The Evolution of Engineering Thought

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Why is this Lecture Important for Senior Engineering Design Students?

- Most Engineers do not know the History of our Profession.
- Those who do not know their history, fail to understand the legacy and responsibility to society that we carry

- **These are the shoulders of Giants that I have stood upon in my 40+ year career as an Engineer, Engineering Manager/Executive and Professor**

Leonardo da Vinci,
Manuscript G,f.8r (circa. 1490)

- ***Those who are in love with the practice without knowledge are like the sailor who gets into a ship without rudder or compass and who never can be certain whether he is going***

Who are We and What do we Do?

- *"It is customary to think of engineering as a part of a trilogy, pure science, applied science, and engineering. It needs emphasis that this trilogy is only one of a triad of trilogies into which engineering fits. The first is pure science, applied science, engineering; the second is economic theory, finance and engineering; and the third is social relations, industrial relations, and engineering. Many engineering problems are as closely allied to social problems as they are to pure science."*

1953 Stanford Univ. Committee on Evaluation of Engineering Education

- *"By and large engineers are paid by society to work on systems dealing with problems whose solutions are of interest to that society. These systems seem to group conveniently into (a) systems for material handling, including transformation of and conservation of raw and processed materials; (b) systems for energy handling, including its transformation, transmission, and control; and (c) systems for data or information handling, involving its collection, transmission, and processing."*
- *"In carrying out this work engineers engage in various activities ranging through engineering research, design and development, construction, operation, and management."*

Laws we Live By

- Conservation of Mass
- Conservation of Momentum
- Conservation of Energy
- 2nd Law of Thermodynamics
- Maxwell's Equations
- Ohm's Law
- Equation of State

Archimedes of Syracuse
(c.287-212 BCE)

- **Great Greek Mathematician and Military Engineer killed in 2nd Punic War against Rome**
- **Sum of the Forces F = 0**
- **Sum of the Moments (F x L) = 0**
- **Buoyancy force = weight of displaced fluid**
- : *"The ratio of the circumference of any circle to its diameter is less than 3 1/7 but greater than 3 10/71."* – calculus like derivation

Leonardo da Vinci
(c. 1452-1519 CE)

- Italian Artist and Military Engineer
- Engineering Designs poorly documented
- Art works better known
- Self Educated student of light, motion and the human body
- Continuity Equation of fluid motion
  - $A_1 v_1 = A_2 v_2$.
- Precursor to “Conservation of Mass” in the 18th century

Robert Boyle (1627-1691 CE)

- **Irish Chemist**
- **pV= constant**
- addition of temperature (T) in Charles's law
  - **pV/T=constant (Gas Law)**

- **Thermodynamic Equation of State**
  - **Used in Mechanical , Aerospace and Chemical Engineering**

Isaac Newton (1642-1727 CE)

- **Great British Mathematician, Physicist**
  - **Vector Calculus**
- **Law of Gravity**
- **Vector Relationships**
- **Conservation of Momentum (beyond Statics)**
- **$m\underline{v}$ = constant**
- **$\underline{F} = m\underline{a}$.**
- **Sigma $\underline{F} = 0$**
- ***"If I have seen further, it is by standing on the shoulders of Giants"***

Gottfried Wilhelm Leibniz (1646-1716 CE)

- **Great Dutch Statesman, Mathematician, Physicist (contemporary of Newton)**
  - **Calculus**
- **Altitude + *Vis Viva (mv^2)* = Constant**
- Today, we state this as the:
  - **"Law of Conservation of Energy"** for solid bodies:
  - **Potential Energy + Kinetic Energy = Constant**

Daniel Bernoulli (1700-1782 CE)

- **Medical Doctor with a love of Math, Physics and experimentation**
- **Famous Father and Brothers (Math)**
- **Recognized Leibniz *vis vita* applied to fluid motion as well**
- **Conservation of fluid Energy**
- **Pressure + *rho* v^2 = Constant**
  - Where ***rho*** is the fluid density and ***v*** is the fluid velocity magnitude.

Michael Faraday (1791-1867 CE)

- London printers apprentice - Self Educated to become honored by the British Royal Academy
- Great Experimentalist but no knowledge of Mathematics
- Current = Voltage / Resistance (Ohm)
- *"Whenever a magnetic force increases or decreases, it produces electricity* [in a conductor] *;the faster it increases or decreases, the more electricity it produces"*
  - Fundamental EM relationship required to design electric motors and generators

James Clerk Maxwell (1831-1879)

- Great Scottish Physicist, Mathematician
- Theoretical Foundations for much of Mechanical and Electrical Engineering
- Field Theory, Thermodynamics

$$\nabla \cdot \mathbf{E} = 0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}.$$

Rudolf Julius Emanuel Clausius (1822-1888)

- **German Professor of Physics w/ Profound Theories**
- **The net change in the total energy of the universe is zero – 1st Law of Thermodynamics**
- **For a thermodynamic cycle, the net heat supplied to the system equals the net work done by the system.**
- **Young French Engineer (Carnot) Max efficiency = 1 – Low Absolute Temperature/High Absolute Temperature is ALWAYS <100%**
- **The net change in the total entropy of the universe is always greater than zero – 2nd Law of Thermodynamics**
- ***Perpetual Motion Machine is impossible and the Universe is running down, Information order decays***

William Thomson, 1st Baron Kelvin (1824-1907)

- Prof., Univ. of Glasgow, Scotland
- Scientist and Engineer
- Pioneer in Thermodynamics (0 deg. K, Absolute Zero)
- Thermoelectric discoveries (Joule-Thomson effect)
- Outstanding Experimentalist & Instrument designer (esp. electrical current measurement)
- Calculated the Data Rate of the 1st Transatlantic cable
- In 1902 predicted that no airplane will ever be “practically successful”

Nickola Tesla (1856-1943)

- Austrian/Serbian/US engineer
- AC motors, generators, transformers that are the basis of our world wide electric power distribution system
- Pioneer in wireless telecommunications and remote control
- Pioneer in X-ray technology
- Futurist and showman

Henry Ford (1863-1947)

- Self taught engineer
- Worked for both Westinghouse and Edison
- Developed Model T automobile in 1908
- Perfected Assembly Line (min. space) manufacturing system for identical items
- Iron-ore to Shipment of car (>5,000 parts) in 81 hours
- 1916 sold 472,000 Model T cars at $7,000 ($2008)
- By 1927, over 15,000,000 produced and sold
- Pioneer of “Welfare-Capitalism” to allow labor to earn enough $ to purchase goods

Taiichi Ohno (1912-1990)

- Japanese graduate of Nagoya Tech HS
- Father of Flexible "Lean Mfg" and "Just-in-Time" flow Control (moved from "space" control to "time" control)
- Identified 9 "Wastes"
  - Time-in-Queue
  - Over-production
  - Non value-added activity
  - Transportation
  - Unnecessary motion
  - Inventory
  - Production Defects
  - Human Intellectual Capital
  - Producing something the customer does not use

Kelly Johnson (1910-1990)

- Aeronautical and Systems Engineer (USA)
- Leader of Lockheed “Skunk Works”
- Involved in over 40 aircraft designs (e.g. P-38, U-2, SR-71)
- Developed 14 “Rules of Program Management”
- Developed first “Stealthy Aircraft” – SR-71 @ M3.3
- Some Awards:
  - Wright Brothers Medal (1940)
  - Collier Trophy (1959, 1964)
  - Theodore von Karman Award (1963, 1964)
  - Medal of Freedom (1964)
  - Member Nat. Acad. Sciences and Engineering (Founders Medal, 1971)
  - Daniel Guggenheim Medal (1981)
  - National Security Medal (1983)

Kelly Johnson's 14 Rules of Management
"Be quick, be quiet, and be on time."

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- **Project Manager must be delegated practically complete control of his/her program in all aspects.**
- **Strong but small project offices must be provided both by the military and industry.**
- **The number of people having any connection with the project must be restricted in an almost vicious manner. Use a small number of good people (10% to 25% compared to the so-called normal systems).**
- **Simple drawing and drawing release system with great flexibility for making changes.**
- **A minimum number of reports required, important work must be recorded thoroughly.**
- **Monthly cost review covering not only what has been spent and committed but also projected costs to the conclusion of the program.**
- **Contractor must be delegated and must assume more than normal responsibility.**
- **Basic inspection responsibility to subcontractors and vendors. Don't duplicate so much inspection.**
- **Contractor must be delegated the authority to test his final product in flight.**
- **The specifications applying to the hardware must be agreed to well in advance of contracting.**
- **Funding a program must be timely so that the contractor doesn't have to keep running to the bank.**
- **There must be mutual trust between the military project organization and the contractor with very close cooperation and liaison on a day-to-day basis. This cuts down misunderstanding and correspondence to an absolute minimum.**
- **Access by outsiders to the project and its personnel must be strictly controlled by appropriate security measures.**
- **Because only a few people will be used in engineering and most other areas, ways must be provided to reward good performance by pay not based on the number of personnel supervised.**

Bradford Parkinson (1935-)

- Aero Engineer, Educated USNA, MIT, Stanford Univ. (Ph.D.)
- USAF Col. Retired (1957-1978)
  - >170 combat mission hours in Vietnam
  - Bronze Star, unit citation
  - Aero Prof. at USAFA
- Co-Inventor and Program Manager of the GPS system (1973-1978)
  - Coordinated universal time measurement to 3 ns (~3meters)
- Awards:
  - Draper Prize
  - National Inventor Hall of Fame
  - Member Nat. Acad. of Engineers

Brief History of Time and Position Measurement and Precision

- **~700 BCE Babylonians noted Solar/Lunar 12mo @ ~30 days/mo. cycle = 360 degree numbering system for time and position**
- **~330BCE Aristotle noted that the earth is round**
- **~150BCE Hipparchus divided earth into 360 degrees**
- **~150CE Ptolemy of Alexandria subdivided degree into 60 minutes and 60 seconds**
- **~1400CE Galileo Galilee noted 1 meter pendulum had a 2 second period**
- **1759CE John Harrison designs stable, accurate, mechanical nautical clock to measure Longitude (earth rotates at 15 deg/hr)**
- **1949CE 1st Atomic clock at NIST – nanosecond timing**
- **1978-85 1st GPS satellites launched - <10 meter position accuracy**

20th Century Engineering Milestones

- Exponential Growth in the use of Oil and Natural Gas as Energy sources
- Ubiquitous Electric Power generation and Distribution
- Automobile allows society enhanced mobility
- World-wide Air Transportation
- Telecommunications
- Satellite and Fiber-optic High Bandwidth Communication
- Internet and World Wide Web – Information Access
- Ubiquitous accurate Time & Position (GPS)
- Acceleration of Global Climate Change (CO2)

Challenges for the 21st Century

- **Energy**
  - **Natural Gas, Hybrid Cars, Synfuels, Transition to renewable:**
    - **Wind, Solar, ???**
- **Global Climate Change (Warming)**
  - **Slow CO2 Growth, minimize damage**
  - **Adapt to an already changing climate**
- **Cyber Security, Privacy**
- **Automation, Robotics and human roles in society**

- ***“Teaching is Successful only as it causes people to think for themselves. What the teacher thinks matters little; What he makes the student think matters much”***

- **Alice Moore Hubbard**

Discussion Questions

- How much do you already know?
- Does this history add anything to your understanding of the engineering profession?
- How many of these men were involved with medical research? Compare and contrast their involvements.
- Compare and contrast the ethical issues raised by charges of plagiarism highlighted in these case studies.
- Why were there not any women included in these case studies?
- Compare and contrast the educational backgrounds.
- How many of these individuals conducted their own experimental research?
- How many of these individuals carried their designs to practice?
- Expand on the lives of any of these individuals.
- What do you think the major challenges are in the 21st Century?