

Important Fields of Engineering



Kelley Mccaffrey

First Edition, 2012

ISBN 978-81-323-3606-8

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Published by:

University Publications

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: info@wtbooks.com

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Chapter- 1

Aerospace Engineering

Aerospace engineer



NASA engineers, like the ones depicted in Apollo 13, worked diligently to protect the lives of the astronauts on the mission.

Occupation

Names engineer
aerospace engineer

Type profession

Activity sectors aeronautics, astronautics, science

Description

Competencies technical knowledge, management skills

Education required

Fields of employment technology, science, military

Aerospace engineering is the branch of engineering behind the design, construction and science of aircraft and spacecraft . It is broken into two major and overlapping branches: aeronautical engineering and astronautical engineering. The former deals with craft that stay within Earth's atmosphere, and the latter deals with craft that operate outside of Earth's atmosphere.

While **aeronautical engineering** was the original term, the broader "aerospace" has superseded it in usage, as flight technology advanced to include craft operating in outer space. Aerospace engineering, particularly the astronautics branch, is often informally called rocket science.

Overview

Flight vehicles undergo severe conditions such as differences in atmospheric pressure, and temperature, with structural loads applied upon vehicle components. Consequently, they are usually the products of various technological and engineering disciplines including aerodynamics, propulsion, avionics, materials science, structural analysis and manufacturing. These technologies are collectively known as aerospace engineering. Because of the complexity of the field, aerospace engineering is conducted by a team of engineers, each specializing in their own branches of science.

The development and manufacturing of a modern flight vehicle is an extremely complex process and demands careful balance and compromise between abilities, design, available technology and costs. Aerospace engineers design, test, and supervise the manufacture of aircraft, spacecraft, and missiles. Aerospace engineers develop new technologies for use in aviation, defense systems, and space exploration.

History

Alberto Santos-Dumont, a pioneer who built the first machines able to fly, played an important role in the development of aviation. Some of the first ideas for powered flight may have come from Leonardo da Vinci, who, although he did not build any successful models, did develop many sketches and ideas for "flying machines".

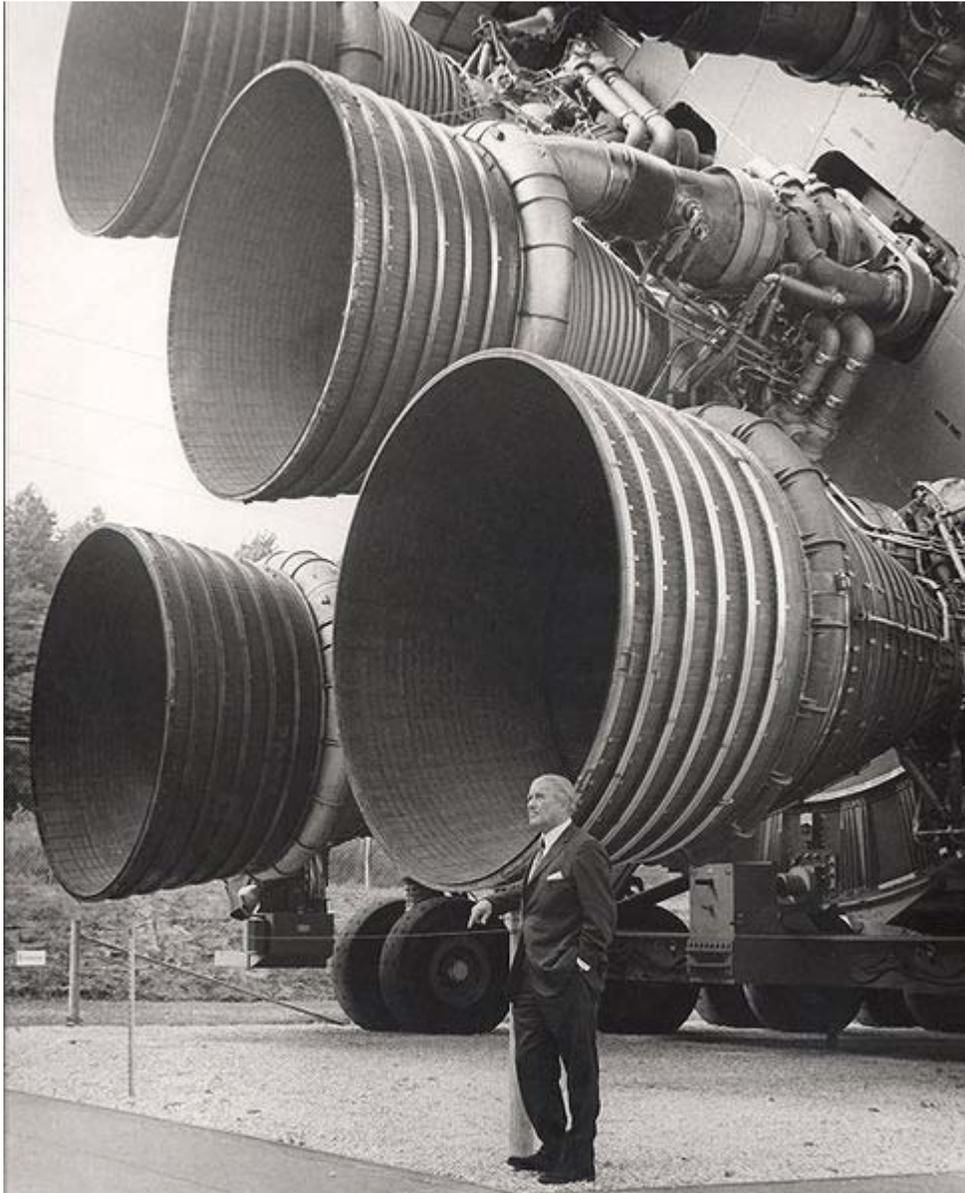


Orville and Wilbur Wright flew the Wright Flyer I, the first airplane, on December 17, 1903 at Kitty Hawk, North Carolina.

The origin of aerospace engineering can be traced back to the aviation pioneers around the late 19th century to early 20th centuries, although the work of Sir George Cayley has recently been dated as being from the last decade of the 18th to mid 19th century. One of the most important people in the history of aeronautics, Cayley was a pioneer in aeronautical engineering and is credited as the first person to separate the forces of lift and drag, which are in effect on any flight vehicle. Early knowledge of aeronautical engineering was largely empirical with some concepts and skills imported from other branches of engineering. Scientists understood some key elements of aerospace engineering, like fluid dynamics, in the 18th century. Several years later after the successful flights by the Wright brothers, the 1910s saw the development of aeronautical engineering through the design of World War I military aircraft.

The first definition of aerospace engineering appeared in February 1958. The definition considered the Earth's atmosphere and the outer space as a single realm, thereby encompassing both aircraft (*aero*) and spacecraft (*space*) under a newly coined word *aerospace*. The National Aeronautics and Space Administration was founded in 1958 as a response to the Cold War. United States aerospace engineers launched the first American satellite on January 31, 1958 in response to the USSR launching Sputnik on October 4, 1957.

Elements



Wernher von Braun, with the F-1 engines of the Saturn V first stage at the US Space and Rocket Center

Some of the elements of aerospace engineering are:



A fighter jet engine undergoing testing. The tunnel behind the engine muffles noise and allows exhaust to escape.

- Fluid mechanics – the study of fluid flow around objects. Specifically aerodynamics concerning the flow of air over bodies such as wings or through objects such as wind tunnels.
- Astrodynamics – the study of orbital mechanics including prediction of orbital elements when given a select few variables. While few schools in the United States teach this at the undergraduate level, several have graduate programs covering this topic (usually in conjunction with the Physics department of said college or university).
- Statics and Dynamics (engineering mechanics) – the study of movement, forces, moments in mechanical systems.
- Mathematics – in particular, calculus, differential equations, and linear algebra.
- Electrotechnology – the study of electronics within engineering.
- Propulsion – the energy to move a vehicle through the air (or in outer space) is provided by internal combustion engines, jet engines and turbomachinery, or rockets. A more recent addition to this module is electric propulsion and ion propulsion.
- Control engineering – the study of mathematical modeling of the dynamic behavior of systems and designing them, usually using feedback signals, so that their dynamic behavior is desirable (stable, without large excursions, with minimum error). This applies to the dynamic behavior of aircraft, spacecraft, propulsion systems, and subsystems that exist on aerospace vehicles.

- Aircraft structures – design of the physical configuration of the craft to withstand the forces encountered during flight. Aerospace engineering aims to keep structures lightweight.
- Materials science – related to structures, aerospace engineering also studies the materials of which the aerospace structures are to be built. New materials with very specific properties are invented, or existing ones are modified to improve their performance.
- Solid mechanics – Closely related to material science is solid mechanics which deals with stress and strain analysis of the components of the vehicle. Nowadays there are several Finite Element programs such as MSC Patran/Nastran which aid engineers in the analytical process.
- Aeroelasticity – the interaction of aerodynamic forces and structural flexibility, potentially causing flutter, divergence, etc.
- Avionics – the design and programming of computer systems on board an aircraft or spacecraft and the simulation of systems.
- Software – the specification, design, development, test, and implementation of computer software for aerospace applications, including flight software, ground control software, test & evaluation software, etc.
- Risk and reliability – the study of risk and reliability assessment techniques and the mathematics involved in the quantitative methods.
- Noise control – the study of the mechanics of sound transfer.
- Flight test – designing and executing flight test programs in order to gather and analyze performance and handling qualities data in order to determine if an aircraft meets its design and performance goals and certification requirements.

The basis of most of these elements lies in theoretical mathematics, such as fluid dynamics for aerodynamics or the equations of motion for flight dynamics. There is also a large empirical component. Historically, this empirical component was derived from testing of scale models and prototypes, either in wind tunnels or in the free atmosphere. More recently, advances in computing have enabled the use of computational fluid dynamics to simulate the behavior of fluid, reducing time and expense spent on wind-tunnel testing.

Additionally, aerospace engineering addresses the integration of all components that constitute an aerospace vehicle (subsystems including power, aerospace bearings, communications, thermal control, life support, etc.) and its life cycle (design, temperature, pressure, radiation, velocity, life time).

Aerospace engineering degrees



Aerospace engineering

Aerospace engineering may be studied at the advanced diploma, bachelor's, master's, and Ph.D. levels in aerospace engineering departments at many universities, and in mechanical engineering departments at others. A few departments offer degrees in space-focused astronautical engineering. The Delft University of Technology (TU Delft) in the Netherlands offers one of the top European aerospace educational and research platforms, while the programs of the Massachusetts Institute of Technology and Rutgers University are two such examples. In 2009, U.S. News & World Report ranked the undergraduate aerospace engineering programs at the Massachusetts Institute of Technology, Georgia Institute of Technology, and the University of Michigan as the top three best programs for doctorate granting universities in the United States. The other programs in the top ten were Purdue University, California Institute of Technology, University of Maryland, University of Illinois, Stanford University, University of Texas at Austin, and Virginia Tech in that order. The magazine also rates Embry-Riddle Aeronautical University, the United States Air Force Academy, and the United States Naval Academy as the premier aerospace engineering programs at universities that do not grant doctorate degrees. University of Kansas School of Engineering has earned more first and second place AIAA awards than any other academic institution in the world in the 42-year history of the competition. Wichita State University is renowned for its Aerospace Engineering program and also has the third highest research budget for Aerospace Engineering in the United States.

In Canada, the University of Toronto has a quality aerospace engineering program. The aerospace program requires the students to go through a competitive program called engineering science. The academic program in aerospace science and engineering at U of

T includes undergraduate and graduate studies. At the graduate level U of T offers research-intensive programs leading to MSc and PhD degrees, and a professionally-oriented program leading to the MEng degree. The scope of U of T's research includes aeronautical engineering (aircraft flight systems, propulsion, aerodynamics, computational fluid dynamics, and structural mechanics) and space systems engineering (spacecraft dynamics and control, space robotics and mechatronics, and microsatellite technology). Carleton University and Ryerson University are other top aerospace and mechanical engineering universities in Canada which offer accredited graduate and under-graduate degrees.

In the UK, Aerospace (or aeronautical) engineering can be studied for the B.Eng., M.Eng., MSc. and Ph.D. levels at a number of universities. The top 10 universities are University of Cambridge, University of Surrey, University of Bristol, University of Southampton, Queens University Belfast, University of Sheffield, Newcastle University, University of Bath, Imperial College London, Loughborough University and University of Nottingham for 2010. The Department of Aeronautics at Imperial College London is noted for providing engineers for the Formula One industry, an industry that uses aerospace technology.

Aerospace can be studied at University of Limerick in Ireland. In Australia, the RMIT University offers Aerospace (or aeronautical) engineering and has more than 60 years teaching experience in this profession. Monash University, University of New South Wales, University of Sydney, University of Queensland, University of Adelaide and Queensland University of Technology also offers Aerospace Engineering.

European universities that are renowned for their teaching and expertise in aerospace engineering include TU Delft in the Netherlands, ISAE, ENAC and ESTACA in France, RWTH Aachen, TU München, the University of Stuttgart, TU Berlin and TU Braunschweig in Germany. In Austria the FH Joanneum. In Portugal the Instituto Superior Técnico. In Spain the Universidad Politecnica de Madrid, the Universidad Carlos III de Madrid, and Universitat Politècnica de Catalunya offer the degree, while in Italy there also several universities where aerospace engineering can be studied including the Politecnico di Torino, the Politecnico di Milano, the University of Pisa, the University of Padua and the Sapienza University of Rome. In Eastern Europe they are the University of Belgrade, the Warsaw University of Technology and Rzeszów University of Technology in Poland and Brno University of Technology in Brno, Czech Republic.

In India IIT Kanpur possesses its own flight test aircraft and airfield for students in the discipline, while the other IITs also offer degrees in this discipline. From academic year 2010 onwards Bengal Engineering and Science University, Shibpur has started offering an undergraduate course Bachelor of Engineering in Aerospace Engineering. university of petroleum and energy studies, dehradun also one of the leading institute. While in China Nanjing Aeronautics and Astronautics University is a regional leader in the field of aerospace engineering education. In Pakistan Aerospace Engineering can be studied at National University of Sciences and Technology at (CAE), at PAF Academy in Risalpur & at Air University which is Pakistan's only university that grants a Doctorate degree in

Aerospace Engineering & Avionics Engineering. In 2002, SUPARCO established IST which is a federally chartered public sector institute of Pakistan offering under graduate and graduate degree in Aerospace Engineering. The MS degree at IST is being offered in collaboration with Beihang University (BUAA), China and Seoul National University, South Korea

Chapter- 2

Genetic Engineering

Genetic engineering, also called **genetic modification**, is the direct human manipulation of an organism's genetic material in a way that does not occur under natural conditions. It involves the use of recombinant DNA techniques, but does not include traditional animal and plant breeding or mutagenesis. Any organism that is generated using these techniques is considered to be a genetically modified organism. The first organisms genetically engineered were bacteria in 1973 and then mice in 1974. Insulin producing bacteria were commercialized in 1982 and genetically modified food has been sold since 1994.

The most common form of genetic engineering involves the insertion of new genetic material at an unspecified location in the host genome. This is accomplished by isolating and copying the genetic material of interest, generating a construct containing all the genetic elements for correct expression, and then inserting this construct into the host organism. Other forms of genetic engineering include gene targeting and knocking out specific genes via engineered nucleases such as zinc finger nucleases or engineered homing endonucleases.

Genetic engineering techniques have been applied in numerous fields including research, biotechnology, and medicine. Medicines such as insulin and human growth hormone are now produced in bacteria, experimental mice such as the oncomouse and the knockout mouse are being used for research purposes and insect resistant and/or herbicide tolerant crops have been commercialized. Genetically engineered plants and animals capable of producing biotechnology drugs more cheaply than current methods (called pharming) are also being developed and in 2009 the FDA approved the sale of the pharmaceutical protein antithrombin produced in the milk of genetically engineered goats.

Definition

Genetic engineering alters the genetic makeup of an organism using techniques that introduce heritable material prepared outside the organism either directly into the host or into a cell that is then fused or hybridized with the host. This involves using recombinant nucleic acid (DNA or RNA) techniques to form new combinations of heritable genetic material followed by the incorporation of that material either indirectly through a vector system or directly through micro-injection, macro-injection and micro-encapsulation

techniques. Genetic engineering does not include traditional animal and plant breeding, in vitro fertilisation, induction of polyploidy, mutagenesis and cell fusion techniques that do not use recombinant nucleic acids or a genetically modified organism in the process. Cloning and stem cell research, although not considered genetic engineering, are closely related and genetic engineering can be used within them. Synthetic biology is an emerging discipline that takes genetic engineering a step further by introducing artificially synthesized genetic material from raw materials into an organism.

If genetic material from another species is added to the host, the resulting organism is called transgenic. If genetic material from the same species or a species that can naturally breed with the host is used the resulting organism is called cisgenic. Genetic engineering can also be used to remove genetic material from the target organism, creating a knock out organism. In Europe genetic modification is synonymous with genetic engineering while within the United States of America it can also refer to conventional breeding methods.

History

Humans have altered the genomes of species for thousands of years through artificial selection and more recently mutagenesis. Genetic engineering as the direct manipulation of DNA by humans outside breeding and mutations has only existed since the 1970s. The term "genetic engineering" was first coined by Jack Williamson in his science fiction novel *Dragon's Island*, published in 1951, one year before DNA's role in heredity was confirmed by Alfred Hershey and Martha Chase, and two years before James Watson and Francis Crick showed that the DNA molecule has a double-helix structure.

In 1972 Paul Berg created the first recombinant DNA molecules by combined DNA from the monkey virus SV40 with that of the lambda virus. In 1973 Herbert Boyer and Stanley Cohen created the first transgenic organism by inserting antibiotic resistance genes into the plasmid of an *E. coli* bacterium. A year later Rudolf Jaenisch created a transgenic mouse by introducing foreign DNA into its embryo, making it the world's first transgenic animal. In 1976 Genentech, the first genetic engineering company was founded by Herbert Boyer and Robert Swanson and a year later and the company produced a human protein (somatostatin) in *E.coli*. Genentech announced the production of genetically engineered human insulin in 1978. In 1980, the U.S. Supreme Court in the *Diamond v. Chakrabarty* case ruled that genetically altered life could be patented. The insulin produced by bacteria, branded humulin, was approved for release by the Food and Drug Administration in 1982.

The first field trials of genetically engineered plants occurred in France and the USA in 1986, tobacco plants were engineered to be resistant to herbicides. The People's Republic of China was the first country to commercialize transgenic plants, introducing a virus-resistant tobacco in 1992. In 1994 Calgene attained approval to commercially release the Flavr Savr tomato, a tomato engineered to have a longer shelf life. In 1994, the European Union approved tobacco engineered to be resistant to the herbicide bromoxynil, making it the first genetically engineered crop commercialized in Europe. In

1995, Bt Potato was approved safe by the Environmental Protection Agency, making it the first pesticide producing crop to be approved in the USA. In 2009 11 transgenic crops were grown commercially in 25 countries, the largest of which by area grown were the USA, Brazil, Argentina, India, Canada, China, Paraguay and South Africa.

In 2010, scientists at the J. Craig Venter Institute, announced that they had created the first synthetic bacterial genome, and added it to a cell containing no DNA. The resulting bacterium, named Synthia, was the world's first synthetic life form.

Process

Isolating the Gene



Elements of genetic engineering

First, the gene to be inserted into the genetically modified organism must be chosen and isolated. Presently, most genes transferred into plants provide protection against insects or tolerance to herbicides. In animals the majority of genes used are growth hormone genes. Once chosen the genes must be isolated. This typically involves multiplying the gene using polymerase chain reaction (PCR). If the chosen gene or the donor organism's genome has been well studied it may be present in a genetic library. If the DNA sequence is known, but no copies of the gene are available, it can be artificially synthesized. Once isolated, the gene is inserted into a bacterial plasmid.

Constructs

The gene to be inserted into the genetically modified organism must be combined with other genetic elements in order for it to work properly. The gene can also be modified at this stage for better expression or effectiveness. As well as the gene to be inserted most constructs contain a promoter and terminator region as well as a selectable marker gene. The promoter region initiates transcription of the gene and can be used to control the location and level of gene expression, while the terminator region ends transcription. The selectable marker, which in most cases confers antibiotic resistance to the organism it is expressed in, is needed to determine which cells are transformed with the new gene. The constructs are made using recombinant DNA techniques, such as restriction digests, ligations and molecular cloning.

Gene Targeting

The most common form of genetic engineering involves inserting new genetic material randomly within the host genome. Other techniques allow new genetic material to be inserted at a specific location in the host genome or generate mutations at desired genomic loci capable of knocking out endogenous genes. The technique of gene targeting uses homologous recombination to target desired changes to a specific endogenous gene. This tends to occur at a relatively low frequency in plants and animals and generally requires the use of selectable markers. The frequency of gene targeting can be greatly enhanced with the use of engineered nucleases such as zinc finger nucleases, engineered homing endonucleases, or nucleases created from TAL effectors. In addition to enhancing gene targeting, engineered nucleases can also be used to introduce mutations at endogenous genes that generate a gene knockout.

Transformation



A. tumefaciens attaching itself to a carrot cell

About 1% of bacteria are naturally able to take up foreign DNA but it can also be induced in other bacteria. Stressing the bacteria for example, with a heat shock or an electric shock, can make the cell membrane permeable to DNA that may then incorporate into

their genome or exist as extrachromosomal DNA. DNA is generally inserted into animal cells using microinjection, where it can be injected through the cells nuclear envelope directly into the nucleus or through the use of viral vectors. In plants the DNA is generally inserted using *Agrobacterium*-mediated recombination or biolistics.

In *Agrobacterium*-mediated recombination the plasmid construct must also contain T-DNA. *Agrobacterium* naturally inserts DNA from a tumor inducing plasmid into any susceptible plant's genome it infects, causing crown gall disease. The T-DNA region of this plasmid is responsible for insertion of the DNA. The genes to be inserted are cloned into a binary vector, which contains T-DNA and can be grown in both *E. Coli* and *Agrobacterium*. Once the binary vector is constructed the plasmid is transformed into *Agrobacterium* containing no plasmids and plant cells are infected. The *Agrobacterium* will then naturally insert the genetic material into the plant cells.

In biolistics particles of gold or tungsten are coated with DNA and then shot into young plant cells or plant embryos. Some genetic material will enter the cells and transform them. This method can be used on plants that are not susceptible to *Agrobacterium* infection and also allows transformation of plant plastids. Another transformation method for plant and animal cells is electroporation. Electroporation involves subjecting the plant or animal cell to an electric shock, which can make the cell membrane permeable to plasmid DNA. In some cases the electroporated cells will incorporate the DNA into their genome. Due to the damage caused to the cells and DNA the transformation efficiency of biolistics and electroporation is lower than agrobacterial mediated transformation and microinjection.

Selection

Not all the organism's cells will be transformed with the new genetic material; in most cases a selectable marker is used to differentiate transformed from untransformed cells. If a cell has been successfully transformed with the DNA it will also contain the marker gene. By growing the cells in the presence of an antibiotic or chemical that selects or marks the cells expressing that gene it is possible to separate the transgenic events from the non-transgenic. Another method of screening involves using a DNA probe that will only stick to the inserted gene. A number of strategies have been developed that can remove the selectable marker from the mature transgenic plant.

Regeneration

As often only a single cell is transformed with genetic material the organism must be regrown from that single cell. As bacteria consist of a single cell and reproduce clonally regeneration is not necessary. In plants this is accomplished through the use of tissue culture. Each plant species has different requirements for successful regeneration through tissue culture. If successful an adult plant is produced that contains the transgene in every cell. In animals it is necessary to ensure that the inserted DNA is present in the embryonic stem cells. When the offspring is produced they can be screened for the

presence of the gene. All offspring from the first generation will be heterozygous for the inserted gene and must be mated together to produce a homozygous animal.

Confirmation

Further tests using PCR, Southern Blots and Bioassays are needed to confirm that the gene is expressed and functions correctly. The organism's offspring are also tested to ensure that the trait can be inherited and that it follows a Mendelian inheritance pattern.

Applications

Genetic engineering has applications in medicine, research, industry and agriculture and can be used on a wide range of plants, animals and micro organism.

Medicine

In medicine genetic engineering has been used to mass-produce insulin, human growth hormones, follistim (for treating infertility), human albumin, monoclonal antibodies, antihemophilic factors, vaccines and many other drugs. Vaccination generally involves injecting weak live, killed or inactivated forms of viruses or their toxins into the person being immunized. Genetically engineered viruses are being developed that can still confer immunity, but lack the infectious sequences. Mouse hybridomas, cells fused together to create monoclonal antibodies, have been humanised through genetic engineering to create human monoclonal antibodies.

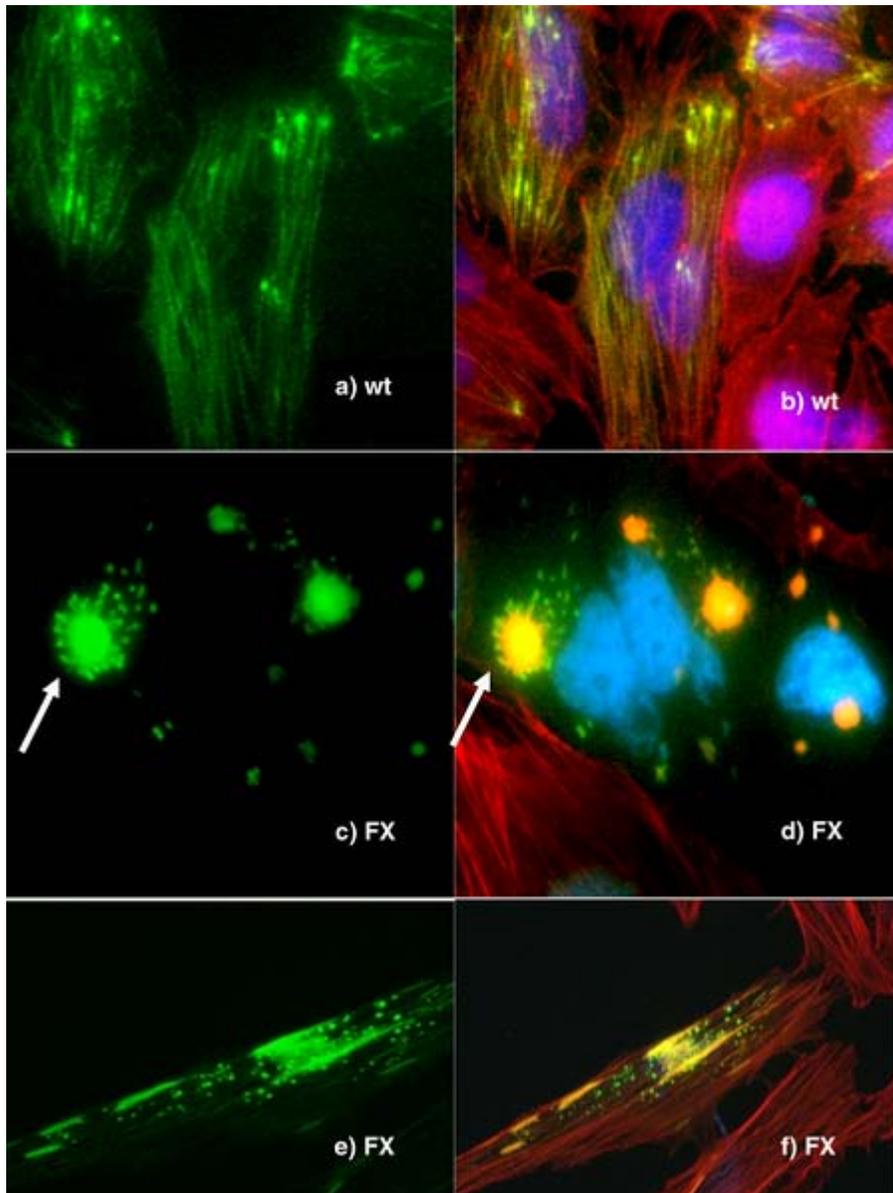
Genetic engineering is used to create animal models of human diseases. Genetically modified mice are the most common genetically engineered animal model. They have been used to study and model cancer (the oncomouse), obesity, heart disease, diabetes, arthritis, substance abuse, anxiety, aging and Parkinson disease. Potential cures can be tested against these mouse models. Also genetically modified pigs have been bred with the aim of increasing the success of pig to human organ transplantation.

Gene therapy is the genetic engineering of humans by replacing defective human genes with functional copies. This can occur in somatic tissue or germline tissue. If the gene is inserted into the germline tissue it can be passed down to that person's descendants. Gene therapy has been used to treat patients suffering from immune deficiencies (notably Severe combined immunodeficiency) and trials have been carried out on other genetic disorders. The success of gene therapy so far has been limited and a patient (Jesse Gelsinger) has died during a clinical trial testing a new treatment. There are also ethical concerns should the technology be used not just for treatment, but for enhancement, modification or alteration of a human beings' appearance, adaptability, intelligence, character or behavior. The distinction between cure and enhancement can also be difficult to establish. Transhumanists consider the enhancement of humans desirable.

Research



Knockout mice



Human cells in which some proteins are fused with green fluorescent protein to allow them to be visualised

Genetic engineering is an important tool for natural scientists. Genes and other genetic information from a wide range of organisms are transformed into bacteria for storage and

modification, creating genetically modified bacteria in the process. Bacteria are cheap, easy to grow, clonal, multiply quickly, relatively easy to transform and can be stored at -80°C almost indefinitely. Once a gene is isolated it can be stored inside the bacteria providing an unlimited supply for research.

Organisms are genetically engineered to discover the functions of certain genes. This could be the effect on the phenotype of the organism, where the gene is expressed or what other genes it interacts with. These experiments generally involve loss of function, gain of function, tracking and expression.

- **Loss of function experiments**, such as in a gene knockout experiment, in which an organism is engineered to lack the activity of one or more genes. A knockout experiment involves the creation and manipulation of a DNA construct *in vitro*, which, in a simple knockout, consists of a copy of the desired gene, which has been altered such that it is non-functional. Embryonic stem cells incorporate the altered gene, which replaces the already present functional copy. These stem cells are injected into blastocysts, which are implanted into surrogate mothers. This allows the experimenter to analyze the defects caused by this mutation and thereby determine the role of particular genes. It is used especially frequently in developmental biology. Another method, useful in organisms such as *Drosophila* (fruit fly), is to induce mutations in a large population and then screen the progeny for the desired mutation. A similar process can be used in both plants and prokaryotes.
- **Gain of function experiments**, the logical counterpart of knockouts. These are sometimes performed in conjunction with knockout experiments to more finely establish the function of the desired gene. The process is much the same as that in knockout engineering, except that the construct is designed to increase the function of the gene, usually by providing extra copies of the gene or inducing synthesis of the protein more frequently.
- **Tracking experiments**, which seek to gain information about the localization and interaction of the desired protein. One way to do this is to replace the wild-type gene with a 'fusion' gene, which is a juxtaposition of the wild-type gene with a reporting element such as green fluorescent protein (GFP) that will allow easy visualization of the products of the genetic modification. While this is a useful technique, the manipulation can destroy the function of the gene, creating secondary effects and possibly calling into question the results of the experiment. More sophisticated techniques are now in development that can track protein products without mitigating their function, such as the addition of small sequences that will serve as binding motifs to monoclonal antibodies.
- **Expression studies** aim to discover where and when specific proteins are produced. In these experiments, the DNA sequence before the DNA that codes for a protein, known as a gene's promoter, is reintroduced into an organism with the protein coding region replaced by a reporter gene such as GFP or an enzyme that catalyzes the production of a dye. Thus the time and place where a particular protein is produced can be observed. Expression studies can be taken a step further by altering the promoter to find which pieces are crucial for the proper

expression of the gene and are actually bound by transcription factor proteins; this process is known as promoter bashing.

Industrial

By engineering genes into bacterial plasmids it is possible to create a biological factory that can produce proteins and enzymes. Some genes do not work well in bacteria, so yeast, a eukaryote, can also be used. Bacteria and yeast factories have been used to produce medicines such as insulin, human growth hormone, and vaccines, supplements such as tryptophan, aid in the production of food (chymosin in cheese making) and fuels. Other applications involving genetically engineered bacteria being investigated involve making the bacteria perform tasks outside their natural cycle, such as cleaning up oil spills, carbon and other toxic waste.

Agriculture



Bt-toxins present in peanut leaves (bottom image) protect it from extensive damage caused by European corn borer larvae (top image).

One of the best-known and controversial applications of genetic engineering is the creation of genetically modified food. There are three generations of genetically modified crops. First generation crops have been commercialized and most provide protection from insects and/or resistance to herbicides. There are also fungal and virus resistant crops developed or in development. They have been developed to make the insect and weed management of crops easier and can indirectly increase crop yield.

The second generation of genetically modified crops being developed aim to directly improve yield by improving salt, cold or drought tolerance and to increase the nutritional value of the crops. The third generation consists of pharmaceutical crops, crops that

contain edible vaccines and other drugs. Some agriculturally important animals have been genetically modified with growth hormones to increase their size while others have been engineered to express drugs and other proteins in their milk.

The genetic engineering of agricultural crops can increase the growth rates and resistance to different diseases caused by pathogens and parasites. This is beneficial as it can greatly increase the production of food sources with the usage of fewer resources that would be required to host the world's growing populations. These modified crops would also reduce the usage of chemicals, such as fertilizers and pesticides, and therefore decrease the severity and frequency of the damages produced by these chemical pollution.

Ethical and safety concerns have been raised around the use of genetically modified food. A major safety concern relates to the human health implications of eating genetically modified food, in particular whether toxic or allergic reactions could occur. Gene flow into related non-transgenic crops, off target effects on beneficial organisms and the impact on biodiversity are important environmental issues. Ethical concerns involve religious issues, corporate control of the food supply, intellectual property rights and the level of labeling needed on genetically modified products.

Other uses

In materials science, a genetically modified virus has been used to construct a more environmentally friendly lithium-ion battery. Some bacteria have been genetically engineered to create black and white photographs while others have potential to be used as sensors by expressing a fluorescent protein under certain environmental conditions. Genetic engineering is also being used to create BioArt and novelty items such as blue roses, and glowing fish.

Opposition and criticism

A 2010 study of Canola found transgenes in 80% of wild (uncultivated or "feral") varieties in North Dakota, meaning 80% of the plants which had established themselves in the area were genetically engineered varieties. The researchers stated that "we found the highest densities of [such transgene-containing] plants near agricultural fields and along major freeways, but we were also finding plants in the middle of nowhere" adding that "over time,..the build-up of different types of herbicide resistance in feral [natural] canola and closely related weeds, like field mustard, could make it more difficult to manage these plants using herbicides."

Chapter- 3

Civil Engineering



The Petronas Twin Towers, designed by architect Cesar Pelli and Thornton-Tomasetti and Ranhill Bersekutu Sdn Bhd engineers, were the world's tallest buildings from 1998 to 2004.

Civil engineering is a professional engineering discipline that deals with the design, construction, and maintenance of the physical and naturally built environment, including works like bridges, roads, canals, dams, and buildings. Civil engineering is the oldest engineering discipline after military engineering, and it was defined to distinguish non-military engineering from military engineering. It is traditionally broken into several sub-disciplines including environmental engineering, geotechnical engineering, structural engineering, transportation engineering, municipal or urban engineering, water resources engineering, materials engineering, coastal engineering, surveying, and construction engineering. Civil engineering takes place on all levels: in the public sector from municipal through to federal levels, and in the private sector from individual homeowners through to international companies.

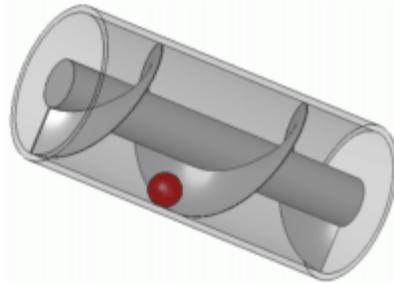
History of the civil engineering profession



The Falkirk Wheel in Scotland.

Engineering has been an aspect of life since the beginnings of human existence. The earliest practices of Civil engineering may have commenced between 4000 and 2000 BC in Ancient Egypt and Mesopotamia (Ancient Iraq) when humans started to abandon a nomadic existence, thus causing a need for the construction of shelter. During this time, transportation became increasingly important leading to the development of the wheel and sailing.

Until modern times there was no clear distinction between civil engineering and architecture, and the term engineer and architect were mainly geographical variations referring to the same person, often used interchangeably. The construction of Pyramids in Egypt (circa 2700-2500 BC) might be considered the first instances of large structure constructions. Other ancient historic civil engineering constructions include the Parthenon by Iktinos in Ancient Greece (447-438 BC), the Appian Way by Roman engineers (c. 312 BC), the Great Wall of China by General Meng T'ien under orders from Ch'in Emperor Shih Huang Ti (c. 220 BC) and the stupas constructed in ancient Sri Lanka like the Jetavanaramaya and the extensive irrigation works in Anuradhapura. The Romans developed civil structures throughout their empire, including especially aqueducts, insulae, harbours, bridges, dams and roads.



The Archimedes screw was operated by hand and could raise water efficiently.

In the 18th century, the term civil engineering was coined to incorporate all things civilian as opposed to military engineering. The first self-proclaimed civil engineer was John Smeaton who constructed the Eddystone Lighthouse. In 1771 Smeaton and some of his colleagues formed the Smeatonian Society of Civil Engineers, a group of leaders of the profession who met informally over dinner. Though there was evidence of some technical meetings, it was little more than a social society.

In 1818 the Institution of Civil Engineers was founded in London, and in 1820 the eminent engineer Thomas Telford became its first president. The institution received a Royal Charter in 1828, formally recognising civil engineering as a profession. Its charter defined civil engineering as:

the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and lighthouses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and application of machinery, and in the drainage of cities and towns.

The first private college to teach Civil Engineering in the United States was Norwich University founded in 1819 by Captain Alden Partridge. The first degree in Civil Engineering in the United States was awarded by Rensselaer Polytechnic Institute in

1835. The first such degree to be awarded to a woman was granted by Cornell University to Nora Stanton Blatch in 1905.

History of civil engineering



Pont du Gard, France, a Roman aqueduct built circa 19 BC.

Civil engineering is the application of physical and scientific principles, and its history is intricately linked to advances in understanding of physics and mathematics throughout history. Because civil engineering is a wide ranging profession, including several separate specialized sub-disciplines, its history is linked to knowledge of structures, materials science, geography, geology, soils, hydrology, environment, mechanics and other fields.

Throughout ancient and medieval history most architectural design and construction was carried out by artisans, such as stone masons and carpenters, rising to the role of master builder. Knowledge was retained in guilds and seldom supplanted by advances. Structures, roads and infrastructure that existed were repetitive, and increases in scale were incremental.

One of the earliest examples of a scientific approach to physical and mathematical problems applicable to civil engineering is the work of Archimedes in the 3rd century

BC, including Archimedes Principle, which underpins our understanding of buoyancy, and practical solutions such as Archimedes' screw. Brahmagupta, an Indian mathematician, used arithmetic in the 7th century AD, based on Hindu-Arabic numerals, for excavation (volume) computations.

The civil engineer

Education and licensure



The Institution of Civil Engineers headquarters in London

Civil engineers typically possess an academic degree with a major in civil engineering. The length of study for such a degree is usually three to five years and the completed degree is usually designated as a Bachelor of Engineering, though some universities designate the degree as a Bachelor of Science. The degree generally includes units covering physics, mathematics, project management, design and specific topics in civil engineering. Initially such topics cover most, if not all, of the sub-disciplines of civil engineering. Students then choose to specialize in one or more sub-disciplines towards the end of the degree. While an Undergraduate (BEng/BSc) Degree will normally provide successful students with industry accredited qualification, some universities offer postgraduate engineering awards (MEng/MSc) which allow students to further specialize in their particular area of interest within engineering.

In most countries, a Bachelor's degree in engineering represents the first step towards professional certification and the degree program itself is certified by a professional body. After completing a certified degree program the engineer must satisfy a range of requirements (including work experience and exam requirements) before being certified. Once certified, the engineer is designated the title of Professional Engineer (in the United States, Canada and South Africa), Chartered Engineer (in most Commonwealth countries), Chartered Professional Engineer (in Australia and New Zealand), or European Engineer (in much of the European Union). There are international engineering agreements between relevant professional bodies which are designed to allow engineers to practice across international borders.

The advantages of certification vary depending upon location. For example, in the United States and Canada "only a licensed engineer may prepare, sign and seal, and submit engineering plans and drawings to a public authority for approval, or seal engineering work for public and private clients.". This requirement is enforced by state and provincial legislation such as Quebec's Engineers Act. In other countries, no such legislation exists. In Australia, state licensing of engineers is limited to the state of Queensland. Practically all certifying bodies maintain a code of ethics that they expect all members to abide by or risk expulsion. In this way, these organizations play an important role in maintaining ethical standards for the profession. Even in jurisdictions where certification has little or no legal bearing on work, engineers are subject to contract law. In cases where an engineer's work fails he or she may be subject to the tort of negligence and, in extreme cases, the charge of criminal negligence. An engineer's work must also comply with numerous other rules and regulations such as building codes and legislation pertaining to environmental law.

Careers

There is no one typical career path for civil engineers. Most people who graduate with civil engineering degrees start with jobs that require a low level of responsibility, and as the new engineers prove their competence, they are trusted with tasks that have larger consequences and require a higher level of responsibility. However, within each branch of civil engineering career path options vary. In some fields and firms, entry-level engineers are put to work primarily monitoring construction in the field, serving as the "eyes and ears" of senior design engineers; while in other areas, entry-level engineers perform the more routine tasks of analysis or design and interpretation. Experienced engineers generally do more complex analysis or design work, or management of more complex design projects, or management of other engineers, or into specialized consulting, including forensic engineering.

Sub-disciplines

In general, civil engineering is concerned with the overall interface of human created fixed projects with the greater world. General civil engineers work closely with surveyors and specialized civil engineers to fit and serve fixed projects within their given site, community and terrain by designing grading, drainage, pavement, water supply, sewer

service, electric and communications supply, and land divisions. General engineers spend much of their time visiting project sites, developing community consensus, and preparing construction plans. General civil engineering is also referred to as site engineering, a branch of civil engineering that primarily focuses on converting a tract of land from one usage to another. Civil engineers typically apply the principles of geotechnical engineering, structural engineering, environmental engineering, transportation engineering and construction engineering to residential, commercial, industrial and public works projects of all sizes and levels of construction.

Coastal engineering

Coastal engineering is concerned with managing coastal areas. In some jurisdictions the terms sea defense and coastal protection are used to mean, respectively, defence against flooding and erosion. The term coastal defence is the more traditional term, but coastal management has become more popular as the field has expanded to include techniques that allow erosion to claim land.



Building construction for several apartment blocks

Construction engineering

Construction engineering involves planning and execution of the designs from transportation, site development, hydraulic, environmental, structural and geotechnical engineers. As construction firms tend to have higher business risk than other types of

civil engineering firms, many construction engineers tend to take on a role that is more business-like in nature: drafting and reviewing contracts, evaluating logistical operations, and closely-monitoring prices of necessary supplies.

Earthquake engineering

Earthquake engineering covers ability of various structures to withstand hazardous earthquake exposures at the sites of their particular location.



Earthquake-proof and massive pyramid El Castillo, Chichen Itza

Earthquake engineering is a sub discipline of the broader category of Structural engineering. The main objectives of earthquake engineering are:



Snapshot from shake-table video of testing base-isolated (right) and regular (left) building model

- Understand interaction of structures with the shaky ground.
- Foresee the consequences of possible earthquakes.
- Design, construct and maintain structures to perform at earthquake exposure up to the expectations and in compliance with building codes.

Environmental engineering



A filter bed, a part of sewage treatment

Environmental engineering deals with the treatment of chemical, biological, and/or thermal waste, the purification of water and air, and the remediation of contaminated sites, due to prior waste disposal or accidental contamination. Among the topics covered by environmental engineering are pollutant transport, water purification, waste water treatment, air pollution, solid waste treatment and hazardous waste management. Environmental engineers can be involved with pollution reduction, green engineering, and industrial ecology. Environmental engineering also deals with the gathering of information on the environmental consequences of proposed actions and the assessment of effects of proposed actions for the purpose of assisting society and policy makers in the decision making process.

Environmental engineering is the contemporary term for sanitary engineering, though sanitary engineering traditionally had not included much of the hazardous waste management and environmental remediation work covered by the term *environmental engineering*. Some other terms in use are public health engineering and environmental health engineering.

Geotechnical engineering



Construction of an Embankment Dam in Navarra, Spain

Geotechnical engineering is an area of civil engineering concerned with the rock and soil that civil engineering systems are supported by. Knowledge from the fields of geology, material science and testing, mechanics, and hydraulics are applied by geotechnical engineers to safely and economically design foundations, retaining walls, and similar structures. Environmental concerns in relation to groundwater and waste disposal have spawned a new area of study called geoenvironmental engineering where biology and chemistry are important.

Some of the unique difficulties of geotechnical engineering are the result of the variability and properties of soil. Boundary conditions are often well defined in other

branches of civil engineering, but with soil, clearly defining these conditions can be impossible. The material properties and behavior of soil are also difficult to predict due to the variability of soil and limited investigation. This contrasts with the relatively well defined material properties of steel and concrete used in other areas of civil engineering. Soil mechanics, which describes the behavior of soil, is also complicated because soils exhibit nonlinear (stress-dependent) strength, stiffness, and dilatancy (volume change associated with application of shear stress).

Water resources engineering



Hoover dam

Water resources engineering is concerned with the collection and management of water (as a natural resource). As a discipline it therefore combines hydrology, environmental science, meteorology, geology, conservation, and resource management. This area of civil engineering relates to the prediction and management of both the quality and the quantity of water in both underground (aquifers) and above ground (lakes, rivers, and streams) resources. Water resource engineers analyze and model very small to very large areas of the earth to predict the amount and content of water as it flows into, through, or out of a facility. Although the actual design of the facility may be left to other engineers. Hydraulic engineering is concerned with the flow and conveyance of fluids, principally water. This area of civil engineering is intimately related to the design of pipelines, water supply network, drainage facilities (including bridges, dams, channels, culverts, levees,

storm sewers), and canals. Hydraulic engineers design these facilities using the concepts of fluid pressure, fluid statics, fluid dynamics, and hydraulics, among others.

Materials engineering

Another aspect of Civil engineering is materials science. Material engineering deals with ceramics such as concrete, mix asphalt concrete, metals Focus around increased strength, metals such as aluminum and steel, and polymers such as polymethylmethacrylate (PMMA) and carbon fibers.

Materials engineering also consists of protection and prevention like paints and finishes. Alloying is another aspect of material engineering, combining two different types of metals to produce a stronger metal.

Structural engineering



Burj Khalifa, the world's tallest building, in Dubai



Clifton Suspension Bridge, designed by Isambard Kingdom Brunel, in Bristol, UK

Structural engineering is concerned with the structural design and structural analysis of buildings, bridges, towers, flyovers, tunnels, off shore structures like oil and gas fields in the sea, and other structures. This involves identifying the loads which act upon a structure and the forces and stresses which arise within that structure due to those loads, and then designing the structure to successfully support and resist those loads. The loads can be self weight of the structures, other dead load, live loads, moving (wheel) load, wind load, earthquake load, load from temperature change etc. The structural engineer must design structures to be safe for their users and to successfully fulfill the function they are designed for (to be *serviceable*). Due to the nature of some loading conditions, sub-disciplines within structural engineering have emerged, including wind engineering and earthquake engineering.

Design considerations will include strength, stiffness, and stability of the structure when subjected to loads which may be static, such as furniture or self-weight, or dynamic, such as wind, seismic, crowd or vehicle loads, or transitory, such as temporary construction loads or impact. Other considerations include cost, constructability, safety, aesthetics and sustainability.

Surveying



US Navy Surveyor at work with a leveling instrument.

Surveying is the process by which a surveyor measures certain dimensions that generally occur on the surface of the Earth. Surveying equipment, such as levels and theodolites, are used for accurate measurement of angular deviation, horizontal, vertical and slope distances. With computerisation, electronic distance measurement (EDM), total stations, GPS surveying and laser scanning have supplemented (and to a large extent supplanted) the traditional optical instruments. This information is crucial to convert the data into a graphical representation of the Earth's surface, in the form of a map. This information is then used by civil engineers, contractors and even realtors to design from, build on, and trade, respectively. Elements of a building or structure must be correctly sized and positioned in relation to each other and to site boundaries and adjacent structures. Although surveying is a distinct profession with separate qualifications and licensing arrangements, civil engineers are trained in the basics of surveying and mapping, as well as geographic information systems. Surveyors may also lay out the routes of railways, tramway tracks, highways, roads, pipelines and streets as well as position other infrastructures, such as harbors, before construction.

Land Surveying

In the United States, Canada, the United Kingdom and most Commonwealth countries land surveying is considered to be a distinct profession. Land surveyors are not considered to be engineers, and have their own professional associations and licencing requirements. The services of a licenced land surveyor are generally required for boundary surveys (to establish the boundaries of a parcel using its legal description) and subdivision plans (a plot or map based on a survey of a parcel of land, with boundary

lines drawn inside the larger parcel to indicated the creation of new boundary lines and roads), both of which are generally referred to as cadastral surveying.

Construction Surveying

Construction surveying is generally performed by specialised technicians. Unlike land surveyors, the resulting plan does not have legal status. Construction surveyors perform the following tasks:

- Survey existing conditions of the future work site, including topography, existing buildings and infrastructure, and even including underground infrastructure whenever possible;
- Construction surveying (otherwise "lay-out" or "setting-out"): to stake out reference points and markers that will guide the construction of new structures such as roads or buildings for subsequent construction;
- Verify the location of structures during construction;
- As-Built surveying: a survey conducted at the end of the construction project to verify that the work authorized was completed to the specifications set on plans.

Transportation engineering

Transportation engineering is concerned with moving people and goods efficiently, safely, and in a manner conducive to a vibrant community. This involves specifying, designing, constructing, and maintaining transportation infrastructure which includes streets, canals, highways, rail systems, airports, ports, and mass transit. It includes areas such as transportation design, transportation planning, traffic engineering, some aspects of urban engineering, queueing theory, pavement engineering, Intelligent Transportation System (ITS), and infrastructure management.

Municipal or urban engineering

Municipal engineering is concerned with municipal infrastructure. This involves specifying, designing, constructing, and maintaining streets, sidewalks, water supply networks, sewers, street lighting, municipal solid waste management and disposal, storage depots for various bulk materials used for maintenance and public works (salt, sand, etc.), public parks and bicycle paths. In the case of underground utility networks, it may also include the civil portion (conduits and access chambers) of the local distribution networks of electrical and telecommunications services. It can also include the optimizing of waste collection and bus service networks. Some of these disciplines overlap with other civil engineering specialties, however municipal engineering focuses on the coordination of these infrastructure networks and services, as they are often built simultaneously, and managed by the same municipal authority.

Chapter- 4

Security Engineering

Security engineering is a specialized field of engineering that focuses on the security aspects in the design of systems that need to be able to deal robustly with possible sources of disruption, ranging from natural disasters to malicious acts. It is similar to other systems engineering activities in that its primary motivation is to support the delivery of engineering solutions that satisfy pre-defined functional and user requirements, but with the added dimension of preventing misuse and malicious behavior. These constraints and restrictions are often asserted as a security policy.

In one form or another, security engineering has existed as an informal field of study for several centuries. For example, the fields of locksmithing and security printing have been around for many years.

Due to recent catastrophic events, most notably 9/11, Security Engineering has quickly become a rapidly growing field. In fact, in a recent report completed in 2006, it was estimated that the global security industry was valued at US\$150 billion.

Security engineering involves aspects of social science, psychology (such as designing a system to 'fail well' instead of trying to eliminate all sources of error) and economics, as well as physics, chemistry, mathematics, architecture and landscaping. Some of the techniques used, such as fault tree analysis, are derived from safety engineering.

Other techniques such as cryptography were previously restricted to military applications. One of the pioneers of security engineering as a formal field of study is Ross Anderson.

Qualifications

Typical qualifications for a security engineer are:

- Security+ - Entry Level
- Professional Engineer, Chartered Engineer, Chartered Professional Engineer
- Certified Protection Professional (CPP) - International certification by ASIS International
- Physical Security Professional (PSP) - International certification by ASIS International

- Certified Information Systems Security Professional (CISSP)

However, multiple qualifications, or several qualified persons working together, may provide a more complete solution.

Security stance

The two possible default positions on security matters are:

1. **Default deny** - "Everything, not explicitly permitted, is forbidden"

Improves security at a cost in functionality.

This is a good approach if you have lots of security threats.

2. **Default permit** - "Everything, not explicitly forbidden, is permitted"

Allows greater functionality by sacrificing security.

This is only a good approach in an environment where security threats are non-existent or negligible.

Core practices

- Security Requirements Analysis
- Security architecture
- Secure coding
- Security testing
- Security Operations and Maintenance
- Economics of security

Sub-fields

- Physical security
 - deter attackers from accessing a facility, resource, or information stored on physical media.
- Information security
 - protecting data from unauthorized access, use, disclosure, destruction, modification, or disruption to access.
- Economics of security
 - the economic aspects of economics of privacy and computer security.

Methodologies

Technological advances, principally in the field of computers, have now allowed the creation of far more complex systems, with new and complex security problems. Because modern systems cut across many areas of human endeavor, security engineers not only need consider the mathematical and physical properties of systems; they also need to consider attacks on the people who use and form parts of those systems using social engineering attacks. Secure systems have to resist not only technical attacks, but also coercion, fraud, and deception by confidence tricksters.

Web applications

According to the *Microsoft Developer Network* the patterns & practices of Security Engineering consists of the following activities:

- Security Objectives
- Security Design Guidelines
- Security Modeling
- Security Architecture and Design Review
- Security Code Review
- Security Testing
- Security Tuning
- Security Deployment Review

These activities are designed to help meet security objectives in the software life cycle.

Physical



Canadian Embassy in Washington, D.C. showing planters being used as vehicle barriers, and barriers and gates along the vehicle entrance

- Understanding of a *typical* threat and the usual risks to people and property.
- Understanding the incentives created both by the threat and the countermeasures.
- Understanding risk and threat analysis methodology and the benefits of an empirical study of the physical security of a facility.
- Understanding how to apply the methodology to buildings, critical infrastructure, ports, public transport and other facilities/compounds.
- Overview of common physical and technological methods of protection and understanding their roles in deterrence, detection and mitigation.
- Determining and prioritizing security needs and aligning them with the perceived threats and the available budget.

Target hardening

Whatever the target, there are multiple ways of preventing penetration by unwanted or unauthorised persons. Methods include placing Jersey barriers, stairs or other sturdy obstacles outside tall or politically sensitive buildings to prevent car and truck bombings. Improving the method of visitor management and some new electronic locks take

advantage of technologies such as fingerprint scanning, iris or retinal scanning, and voiceprint identification to authenticate users.

Employers of security engineers

- US Department of State, Bureau of Diplomatic Security (ABET certified institution degree in engineering or physics required)

Criticisms

Use of the term engineer

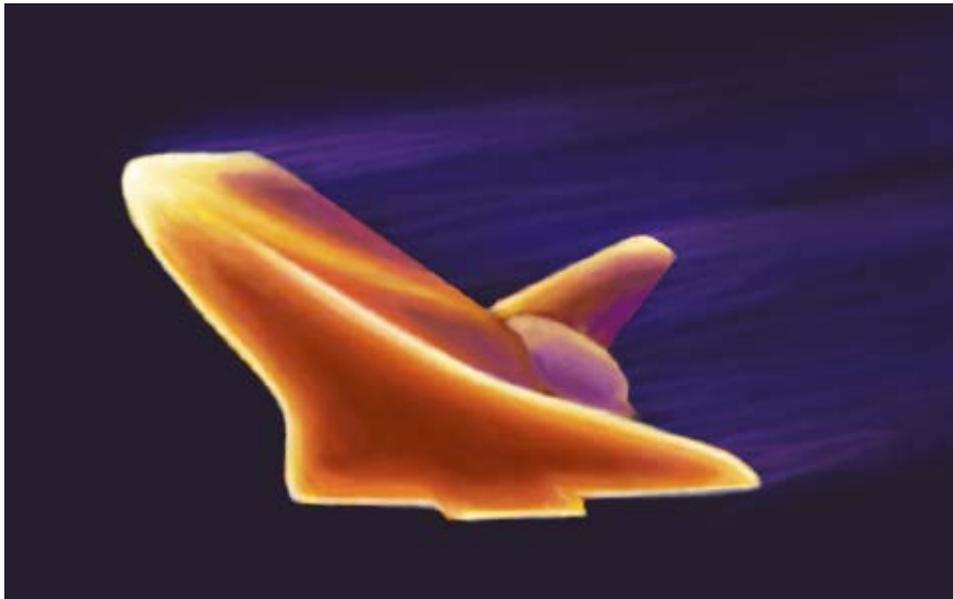
Some criticize this field as not being a bona fide field of engineering because the methodologies of this field are less formal or excessively ad-hoc compared to other fields and many in the practice of security engineering have no engineering degree.

Security engineering as a systems engineering discipline

Security engineering is not considered to be a true form of systems engineering by some . Part of the problem lies in the fact that while conforming to positive requirements is well understood; conforming to negative requirements requires complex and indirect posturing to reach a closed form solution. In fact, some rigorous methods do exist to address these difficulties but are seldom used, partly because they are viewed as too old or too complex by many practitioners. As a result, many ad-hoc approaches simply do not succeed.

Chapter- 5

Materials Science



Outside of the Space Shuttle as it heats up to over 1,500 °C (2,730 °F) during re-entry into the Earth's atmosphere

Materials science is an interdisciplinary field applying the properties of matter to various areas of science and engineering. This scientific field investigates the relationship between the structure of materials at atomic or molecular scales and their macroscopic properties. It incorporates elements of applied physics and chemistry. With significant media attention focused on nanoscience and nanotechnology in recent years, materials science has been propelled to the forefront at many universities. It is also an important part of forensic engineering and failure analysis. Materials science also deals with *fundamental properties* and *characteristics* of materials.

History

The material of choice of a given era is often its defining point. Phrases such as Stone Age, Bronze Age, and Steel Age are good examples. Originally deriving from the manufacture of ceramics and its putative derivative metallurgy, materials science is one of the oldest forms of engineering and applied science. Modern materials science evolved directly from metallurgy, which itself evolved from mining and (likely) ceramics and the use of fire. A major breakthrough in the understanding of materials occurred in the late 19th century, when the American scientist Josiah Willard Gibbs demonstrated that the thermodynamic properties related to atomic structure in various phases are related to the physical properties of a material. Important elements of modern materials science are a product of the space race: the understanding and engineering of the metallic alloys, and silica and carbon materials, used in the construction of space vehicles enabling the exploration of space. Materials science has driven, and been driven by, the development of revolutionary technologies such as plastics, semiconductors, and biomaterials.

Before the 1960s (and in some cases decades after), many *materials science* departments were named *metallurgy* departments, from a 19th and early 20th century emphasis on metals. The field has since broadened to include every class of materials, including: ceramics, polymers, semiconductors, magnetic materials, medical implant materials and biological materials (materiomics).

Fundamentals

The basis of materials science involves relating the desired properties and relative performance of a material in a certain application to the structure of the atoms and phases in that material through characterization. The major determinants of the structure of a material and thus of its properties are its constituent chemical elements and the way in which it has been processed into its final form. These characteristics, taken together and related through the laws of thermodynamics, govern a material's microstructure, and thus its properties.

The manufacture of a perfect crystal of a material is currently physically impossible. Instead materials scientists manipulate the defects in crystalline materials such as precipitates, grain boundaries (Hall-Petch relationship), interstitial atoms, vacancies or substitutional atoms, to create materials with the desired properties.

Not all materials have a regular crystal structure. Polymers display varying degrees of crystallinity, and many are completely non-crystalline. Glasses, some ceramics, and many natural materials are amorphous, not possessing any long-range order in their atomic arrangements. The study of polymers combines elements of chemical and statistical thermodynamics to give thermodynamic, as well as mechanical, descriptions of physical properties.

In addition to industrial interest, materials science has gradually developed into a field which provides tests for condensed matter or solid state theories. New physics emerge because of the diverse new material properties which need to be explained.

Materials in industry

Radical materials advances can drive the creation of new products or even new industries, but stable industries also employ materials scientists to make incremental improvements and troubleshoot issues with currently used materials. Industrial applications of materials science include materials design, cost-benefit tradeoffs in industrial production of materials, processing techniques (casting, rolling, welding, ion implantation, crystal growth, thin-film deposition, sintering, glassblowing, etc.), and analytical techniques (characterization techniques such as electron microscopy, x-ray diffraction, calorimetry, nuclear microscopy (HEFIB), Rutherford backscattering, neutron diffraction, small-angle X-ray scattering (SAXS), etc.

Besides material characterization, the material scientist/engineer also deals with the extraction of materials and their conversion into useful forms. Thus ingot casting, foundry techniques, blast furnace extraction, and electrolytic extraction are all part of the required knowledge of a metallurgist/engineer. Often the presence, absence or variation of minute quantities of secondary elements and compounds in a bulk material will have a great impact on the final properties of the materials produced, for instance, steels are classified based on 1/10th and 1/100 weight percentages of the carbon and other alloying elements they contain. Thus, the extraction and purification techniques employed in the extraction of iron in the blast furnace will have an impact of the quality of steel that may be produced.

The overlap between physics and materials science has led to the offshoot field of *materials physics*, which is concerned with the physical properties of materials. The approach is generally more macroscopic and applied than in condensed matter physics.

Metal alloys

The study of metal alloys is a significant part of materials science. Of all the metallic alloys in use today, the alloys of iron (steel, stainless steel, cast iron, tool steel, alloy steels) make up the largest proportion both by quantity and commercial value. Iron alloyed with various proportions of carbon gives low, mid and high carbon steels. For the steels, the hardness and tensile strength of the steel is directly related to the amount of carbon present, with increasing carbon levels also leading to lower ductility and toughness. The addition of silicon and graphitization will produce cast irons (although some cast irons are made precisely with no graphitization). The addition of chromium, nickel and molybdenum to carbon steels (more than 10%) gives us stainless steels.

Other significant metallic alloys are those of aluminium, titanium, copper and magnesium. Copper alloys have been known for a long time (since the Bronze Age), while the alloys of the other three metals have been relatively recently developed. Due to the chemical reactivity of these metals, the electrolytic extraction processes required were only developed relatively recently. The alloys of aluminium, titanium and magnesium are also known and valued for their high strength-to-weight ratios and, in the case of magnesium, their ability to provide electromagnetic shielding. These materials are ideal

for situations where high strength-to-weight ratios are more important than bulk cost, such as in the aerospace industry and certain automotive engineering applications.

Polymers

Polymers are also an important part of materials science. Polymers are the raw materials (the resins) used to make what we commonly call plastics. Plastics are really the final product, created after one or more polymers or additives have been added to a resin during processing, which is then shaped into a final form. Polymers which have been around, and which are in current widespread use, include polyethylene, polypropylene, PVC, polystyrene, nylons, polyesters, acrylics, polyurethanes, and polycarbonates. Plastics are generally classified as "commodity", "specialty" and "engineering" plastics.

PVC (polyvinyl-chloride) is widely used, inexpensive, and annual production quantities are large. It lends itself to an incredible array of applications, from artificial leather to electrical insulation and cabling, packaging and containers. Its fabrication and processing are simple and well-established. The versatility of PVC is due to the wide range of plasticisers and other additives that it accepts. The term "additives" in polymer science refers to the chemicals and compounds added to the polymer base to modify its material properties.

Polycarbonate would be normally considered an engineering plastic (other examples include PEEK, ABS). Engineering plastics are valued for their superior strengths and other special material properties. They are usually not used for disposable applications, unlike commodity plastics.

Specialty plastics are materials with unique characteristics, such as ultra-high strength, electrical conductivity, electro-fluorescence, high thermal stability, etc.

The dividing lines between the various types of plastics is not based on material but rather on their properties and applications. For instance, polyethylene (PE) is a cheap, low friction polymer commonly used to make disposable shopping bags and trash bags, and is considered a commodity plastic, whereas Medium-Density Polyethylene MDPE is used for underground gas and water pipes, and another variety called Ultra-high Molecular Weight Polyethylene UHMWPE is an engineering plastic which is used extensively as the glide rails for industrial equipment and the low-friction socket in implanted hip joints.

Ceramics and glasses

Composite materials

Another application of material science in industry is the making of composite materials. Composite materials are structured materials composed of two or more macroscopic phases. Applications range from structural elements such as steel-reinforced concrete, to the thermally insulative tiles which play a key and integral role in NASA's Space Shuttle

thermal protection system which is used to protect the surface of the shuttle from the heat of re-entry into the Earth's atmosphere. One example is Reinforced Carbon-Carbon (RCC), The light gray material which withstands reentry temperatures up to 1510 °C (2750 °F) and protects the Space Shuttle's wing leading edges and nose cap. RCC is a laminated composite material made from graphite rayon cloth and impregnated with a phenolic resin. After curing at high temperature in an autoclave, the laminate is pyrolyzed to convert the resin to carbon, impregnated with furfural alcohol in a vacuum chamber, and cured/pyrolyzed to convert the furfural alcohol to carbon. In order to provide oxidation resistance for reuse capability, the outer layers of the RCC are converted to silicon carbide.

Other examples can be seen in the "plastic" casings of television sets, cell-phones and so on. These plastic casings are usually a composite material made up of a thermoplastic matrix such as acrylonitrile-butadiene-styrene (ABS) in which calcium carbonate chalk, talc, glass fibres or carbon fibres have been added for added strength, bulk, or electrostatic dispersion. These additions may be referred to as reinforcing fibres, or dispersants, depending on their purpose.

Classes of materials

Materials science encompasses various classes of materials, each of which may constitute a separate field. Materials are sometimes classified by the type of bonding present between the atoms:

1. Ionic crystals
2. Covalent crystals
3. Metals
4. Intermetallics
5. Semiconductors
6. Polymers
7. Composite materials
8. Vitreous materials

Overview

- Nanotechnology – rigorously, the study of materials where the effects of quantum confinement, the Gibbs-Thomson effect, or any other effect only present at the nanoscale is the defining property of the material; but more commonly, it is the creation and study of materials whose defining structural properties are anywhere from less than a nanometer to one hundred nanometers in scale, such as molecularly engineered materials.
- Microtechnology - study of materials and processes and their interaction, allowing microfabrication of structures of micrometric dimensions, such as MicroElectroMechanical Systems (MEMS).

- Crystallography – the study of how atoms in a solid fill space, the defects associated with crystal structures such as grain boundaries and dislocations, and the characterization of these structures and their relation to physical properties.
- Materials Characterization – such as diffraction with x-rays, electrons, or neutrons, and various forms of spectroscopy and chemical analysis such as Raman spectroscopy, energy-dispersive spectroscopy (EDS), chromatography, thermal analysis, electron microscope analysis, etc., in order to understand and define the properties of materials.

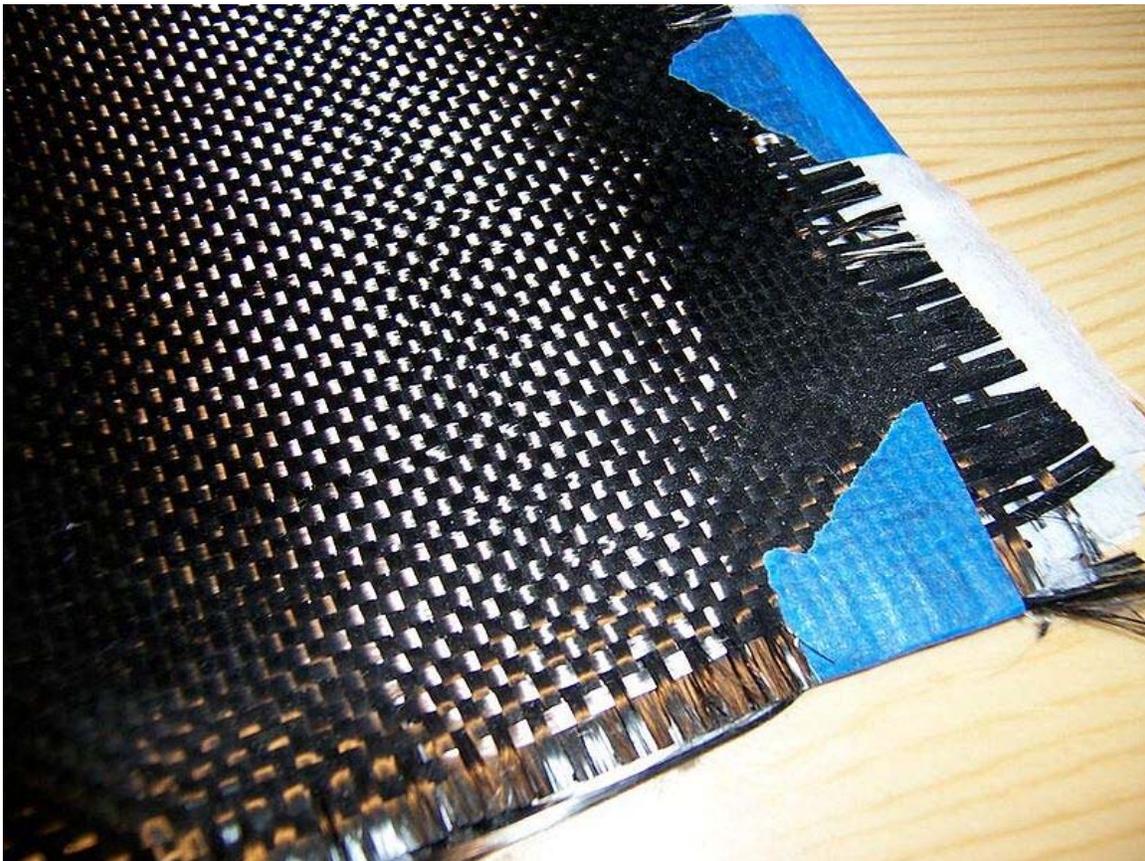


Si₃N₄ ceramic bearing parts

- Metallurgy – the study of metals and their alloys, including their extraction, microstructure and processing.
- Biomaterials – materials that are derived from and/or used with biological systems.
- Electronic and magnetic materials – materials such as semiconductors used to create integrated circuits, storage media, sensors, and other devices.
- Tribology – the study of the wear of materials due to friction and other factors.
- Surface science/Catalysis – interactions and structures between solid-gas solid-liquid or solid-solid interfaces.

- Ceramography – the study of the microstructures of high-temperature materials and refractories, including structural ceramics such as RCC, polycrystalline silicon carbide and transformation toughened ceramics

Some practitioners often consider rheology a sub-field of materials science, because it can cover any material that flows. However, modern rheology typically deals with non-Newtonian fluid dynamics, so it is often considered a sub-field of continuum mechanics.



A cloth of woven carbon fiber filaments is commonly used for reinforcement in composite materials.

- Glass Science – any non-crystalline material including inorganic glasses, vitreous metals and non-oxide glasses.
- Forensic engineering – the study of how products fail, and the vital role of the materials of construction
- Forensic materials engineering – the study of material failure, and the light it sheds on how engineers specify materials in their product
- Textile Reinforced Materials - materials in the form of ceramic or concrete are reinforced with a primarily woven or non-woven textile structure to impose high strength with comparatively more flexibility to withstand vibrations and sudden jerks.

Primary topics

- Thermodynamics, statistical mechanics, and physical chemistry, for phase equilibrium conditions, phase diagrams of materials systems (multi-phase, multi-component, reacting and non-reacting systems)
- Phase transformation kinetics, for the kinetics of phase transformations (with particular emphasis on solid-solid phase transitions)
- Transport phenomena for the transport of heat, mass, and momentum in materials processing.
- Crystallography, quantum chemistry or quantum physics, for the structure (symmetry and defects) and bonding in materials (e.g., ionic, metallic, covalent, and van der Waals bonding)
- Mechanical behavior of materials, to understand the mechanical properties of materials, defects and their propagation, and their behavior under static, dynamic, and cyclic loads
- Electronic properties of materials, and solid-state physics, for the understanding of the electronic, thermal, magnetic, and optical properties of materials
- Diffraction and wave mechanics, for the science behind characterization systems, e.g., transmission electron microscopy (TEM)



Household items made of various kinds of plastic.

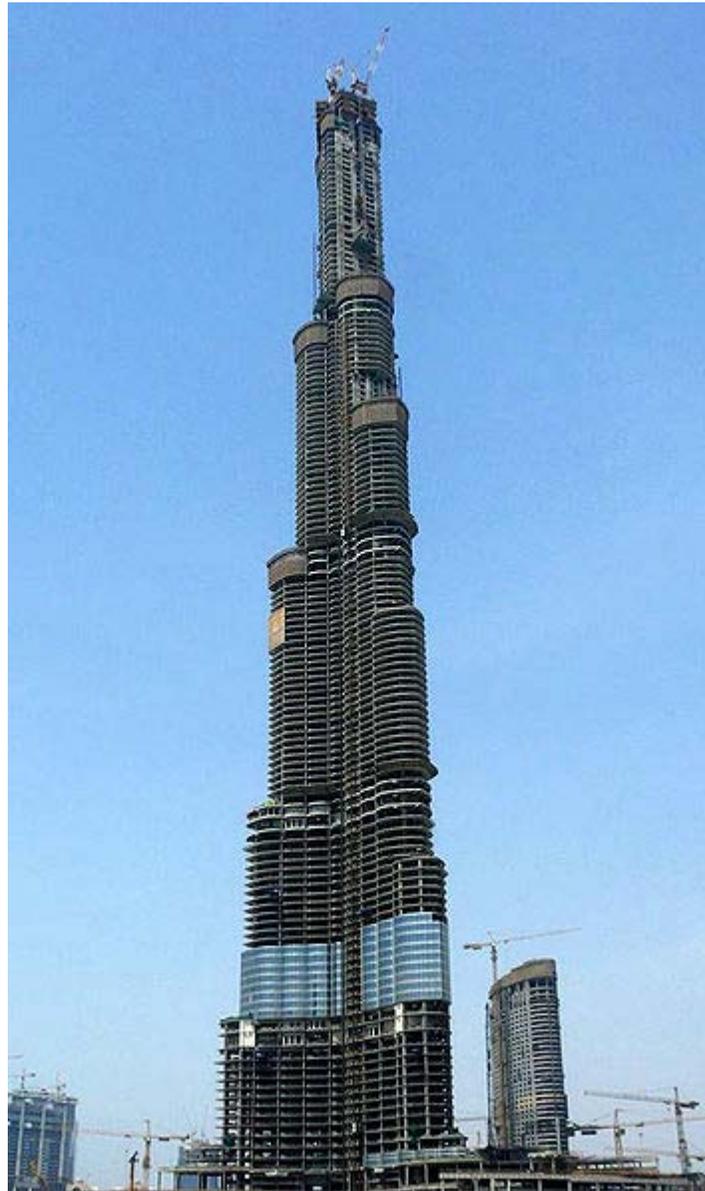
- Polymer properties, synthesis, and characterization, for a specialized understanding of how polymers behave, how they are made, and how they are characterized; exciting applications of polymers include liquid crystal displays (LCDs, the displays found in most cell-phones, cameras, and iPods), novel

photovoltaic devices based on semiconductor polymers (which, unlike the traditional silicon solar panels, are flexible and cheap to manufacture, albeit with lower efficiency), and membranes for room-temperature fuel cells (as proton exchange membranes) and filtration systems in the environmental and biomedical fields

- Biomaterials, physiology, biomechanics, biochemistry, for a specialized understanding of how materials integrate into biological systems, e.g., through materiomics
- Semiconductor materials and semiconductor devices, for a specialized understanding of the advanced processes used in industry (e.g. crystal growth techniques, thin-film deposition, ion implantation, photolithography), their properties, and their integration in electronic devices
- Alloying, corrosion, and thermal or mechanical processing, for a specialized treatment of metallurgical materials—with applications ranging from aerospace and industrial equipment to the civil industries

Chapter- 6

Structural Engineering



Burj Khalifa, in Dubai, the world's tallest building, shown under construction in 2007 (since completed)

Structural engineering is a field of engineering dealing with the analysis and design of structures that support or resist loads. Structural engineering is usually considered a specialty within civil engineering, but it can also be studied in its own right. Structural engineers are most commonly involved in the design of buildings and large nonbuilding structures but they can also be involved in the design of machinery, medical equipment, vehicles or any item where structural integrity affects the item's function or safety. Structural engineers must ensure their designs satisfy given design criteria, predicated on safety (e.g. structures must not collapse without due warning) or serviceability and performance (e.g. building sway must not cause discomfort to the occupants). Buildings are made to endure massive loads as well as changing climate and natural disasters.

Structural engineering theory is based upon physical laws and empirical knowledge of the structural performance of different landscapes and materials. Structural engineering design utilises a relatively small number of basic structural elements to build up structural systems that can be very complex. Structural engineers are responsible for making creative and efficient use of funds, structural elements and materials to achieve these goals.

Structural engineer

Structural engineers are responsible for engineering design and analysis. Entry-level structural engineers may design the individual structural elements of a structure, for example the beams, columns, and floors of a building. More experienced engineers would be responsible for the structural design and integrity of an entire system, such as a building.

Structural engineers often specialize in particular fields, such as bridge engineering, building engineering, pipeline engineering, industrial structures, or special mechanical structures such as vehicles or aircraft.

Structural engineering has existed since humans first started to construct their own structures. It became a more defined and formalised profession with the emergence of the architecture profession as distinct from the engineering profession during the industrial revolution in the late 19th Century. Until then, the architect and the structural engineer were usually one and the same - the master builder. Only with the development of specialised knowledge of structural theories that emerged during the 19th and early 20th centuries did the professional structural engineer come into existence.

The role of a structural engineer today involves a significant understanding of both static and dynamic loading, and the structures that are available to resist them. The complexity of modern structures often requires a great deal of creativity from the engineer in order to ensure the structures support and resist the loads they are subjected to. A structural engineer will typically have a four or five year undergraduate degree, followed by a minimum of three years of professional practice before being considered fully qualified.

Structural engineers are licensed or accredited by different learned societies and regulatory bodies around the world (for example, the Institution of Structural Engineers in the UK). Depending on the degree course they have studied and/or the jurisdiction they are seeking licensure in, they may be accredited (or licensed) as just structural engineers, or as civil engineers, or as both civil and structural engineers.

History of structural engineering



Pont du Gard, France, a Roman era aqueduct circa 19 BC.

Structural engineering dates back to 2700 BC when the step pyramid for Pharaoh Djoser was built by Imhotep, the first engineer in history known by name. Pyramids were the most common major structures built by ancient civilizations because the structural form of a pyramid is inherently stable and can be almost infinitely scaled (as opposed to most other structural forms, which cannot be linearly increased in size in proportion to increased loads).

Throughout ancient and medieval history most architectural design and construction was carried out by artisans, such as stone masons and carpenters, rising to the role of master builder. No theory of structures existed, and understanding of how structures stood up was extremely limited, and based almost entirely on empirical evidence of 'what had

worked before'. Knowledge was retained by guilds and seldom supplanted by advances. Structures were repetitive, and increases in scale were incremental.

No record exists of the first calculations of the strength of structural members or the behaviour of structural material, but the profession of structural engineer only really took shape with the industrial revolution and the re-invention of concrete. The physical sciences underlying structural engineering began to be understood in the Renaissance and have been developing ever since.

Structural failure

The history of structural engineering contains many collapses and failures. Sometimes this is due to obvious negligence, as in the case of the Pétionville school collapse, in which Rev. Fortin Augustin said that *"he constructed the building all by himself, saying he didn't need an engineer as he had good knowledge of construction"* following a partial collapse of the three-story schoolhouse that sent neighbors fleeing. The final collapse killed at least 362 people, mostly children.

In other cases structural failures require careful study, and the results of these inquiries have resulted in improved practices and greater understanding of the science of structural engineering. Some such studies are the result of Forensic engineering investigations where the original engineer seems to have done everything in accordance with the state of the profession and acceptable practice yet a failure still eventuated. A famous case of structural knowledge and practice being advanced in this manner can be found in a series of failures involving Box girders which collapsed in Australia during the 1970s.

Specializations

Building structures



Sydney Opera House, designed by Ove Arup & Partners, with the architect Jørn Utzon



Millennium Dome in London, UK, by Buro Happold and Richard Rogers

Structural building engineering includes all structural engineering related to the design of buildings. It is the branch of structural engineering that is close to architecture.

Structural building engineering is primarily driven by the creative manipulation of materials and forms and the underlying mathematical and scientific ideas to achieve an

end which fulfills its functional requirements and is structurally safe when subjected to all the loads it could reasonably be expected to experience. This is subtly different from architectural design, which is driven by the creative manipulation of materials and forms, mass, space, volume, texture and light to achieve an end which is aesthetic, functional and often artistic.

The architect is usually the lead designer on buildings, with a structural engineer employed as a sub-consultant. The degree to which each discipline actually leads the design depends heavily on the type of structure. Many structures are structurally simple and led by architecture, such as multi-storey office buildings and housing, while other structures, such as tensile structures, shells and gridshells are heavily dependent on their form for their strength, and the engineer may have a more significant influence on the form, and hence much of the aesthetic, than the architect.

The structural design for a building must ensure that the building is able to stand up safely, able to function without excessive deflections or movements which may cause fatigue of structural elements, cracking or failure of fixtures, fittings or partitions, or discomfort for occupants. It must account for movements and forces due to temperature, creep, cracking and imposed loads. It must also ensure that the design is practically buildable within acceptable manufacturing tolerances of the materials. It must allow the architecture to work, and the building services to fit within the building and function (air conditioning, ventilation, smoke extract, electrics, lighting etc.). The structural design of a modern building can be extremely complex, and often requires a large team to complete.

Structural engineering specialties for buildings include:

- Earthquake engineering
- Façade engineering
- Fire engineering
- Roof engineering
- Tower engineering
- Wind engineering

Earthquake engineering structures

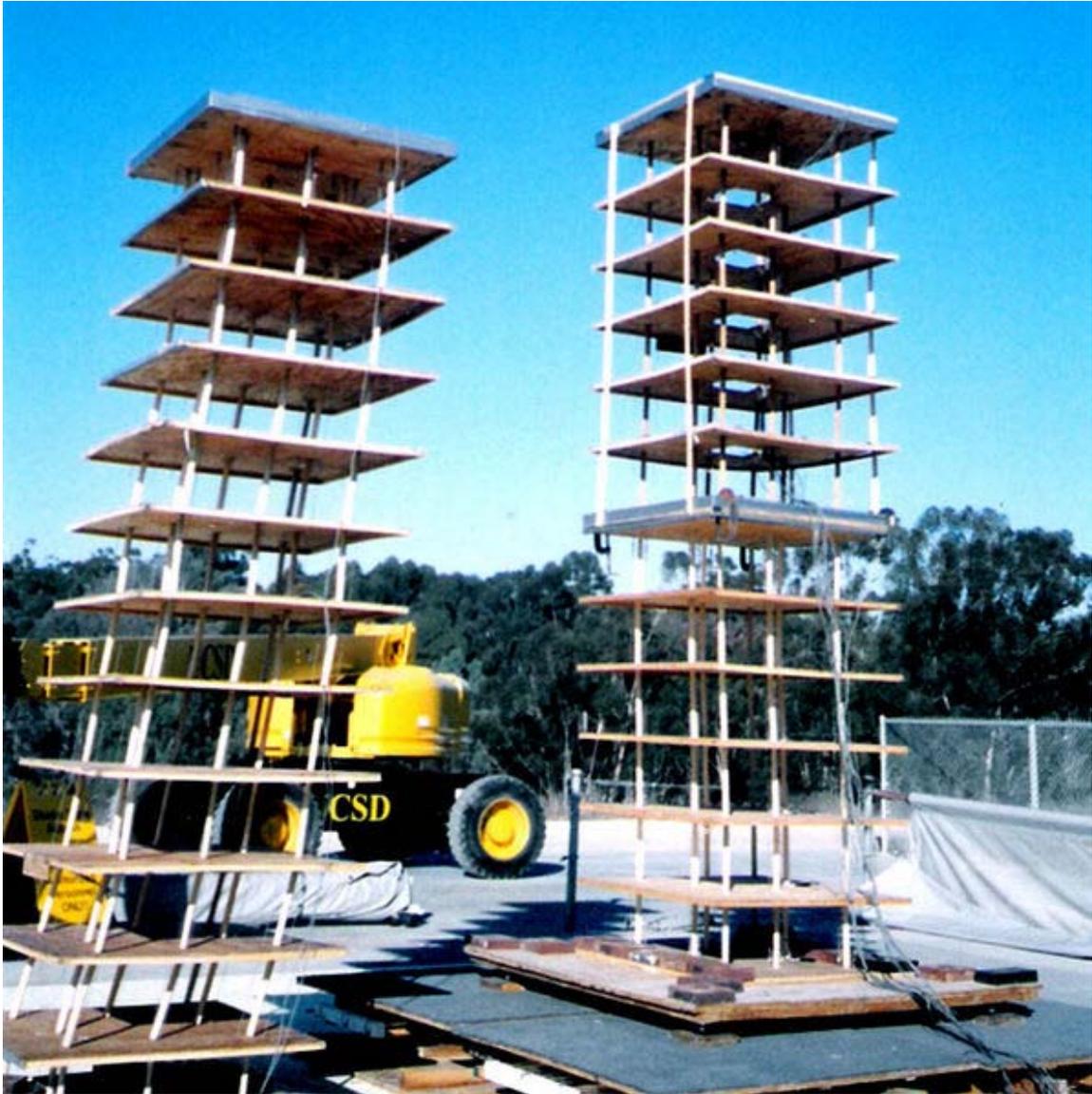
Earthquake engineering structures are those engineered to withstand various types of hazardous earthquake exposures at the sites of their particular location.



Earthquake-proof and massive pyramid El Castillo, Chichen Itza

Earthquake engineering is treating its subject structures like defensive fortifications in military engineering but for the warfare on earthquakes. Both earthquake and military general design principles are similar: be ready to slow down or mitigate the advance of a possible attacker.

The main objectives of **earthquake engineering** are:



Snapshot from shake-table video of testing base-isolated (right) and regular (left) building model

- Understand interaction of structures with the shaky ground.
- Foresee the consequences of possible earthquakes.
- Design and construct the structures to perform while being exposed to an earthquake.

Earthquake engineering or **earthquake-proof structure** does not, necessarily, mean *extremely strong* and *expensive* one like El Castillo pyramid at Chichen Itza shown above. In fact, many structures considered *strong* may in fact be actually *stiff*, which may result in poor seismic performance.

Now, the most *powerful* and *budgetary* tool of the earthquake engineering is base isolation which pertains to the passive structural vibration control technologies.

Civil engineering structures

Civil structural engineering includes all structural engineering related to the built environment. It includes:

- Bridges
- Dams
- Earthworks
- Foundations
- Offshore structures
- Pipelines
- Power stations
- Railways
- Retaining structures and walls
- Roads
- Tunnels
- Waterways
- Water and wastewater infrastructure

The structural engineer is the lead designer on these structures, and often the sole designer. In the design of structures such as these, structural safety is of paramount importance (in the UK, designs for dams, nuclear power stations and bridges must be signed off by a chartered engineer).

Civil engineering structures are often subjected to very extreme forces, such as large variations in temperature, dynamic loads such as waves or traffic, or high pressures from water or compressed gases. They are also often constructed in corrosive environments, such as at sea, in industrial facilities or below ground.

Mechanical structures



An Airbus A380, the world's largest passenger airliner

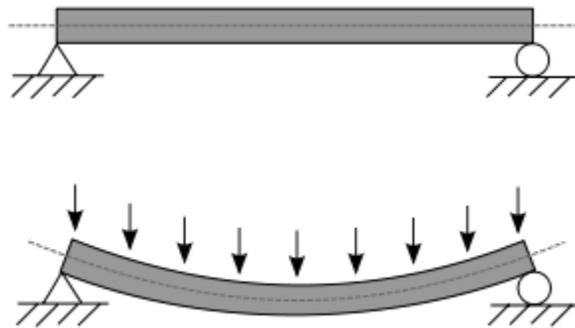
Principals of structural engineering are applied to variety of mechanical (moveable) structures. The design of static structures assumes they always have the same geometry (in fact, so-called static structures can move significantly, and structural engineering design must take this into account where necessary), but the design of moveable or moving structures must account for fatigue, variation in the method in which load is resisted and significant deflections of structures.

The forces which parts of a machine are subjected to can vary significantly, and can do so at a great rate. The forces which a boat or aircraft are subjected to vary enormously and will do so thousands of times over the structure's lifetime. The structural design must ensure that such structures are able to endure such loading for their entire design life without failing.

These works can require mechanical structural engineering:

- Airframes and fuselages
- Boilers and pressure vessels
- Coachworks and carriages
- Cranes
- Elevators
- Escalators
- Marine vessels and hulls

Structural elements



A statically determinate simply supported beam, bending under an evenly distributed load.

Any structure is essentially made up of only a small number of different types of elements:

- Columns
- Beams
- Plates
- Arches
- Shells
- Catenaries

Many of these elements can be classified according to form (straight, plane / curve) and dimensionality (one-dimensional / two-dimensional):

	One-dimensional		Two-dimensional	
	straight	curve	plane	curve
(predominantly) bending	beam	continuous arch	plate, concrete slab	lamina, dome
(predominant) tensile stress	rope	Catenary	shell	
(predominant) compression	pier, column		Load-bearing wall	

Columns

Columns are elements that carry only axial force - either tension or compression - or both axial force and bending (which is technically called a beam-column but practically, just a column). The design of a column must check the axial capacity of the element, and the buckling capacity.

The buckling capacity is the capacity of the element to withstand the propensity to buckle. Its capacity depends upon its geometry, material, and the effective length of the

column, which depends upon the restraint conditions at the top and bottom of the column. The effective length is $K * l$ where l is the real length of the column.

The capacity of a column to carry axial load depends on the degree of bending it is subjected to, and vice versa. This is represented on an interaction chart and is a complex non-linear relationship.

Beams

A beam may be defined as an element in which one dimension is much greater than the other two and the applied loads are usually normal to the main axis of the element. Beams and columns are called line elements and are often represented by simple lines in structural modeling.

- cantilevered (supported at one end only with a fixed connection)
- simply supported (supported vertically at each end; horizontally on only one to withstand friction, and able to rotate at the supports)
- continuous (supported by three or more supports)
- a combination of the above (ex. supported at one end and in the middle)

Beams are elements which carry pure bending only. Bending causes one part of the section of a beam (divided along its length) to go into compression and the other part into tension. The compression part must be designed to resist buckling and crushing, while the tension part must be able to adequately resist the tension.

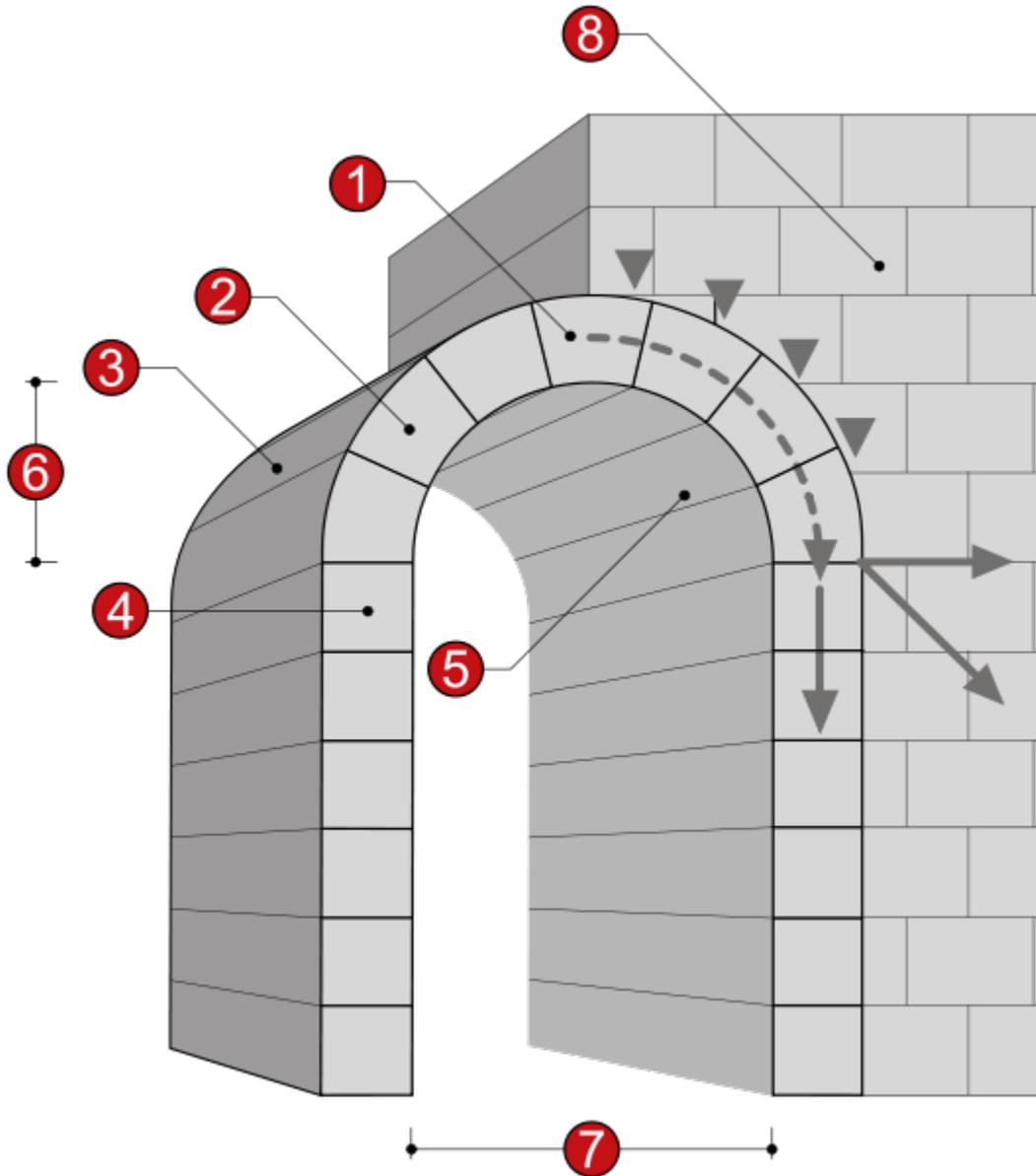
Struts and ties



Little Belt: a truss bridge in Denmark



The McDonnell Planetarium by Gyo Obata in St Louis, Missouri, USA, a concrete shell structure



A masonry arch

1. Keystone
2. Voussoir
3. Extrados
4. Impost
5. Intrados
6. Rise
7. Clear span
8. Abutment

A truss is a structure comprising two types of structural elements; compression members and tension members (i.e. struts and ties). Most trusses use gusset plates to connect intersecting elements. Gusset plates are relatively flexible and minimize bending moments at the connections, thus allowing the truss members to carry primarily tension or compression.

Trusses are usually utilised in span large distances, where it would be uneconomical to use solid beams.

Plates

Plates carry bending in two directions. A concrete flat slab is an example of a plate. Plates are understood by using continuum mechanics, but due to the complexity involved they are most often designed using a codified empirical approach, or computer analysis.

They can also be designed with yield line theory, where an assumed collapse mechanism is analysed to give an upper bound on the collapse load. This is rarely used in practice.

Shells

Shells derive their strength from their form, and carry forces in compression in two directions. A dome is an example of a shell. They can be designed by making a hanging-chain model, which will act as a catenary in pure tension, and inverting the form to achieve pure compression.

Arches

Arches carry forces in compression in one direction only, which is why it is appropriate to build arches out of masonry. They are designed by ensuring that the line of thrust of the force remains within the depth of the arch.

Catenaries

Catenaries derive their strength from their form, and carry transverse forces in pure tension by deflecting (just as a tightrope will sag when someone walks on it). They are almost always cable or fabric structures. A fabric structure acts as a catenary in two directions.

Structural engineering theory

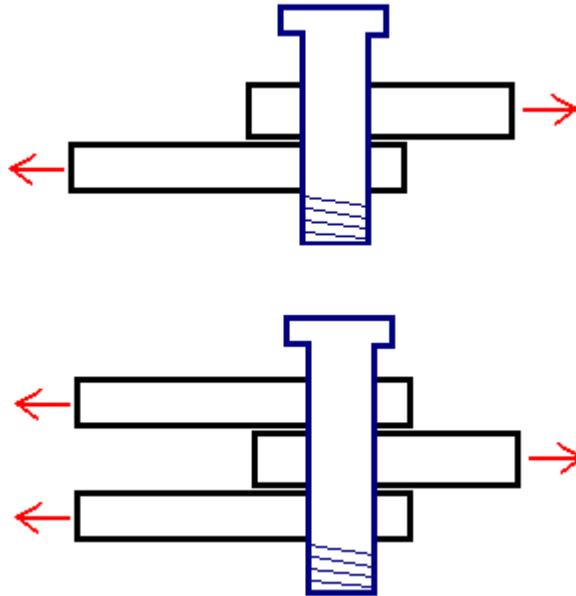


Figure of a bolt in shear stress. Top figure illustrates single shear, bottom figure illustrates double shear.

Structural engineering depends upon a detailed knowledge of loads, physics and materials to understand and predict how structures support and resist self-weight and imposed loads. To apply the knowledge successfully a structural engineer generally requires detailed knowledge of mathematics and relevant empirical and theoretical design codes. As well as, typically, some knowledge of the corrosion resistance of the materials and structures, especially when those structures are exposed to the external environment. Since the 1990s, specialist software has become available to aid in the design of structures, with the functionality to assist in both the drawing and designing of structures with maximum precision; examples include AutoCAD, StaadPro, ETABS etc. Such software may also take into consideration environmental loads, such as from earthquakes and winds.

Materials



The 630 foot (192 m) high, stainless-clad (type 304) Gateway Arch in Saint Louis, Missouri

Structural engineering depends on the knowledge of materials and their properties, in order to understand how different materials support and resist loads.

Common structural materials are:

- Iron:
 - Wrought iron
 - Cast iron
 - Steel
 - Stainless steel

- Concrete:
 - Reinforced concrete
 - Prestressed concrete

- Aluminium
- Composites
- Alloy
- Masonry
- Timber
- Other structural materials:
 - Adobe

- Bamboo
- Carbon fibre
- Fiber reinforced plastic
- Mudbrick
- Roofing materials

Chapter- 7

Geoengineering



An oceanic phytoplankton bloom in the South Atlantic Ocean, off the coast of Argentina. Encouraging such blooms with iron fertilization could lock up carbon on the seabed.

The modern concept of **geoengineering** (or **climate engineering**) is usually taken to mean proposals to deliberately manipulate the Earth's climate to counteract the effects of global warming from greenhouse gas emissions. The National Academy of Sciences defined geoengineering as "options that would involve large-scale engineering of our environment in order to combat or counteract the effects of changes in atmospheric chemistry." IPCC (2007) concluded that geoengineering options, such as ocean fertilization to remove CO₂ from the atmosphere, remained largely unproven. It was judged that reliable cost estimates for geoengineering had not yet been published.

Geoengineering accompanies mitigation and adaptation to form a 3-stranded 'MAG' approach to tackling global warming, notably advocated by the Institution of Mechanical Engineers. Some geoengineering techniques are based on carbon sequestration. These techniques seek to reduce greenhouse gases in the atmosphere directly. These include direct methods (e.g. carbon dioxide air capture) and indirect methods (e.g. ocean iron fertilization). These techniques can be regarded as mitigation of global warming. Alternatively, solar radiation management techniques do not reduce greenhouse gas concentrations, and can only address the warming effects of carbon dioxide and other gases; they cannot address problems such as ocean acidification, which are expected as a result of rising carbon dioxide levels. Examples of proposed solar radiation management techniques include the production of stratospheric sulfur aerosols, which was suggested by Paul Crutzen, space mirrors, and cloud reflectivity enhancement. Most techniques have at least some side effects.

To date, no large-scale geoengineering projects have been undertaken. Some limited tree planting and cool roof projects are already underway, and ocean iron fertilization is at an advanced stage of research, with small-scale research trials and global modelling having been completed. Field research into sulfur aerosols has also started. Some commentators have suggested that consideration of geoengineering presents a moral hazard because it threatens to reduce the political and popular pressure for emissions reduction. Typically, the scientists and engineers proposing geoengineering strategies do not suggest that they are an alternative to emissions control, but rather an accompanying strategy. Reviews of geoengineering techniques have emphasised that they are not substitutes for emission controls and have identified potentially stronger and weaker schemes.

Definition

Geoengineering is the idea of applying planetary engineering to Earth. Geoengineering would involve the deliberate modification of Earth's environment on a large scale "to suit human needs and promote habitability". Typically, the term is used to describe proposals to counter the effects of human-induced climate change. However, others define it more narrowly as nature-integrated engineering projects. The term *geoengineering* is distinct from environmental damage and accidental anthropogenic climate change, which are side-effects of human activity, rather than an intended consequence. The global recovery of hydrocarbons from the subsurface using integrated geoscience and engineering technology has been termed 'petroleum geoengineering' as an activity with global impact. Definitions of the term are not universally accepted.

Background

The field is currently experiencing a surge of interest as it has now become broadly accepted that global warming is both real and dangerous. A degree of urgency in efforts to research and implement potential solutions is based on the historic failure to control emissions, and the possibility that tipping points in the Earth's climate system are close at hand. In particular the Arctic shrinkage is causing accelerated regional warming. Rapid action with geoengineering may be necessary. Other tipping points might be avoided by reducing the impact of global warming in order to stifle positive feedback and prevent the resulting accelerated climate change.

The study of geoengineering is a complex discipline, as it requires the collation of knowledge in:

- scientific disciplines including atmospheric chemistry, ecology, meteorology, plant biology
- engineering disciplines including aeronautical engineering, naval architecture, ballistics
- management and control disciplines such as risk management, operational research, cost-benefit analysis

Several notable organisations have recently, or are soon to, investigate geoengineering with a view to evaluating its potential. Notably, NASA, the Royal Society, the Institute of Mechanical Engineers, and the UK Parliament, have all held inquiries or contests aimed at discovering and evaluating current knowledge of the subject. The Asilomar International Conference on Climate Intervention Technologies was convened to identify and develop risk reduction guidelines for climate intervention experimentation.

The major environmental organisations such as Friends of the Earth and Greenpeace have typically been reluctant to endorse geoengineering. Some have argued that any public support for geoengineering may weaken the fragile political consensus to reduce greenhouse gas emissions.

Proposed strategies

Several geoengineering strategies have been proposed. The documentaries *Five ways to save the world* and *La temperatura grimpe* describe many of the most notable projects. IPCC documents also detail several proposed projects.

Solar radiation management

Solar radiation management (SRM) projects seek to reduce the amount of sunlight hitting the Earth and thus counteract global warming. They do not reduce greenhouse gas concentrations in the atmosphere, and thus do not address problems such as ocean acidification caused by these gases. The phenomenon of global dimming as a side-effect

of fossil fuel use is widely known, and is not necessarily a geoengineering technique, also occurring naturally as a result of volcanoes and major forest fires. However, its deliberate manipulation is a tool of the geoengineer.

Solar radiation management projects often have the advantage of speed. While greenhouse gas remediation offers a comprehensive possible solution to climate change, it does not give instant results; for that, solar radiation management is required.

Techniques that fall into this category include:

- Creating stratospheric sulfur aerosols
- Cool roof—using pale-coloured roofing and paving materials
- Cloud reflectivity enhancement – using fine sea water spray to whiten clouds and increase cloud reflectivity.
- Space sunshade—obstructing solar radiation with space-based mirrors or other structures
- Cloud seeding of cirrus clouds, possibly using airliners.

Greenhouse gas remediation

Greenhouse gas remediation projects seek to remove greenhouse gases from the atmosphere, and thus tackle the root cause of global warming. They either directly remove greenhouse gases, or alternatively seek to influence natural processes to remove greenhouse gases indirectly. These projects offer a comprehensive solution to the problem of excess greenhouse gases in the atmosphere, but they will take many years to work fully. Many projects overlap with carbon capture and storage and carbon sequestration projects, and may not be considered to be geoengineering by all commentators. Techniques in this category include:

- Ocean nourishment including Iron fertilisation of the oceans
- Creating biochar (anaerobic charcoal) and burying it to create terra preta
- Bio-energy with carbon capture and storage
- Carbon air capture to remove carbon dioxide from ambient air

Arctic geoengineering

Various hydrological geoengineering projects aim to change the climate without directly or indirectly removing greenhouse gases, or directly influencing solar radiation. These principally act by limiting Arctic sea ice loss. Keeping the Arctic ice is seen by many commentators as vital, due to its role in the planet's albedo and in keeping methane, which is an important greenhouse gas, locked up in permafrost.

Heat transport

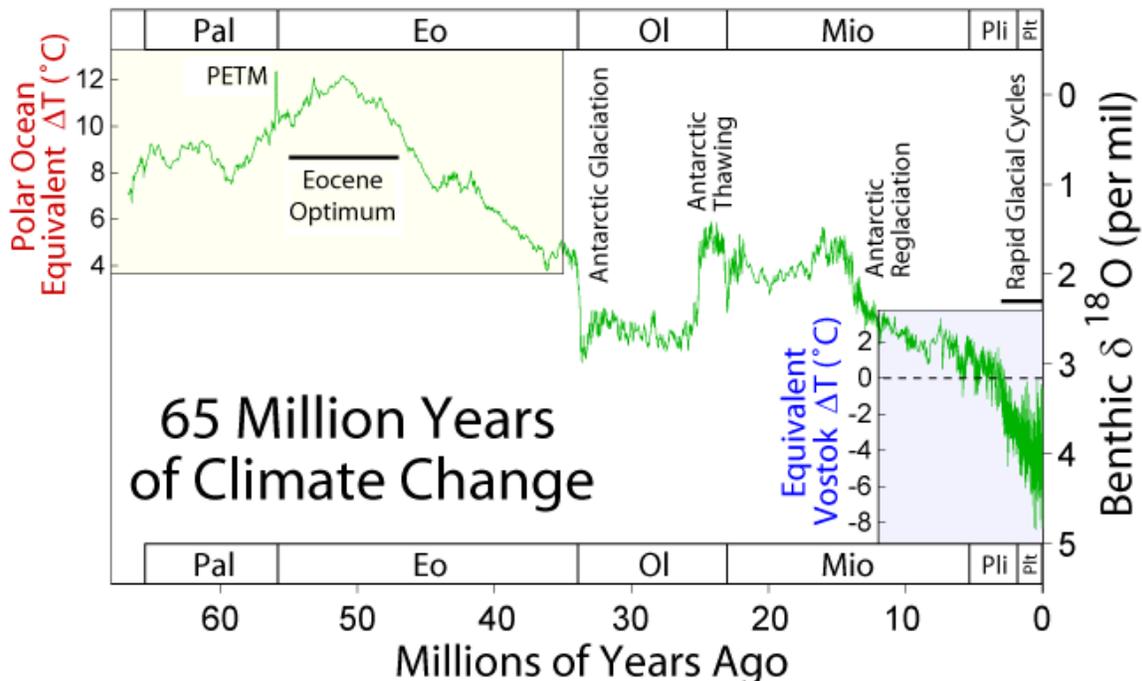
The use of vertical ocean pipes to mix cooler deep water and warmer surface water has been proposed. This technology has also been suggested for the disruption of hurricanes

by Bill Gates and others in a recent patent application. Modification of hurricanes may be considered weather modification rather than geoengineering, depending on the definition used.

Justification

The use of geoengineering to tackle climate change is advocated for several specific reasons:

Tipping points and positive feedback



Climate change during the last 65 million years. The Paleocene–Eocene Thermal Maximum is labelled PETM.

It is argued that climate change has already, or is soon to have passed one or more tipping points where aspects of the climate system may 'tip' from one stable state to another stable state, much like a glass tipping over. When the new stable state is reached, it may trigger or accelerate warming positive feedback effects, such as the collapse of Arctic sea ice triggering the release of methane from permafrost in Siberia. The "nightmare scenario" is that a domino effect will occur, with successive parts of the climate system tipping one after the other, with each change being caused by the previous one and causing the next one. Such a situation will lead to spiralling and potentially sudden climate change.

The precise identity of such "tipping points" is not clear, with scientists taking differing views on whether specific systems are capable of "tipping" and the point at which this "tipping" will occur. An example of a previous tipping point is that which preceded the

rapid warming leading up to the Paleocene–Eocene Thermal Maximum. Once the tipping point is reached, cuts in greenhouse gas emissions will not be able to reverse the change. Depending on the precise nature of the individual system that "tips", positive feedbacks may occur, with warming causing more warming, which causes yet more warming—a runaway global warming event. Therefore, some commentators suggest that more conservative use of resources is not enough to mitigate global warming. Even if all greenhouse emissions suddenly came to a complete halt, the world would continue to be affected for centuries, and further warming may occur due to positive feedback. Conservation of resources and reduction of greenhouse emissions, used in conjunction with geoengineering, are therefore considered a viable option. Geoengineering offers the hope of temporarily reversing some aspects of climate change and allowing the natural climate to be substantially preserved whilst greenhouse gas emissions are brought under control and removed from the atmosphere by natural or artificial processes.

Precautionary principle

Bearing in mind the threats from climate change, it can be argued that attempting geoengineering represents a lesser risk than not pursuing such strategies. While the understanding of geoengineering techniques is limited, the risks of global warming are at least partially understood, and are severe.

Costs

Some geoengineering techniques, such as the use of pale-coloured materials for roofing and paving, can be achieved at little or no cost, and may even offer a financial payback. IPCC (2007) concluded that reliable cost estimates for geoengineering options had not been published. This finding was based on medium agreement in the literature and limited evidence.

Political viability

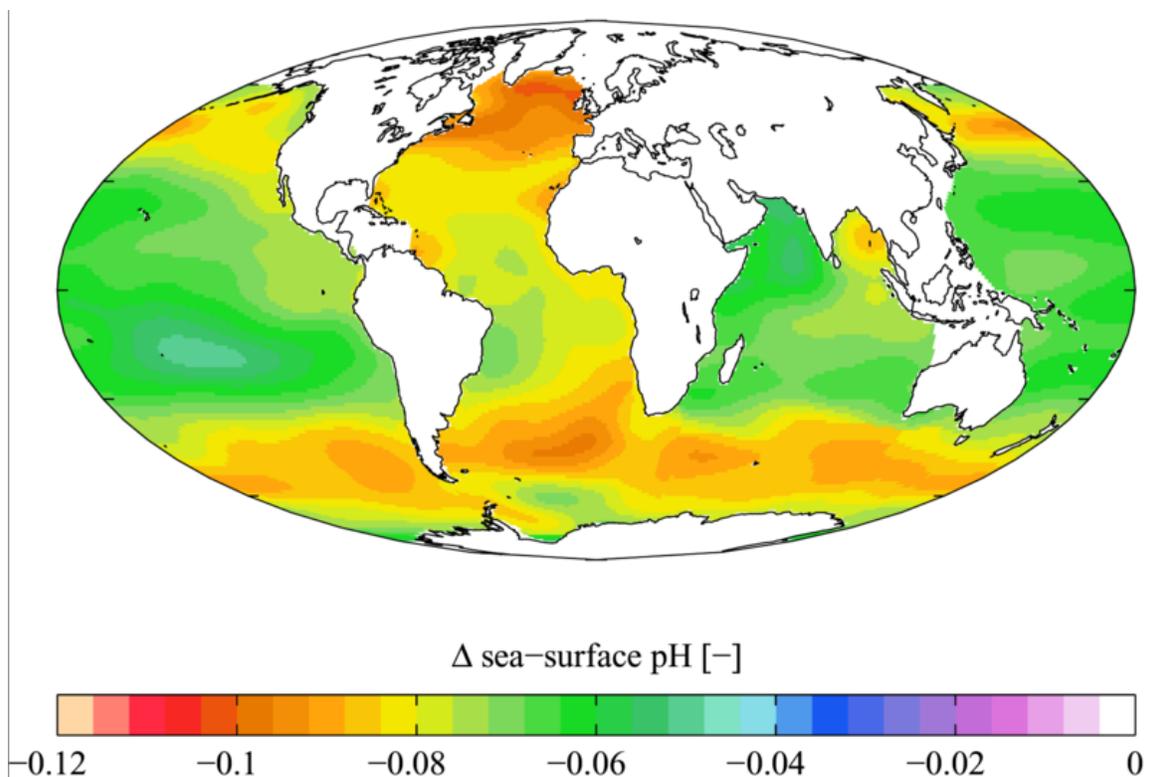
It has been argued that regardless of the economic, scientific and technical aspects, the difficulty of achieving concerted political action on climate change requires other approaches. Those arguing political expediency say the difficulty of achieving meaningful emissions cuts and the effective failure of the Kyoto Protocol demonstrate the practical difficulties of achieving carbon dioxide emissions reduction by the agreement of the international community. However, others point to support for geoengineering proposals among think tanks with a history of climate change skepticism and opposition to emissions reductions as evidence that the prospect of geoengineering is itself already politicized and being promoted as part of an argument against the need for (and viability of) emissions reductions; that, rather than geoengineering being a solution to the difficulties of emissions reductions, the prospect of geoengineering is being used as part of an argument to stall emissions reductions in the first place.

Risks and criticisms

Various criticisms have been made of geoengineering. However, the existence of criticism should not be taken to mean that those raising it are opposed to a particular technique, but rather that they are pointing out a potential disadvantage or downside which may need to be monitored or controlled, or may alternatively weigh against a particular technique. Some commentators appear fundamentally opposed, however. Individuals such as Raymond Pierrehumbert have called for a moratorium on geoengineering techniques.

Ineffectiveness

The effectiveness of the schemes proposed may fall short of predictions. In ocean iron fertilization, for example, the amount of carbon dioxide removed from the atmosphere may be much lower than predicted, as carbon taken up by plankton may be released back into the atmosphere from dead plankton, rather than being carried to the bottom of the sea and sequestered.



Change in sea surface pH caused by anthropogenic CO₂ between the 1700s and the 1990s. This ocean acidification will still be a major problem unless atmospheric CO₂ is reduced.

Incomplete solution to CO₂ emissions

Techniques that do not remove greenhouse gases from the atmosphere may control global warming, but do not reduce other effects from these gases, such as ocean acidification. While not an argument against geoengineering *per se*, this is an argument against reliance on geoengineering to the exclusion of greenhouse gas reduction.

Control and predictability problems

The full effects of various geoengineering schemes are not well understood. Matthews et al. compared geoengineering to a number of previous environmental interventions and concluded that "Given our current level of understanding of the climate system, it is likely that the result of at least some geoengineering efforts would follow previous ecological examples where increased human intervention has led to an overall increase in negative environmental consequences."

Performance of the systems may become ineffective, unpredictable or unstable as a result of external events, such as volcanic eruptions, phytoplankton blooms, El Niño, solar flares, etc., potentially leading to profound and unpredictable disruption to the climate system.

It may be difficult to predict the effectiveness of projects, with models of techniques giving widely varying results. In the instances of systems which involve tipping points, this may result in irreversible effects. Climate modelling is far from an exact science even when applied to comparatively well-understood natural climate systems, and it is made more complex by the need to understand novel and unnatural processes which by definition lack relevant observation data.

Side effects

The techniques themselves may cause significant foreseen or unforeseen harm. For example, the use of reflective balloons may result in significant litter, which may be harmful to wildlife.

Ozone depletion is a risk of some geoengineering techniques, notably those involving sulfur delivery into the stratosphere.

The active nature of geoengineering may in some cases create a clear division between winners and losers. Most of the proposed interventions are regional, such as albedo modification in the Arctic. Necessarily, such interventions compel those in the affected regions to tolerate the effects of geoengineering for the supposed benefit of the global climate.

There may be unintended climatic consequences, such as changes to the hydrological cycle including droughts or floods, caused by the geoengineering techniques, but

possibly not predicted by the models used to plan them. Such effects may be cumulative or chaotic in nature, making prediction and control very difficult.

Unreliable systems

The performance of the interventions may be inconsistent due to mechanical failure, non-availability of consumables or funding problems.

The geoengineering techniques would, in many instances, be vulnerable to being switched off or deliberately destroyed. As examples, cloud making ships could be switched off or sunk and space mirrors could be tilted to make them useless. Anyone capable of exerting such power may seek to abuse it for commercial gain, military advantage or simple terrorism.

Weaponisation

The Environmental Modification Convention generally prohibits weaponising geoengineering techniques. However, this does not eliminate the risk. Geoengineering techniques may serve as weapons of mass destruction, creating droughts or famines designed to destroy or disable an enemy. They could also be used simply to make battlefield conditions more favourable to one side or the other in a war (such as in Operation Popeye). For example, laser-guided weapons are confounded by clouds, and thus switching off cloud machines would favour forces using such weapons, and switching them on would favour ground forces defending against them.

Whilst laws or treaties may prevent the manipulation of the climate as a weapon of war, it could be argued that geoengineering is itself a manipulation, and thus destroying or disabling the geoengineering structures is not prohibited. A new legal framework may be necessary in the event that large-scale geoengineering becomes established.

Carnegie's Ken Caldeira said, "It will make it harder to achieve broad consensus on developing and governing these technologies if there is suspicion that gaining military advantage is an underlying motivation for its development..."

Effect on sunlight, sky and clouds

Managing solar radiation using aerosols or cloud cover will change the ratio between direct and indirect solar radiation. This may affect plant life and solar energy. There will be a significant effect on the appearance of the sky from aerosol projects, notably a hazing of blue skies and a change in the appearance of sunsets. Aerosols may affect the formation of clouds, especially cirrus clouds.

Moral hazard

The existence of such techniques may reduce the political and social impetus to reduce carbon emissions.

Other criticism comes from those who see geoengineering projects as reacting to the symptoms of global warming rather than addressing the real causes of climate change. Because geoengineering is a form of controlling the risks associated with global warming, it leads to a moral hazard problem. The problem is that knowledge that geoengineering is possible could lead to climate impacts seeming less fearsome, which could in turn lead to a weaker commitment to reducing greenhouse gas emissions.

Lack of global control

Geoengineering opens up various political and economic issues. David Keith argues that the cost of geoengineering the Earth is within the realm of small countries, large corporations, or even very wealthy individuals. Steve Rayner agrees that not all geoengineering possibilities are expensive, and that some, such as ocean iron fertilisation, are within the reach of very wealthy individuals, calling them a "Greenfinger" (after the fictional Goldfinger). David Victor suggests that geoengineering is within the reach of any individual who has a small fraction of the bank account of Bill Gates, who takes it upon him or her self to be the "self-appointed protector of the planet".

This effectively eliminates any control over who gets to decide when to cool the Earth and how often this should be done. The resulting power would be enormous, and could not necessarily be readily controlled by legal, political or regulatory systems. These legal and regulatory systems may themselves be far less powerful than the geoengineers controlling the climate become.

It is quite feasible for carbon offsetting firms to set up unregulated, unsupervised and dangerous geoengineering projects. This may be done in order to sell carbon credits to individuals and firms.

Geoengineering schemes have the potential to cause significant environmental damage, and may even end up releasing further greenhouse gases into the atmosphere. Opposition to some early schemes has been intense, with respected environmental groups campaigning against them.

Rapid warming if stopped

If solar radiation management were to abruptly stop, the climate would rapidly warm. This would cause a sudden rise in global temperatures towards levels which would have existed without the use of the geoengineering technique. The rapid rise in temperature may lead to more severe consequences than a gradual rise of the same magnitude.

Implementation issues

There is no general consensus that geoengineering is safe, appropriate or effective, for the reasons listed above. The issue of moral hazard means that many environmental groups and campaigners are reluctant to advocate geoengineering for fear of reducing the

imperative to cut greenhouse gas emissions. Other environmentalists see calls for geoengineering as part of an explicit strategy to delay emissions reductions on the part of those with connections to coal and oil industries.

All proposed geoengineering techniques require implementation on a relatively large scale, in order to make a significant difference to the Earth's climate. The least costly schemes are budgeted at a cost of millions, with many more complex schemes such as space sunshade costing far more.

Many techniques, again such as space sunshade, require a complex technical development process before they are ready to be implemented. There is no clear institutional mechanism for handling this research and development process. As a result, many promising techniques do not have the engineering development or experimental evidence to determine their feasibility or efficacy at present.

Once a technique has been developed and tested, its implementation is still likely to be difficult. Climate change is by nature a global problem, and therefore no one institution, company or government is responsible for it. The substantial costs of most geoengineering techniques therefore cannot currently be apportioned. Roll-out of such technologies is therefore likely to be delayed until these issues can be resolved. A notable exception is the use of small albedo manipulation projects, known as *cool roof*, in which the colour of roofing or paving surfaces can be manipulated to reflect solar radiation back into space. These can be, and are, implemented by individuals, companies and governments without controversy.

Due to the radical changes caused by geoengineering interventions, legal issues are also an impediment to implementation. The changes resulting from geoengineering necessarily benefit some people and disadvantage others. There may therefore be legal challenges to the implementation of geoengineering techniques by those adversely affected by them.

Evaluation of geoengineering

Few field experiments in geoengineering have been carried out. Most of what is known about the suggested techniques is based on small-scale trials and from simulations of global climate models and other computer modelling techniques. Some geoengineering schemes employ methods that have analogues in natural phenomena such as stratospheric sulfur aerosols and cloud condensation nuclei. As such, studies about the efficacy of these schemes can draw on information already available from other research, such as that following the 1991 eruption of Mount Pinatubo. However, comparative evaluation of the relative merits of each technology is complicated, especially given modelling uncertainties and the early stage of engineering development of many geoengineering schemes.

In a 2009 review study, Lenton and Vaughan evaluated a range of geoengineering schemes from those that sequester CO₂ from the atmosphere and decrease longwave

radiation trapping, to those that decrease the Earth's receipt of shortwave radiation. In order to permit a comparison of disparate techniques, they used a common evaluation for each scheme based on its effect on net radiative forcing. As such, the review examined the scientific plausibility of schemes rather than the practical considerations such as engineering feasibility or economic cost. Lenton and Vaughan found that "[air] capture and storage shows the greatest potential, combined with afforestation, reforestation and bio-char production", and noted that "other suggestions that have received considerable media attention, in particular "ocean pipes" appear to be ineffective". They concluded that "[climate] geoengineering is best considered as a potential complement to the mitigation of CO₂ emissions, rather than as an alternative to it".

Reports into geoengineering have also been published in the United Kingdom by the Institution of Mechanical Engineers and the Royal Society. The IMechE report examined a small subset of proposed schemes (air capture, urban albedo and algal-based CO₂ capture schemes), and its main conclusions were that geoengineering should be researched and trialled at the small scale alongside a wider decarbonisation of the economy.

The Royal Society review examined a wide range of geoengineering schemes and evaluated them in terms of effectiveness, affordability, timeliness and safety (assigning qualitative estimates in each assessment). Similarly to Lenton and Vaughan, the report divided schemes into "carbon dioxide removal" (CDR) and "solar radiation management" (SRM) approaches that respectively address longwave and shortwave radiation. The key recommendations of the report were that "Parties to the UNFCCC should make increased efforts towards mitigating and adapting to climate change, and in particular to agreeing to global emissions reductions", and that "[nothing] now known about geoengineering options gives any reason to diminish these efforts". Nonetheless, the report also recommended that "research and development of geoengineering options should be undertaken to investigate whether low risk methods can be made available if it becomes necessary to reduce the rate of warming this century".

Chapter- 8

Reverse Engineering

Reverse engineering is the process of discovering the technological principles of a human made device, object or system through analysis of its structure, function and operation. It often involves taking something (e.g., a mechanical device, electronic component, or software program) apart and analyzing its workings in detail to be used in maintenance, or to try to make a new device or program that does the same thing without using or simply duplicating (without understanding) any part of the original.

Reverse engineering has its origins in the analysis of hardware for commercial or military advantage. The purpose is to deduce design decisions from end products with little or no additional knowledge about the procedures involved in the original production. The same techniques are subsequently being researched for application to legacy software systems, not for industrial or defence ends, but rather to replace incorrect, incomplete, or otherwise unavailable documentation.

Motivation

Reasons for reverse engineering:

- Interoperability.
- Lost documentation: Reverse engineering often is done because the documentation of a particular device has been lost (or was never written), and the person who built it is no longer available. Integrated circuits often seem to have been designed on obsolete, proprietary systems, which means that the only way to incorporate the functionality into new technology is to reverse-engineer the existing chip and then re-design it.
- Product analysis. To examine how a product works, what components it consists of, estimate costs, and identify potential patent infringement.
- Digital update/correction. To update the digital version (e.g. CAD model) of an object to match an "as-built" condition.
- Security auditing.
- Acquiring sensitive data by disassembling and analysing the design of a system component.

- Military or commercial espionage. Learning about an enemy's or competitor's latest research by stealing or capturing a prototype and dismantling it.
- Removal of copy protection, circumvention of access restrictions.
- Creation of unlicensed/unapproved duplicates.
- Materials harvesting, sorting, or scrapping.
- Academic/learning purposes.
- Curiosity.
- Competitive technical intelligence (understand what your competitor is actually doing versus what they say they are doing).
- Learning: learn from others' mistakes. Do not make the same mistakes that others have already made and subsequently corrected.

Reverse engineering of machines

As computer-aided design (CAD) has become more popular, reverse engineering has become a viable method to create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE or other software. The reverse-engineering process involves measuring an object and then reconstructing it as a 3D model. The physical object can be measured using 3D scanning technologies like CMMs, laser scanners, structured light digitizers or Industrial CT Scanning (computed tomography). The measured data alone, usually represented as a point cloud, lacks topological information and is therefore often processed and modeled into a more usable format such as a triangular-faced mesh, a set of NURBS surfaces or a CAD model.

Reverse engineering is also used by businesses to bring existing physical geometry into digital product development environments, to make a digital 3D record of their own products or to assess competitors' products. It is used to analyse, for instance, how a product works, what it does, and what components it consists of, estimate costs, and identify potential patent infringement, etc.

Value engineering is a related activity also used by businesses. It involves de-constructing and analysing products, but the objective is to find opportunities for cost cutting.

Reverse engineering of software

The term *reverse engineering* as applied to software means different things to different people, prompting Chikofsky and Cross to write a paper researching the various uses and defining a taxonomy. From their paper, they state, "Reverse engineering is the process of analyzing a subject system to create representations of the system at a higher level of abstraction." It can also be seen as "going backwards through the development cycle". In this model, the output of the implementation phase (in source code form) is reverse-engineered back to the analysis phase, in an inversion of the traditional waterfall model. Reverse engineering is a process of examination only: the software system under consideration is not modified (which would make it re-engineering). Software anti-

tamper technology is used to deter both reverse engineering and re-engineering of proprietary software and software-powered systems. In practice, two main types of reverse engineering emerge. In the first case, source code is already available for the software, but higher-level aspects of the program, perhaps poorly documented or documented but no longer valid, are discovered. In the second case, there is no source code available for the software, and any efforts towards discovering one possible source code for the software are regarded as reverse engineering. This second usage of the term is the one most people are familiar with. Reverse engineering of software can make use of the clean room design technique to avoid copyright infringement.

On a related note, black box testing in software engineering has a lot in common with reverse engineering. The tester usually has the API, but their goals are to find bugs and undocumented features by bashing the product from outside.

Other purposes of reverse engineering include security auditing, removal of copy protection ("cracking"), circumvention of access restrictions often present in consumer electronics, customization of embedded systems (such as engine management systems), in-house repairs or retrofits, enabling of additional features on low-cost "crippled" hardware (such as some graphics card chip-sets), or even mere satisfaction of curiosity.

The Certified Reverse Engineering Analyst (CREA) is a certification provided by the IACRB that certifies candidates are proficient in reverse engineering software.

Binary software

This process is sometimes termed *Reverse Code Engineering*, or RCE. As an example, decompilation of binaries for the Java platform can be accomplished using Jad. One famous case of reverse engineering was the first non-IBM implementation of the PC BIOS which launched the historic IBM PC compatible industry that has been the overwhelmingly dominant computer hardware platform for many years. An example of a group that reverse-engineers software for enjoyment (and to distribute registration cracks) is CORE which stands for "Challenge Of Reverse Engineering". Reverse engineering of software is protected in the U.S. by the fair use exception in copyright law. The Samba software, which allows systems that are not running Microsoft Windows systems to share files with systems that are, is a classic example of software reverse engineering, since the Samba project had to reverse-engineer unpublished information about how Windows file sharing worked, so that non-Windows computers could emulate it. The Wine project does the same thing for the Windows API, and OpenOffice.org is one party doing this for the Microsoft Office file formats. The ReactOS project is even more ambitious in its goals, as it strives to provide binary (ABI and API) compatibility with the current Windows OSes of the NT branch, allowing software and drivers written for Windows to run on a clean-room reverse-engineered GPL free software or open-source counterpart.

Binary software techniques

Reverse engineering of software can be accomplished by various methods. The three main groups of software reverse engineering are

1. Analysis through observation of information exchange, most prevalent in protocol reverse engineering, which involves using bus analyzers and packet sniffers, for example, for accessing a computer bus or computer network connection and revealing the traffic data thereon. Bus or network behavior can then be analyzed to produce a stand-alone implementation that mimics that behavior. This is especially useful for reverse engineering device drivers. Sometimes, reverse engineering on embedded systems is greatly assisted by tools deliberately introduced by the manufacturer, such as JTAG ports or other debugging means. In Microsoft Windows, low-level debuggers such as SoftICE are popular.
2. Disassembly using a disassembler, meaning the raw machine language of the program is read and understood in its own terms, only with the aid of machine-language mnemonics. This works on any computer program but can take quite some time, especially for someone not used to machine code. The Interactive Disassembler is a particularly popular tool.
3. Decompilation using a decompiler, a process that tries, with varying results, to recreate the source code in some high-level language for a program only available in machine code or bytecode.

Source code

A number of UML tools refer to the process of importing and analysing source code to generate UML diagrams as "reverse engineering".

Reverse engineering of protocols

Protocols are sets of rules that describe message formats and how messages are exchanged (i.e., the protocol state-machine). Accordingly, the problem of protocol reverse-engineering can be partitioned into two subproblems; message format and state-machine reverse-engineering.

The message formats have traditionally been reverse-engineered through a tedious manual process, which involved analysis of how protocol implementations process messages, but recent research proposed a number of automatic solutions . Typically, these automatic approaches either group observed messages into clusters using various clustering analyses, or emulate the protocol implementation tracing the message processing.

There has been less work on reverse-engineering of state-machines of protocols. In general, the protocol state-machines can be learned either through a process of offline learning, which passively observes communication and attempts to build the most general

state-machine accepting all observed sequences of messages, and online learning, which allows interactive generation of probing sequences of messages and listening to responses to those probing sequences. In general, offline learning of small state-machines is known to be NP-complete, while online learning can be done in polynomial time. An automatic offline approach has been demonstrated by Comparetti et al. and an online approach very recently by Cho et al.

Other components of typical protocols, like encryption and hash functions, can be reverse-engineered automatically as well. Typically, the automatic approaches trace the execution of protocol implementations and try to detect buffers in memory holding unencrypted packets.

Reverse engineering of integrated circuits/smart cards

Reverse engineering is an invasive and destructive form of analyzing a smart card. The attacker grinds away layer by layer of the smart card and takes pictures with an electron microscope. With this technique, it is possible to reveal the complete hardware and software part of the smart card. The major problem for the attacker is to bring everything into the right order to find out how everything works. Engineers try to hide keys and operations by mixing up memory positions, for example, bus scrambling. In some cases, it is even possible to attach a probe to measure voltages while the smart card is still operational. Engineers employ sensors to detect and prevent this attack. This attack is not very common because it requires a large investment in effort and special equipment that is generally only available to large chip manufacturers. Furthermore, the payoff from this attack is low since other security techniques are often employed such as shadow accounts.

Reverse engineering for military applications

Reverse engineering is often used by militaries in order to copy other nations' technologies, devices or information that have been obtained by regular troops in the fields or by intelligence operations. It was often used during the Second World War and the Cold War. Well-known examples from WWII and later include

- Jerry can: British and American forces noticed that the Germans had gasoline cans with an excellent design. They reverse-engineered copies of those cans. The cans were popularly known as "Jerry cans".
- Tupolev Tu-4: Three American B-29 bombers on missions over Japan were forced to land in the USSR. The Soviets, who did not have a similar strategic bomber, decided to copy the B-29. Within a few years, they had developed the Tu-4, a near-perfect copy.
- V2 Rocket: Technical documents for the V2 and related technologies were captured by the Western Allies at the end of the war. Soviet, and captured German engineers, had to reproduce technical documents and plans, working from captured hardware, in order to make their clone of the rocket, the R-1, which

- began the postwar Soviet rocket program that led to the R-7 and the beginning of the space race.
- K-13/R-3S missile (NATO reporting name **AA-2 Atoll**), a Soviet reverse-engineered copy of the AIM-9 Sidewinder, made possible after a Taiwanese AIM-9B hit a Chinese MiG-17 without exploding; amazingly, the missile became lodged within the airframe, the pilot returning to base with what Russian scientists would describe as a university course in missile development.
 - BGM-71 TOW Missile: In May 1975, negotiations between Iran and Hughes Missile Systems on co-production of the TOW and Maverick missiles stalled over disagreements in the pricing structure, the subsequent 1979 revolution ending all plans for such co-production. Iran was later successful in reverse-engineering the missile and are currently producing their own copy: the Toophan.
 - China has reversed engineered many examples of Western and Russian hardware, from fighter aircraft to missiles and HMMWV cars.

Legality

In the United States even if an artifact or process is protected by trade secrets, reverse-engineering the artifact or process is often lawful as long as it is obtained legitimately. Patents, on the other hand, need a public disclosure of an invention, and therefore, patented items do not necessarily have to be reverse-engineered to be studied. (However, an item produced under one or more patents could also include other technology that is not patented and not disclosed.) One common motivation of reverse engineers is to determine whether a competitor's product contains patent infringements or copyright infringements.

The reverse engineering of software in the US is generally illegal because most EULA prohibit it, and courts have found such contractual prohibitions to override the copyright law; *Bowers v. Baystate Technologies*. Article 6 of the 1991 EU Computer Programs Directive allows reverse engineering for the purposes of interoperability, but prohibits it for the purposes of creating a competing product, and also prohibits the public release of information obtained through reverse engineering of software.

Chapter- 9

Safety Engineering

Safety engineering is an applied science strongly related to systems engineering and the subset System Safety Engineering. Safety engineering assures that a life-critical system behaves as needed even when pieces fail.

Overview

Ideally, safety-engineers take an early design of a system, analyze it to find what faults can occur, and then propose safety requirements in design specifications up front and changes to existing systems to make the system safer. In an early design stage, often a fail-safe system can be made acceptably safe with a few sensors and some software to read them. Probabilistic fault-tolerant systems can often be made by using more, but smaller and less-expensive pieces of equipment.

Far too often, rather than actually influencing the design, safety engineers are assigned to prove that an existing, completed design is safe. If a safety engineer then discovers significant safety problems late in the design process, correcting them can be very expensive. This type of error has the potential to waste large sums of money.

The exception to this conventional approach is the way some large government agencies approach safety engineering from a more proactive and proven process perspective, known as "system safety". The system safety philosophy is to be applied to complex and critical systems, such as commercial airliners, complex weapon systems, spacecraft, rail and transportation systems, air traffic control system and other complex and safety-critical industrial systems. The proven system safety methods and techniques are to prevent, eliminate and control hazards and risks through designed influences by a collaboration of key engineering disciplines and product teams. Software safety is a fast growing field since modern systems functionality are increasingly being put under control of software. The whole concept of system safety and software safety, as a subset of systems engineering, is to influence safety-critical systems designs by conducting several types of hazard analyses to identify risks and to specify design safety features and procedures to strategically mitigate risk to acceptable levels before the system is certified.

Additionally, failure mitigation can go beyond design recommendations, particularly in the area of maintenance. There is an entire realm of safety and reliability engineering

known as Reliability Centered Maintenance (RCM), which is a discipline that is a direct result of analyzing potential failures within a system and determining maintenance actions that can mitigate the risk of failure. This methodology is used extensively on aircraft and involves understanding the failure modes of the serviceable replaceable assemblies in addition to the means to detect or predict an impending failure. Every automobile owner is familiar with this concept when they take in their car to have the oil changed or brakes checked. Even filling up one's car with fuel is a simple example of a failure mode (failure due to fuel exhaustion), a means of detection (fuel gauge), and a maintenance action (filling the car's fuel tank).

For large scale complex systems, hundreds if not thousands of maintenance actions can result from the failure analysis. These maintenance actions are based on conditions (e.g., gauge reading or leaky valve), hard conditions (e.g., a component is known to fail after 100 hrs of operation with 95% certainty), or require inspection to determine the maintenance action (e.g., metal fatigue). The RCM concept then analyzes each individual maintenance item for its risk contribution to safety, mission, operational readiness, or cost to repair if a failure does occur. Then the sum total of all the maintenance actions are bundled into maintenance intervals so that maintenance is not occurring around the clock, but rather, at regular intervals. This bundling process introduces further complexity, as it might stretch some maintenance cycles, thereby increasing risk, but reduce others, thereby potentially reducing risk, with the end result being a comprehensive maintenance schedule, purpose built to reduce operational risk and ensure acceptable levels of operational readiness and availability.

Analysis techniques

The two most common fault modeling techniques are called failure mode and effects analysis and fault tree analysis. These techniques are just ways of finding problems and of making plans to cope with failures, as in probabilistic risk assessment. One of the earliest complete studies using this technique on a commercial nuclear plant was the WASH-1400 study, also known as the Reactor Safety Study or the Rasmussen Report.

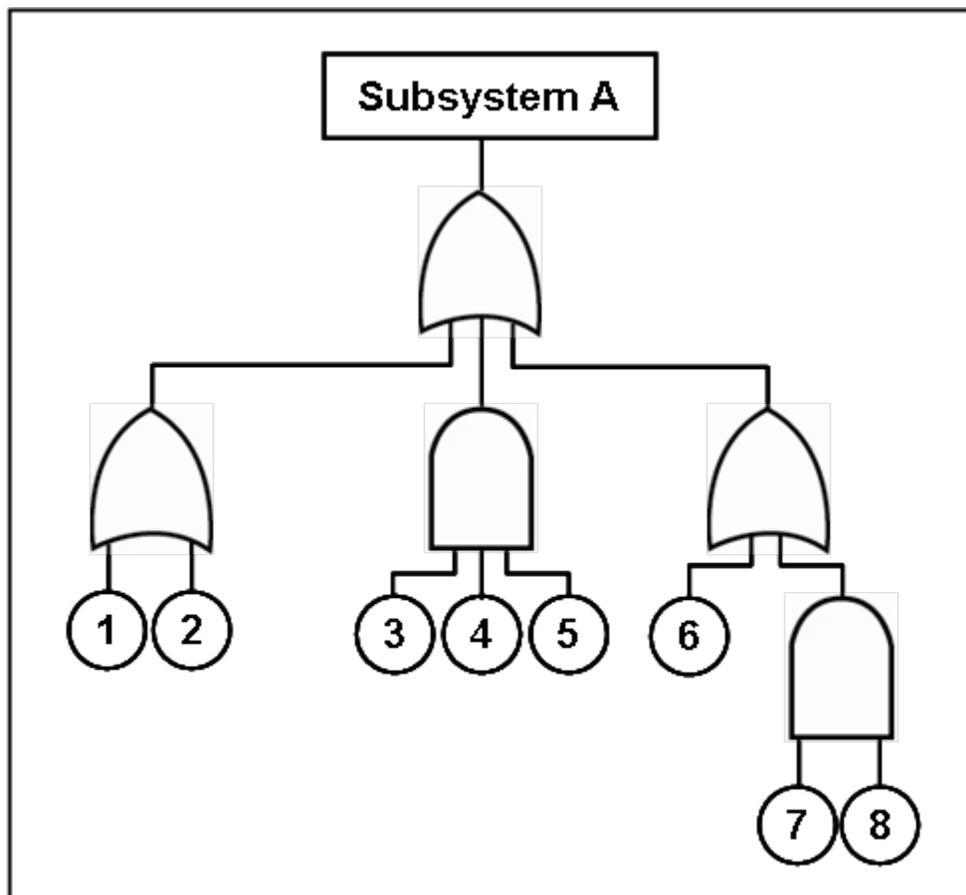
Failure modes and effects analysis

Failure Mode and Effects Analysis (FMEA) is a bottom-up, inductive analytical method which may be performed at either the functional or piece-part level. For functional FMEA, failure modes are identified for each function in a system or equipment item, usually with the help of a functional block diagram. For piece-part FMEA, failure modes are identified for each piece-part component (such as a valve, connector, resistor, or diode). The effects of the failure mode are described, and assigned a probability based on the failure rate and failure mode ratio of the function or component.

Failure modes with identical effects can be combined and summarized in a Failure Mode Effects Summary. When combined with criticality analysis, FMEA is known as Failure Mode, Effects, and Criticality Analysis or FMECA, pronounced "fuh-MEE-kuh".

Fault tree analysis

Fault tree analysis (FTA) is a top-down, deductive analytical method. In FTA, initiating primary events such as component failures, human errors, and external events are traced through Boolean logic gates to an undesired top event such as an aircraft crash or nuclear reactor core melt. The intent is to identify ways to make top events less probable, and verify that safety goals have been achieved.



A fault tree diagram

Fault trees are a logical inverse of success trees, and may be obtained by applying de Morgan's theorem to success trees (which are directly related to reliability block diagrams).

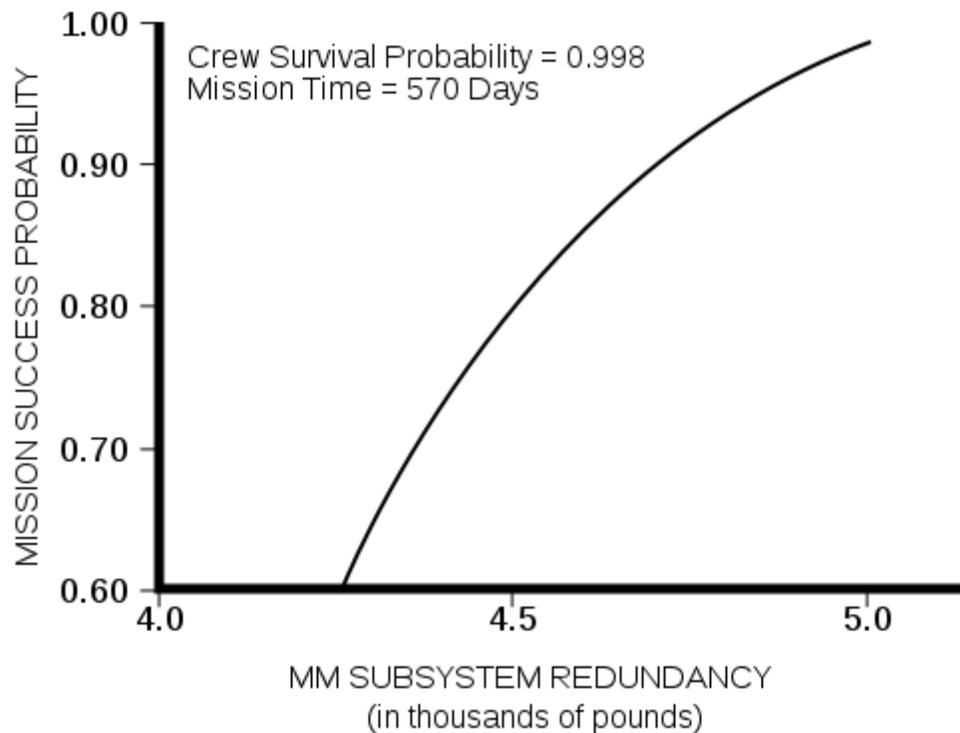
FTA may be qualitative or quantitative. When failure and event probabilities are unknown, qualitative fault trees may be analyzed for minimal cut sets. For example, if any minimal cut set contains a single base event, then the top event may be caused by a single failure. Quantitative FTA is used to compute top event probability, and usually requires computer software such as CAFTA from the Electric Power Research Institute or SAPHIRE from the Idaho National Laboratory.

Some industries use both fault trees and event trees. An event tree starts from an undesired initiator (loss of critical supply, component failure etc.) and follows possible further system events through to a series of final consequences. As each new event is considered, a new node on the tree is added with a split of probabilities of taking either branch. The probabilities of a range of "top events" arising from the initial event can then be seen.

Safety certification

Usually a failure in safety-certified systems is acceptable if, on average, less than one life per 10^9 hours of continuous operation is lost to failure. Most Western nuclear reactors, medical equipment, and commercial aircraft are certified to this level. The cost versus loss of lives has been considered appropriate at this level (by FAA for aircraft under Federal Aviation Regulations).

Preventing failure



A NASA graph shows the relationship between the survival of a crew of astronauts and the amount of redundant equipment in their spacecraft (the "MM", Mission Module).

Probabilistic fault tolerance: adding redundancy to equipment and systems

Once a failure mode is identified, it can usually be prevented entirely by adding extra equipment to the system. For example, nuclear reactors contain dangerous radiation, and nuclear reactions can cause so much heat that no substance might contain them. Therefore reactors have emergency core cooling systems to keep the temperature down, shielding to contain the radiation, and engineered barriers (usually several, nested, surmounted by a containment building) to prevent accidental leakage.

Most biological organisms have a certain amount of redundancy: multiple organs, multiple limbs, etc.

For any given failure, a fail-over or redundancy can almost always be designed and incorporated into a system.

When does safety stop, where does reliability begin?

Inherent fail-safe design

When adding equipment is impractical (usually because of expense), then the least expensive form of design is often "inherently fail-safe". The typical approach is to arrange the system so that ordinary single failures cause the mechanism to shut down in a safe way (for nuclear power plants, this is termed a passively safe design, although more than ordinary failures are covered).

One of the most common fail-safe systems is the overflow tube in baths and kitchen sinks. If the valve sticks open, rather than causing an overflow and damage, the tank spills into an overflow.

Another common example is that in an elevator the cable supporting the car keeps spring-loaded brakes open. If the cable breaks, the brakes grab rails, and the elevator cabin does not fall.

Inherent fail-safes are common in medical equipment, traffic and railway signals, communications equipment, and safety equipment.

Containing failure

It is also common practice to plan for the failure of safety systems through containment and isolation methods. The use of isolating valves, also known as the block and bleed manifold, is very common in isolating pumps, tanks, and control valves that may fail or need routine maintenance. In addition, nearly all tanks containing oil or other hazardous chemicals are required to have containment barriers set up around them to contain 100% of the volume of the tank in the event of a catastrophic tank failure. Similarly, in a long

pipeline, there are remote-closing valves at regular intervals so that a leak can be isolated. The goal of all containment systems is to provide means of mitigating the consequences of failure.