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Why Society Needs Engineers, especially Naval Architects, Marine & Ocean Engineers

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Abstract

Firstly, the premise that engineering and technology are important and necessary parts of our human society and have been since the beginning of time; and secondly, the premise that, since we live on a planet that has approximately seventy percent (70%) of its surface area covered by water, there is an inherent need for development of technology and engineering solutions relating to the world's oceans.

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Engineering Ancient and Modern

In these times we engineers often seem to be on the defensive, with our professional work presented by the media and special interest activists as "grubby and even dangerous" while science seems to be championed as "pure and good". The reality, however, is that in the developed world we generally live, safe, comfortable and rewarding lives due to the availability of technology and, in the developing world, engineers are responsible for bringing clean water, power, and transportation infrastructure that reduce infant mortality rates and increase life spans in places like India and China.

Unlike science, engineering and technology have been an integral part of human development from earliest times. Historically, tool-use has been considered a typically human behavior and the emergence of tool-use was considered an important step in evolution, even serving to delineate the appearance of the genus Homo. This is now a somewhat dated definition but it is still clear that our cave-dwelling ancestors survived and developed through the use of primitive technology. They did not, however, need to understand the science of combustion chemistry to use fire, only that its use allowed families to stay warm and cook their food; similarly their need for transport drove the construction of log canoes without any understanding of the finer points of metacentric stability.

As human society developed, engineering and technology played an increasing important role in advancing civilization. For example, the Egyptians built great pyramids to honor their Pharaohs around 2500 B.C. (and developed marine infrastructure to support these efforts); the Romans developed water supply and sewage infrastructure, central heating and an impressive network of roads, (including major defense systems such as Hadrian's Wall); and the Vikings designed and built ships which carried them across the stormy North Atlantic to Iceland and beyond, around 870 A.D. All these "engineering" feats were accomplished millennia before science was part of our regular lexicon.

While I stated earlier that engineers have not always had a good public image, in an encouraging turn of events, I read a recent Veracity Index poll of the most trusted professions and found that, at 87%, engineering is the second most trusted profession after nursing, 89%. Interestingly lawyers scored 57%, journalists 27% and politicians 12%. As an engineer I find this is quite encouraging but I am not sure that this easily translates into improving our societal or governmental systems.

The problem remains that there is a gap between what engineers do and their public trust recognition, and how engineers are projected by the media and how their value to society is often ignored by governments. At a governmental level engineers tend to be involved in reactive rather than proactive ways. For example, engineers may be called to investigate technical failures but are seldom asked to help in defining policy which has a technological component, (that is just about everything from policies relating to energy, to national security, to financial systems and to health care). This is of course not a new phenomenon. Plato stated it well ~400 B.C. *"Those who are too smart to engage in politics are punished by being governed by those who are inferior."*

In order to explore the premise that society needs engineers, it is useful to explore the status quo, particularly the relationship between engineering and science which I find to be poorly understood by many.

I have long held that a quote attributed to Theodore von Karam, the distinguished engineer and fluid dynamist, succinctly describes the fundamental difference between scientists and engineers:

"Scientists seek to understand what is, Engineers seek to create what has not yet been."

And, in a more philosophical way the following quote from Carl Mitcham, Philosopher, Colorado School of Mines, further explains why we should value engineering:

"Design & Invention cause things to come into existence from ideas, they make the world conform to thought; whereas Science, by deriving ideas from observation and analysis, makes thought conform to existence."

Definitions

It may be useful to define science, engineering and technology:

Science can be defined as the intellectual and practical activity encompassing the systematic study of the structure and behavior of the physical and natural world through observation and experiment.

An all-encompassing but somewhat clumsy definition of engineering is that it is a process of inventing, innovating, designing, building, maintaining, researching, and improving structures, machines tools systems materials, components, processes, solutions and organizations, all this is achieved by utilizing creativity, ingenuity, empirical evidence, heuristic rules, practical knowledge, mathematics, economics, science, and social knowledge.

Technology is defined as the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, and science. Or a little more succinctly, technology is the sum of the ways in which social groups provide themselves with the material objects of their civilization. It is interesting to note that the definition of technology brings together human society and civilization with engineering.

In past years much technical discussion and professional education has centered around what has become known as the "Scientific Method". This can be described as consisting in systematic observation, measurement, and experiment, applying rigorous skepticism about what is observed, and leading to the formulation, testing, and modification of hypotheses. It is a systematic way to develop knowledge of our world.

Less referenced is the "Engineering Method", partly described in its application to non-engineering activities in Iain MacLeod's paper *System Planning in Government and in Education* in this Journal.-

The engineering method (design) can be defined as a systematic approach used to reach the desired solution to a problem, remembering that as they seek solutions, engineers are answerable within a broad and diverse environment of actors and forces: socio-political, material, temporal, and financial.

To quote from the 2021 paper *"The Life and Legacy of William Rankine"* by Andy Pearson[1]:

> *"Rankine was the Regius Professor of Civil Engineering and Mechanics at the University of Glasgow … and for almost his whole tenure he fought vigorously to have engineering recognized as a degree subject in its own right."*

Although Rankine faced significant resistance from the university establishment, Glasgow did in fact start to award B.Sc. degrees in Engineering Science in the year of his untimely death 1872.

This has proved to be a significant step in engineering education, fulfilling Rankine's desire to reunite theory and practice by using science to help in solving real world engineering problems, a theme that runs as a recurring element through much his work.

Today, we have engineering schools around the world teaching engineering and awarding degrees in either Engineering or in Engineering Science, but we need to be careful, however, as engineering science and engineering are not the same thing. It should be noted that engineering science is but one of the tools that engineers use to solve problems. As stated in the earlier definition of engineering above, engineers use many tools including: creativity, ingenuity, empirical evidence, practical knowledge, mathematics, economics, science and social knowledge.

In the history of humankind engineering and technology, most often precedes science. Engineering and technology are not the children of science, but are more often the progenitors of it!

A prime example is from our own James Watt who developed the working steam engine and initiated the Industrial Revolution, decades before Kelvin and Rankine were able to articulate the laws of thermodynamics which describe why steam engines work. And, as a side note, today we still use steam to generate around 80% of all the world's electricity.

Further, after a recent visit to the Science Museum in Kensington, I left asking myself the question *"Where is the science in the Science Museum?"* On entering the museum, I saw the Energy Hall with wonderful examples of the work of the aforementioned James Watt and my further explorations brought me to space capsules, telescopes, microscopes and even to the Julius Totalizer Machine using for calculating betting odds at greyhound tracks. All of these and many more are examples of engineering and technological creativity, many of which were critical in allowing scientists to carry out their work of discovery. Without the microscope or telescope the scientific fields of biology and astronomy would have been slow to advance.

Scientists seek knowledge – Engineers find solutions

It is worth looking at the etymology of the words engineer and scientist: the word "scientist" first appears to have been used at the University of Cambridge in 1834 to describe a "cultivator of science, while the word "engineer" dates from at least the late 1300s where it refers to a "constructor of machines".

Of course, looking at the Latin roots also helps us understand the role of engineers in society in that it is derived from the Latin words 'ingeniare' (to contrive, devise) and "ingenium" (cleverness).

Sir Francis Bacon, 1561-1626, has been styled as "the father of modern science", although he seemed to have had more respect for the engineers of his day, the smiths, masons and artisans, who practiced the mechanical arts, than for the scientist. He was driven in this work by a recognition that technology was advancing while natural philosophy (physics) had been stagnant since the time of Aristotle.

> *"Observe also, that if the sciences of this kind had any life in them, that could never have come to pass which has been the case now for many ages – that they stand almost at a stay…. and all the tradition and succession of schools is still a succession of masters and scholars and not of inventors or those who bring to future perfection things invented.*
>
> *In the mechanical arts we do not find this so: they, on the contrary, as having in them some breath of life, are continually growing and becoming more perfect. As originally invented they are commonly rude, clumsy and shapeless: afterwards they acquire new powers and more commodious arrangements and constructions….Philosophy and the intellectual sciences, on the contrary stand like statues."*

Bacon's description of the process of improvement built into the development of "mechanical arts" well describes the way in which engineering advances are made. Some may call this approach "trial and error" but I prefer to call it "continuous experimentation".

1 *Pearson A (2021) The Life and Legacy of William Rankine, Proc. Interenational Conference on Refirgeration and Air Conditioning, Institute of Refrigeration.*

We can see this continuous experimentation taking place all around us since a key part is to gain feed-back to make improvements in products or systems. The cell phone growing from being a limited capability shoebox-sized wireless communication unit to being a powerful multi-function pocket-sized communicator/computer/camera/navigation device; or the ocean crossing container ship growing from a small 4000 TEU (Twenty foot Equivlaent Unit) capacity in the mid 1950s to today's 24,000 plus capacity giants are both good examples of continuous experimentation, with multiple generations of product being introduced in a relatively short time. These and many more cases illustrate Bacon's observation that "A*s originally invented they are commonly, rude, clumsy and shapeless: afterwards they acquire new powers and more commodious arrangements and constructions….*"

This kind of engineering experimentation is different from scientific experimentation which is specifically designed to confirm or to reject new hypotheses. In engineering, continuous experimentation is a concurrent activity embedded in the engineering process. It is different in that it is carried out in parallel to the design and production of real products which in themselves are designed to fulfill the current requirements as best can be done with current knowledge, tools, budgets and schedules. Examination of the subsequent use of the developed product or process is the key part to the experiment. This in-service experience along with what was learned during the original design and construction, can then identify new opportunities for improvement in function, cost and schedule, which can be circled back to the design of the next generation of product or design.

Certainty versus Uncertainty

Scientists seek knowledge and certainty while engineers seek solutions and deal with uncertainty.

Some years ago, former US Secretary of Defense, Donald Rumsfeld stated:

> *"Reports that say that something hasn't happened are always interesting to me because, as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say, we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know. … and it is the latter category that tends to be the difficult ones."*

As engineers we spend considerable effort on understanding uncertainty and have developed methodologies for addressing it. Fifty years ago we tended to use design margins or factors of safety (factors of ignorance?) to address the uncertainty we encountered. For example, in naval architecture we would add an arbitrary corrosion margin to ship's hull plating to allow for a what we thought might be the reduction in plate thickness over the life of a vessel; or we limited the design stress in a pressure vessel to a percentage of the yield value of the material used for construction. Today we have reduced our levels of uncertainty by having developed better analytical techniques, such as finite element structural modelling, and computational fluid dynamics, that can give us a better understanding of the expected performance of our designs, although some level of uncertainty remains.

We have a whole range of tools that have been developed to assist in understanding and mitigating the risks associated with uncertainty, tools such as, Technology Readiness Factors, Risk Matrices, Hazard Identification, HAZIDs, and Hazard and Operability studies, HAZOPs.

Engineering science has provided useful tools in understanding uncertainty and in many cases reducing it, but in the end the engineer must also use creativity, ingenuity, empirical evidence, practical knowledge, mathematics, economics, and social knowledge, to develop safe, practical, cost-effective designs.

Engineering for the Oceans

One of the areas of engineering which may have more uncertainty, that is, the known-unknowns and unknown-unknowns, is the field of engineering for the ocean. Our planet might better be named Ocean rather than Earth since it is largely covered by water, and much of it remains unexplored and undeveloped. The second part of the paper will examine our current areas of naval architecture, marine and ocean engineering where present and future technology will be deployed.

The importance of the planet's oceans and seas cannot be overstated:

~ 70% of the earth's surface is covered by water
~ 80% of the world's population lives within 250 km of the coast
~ 90% of the world's trade moves by sea
~ 100% of life as we know it depends on water

For as long as humans have taken to the sea, ships and other craft have served as a means of material and technological exchange and have embodied the culture that has produced them. The materials to build a ship reflect the ability to procure resources; the construction process reflects the ability to organize labor, and the construction techniques define the level of skill and technology available. Even the size of a ship is indicative of the risks that a society is willing to assume.

The *Pesse* log-canoe, now on display in the Drents Museum, Assen, Netherlands is believed to be the world›s oldest known boat. Carbon dating indicates that the boat was constructed during the early Mesolithic period between 8040 BC and 7510 BC, which places if firmly in the Stone Age.

To examine true shipbuilding, defined as the construction of large marine craft using manufactured component parts, however, we need to look to the southeast corner of the Mediterranean. While there is no precise date for when the building of ships began, the current archeological evidence suggests that it was in the early Bronze Age which began around 3,000 BC.

The earliest known physical example of a large vessel is the funerary boat discovered in Egypt in 1954. This ship, known as the Khufu ship, was almost certainly built for the second pharaoh of the 4th Dynasty of the Old Kingdom. It is the oldest, largest and best-preserved vessel in the world from antiquity. It measures 43.6 m (143 ft) in overall length and has a beam of 5.9 m (19.5 ft) and demonstrates a level of ingenuity and practical skill which are foundational in the design and construction of any waterborne craft.

The development of ships seems to have spread along what we might call the Maritime Crescent, with initial developments in Egypt, and then spreading along the eastern end of the Mediterranean through the Levant and into modern day Turkey and Greece.

From that time forward, ships and marine transportation systems have been an essential element in the development of civilization and this has led to those who design and build ships, be they shipwrights, naval architects or marine engineers being seen as important.

John Adams, 2nd President of the United States of America. recognized the importance of naval architecture as a step towards a more refined degree of civilization in a letter to his wife Abigail Adams (May 12, 1780):

> *"I must study politics and war, that our sons may have liberty to study mathematics and philosophy. Our sons ought to study mathematics and philosophy, geography, natural history and **naval architecture**, navigation, commerce and agriculture in order to give their children a right to study painting, poetry, music, architecture, statuary, tapestry and porcelain."*

And less than 100 years later the Scottish naval architect and engineer John Scott Russell, described the almost super-human attributes that a naval architect must possess in his massive treatise "The Modern System of Naval Architecture", published in 1865

> *"A naval architect should be able to design, draw, calculate, lay down, cut out, set up, fasten, fit, finish, equip, launch and send to sea a ship out of his own head. He should be able to tell beforehand at what speed she will go, what freight she will carry, what qualities she will show in a sea, – before it, athwart it, against it, – on a wind, close hauled, going free, – what she will stow, and carry, and earn and expend. On his word you should be able to rely, that what he says, that his ship will infallibly do."*

Today, the role of the naval the architect has been extended beyond the tradition role of ship designer into the broader field of engineering for the ocean space. But the need for the multi-facetted skill set described by Scott-Russell over 150 years ago has not diminished although the range of engineering projects has moved far beyond ship design and construction.

The oceans present challenges and opportunities to accommodate the ever-increasing needs of the world's population for expanded services and resources in areas such as:

Trade and Transportation

- current fleet of ships >1000GT is ~54000 vessels with a combined deadweight (cargo capacity) of ~2.1 million tons.
- Total cargo transported ~ 10.7 billion tons of which 28% was oil.
- Rapid changes in, ships fuel – (low or zero carbon); autonomous and unmanned systems; digital twins etc.
- Advances being made in port technology and ship design and construction.

Energy

- Offshore oil accounts for about 29% of all production world-wide in waters from a few meters deep to over 3500m deep.
- Offshore wind energy production, both bottom fixed and floating, is increasing rapidly in some part of the world.
- Wave, ocean thermal and tidal energy sources are at early stage of development with prototypes already developed.

Food

- The oceans are an important food source. ~ 185 million tons of fish and seafood, both wild caught and farmed are produced per annum, which represent about 15% of all protein consumed. By comparison, global annual production of beef is ~130 million tons.
- Further the UN estimates that ~58 million people make their living from fishing and mariculture and the global fishing fleet numbers ~4.6 million craft.

Living Space & Working Space

- While a large percentage of the world's population live in coastal areas, many actually live in low-lying or below sea-level areas where engineering has made that possible. The Netherlands, Singapore and Venice are examples of engineered solutions. Engineers need to continue to develop recovery of coastal lands and protect existing land from rising sea levels.
- Future floating cities are already being proposed.
- Floating plants for oil production, nuclear power production, data centers etc. are already with us and other similar opportunities will appear.

Mineral Resources

- Current seabed mineral extraction includes diamond mining and tin dredging.
- New developments include the exploration for and development of deep-seabed mineral resources such as manganese nodule that contain amongst other material, copper, nickel, titanium, and rare earth oxides.

Recreation

- Recreation is an important part of human existence and the ocean provide many opportunities from lying on a sunny beach, to swimming in the ocean, taking a cruise, sailing, surfing, fishing etc. It is estimated that there are currently ~30 million recreation craft in the world.

While there are no doubt exciting opportunities ahead for those who choose to work in the broad field of ocean engineering, we must take care.

Modern civilization has not always shown much restraint in the use of technologies which make engineering our environment or extracting resources from the earth or ocean easier. And new developments will make it even simpler to build, harvest, drill, mine or fish in ways that may not be sustainable.

The choice, however, is not between taking these risks and taking no risks. The choice is about judging those risks against the capacity to lessen any harm being done to our oceans, while providing benefit to society in general, recognizing that that capacity for good is also one that new technologies will increase.

That is our challenge in engineering the future of our oceans and our planet!