements, the harnessing of steam power. The first workable steam engine was a product of several decades of research by scientists into the nature of air and the creation of a vacuum. It was a pump which operated by condensing steam into a vessel to make a vacuum into which water was forced by atmospheric pressure.

The valves were then changed to allow more steam into the vessel, forcing the water up the exit pipe, and the process was repeated. It was not very efficient, but for its time it was a remarkable advance over all other methods. It was put to work immediately pumping water from the coal mines.

Soon after, a piston operated steam engine was invented. Both of these engines were low pressure engines, working at little more than atmospheric pressure. The next great advance, early in the nineteenth century, was the development of high-pressure, non-condensing engines relying entirely upon the expansive power of steam. This type of engine gradually replaced the atmospheric design for all pumping and industrial functions and was readily adapted for use as a locomotive engine on the new railways. By the middle of the nineteenth century, Britain had become the predominant industrial nation of the world, and this superiority was due in large part to the quantity and quality of its steam engines in industry and transport. Steam had become the major source of power, making possible an unprecedented expansion in the industrial production and a rising standard of living.

Although steam engines were to be used for a considerable period to come, two new sources of energy, introduced at the Great Exhibition in 1851, internal combustion and electricity, were soon to rival steam as sources of power. The first internal combustion engine used as a fuel, a gas derived from coal. By the end of the century, coal gas rapidly lost ground to liquid oil products such as kerosene and gasoline as a fuel for this type of engine, however, it was not until into the twentieth century that extensive use was made of internal combustion engines.

In the development of electricity as a source of power, the contributions of the scientist became increasingly important, such scientists as Benjamin Franklin, Coulomb, Volta, Oersted, and Ampere. An experimental electric motor and generator were produced early in the nineteenth century which led to the "electro-magnetic" engine of the Great Exhibition. It had a pull of 160 pounds. The first electro-magnetic generator which was commercially successful was installed in France later in the century. Soon after, with the invention of alternating-current generators and alternating-current motors, electricity was established as an outstanding source of power. For all its importance as an easily distributed, versatile form of energy, electricity does not provide its own prime movers. It has to be generated by some other agency, and until the end of the nineteenth century, the only significant means of mechanical generation was the steam engine. One of the problems baffling the electrical engineers of that time was that of producing a steam engine capable of turning the generators at a speed sufficient to achieve the greatest efficiency. The invention of the steam turbine late in the nineteenth century solved this problem, significantly advancing the use of electricity. A recent historian of electrical engineering has described it thus: "Beyond question the invention of the steam turbine with its connected generator has proved to be the most potent factor in the history of electrical engineering throughout the world over the past 60 years" (Dunsheath 1962).

Other developments in electrical generation were also made. A hydro-electric plant was put into operation at Niagara Falls in the 1880's heralding many other such installations which were to become very important in the twentieth century.

Transportation

Ease of transport is an important feature in any industrial society because it permits the mobility of men and merchandise necessary to stimulate trade and to encourage the growth of manufacturing industries. During the Industrial Revolution, the transportation systems in the highly industrialized countries were rapidly improved. This improvement was achieved, initially, by the application of the systematic techniques of Civil Engineering to the construction of roads, canals, bridges and aqueducts, and then by the harnessing of a series of new prime movers to the needs of transport on land, sea and air. The power of the steam engine, the steam turbine, the internal combustion engine and the electric motor was made available for a steady acceleration in mechanical means of transport.

For example, the population of North America by Europeans was effected with remarkable speed, but only because of the extension of roads and railways to the the interior and the far west. President Thomas Jefferson expressed the opinion in 1803 that it would be 200 years before the region east of the Mississippi could be settled, and another 200 years before it reached the Pacific. He might have been right had it not been for the engineer and his co-workers.

During the Industrial Revolution, road construction methods were considerably improved and canals were widened to increase their transportation capabilities. The roads and canals built before and after the turn of the nineteenth century were essentially complimentary to each other. The new roads, with their flourishing stage coach services, made possible the rapid movement of people about the country and a quick and reliable mail service, while the canals made transport of heavy commodities physically possible and comparatively cheap. Taken together, they brought hitherto remote areas within the influence of economic activity and civilization, cut the prices of raw materials and manufactured goods and promoted the industrial activity of the industrialized world. Possibly even more important, for the subsequent technological growth, was the establishment of a body of professional engineers and skilled workmen who had acquired the techniques of what already was being called "civil engineering" (Pannell 1964).

However, in the second half of the nineteenth century, roads and canals were eclipsed by the construction and use of railways. The supremacy of the railway steam locomotive over all other means of land transport lasted from the 1830's to World War I. In England, by the middle of the nineteenth century, there were already 2,000 miles of track, and six years later the figure had risen to 5,000 miles. By the end of the century all the main towns had been linked in the railway network. In the United States, governmental support hastened the construction of the transcontinental railways, thus helping to negate Thomas Jefferson's prediction.

Increased transportation capabilities at sea were also introduced during the Industrial Revolution. In the early part of the nineteenth century the effectiveness of the sailing ship was dramatically improved with the design of the "Yankee Clippers" which were extraordinarily fast ships with enormous spreads of canvas and which outsailed everything else on the high seas. However, the sailing ship was soon to be replaced as steam propulsion was applied to marine transport. The ability of the steam ship to keep a tight schedule in almost all seasons and weather conditions removed the barrier to easy movement of men and material between continents previously set up by the oceans.

Although the rate of transport capabilities began to increase during the Industrial Revolution, it was accelerated even more during the twentieth century with the advent of the motor car, the aeroplane and the building elevator.

Communications

Although the printing press had been invented during the Middle Ages its widespread use did not flourish until the Industrial Revolution. In the eighteenth century, the scope of the printed word increased further with the growing popularity of newspapers and magazines. This expansion required an advance in the technology of printing. A mechanized printing press which harnessed steam power to a reciprocating type-bed was first used early in the nineteenth century. It turned out sheets at the rate of 1100 an hour (Buchanan 1965). Inventors soon realized that the key to really high-speed printing was rotary action permitting the continuous running of the press. By the middle of the century, a satisfactory rotary press was invented capable of running off 20,000 impressions an hour. Type-casting was successfully mechanized with the invention of a machine capable of casting 60,000 characters an hour.

Another means of communication developed during the Industrial Revolution was photography. Considerable progress was made in the process from the first recognizable photograph in the 1820's to the development of the "Kodak" camera by George Eastman in the latter half of the century which made photography available to everyone with modest financial resources. The development of the Kodak camera and the subsequent movie camera were made possible by the chemical engineer's development of celluloid, one of the first synthetic materials. Thomas Edison introduced celluloid film with perforations and toothed wheels to control its movement in the 1890's initiating the movie industry. This industry was to grow considerably during the twentieth century and was also to be augmented by the television industry.

Probably the most important communication advance during this period came with the application of electricity as a means of communication. The electric telegraph was first installed in Britain in the 1830's, soon to be followed with installations in the United States. The opening of the cross-channel cable at the middle of the century brought the business communities of Paris and London into close contact, and demonstrated the practicability of marine cables. Although several attempts to lay a trans-Atlantic cable ended in frustration, it was finally accomplished in the 1860's. By this time there were about 150,000 miles of electric telegraph in the world.

Hardly had the world-wide telegraph network been established than another great step was taken in communication technology with the invention of the telephone in 1876. Six years later there were 11,000 telephones in Great Britain and 148,000 in the United States (Buchanan 1965).

Meanwhile techniques of preserving sound had been developed and had provided a valuable means of communication. In the 1870's Thomas Edison patented the phonograph.

A final communications advance made during this period was the development during the 1890's of the "wireless" telegraph. From this system was to grow the radio and television broadcast systems of the twentieth century.

New Machines

Throughout all of the Industrial Revolution, new machines were constantly being introduced, to such a scale that this period of time has been called by several, the "Machine Age." Many of the more important machines have been listed previously, involved in power production and transportation. Still others were involved in the production and refining of raw materials. The Industrial Revolution was begun with iron and came of age with steel.

Still other machines were developed to form raw materials into necessary forms for the construction of bridges, railroads, buildings, vehicles and still other machines. These include bending, cutting, milling, stamping and drilling machines.

The Technological Revolution

Since the beginning of the twentieth century, technological innovation and implementation has increased at such an overwhelming pace that it would be difficult to summarize it briefly. However, there are certain engineering elements which stand out and typify the technological revolution now in progress. These include the development of the electron tube and the transistor with their many variations; new processes for obtaining chemical materials such as metals, plastics and organic products; the use of nuclear processes; improved methods of communication and transportation; automation and the wide spread use of the computer.

In terms of new materials, contrary to the past when the engineer had to work with a limited number of different materials to accomplish a specific task, he now can practically define the properties of the material which he needs and create the material. The development of synthetic materials which began with the creation of celluloid in the nineteenth century continued with the development of new artificial fibers before and after World War I which were mostly derived from cellulostic material and were based upon the long molecular chains existing naturally in cellulose. All such fibers are known under the general name, "rayon". The attention of the engineer turned in the twentieth century to the possibility of tailoring molecules in such a way that they could be assembled in chains or alternative patterns. Most modern plastics and synthetic fibers are the successful products of these researches. Nylon, which started commercial production before World War II, demonstrated its tremendous versatility during the war, and it has since been manufactured in an ever widening range of products, both in fiber and solid form.

The chemical industry is also responsible for the preparation of artificial fertilizers, for the manufacture of drugs and other medical materials, for the production of paints and insecticides and for photographic materials, to mention only a few.

In the metallurgical industry, new alloys of steel, aluminum and copper are constantly being developed to meet engineering specifications. In addition, a new industry is now being developed to meet the increasing heat-resistant needs of modern industry. This is in the area of ceramics.

Building upon successes in the development of communications during the Industrial Revolution, radio and television developed into major instruments of mass communication. This growth was made possible by the development of the thermionic valve. Experimental broadcasting began in the early 1920's and soon radio broadcast stations were scattered throughout the industrialized world.

Practical television was first demonstrated in 1926, however, the first regular use was started in 1936 by the British government. World War II interrupted the British television services, but shortly after the war they were resumed in Britain and also started in the United States.

Within a decade, television became the most popular of all means of mass communication and an element of tremendous significance in the social life of the world.

Color television was first introduced in the United States in the early 1950's. Another technological improvement has been the introduction of video tape-recording, by which a picture is recorded on magnetic tape for reproduction of television. This first appeared in the United States in the late 1950's. The technical success of the communications satellites, Telstar and Earlybird, indicates another probable line of development in future television services.

In the area of transportation, the development of the automobile and the airplane were to have tremendous effect upon society. Although developed in the last part of the nineteenth century, the automobile was not to become a major means of transportation until mass-produced by Henry Ford. The first automobiles used, as a means of propulsion, either steam or electric motors, but with continued improvement of the internal combustion engine this soon became the major means of propulsion. The Ford Motor Company was set up in 1903 and installed its first moving assembly line in 1913, continually improving it afterwards. In 1914 it produced 265,000 automobiles, and by 1923 the production had risen to more than 2,000,000 and the Model T was commanding a world market (Buchanan 1965). The increasing use of the automobile revitalized the road systems of the industrialized world and eventually put highway transportation back into competition with the railroads.

An even more spectacular process of evolution than that of the automobile has been performed in an even shorter space of time by the other outstanding product of the internal combustion engine, the airplane. The first powered, sustained and controlled flight by a heavier than air machine was made on December 17, 1903, by the Wright brothers lasting for a total time of 12 seconds. During the quarter century following the Wright's first flight the evolution of the airplane progressed rapidly. Speed had increased from 30 miles an hour at first to 280 miles an hour in the 1920's, and, at the beginning of World War II, record speeds were pushed up to 470 miles an hour (Kirby et al 1956).

It was about 1940 that engineers made the first innovation in airplane motive power. The quest for speed and for operation at high altitudes had become increasingly important, and since it was obvious that the limits of motive power provided by the reciprocating engine were being approached, tests were made using the gas-turbine jet engine. With the use of the jet engine, commercial airline speeds have been pushed to 600 miles an hour and are planned to 1500 miles per hour. Military aircraft now fly at the speed of 1500 miles per hour.

The helicopter design is the second important innovation in recent aircraft history. The helicopter is a vertically rising device, the main characteristic of which is a large propellor rotating slowly on a vertical shaft. Leonardo da Vinci, who speculated much on aerial flight, suggested the idea in one of his sketches. The first flight of any length in a helicopter was made in 1922 and lasted for one minute and 25 seconds.

As seen above, the airplane's most important contribution to transportation is speed. Its commercial importance other than its speed is relatively meager, except in certain special instances where it provides access to otherwise inaccessible localities. In these cases it is often cheaper to send goods by air-freight rather than by other means. Nevertheless, fast transportation over vast distances is having its impact on political, social and economic activities.

Two new developments in transportation which are likely to have a significant effect are the hovercraft, or ground-effect-machine, and the hydrofoil boat.

The development of automatic controls in the twentieth century may have as great an effect on human welfare as has mechanical power. An automatic control is a device which performs automatic self-regulation by feeding back, to an earlier stage, information regarding the status of a process at a later stage, to alter the action of the process and thereby to control the output. One of the most familiar automatic controls is the household thermostat. It shuts off the furnace when the temperature of the room rises above a given setting and restarts the furnace when the room falls below that setting.

The application of automatic controls to manufacturing processes, elevators, and other so-called "labor-saving" devices has resulted in increased reliability and reduced costs.

A transportation device which, more than most influences, has made possible the high-density of urban growth, is the building elevator. As elevator speeds and safety increased and building technology improved, higher and higher buildings have been possible, concentrating larger populations in smaller areas.

Developed along with automatic controls from very primitive forms in the early 1900's are the various forms of computing machines or computers. By adapting every new invention or technique that was suitable, engineering teams have developed the modern computer to a marvel of complexity, yet it is a machine that an operator can learn to use within a relative short period of time and which eliminates much of the tedium of mathematics from the computations of engineers.

Conclusions

Thus, the history of Engineering and Technology has paralleled that of civilization, sometimes being prodded by the social needs of civilization but generally encouraging and necessitating social change. Since, from each engineering application of science or of past engineering technology, several new applications can spring, the rate of technological change in the future can only increase the rate of social change. Since the engineer is primarily responsible for this rapid rate of technological change, it is necessary to understand his methods, his philosophy and the influence of his end products on society in order to understand society itself.

THE ENGINEERING METHOD

If one were to define the role of an engineer as simply as possible, it would be to state that an engineer is a problem solver. As has been demonstrated by engineers throughout history their role has been to solve the problems of mankind whether it be how to cross the river, to irrigate the crops, to defeat the enemy, to be protected from the environment, to communicate instantly around the world, to fly or to reach the moon. In solving his problems down through the ages the engineer has arrived at his solutions in a variety of ways. In recent times, however, there has evolved a general problem-solving procedure (of which there are many variations) which broadly defined, might be called the engineering method.

The Engineer As a Problem Solver

Many writers have emphasized the problem-solving nature of engineering. Most of them have presented it as a method whereby the engineer takes the resources of the universe, transforms them by means of physical devices, structures and processes in forms that satisfy the needs of mankind. (Alger and Hays 1964, Futrell 1961, Gest 1963, Hodnett 1955, Johnson 1960, Krick 1965, Leach and Beakley 1960, and Mantell et al 1963.) This solution of engineering problems may vary from a very complex solution upon which hundreds or thousands of engineers may work (for example, manned travel to the moon) to a reasonably simple solution by one engineer.

A characteristic of most engineering problems is the large number of alternative solutions possible, that is, different means of getting from one state of affairs, the input, to another state of affairs, the output. For example, there are many possible modes of travel and many possible routes between any two locations on the earth, not all of which would be given serious consideration, but the alternatives do exist. In fact, if there are no alternative means of accomplishing the desired result, there is no problem. Similarily, if all possible solutions are equally desirable, no problem exists. A problem involves more than just finding any solution, it requires finding the most desired solution. Regarding travel between two locations on the earth, for instance, most people are not indifferent to the differing costs, speeds, degrees of safety, comfort and reliability associated with alternative modes of travel. To arrive at the desired solution, the engineer must apply his knowledge and his inventiveness to uncover a reasonable proportion of the many alternative solutions in the face of numerous intangible, and often conflicting criteria. The limit of time available for proposing a solution precludes an exhaustive exploration of all possible solutions. In lieu of complete information, the engineer makes extensive use of judgment.

In addition, one of the most important aspect of almost all engineering problems is a consideration of its economics. A private enterprise ordinarily accepts an engineer's solution to a problem only if it shows commercial promise; a public enterprise insists on an attractive benefit-to-cost ratio.

One writer states (Harrisberger 1966): "Everything an engineer does costs money and lots of it. Every time an engineering project gets underway, someone is worrying about cost. Someone is also worrying about quality. When cost is the only concern, you are apt to wind up with a cheap and chintzy piece of junk. When quality is the only objective, you will quite likely produce a gem that will be quite expensive; but when cost and quality are both sought after, you are concerned about value--getting the most for the money." Thus an engineer is interested in an economical design, which, in general, is the development of an end product to do only and exactly what it was designed to do, and no more, with the least expenditure of materials, resources, production effort, and labor.

Also compounding the economic picture for the engineer is the fact that many of the costs of his problem solution are difficult to evaluate. Social costs fall into this category. For instance, in comparing the alternative methods and costs of sewage treatment for a city or town, the engineer must consider the other uses to which the receiving water of the sewage effluent is put. He must somehow be able to evaluate the cost of the loss of this receiving water for use for transportation, fishing, bathing or as a drinking water source.

Another element complicating the solution of engineering problems is the human element. People have to "live" with what the engineer designs and people have to "keep it up". For example, an engineer does not necessarily succeed by building an automobile engine which runs smoothly and efficiently. He fails if the mechanic in the garage down the street has to tear the motor apart to change spark plugs or if the filling station attendant has to remove the oil filter to check the oil. An engineer has not necessarily succeeded when he has calculated the size of the members of a bridge to span a large river. He fails if the bridge is too low to allow merchant vessels and war ships to pass. He fails if the location of the bridge snarls the traffic pattern of the city streets or if the approaches to the bridge are too steep and dangerous for automobiles in wet weather.

In the solution of the typical engineering problem, the engineer usually begins with the recognition of some need, desired result or objective. At this stage the problem is ordinarily expressed in very general terms. For example, "find an economical means of transforming the energy contained in ocean tides into electric power", or, more broadly, "find an economical means of generating electric power". Or, more specifically, he may have been asked to find a system of dams, gates, pumps, turbines and generators which, in a few specific locations, can economically produce electrical power. Or, the engineer may be asked to design a motor bike which will be able to capture a significant portion of the growing public demand for motor bikes. These are typical of engineering assignments. The engineer is given the general function or purpose to be served and perhaps some loosely specified requirements and preferences for a solution. Such functional and performance specifications are usually selected, often in collaboration with the engineer, by his employer, client or sponsor.

In almost all of these problems there is generally a large number of ways of accomplishing the specified objective. It is up to the engineer to explore a number of them. The knowledge that he has gained through education and experience is an important source, but not the only source of such solutions; the engineer must also exercise considerable ingenuity. Typically, the engineer extends what he already can do, from a ship to a submarine to deep sea submergence, from a propellor airplane to a jet to a missile to a space vehicle. In evaluating the many possibilities he finds it necessary to rely rather heavily on his judgment, since he cannot spend too much time in exhaustive evaluation of every feasible solution. The amount of judgment he must exercise in his day-to-day activities is a demanding feature of an engineer's job. Thus, two of the major aspects of engineering problem solution are creativeness in inventing solutions and judgment in evaluating them.

In addition, the engineer does not have an unlimited amount of time in which to accomplish the desired result. In almost every engineering project there is an air of urgency. Often there is a definite target date for producing a solution and, as a consequence, the engineer generally must recommend a solution long before he has had time to uncover all possible solutions. Furthermore, he must usually decide which one of the alternative solutions that he has generated is best, without the benefit of complete knowledge of their relative merits.

Also, in most engineering problems there are conflicting objectives. For example, an airline wants its planes to be safe, fast, and comfortable, to have a large carrying capacity, and to be economical to operate and maintain. However, if the designer of a plane does everything he can to make the plane as safe as possible, then speed, comfort, carrying capacity and operating costs will suffer. Conversely, if he does everything possible to maximize speed, then he sacrifices in comfort, carrying capacity, safety and fuel costs. In the end, the engineer must reach a compromise between these conflicting criteria by striking a satisfactory balance between them. Such decisions are made difficult by the conflicts present and by the impracticality of measuring criteria like safety and comfort, especially when safety is dependent on humans (pilot, air controller, maintenance crew) the weather, and the quality and quantity of air traffic within the life of the plane.

As stated above, human needs and desires also complicate his solution. He must concern himself with the detection and appraisal of human needs and also with society's acceptance of his solutions. Therefore, he must become familiar with the manner in which people will use his creations, the manner in which they will react to them, and the features preferred by potential users. He must also work with people in the synthesis and implementation of his designs, such people as governmental employees, lay boards, financial and legal advisors. It is this social involvement combined with the economic aspects of his problems that make an engineer's work less technical, but certainly not any easier (for some of his most difficult problems are with people) than the laymen generally suspect. These are additional reasons for non-engineers to become knowledgeable about engineering, for only through this understanding can he be able to understand whether or not his demands or desires are reasonable.

As society's needs and technological innovations become more and more complex, the number of problem solutions achieved by a single engineer become less and less. As a consequence of this complexity required in such projects, many engineering problems are handled by a team of engineers of varying backgrounds. When a problem concerns a large system, it becomes customary to assign portions of it, called subsystems, to different teams. The solution of a single complex problem by the use of a number of subsystems is called systems engineering and is being used more and more today in the aerospace industry, transportation, communication, and many other aspects of engineering. It is this approach to the solution of complicated problems by systems engineering that is being considered one of engineering's most important contributions to the possible solution of the complex social problems of today's society, such as overpopulation, inadequate education, and poverty.

Thus, in the engineer's solution of his problems it is apparent that neither his problems nor his solutions are neat, simple, or completely satisfying. He must come up with a solution immediately for a problem which is vaguely stated, which has constraints, some of them conflicting, some of them ridiculous, all the while lacking facts or relationships which are unknown and/or unknowable. Some of these types of facts and relationships include: actual conditions in the turbulent boundary layer of a fluid (liquid or gas) as it flows in a pipe or river or around a plane or ship; effects of prolonged weightlessness on humans; future conditions such as occurance and strength of earthquakes, floods and windstorms; and the size, location and desires of future populations and the effects on traffic densities, water demands, power demands, etc.

Engineering Projects

Before one can have an understanding of, or appreciation for, the engineering problem solving procedure, he should have some knowledge of some engineering projects in which an engineer or groups of engineers tackled a problem and solved it. These projects range from very large, complex ones on which many thousands of people work for many years to the small ones which are solved by an engineer in a matter of minutes. Typical examples of large engineering projects include the exploitation of iron ore deposits in Venezuela by U. S. Steel and the Apollo Landing Mission. Typical of small engineering projects is the design of a culvert.

U. S. Steel in Venezuela

Very typical of large engineering projects for private commercial enterprises is the development of iron ore deposits in Venezuela by U. S. Steel. In projects of this nature when a profit must ultimately be shown, quite often engineering decisions must be made on limited information and limited amounts of time whereas a careful investigation over an extended period of time might reduce the risk involved. This aspect is very evident in a number of instances in the Venezuelan project. It also illustrates engineering ingenuity and the recycling of various stages of the engineering problem solution.

The development of the Venezuelan iron ore deposits was the result of a search for new deposits initiated by U. S. Steel Corporation in 1944. The First and Second World Wars had used up the most easily mineable iron ores at an unprecedented rate (Wanamaker 1953). After an initial engineering decision to investigate Venezualan ore deposits in competition with other areas, the geologists first investigated the area which Venezuela had considered to be the only potential iron ore area and found nothing satisfactory. They then conceived the idea of aerially photographing another area not easily accessible by rail, highway or water. In early 1947 about 11,000 square miles were photographed and the resulting aerial photographs were intensively studied. As a result of this study and subsequent drilling of a hill now known as Cerro Bolivar, still during 1947, it was clear that an immense deposit of high grade iron ore had been discovered. Its length is about four miles, its maximum width about 4,000 feet and its average thickness about 230 feet. The rest of the story of Cerro Bolivar is a continual story of engineering decisions resulting in the development of the ore despoits, the construction of a 90-mile railroad to the Orinoco River, the construction of an ore crusher and ore-loading facility, the construction of a dock in less than four months, the dredging of a 178-mile channel to tide water (which is about 2500 miles from markets in Philadelphia), the construction of two towns and two power plants, the installation of a high-frequency radio system, and the construction of new smelters, all in record time.

The design of the 90-mile railroad involved many difficult problems, among them a very steep initial downgrade from the mine and difficult drainage problems. To overcome the problem involved in the initial seven-mile downgrade which averaged three percent from the mining operations to a savannah, specially designed braking systems were used on the ore cars giving an added degree of safety. Also, two runaway tracks were provided in this section with switches which were automatically thrown if the speed of the train exceeded 21 miles per hour which then allowed the ore train to leave the main track and to be stopped by the adverse grade of the runaway track. Drainage was a very difficult problem since the area is subject to sudden thunderstorms during eight months of the year when as much as a maximum of six inches of rain can fall in a localized area in two hours. Normally dry water courses become raging torrents in a few minutes with water depths of ten feet or more. Thirteen multiple-span bridges and 601 separate corregated culvert structures were built, some of the culverts as large as 120 inches in diameter. This railroad, although located in a very isolated area, was constructed in less than two years.

Initially, the project engineers had several means of reaching tidewater. One of them being the construction of the railroad the total distance to a tidewater port. Another alternative, subsequently chosen, was the construction of the railroad to the Orinoco River as stated above and the dredging of a channel to tidewater. One of the complexities in the total railroad route would have been a bridge with a total length of about 17,000 feet, or the equivalent of bridging a wide section of the lower Mississippi. The choice of a particular water route was a difficult one since 100 or more miles of the Orinoco River is in delta region with many branches to the river. Also, with very few exceptions, no engineering information was available regarding these rivers. At the time of the original survey an answer was needed as soon as possible and a thorough engineering investigation was, therefore, out of the question. Every short-cut had to be utilized. Based upon aerial photographs and limited soundings, a route decision was made and two large dredges started work on the channel. During a record one year operation, 33 million cubic yards of material was dredged from the river.

One of the unique aspects of the Venezuelan project was the installation of a prefabricated, ocean-going steel pier which was installed at the ore loading site (Maxton 1953). This pier, which was fabricated in three sections, each 377 feet long, had a total length of 1,131 feet and a width of 82 feet. It was fabricated in a Texas shipyard and towed 3,000 miles to the erection site, each section carrying its own oil and water pipes, ship mooring devices, tracks for a traveling crane, its own 100-foot long caissons (or pilings), a crawler crane, air compressors, welding equipment and all other gear necessary for the complete erection of the structure. After each section was positioned at the ore-loading area its crane lifted its caissons, dropping them into place through the pier section. Then a jacking system took over, lifting the pier out of the water by inching it up the caissons. Each caisson was then released and driven to firm foundation, cut off flush with the deck, welded to the section, and then filled with concrete and sand. This simplified operation cut field installation time to about one-tenth that required for conventional pier construction. Total elapsed time from the signing of the contract to the completion of the structure was less than four months.

As a result of this crash program of engineering design and construction, iron ore was first delivered from Cerro Bolivar over 2,700 miles to the United States in profitable competition with Labrador and Lake Superior ores only five years from the first exploration.

Apollo Lunar Landing Mission

The Apollo system is the greatest engineering system ever attempted, dwarfing in size and scope the most spectacular undertakings of the past (Furnas and McCarthy 1966). Project Apollo's major objective is the successful landing of a team of astronauts on the moon and their safe return to earth. Before its purpose is accomplished, sometime prior to 1970, the Apollo will have cost the United States an estimated $20 billion and will have involved the precisely coordinated efforts of nearly 5,000 industrial companies and some 300,000 engineers, scientists and technicians. Project Apollo differs radically from U. S. Steel's efforts in Venezuela in that, whereas U. S. Steel must eventually end with a profitable enterprise, project Apollo need not.

Within the framework of this project are many component systems, each of which is a tremendous engineering enterprise. One such component system involves the construction of the Lunar Excursion Module or LEM, the 15-ton vehicle which will place the astronauts directly on the bleak and airless surface of the moon. This vehicle will start its journey from the earth with an immense thrust from a mammoth three-stage rocket, as tall as a 36-story building. During the 240,000 mile, 70-hour trip to the moon, three astronauts will ride in a cone shaped unit called a Command Module, which will be attached to another unit, a Service Module, containing oxygen, electronic gear and other vital flight equipment as well as the rocket power to return the spacecraft to earth. The craft's third unit is the LEM. Ninety miles above the moon the spacecraft will go into orbit, and two of the three men will squeeze through a hatch into the LEM, which will then be detached from the parent spacecraft to descend to the moon's surface. After a 24-hour stay on the surface of the moon, during which time the astronauts will carry out scientific tasks which include collecting soil samples, measuring temperature, gravity and magnetic-field strength, conducting communications experiments, the astronauts will reenter the LEM which will boost them back into space for a docking with the parent craft. The astronauts will then reenter the parent craft for the trip back to earth, leaving the LEM to orbit endlessly around the moon.

At the beginning of the study of the design for this vehicle, late in the 1950's, the engineers were in their normal position, having very little actual knowledge on which to base their designs. For example, they knew little about the surface of the moon which would be used as a landing area as well as a takeoff area. However, they made their preliminary designs, based upon their knowledge and judgment. As more information was gained through manned and unmanned space flights and earth orbits and unmanned orbits and space flights to the moon, their design was re-evaluated and re-adjusted as necessary.

Two problems which proved especially troublesome in the design of LEM were weight and reliability. Because each extra pound of equipment requires many extra pounds of fuel to lift it into space, the engineers are under constant pressure to eliminate every ounce that can be spared. Also, in a project such as this there is no margin of error. Everything must work exactly right the first time. To insure the reliability of the LEM and the success of its missions, a fantastic array of testing devices have been set up at various space centers across the nation.

From the initiation of the original feasibility study to the final design of the LEM many different designs of the craft and its sub-systems will have been drawn, discussed, built and modified, continuing until the late 1960's when the astronauts will reach the surface of the moon. All of this for 24 hours on the moon.

Design of a Culvert

In the course of the design of highways, streets, roads and sidewalks, the engineer often encounters the problem of designing a culvert with which to pass rainfall runoff or small streams underneath the pavement, so as to eliminate for the user the hazard and inconvenience of water over the pavement. Most commonly this situation occurs when there is no stream and the designer is concerned only with rainfall runoff. Since a culvert is of nominal cost, it cannot bear the cost of an extensive hydraulic or structural investigation. Still the engineer needs to have sufficient information to design the culvert in three ways: hydrologically, or a determination of how much water must be carried by the culvert; hydraulically, or how much can be carried; and structurally, or how much superimposed load it can withstand.

Hydrologically, he uses the formula, $Q = CiA$, which states that the quantity of water equals a coefficient times the maximum rainfall intensity expected times the size of the drainage area contributing flow toward the culvert. The area contributing the flow can be fairly accurately determined by means of survey or map measurement, but the other two factors can not. Due to the inexact state of the science of meteorology, the exact amount of future rainfall can not be computed but can only be estimated based upon the experiences of the past. The coefficient, C, sometimes called the percent imperviousness, is a collection of several contributing factors. If all the rainfall in the given area were to arrive at the culvert, with no infiltration and the attainment of a steady state condition, the total flow would be $Q = iA$. But this does not happen, since some water percolates into the soil and other porous surfaces, or evaporates, or is held in puddles and depressions. Thus "C" is less than one but dependent on the nature of the surface of the area. However, it is not a constant for all conditions but tends to increase as rainfall continues, due to the saturating of the soil and the filling of depressions. Here again engineering judgment enters in.

Hydraulically, the design of the culvert is generally based on the discharge, as determined above, an assumed geometry determined by "standards", or typical configurations, topography, and other aspects of highway design. Other elements compounding the problem, but usually ignored or assumed to be taken care of by "maintenance" are: ponding above the culvert, silting (deposition of material in the culvert).

Structurally, again, the engineer for the sake of economy, generally relies on "standards" which take into account the height and type of earth fill above the pipe, its placement in the ground and the type and weight of traffic above it.

Thus, although the selection of culvert size may be done rather quickly, it involves considerable engineering experience and judgment in the selection of data for use in empirical formulae and engineering standards developed and refined through experience and experimentation over many years.

Problem Solving Procedure

Basically, the engineer's problem solving procedure involves searching for the optimum solution among those that satisfy the restrictions of the problem. The engineering method of problem solution has been defined by many writers. Typical of these is one outlined by Johnson (1960).

1. Definition of the problem.
2. Selection of methods and procedures.
3. Collection of data.
4. Application of methods and procedures.
5. Conclusions and recommendations.

In this definition, alternatives are not clearly exposed; there is also an implication that the nature of the solution is known from the beginning. Another typical outline of engineering problem solution is presented by Mantell et al (1963). This adds a checking process to the above definition.

1. Recognition and understanding of the problem.
2. Accumulation of the facts (physical system).
3. Selection of the applicable theory (mathematical model) or principle.
4. Solution (deduction of answer from the mathematical model, graphical analysis, trial and error, etc.).
5. Verification or check.

These and other outlines of the engineering method follow, in general, the normal procedure for solving any problem whether it be technical, personal, social, scholastic, or otherwise (Hodnett 1955). The first logical step in the solution of any problem is the definition of that problem. It has been said that a problem properly defined is virtually solved (Kogan 1956). Although this is an overly strong claim, it does serve to dramatize the crucial nature of this phase. Following problem definition, the next phase is normally a search for possible solutions and, following the search, is the last phase of the basic problem-solving procedure, that of decision. Most of the alternative solutions generated will no doubt be of unequal desirability, and therefore must be evaluated in order to identify the preferred solution. This is a weeding-out process, based on the given criteria, which culminates in the emergence of a preferred solution.

In regard to engineering problem solution, however, this three step procedure does not illustrate the uniqueness of the engineering method of problem solution as opposed to that of others. A more careful definition of the engineering method of problem solution would include the following phases:

1. Problem formulation. A phase in which the problem is defined in a relatively broad, detail-free manner, with emphasis on the identification of the input, or raw materials, and the output, or desired end product.
2. Problem analysis. A phase during which, first, the feasibility is demonstrated and then, if feasible, the problem is defined in relatively detailed terms. This detailed definition specifies needed facts and relationships. It involves the gathering, investigation, processing and screening of information in order to determine the specific characteristics of the problem.
3. Search for alternative solutions, which may require further information.
4. Determination of optimum solution, which may require re-evaluation of the desired result.

5. Specification of solution, which may include various alternatives, in which case a final bid, or cost estimate, may determine the optimum solution.

This five step procedure differs with the general problem solving process outlined above in two ways. One is the manner of defining a problem. The problem solving procedure advocated herein begins with a definition of the problem in general terms, followed by an appropriately detailed definition. The purpose of the two stage definition is to discourage a rather natural tendency on the part of problem solvers to become enmeshed in details before viewing the problem in broad perspective. The other change is the addition of a specification phase, which is necessary because an engineer's proposed solution must be communicated in detail to persons who approve, construct, service and operate it. Not taken into account in the simplified five-step procedure above is the cycling of a part of, or all of, the procedure, which is quite typical of the engineering method. An example of this successive refining process begins with a feasibility study, then on to other feasibility studies, preliminary design, final design and evaluation studies. Between steps it may be necessary to obtain additional data or relationships, rough out and compare alternative designs and go back for additional facts before proceeding on. In the problem formulation phase an engineer attempts to stop from restricting the problem too soon. He attempts to look at the entire problem, all of its ramifications, restrictions and possibilities. Pursuance of a broad formulation often brings the engineer into direct conflict with the decisions already made by the client or employer. For example, an engineer consulting for a city may have been asked to design a large parking garage to relieve parking congestion in the downtown area; however, if he takes the problem in broad perspective, he may recognize that the parking congestion can be relieved much more satisfactorily and economically by the development of a rapid tansit system. In doing so, however, he is recommending against a decision already made by the city officials.

During the problem analysis phase, contrary to the problem formulation phase, the engineer becomes concerned with details. He is now concerned with all aspects of the input and output, with constraints, restrictions and criteria. If he has been asked to design a water system for a city or town, he needs to know possible sources of water supply, water usage characteristics of the population and its industries, street patterns, frost level, variations in ground levels, fire-fighting requirements, water quality requirements, types of pipe and other equipment available, and a multitude of other data. It may be during this phase that a number of possible alternative solutions to the problem may appear; however, this is only secondary during this phase.

As the engineer becomes involved in the search for alternative solutions, he becomes actively involved in a search of the literature, his mind, existing practices, and many other potential sources of alternative solutions. This phase seldom culminates in the generation of a set of complete, mutually exclusive solutions. Rather, the results will probably consist primarily of partial solutions that only concern one or several of the steps or variables that a complete solution must eventually encompass. For instance, in the design of the water system for the community, the alternative sources of supply may have little bearing upon the pipe materials, the location of the distribution system, or the storage facilities. This search phase is the creative phase of the engineering method. An engineer's storehouse of specialized scientific and technological know-how is the source of many alternative solutions, but he must also rely heavily on ingenuity to solve those many unique problems for which no generalized principles are available. For many engineers, it is this creative aspect of their work that they find most appealing. The effectiveness of this search can be maximized by pushing back the boundaries on the areas of possibility that can be considered, and then by sampling those areas effectively.

It is difficult to generalize concerning decision-making procedures in engineering problem solution. The specialized knowledge and procedures employed depend on the nature of the problem, the complexity and competitiveness of the alternatives, the relative importance of the decision and other circumstances. The decision process ranges from the most elaborate, exhaustive procedures involving much measurement, investigation, prediction and cost comparison, to quick, simple, informal judgment. Although the specifics vary greatly from situation to situation, in almost every instance there are four general steps which must be fulfilled before an intelligent decision can be reached: selection of criteria, prediction of the effectiveness of alternative solutions, comparison of these predicted effectivenesses, and finally the choice of the optimum solution. During this phase of problem solution the engineer must rely heavily upon most of his skills, including his highly developed, specialized judgment. Part of this judgment is the recognition of the "important" which must be checked out carefully and the "unimportant" which can be overdesigned or corrected later, if necessary. The inherent errors associated with all measurement and prediction processes, the frequent necessity of making evaluation of alternatives in their conceptual stage, the large number of sub-criteria that ordinarily must be considered, the proportion of criteria that defy quantification, conflicts among criteria, and the rather limited time available for evaluation of alternative designs, combine to make this phase of the design process a challenging one indeed.

After the engineer has selected a solution, its physical attributes and performance characteristics must be specified in detail so that those persons who must approve it, those charged with its physical creation, and those responsible for its operation and maintenance can satisfactorily fulfill their responsibilities. This fact makes it especially important that the engineer carefully document and effectively communicate his solution to others. In this phase of engineering problem solution, the engineer uses two major tools, one is a graphical tool, generally a set of engineering drawings of the proposed device, structure, or process. These carefully prepared, detailed, dimension drawings, are the main vehicle for documenting and communicating the solution of an engineering problem. Another means of communicating specifications is an engineering report which, among other things, describes the need for the proposed solution, the solution itself, and the justification for it.

One writer summarizes the engineering method of problem solution as involving: "Meticulous attention to detail, the coordination of a wealth of information, the search for a variety of ideas at every stage, and an overall necessity to achieve the best performance at the lowest cost in the shortest possible time" (Harrisberger 1966).

TOOLS OF ENGINEERING

In the solution of problems, as stated in the previous chapter, the engineer brings to bear a large number of varied elements which might be considered the "tools" of engineering. These include a certain body of knowledge, a certain set of skills, and a certain attitude. In addition, the resources of the universe, such as materials and energy, which are used by the engineer, might also be considered among these tools.

Body of Knowledge

Included in the engineer's body of knowledge, which he brings to bear in the problem solving process, are basic physical science and engineering technology. In addition, there are some important non-technical aspects of an engineer's knowledge. If he is to be professionally competent, an engineer's knowledge must extend considerably beyond physical science and engineering technology. It must extend into such areas as economics, government, law, marketing, labor relations, psychology, and sociology.

In regard to basic physical science, a very important part of an engineer's formal education concerns the physical sciences, primarily physics and chemistry. In order to develop the complex devices, structure and processes that an engineer creates, he must have a fundamental understanding of the laws of motion, the structure of matter, the behavior of fluids, the conversion of energy and many other aspects of the physical world. Familiarity with basic physical science provides this understanding and the foundation upon which much of engineering technology rests.

An engineer also brings to bear upon his problems a body of knowledge called engineering technology which includes applied physical science and a storehouse of empirical knowledge, accumulated throughout the history of engineering. An engineer, through his training and experience is aware of the applications of physical science which have been made by engineers in the past. Applied physical science courses which he takes during his formal education include mechanics of solids, fluid mechanics, thermo-dynamics, electrical circuit analysis and properties of materials.

Although most designs are based partly on scientific knowledge, they are of necessity based partly on experience, judgment and invention. Over a period of years, many ideas, practices and observations, although not based on any known scientific principles, have been shown through experience to be sound and generally useful. These have been recorded and perpetuated and constitute an accumulation of empirical knowledge that engineers rely on quite extensively in the solution of their problems. Both engineering successes and failures contribute to this general knowledge. Part of the engineer's formal education is devoted to the study of this empirical knowledge.

Economics is an extremely important tool of engineering. An engineer must be well aware of the "economic facts of life". If he is to be of value to his employer and a benefit to society, the engineer must be aware of the importance and intricacies of profits, costs, return on investment, depreciation, interest charges and other economic realities. The engineer is constantly involved in economic decisions from the start of his project to the end. To cope with these decisions effectively, he must be as profit-and-cost-conscious as the business man himself. In addition, the engineer must work with persons in many fields of endeavor; for example, economists, accountants, politicians, sociologists, psychologists, lawyers, union leaders and many others. He should be aware of the contribution these people can make; he should be able to talk with them intelligently, work with them and understand their problems (as they should his).

And, finally, an engineer must be well aware of society itself, in as much as he is as much a creator of social change as of technological change. Many of his creations have far-reaching effects on our daily life in a variety of respects, not all for the better. For example, the engineer is the prime creator of automation and should not ignore the economic and social problems which are usually created as automatic machines are introduced into factories and electronic computers in offices. Regarding this phase of engineering education one engineer states (Raymo 1962):

> Engineering education should impart to the student an understanding of the world that asks for, needs, and will use engineering developments. The student should understand that an engineering job is not complete--that indeed it will not start or end successfully, and he will not be doing his part well--unless his matches and fits the outside non-technological world. It is necessary that he be broadly educated, not as a luxury and personal development, but as a key part of his preparation, so that his professional activity will truly be competent.

Engineering Skills

In the solution of his varied problems, an engineer also brings to bear a set of skills, including mathematics, graphics, communications, measurement, simulation, experimentation and many others.

Mathematics provides a means of representing important characteristics of physical science in terms of symbols. It also provides a system of conventions, rules and procedures for manipulating the equations stating a physical relationship in symbolic form in order to yield useful predictions about the phenomena that the symbols represent. The great utility of mathematics for predicting the behavior of metals, gases, electricity, people, etc., is one of the main reasons it is given heavy emphasis in engineering education.

Also being employed today in all areas of engineering are a number of computational techniques and tools, including the electronic computer, the rapidly increasing use of which is one the most significant changes ever to take place in engineering. With the use of the electronic computer, mathematical methods never before feasible are now being used. The computer is also being used extensively in the process of simulation, another one of the tools of engineering. It is possible to have a computer behave analogously to a different device or process. With this aid, an engineer can try out alternative designs while they are still in the idea stage. For example, an electrical network or a water distribution system can be simulated by an analog computer. Other types of simulation include the model of a proposed airplane design in a wind-tunnel and the evaluation of water flow characteristics in model studies. In each of these cases the model in some respect resembles or describes a structure and/or behavior of a real life counterpart. However, the simulation or analogy is seldom perfect and the engineer must understand the underlying phenomena involved if he is to correctly interpret the model.

The graphical skill of the engineer is his ability to present the information in the form of drawings, sketches and graphs and is essential to successful communication of many of the engineer's ideas. Another skill of the successful engineer is his oral and written communications ability.

One of the earliest skills which the engineer developed is that of measurement as evidenced in the careful layout of many of the magnificent structures of classical civilizations. Closely allied to skill in measurement is skill in experimentation, or the ability to obtain a maximum amount of reliable information with a minimum of time and expense by devising experiments to study possible problem solutions. Closely related to the engineer's measurement and experimentation skills is his ability to draw intelligent conclusions from the observations that he makes.

Even if these observations are measurements of a very simple nature, skillful interpretation of them is not as straightforward as it may seem. That is so because of the uncontrollable variation in the characteristics of all materials, objects and devices along with the fact that no measurement system is perfect and the fact that most conclusions must be based on a relatively small sample of observations. Therefore, it is important to the engineer that he learn the many potential sources of errors involved in drawing conclusions, the limitations of small samples, the role of chance, uncertainty, and prejudice, and the importance of carefully evaluating the reliability of the evidence available.

Engineering Attitudes

There are certain qualities that an engineer brings to bear on a problem that are neither factual knowledge nor skill. They constitute a certain attitude, which includes a questioning attitude, objectivity, open mindedness and a professional attitude.

The engineer's curiosity, or questioning attitude, concerning the "how" and "why" of things leads him to much useful information and many profitable ideas. Some of this questioning results from inquisitiveness, some from a certain skepticism. This challenging of the profitability of some practice, or the validity of some "fact" or the advisability of a certain feature or the necessity of some component is a very important aspect of the engineering attitude.

Another conspicuous characteristic of the engineer's attitude is objectivity. In the course of a typical project an engineer is the focal point of a multitude of opinions, many of which are biased, conflicting and representing special interests. Furthermore, he is confronted by many situations that owe their existance to custom rather than reason. In the face of biases, pressures and traditions, the engineer strives to be objective in the course of making his evaluations and decisions. He is also open-minded to the new and different. His mind is flexible and receptive to the changing theories, new ideas and innovations and engineering methodology, etc., that are becoming increasingly evident.

But above all, the engineer takes a professional attitude in the execution of his functions, assuming a moral obligation to society, his employer, and his colleagues in this field, in the traditional manner of the professions. The professional person serves society as an expert with respect to some type of relatively complicated problem. Under these circumstances the layman trusts the professional person and, because of this trust, the latter has an obligation to perform his services on a high ethical level. Most of an engineer's creations (for example, the bridge, the elevator and the power lawn mower) directly affect the well-being of many people. Under these circumstances, the public trusts that the engineer's decisions will be safe and otherwise beneficial to the welfare of mankind.

Material and Energy Sources

In addition to bringing to bear upon his problems a certain body of knowledge, a certain set of skills and his engineering attitudes, the engineer must also be well aware of the resources of the universe, such as materials and energy, and their limitations.

Engineering materials include animal, vegetable and mineral matter--some natural and some produced. Materials are useful because of their properties, i.e., their strength, ease of fabrication, lightness, or durability, their ability to insulate or conduct, their thermal, electrical or acoustical characteristics. A list of these materials would be almost limitless. For example, there are 45 metallic elements and nearly 8,000 alloys of those metals in commercial use today (Young 1947).

The number of important sources of energy is much smaller, and includes coal, petroleum, gas, wind, sunlight, falling water, and nuclear fission. Each energy form has characteristics which dictate its use in certain situations. Coal is inexpensive. Petroleum products can be stored and converted into heat under carefully controlled conditions. Wind power is cheap, but undependable. Use of water power is feasible only in certain places. Nuclear fuel is cheap, but the conversion equipment is expensive. Electrical energy is obtained indirectly from some natural form and therefore is expensive and cannot be stored, as such; however, it possesses the great advantages of efficient transmission, distribution and utilization in a great variety of applications. At the present time we are not making direct use of the tremendous amounts of energy which are obtained from the sun. Each day there comes to the earth as sunshine more than 10,000 times as much energy as mankind uses for all purposes. (Winnery 1965).

THE PHILOSOPHY OF ENGINEERING

Throughout the history of civilization, man has contemplated the natural surroundings in which he has found himself and also his relationship to those surroundings. Consequently, he has recorded his philosophies concerning nature and man. These philosophies have undergone rather radical changes from time to time with rather distinct philosophies being espoused by the Egyptians, the Greeks, medieval man, sixteenth and seventeenth century man, and modern man.

During the time these philosophies were being developed, the engineers of those periods were working, developing their structures, devices and processes, generally in contradiction to the philosophies expressed by the learned men of the period. This contradiction has become very evident in the modern era, to such an extent that modern philosophies are being changed by the influences of engineering and technology, despite the lack of understanding or awareness on the part of the philosopher.

In order to more carefully indicate the influence of engineering and technology on modern philosophy it is necessary to chart the path of the philosophy of nature, showing the similarities of those philosophies throughout history, and then indicating the basic contradiction which engineering and technology makes. Concomitantly, there have been philosophies of man's nature and theologies, all of which became somewhat confused. However, this discussion will be limited to nature, science and technology.

The Egyptian Philosophy of Nature

In nearly all ancient civilizations the concept of nature was much broader than ours. It meant the totality of everything and included man because man, and everything human, was thought of more or less as a passive part of the cosmos. There was hardly a question of any clear opposition between man and nature. There was, however, an over-all influence of the divinity, that of providing order to nature and to human affairs. In the Egyptian view the realm of nature, the moral realm of interhuman relationships and the realm of culture with everything implied by it were inseparably united; an infringement of that order in any of these realms led inevitably to disaster in the other realms (Frank 1949). Accordingly, the whole of society and whole of nature were seen as a single fixed order in which human life runs its course. It was an order in which even the smallest details were naturally determined. "Naturally determined" contained the connotation of "determined by the divinity". The natural order possessed at the same time a natural sacredness. It contained not only man's possibilities and limitations, but also his duties and his rights.

The Greek Philosophy of Nature

The ancient Greek view of nature closely followed that of the Egyptians. True, in Greek philosophy, man became conscious of his ability to penetrate into nature through his reflection and thus to discover its principles and laws. On the other hand, in the Greek view, man could not interfere in the order of nature as a result of his thinking. However, nature was no longer viewed as a cosmos governed by the whims of gods as was the case of earlier mythology, but as a cosmos ruled by rational principles. The substitution of a rational order for a mythological order did not mean at all that all religious ideas were eliminated. Belief in myths was, of course, undermined but the same may not be said of religious ideas in general, rather the opposite was the case. The clear realization that the cosmos constituted a single order to which man himself also belonged, strengthened the awareness of a bond with something transcending individual man as well as human society. The divine, as the primordial element of the world, manifested itself in the beautiful order of the cosmos. In this way, the natural and the supernatural were practically the same as far as the Greeks were concerned.

One of the major Greek philosophies of nature was developed by Plato (about 427-347 B. C.). The cardinal doctrine of the Platonic philosophy is the theory that true reality resides not in the individual phenomenon, such as a particular book, tree or man, but in the general idea of the book, tree or man. Individual phenomena are but the fleeting perishable semblances of the indestructable and essential form or idea. Being eternal and unchangeable, ideas are outside space and time; they are the object of all longing and aspiration, the object of all knowledge, and they are also in the forms in which the one final and absolutely real Being, the supreme Idea of the Good, manifests itself (Jeans 1951). Plato believed that perfection and reality necessarily went together and thus argued that the eternal and unchanging forms must be the true realities of the world, while the material objects which come and go, and at best provide only fleeting impressions and imperfect representations of the forms, have a lower degree of reality (their relations to the realities is of the circles which mathematicians draw in the sand to true circles).

A disciple of Plato's, Aristotle (384-322 B.C.) shares with Plato the distinction of being the most famous of ancient philosophers. He opposed the Platonic doctrine of "ideas", holding that an "idea" has no power to produce the corresponding concrete object, and that it thus introduces a new complication, while explaining nothing. In place of the barren concept of the "idea" he introduces that of "form". He accepted the four elements of Empedocles, an earlier philosopher, those of earth, water, air and fire, as constituents of matter, but added a fifth, the quintessence, to form the basic substances of the universe (Jeans 1951).

Aristotle conceived of the earth consisting of the element earth and as placed in the center of the cosmos. The earth was supposed to be surrounded by the sphere of the element water about which were the spheres of air and fire. Things consisting of earth, i.e., solids tended to move toward the center of the earth, because this center was their "natural place". They were heavy. Fire and air were, however, "light", because their "natural place" lay above the earth; hence they moved upward. This "theory" was used to explain natural phenomena, or observations; the reason the assumptions were made as they were was because from these assumptions one could logically demonstrate what one could observe. Qualitatively, modern theories are similar.

The sphere of celestial bodies lay beyond the spheres of terrestial elements. These bodies were supposed to be of an entirely different nature from terrestial bodies. Their matter was incorruptible, immutable and subject only to endless perfect local movement, or circular motion. Aristotle is also famous as the creator of the deductive science of logic and, also as its perfector.

Two qualities of Greek philosophy stand out in direct contrast to modern philosophies. In one, the modern philosopher and scientist quite often begin with some special phenomenon, or some special property of matter, in the hope that in the study of this isolated phenomenon, law and order may be detected in one small corner of the universe (Durant 1962). In contrast, the Greeks did not want scraps of knowledge about isolated corners of the universe but a balanced and comprehensive view of the whole. In the second place, the Greek general attitude toward life resulted in many cases in a positive aversion against increasing knowledge by experiment. In the ordinary affairs of life, they esteemed mental activity far more highly than physical which they thought unworthy for free men and fit only for slaves.

The Medieval Philosophy of Nature

In the Middle Ages, scientific knowledge rose very little above that of the Greeks, and principally because of this, the medieval conception of nature was in many respects very little different from that of the Greeks. There was, however, one very important difference. The world was seen as a creation of the transcendent and sovereign God upon whom this world was wholly dependent while He Himself was not in any way dependent upon the world. He had placed this world at the disposal of man, whom He had created to His image and likeness. Thus man was assigned a position with respect to nature which implied much more freedom than was allotted in the previous philosophies of nature. Man's greatness, however, was seen primarily in his capacity to know his Creator and to serve Him freely, to serve Him especially in spirit and truth. For this reason, medieval man paid attention to the world insofar as this world spoke to him of God. The highest science was theology, in which man reflected upon his place before His Creator and Redeemer in the light of the truth revealed by God Himself. Philosophy was the handmaid of theology.

Although in this way the light in which the world and the order of nature was viewed differently, the world itself, in its natural order, remained the same as that of the Greeks. This statement is true not only because of the concept of a geocentric universe, but also and especially because of the givenness of the natural order; man had to accept it precisely because the Creator had placed it at his disposal. Throughout this period, as engineers learned more about water wheels, windmills, bridges, etc., they were advancing science and engineering unnoticed.

Sixteenth and Seventeenth Century Philosophies of Nature

The rise of physical science in the sixteenth and seventeenth centuries caused a radical change in the familiar Greek and Medieval philosophies of nature. No longer were the celestial bodies subject to a completely different set of forces than those present in the world or on earth. It was now shown that the mechanics of celestial bodies was also applicable to earthly bodies, and then it became evident that the sun did not revolve around the earth but just the opposite. This was a terrible blow, because it caused the collapse of the trusted old view of nature which was so mixed up with theology. The apparent stable cosmos, built protectively around the earth, the abode of man, was exposed as fiction. The famous Galileo dispute was certainly not only concerned with the question of whether the earth or the sun was the center of the system but with man's place in the universe--a question which is not so very important from the viewpoint of pure physical science. The crucial issue overriding everything else was the place of man in the cosmos (Jeans 1951). From being king of the earth, in the heart of a universe created for his sake, man became the inhabitant of just another planet somewhere in cosmic space, which through an accidental combination of cosmic forces has been rendered suitable as the abode of living beings. Man lost his trusted "natural place" just as the elements of the old world picture, such as fire, water, earth, air, etc., lost theirs.

It was inevitable that these radical changes in the scientific world view would have equally radical consequences for the concept of nature and man's view of nature. Nature no longer was what revealed itself immediately but something which manifested itself only through science. In other words, nature began to lose its formed character to become something elementary which is subject to laws and capable of being given form in a multitude of ways. It became the sum-total of elementary forces in materials. True, nature remained something primordially given, but no longer something that was originally formed; it was now something which could be formed and reorganized in many fashions by virtue of elementary laws. Although nature became predictable in its concrete forms of appearance, it did not yet manifest itself as subject to control. Despite man's familiarity with nature because of its knowability, nature continued at first to impose itself in its totality as something which man was capable of considering and investigating but unable to change.

It was during this period that science took on a new character. With the use of the experimental method (which engineers had used for centuries) it began to use an inductive method of reasoning rather than deductive (Ritchie 1960). With the use of the constantly increasing sophistication of investigating tools such as the telescope, balance, microscope, and other instruments as provided by engineering and technology, the scientific method was born. From the investigation of isolated phenomena in nature the scientist now made broad sweeping generalizations, or laws, about the nature of the world and universe in general. The classical physicist of this period lived in the belief that his theoretical structure of the universe was definitive and therefore put absolute confidence in that view.

The Modern Philosophy of Nature

A conception of nature and of the world presented by modern science differs in two important points from those of classical science. One of these concerns the trust, previously mentioned, placed in the theoretical structure as developed by the scientist and the other concerns the relativity, or the similarity, of scientific models of the universe to the actual universe (van Melsen 1961).

The trust which scientists placed in their theoretical structure of the universe was severely tempted in the twentieth century when it became clear that the traditional models, the particle model and the wave model, were inadequate for the understanding of certain phenomena. Perhaps even worse was the fact that it remained necessary to make use of both of these models. For instance, the wave model had hitherto been satisfactory to explain light, but now the discovery of new properties caused science to make an appeal also to the particle model. The particle model alone, however, was not able to explain all the phenomena of light. Thus, both models had to be retained. The other quandary in which modern science finds itself is the uncertainty of the relativity of its models and consequently also the relativity proper to the view of nature and the world based upon these models. To say it differently, physical science has become aware of the human character of its models. As Heisenberg expresses it, "even in physical science, the object of the research is no longer nature in itself, but nature as exposed to man's questioning, and in this sense man here also encounters again himself" (van Melsen 1961). Also, most scientific philosophers have in the past had an inborn feeling that anyone who really knew enough of the present state of a world or a universe, and what happened to it in the past, could predict what would happen to it in the future. Recently they have been greatly shaken by the discovery of a law of nature, now usually called Heisenberg's Uncertainty Relation which indicates that no one can predict exactly how an electron or any other tiny particle will move if he knows exactly where it is, or conversely can find where such a particle is if he can predict how it is going to move. This has been taken by some as meaning that there is no possibility of predicting the future, but such is not the case. Heisenberg's Law indicates that we cannot predict individual actions on the sub-atomic level as exactly as we thought, and that the very act of making an observation affects any particle we may observe (Harrison 1956). However, Heisenberg's relation may later be found to arise from our present limited understanding of quantum phenomenon and, in any case, that has to do only with individual actions on a very minute scale. In terms of the statistics governing the behavior of millions of particles there is much that can be predicted from the vantage point of man. Also, the "chance" that something will happen one way or the other can be predicted.

Philosophy of Science

Up to this point only the philosophical views of nature have been considered, and these views will be used subsequently to show how the philosophy of engineering differs radically in the view of nature. However, in order to understand the philosophy of engineering, the general philosophy of science must also be considered. This is particularly applicable since engineering, in applying more and more scientific concepts, should also accept the philosophy of science and the scientific method as one beginning point.

(However, it might be stated that the unwritten philosophy of engineering which has guided the engineer throughout history may have predated the philosophy of science.)

The philosophy of science has been the subject of many books and articles and is extremely difficult to summarize in a few words. In attempting to simplify the subject, one writer, who represents a predominant modern school of thought on the subject, states that an understanding of scientific theory is, in essence, an understanding of the philosophy of science (Bergmann 1957). In describing scientific theory he states:

> One might say that a theory is a group of laws deductively connected. More accurately, a theory is a group of laws, usually rather few, from which others, usually a large number, have actually been deduced and from which one expects to deduce still further ones. The laws that serve as the premises of these deductions are called the *axioms* of the theory; those which appear as conclusions are called its *theorems*. Given a group of laws, there is sometimes more than one way of selecting a sub-group so that all others in the group follow deductively from those of the sub-group. This shows that to call a law either an axiom or a theorem is not to say anything about the law itself; it merely says something about its position in a theory. The descriptive words that occur in the propositions of a theory may be called its vocabulary. . . . A scientific theory consists of (1) axioms, (2) definitions, (3) theorems, and (4) the proof of these theorems.

Bergmann then uses this basic set of criteria to develop the axiomatic system of scientific theory. In discussing the axioms, which form the basis of the axiomatic system, Caws (1965) describes them in the following way:

> In particular, if any sentence can be inferred from another, only the latter can be an axiom because axioms have the property which before we attributed to hypotheses: they cannot be arrived at by any chain of logical inferences but constitute the starting points of such chains. Since they stand at the

same uncomfortable isolation as hypotheses, we wish to have as few of them as possible. It is a matter of choice how many axioms one has, but they have to fulfill two conditions if they are to lead to a useful calculus: they must be independent, that is, none of them must be able to be inferred from any of the others; and they must be consistant, that is, no contradictions must follow from using them together.

Thus, the philosophy of science is, in general, a description of scientific theory as an axiomatic system consisting of axiomatic statements (which may well be unproveable) and the logical deductions there from, this theory not being true or false, but merely useful, and subject to change when a different set of axioms explains more things or explains things better. Bergmann goes on to state the usefulness of scientific theory in the following manner:

> As a science develops, a store of laws and concepts accummulates together with an awareness of some connections, deductive among the laws, definitional among the concepts. At a certain point in the development it pays to arrange this material into a theory. The advantages are of two kinds. Positively, one will then know, accurately and as one could not possibly know otherwise, what depends upon what and how and why. Also, a theory guides the search for new laws and for new significant definitions. . . . Negatively, one's attention will be drawn to what has either been overlooked or taken for granted, either by way of premises or by way of definitions. Thus past errors and ambiguities or simply gaps may be discovered; future ones may be avoided. Euclid was the first to do this sort of thing when he axiomatized the geometrical knowledge of his time. If one wants to take all possible precautions that nothing has been overlooked or taken for granted so that the deductive structure is completely tight, one may sometimes with profit proceed formally or formalize the theory by replacing all descriptive words with letter symbols. This Euclid did not do; and he did, in fact, overlook a few things.

The above illustrates the pragmatic nature of the philosophy of science. The scientist begins with as few axioms as possible, tests them against one another, and proceeds in a deductive manner to develop a scientific theory which, in most cases, he either affirms or reputes by means of experimentation since axioms are made up to explain old observations. If the experimentation irrefutably denies the theory, and the deductive process contains no errors, the scientist then denies one or more of his fundamental axioms and pragmatically replaces it with another. As will be seen later, this pragmatic view fits the engineer's needs perfectly. If the "comprehensive" theory cannot explain things well enough he can go on using his approximate methods for solutions until an adequate "comprehensive" theory is developed.

The Philosophy of Engineering

In viewing nature, despite their many differences, the various philosophies of the preceding sections had a common feature in their contemplative character: these views were primarily cognitive pictures. They belong to the realm of theoretical knowledge. In the planning of such a philosophy man aimed at arriving at an understanding of nature as nature essentially was. This contemplative character of nature was, of course, connected with the classical and ancient conception of science. The meaning of science was not sought in its possible application, but science was pursued for its own sake, for the sake of the enrichment and spiritual satisfaction that was offered man in his search for understanding.

Only recently has man, in general, begun to look at nature in a different way. No longer is man content to accept the cosmos as something like an object to be studied, but just as much as something of which man actually takes possession. The scientific philosophies of nature have provided man only with an extremely limited range of possibilities of material development, because these possibilities did not extend beyond that which nature placed at his disposal. The engineer, on the other hand, views nature as something which he can alter to his satisfaction as he has done in the past and will be able to do increasingly more so in the future.

The engineer has always viewed nature as workable, but this workability did not apply to nature as a whole but only to those aspects of it which, one could rightly say, invited man to utilize them. The soil, for instance, invited him to till it and to make use of its natural fertility. Cleavable rock indicated the most obvious way of using it for making tools. Spontaneous fires showed man how to utilize fire to satisfy his need for light and heat. Soft stone bluffs invited him to construct a cave dwelling. The experience of strong river currents pointed the way to the building of water wheels. The same applied to windmills, as well as to the use of the muscular power of animal and man. Briefly put, prior to the last 200 years, man made use of the materials that nature invitingly placed at his disposal, such as stones, skins, wood and many others. In working them, he made use again of the forces indicated by nature itself such as muscular power, water power and wind power.

But with the increasing sophistication of scientific knowledge and its availability for engineering and technological applications, the engineer has gone beyond the materials and forces indicated by nature. With the discovery of nuclear energy, man has at his disposal energy which is almost unlimited and, thinks to the possibilities of transforming elements into new elements through nuclear reaction, he has likewise an enormous supply of raw materials. In principle, every kind of matter is now usable either as a raw material or as a source of energy. In this way nature has become more than ever a source of available material which can be changed into everything. It has ceased to be a fixed order of natural formations. Through the apparently fixed order of nature, the engineer sees an unlimited field of possibilities based upon the fundamental forces of nature. Nature is no longer for him the Mother Nature or the Deified Nature which produces him and provides him with the necessary conditions of life, but has become a kind of warehouse, filled with the neutral raw materials needed for the creations of man. Nature has ceased to be a naturally formed world in which man finds his dwelling. It has become available matter which man can transform at will.

At the present, the engineer's alteration of nature takes place mostly in the reorganization of crystalline and molecular structures. Instead of using the materials with which nature has provided him, such as stone, natural metals, animal fibers and others, he creates new materials which have the properties he desires. These include the new metallic alloys of which thousands exist, and the broad spectrum of new synthetic materials constantly being developed in the chemical laboratory. He also is beginning to change atomic structure itself, creating new elements which in the future may have significant use for the needs of man. And, as has been pointed out, the advent of nuclear power gives him an almost unlimited source of power for the technological future.

Throughout his history, before the advent of useable scientific theories as well as for a time after their development and even now the engineer has appeared to be guided by an unwritten philosophy very much akin to the pragmatic philosophy of science. Although his view of nature has always been somewhat different than that of the philosopher or scientist, the engineer has always been a pragmatist similar to the modern scientist. He has used his "axioms" extending their usefulness into the realm of the unknown (for example, extending the use of the true arch used on simple structures to the construction of the medieval cathedrals), discarding them and substituting new ones when they fail to be of use. Even in the present day, our scientific knowledge, theories, mathematics and logic cannot come even close to explaining many things we do or need to know (for example, turbulent flow). Therefore the engineer uses all kinds of little restricted, often ill-expressed, theories--bits and pieces explaining this and that, approximations tied to experience and judicious reasoning.

Thus the engineer goes about his work as a problem solver guided by an unwritten pragmatic philosophy which allows him to use the carefully developed theories of former engineers and scientists, extending them and filling their gaps with his ingenuity, inventiveness and judgment, all the while viewing nature as something, not preordained, but which can be altered for the benefit of man. Not only does he view nature and its resources as workable but also as something to be conserved and not wasted. There have been violations of this philosophy in the past (for example, ruined forests, strip mining, pollution, etc.) but, in general, these have not been engineering decisions but decisions by others based often on the profit motive. In the conservation of resources, the philosophy of engineering does not ascribe to hoarding of scarce resources, rather he develops a substitute, for example, nuclear energy to replace rapidly depleting organic fuels, synthetic fibers for animal fibers, and synthetic rubber for natural rubber.

Of course, not all advances have been used for the benefit of man. Arguments rage as to whether or not the atomic bomb has actually benefited man. However, we must return to the fact that engineering, itself, is essentially amoral and that only through the engineer and his social consciousness can its results be used for the benefit of man. Similar concerns have been raised concerning the long-range detrimental effects of public health and infant care, which state that the population explosion and its effect on food supply will ultimately lead to starvation.

ENGINEERING AND SOCIETY

Underlying the brief look at history as outlined previously is a constant implication of the tremendous influence which engineering has exerted on society down through the ages. This influence has been felt by all aspects of society, including government, politics, peace, war, transportation, communications, art, science, philosophy, education, and life itself. The counter influence of society upon engineering can also be demonstrated in the demands made upon engineering.

One of the simplest examples of the engineering influence on society is in the protection of man from his environment, by altering the form of nature itself. Prehistoric man took animal skins and after treating them was able to make clothing and bedding. From that time on man has used many natural fibers in the construction of his clothing for warmth including animal and vegetable fibers, such as wool and cotton. Modern man now creates his own fibers to give him protection from the cold and from the moisture of nature. Prehistoric man dug into the soft bluffs to create caves to protect him from weather. From his time on, men have used a variety of natural materials to create dwelling for this same purpose. Modern man has improved upon this situation to create an artificial environment within his dwelling so that if the temperature outside is too cold, he heats the house; if the temperature is too hot, he refrigerates it; if the humidity outside is not at an optimum level he adjusts it. This creation of an artificial and optimum environment for man will soon be used under the most adverse conditions. Plans have been drawn for entire cities in the Arctic areas to be housed under a very large dome, while other plans have been made to create artifical environments underneath the sea, out in space and as colonies on other planets. Major steps have also been made in the protection of man from his environment in the development of drugs and better foods.

Two of the most important developments of engineering and technology so far as society is concerned is the increased ability of transportation and communications (Scientific American 1963). In the past two hundred years transport has expanded and has been accelerated to meet industrial and social needs, and in the process of satisfying these needs it has created others, requiring further developments in transport. New industries have therefore been stimulated, and ordinary men and women have acquired a degree of mobility undreamed of in previous generations. Improved transport has played its part in the increased production, increased wealth and high standard living of the modern industrial society. The transport revolution, moreover, is by no means at an end. So tremendous has been the progress of technology in the field of transport that in the mid-twentieth century, man has been able to stand on the threshold of space itself and to plan its exploration. Meanwhile, the development of supersonic flight, atomic power units and such ingenious inventions as the hovercraft and the VTOL (Vertical Takeoff and Landing) plane, hold out a promise of further spectacular advances in man's means of self-transportation in the coming decades.

In the field of communications, the last two hundred years have seen a complete transformation. Prior to this, although better roads and the stage coach had brought an improvement in postal services, the only efficient means of communication remained as it had always been, by direct man-to-man contact. Since then, rapidly increasing technical competence has brought a tremendous growth in the output of the printing presses, the introduction of the photographic process, the coming of instantaneous communications through the electric telegraph and telephone, and the growth of the modern mass media of communication in the shape of radio and television. The improved means of communications have influenced society in many ways, two of which are of principal concern to society itself, the growth of public opinion and the impact of mass media.

Public opinion is of great importance in any democratic society. It represents a consensus of feeling among the predominant part of the society and implies a measure of participation by all members of the society in the process of decision making. It is obviously not appropriate to speak of public opinion in a dictatorial society in which the bulk of the members are never consulted on any matter of public policy, or is it appropriate in a society which does not possess the means of communications whereby such public opinion can be formulated and expressed. By making available the means of easy and rapid communications, through newspapers, books and magazines and through the telephone and broadcasting, modern technology has thus made an outstanding contribution to the development of a genuine body of public opinion.

The other principal social impact of increased communications, that of mass media, has a history which is both good and bad. Experience in Europe before and during World War II demonstrated the power of the radio as a means of mass persuasion in political propaganda, while experience of commercial television advertising has shown how the clever use of this media can be used to stimulate the demand for consumer goods. The impact of the mass media, however, is not limited to the influences of such questionable value and morality as these. They have also performed a function of great social value in disseminating a common culture which has immediately enriched the imaginative experience of those to whom it has been communicated. Whether or not the tendency of this culture is towards leveling down and standardization is a matter of contemporary debate. Whatever the conclusion, there can be no legitimate doubt that for many people previously cut-off from the metropolitan sources of cultural activity, radio and television have added enormously to the variety and quality of their entertainment. Thus the new forms of mass media have provided the most far-reaching means for the communication of all sorts of educational and cultural influences.

As has been mentioned before, not only has engineering exerted an influence on society but society an influence on engineering itself. This latter influence is exerted in two different ways, one as a demand for engineering end-products not presently available and the other as a dampening effect on engineering possibilities. The first influence has been documented in previous chapters in that society has, in different periods, demanded of engineers certain accomplishments, such as increased power, a bridge across a certain river or a defense against atomic attack by foreign missiles.

In regard to the dampening effect of society, it can be said that no engineering innovation can become established in a society without the conjunction of certain factors such as social need and social resources (Allen 1957). To say that innovation depends on social needs is to say that no innovation can hope for success unless it meets a genuine demand. This might take many forms, such as a demand for a new prime mover arising from a shortage of the conventional fuel, or the demand for a machine raising output in order to remove a particular bottleneck in a manufacturing process. Alternatively, the demand might arise from a rapidly expanding market or from a shortage of labor. One way or the other, there must be a consciously felt need for an innovation before it can hope to find a sponsor to develop and apply it. Many inventions of undoubted brilliance and ingenuity have failed to gain acceptance because they have met no specific social need. In our own time, the development of the hovercraft seems to be delayed precisely because of the hesitance of potential users about its superiority over, or competitiveness with, alternative means of transport.

Many innovations have failed also because they require social resources for their development beyond the capacity of the society in which they are conceived. The two major resources are capital and "know-how". A modern skyscraper or jetliner can only be constructed in societies such as our own in which an immense amount of wealth is available for such enterprises and in which the technological knowledge and equipment can be provided. Inventors since Leonardo da Vinci have often been unable to fulfill a design which was workable on paper because of defective materials, lack of tools and other engineering resources. Watt's first steam engine almost came to grief because of the inadequate workmanship of the craftsman engaged in its construction. Other inovations may be held back by the manufacturer because of the lack of profit when compared to an existing product.

In the modern technological society, engineering and technology have had a profound effect upon the composition and way of life of the population. A number of examples will be used to indicate this influence. In the first place, it has produced an enormous growth of population so that the physical pressure of an increasing number of mouths to feed has been a constant incentive to raise productivity. Secondly, the increased population has not been spread evenly across the country but has been concentrated in towns and cities. Increased technology has also exerted a significant influence on the standard of living, causing some critics to be concerned regarding the standardization and uniform nature of modern society. Although engineering and technology has exerted an influence on all aspects of society, two aspects which are significantly influenced are education and government.

The Growth of Population

Although census figures have been scattered and somewhat inaccurate throughout recorded history, they do indicate a gradually increasing world population growth. With the advent of official census figures in many countries during the nineteenth century, this growth was documented and its geometric trend affirmed. For instance, England had a population of nine million in 1800, eighteen million in 1850, 32 million in 1900 and 46 million in 1960. Similar figures for the United States indicate a population in 1800 of 5 million, of 23 million in 1850, 76 million in 1900 and 179 million in 1960 (World Almanac 1966). Although the figures for the United States also include a considerable immigration, nonetheless they do indicate the dramatic increase in world population. This continuing increase in population is undoubtedly one of the most important social facts of the modern industrial society. The first attempts to explain it attributed it to an increase in the birth rate. Although there is some evidence of a slight increase in the early stages of the Industrial Revolution, the birthrate actually remained fairly stable at about 35 per thousand of the population throughout the last three-quarters of the nineteenth century, after which it began to fall with the increasing practice of birth control and the custom of having smaller families (Buchanan 1965). It dropped to about 15 per thousand in 1938, rose to 18 per thousand in the years immediately following World War II and then dropped again to 15 per thousand in the mid 1950's. Since 1955 the birthrate has been gradually rising again to an estimated 18 per thousand in 1962.

Since the increased population cannot therefore be attributed to an increase in the birthrate there is now a fairly general agreement that the expansion of the population during the last two hundred years has been due primarily to a fall in the death rate. This has been estimated at about 36 per thousand in the middle of the eighteenth century, 21 per thousand by 1820 and is calculated at about 11 or 12 per thousand during the last 10 years (Buchanan 1965). From this leveling off of the birthrate and a falling figure in the death rate, an increase in the expectancy of life and thus a rise in the population can be anticipated. In human terms, it has been estimated that whereas the expectancy of life in the Bronze Age was about 20 years, this had lengthened to about 35 by the middle of the eighteenth century and has almost doubled to about 70 in our own time. In this century the average length of life in the United States has increased from 47.3 years in 1900 to 59.0 in 1925, 68.2 in 1950 and 70.2 in 1964 (World Almanac 1966). Thus, to explain the increasing population one must look to the causes for the decline in the death rate. These causes may be summarized under four headings: diet, medical knowledge, personal hygiene and public health. Although technology has been instrumental in all four of these areas, engineering has been involved in the first and last, while medical technology, primarily, in the other two.

One of the most important factors in improving the health of the population, thus enabling people to live longer, has been the rise in the quantity, quality and variety of food. During the last two hundred years there have been significant advances in all these respects, due to the technological improvements in farming techniques, the development of food processing, food preservation and transportation. Improvements in farming include improved cultivation methods, better drainage, irrigation, extensive use of artificial fertilizers and farm mechanization. Food processing has become almost completely mechanized and food spoilage reduced to a minimum with the improved methods of food preservation created by the engineer. These include various types of food canning processes, refrigeration and refrigerated transportation, dehydration and deep freezing.

In the field of public health the engineer has made a significant contribution to society. Problems of disease have always been increased when people have settled in large communities, and the new towns which sprang up during the eighteenth and nineteenth centuries were no exceptions. Lacking proper facilities for the provision of pure water and the removal of organic wastes they provided the unsanitary conditions on which typhus and the other fever diseases thrived. Since that time engineers have improved upon water treatment and distribution systems, sewage collection and sewage treatment systems. To cite one example, deaths from typhoid fever in the large cities in the United States dropped from 24.5 per hundred thousand in 1910 to 0.2 per hundred thousand in 1945--a 99% reduction (Kirby et al 1956). Moreover, 1945 was before the discovery of a specific and effective curative treatment of the disease. In other words, this remarkable mortality reduction was due almost entirely to the advances in the preventive methods consisting largely of the purification of water. Although, in this case, engineering was almost solely responsible for an improvement in public health, many others, together with engineers, have contributed to rising standards of health in the development of such things as drugs, instruments and X-rays.

Urban Growth

Prior to the eighteenth and nineteenth centuries, very little of the world population was concentrated in urban area. With the advent of the Industrial Revolution, however, cities began to grow around the developing industries, located through their convenience of access to raw material or coal, or because they were well placed in transportation networks. As the industrial society continued to develop and urbanization became more marked, increasing percentages of the world population began to be concentrated in the urban areas rather than in rural areas. Engineering, by influencing the industrialization of the society, has been a principle stimulus to this urbanization and continues to influence it by making feasible television and high rise buildings, transportation services, water supplies, lighting, sanitation, building elevators and new sources of power.

Technology has even been involved in the growth of the suburbs in urban areas by providing the transportation facilities, telephone, radio, television and other innovations. Given these, people are disposed to move farther and farther away from the congestion of the center of cities (Young 1947). This does not indicate a reversal of the trend toward urbanization but rather a spreading outward of urbanized areas and an increasing concentration of population in cities.

Standard of Living

In consideration of the standard of living of the modern industrialized societies, engineering has certainly been one of the major contributors to man's material welfare. Few people in western societies would elect to revert to the physical hardships of the middle ages or even to those of the mid-nineteenth century with its endemic intestinal diseases, its lack of widely available power, its 70-hour work week and its low average earned income (Rapport and Wright 1963). Improvement and prosperity in general health have been dramatic in recent decades. Power, machines and automatic controls have made possible a reduction in the average number of hours worked per week. Not long ago a 60-hour week was standard for most workers and many worked 12 hours a day for 6 or 7 days a week. In the United States the normal present work week is five days, which gives two days of leisure each week. Two or three paid vacation weeks are not uncommon. This increase in the individual worker's output capacity has been made possible by control of mechanical power and has given him more hours of leisure to say nothing of the remarkable improvement in the standard of living. The average housewife in the United States has at her disposal, in terms of her small appliances, the equivalent of 33 slaves. Thus, even if slavery were socially acceptable today, it would have been abolished by engineering and technology since it would be too costly to feed that number of human beings even with a minimum diet.

Despite the comfortable standard of living enjoyed by many in western society and the real social progress promoted by modern technology, certain qualifications should be made. In the first place, it must be noted that the Social Revolution is by no means complete. A sizable minority of the population in western society still live in slums or sub-standard houses. Moreover, the majority of the world population has been unaffected by the rising standard of living afforded by the industrialization of the rest of society. As C. P. Snow indicates (1963): "In the rich countries people are living longer, eating better, working less. In a poor country, like India, the expectation of life is less than half of what it is in England. There is some evidence that Indians and other Asians are eating less, in absolute quantities, than they were a generation ago". Dr. Snow goes on to state that we presently have the technological know-how and resources to raise the standard of living of the entire world to the norm of that of western society. This can be accomplished, not by dividing up present material possessions of the world, but by assisting emerging nations in duplicating the history of the wealthy nations, but at an accelerated rate.

Another aspect of engineering and its influence on society which has been constantly illustrated has been that investment in an engineering device, structure or product, which by being more efficient, pays for itself, and in many instances pays for itself and the device it made obsolete.

Fears of Technology

Although many writers have written about engineering and technology and their beneficial effect on society, several have expressed grave concerns about the detrimental effects of engineering and technology (Spengler 1932, Mumford 1934 and Juenger 1956). Mumford (1934) lists three negative aspects of the influence of engineering and technology on society. These three are the mechanical routine, purposeless materialism and uniformity, standardization and replaceability.

In discussing the mechanical routine, Mumford enlarges upon his statement that the clock was the most influencial invention of all times. He states:

> The first characteristic of modern machine civilization is its temporal regularity. From the moment of waking, the rhythm of the day is punctuated by the clock. Irrespective of strain or fatigue, despite reluctance or apathy, the household rises close to its set hour. Tardiness in rising is penalized by extra haste in eating breakfast or in walking to catch the train: in the long run, it may even mean the loss of a job or of advancement in business. Breakfast, lunch, dinner, occur at regular hours and are of definitely limited duration: a million people perform these functions within a very narrow band of time and only minor provisions are made for those who would have food outside this regular schedule. As the scale of industrial organization grows, the punctuality and the regularity of the mechanical regime tend to increase with it: the time clock enters automatically to regulate the entrance and exit of the worker, while an irregular worker--tempted by the trout in spring streams or ducks on salt meadows--finds that these impulses are as unfavorably treated as habitual drunkeness: if he would retain them, he must remain attached to the less routinized provinces of agriculture.

In terms of purposeless materialism, Mumford states:

> There is a disproportionate emphasis on the physical means of living: people sacrifice time and present enjoyments in order that they acquire a greater abundance of physical means; for there is supposed to be a close relation between well-being and the number of bath tubs, motor cars, and similar machine-made products that one may possess. . . .Its particular defect is that it casts a shadow of reproach upon all the non-material interests and occupations of mankind: in particular, it condemns liberal esthetic and intellectual interests because 'they serve no useful purpose'.

Of course, in extending this concept to the above extreme, Mumford does not sufficiently recognize that, unless one is assured of the basic minimums of food, shelter and clothing, which many in the world today are denied, that more ideal pursuits in life are not possible. And even though a few are paranoic about positions and power, this is not true of the general population.

The third important characteristic of the machine process and machine environment according to Mumford, is uniformity, standardization and replaceability. Whereas handicraft by the very nature of human work, exhibits constant variations and adaptations and boasts of the fact that no two products are alike, machine work has just the opposite characteristic: it prides itself on the fact that the millionth automobile built to a specific pattern is exactly like the first. Thus the machine has replaced an unlimited series of variables with a limited number of constants. (Of course, Mumford does not imply that hand-ground corn is superior to machine grown corn.) Although Mumford does not carry this characteristic across to the human being, other writers do and concern themselves with the uniformity and standardization of human behavior.

One writer states that, "One of the most serious reproaches addressed to technology is that it levels man and reduces mankind to an anonymous mass. Technology seems to disown even the way in which nature itself works with its elements. Nature manages to endow everything with something special to it, technology wants to standardize everything" (van Melsen 1961). The old technical product resulted from the labor of the single man and thus expressed something of his own personal being and his personality. The machine-made object, on the other hand, results from the pre-calculated collaboration of many and merely expresses a function. The leveling influence of technology makes itself felt not only in the manufacturing of products but perhaps even more in their use. In principle, everyone drives the same car, (albeit, instead of walking) which is, in general, powered the same way, controlled the same way and travels along the same kind of road. The reason for the various types of cars lies in competitive considerations rather than in the nature of the car itself. Everyone watches the same television program or listens to the same music on the radio. The programs are standardized, atuned to the average taste, just as technology atunes its entire production to the average consumer, neatly divided perhaps into a few price classes and standard wishes.

According to this group of writers, this tendency to standardize mass products is not limited to material goods, but extends to the whole of life. Man's entire life is becoming standardized to the point where the technological order absorbs everything. Education, for instance, is affected. Certificates and diplomas have to be standardized, because man has to be certain that their bearers fit exactly into the interlocking wheels of the technological order, just as the spare parts of an engine have to be exactly according to standard. Cultural differences tend to disappear. With the technological ability to spread a uniform culture, former cultural differences tend to remain alive artificially only as a tourist attraction.

They also assert that housing is becoming standardized. Climatic differences no longer count because engineering eliminates them or reduces them to a minimum. Even in the case of food, technologists determine the most desirable food, and modern preservation and transportation make this food, in principle, available all over the world. (Is this bad when the major diet of most of the world before the advent of food technology was beans and rice?)

Summarizing these considerations of the dangers contained in technology, we may say that they possibly constitute an impressive indictment, even if here or there it contains a certain amount of exaggeration. Modern technology, the indictment states, leads to dehumanized materialism, unnaturalness and general leveling of man. It dehumanizes because technology becomes the norm and man is made sub-servient to it. It leads to materialism, because man's entire attention goes out to matter and to controlling matter in such an intense fashion that there remains no room for the things of the spirit, for reflection and contemplation. It leads to unnaturalness and general leveling, because it undermines the natural basis of culture and thus produces a kind of uniformity which restricts man's personality and reduces him to an anonymous entity. It remains, however, to look at the future of engineering and technology to see whether these claims of the dangers are reality, myth, a result of a primitive stage in the development of technology, or comparison to some vague utopia--that in reality, might not be so nice at all.

An Answer

We have quoted several writers who have expressed grave concern regarding the tendency of technology to increasingly standardize life. However, these writers have failed to take into account the species-individual, or unique, structure of matter and, in particular, that of human life. Some of these writers, in describing the glories of past life, fail to realize that the life of the caveman was not very pleasant, neither was that of the slave or serf. In fact, even if they were allowed to be a member of royal society of 200 years ago, after careful thought would reject it for their present and future life. It could be said that the Heisenberg Uncertainty Relation could very definitely be applied to the individial human being, inasmuch as the prediction of individual human behavior, does not appear to be on the horizon. In contrast, any mechanically produced object owes its origin to the constant, exact repetition of certain operations. By virtue of its deterministic way of working, which cannot make any contribution of its own, but is wholly dependent upon on the specific arrangements embodied in its construction, the machine cannot do anything else than repeat the same action over and over again. The entire modern technological order shares in this typical character of mechanical production because, if man is to profit from machines, he has to adapt himself to their ways of operating, thus man's activity is likewise reduced to constantly repeated manipulations. And it is from this that the critics infer that the leveling influence of the technical order may appear to be imbedded in its very essence and consequently inescapable.

These writers fail to take into account the very factors which make technological uniformity necessary. One of these factors is the primitive condition in which technology presently exists, modern technology being measured in terms of decades rather than centuries. Even in countries, like the United States, in which technology has made the greatest progress and in which practically everyone enjoys a fairly decent standard of living, this happy condition has come about in the lifetime of a single generation. Another factor necessitating uniformity in technology is caused by the limited economic possibilities, based on an economy of scarcity rather than abundance. A last factor is that because of its recent origin, it tends to replace many other forms of human activity and, in doing so, technology is not unique since this is a natural social phenomenon. Of course, machine production will always remain based upon repetition, because its very essence implies this, but this repetition allows many more possibilities than are being exploited at the present. If, in a given area, only one television program can be received, all viewers are forced to watch the same average show; but it would not do to claim that this situation is an essential consequence of television as a means of communication.

Thus, as technology moves from its present primitive form into that of the future its leveling influences will be minimized, for as soon as the first necessities are satisfied it becomes possible, thanks in part to technological progress, to produce many small series of objects and to embody in each of them original artistic ideas.

Moreover, the constant shortening of the time required for making a living can contribute to a renewed bloom of all kinds of work which demands personal care and love and which have been neglected in the first stages of technology and its leveling influence. It could very well be that such work would be undertaken as "liberal arts", i.e., as work of human beings who have been liberated by technology.

However, it could easily happen that the results of engineering and technology would become wholly different from what at first sight should be expected. A large part of man's activity has hitherto always been spent in constant hard labor, hard because it demanded much exertion, but also and especially, because for the majority of mankind it had to be repeated every day in exactly the same fashion. Technology not only removes this physical exertion but also takes care of what is routine-like and automatic, and this is at least just as important. Routine operations can be more and more left to genuine automatons. Thus modern technology creates room for man's creative activity in all realms, to such an extent that its original seemingly leveling influence could easily change into actually the opposite. In other words, if at first the influence of technology tended to level man and to make him superficial, the reason for this must be sought in the fact that because of its imperfect state of development, technology has had to use man unduly as an automaton.

Thus it can be shown that engineering and technology can create in the future, contrary to dire warnings of increased automation of life, a future full of promise and prospect for the species-individual nature of the human race. Man has always adjusted to his environment down through the ages without loss of identity and there is no reason to suspect that he will not be able to adjust to the technological present and future and still retain his individuality.

THE FUTURE

One of the certainties of the future is that there will be technological change, and corresponding social change, and that it will occur at an ever increasing pace. Every new scientific discovery spawns several other scientific discoveries as well as a number of engineering applications. Every new engineering application promotes several other applications and thus technological change tends to proceed at a logarithmic, or geometric, rate. As has been shown in the last chapter, the increasing engineering activity has not only solved many of society's problems but has also created new ones in the process and herein lies the challenge of the future; if the engineer can help create the complex technological society in the present, can he not also use his methods and tools to solve the problems created by it?

Challenge of the Future

Recently, an engineer in Phoenix, Arizona, signed up for home computer service as an experiment, in which a teletypewriter connected to an electronic computer in Phoenix was used to see whether the placing of a computer in the home was a feasible possibility (Furnas and McCarthy 1966). He used it to figure out his income tax return, check household bills and reconcile his bank account and also to calculate complex engineering problems when he brought home work at night. His wife used it for such problems as converting a recipe for six people into one for eleven dinner guests and for guidance in cutting and sewing intricately patterned material for living room draperies. His children used it to practice their arithmetic and even to match wits against the machine in games of tic-tac-toe. By the twenty-first century, hardly more than a generation away, computer service may be so inexpensive and easy to use that it will become as common in the American home as electricity, gas, the telephone and running water. This one result of the engineer's work could make a vast change in our way of life: any child no matter where he lived, could draw upon the educational resources of the world for his education; business executives could base decisions on more accurate information literally at their finger tips, and some people might prefer to work at home without commuting.

The various aspects of social change as noted in the previous chapter, those of increased population and urban growth will continue on into the future. There will be far more people (a prediction for the year 2000 indicates that the world population will be nearly 7 billion) and far more of them will dwell in cities. These enormous cities will stretch horizontally for miles besides parks and playing fields, with various sections rising vertically, set on stilts high above grass and shrubs. Accompanying this unprecedented growth of urban society and population will be the same problems which confront society today yet on a much vaster scope. People will require considerably more food, materials, equipment, supplies, power and entertainment. People will demand not only new kinds of housing, but also improved transportation, varied and extensive education for both children and adults, clean air and water and occasional respite in an accessible, unspoiled countryside from the technology-orientated lives of Megalopolis.

Many of these problems which will be presented to the engineer of the future will be similar to those of the past. It has always been the engineer's task to exploit nature economically in order to satisfy the material needs of his society. He has mined the minerals, constructed the buildings, laid out the transportation systems and protected man from his environment. He will continue to do these tasks, possibly in different ways. But now he is being asked to solve a new and more formidable class of problems, those of man's relationship to his fellow man. If the engineer can erect great cities, can he help control the crime that may plague them? Can he help provide the higher levels of education needed to sustain them? If he can help bring the high standard of living now enjoyed in western society, can he also assist in the spreading of that standard of living to all peoples on the earth? The engineer is being asked to solve these broader problems now, for the first time, because his tools and methods seem suited to them and/or, possibly, because others have failed and now turn to him. In the modern computer he has a tool that can calculate answers to questions involving a great number of varying factors, typical of most human questions. In the technique of systems analysis he has a method that can handle the multiple factors of a problem and categorize them for submission to a computer's unbelievable swiftness in calculating the answers to involved questions. One of the first applications of the social usefulness of systems engineering has been accomplished in an experiment carried out in California. In 1965, Governor Edmond Brown asked engineers in the aerospace industries to focus on four of the state's most pressing political and economic problems, those of transportation, waste and pollution, state and local government information processing and crime prevention. He believed that an engineering method capable of sending an astronaut around the world in 90 minutes should be able to solve the earthly problems of civilization (Furnas and McCarthy 1966).

Although total results are not yet available as a result of these studies, some of the suggestions and predictions resulting from these studies were: tunnels as an alternative to overcrowded and costly highways in urban areas, jet-propelled trains in tunnels, underground pipelines for transportation of consumer goods, atomic power production, and fuel cell power for automobiles.

This is but a start to the broader application of engineering methods and techniques to a broad range of social problems. The problem of the inequality of rich and poor nations is one of several likely to challenge our civilization in the remaining decades of the twentieth century, and will certainly require the services of the engineer in assisting in a solution. This inequality, brought about ostensibly by the modern industrial society, has many facets. First, there is much that we still do not understand about the dynamics of industrialization. We have discovered the means of creating a high-standard of living, but we have also acquired the means of mass destruction. We have gone far toward the conquest of disease, but we have made no corresponding increase in the educational techniques necessary to control the resulting world population explosion. While our engineers and technologists press forward to the exploration of space and the discovery of the life process, we find ourselves still unable to control the impulses of selfishness, greed, and violence, within our society.

In solving the problem of inequality between rich and poor nations, one of the important questions which arises is that of whether or not it is possible to export a western-style industrial revolution to the underdeveloped countries. Looking into the past at the early phases of industrialization in the west it appears that population was limited by restrictions on marriage until economic growth was well established, by which time increasing populations acted as a stimulus to further growth and technological innovation. In the present underdeveloped parts of the world, on the other hand, medical and technological advances have caused a tremendous increase in population by reducing mortality rates, without a corresponding increase in industrialization. Moreover, with the pressure of population on available resources, preventing capital accumulation, and with the strong traditional conservatism of eastern cultures, it is almost impossible for a process of economic growth on the western pattern to begin (Buchanan 1965). The challenge here, therefore, is one of finding ways of raising standards of living without a complete upheaval of existing social structures.

World peace is another challenge of the future, not just in this decade or in the next, but in perpetuity. When it is recalled that men have rarely, if ever, lived together for a generation without fighting each other, this task seems particularly overwhelming.

In the current situation, where nation states are now joined in huge power-blocks, the possibility of war breaking out between rival groups or nations remains a serious danger to world peace, particularly since modern technology has enormously enhanced the striking power of these nations. Serious thought and tentative experiments have been conducted in the creation of effective international authorities leading ultimately to a genuine world government. Modern technology has largely removed the difficulties of administering such a world state, and, in fact, has done much to make it necessary. In addition, modern and future methods of surveillance have tremendous implications for peace.

Thus it appears that the challenge of the future moves more from the level of material achievements to problems of value and morality. Engineering and technology have enabled industrial society to make tremendous material progress, in terms of a high standard of living. But technology cannot supply the total answer, for technology is essentially amoral, a thing apart from values, a instrument which can be used for good or ill. The ultimate challenge to our civilization is that of using the vast achievements and resources of technology for the extension of a society which is good and wholesome rather than as a means for self-destruction.

In looking to the future promises and propects of engineering and technology, there are a large number of predictions which can be made with a fair degree of certainity. Many of these are presently in the stage of research and development but others go beyond that stage and can still be predicted based upon the direction of our scientific and engineering advances during the last 50 years.

Future Engineering Contributions to Society

Among the possible future engineering contributions to society are solutions to problems of enormous and complicated scope as well as rather mundane ones which have perplexed man for some time. A random sampling of these contributions would include:

1. World wide information system that will store all general knowledge, provide for information exchange between interested parties and provide quick access when inquiry is made about any subject. When new knowledge is added, this system will automatically distribute this knowledge to all participants who have registered a previous interest in that type of information. It will also translate requested information to the requestor's native tongue.
2. A solution to the permafrost problem. Approximately 20% of the earth's top crust is permanently frozen, sometimes to a depth of hundreds of feet. Permafrost problems are usually associated with heat exchange, of protecting the environment from man, rather than man from the environment. Heat from pipes, houses, and highways tends to melt the permafrost and reduce its stability.
3. Future space travel. Programs already outlined include manned vehicles traveling to the moon and unmanned reconnaissance of Mars and Venus. Farther into the future are manned travel and colonization of other celestial bodies.

4. Uses of atomic radiation. Research is presently being carried on to utilize irradiation in the sterilization of food stuffs and in eliminating the need of refrigeration for preservation of many perishable foods. In the petroleum industry, irradiation effects on fuels and lubricants hold promise of providing products from crude oil which will have vastly improved properties. Other experimentation has shown that irradiation may change the crystal arrangement in solid materials with an accompanying change in energy. For example, graphite that has been irradiated has been found to burn with a hotter flame.
5. A system of synchronous satellites that will act as a weather observer-reporter, serve as a television-telephone relay medium, provide a detection system for atomic blasts, missile firing and perhaps other military activity, and provide facilities for space research.
6. An air-travel system that enables a traveler to board a vehicle in the heart of a city and does not require him to leave his seat until he reaches the terminal in the center of his destination city.
7. An attachment for the present telephone system that will print a message whether or not someone lifts the receiver.
8. A limited-range, light-weight economical non-air-polluting automobile, especially suited for commuting.

9. A telephone and television combination. This combination, with which one would be able to see as well as hear the person to whom he is talking, is well within the realm of application of present knowledge.
10. A completely automated postal system. In this system, letter mail will be scanned by photocell devices and automatically routed to destinations. Helicopter transport for short distances, airplanes for intermediate distances and rockets for long distances will speed mail from originator to destination in a matter of hours.
11. Computerized banking service which will make money and checks unnecessary. A housewife who wants to pay a bill will dial a code number for the store, another series of numbers representing the amount of the bill and a third number identifying her bank account. Without a word of conversation, the bank's computer will transfer the amount from her account to the account of the store.
12. Increased use of solar energy. Experimentation has shown that it is possible for a field of about 50 acres to provide the energy requirements for a city of ten thousand persons. Improved methods of producing electricity by thermocouples and solar batteries will make this source of energy a reality.
13. Use of nuclear explosion for excavation. Nuclear explosions will be used in the future to perform excavation jobs not presently feasible, such as the creation of certain

harbors and canals. These explosions will also be used to blast the cover from ore deposits and permit strip mining in places where only shaft mining has been practical.

14. Sophisticated diagnostic treatment and instruments. One possibility is a device that will continuously check the insulin level in the body of a diabetic and that will automatically inject the required amount of insulin into the blood stream when replenishment becomes necessary. This device might be attached within the body as an artificial gland.

15. A device that "reads" printed matter and converts it to oral form. This can be very useful to blind persons for educational and recreational purposes, to sick persons and to others.

16. A device which will type directly from voice sounds. In this way an executive may dictate into a machine and receive typed copy automatically.

17. A device for translating messages into various foreign languages.

18. A treatment process for converting sewage and industrial wastes into potable water. This process is now possible and will soon be economically feasible, however, it may wait sometime for social acceptance.

19. A household robot. Housework, and probably baby watching, will be handled in the future by multi-armed computerized

robots. One official said recently that most of the technology for the design of such robots has already been solved (Furnas and McCarthy 1966). This device will run the vacuum cleaner, empty ashtrays, scrub bathroom floors, dump garbage and trash into wall inlets, pick up fallen magazines and newspapers and rearrange disordered furniture with more meticulous efficiency than most human employees.

20. Another Panama Canal. This new canal, now under study, will handle much larger vessels than the present one and may be excavated by nuclear explosives.

21. Water for the Southwest from Alaska. Water from the Yukon River and others may be transported to southwestern United States by means of a canal or an undersea pipeline.

Other predictions which engineering makes for the future are those of optimism for an increasingly controlled universe. The previously limited input into the engineers storehouse of materials and energy, no longer limit the possibilities. It has already been shown that engineers in the future will tap the almost unlimited amount of energy available in the atom and in solar radiation. In the creation of new synthetic materials and in the rearrangement of crystalline and atomic structure of native materials, it appears that the supplies of materials is also unlimited. One author writes, "We need not fear the depletion of our natural resources as long as engineering ingenuity exists...the future of engineering is determined only by the problems to be solved and by the possibilities to be explored" (Leach and Beakley 1960).

It is also becoming increasingly possible, with the use of the computer, to compile a very detailed record of each individual in the society (Gosling 1962). Records of a man's history, medical ailments, law violations and military service, now widely dispersed and generally inaccessible, may be gathered together in one compact and easily available capsule under the computerized record system of a future government. Many critics have been quick to point out the threat of this possibility to personal privacy. Loss of our personal rights, restrictions on our choice of actions, failures of "fool proof" machines are all possibilities in our engineered society.

The engineer recognizes that, in this case as in many others, new problems inevitably accompany every solution to an old problem. The balancing of dangers against benefit has always been his task. He does not forget his ancient predecessor, the first man to build a fire. That unknown genius knew he could get burned, but he also may have realized that he was changing the course of his species toward what would be called civilization. The engineer helped make civilization. He continues to extend it, to make the twentieth century, in the words of the historian Arnold Toynbee, "The first age since the dawn of civilization, some five or six thousand years back, in which people dared to think it practicable to make the benefits of civilization available to the whole human race" (Furnas and McCarthy 1966).

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