Engineering, Civilization, and Society

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In dealing with the subject engineering, civilization, and society, I shall consider only the Western world. The very differences between today's Western world and the early civilizations of the East are striking evidence of the role which engineering has played in forming our civilization and society. In our modern world, engineering is integral to civilization and society. Let us look at the part engineering has played in our world over the years, and at what its role may be in the future.

It is a long way from the original engineering act of the caveman—the rolling of a large rock into the entrance to his cave for a door—to construction of the modern skyscraper. It is an equally long way from the first wheel and axle, which the caveman made by putting a stick into a hollow log, to today's laser. The last 6000 years have shown many major advances, but it is really only very recently that the effect of engineering on our civilization and society has been a major, if not *the* major, factor. In those 6000 years that preceded the harnessing of steam, in 1765, engineering simply served society and had little impact on its evolution. Engineering started by serving government, then served the individualistic community, and now again it is serving government. Let us see how this worked.

The Ancient World

The ancient governments of Babylon and Egypt were monarchies. The function of the engineer in these societies was simply to glorify the monarch and the gods, of which the monarch was one. These civilizations produced the Hanging Gardens and the Pyramids, as well as stone temples. The pyramids have no tension member; no true engineering concepts are involved. They are really just piles of blocks. And the temples, too, are just forests of massive columns, with no tension members. In all these structures everything is in compression. They are expressions in stone of the might of the monarch—monuments to his power to harness the muscles of thousands of men for his own glory, and to command the skill of the engineer. The only useful engineering efforts in these civilizations were directed toward the construction of irrigation systems and the measuring of land for purposes of taxation. Again, these efforts were government-inspired.

Passing on to the Greeks, we find an oligarchy based on slavery. The free men of the ruling class were relatively few, but they had the leisure to enjoy beauty for its own sake. The engineer served this group by constructing temples which achieved greater beauty through the use of a few tension members. He also made possible the famous Greek vase, by developing a superior potter's wheel. The engineer of those days was as much an artist as an engineer and was the forerunner of the architect, who combined engineering and art. In addition to serving as public architect, the Greek engineer served government in time of war. Few of the scientific discoveries of the Greek intellectuals were put to practical use, since slavery provided whatever labor was necessary, and the labor-saving potential of the scientific discoveries was neither looked for nor appreciated. War provided the one motivating force. Greek engineers fashioned ingenious machines — ratchet-equipped catapults and wheeled assault towers pulled by block and tackle—demonstrating the impetus war historically gives to human invention.

The government of Rome, again in essence an oligarchy but one involving much larger numbers, required more services of its engineers. The engineer served government in a slightly more sophisticated, but still a basically very simple, way. He served the government's military and civil requirements. His construction of an adequate system of roads made possible the mobility and intercommunication upon which the military security of the empire depended. Aqueducts made possible the support of the huge urban populations that grew up when people gathered in the cities as the economy became based upon overseas agriculture. And the engineer made it possible for the government to control that enormous urban population by providing great baths, circuses, and coliseums for the entertainment of the people, with their oddly won leisure. These achievements were all based on relatively simple engineering concepts, but the scale of their application was enormously enlarged. The engineer's greatest original contribution here was the Roman arch—again, it may be noted, a compression member. For the most part, Roman engineering provided little that was new in the way of design. Aside from the arch, the Romans' most lasting engineering achievement was conversion of the horizontal water-powered mill, invented by farmers, into the vertical water wheel. This development, which enabled the empire to construct gigantic flour mills to feed the populace, is a typical example of engineering following the needs of society. These mills were devised when the empire was on the decline and slave labor to run the treadmills was no longer easily obtainable.

The Middle Ages and the Renaissance

Almost a thousand years of near-stagnation followed the disintegration of the Roman Empire. During this period the only large engineering works were massive defensive fortifications, castle fortresses, and a few more temples, then called cathedrals. Social organization was for self-protection and involved relatively small numbers; religion was the one unifying factor. The construction of the cathedrals primarily involved refinements on past engineering discoveries; a few new architectural concepts, such as the flying buttress, were added.

Although these years are usually thought to have produced little in the way of engineering achievement by comparison with the accomplishments of the Greeks and the Romans, on the large scale of human history they are seen not only to have surpassed the achievements of earlier millennia but to have presaged later engineering developments. The slow development of

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techniques culminated during the Renaissance in one of the most important engineering feats man has achieved, the printing press.

When the intrepid seafaring traders broke the thrall in which the medieval world had been held, the ensuing prosperity and the greater leisure which the new wealth made possible combined to encourage the arts and to open the minds of men to consideration of the new. The printing press enabled man to communicate in another medium, made knowledge widely available, disseminated new ideas to an ever-widening reading public. The printing press opened the way to the modern world. With it we have the first real impact of engineering on civilization and society. Its engineering required the combination of much hard-won knowledge and many skills—the technologies of paper-making, ink-making, metallurgy, block printing, printing with metal type, and production of the screw press itself. The printing press not only made information available but was itself the first standardized product of machine mass production.

Other improvements in techniques had been made, and other concepts developed, over the course of the long years of apparent somnolence—improvements and concepts which were to be essential to development of our modern technology. These included the concept of the spring pole, used to process ore and to improve the lathe; the crank and connecting rod, used in mill operation; conversion of the rotary motion of the waterwheel to reciprocating motion through the use of cams; and, most significant, development of increasingly intricate clockwork mechanisms. Engineering helped bring about the ending of the era, when the introduction of gunpowder from China brought about a technological concentration on weaponry. The progressive improvement of the cannon meant the end of the castle fortress as a social focal point and a military stronghold.

The Industrial Revolution

With the Industrial Revolution, brought about by the application of steam, the engineer steps to the fore as a causative factor in our civilization. For the first time, thanks to the engineer, power other than muscle-power, wind-power, and water-power was made readily available—enormous power, independent of the mortality of men and of draft animals, the vagaries of wind, and the location of streams and rivers. By the time of the Industrial Revolution, feudalism had given way to a form of democracy. True, many governments still went under the guise of monarchies and many were still expanded oligarchies, but the number of free men who took pride in their status as free human beings had increased explosively. But this democracy, such as it was, was paralleled by economic serfdom. As the Industrial Revolution evolved and society began to iron out some of the unfortunate consequences of that revolution, engineering had a greater and greater impact, so that, by the end of the 19th century, economic serfdom had changed to an economic oligarchy, with democracy as the governmental form.

During all this time engineering was primarily based on experience—on cutting and trying. It was strictly functional. Any thought of beauty was left to the architects. And then in the middle of the 19th century engineering itself changed; it was no longer just a matter of cut and try. Electricity had entered upon the scene. Here was something you could neither see nor grasp—something whose application required 100-percent conceptualization—and the habit of conceptualizing was born. Engineers applied it in communication and transportation. Economic oligarchy changed to economic democracy. Our standard of living began to rise at an ever-accelerating pace. And then the advent of assembly-line mass production in the first half of the 20th century provided the means of attaining true economic freedom.

Modern mass production—a true engineering achievement—was based on a complex of techniques, especially on the precision manufacture of components, so that parts would be interchangeable. Eli Whitney had originated and used this concept in the production of firearms a century earlier, but it was the refinement of machining and measuring methods that made its application to modern needs possible. Leland's manufacture of the first two automobiles with interchangeable parts illustrates this advance. He built two Cadillacs, disassembled them, mixed up the parts, reassembled the cars, and, lo and behold, they ran! He was able to do this by virtue of the standardization made possible by precision measurement. Precise measurements were made possible by the availability of standards of length known as Erickson blocks. Erickson, in Sweden, had learned how to heat-treat steel so that it would not change size on aging, and Leland went to Sweden and came back with a set of Erickson blocks. Not to be outdone, Henry Ford, too, went to Sweden and came back with Erickson! And it was Ford who added to precision tooling and standardization of parts the other elements necessary to achieve modern mass production: the division of labor, the assembly line, and, through his pricing policies, the mass market. But it was engineering that made it all possible.

Mass production not only provided true economic freedom, it also stimulated the engineers to apply scientific findings at an ever-increasing rate. The interval from Watt's first setting forth of the principles of the steam engine to the time of the railroad's major impact on our civilization was about 100 years. The interval from Carnot's establishment of the principles of the internal-combustion engine to the time of the automobile's major impact was 100 years. But the interval from the Wrights' establishment of the basic principle of aerodynamics to the time of the airplane's full impact was 50 years; the interval from Goddard's establishment of the function of rocketry to development of today's satellites was 40 years; and the interval from Shockley, Bardine, and Brittain's invention of the transistor to the time when it came into common use was 12 years. Along with this speedup, the engineer began to design for beauty as well as for function. He even designed for fashion, sometimes at the expense of function. Witness the present commotion about designing for safety in automobiles, not to mention the difficulty of getting in and out of many of the latest models.

Yes, today the masses have true economic freedom. We are living in an affluent society. Computers are taking loads off of men's minds, just as steam took the load off their backs. Transportation has been revolutionized. We can have breakfast in London, lunch in New York, dinner in San Francisco, and our baggage in Buenos Aires all in the same day. Communications no longer depend on the written word; we can see and hear instantly around the world with modern television.

Engineering is undergoing another change in concept, commonly known as systems engineering. The engineer now designs, not a telephone speaker and receiver or an automobile or an airplane, but rather the entire system of telephonic communication, the entire highway system, or the entire system for air transportation. For example, with the advent of the airplane the engineer was interested only in getting the plane from one airstrip to another. Then he found he had to have airports to get the airplane from the strip to the ramp. The system was enlarged. Then he found it necessary to get the passenger from the check-in desk to the airplane. Now he is even concerned with getting the passenger from his home to the check-in desk. Yes, an ever-enlarging system.

One of the simplest examples of systems engineering is the Program Evaluation Review Technique (PERT) system, whereby we organize construction or any other activity on the basis of sequential time requirements for each part. Using this system we can build industrial complexes in half the time and speed up many endeavors. There is nothing new about this. Every housewife uses it in preparing breakfast. She knows that if she wants to get breakfast quickly she must put the coffee on first, and that she can't butter the toast until she toasts the bread. It is the application of this concept to goals involving thousands of steps that is new.

As the systems enlarge, the involvements, social and otherwise, become too great for private enterprise, and the large systems are either supervised and regulated, or run, by government. So the engineer who, at the time of the Industrial Revolution, stopped serving government to serve private enterprise is once again serving government. And the net result of all this is that today there is leisure for all, and freedom to think.

But new problems arise. These new problems are of two kinds. The first concerns the consequences of our engineering acts. In the past these acts, being minor in scope as compared with natural processes, upset the balance of nature in a degree too small to be cause for much concern. Today the engineering applications are so vast that they can easily upset the balance of nature in a large degree. Air pollution and water pollution are obvious examples. Nature's ecology is upset by the use of nondisintegrating detergents and the use of insecticides which kill species other than those for which they were intended. All this is recognized. However, new engineering will restore the balance of nature in the case of insecticides, as it is already doing in the case of the detergents. The other new problem facing the engineer is that of providing an environment which not only promotes man's material welfare but also enhances his psychological well-being—an environment relatively free from unwanted man-produced stress. Today's engineer is meeting these problems with a free and unfettered mind, encouraged by a public anxious for improvements and a government conscious of technology's central role.

The Future

And now let us look at the future—first, the near future, let us say 1980. We will be able to provide new materials and abundant energy, atomic or otherwise. In 1980 we will have electric cars run either by storage batteries or by hydrogen, rather than by fossil fuels. The product of the combustion of hydrogen is water—a non-smog-producing chemical; therefore, purer air will be a welcome by-product of this development. In the home we will eliminate glare by having wall-panel lights with low candle power at any one point but greater total candle power than we now get from bulbs. Home machinery will be designed for quiet operation. We will have learned how to circulate air noiselessly and to take dust out of it continuously. Odors will be controlled selectively—we will be able to substitute the fragrance of lilac for the smell of cabbage. Household chores will be markedly reduced—for example, we will have a bed-making machine. And the bathroom will be redesigned, with a shower for cleanliness and the "euphoric tank," with water circulating very slowly at 94°F, for relaxation and the relief of stress. All these innovations will cut down on the undesirable impact of the external environment.

But the greatest change we are going to see in the future has to do with the internal, not the external, environment. It will be brought about by the explosion in biological knowledge already taking place. With the unraveling of the DNA molecule and with increased knowledge of proteins, antibodies, and the like, we can reasonably expect that, by 1980, we will be able to handle and control diseases due to changes in the internal environment just as we now handle and have essentially eliminated, at least in limited areas, a host of communicable diseases due to external assault: smallpox, diphtheria, tuberculosis, yellow fever, measles, and the like. We can expect the same success in handling the allergies, sclerosis, dystrophy, arthritis, and cancer. And, in addition, we can expect sex predetermination by 1980, and control of the aging process which will provide the same productivity in the years 65 to 75 that we now have in the span 45 to 55. I need not dwell on the changes in our society that this will necessitate. For example, most couples will want a boy first, a girl next, and then a boy, and most couples will want three children. Result: twice as many boys as girls. How will society handle this? Eliminate the option? Restrict all families to two children? Dictate what the sex shall be? I won't predict the answer, but, obviously, important social decisions will be needed.

And if we look to the long-term future we see a still greater impact of technology on both civilization and society. As for the external environment, we will have electricity from heat, wireless transmission of energy, and new materials, such as nonorganic polymers and the like. As for the internal environment, we will be really able to manipulate the DNA molecule and predetermine heredity. We will lick the problem of aging completely, so that accidents will be essentially the only cause of death. The implication for society is staggering. It may be necessary to penalize someone for giving birth without a permit as heavily as we now penalize an individual for murder. We will be able to design supermen. The systems engineer will design a society with optimum stress, directing aggression so that strife between man and man is eliminated. We will then need only to eliminate strife between man and woman. Yes, engineering will both require and supply a new organization of society.

If you think all this is a dream, I can only tell you about a young science teacher shortly before the turn of the century. He lived with a bishop in Ohio and was telling the bishop about the wonders to come, maintaining that a person in Cleveland would soon be able to talk by telephone to someone in New York; that man would someday have automobiles that would do 35 miles an hour; and that it was even possible that man might someday fly. Here the bishop interrupted—this was rank heresy and he would have none of it. I tell this story for a particular reason—the bishop had two sons, whose names were Wilbur and Orville!