The Engineered Century

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Fellow engineers, honored guests, ladies and gentlemen: It is National Engineers Week, and I am honored to be speaking on behalf of the National Academy of Engineering and our nation's professional engineering societies.

I am, and ever will be, a white-socks, pocket-protector, nerdy engineer—born under the second law of thermodynamics, steeped in the steam tables, in love with free-body diagrams, transformed by Laplace, and propelled by compressible flow.

As an engineer, I take a substantial amount of pride in the accomplishments of my profession. Bill Wulf, president of the National Academy of Engineering, has said that science is about what *is*, and engineering is about what *can be*. The Greek letter eta, in lower case, often shows up in engineering documents. Engineers pay a good bit of attention to improving eta because it is a symbol for efficiency—doing an equivalent or better job with less weight, less power, less time, less cost. The entire existence of engineers is dedicated to doing things better and more efficiently.

When knowledge, facts, or solutions are sought, there are a number of techniques available from which to select. These techniques can be ranked according to their effectiveness, from the most certain to the most uncertain. At the top, or level one, is measurement; but even excellent measurements can be subject to small amounts of error. Level two is cause and effect. That's a rigorous deduction based on the laws of nature; on the conservation of mass, energy, and momentum; on Newtonian mechanics, Ohm's law, Charles's law, and all those kinds of relationships. These techniques for solving problems are not error free, but they do provide reliable and repeatable results.

At the third level I put correlation studies. These are statistical techniques which allow the drawing of general and reasonable conclusions, but imprecise conclusions. An example of this is when you hear a conclusion such as 62 percent of the people who eat pistachio ice cream 20 or more times a week tend to gain weight.

The fourth level is opinion sampling. Conclusions here can be useful, but they are often temperable and not repeatable. Levels five, six, seven, and eight include a variety of techniques that vary from focus groups to intuition to dream analysis and just plain guessing.

Uncertainty increases with the number of independent variables. So engineers use measurement and cause-and-effect methods for problem solving as much as possible, and use correlation studies only when the number of independent variables is too great for explicit solutions.

Engineering is a profession which leaves its imprint on our society in countless ways. We all intuitively understand the term “quality of life,” but we have difficulty in attempting to define it. Each individual has a unique group of factors which are important to him or her in quality of life. One person might think having no obligation to work whatsoever would be ideal, while another person would think having a great deal of work to do would be ideal. We do know that a century ago the world really needed improvements in quality of life—health, mobility, living standards.

At that time, life was a constant struggle. There were epidemics of tuberculosis. Child labor and 12-hour work days were used to ensure economic output. The average life expectancy had barely budged in a thousand years. If you reached senior citizen status you beat the odds; to have all your children reach adulthood was rare. Waterborne diseases like typhoid fever and cholera were scourges around the globe. Industries blanketed cities with soot. Streets were filled with garbage and sewage. The world's forests were being decimated to fuel burgeoning industries and to build and heat homes for the world's growing population.

The twentieth was a century often punctuated with the terror of war and darkened with societal struggles to overcome injustice. But it was also the first century in which technology enabled the tenets and the images of those traumas to reach across the world and touch people in ways that were previously unimagined. John Pierce, the engineer who fathered Telstar, the first satellite to relay television signals across the Atlantic, said that engineering helped create a world in which no injustice could be hidden.

Engineers are dedicated to solving problems and creating new, useful, and efficient things. So should not the world admire and respect them? Answer: Only occasionally. Many of our fellow citizens are mistrustful of logic and critical of technocrats, and often with reason. Bridges fail, airplanes crash, storage tanks leak, radiation escapes, and automobiles are recalled. Such failures are reported widely, and the search for whom to blame is initiated. But there are a couple of problems here. Engineers are not good communicators. We are mistrusted because we are perceived as being slaves to technology, as technocrats who don't care a whit about the environment or safety or human values. And I reject those criticisms. In my experience, engineers aren't really bad folks. A little too focused, maybe too intense for some, but they are as caring and concerned as other segments of our society. The fact that their failures are so widely reported is evidence of their rarity.

Now, in this final year of the twentieth century, many will look back to see how we have changed and what we have accomplished. By measuring our successes and our failures, they will gauge the progress that we have made as individuals and as a society. The evolution of popular culture, politics, and business has given us a world that is vastly different from that of our grandparents, and engineering has played a significant role in those changes. So we decided we would take a focused look at how engineering has affected the quality of life in this past century.

Over the past year, a rather impressive consortium of professional engineering societies, representing nearly every engineering discipline, has given its time, resources, and attention to a nationwide effort to identify and communicate the ways that engineering has affected our lives. Engineering is the second largest profession in the United States, behind teaching, and so a large group of minds was looking at this issue.

Each organization independently polled its membership to find out what individual engineers believed to be the greatest achievements in their respective fields. This effort covered areas as diverse as agricultural engineering, chemical engineering, electrical and mechanical engineering, aerospace engineering, and so on. Because these professional societies are unrelated to each other, the American Association of Engineering Societies and the National Academy of Engineering (NAE) provided the groundwork to coordinate the effort. The Academy, in particular, took a leadership role in this effort because of its unique ability to convene the world's greatest engineering minds under the congressional charter that it shares with the National Academy of Sciences.

The NAE issued the call for nominations to the societies, convened a selection committee of top engineers from all fields, and set about the laborious practice of qualifying and quantifying the information in the nominations. I was pleased to be asked to serve on the selection committee, which was chaired so capably by Guy Stever.

After several rounds of narrowing the nominations, the committee met for two full days toward the end of last year and debated about just how to tackle this task and determine which engineering achievements of the twentieth century had the greatest positive effect on mankind. While intercontinental ballistic missiles and laser-guided bombs were undoubtedly technological marvels with important and perhaps justifiable reasons for their existence, projects of this type were somewhat disadvantaged on the quality-of-life basis.

Engineers should, and often do, present their projects, their ideas, and their conclusions with both the strengths and the weaknesses in full view. And I feel an obligation to maintain that tradition. A popular 14th century phrase was "comparisons are odious," and perhaps they are. Nevertheless, we are, in contemporary society, engulfed in comparisons and ratings and lists: the top 25 teams, the top 10 money winners, the Oscars, the Emmys, the Grammys, the bestsellers, etc. And we engineers, not to be left out, have developed our own list.

Such lists are, admittedly, somewhat self-serving. This one certainly is. In making comparisons among engineering achievements, we could not use measurements, and we found it difficult to use cause and effect or correlation studies. So we were obliged to reach way down to level four, opinion sampling, to reach consensus. Although this was an uncomfortable process for engineers, the NAE did aggregate a committee of exceptional breadth and experience, considered seriously the recommendations of the nominators—all well-informed and experienced engineers in their respective fields—and sifted.

Now, as we take a look at the things considered by the NAE, we will see that if any of them were removed, our world would be a very different and less hospitable place. Each one of these achievements has been important to the change in our society.

If you were to ask a person on the street to name a great engineering achievement, he or she might say the Golden Gate Bridge, or the Panama Canal, or the Empire State Building. And while each of those is a great engineering achievement, none of them made the list. What *did* make the list were technologies that have become inextricable parts of the fabric of our lives—some spectacular, some nearly invisible, but all critically important. So, let me introduce you to the list, the 20 engineering achievements that had the greatest positive impact on society in the twentieth century.

At number 20 we have high-performance materials. Early in the century the first synthetic resins were developed, and plastics have since become ubiquitous worldwide. In the second half of the century, polymers, composites, and ceramic materials found extensive applications.

Number 19 is nuclear technology. Although controversial in the public mind, the engineering achievements related to conflict deterrence, power generation, and medical diagnostics and treatment remain among the most important of the twentieth century.

At number 18 are lasers and fiber optics. Lasers brought xerographic printers and bar code readers, transformed survey methods, and revolutionized the storage of music, data, and images. And when the laser was combined with optical fiber, the rate of information flow was dramatically increased. Tonight, three engineers who were key players in the development of optical fiber will receive the NAE's Charles Stark Draper Prize.

Number 17 is petroleum and petrochemical technologies. Transportation became petroleum-based in the twentieth century, as did much of the energy and chemical industries. Next, at 16, are health technologies, which include devices such as pacemakers, artificial limbs, eye lens implants, and so on.

Fifteen is household appliances, which radically reduced the drudgery and time required to maintain a home. At number 14 are imaging technologies, like those used for medical diagnostics and weather forecasting. Next is the Internet, which to the surprise of many made it only to number 13. It was the consensus of the committee that the impact of the Internet will be felt more significantly in the twenty-first century. Check later.

I believe that space flight was certainly one of, and perhaps *the* greatest engineering achievement of the century, but it was selected number 12 on the basis of its effect on the quality of life, and I do not disagree. While the impact of seeing our planet from afar had an overpowering effect on people around the Earth and provided the technology for tens of thousands of new products, other nominees were judged to have a greater impact on worldwide living standards.

Next is the interstate highway system. With 44,000 miles of limited-access, multiple-lane roads without a single stop sign or stop light, it's a model of efficiency and an engineer's dream. While it clearly improves the lives of all who travel on it and all who are served by it, its rating suffers because it is not worldwide.

Moving on to the top 10, we have air conditioning and refrigeration, which provided improvements in comfort and health and gave us the ability to transport fresh food and extend its shelf life. Next is the telephone. Instantaneous worldwide communications serve both family and business needs, and have introduced telemarketing to the dinner hour.

When the founder of IBM, Tom Watson, reportedly predicted before World War II that there was a world market for about 5 computers, he slightly underestimated the number of machines and applications for these devices, which reached number 8 on our list.

The world's population grew from 1.6 billion to 6 billion souls during this past century, a milestone that could not have been reached without number 7, agricultural mechanization. More impressive is the fact that the portion of the population necessary to feed the world has been reduced from slightly more than half in 1900 to just a few percent today.

One step higher, at number 6, are radio and television. Although Marconi first demonstrated radio in 1895, he broadcast the first transoceanic signal in 1901, sufficient justification for the committee to include radio on the list. Some countries first introduced television to enable their citizenry to watch the Apollo achievements as they happened. And now it's difficult to find a place on the entire globe that is not burdened with daytime television.

In the fifth position is electronics, from vacuum tubes to transistors, integrated circuits, and microcircuitry. I'm told that in midcentury the transistorized radio was the fastest-selling retail item of all time—at least up until the time of Pokémon. Fourth are the technologies that purify and deliver safe and abundant water. At the outset of the century in the United States, typhoid alone killed more than 150 of each 100,000 citizens. Water treatment and distribution techniques led to longer lives and better living standards around the globe.

The airplane is ranked third. From its birth in 1903 with no obvious important use, aircraft rapidly changed the character of warfare, found dozens of new uses, and in the latter half of the century decimated passenger competition in trains and ships.

The second ranked engineering contribution is the automobile. It too was a nineteenth century invention, but its development in the twentieth century demanded that it be considered a competitor. Passenger cars and trucks are the major transporter of people and cargo around the world, and the automobile has expanded the ease, practicality, and affordability of short- to medium-range travel enormously.

Now, at this point, if we were in the entertainment world, we would have drum rolls, fanfares, and rockets. But as engineers we are not so inclined—well, maybe a few rockets. The winner, the top-rated engineering improvement to the life of earthlings in this century was electrification. The majority of the top 20 achievements would not have been possible without electricity. Electrification changed the country's economic development and gave rural populations the same opportunities and amenities as people in the cities. It provides the power for small appliances in the home, for computers in control rooms that route power and telecommunications, and for the machinery that produces capital goods and consumer products. If anything shines as an example of how engineering has changed the world during the twentieth century, it is clearly the power that we use in our homes and businesses.

So, there you have it, the top 20. My descriptions have been sometimes trite, and it's likely that I missed some of the most important societal contributions from the nominees. And, without question, I did not even mention the work from those nominations that did not make the top 20 list, yet in many cases were of enormous importance to certain sectors of society or certain parts of the world. And in all honestly, I am guilty of a bit of subterfuge. Certainly the nominations were worthy and the committee was honest and diligent in evaluating them. And certainly you have been given their well-reasoned conclusions. The subterfuge is that my purpose was not to promote the competitive nature of the event, or to congratulate the winner, or to convince you that electrification was the most important technical activity of this past century. All of you have your own opinions on the importance of various technical developments to our society. What I really hoped to do was shamelessly use this occasion to remind you of the breadth, and the depth, and the importance of engineering as a whole to human existence, human progress, and human happiness.

There are perhaps, even more far-reaching consequences of this exercise. The likelihood of today marking the end of creative engineering is nil. The future is a bit foggy, but it's not unreasonable to suggest that the twenty-first century will enjoy a rate of progress not unlike the twentieth. And a century hence, 2000 may be viewed as quite a primitive period in human history. It's something to hope for.

For three decades I have enjoyed the work and friendship of Arthur Clarke, a prolific science and science fiction writer, who back in 1945 first suggested the possibility of the communications satellite. In addition to writing some wonderful books, he has also proposed a few memorable laws. Clarke's third law seems particularly apt today: Any sufficiently developed technology is indistinguishable from magic.

Truly, it has been a magical century.