MECHANICAL ENGINEERING STUDENTS’ PERSPECTIVE

A Snapshot in Time

MESP 2020
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FOREWORD

At Texas A&M University at Qatar, we create engineering leaders of character dedicated to the greater good. Our engineers excel at not just classroom learning; they are problem solvers and creative thinkers who apply their engineering knowledge to real-world challenges to improve the community around them.

Embedded within the world-class engineering education Texas A&M at Qatar provides is an emphasis on communications and on creativity. This book is the brainchild of the mechanical engineering students in MEEN 381, the junior seminar course that teaches students the principles of effective communications, professional ethics and competencies, importance of long-life learning, and the impact of technology on society.

Mechanical engineering students highlight in this book the technical topics that interest them and the engineering applications that capture their attention. It also summarizes their views about professional and educational topics that are of interest to the engineering community.

Within these pages are examples of student papers and reports, as well as infographics designed to communicate the students’ input on specific professional topics. Several faculty members and professionals have also contributed chapter introductions.

We are proud of the creativity, knowledge and skills of our engineering leaders in Qatar and I hope you are, too.

Dr. César Octavio Malavé
Dean, Texas A&M University at Qatar
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Introduction

The original idea for this book was to have a collection of our student’s research reports in one place. However, in our journey to create the book, it evolved into something much bigger than we originally planned. It is now not only a compilation of student reports, but also a collection of the opinions and interests of mechanical engineering students at Texas A&M University at Qatar (TAMUQ). This book reflects the diversity of thoughts of our mechanical engineering students. As of Spring 2020, the Mechanical Engineering Department (MEEN) had 151 students enrolled, 115 of whom were men and 36 of whom were women. This department also includes a wide range of nationalities. As a result, this book represents the diversity of thoughts and interests.

The book is divided into five chapters, each of which contains technical reports students wrote for their MEEN 381 seminar. The first chapter, called Pioneering Research, contains several papers that delve into new and upcoming engineering research. These papers show what our current students are interested in, what matters to them, and how they can use their engineering background to make a difference. The topics cover subjects such as 3D printed prosthetics, compliant mechanisms, self-cleaning materials, and virtual reality. When asked about her interest in her chosen topic included in this chapter, Fatima Al-Khuzaei said, “As a mechanical engineering undergraduate, I often find it cumbersome to generate ideas and visualize them, and so discovering compliant mechanisms has been a stepping stone into brainstorming. I think the importance of this technology lies in its reach into ideation. I think, as students, we find ourselves engulfed in the complicated particulars of engineering. With compliant mechanisms, it is easy to see that sometimes the more ornate could be less valuable.”

The book’s second chapter is titled Engineered Technology and covers topics that have years’ worth of foundations. Some of the engineering behind those topics have been taught in our university courses. The
topics in this chapter include recreational quadcopters, tower cranes, and stealth fighters.

The third chapter, Sustainability, covers a crucial aspect of engineering. It is important for future engineers to know the severity of environmental problems and be motivated to make positive changes. The topics range from plastic and environment sustainability; social, economic, and environmental sustainability; and solid waste management methods such as incineration and recycling.

The fourth chapter, named Energy, focuses on energy-related topics. The student papers in this chapter cover different energy sectors such as solar energy, geothermal energy, and wind energy, among others.

The fifth and final chapter of this book, Aerodynamics, covers topics related to aerodynamics, which is a subject that is briefly covered in courses such as Fluid Mechanics and Heat Transfer. The students found an interest in the effects of aerodynamics on performance and fuel economy and the use of wind tunnels to study aerodynamics. They went into detail, explaining and relating the Navier-Stokes equation and the Prandtl logarithmic law to their respective topics. Mohamad Shehabi, a MEEN senior, is very passionate about his topic. When asked about the motivation behind the topic he said, “I found the course Fluid Mechanics very intriguing when I took it in the Fall of 2019. However, the material covering aerodynamics wasn't given in full; it left me wanting to further explore this topic on my own. Trying to relate everything that happens in real life to what I learn, although it annoys people, gives me great pleasure and a sense of engineering that I could only get through practice otherwise.”

Between each chapter are a few pages containing student reflections on professional and educational subjects that were presented during the Spring 2020 seminar course. These topics are Work Competency, Intellectual Property Commercialization, Sustainability, Distance Education, and Coronavirus Innovations. The students all wrote reviews on issues that affect engineering and their opinions were then compiled and synthesized into infographics and word clouds. These
infographics were created to reflect our student’s opinions in the writing as well as their cultural backgrounds in the drawings.

Our hope is that this book encourages and motivates students to always be curious and further their engineering learning beyond our classrooms. We also hope that this showcases the diversity of topics and people in the mechanical engineering field and inspires more students to follow this riveting path. Another goal we hope this book accomplishes is to help educators teach engineering using a more current and fresher approach. As our title claims, this book is a snapshot in time. It captures what interests engineering students at TAMUQ in 2020.
Chapter I

PIONEERING RESEARCH
Introduction: Simulation and Design

Eng. Sara Khorasani

The word simulation has multiple meanings in the engineering world, so saying you are a simulation engineer can cause a lot of confusion. Some simulation engineers build mathematical models for airflow dynamics around a jet engine or rocket; however, Counterstrike and many other games can also be considered a form of simulation. In Formula 1 racing, simulation engineers simulate how different adjustments to cars affect cornering dynamics. This information can be used to design a better car, and it can also be used to build a driving simulator that allows drivers to perfect their cornering skills without having to worry about crashing a real car.

Simulation has applications in every industry. Amid the COVID-19 pandemic, simulation engineers at hospitals simulate the flow of doctors, nurses, and patients in buildings to minimize exposure to the virus, while ensuring the building is used efficiently and effectively. In the gaming industry, can you imagine the artificial intelligence engine required for all elements of a game like Grand Theft Auto to interact with the player and create a seamless simulation experience? Imagine using that technology more broadly for education. Imagine if students in engineering ethics classes could use role-playing simulation games that allow them to enact decision-making processes that engineers must use when ensuring safe structural design, managing teams, or even handling a lawsuit.

We cannot talk about simulation without mentioning virtual reality (VR), augmented reality, mixed reality, and cross reality. Pokémon Go is an augmented reality-based simulation experience. If you have ever tried "Ricky's Plank Experience," a VR experience in which a user on top of a building walks a plank and jumps off, you can imagine how VR has the potential to thoroughly shake one's previously held beliefs and assumptions or even the nature of reality. Psychologists and neuroscientists are using this type of simulation to diagnose and treat post-traumatic stress disorder (PTSD) by immersing soldiers in
situations that could trigger PTSD symptoms and desensitizing them. Human resource managers are also using VR experiences to put employees in the "shoes" of people of color, people with disabilities, or women to expose them to biases these individuals face daily at work. If you want to learn more about how humans interact with simulations and the design principles involved, just search Google for the term embodied cognition. This opens an entire world around how human interaction data in simulated experiences can give us deep insights into our learning potentials.

I may be biased, but I believe simulation is not just a tool for design, but also a powerful tool to train our brains to experience the world differently. Simulation engineers are going to be responsible for creating these new virtual worlds that trigger mental shifts and help us imagine a better world.
I.1 3D Printed Prosthetics
By Dana K. Alyafei

About 30 million people around the world need prosthetic and orthotic devices; however, access to such care options are limited [1]. More than 75% of developing countries do not provide training programs for such care, leading to poorer clinical coverage of patients in need [1]. Today, the evolution and great advancement of technology is making the process of creating prosthetics is much easier and faster through the use of computer-aided design (CAD) software. Having a relatively fast process compared to traditional prosthetic production provides room to create personalized prosthetics that are much more effective and useful for patients. However, achieving prosthetics that are even more personalized requires higher-performance applications. Currently, advances in prosthetic actuators are being investigated to reach natural muscle functionality, and unorthodox prosthetics are also being explored to expand wearer’s abilities and skills.

3D printing
Additive manufacturing processes build three-dimensional (3D) objects from CAD models by successively adding material layer by layer, a procedure commonly known as 3D printing. There are many different types of 3D printing processes that differ in cost, quality, printing speed, and other characteristics. This paper discusses different types of 3D printers and their roles in prosthetics manufacturing.

Fused deposition modeling (FDM)
Fused deposition modeling (FDM) is a process in which a coil of thermoplastic filament (e.g., PLA, ABS, or polyurethane) is heated to a temperature close its melting temperature. This allows the material to melt before it is extruded and deposited layer by layer on a platform [2]. The cooling of the material is sped up by cooling fans attached to
the extrusion head. The manner of the filament’s deposition is based on information from the CAD model in the form of a STL file.

**Stereolithography (SLA)**

Stereolithography (SLA) is a process that uses an ultraviolet (UV) laser beam to selectively cure a resin consisting of photosensitive thermoset polymers to form a desired object [3]. This process is shown in *Figure I.1.1*.

![Figure I.1.1. SLA 3D printing process [3]](image)

**Digital light processing (DLP)**

Digital light processing (DLP) works similarly to SLA; however, it uses a light bulb instead of a UV laser to cure resins. DLP can create objects faster than SLA because a single layer can be created in one step. In contrast, SLA creates only a single point at a time. An object created using DLP has fewer visible layers than other processes such as FDM, meaning that DLP can be used to create highly detailed artwork and non-functional prototypes and make molds for investment casting applications [4].

**Selective laser sintering (SLS)**

The selective laser sintering (SLS) process creates an object by tracing the object’s cross section using a high-power laser that causes powdered material particles to fuse together and form a solid [5] as
shown in Figure 1.1.2. Nylon is the most commonly used plastic in SLS.

Figure 1.1.2. SLS 3D printing process [5]

Selective laser melting (SLM)

Selective laser melting (SLM) uses a high-powered laser beam to create 3D objects [6]. The laser selectively welds metallic particles together in each layer, and this process is repeated until the final object is created. SLM printers are common in the aerospace and medical orthopedics industries, where precision durability and lightweight parts are desired [6]. The SLM process is illustrated in Figure 1.1.3.

Figure 1.1.3. SLM 3D printing process [6]


**Laminated object manufacturing (LOM)**

Laminated object manufacturing (LOM) uses heat and pressure to fuse or laminate layers of plastic or paper [6]. After each successive layer, a new sheet of material is added until the final object is created. The LOM process can be seen in Figure I.1.4.

![LOM 3D printing process](image)

*Figure I.1.4. LOM 3D printing process [6]*

**Electron beam melting (EBM)**

The electron beam melting (EBM) process is like SLM, but uses a powder bed fusion technique [6]. The difference lies in the power source, as EBM uses a powerful electron beam in a vacuum to create the object. EBM can produce complex objects that are also very strong and dense [6], as shown in Figure I.1.6.
3D printed prosthetics versus traditional prosthetics

Time is a crucial factor in production. Producing a traditional prosthetic may take anywhere from a few weeks to several months, depending on accessibility and the patient’s structure [7]. As patients wait for a prosthetic, many attempt to find alternative solutions, which could increase the risk of the body rejecting the prosthetic. Moreover, research has shown that patient adaptability to prosthetics decreases six months after an amputation [7].

In addition, traditional prosthetics last for five years; however, child amputees outgrow their prosthetics quickly and thus need frequent updates. Time is very crucial in such cases; therefore, 3D printed prosthetics seem to be more reliable as they take less than a day to prepare [7]. Furthermore, 3D printed prosthetics are cost effective, whereas traditional prosthetics are too expensive to be replaced as frequently. Also, because 3D printed prosthetics are highly personalized, they are considered more comfortable and can last longer. These prosthetics can also be customized, which can help with the social stigma of prosthetics.

The average cost of traditional prosthetics ranges $1500 to $8000 [7], whereas 3D printed prosthetics cost at least $50. Moreover, many patients in developing countries tend to take long expensive journeys
to reach prosthetics laboratories, most of which are in large cities [7]. Thus, providing 3D printed prosthetics is both timesaving and cost effective.

One drawback of 3D printed prosthetics is the fact that 3D printers require heat to melt fibers, which consumes 50 to 100 times more electricity than traditional injection molding processes used to create the same prosthetic [8]. However, industrial developments such as the Perpetual Plastic Project organization that recycles polyethylene terephthalate (PET), which is used in 3D printing of prosthetics [8]. In addition, an NGO known as Field Ready focuses on 3D printing in areas of crisis, as this process can be used to create prosthetics whenever needed in a short time. This NGO has also experimented with fibers that can be broken into smaller pieces, melted, and reused [8] to reduce environmental impacts.

**Advancements in 3D printed prosthetics**

*Actuators*

Research shows that almost 14.3% of amputees do not use their prostheses because of discomfort and prosthetics are often not easy to wear [8]. Advancements in 3D printed prosthetics are often related to the materials used and the actuators. 3D printed prosthetics are rigid, with limited flexibility compared to natural biological structures. The aim in advancing these prosthetics is to create a prosthetic that behaves like an organic structure in an energy efficient way [9]. By combining the power and accuracy of mechanical systems with the safety and efficiency of natural muscles, users can fully utilize their prosthetics, which may help improve their daily lives [9]. This also provides an opportunity to connect technology with the natural world, which may lead to developing even more useful innovations. It is not currently possible to replicate muscular structures with technology; however, because the aim is to imitate muscle functionality on a macroscopic level, there is a possibility of developing such prosthetics [9].
Leaf springs

The moving part with the lowest cross-sectional area in a prosthetic hand, known as the leaf spring, is most prone to failure. Leaf springs experience tensile and bending loads as the prosthetic hand moves [10], which allows the prosthetic to perform a grasping motion that depends on the object’s shape. In one study, a prosthetic hand, as seen in Figure I.1.7, was used to test the fatigue life and ultimate strength of its leaf springs.

![Figure I.1.7](image)

Figure I.1.7. Design of our 3D-printed prosthetic hand. Left: 3D prosthetic hand with translucent palm to show inner mechanisms; Right: 3D-printed prosthetic hand without palm [11]

Unorthodox prosthetics: The Third Thumb

When it comes to prosthetics, people often think of them as replacements to a lost or dysfunctional limb; however, prosthetics such as the Third Thumb can be used to broaden the wearer’s ability. The Third Thumb is a 3D printed prosthetic of an additional finger attached to the hand. London-based product designer Dani Clode designed the Third Thumb prosthetic shown in Figure I.1.8 [12].
The Third Thumb prosthetic is made using interconnected parts including a hand piece, an attachment, cables, motors, two wireless control boards, and pressure sensors as shown in Figure I.1.9 [12]. The Third Thumb is controlled by the wearer’s feet through pressure sensors, with each foot controlling a specific movement of the prosthetic. The signal from the sensors wirelessly controls the motors. The received signal causes the motor to move the cables attached to it and allows the flexible 3D printed thumb to grip or release.
Researchers have estimated that one in every 700 to 1000 newborns have polydactyly [13], a condition in which an individual has an extra finger on their hands, extra toes on their feet, or even both. Research shows that there are benefits to polydactyly. For example, a person with an extra thumb would have significantly improved manipulation abilities and skills compared to people with five fingers on each hand [13]. Those with six fingers can also perform movements with one hand that people with five fingers need both hands for. With six fingers, the number of degrees of freedom the brain must control also increases. This allows the advancement in developing additional artificial limbs such as the Third Thumb to broaden and expand human motor abilities.

In conclusion, advancements in prosthetics aim to produce more realistic and comfortable prosthetics and normalize their use. In addition to prosthetics used as replacements, these advancements can be used for prosthetics that extend human capabilities when performing daily tasks. Additional unorthodox prosthetics may be introduced and normalized in the future, such as an additional pair of arms to allow a surgeon to operate without an assistant. However, many experiments and prototypes are required to reach such goals. The use of 3D printed prosthetics is effective in such cases because prototypes can be developed in less time and would be cheaper to produce frequently than traditional prosthetics. 3D printed prosthetics also outperform traditional ones in terms of comfortability, customizability, size, and weight. Furthermore, new materials are being experimented with to increase prosthetic flexibility and fatigue life, as are advanced actuators and leaf springs. 3D printing of prosthetics also allows the exploration and expansion of the boundaries of neuroplasticity, hence improving the usability and control of prosthetics.
I.2 Compliant Mechanisms
By Fatima J. Al-Khuzaei

Minimalism is an inescapable word that has been progressively appearing in design and engineering. In design, minimalism essentially refers to the use of limited materials to produce the desired product, which can often lead to cheaper and more efficient designs. One method many mechanical engineers use to create minimalistic designs is the ancient technique of paper folding known as origami. Although originally intended for recreational and aesthetic purposes, many researchers and engineers have recently been using origami to convert energy into usable mechanical energy and, most importantly, to reduce the amount of space an object requires [1].

Nowadays, origami structures are created from various materials that include, but are not limited to, metals and polymers. Two-dimensional (2D) components are relatively easier to manufacture than three-dimensional (3D) bodies because manufacturing sheets and plates is relatively inexpensive [4]. In addition, rather than having materials permanently in 2D or 3D structures, researchers have developed so-called active materials that can fold into 3D bodies and then unfold back into their original 2D structures. This property of makes active materials valuable to the aerospace industry as dimensions and weight can dramatically inflate costs [2]. Recently, National Aeronautics and Space Administration (NASA) created many origami-inspired structures in partnership with research groups to possibly deploy into space, due to their useful properties [6]. Figure I.2.1 shows an origami-inspired solar panel developed by NASA.
Understanding the usefulness of origami structures in engineering applications can easily explain the growth of compliant mechanisms in mechanical engineering. In fact, because it relies on the deflection of flexible materials, origami is a type of compliant mechanism [5]. To begin, a mechanism is commonly defined as “a mechanical device that is utilized to transform motion, force, or energy” [3]. As traditionally seen in the mechanics of materials and rigid bodies, bodies are often connected by joints that are restricted in various ways. For example, some joints move only in certain directions and restrict motion in others. Screws and bolts are two common types of joints. Figure I.2.2 shows a schematic of two rigid bodies linked by a joint.

A compliant mechanism is one that “gains its capability to move by the deflection of its flexible members” rather than joints [3]. Deflection is created by an applied external force, which can cause the
structure to bend, meaning that one or more parts of the structure will shift position.

**Pseudo-rigid body models**

In statics and dynamics, a free-body diagram is an important representation of a body to be analyzed [7]. In compliant mechanisms, body structure is analyzed using pseudo-rigid bodies (PRB). These models are used to describe bodies that experience nonlinear behavior due to large deflections [9]. Each flexure joint in a PRB model is shown as a pin joint combined with a torsional spring as shown in **Figure I.2.3**.

![Figure I.2.3. Pseudo-rigid body model and main types of flexure joints [9]](image)
There are three main types of flexure joints. Each type of flexure joint produces a different stiffness, $K$, that varies depending on the difference between the rigid link length and the length of the joint.

In the first type of joint, the rigid link length is significantly longer than that of the flexure joint, so a small-length flexural pivot approach is used. **Equation I.2.1** shows the stiffness of this type of joint.

$$K = \frac{(EI)l}{l}$$

**Equation I.2.1.** Stiffness type 1

In the second case, there is only one joint, which means that the rigid link length is equal to zero. In this case, a fixed-guide segment approach is used for translational motion. **Equation I.2.2** shows the stiffness of this type of joint.

$$K = 2\gamma K \theta \frac{EI}{l}$$

**Equation I.2.2.** Stiffness type 2

In the third case, the length of the rigid link is greater than zero but less than that of the flexure joint. A fixed-pinned segment approach is used in this case. An added load on the rigid link causes a bending moment, meaning that the resulting deflection is magnified due to the rigid link.

**Equation I.2.3** shows the stiffness of this type of joint.

$$K = 0.7346K \theta \frac{EI}{l}$$

**Equation I.2.3.** Stiffness type 3
To demonstrate how the PRB model relates to the actual application and design of products, the shape shown in Figure I.2.3 will actually resemble the shape shown in Figure I.2.4.

![Figure I.2.4. Actual pseudo-rigid body][1]

One can easily analyze the motion, stresses, and input requirements of a compliant mechanism system using PRB models. One of the main uses of PRB models is designing compliant mechanisms, as they can be used to produce an initial design before prototyping and testing. In addition, a designer can determine how the PRB model will meet certain objectives from the start, allowing the creation of products capable of complex tasks [3].

**Advantages of compliant mechanisms**

The use of compliant mechanisms has many advantages over traditional rigid bodies. The next section discusses the various advantages of compliant mechanisms more thoroughly. The use of compliant mechanisms significantly reduces the number of components in a product and eliminates the use of springs, pins, and hinges, thus eliminating the need for assembly.
The production process of compliant mechanisms relates back to origami structures. Several manufacturing processes can be used to produce flat 2D planar sheets of the required material. Common methods of compliant mechanism manufacturing include traditional CNC machining, 3D printing, laser/waterjet cutting, and injection molding.

Traditionally designed products often fail due to fatigue, wear, and corrosion, and these factors that affect product lifespan can also affect mechanism precision. In traditional materials, wear occurs at different parts of the components, especially in pins and hinges that continuously rub against each other, causing deformation or material removal at the contact surface. Such deformations and changes alter the component’s geometry and motion. One example is how a door handle gradually wears out and becomes looser and less functional in motion and rotation. In compliant mechanisms, such deformation and wear are eliminated and other factors, such as dynamic vibration, are significantly reduced.

One of the most promising advantages of compliant mechanisms is that they are cheap to manufacture as they only require the construction of 2-D components and have a limited number of parts. Therefore, manufacturing time is greatly reduced, which in return reduces manufacturing cost. One the most inexpensive methods for producing compliant mechanisms is injection molding. Using one injection molded component, many of the same component can be produced. The resulting material is then sliced into multiple instances of the same product. The part shown in Figure I.2.5 was produced using injection molding.
As mentioned previously, compliant mechanisms have fewer joints, which leads to less friction and material wear. In various industrial applications, many of the machines require constant lubrication to improve their performance and reduce the effects of friction and resistance. Therefore, the use of compliant mechanisms could be valuable in many extreme industrial environments as they can increase the efficiency of the processes. For example, in aerospace engineering, compliant mechanisms operate in an extremely harsh environment where lubricants often evaporate [8].

It is easy to scale down compliant mechanisms for small miniaturized processes. For example, microelectromechanical systems often use micro actuators and sensors. Once again, the reduced number of components in these mechanisms makes it easier to miniaturize them. Miniaturized compliant mechanisms have recently been used in the creation of integrated circuits as shown in Figure I.2.6.
Energy in compliant mechanisms is stored as strain energy in its members, similarly to springs, thus it is easy to predict the deflection in the design phase. This property means that the flexible members can store energy when needed and then transform it to mechanical or kinetic energies at different times.

**Disadvantages of using compliant mechanisms**

Compliant mechanisms have several advantages; however, they also have multiple disadvantages that limit their use in industry. In addition, these mechanisms also face several challenges during application.

Linearized equations cannot be used to analyze compliant mechanisms. Most of the members in compliant mechanisms undergo large deflections, thus linearized beam equations are not valid [3]. Energy stored in the flexible members could be described as being similar to energy stored in springs. On the other hand, if a compliant mechanism’s function is to transfer energy from an input to an output, not all of the energy will be transferred as some will remain as stored energy within the members.
One of the largest concerns in the use of compliant mechanisms is fatigue. Although compliant mechanisms do not experience wear due to continuous contact between joints, the members are loaded in a cyclic manner to produce the required deflection. This constant loading and unloading causes a lower lifespan for the material, even more so than for a traditional rigid body.

The deflection of a flexible member within a compliant mechanism is limited by the member’s strength. Also, unlike traditional rigid bodies that can rotate about their connecting pins a compliant mechanism cannot produce full rotations as it is bounded by its members.

**Applications of compliant mechanisms**

Uses of compliant mechanisms in solar panels and consumer products was discussed previously to show its range of applications. Lately, much research has been conducted on the use of compliant mechanisms in prosthetics. In the case of prosthetics, it is extremely important that prosthetic limbs face minimal wear, have few parts, and be lightweight, properties that compliant mechanisms possess. The issues compliant mechanisms face in prosthetic designs is that they cannot withstand high compression applications [10]. In addition, the manufacturing process of compliant mechanism prosthetics is relatively inexpensive, as it is possible to 3D print prototypes of compliant prosthetics.

Lastly, one of the more efficient and popular applications of compliant mechanisms is in consumer products. As shown previously, slicing injection molding of compliant mechanisms is a very inexpensive method to produce scissors, wrenches, and grips. Figure I.2.7 shows a compliant scissor created by injection molding and slicing.
It is easy to observe the usefulness and potential of compliant mechanisms. Other applications of compliant mechanisms are in surgical tools that do not require lubrication. Compliant mechanisms have also been used in law enforcement and other design applications where microactuators are important [3].

**Cost benefit analysis of compliant mechanisms**

A plastic injection mold costs between $1,000 and $80,000 depending on the complexity of the mold shape [16]. However, the price of bulk manufacturing the product could cost only a few cents. In comparison, manufacturing products using other fabrication techniques could cost much more in the long term. For example, sand casting and die casting could cost $32,000 and $16,200 for 1000 parts, respectively, whereas the tool cost is approximately $1,500 for sand casting and $22,000 for die casting [16]. Some reports estimate that the use of compliant mechanisms could cut the cost of produced windshield wipers to as much as 35% less that the current production cost [14].
Another manufacturing method that has been finding a lot of traction in recent years is 3D printing. The cost of a 3D printed product is based on the filament used in the additive manufacturing process. Although, 3D printing may seem to be a very inexpensive method to manufacture materials, its main disadvantage is that the production time is long compared to other manufacturing processes, and a longer production time means less profit.

There is limited knowledge of estimated cost and research on the fabrication of compliant mechanisms. Nevertheless, we can conclude that compared to other manufacturing processes, compliant mechanisms are relatively cheaper to produce in the long run.
I.3 Self-Cleaning Materials
By Seham Al-Baker

Coatings are used to cover a vast range of objects such as textured surfaces, clothing items, and various open-air products like automotive technologies, window covers, and so on. Scientists have developed self-cleaning coatings that are inspired by objects in nature, such as the lotus leaf and the Namib desert beetle. Over the years, interest in researching self-cleaning coatings has increased, but is still not as prominent as other options [1]. The coating–substrate relationship determines the adhesiveness of the surface to the substratum, and thus its longevity. Simultaneously, the other side of the surface that is exposed to the atmosphere can be self-cleaning through either superhydrophobic or superhydrophilic performance.

Hydrophilic and hydrophobic properties

Wettability is the ability of a solid surface to maintain contact with a liquid. It is governed by the surface free energy and surface’s geometrical structure. A surface is hydrophobic if the water contact angle (CA) is greater than 90°, and a surface with a CA greater than 150° is considered superhydrophobic. A drop of water on a hydrophobic/superhydrophobic surface tries to minimize its area of contact with the surface. This increases the CA and consequently causes the drop to become spherical as shown in Figure I.3.1. The drop’s spherical shape and the surface’s tendency to repel water causes the droplet to easily roll off the surface. Hence, a hydrophobic surface is considered non-wetting.

Conversely, a surface with a CA less than 90° is considered hydrophilic and surfaces with a CA less than 10° are called superhydrophilic. A drop of water on a hydrophilic/superhydrophilic surface tries to maximize its area of contact with the surface, causing the water droplet to flatten out as shown in Figure I.3.1. Hence, a liquid can wet hydrophilic surfaces. The smaller the CA, the greater the droplet’s area of contact on the surface [2].
Presence in nature

The following are some of the natural biological materials that display incredible surface wettability/non-wettability.

The lotus leaf

The lotus leaf is an example of incredible surface non-wettability. Due to this non-wettability, it also exhibits self-cleaning abilities and has thus inspired a range of self-cleaning materials [3]. The superhydrophobic property of the lotus leaf is due to microscopic bumps on the surface. Further magnification revealed tubules made of wax, which increased the hydrophobicity [4]. This prevents wetting by making the material more superhydrophobic, causing water droplets to attempt to form a spherical shape to minimize area of contact and lessen surface energy. Figure I.3.2 shows a comparison between drop shapes on a typical leaf and a lotus leaf. When a droplet falls onto the lotus leaf it beads up and rolls off, simultaneously picking up dirt on its way off.
Namib desert beetle

The Namib Desert in Africa is known for its dryness, but every now and then there is fog. The Namib desert beetle that lives there uses the hydrophilic and hydrophobic nature of its back to collect water droplets from fog.

When the fog approaches, the beetle faces the wind to collect water using its back. The beetle’s interesting back consists of bumps that attract water (hydrophilic surfaces) and waxy areas surrounding the bumps that repel water (hydrophobic surfaces) as shown in Figure I.3.3. This composition allows the fog droplets to be collected on the hydrophilic surface and grow. The droplet eventually grows large enough to be repelled by the hydrophobic surface, after which the droplet rolls down the beetle’s back and into its mouth. This process has inspired a new method to help in droughts [5].

Figure I.3.3. Namib desert beetle with formed water droplets.

Theoretical basis

The self-cleaning function is specifically linked to the CA of a fluid droplet on a surface and develops a condition of phase equilibrium.
The drop can either extend to cover the whole surface, retain its initial shape, or ball up and try to leave the surface instead. Therefore, if a surface is seamless, i.e., homogenous, planar, or non-deformable, CA equilibrium can be obtained. The final state of the equilibrium obtained depends on the surface’s characteristics and on external factors such as temperature or pressure.

Three models of wetting are shown and explained below to help get a deeper view of self-cleaning structures. The study of wetting, that is, the behavior of fluid on a substrate surface, will help us understand the self-cleaning process and develop new materials.

**Young’s model**

Young introduced the first model prototype in 1805. Young’s model defines the wettability of smooth and homogenous surface as shown in Figure I.3.4(a). The CA obtained from Young’s model reflects whether a surface is hydrophobic or hydrophilic [6]. However, Young’s equation is inapplicable for actual substances as they are usually rough and chemically heterogeneous.

**Wenzel’s model**

In 1936, Wenzel proposed a formula in which surface roughness and energy are linked to the CA. In Wenzel's equation, water is assumed to pass through hollow areas on the surface that are a function of surface roughness, as shown in Figure I.3.4(b). Therefore, Wenzel’s model usually describes a homogeneous wetting system. From Wenzel's theorem, it can be inferred that surface roughness will improve both wetting and anti-wetting features depending on a material’s surface properties when it is smooth. Therefore, if the smooth layer CA is greater than 90°, surface roughness will increase the CA, and if the CA is less than 90°, surface roughness will decrease the CA [7]. The Wenzel concept refers just to homogeneous layers and cannot be utilized on heterogeneous layers, which have uneven roughness.
**Cassie-Baxter model**

Cassie and Baxter developed another heterogeneous layer method in 1944, as shown in Figure I.3.4(c).

In the Cassie-Baxter method, the drop and the surface contact only at the top of the surface and tiny air bubbles are held under the drop.

It must be remembered that the concept behind the Cassie-Baxter model is not necessarily true for all materials. For instance, if a surface possesses hydrophilic properties, the drop of water may be immersed in the void structure. In addition to these models, there are more sophisticated models for forecasting complex wetting conditions.

![Figure I.3.4. Wetting condition of a droplet under different models: (a) Young’s model (b) Wenzel’s model, (c) Cassie and Baxter model](image)

**Applications/drawbacks of self-cleaning materials**

As previously mentioned, one of the many applications of superhydrophobic and superhydrophilic coatings is self-cleaning surfaces. Superhydrophobic and superhydrophilic surfaces are developed through either coatings or surface modification. Coatings have significant advantages such as lowering maintenance costs, increasing longevity, and avoiding snow or ice. Such self-cleaning layers have tremendous potential uses in textiles, vehicle parts, buildings, domestic applications, and optical uses. Although there are many potential benefits to self-cleaning materials, there are also some drawbacks and limitations. Each application has its own drawbacks, but possible common limitations include high costs due to the
complexity of creating a self-cleaning coated surface, challenges with large-scale fabrication, and limits to long-term stability.

The following are some examples of applications of self-cleaning materials.

**Self-cleaning textiles**

Some fabrics can now self-clean using technology inspired by nature. Self-cleaning textiles can be manufactured using nanotechnology [8]. For instance, one nanotechnology method to control wettability is using a polymer film mixed with silver nanoparticles as a surface coating, as shown in Figure I.3.5 [9].

![Figure I.3.5. Two textile surfaces, one untreated (left) and one treated with silver Nano particles (right).](image)

Another method of producing superhydrophobic cotton fabrics is by using a coating solution composed of SU-8 (a negative photoresist), a fluorinated alkyl silane, and silica nanoparticles. This fabric repels dirt over time as seen in Figure I.3.6.
Fabrics with such self-cleaning abilities are useful for making waterproof garments. For instance, firefighter uniforms, workwear, and outdoor fabrics such as those used in marquees and awnings are a hassle to clean and can benefit from this technology. Some of these examples of coated clothing are commercially available.

However, there are some drawbacks to self-cleaning fabrics. First, it can take a long time for a fabric to clean itself. Qi et al. [11] reported a self-cleaning time of approximately 20 hours. Additionally, the superhydrophobic effect of self-cleaning fabrics decreases over time and is usually damaged after washing.

**Anti-snow and anti-ice layers**

Ice/snow adhesion in cold open-air environments has been a problem of paramount importance for researchers around the world. Different authors have suggested various methods to solve these issues using multiple materials.

Several superhydrophobic coating options have been recommended as they also have anti-icing properties [12]. These superhydrophobic surfaces would cause water droplets to easily slide off the surface before they freeze. This would help reduce damage to electrical
transmission equipment, aerospace facilities, and highways. The superhydrophobic surface shown in Figure I.3.7 reduces ice adhesion by 97% [13].

One drawback in this area is the pinning of multiple water droplets on the surface due to ice/water capillary bridges. Additionally, these coatings are heavy if applied to large structures such as airplanes, and increased weight may bring many negative factors [13].

**Drag reduction**

Inspired by shark skin, many superhydrophobic coatings have been created to reduce drag. Hongyu Dong compared drag between uncoated ships and ships with a superhydrophobic coating and calculated a 38.5% decrease in drag [14].

![Figure I.3.7. Comparison of ice formation on uncoated and superhydrophobic-coated insulators [12]](image-url)
**Improved corrosion resistance**

Another important feature of self-cleaning surfaces is their resistance to corrosion. This feature has prompted several experiments on the application of these coatings to various metals such as iron, copper, aluminum, and titanium, as well as other alloys and metallic oxides. For instance, Yuan et al. effectively deposited self-cleaning coatings on iron using various acid baths, such as perfluoro carboxylic acid. The self-cleaning surface showed great resistance to corrosion, with no rust observed after six months in a natural atmosphere [15].

**Anti-reflective and sheer layers**

Several new optical products such as touchscreens, LCDs, photovoltaics, windows, eyeglasses, optical telescopes, lenses, and visual sensors to have optical clarity or anti-reflectivity. Consequently, most of these products benefit from being water repellent and self-cleaning. The key to making effective anti-reflective or translucent superhydrophobic coatings is to streamline or monitor the roughness of the surface [1].

**Self-cleaning windows**

Glass windows are coated with a thin film of titanium dioxide. The self-cleaning effect is activated through a photocatalytic reaction with UV radiation, which decomposes dirt on the surface. As rain hits the hydrophilic coated surface, droplets expand and wash away dirt on the surface [16]. This phenomenon is shown in Figure I.3.8.
There are a few drawbacks with self-cleaning windows. First, they are dependent on sunlight and rain, making them suitable only for the outer facades of buildings. However, efforts are currently under way to develop self-cleaning glass suitable for indoor applications. Another drawback is that the methods involved are complex and thus not suitable for large-scale applications. Lastly, superhydrophobicity and transparency are properties that conflict with one another.

Future trends

Most of the applications previously mentioned are currently unrefined and are in progress. On the production spectrum, one of the latest research areas is 3D printing of hydrophobic and superhydrophobic surfaces. This process could provide a wider variety of fabricated technologies than traditional fabrication methods that are complex and time-consuming. Potential micro-structured hydrophobic and superhydrophobic surfaces have been fabricated through additive manufacturing (e.g., vat photopolymerization, material jetting, and material extrusion) [17]. Although this approach has shown promise, more research is required to reap its benefits.
Possible uses of self-cleaning materials in Qatar

Qatar’s economy relies on income from the oil and gas industry. Oil and hydrocarbons are a finite resource, so Qatar is trying to use alternative energy sources that are renewable, sustainable, and cleaner. Additionally, the 2022 FIFA World Cup will have a high demand for energy saving infrastructures. Qatar has agreed to build multiple solar photo-voltaic (PV) modules in its efforts to be more sustainable. Unfortunately, there are significant factors, such as dust and humidity, that affect PV module efficiency. A possible solution for this issue is using superhydrophobic coatings on PV panels to repel dust and improve efficiency [18].

In addition to PV modules, superhydrophobic coatings can be used on skyscrapers in Qatar, keeping windows clean without risking human lives to clean them. Moreover, because humidity and fog are common throughout the year in Qatar, superhydrophobic coatings can be used to increase visual clarity and prevent fog buildup on car windows.

Surface engineering knowledge is crucial for enhancing self-cleaning properties. The uses of such materials may include self-cleaning car windscreens, anti-reflective photovoltaic panels, and smudge-resistant textiles, among others. Although considerable progress has been made in the synthesis of biomimetic superhydrophobic and superhydrophilic self-cleaning layers, there are still many barriers to overcome to make them usable for flexible industrial purposes.
I.4 Virtual Reality Applications and Advancements

By Abdo Harami

Virtual reality (VR) was founded in the 20th century, with the first device that explored the concept being created in 1962. This device displayed short films while also engaging multiple senses simultaneously, and it was solely driven mechanically as digital computing was not available during that time. In 1968, Ivan Sutherland created the first head-mounted display system for immersive simulation applications (currently known as VR). Technology at the time was primitive, both in terms of user interface and visual realism, and the VR headset was so heavy it had to be suspended from the ceiling for it to be used. From 1970 to 1990, the VR industry mainly provided devices for medical education, flight simulation, automobile design, and military training purposes. In 1979, Eric Howlett created the Large Expanse Extra Perspective (LEEP) optical system, which could show stereoscopic images with a field of view wide enough to create a convincing sense of space. The original LEEP system was later redesigned for a NASA research center. As time passed, VR advanced immensely due to many people creating different types of VR machines [1].

Figure 1.4.1 shows how VR headsets have changed and been upgraded over time. The latest VR headsets far surpass their predecessors. Furthermore, the latest VR headsets come with different features that allow the user to use all five senses: vision, sound, tactile, smell, and taste. However, the full capacity of such headsets is mostly used in gaming.
Currently, there are several applications for VR, and it has been beneficial in many fields such as militaries, healthcare, education, gaming, sports, construction, and engineering.

Gaming

VR was originally dedicated to gaming where people play games in a virtual world. In this virtual environment, people can feel as if they are inside the game itself rather than playing it while looking at a screen. Also, VR with a five-sense set makes the user feel even more like they are immersed in another world, helping them enjoy the gaming experience. Ever since the Samsung Gear VR was released, the annual growth rate of the VR gaming market has gradually increased. Figure I.4.2 shows the Razer Open Source Virtual Reality for Gaming.
Military training

VR is used for military training purposes as it is helpful for training soldiers for combat and other dangerous situations without risking death or serious injury. Hence, soldiers trained using VR safely gain experience that can be applied in the real world. Another advantage to using VR is that the same environment can be reused multiple times. Having a reusable environment provides trainees a chance to complete the level before moving on to the next level. Also, each trainee gets the same test. It has been proven that this is safer and less costly than traditional training methods [2]. A third advantage is that VR training helps soldiers overcome their fears and the stress disorders that can develop due to trauma experienced on the battlefield. These symptoms can be dealt with in the VR world. Figure I.4.3 shows soldiers receiving parachute training using VR.
Healthcare

Healthcare is one of the biggest industries using VR. They use it for surgery simulation, robotic surgery, and skills training. VR allows healthcare professionals to learn new skills and enhance existing skills without risks or danger to patients. This technology also allows both new and experienced doctors to learn and practice interacting with patients, all within a 3D environment. Inexperienced doctors can use VR simulations to learn how to perform surgeries and can make mistakes as no lives are at risk. It is an immersive experience in which participant emotions can be monitored through a series of sensors. Thus, doctors can train in a stress-free environment in VR until they can confidently perform their duties in the real world. Another interesting technology is virtual robotic surgery, in which surgery is performed by a robotic device controlled by a surgeon. This technology helps reduce the time required and the risks of complications [3].
Education

Education is the basis of knowledge and has thus been a top priority for civilizations since the very beginning. People have always been looking for ways to transfer knowledge that are faster, easier, and more effective. VR is likely to be the next step in enhancing the educational experience. This is because students can be given a visual and immersive scene representing the content that is being taught. For example, schools can use VR to teach astronomy, allowing students to learn about the universe and physically engage with the objects within. They can see stars and track the progress of what is happening, which can be applied in the real world. VR also helps people to learn by doing, meaning that students will be able to learn faster and apply their learning by working within virtual world instead of focusing only on reading instructions [4].

Engineering

VR also plays a major role in the engineering field, where its uses include 3D modeling and visualization techniques as a part of the design process. This technology allows engineers to view their projects in a 3D view, helping them to gain a better understanding of how their projects work. In addition, virtual reality permits engineers to find flaws or potential risks before implementing a project [8].

VR is especially helpful for engineers who are designing structures [11]. This is because one cannot know when parts overlap or do not fit in reality unless a prototype of the structure is built. In contrast, with VR one can sit down, wear a headset, and start designing the prototype. The user can see the design from all angles, yielding clarity on building the structure, hence leading to minimal issues. Engineers create precise structures in SolidWorks software and VR technology allows users to display CAD models on their device in front of them without needing to move from their place. Figure I.4.4 shows a person using VR to visualize and build a design, all while sitting in one place [10].
Welding training

VR is also used in welding training, allowing people to gain welding skills without wasting money or materials. Also, because VR training is safer, users can learn without fear of making mistakes, and hence learn skills quickly. Examples of welding skills gained using VR include body position, angle, speed, and welding gun placement. Once a person gains these skills, they can confidently implement them in reality [5].

Augmented reality

The difference between augmented reality (AR) and VR is that in VR, the user’s perception is based on a virtual world with no relation to the real world, but in AR, the user has computer-generated information that enhances the user’s perception of reality [13].

So far, both VR and AR have been used separately, but mixed reality (MR) combines VR and AR. In other words, with MR, people can
use VR visualization without needing a virtual world. Thus, engineers can build and design prototypes in front of them instead of having to work in a virtual world. In fact, with MR, other people can see the design as it is being built [13].

VR is an important milestone in modern technology, but it faces many challenges. Currently, the technology is expensive for individual gaming and uneconomical for companies. On the other hand, the developers cannot afford to lower prices because the technology and materials required to build a VR device are expensive. In fact, using VR equipment on its own is not enough to bring out the full potential of VR, meaning that user must buy additional equipment, thus adding to the cost. For example, VR use in gaming requires VR gear as well as external equipment to help players feel and hear when playing. In addition, VR technology is still too primitive to be used effectively and to its full potential. Lastly, the negative health effects of using VR are a major issue. People can experience blurred vision and headaches after using VR gear for a long time. Furthermore, it has been speculated that there are short-term and long-term health issues from using VR have that have not been discovered yet [7].
CORONAVIRUS INNOVATIONS
March 15, 2020
Dr. Eyad Masad delivered a lecture on the topic of COVID-19 and the role of engineering innovations in tackling the problem. This section contains the opinions and questions the students had about the topic, and all the engineering innovations that intrigued them. Note that these opinions are based on the earlier stages of COVID-19 (March 2020).
INNOVATIONS OF INTEREST

- Drones that deliver food and medicine
- Robots that deliver meals to quarantined patients in hotels
- Drones and UVD robots that spray streets with sanitizer
- Global Inlet Director (airplane airflow redirecting)
- Dashboards that tracks down and predicts coronavirus data
- 3D printed respirators and face shields
- Antimicrobial coatings
- Artificial Intelligence
- Telemedicine (Vici Device)

QUESTIONS

- Should governments gather personal information if it could help mitigate the spread of the virus?
- Once this virus is over, will there be a market for any of the new technologies?
- How could I best address a need created from this pandemic in order to create a business?

NEWS

TEXAS A&M AT QATAR PRODUCING FACE SHIELDS FOR QATAR RED CRESCENT SOCIETY TO AID IN VIRUS FIGHT

PUBLISHED MAR 27, 2020

OPINIONS

- Coronavirus engineering innovations increased my appreciation for my major.
- One the most dangerous innovations is the increase of surveillance in quarantine.
- The only thing I noticed that matched the growth speed of the virus was the quick human adaptation through utilizing modern engineering.
- Hard times are times of innovations
Chapter II
ENGINEERED TECHNOLOGY
Introduction: What does it mean to be an engineer?
Dr. Marwan Khraisheh

What does it mean to be an Engineer? Future employers are looking for engineering graduates with both knowledge and skills, ready to confidently enter the workplace. Their expectations are that curricula and modes of instruction along with the various learning opportunities outside the classroom to successfully address these trends, to engage learners on programs that will develop their foundational competencies and teach the future skills employers require.

Recent studies and surveys grouped the required future skills into three dimensions. The first dimension focuses on personal skills - being able to learn autonomously, self-motivation, self-initiative, creativity and innovation. The second dimension relates to subject-knowledge and the ability to analyze and reflect upon what has been taught - being able to not only learn the theory, but to also apply in practice. The third dimension looks at social, societal and organizational-related skills – being able to relate to the needs of the community and society and be a global citizen.

Qatar has embarked on an exciting journey to develop a sustainable and diverse economy based on knowledge and innovation. The growth of vital economic sectors and the establishment of new knowledge-based and innovation-driven sectors mainly rely on Research, Development and Innovation (RDI) Ecosystem. Core to the RDI Ecosystem is skilled human capital and a cadre of intellectual engineering leaders to spearhead the transformation to a knowledge-based economy.

The Mechanical Engineering Program at TAMUQ recognizes these needs and provides great opportunities to students to develop and shape these skills through diverse course work that combines theory, lab work, field work and critical thinking. The wide range of professional development activities, including research experience, internships, international travel, student-led competitions and student organizations,
are designed to foster innovation and creativity and to support the development of confident and well-trained engineers.

Students at Texas A&M at Qatar participate in various research programs under the supervision of faculty members. These opportunities allow students to go in-depth in addressing research questions that are relevant to Qatar with global significance. Students will develop research methodology skills and are exposed to recent technological advances. Research often leads to merging ideas from different fields to develop innovative solutions that address societal needs. Research in mechanical engineering encompasses various areas including smart intelligent systems, manufacturing, mechanics and materials, and thermal fluid sciences. The applications span over a wide range of fields such as energy systems, biomedical, oil and gas, and infrastructure systems.

The initiative taken by students to write this book highlights their creativity and their ability to apply what they have learned inside and outside the classroom. Using art and effective communication strategies to discuss recent technological advances and highlight their impact on society demonstrate that they are ready and able to tackle future challenges and contribute to the advancement and wellbeing of their communities and societies. Go Aggies!
II.1 Recreational Quadcopters: Drones
By Maryam AlMulla

A drone is an unmanned aerial vehicle (UAV) that can alternatively be described as a flying vehicle that is piloted remotely [13]. Drones have been intensively used commercially and recreationally over the years and have developed significantly in that time. The first drones were built in 1915 and were designed for military purposes [12], whereas drones are currently used for a variety of applications such as defense, agriculture, waste management, weather forecasting, and photography, and the potential for delivery services and other applications are being researched [14]. The main method for controlling drones from a distance uses a GPS tracking system and a camera. Additional instruments, like ultrasonic, infrared, vision sensors can also be added to drones depending their intended use [13].

Types of drones

Single-rotor: A single-rotor drone has only one propeller and it is most commonly known as a helicopter.

Multi-rotor: A multi-rotor drone has more than one rotor. However, the rotors of a multi-rotor must be symmetrical to stabilize the drone’s motion. The most popular type of multi-rotor drone, known as a quadcopter, has four rotors. However, hexacopters (six rotors) and octocopters (eight rotors) are also types of multi-rotor drones in use.

Fixed-wing: Fixed-wing drones have a similar structure to airplanes, as they consist of wings that create lift. Fixed-wing drones have the highest efficiency and flight time of all three drone types.

Differences between commercial and recreational drones

Commercial drones are drones used professionally by businesses. Commercial drones can be used for advertisements, weather forecasting, security, and other professional applications. In contrast,
recreational drones are bought for personal use, either by hobbyists or for use as toys. The main differences between commercial and recreational drones are their cost, quality, and technology (sensors). A recreational drone can cost $30 to $150, whereas a commercial drone may cost thousands of dollars depending on application requirements.

Although all types of drones are important, this research focus solely on recreational multi-rotor quadcopters. **Figure II.1.1** shows a schematic of a recreational drone and its main components. The motors convert electrical energy to mechanical energy that rotates the rotor blades. The connectivity in the system and the camera allow the user to track of the device. The accelerometer controls rotor speed and the landing gear enables safe landing [15].

![Figure II.1.1. Recreational quadcopter](image)

**Motion and forces**

The drone components that play a major role in its motion are the rotors. **Figure II.1.2** shows an overhead view of a drone’s structure and the rotation direction of its rotors. To understand how motion occurs in a drone, the major forces involved, lift, thrust, drag, and weight, must first be understood [3]. When the rotors spin, they push
air downward, creating a force known as thrust, which can hence be defined as the reaction force to the force created by the rotors. Weight is the force due to gravity, which pulls the drone downward, opposing lift. Drag is usually created by air resistance, which acts parallel to the ground and is induced by horizontal thrust. Note how the lift force and the thrust force are only equal for vertical motion. However, when the drone moves sideways, lift becomes a vertical component of the thrust force, pointing toward the direction of the motion.

![Overhead view schematic of quadcopter](image.png)

**Figure II.1.2.** Overhead view schematic of quadcopter [2]

**Vertical motion**

As shown in **Figure II.1.2**, the vertical motion created by the rotors uses the following motion. Rotors one and three have a clockwise rotation and rotors two and four have an anticlockwise rotation [2]. This orientation cancels out all horizontal forces, allowing the drone to move vertically only. Another factor that affects vertical motion is rotor speed. All four rotors must rotate at the same speed to achieve stable vertical motion [4]. The drone hovers when the thrust force is equal to the gravitational pull, climbs when the thrust force is greater and descends when the thrust force is less than the gravitational pull.

**Horizontal motion**

Horizontal motion occurs by changing rotor speeds. For example, to move the drone shown in **Figure II.1.2** to the right, rotors one and
four increase their rotational speed and rotors two and three decrease their rotational speed. This makes rotors one and four rise higher than rotors two and three, tilting the drone to the right. Hence, the thrust force created by the rotors changes its direction toward that tilt, creating horizontal motion. This motion is described in Figure II.1.3.

![Figure II.1.3. Forces that Result in Horizontal Motion [2]](image)

**Rotation**

The final motion to be considered is rotation. This movement is important as it allows the camera to face the right direction when flying. This is where angular moment plays a role. To achieve clockwise rotation, the clockwise propellers speed up and the anticlockwise propellers slow down. This creates a stronger rotational velocity in the clockwise direction, rotating the drone clockwise. A drone’s angular moment can be calculated using **Equation II.1.1** [9]:

\[
\text{angular moment} = w \cdot l = w \cdot nm_m (y_m^2 - b^2) + m_b y_b^2
\]

**Equation II.1.1.** Angular moment
In this equation, \( w \) is the angular velocity, \( m_m \) is the total mass of the propeller, motor, and support (propulsion system), \( y_m \) is the distance from the center of gravity of the propulsion system to that of the drone, \( b \) is the distance from the motor axle to the drone axle, \( y_b \) is the distance from the center of gravity of the battery to that of the drone, and \( m_b \) is the mass of the battery [9].

**Motor**

A drone’s motor is usually either a brushed or brushless DC electric motor. Although both motors work through the theory of electromagnetism, brushed and brushless motors differ in how they work as well as their efficiencies. Brushless motors are more efficient (85–90% efficient) than brushed motors (75–80% efficient) and are powerful enough to carry heavier drones. However, brushless motors are more expensive. Hence, brushed motors are more likely to be used in toys and small drones. Each rotor in a drone has one DC motor to rotate each rotor, thus, a quadcopter drone has four DC motors.

**Brushed motor**

A brushed motor works by placing a coil (armature/rotor) between the poles of a fixed, strong, and permanent horseshoe magnet (stator) and connecting the coil to an electrical supply. Figure II.1.4 shows a schematic of a brushed motor setup. Current flowing through the coil reacts to the magnetic field produced by the magnets and rotates half a turn. The direction of the rotation can be determined by the left-hand rule. The electromagnetic force of the rotation created by the current and magnetic field is represented by Equation II.1.2 [7], in which \( B \) represents the magnetic field, \( I \) represents the current, and \( L \) is the length of the coil.

\[
F = \vec{I}L \times \vec{B}
\]

**Equation II.1.2. Force of rotation in a DC motor**
However, the coil will return to its original position after rotating half a turn. This happens because one side of the coil is only attracted to one side of the magnet. To make the coil achieve a full turn, a commutator and a brush are used as shown in Figure II.1.4. The commutator changes the direction of the current flowing in the coil, causing the coil to continue rotating in the same direction. This current reversal occurs every half rotation of the coil [6]. The brushes are fixed and connect the commutator and the battery to the coil [17]. However, the brushes cause limitations in this setup by affecting the rotor speed and limiting the number of poles the armature can have. Brushes also tend to wear out quickly and may produce sparks.

![Figure II.1.4. Schematic of a DC motor [4]](image)

Figure II.1.4. Schematic of a DC motor [4]
Brushless motor

Unlike a brushed motor, a brushless motor has permanent magnets on the rotor and the coil (electromagnet) is fixed on the stator, and a computer is used to flip the current instead of brushes. This comparison can be seen in Figure II.1.5, where the left motor is brushed, and the right motor is brushless. The computer in the brushless motor is more precise than brushes and does not wear out [17]. The involvement of a computer also eliminates the previously discussed limitations caused by the brushes. To rotate the permanent magnet, the computer adjusts the direction and magnitude of the current flowing in the coil so two of the three coils generate an electromagnetic field. As the permanent magnet rotates, the computer selects which coil will have current flowing through it to keep the rotator rotating [19].

Battery life and efficiency

Most recreational quadcopter drones have a flight time of about 30 minutes, and that flight time is affected by many factors. One factor is the battery, with a high-capacity battery leading to longer flight times;
however, batteries degrade over time. Therefore, lithium batteries are thought to be the most suitable as they have good energy storage capacity and are long lasting [8]. A bigger battery is also said to store more energy [21]. In addition to the specifics of the battery, weight also plays a role in battery life. Hence, for better battery performance, it is advised to reduce the weight of the camera and other attachments. This weight-based performance was examined in a study that generated the graph shown in Figure II.1.6 [20]. Figure II.1.6 shows the power consumption of a quadcopter drone with different weights attached. It can be observed that as the weight increases, power consumption increases as well.

Weather also plays a role in battery life, due to energy consumption levels. For instance, more force is required to overcome wind speeds in windy weather, leading to greater energy consumption [8]. Figure II.1.7 was obtained from the same study as Figure II.1.6 [20], and shows power consumption at different wind speeds. In this study, the quadcopter was set to fly against the wind (headwind) and along the direction of the wind (tailwind) at a speed of 18 km/h. Figure II.1.7 shows that with a headwind, higher wind speeds led to greater power consumption. In contrast, in a tailwind the wind speed has little to no effect on power consumption.
Quadcopters are not considered to be as efficient as single-rotor drones. This is because larger blades create thrust more easily, meaning that a single rotor can generate more thrust at slow speeds, whereas multiple rotors require high speeds to generate thrust. In other words, the greater the number of rotors, the less efficient the drone becomes. Another factor that effects drone efficiency is motion speed. When drones move in a slow and steady manner, more energy is required to keep the drone stable. Less power is required for drones to fly at high speed [10].

In conclusion, recreational quadcopters have short flight times and inadequate efficiency that could be significantly improved. Although recreational quadcopters are usually bought for personal use, a 30-minute flight time is still insufficient. Some personal applications, such as photography, require a lot of energy. Batteries must be developed that supply adequate energy to the motors as well as a high-quality camera. The drone should also have a stronger connection to avoid lags in control. Additionally, the efficiency of drone motors could also be increased. One method of improving drone efficiency is to switch from brushless DC motors to more efficient brushless motors [16]. Although the high costs of brushless motors may make their adoption uneconomical for recreational quadcopters, hobbyists may prefer them because of their longer lifespan and lower maintenance costs. Lastly, DC motors are also known to produce a lot of noise, which some users may find undesirable [16].
II.2 Simulation and Analysis of Tower Cranes
By Reem Hassan M.A. Elhadi

A tower crane is a machine used to lift a load using a hook suspended from a lever. Anyone who lives in or around a city has probably seen a crane in motion; however, how many people know how that crane works or how it was assembled overnight? This topic provides insight on how these structures are designed, simulated, and manufactured. Common questions people ask when they see a crane include whether the masses placed on the crane ever fall off or what accidents involving a crane have occurred. Accidents can be caused by vibrations induced by the pendulum system, which consists of a trolley and a cable from which the hook is suspended. The load is secured to the hook.

History

The Ancient Greeks developed the concept of cranes in the late 6th century BC to help lift tongs and Lewis iron used to construct temples. Later, the Romans began to use Greek cranes to help with construction and added their own improvements. These cranes were also used in harbors and mines [1]. These old cranes looked vastly different from modern cranes. A schematic of the first design of cranes used by the Ancient Greeks is shown in Figure II.2.1.
The first tower crane was invented in 1949 by Henry Liebherr, an innovator who became a prominent figure in Germany’s reconstruction following the Second World War. Liebherr’s motivation to invent the crane was the damage that Germany underwent during the war. He believed that his country needed the tower crane and that he could profit off it. Furthermore, a year after his first invention, Liebherr went on to commission the first factory abroad to target the British and North American markets. Figure II.2.2 shows an image of his invention and how it folds up for transport [3].
Designs

An understanding of the tower crane and the complexity of its dynamics are necessary to understand its design. The cable that holds the load and the load itself make up the pendulum system. The mast is the vertical support of the tower crane and the horizontal structure it holds up, which is what the pendulum system is suspended from, is known as the jib. These structures have a life span of 20–30 years or more. The continual assembly and disassembly and transportation of these structures affect the lifespan of each tower differently. The structures are mainly made of steel, which is an alloy of iron that contains a small amount of carbon.

Initial design

The first design is that of the Greek crane. This mechanical object, invented by the Ancient Greeks, was initially designed to lift heavy objects. The design of these cranes is simple compared to current designs; however, the basic mechanics are identical. Early crane designs consisted of simple ropes with a wooden structure. Wood had
a much lower load limit than modern day steel cranes. Over time, the Greeks introduced the winch and pulley, which allowed them to lift heavier objects. These cranes were operated by animals, commonly donkeys, but they could also be powered by humans who would carry the weight. In the 6th century, the Greeks possessed most of hand tools needed for designing woods. This explains why the first invention of the crane was made of wood. **Figure II.2.3** shows a simplified model of this first invention. The brown dashed line represents the ropes that support the slanted part and the horizontal base of the structure. The load on the left is placed to support the structure and keep it from tipping over when lifting. The green dashed line represents a rope that passes through four pulleys that allow the load to be lifted through manual rotation. Eventually, the design advanced to being rotated by animals such as donkeys [2].

**Figure II.2.3. Simplified model of the first Greek design**

**Modern tower cranes**

Currently there are three types of tower cranes, which are classified based on the jib’s position. The type of tower crane most seen or used, known as the hammerhead tower crane, has a horizontal jib. The second type of tower crane is the luffing jib tower crane, which uses a
jib that is inclined upward. The third type of tower crane, the articulated jib tower crane, uses two jibs, one that is inclined and one that is horizontal.

The jib in a hammerhead tower crane does not translate in the x-, y-, or z-axis directions; however, it does rotate about the z-axis, which is the axis of the mast. This motion is known as slewing. The crane has three degrees of freedom: the jib rotates about the z-axis (i.e., slewing), the cable that connects the pendulum to the crane translates along the jib’s axis, and the load moves in the z-direction when lifted (i.e., hoisting). The advantage of the hammerhead tower crane is that it reaches higher levels than other types of tower cranes. However, because of its height and size, another tower crane is needed to assemble and disassemble it. Figure II.2.4 represents a schematic and parts of the hammerhead tower crane.

![Figure II.2.4. Hammerhead tower crane [4]](image)

The luffing jib tower crane has different degrees of freedom than the hammerhead tower crane. The difference is that instead relying on a trolley that moves the cable along the jib, the payload is lifted or lowered by raising and lowering the jib. The advantage of this extra degree of freedom is that it is much more suitable for use in tight places, such as those constricted by neighboring areas, or when there are other construction cranes on site [5]. In addition, luffing tower cranes provide maximum lifting capacity to a minimum radius [6].
However, the disadvantage of the luffing jib tower crane is that the frequent alterations of the radius and adjustment of the jib results in it being much slower than a hammerhead tower crane [6], making it relatively inefficient timewise. Figure II.2.5 shows a luffing jib tower crane and its parts.

Figure II.2.5. Luffing jib tower crane [7]

The third crane design is the articulated jib tower crane, which has two jibs, one inclined and one horizontal. The articulated jib tower crane seems to be more compact than the previous two designs. Not only is this advantageous because it works in compact and tight areas, it also can work in sites with airspace restrictions. Moreover, it is much faster and more productive because its jib folds faster and the length of the hoist rope (i.e., the cable that hangs off the crane) is reduced, making load responses much quicker [6]. Figure II.2.6 shows an articulated jib tower crane.

Figure II.2.6.
Comparison of the three cranes

The three cranes have various tower heights, jib lengths, and production companies. To compare these types, three specific company designs were selected. The best way to compare them is to study the power consumption by each design during the slewing, luffing, and hoisting processes. Table II.2.1 shows these comparisons. Because the hammerhead crane has no luffing process, it’s expected to have the lowest power consumption. In addition, the articulated jib’s hoisting height would be much greater than the other two, thus consuming much more power. The installation duration for these crane designs ranges from three to seven hours, including transportation of parts to the jobsite. This duration is for a standard tower height of about 45 to 60 m.
Table II.2.1. Power comparison between the three designs [9]

<table>
<thead>
<tr>
<th>Type</th>
<th>Company Design</th>
<th>Maximum load (kg)</th>
<th>Power (kW)</th>
<th>Slewing</th>
<th>Luffing</th>
<th>Hoisting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammerhead</td>
<td>Raimondi MR 36+3</td>
<td>4,000</td>
<td>3.0</td>
<td>7.35</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Luffing Jib</td>
<td>Raimondi LR60</td>
<td>4,000</td>
<td>3.2</td>
<td>5.8</td>
<td>18.4</td>
<td></td>
</tr>
<tr>
<td>Articulated Jib</td>
<td>Raptor 184</td>
<td>7,250</td>
<td>7.5</td>
<td>60</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

Simulation

Before setting cranes up at a jobsite, a simulation model must be created to demonstrate and visualize how the crane will be laid out. This is important to select the right tower crane, the maximum load it can carry, the size of the payload, the layout of the site on which it will be set up, and the reach of the crane. A configuration is then chosen based on the answers to these factors. Factors essential for the study of these question include the company and destination. That is, where the pickup of the crane’s parts will go, and where the construction will occur.

Assembly

The first step in assembly is ensuring there is a smooth and strong concrete base. The next step is to assemble the mast by placing four frames and hinging them to the base to form an X-shape. The jib is then assembled on the ground by securing the sub-sections. The mast consists of sections of frames that form triangles. After the base had been placed, the first section is fastened to it and then blocks of concrete are placed around the section to secure it in place. The second, third, and fourth sections of the mast are then secured onto the first section. The lifting system lifts each section, creating a gap for other sections to be installed at a height that the mobile crane can
reach. After the lifting system is placed on the mast, the section where the jib and its counter jib will be placed gets installed and secured on top of the lifting system. The counter jib is then installed, after which the jib is installed and fixed while a mobile crane supports it to prevent it from falling. The weights on the counter jib are added to balance the jib. After this, the operator cabin is installed. Lastly, the lifting system lifts the top section and fixes the frame sections into the space it created.
II.3 Stealth Aircraft
By Ahmad Issa

All countries dream of becoming powerful, and to achieve that goal, they are racing to equip themselves with the most advanced military technology and weapons. Air superiority is one of the most effective and powerful ways of combat, because it makes achieving missions much faster and easier. The race to find the best aerial technology started in World War I and continues today, with some countries spending millions of dollars on programs to achieve air superiority [1]. Fighter jets are one of the most dominant military vehicles; however, after the First and Second World Wars, many countries started realizing that even the greatest weapon has weaknesses. They started financing programs to develop weapons that can counter jets, and now countries with advanced technologies such as the United States, China, and Russia can produce weapons that can easily destroy a fighter jet with a single missile. Radars have also been improved, easily detecting incoming jets and firing missiles from the ground that can destroy those jets. This has created a need to design jets that cannot be detected by enemy radar, commonly known as stealth aircraft [2], and countries started spending billions of dollars on such development programs. The following research discusses the importance of stealth aircraft, the effectiveness of their ability to maneuver around enemy anti-air weapons, and their advantages and disadvantages.

Stealth aircraft

The perfect way of describing stealth technology is that “Stealth technology essentially deals with designs and materials engineered for the military purpose of avoiding detection by radar or any other electronic system” [3]. In other words, stealth technology is essential because it is designed to make jets less visible to enemies. There are many ways to achieve this near invisibility, and to fully understand of
these methods, the concept of radars and their function must be understood.

Radar

Radar originates from an acronym that stands for radio detection and ranging. Radars are object-detection systems that use radio waves to detect objects and determine their ranges, directions, and speeds [3]. Radars function using two simple concepts known as echo and Doppler shift.

The echo process can be thought of as being like a person’s voice being reflected and repeated. This phenomenon occurs when sound waves hit a distant surface and are reflected back to a person’s ears. This same principle is used in the radar echo process, only with radio waves substituting for sound. The basic principle behind radars is the transmission of a radio wave and reception of an object’s reflection. The time it takes between transmission and reception can then be used to determine the distance between the plane and the radar station. This calculation technique requires a very accurate value for the speed of light [3].

The second concept, Doppler shift, is an effect that occurs when waves reflect off a moving object [3]. This effect sometimes creates sonic booms, which can be defined as a “shock wave that is produced by an aircraft or other object flying at a speed equal to or exceeding the speed of sound and that is heard on the ground as a sound like a clap of thunder.” Another example of a Doppler shift is the way the pitch of a sound such as a car engine changes as the car moves toward and away from a stationary observer. Figure II.3.1 shows an example of a Doppler frequency shift.
**Figure II.3.1.** Doppler frequency shift

**Figure II.3.2** shows how the pulses are transmitted and reflected from the target back to the radar station. The target range depends on the speed of light and round-trip time for pulses.

**Figure II.3.2.** Radar range measurement
Stealth technology

Visual stealth

This idea was heavily used in the Second World War. The concept was to paint an airplane in such a way that it would be camouflaged. If a plane was to fly during the day, it would be painted a shade of blue-gray known as air-superiority blue-gray [3], allowing it to blend in with the sky. This tactic used to be sufficient because radars were not advanced, and enemy fighters had difficulty spotting aircraft that blended in with the sky [5]. Currently, researchers are working on something known as smart skin technology, which will help aircraft appear to be almost invisible [3]. The difference between this method and previous visual stealth tactics is that smart skin technology can change colors to match the surroundings [3].

Infrared stealth

Infrared stealth is another way to trick air defenses. Jets emit infrared radiation from hot materials such as engine exhaust. As mentioned above, the radar air defense system detects a jet and fires a missile, which in this case is a heat-seeking missile that detects heat coming from the jet and pursues it. This is the reason behind the presence of flare dispensers in jets, which release flares to trick heat-seeking missiles. This system is simple and effective at deflecting these types of missiles. Nevertheless, militaries do not heavily depend on this technique, but rather on infrared jamming systems that are more effective and relatively safer for use in heavily populated areas [6].

Deflection material

Adding deflection material on a jet is crucial. Most radars are monostatic, meaning that when they use the same antenna send and receive signals. The addition of the deflection material deflects incoming wave energy away from the radar. Figure II.3.3 shows how energy is deflected from the target.
Stealth material

Stealth materials absorb waves coming from radar stations and are one of the most important parts making a jet stealthy. The most common stealth materials are iron-ball paint, foam absorbers, and the Jaumann absorber [3]. These materials are known as radar absorbing materials, and their role is to absorb radiation coming from radars.

Radar absorbent surfaces

Radar absorbent surfaces (RAS) are aircraft surfaces that absorb waves coming from radars. In addition, RAS reduce detection range [3]. Figure II.3.4 shows the surface of a normal plane and Figure II.3.5 shows the surface of a stealth jet.
There is clearly a huge difference between the surfaces of a normal plane and those of a stealth jet. Radar can detect a normal plane, but because the radar waves are deflected, the stealth jet cannot be detected.

Radar waves are deflected due to the structure and design of the plane. Stealth planes are designed in such a way that radar waves that hit the plane at any angle are deflected. This process is similar to rotating a
mirror. When a mirror rotates from 0 to 90 degrees, the amount of light reflected in the light beam’s direction increases, and when the rotation reaches 90 degrees, the amount of light reflected equals the light beam’s source. In contrast, when the mirror’s angle increases to greater than 90 degrees, the reflected light drastically decreases [3]. In addition, the jet’s design is extremely crucial. For the jet to remain stealthy, its tail should always remain at an acute angle to reflect radar waves.

**Radar cross section reduction**

Radar cross section (RCS) reduction is one of the most important aspects of stealth jets. RCS can be calculated using Equation II.3.1.

\[
\sigma = \text{Projected Cross Section} \times \text{Reflectivity} \times \text{Directivity}
\]

**Equation II.3.1.** RCS calculation

<table>
<thead>
<tr>
<th>Object</th>
<th>RCS (m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-15 Eagle</td>
<td>25</td>
</tr>
<tr>
<td>B-1A</td>
<td>10</td>
</tr>
<tr>
<td>Birds</td>
<td>0.01</td>
</tr>
<tr>
<td>F-22 Raptor</td>
<td>0.0065</td>
</tr>
<tr>
<td>F-117 Nighthawk</td>
<td>0.003</td>
</tr>
<tr>
<td>B-2 Spirit</td>
<td>0.0014</td>
</tr>
<tr>
<td>Insects</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The F-15 Eagle is a normal jet, whereas the other aircraft in the table can be considered stealth jets. A lower RCS value means that the jet is more stealthy. This table also shows improvements in technology. The B-1A was built in 1974 and has an RCS value of 10 m\(^2\), whereas stealth jets today have RCS values of less than 0.02 m\(^2\).
Advantages and disadvantages

There is no denying that having a stealth jet would be very beneficial during a war, as it can travel long distances and remain undetected above enemy territory. However, stealth jets also have a huge disadvantage as it is a very risky program to start. The two countries that are heavily working on stealth technology are the United States and China, and both have accumulated massive losses and setbacks. For example, an American newspaper said that “America is stuck with a $400 billion stealth fighter that can’t fight” [1].

In conclusion, stealth technology is very important yet extremely hard to perfect as it depends on many factors. Stealth technology depends on materials, aircraft body angles, aircraft surface area, and aircraft design. These components all have important roles to play in making a jet stealthy. There are also many advantages and disadvantages to be considered by countries interested in pursuing stealth technology. The country that can create the perfect program for building stealth jets will have a huge military advantage over other countries.
Work competency reflection
February 9, 2020
Mr. Abdulla Naji, Chief Human Capital Officer at Qatar Petrochemical Company (QAPCO), gave a presentation on the topic of work competency and what is expected of their performance in the workplace. The following section contains the students’ opinions about the topic.
Reflection

Characteristics to competency:

- Humble
- Perseverant
- Responsible
- Goal oriented
- Creative
- Self-manageable
- Integrity
- Good communicator
- Flexible
- Team player
- Self aware

Opinions:

- The workplace dynamics and systems are a chase, the knowledge is not given simply and straightforwardly.
- Any industry is a pool of knowledge.
- Connect theory to industry; contrary to common opinion, university engineering knowledge is essential.
- Out of the three main components of competency, attitude is the most difficult ingredient to get our hands on.
- Good morale and efficiency spread in the workplace.
- Being competent will keep the organization running smoothly and keep customers happy.
Chapter III
SUSTAINABILITY
Introduction: Sustainable Built Environments
Dr. Sami G. Al-Ghamdi

Sustainability means meeting our own needs without compromising the ability of future generations to meet their needs. It is the balance between economic, environmental, and social factors. The general principles of sustainability can be summarized in three words: minimize, maximize, and foster. To achieve sustainability, we need to minimize resource consumption, use of non-renewables, pollution, toxic emissions, and waste. We need to maximize efficiency, reuse, recycling, and renewable resource use. Lastly, we need to foster conservation, understanding of natural systems functions, economic justice, and stewardship.

More than 80% of the world’s population lives in urban environments where humans have drastically engineered the surrounding environment to make it amenable to our way of life. In hot climate regions, such as Qatar and other countries of the Gulf Cooperation Council, people spend more than 20 hours per day indoors on average because of the extreme climate conditions. The quality of the built environment around us has been proven to dramatically affect our behavior, habits, health, well-being, and performance, such as how children perform in school. This reality was stated clearly by Winston Churchill when he said, “We shape our buildings; thereafter, they shape us.”

These effects are prevalent at both the citywide level and the individual building level. For instance, urbanization has dramatically affected the natural landscape from the perspectives of biodiversity, the hydrologic cycle, and climate. Dense urban areas cause a heat island effect, with temperatures in urban areas often being 1–3°C higher than surrounding peri-urban and agricultural areas. This heat island effect is due to limited cooling by vegetative transpiration and the high heat-absorbing capacity of concrete. The prevalence of impervious surfaces in cities also affects the runoff of stormwater and associated pollutants to
waterways and prevents the natural recharge of groundwater, reducing locally available water. At the building level, changes in lighting, chemicals released from building materials, reduced oxygen associated with ventilation and vehicle emissions, and urban noise are just a few of the factors that influence our mental and physical health. These factors are even more critical in Qatar, where the extreme climate forces increased habitation in temperature-controlled indoor environments.

Buildings occupy a significant portion of land in our cities, leaving less space for green areas, which exacerbates the heat island effect. Also, a significant amount of energy is consumed for cooling. For example, electricity consumed for cooling in Qatar represents the most substantial portion of electricity demand in buildings and accounts for about 80% of all electricity produced in Qatar across all sectors. Building efficiency related to land use, design, water, energy, or materials would significantly contribute to the well-being of residents, benefit the local economy, and address environmental sustainability. Achieving building efficiency solutions through technology or social innovation would enhance human and social capital development in Qatar.

Our ultimate goal as engineers is to further our understanding of human impacts on the natural ecosystem through the built environment. From this, we can develop innovative solutions to mitigate climate change, optimize energy and water use and material consumption, and improve quality of life. At the same time, we aim to develop practical tools, materials, and means to build a domestic green economy and promote technological entrepreneurship. The demonstration of research and development outcomes from our work on the sustainable built environment will be instrumental for others in academia and the public.

In conclusion, sustainability is difficult to achieve, but it is ultimately a necessity; however, the present trends in our lifestyle make sustainability impossible. Considerable increases in resource efficiency are required, and the movement toward a sustainable society is under way.
Plastic consumption and pollution have become a recurring topic in today’s news. It is important to understand both the severity of this problem and plausible solutions to be proactive in dealing with the issue. Plastic pollution has an increasing number of negative impacts on the oceans, nature, and wildlife. Plastics do not decompose in nature because most plastics are polymers with long chains of monomers (carbon–carbon bonds). Nature has simply not seen anything of such composition and thus cannot decompose it like organic matter [7]. A simple solution would be to create plastics out of peptide bonds that would make them biodegradable; however, this would have the drawback of products having short life spans. This makes plastic with carbon–carbon bonds more beneficial economically speaking. It is critical to understand and improve plastic waste management, which would therefore decrease plastic pollution. This paper delves into the problem of plastic mismanagement and explores possible solutions to this problem, such as repaving roads from plastic, eco-design of plastics, and fungi packaging.

Plastic world production

To implement the most effective interventions to reduce plastic pollution, it is first essential to understand the magnitude of the problem. The graph in Figure III.1.1 shows global plastic production from 1950 to 2015. There has clearly been massive growth in plastic production since the 1950s, a 200-fold increase, making the production of plastic in 2015 around 350 million tonnes. Out of all this plastic, 55% of it was discarded.
Sector use of plastic

Another way to decrease the amount of waste is to understand where it is mainly generated. This understanding can help with reducing future plastic production. Figure III.1.2 shows the primary plastic production by industrial sector in 2015.

Figure III.1.1. Global Plastic Production [4]

Figure 1.1.2. Plastic production by industrial sector in 2015 [4]
The leading sector in plastic production is packaging, producing more than 146 million tonnes of plastic. Next highest is the building and construction sector, in which plastic is extremely valuable as a construction product because. Plastic is an ideal construction product due to its long-lasting performance. Once understood, these qualities can help us find sustainable alternatives.

**Plastic disposal methods**

There are three methods for disposing of plastic: discarding, incinerating, and recycling. **Figure III.1.3** illustrates the way the plastic has been disposed of between 1980 and 2015. The gray area represents the amount that was discarded. In 1980, almost 100% of plastic that was disposed was discarded. If we extrapolated the data shown in **Figure III.1.3** based on historical trends to 2050, incineration and recycling would increase to 50% and 44%, respectively, and discarded waste would decrease to 6%. However, these are only assumptions and are not based on any concrete projections.

![Global plastic waste by disposal](image)

*Figure III.1.3. Global plastic waste by disposal method [4]*
Mismanagement of plastic waste

A rising issue with such high production of plastic is the mismanagement of plastic waste. This brings a high risk of disposed plastic entering the ocean and nature preserves. Most high-income countries have good waste management systems and infrastructures. Countries such as Japan, Canada, and Australia store their disposed plastic in storage sites that are secured to prevent high tides and winds from relocating the trash. These countries have almost no inadequately managed waste, in contrast to many low- and middle-income countries. However, high-income countries do contribute to the mismanagement problem as some citizens of these countries litter. It is assumed that around 2% of total plastic waste across all countries is due to littering. Countries in Sub-Saharan Africa and South Asia have poor waste management methods, with approximately 80–90% of their plastic being discarded and inadequately kept. This increases the chance of pollution. Figure III.1.4 shows a projection of mismanaged plastic waste in 2025.

![Figure III.1.4. Mismanaged waste production projection 2025](image)

This data provided in the map is calculated based on total mismanaged waste created by populations within 50 km of the coastline. This proximity to the coastline means this waste poses a very high risk for
pollution. This projected waste management distribution does not differ much from the current one. A few observable changes are that China’s waste mismanagement will decrease by a few percentages, whereas India’s will increase slightly. The Middle East, North Africa, Europe, and Latin America will remain around the same. In addition, it can be seen in Figure III.1.4 that South Asia contributes to around 60% of the worldwide mismanagement of waste.

**Impact of plastic waste**

Multiple impacts of plastic waste that affect human life, the ecosystem, and wildlife have been discovered. However, despite numerous impact evaluations, there is no clear and concise evaluation of the full extent of these impacts yet. A few impacts that affect wildlife are entanglement, ingestion, and interactions such as abrasions and obstructions.

Entanglement affects many sea creatures that get entrapped in plastic waste. Furthermore, ingestion is also a problem that has been observed in around 800 creatures worldwide [6]. Plastic ingestion greatly affects wildlife as it can decrease stomach capacity and create a false satiation sense. Interaction, on the other hand, is when plastic waste destroys the ecosystem, such as by suffocating trees and coral reefs.

In addition, microplastics are thought to affect human health, though there is not much evidence to support that claim. However, possible harm should still be considered there are possible toxic effects. The three possible effects that have been discussed are the presence of the physical plastic particle, persistent pollutants in plastics that can be released, and the tendency of plastic additives to leach out of plastic. It is also important to understand that the issue of wildlife plastic consumption can also affect human health, as when humans consume wildlife, they will also ingest the plastic in the organism’s body.

**Solutions**

Understanding the problem is crucial because it portrays the severity of the issue and highlights the major areas where improvement is
required. First, knowing the sector use of plastics gives insight into the waste generated by different sectors. Therefore, it is noticeable that packaging and construction are two important areas for improvement. In addition, it is important to understand the sources of mismanaged waste to find a solution to the problem. In this case, solutions must be found and implemented in South Asian countries to reduce the amount of litter. There are three different solutions to this problem. The first one is repaving roads out of plastic, the second solution is eco-friendly designs of plastic products, and the third solution is creating packaging out of fungi.

**Repaving roads**

One new inventive way of using discarded plastic is by using it to repave roads around the world. Plastic roads have many advantages besides cutting plastic waste. In addition to being ecofriendly, plastic roads do not require a lot of construction time. An average road made of asphalt can take months to be completed, yet plastic roads can be completed in days, and future maintenance is almost non-existent, meaning that maintenance will no longer be a recurrent issue that we face as we do with asphalt roads. Furthermore, the expected lifetime of plastic roads is much longer and the price of producing roads will decrease. **Table III.1.1** shows the benefits of plastic roads compared to asphalt roads [1].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expected Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Lifetime</td>
<td>3 times longer</td>
</tr>
<tr>
<td>Construction Time</td>
<td>70% faster</td>
</tr>
<tr>
<td>Weight</td>
<td>4 times lighter</td>
</tr>
<tr>
<td>Ecofriendly</td>
<td>100% circular</td>
</tr>
</tbody>
</table>

Roads made of plastic-suffused asphalt help reduce the amount of petroleum used in asphalt. It also helps by reusing plastic waste that otherwise would negatively affect the environment. In addition, such roads are cheaper than traditional roads, making their production more beneficial for poorer areas.
One company, MacRebur, is leading new research into plastic roads. The MacRebur CEO found his interest in this project after noticing the threat of plastic waste. The process to build plastic roads begins by making three different types of pellets that consist of recycled plastic that has been compressed to create smaller particles. These pellets are classified into different uses, such as durable or pliable, and are then melted and turned into bitumen, which is the petroleum-based binding agent found in asphalt. This conversion to bitumen is said to make the presence of plastic completely disappear, making its incorporation in asphalt seamless. The only known drawback to this idea is the health consequences that can be brought by microplastic consumption. These roads have been criticized for their potential to spread microplastics in the air [3]. The drawback of this is that microplastics would saturate the air, water, and food we consume. In addition, microplastics also attract pollutants once they are in the environment. They can collect industrial plant chemicals, agriculture pesticides, and greenhouse gas emissions. If solutions can be found for this problem, this project could be widely implemented across the United States and in other countries. This could help not only the plastic pollution issue, but also help countries deal build new roads quickly and more efficiently.

**Eco-friendly design of plastic products**

Creating plastic products with eco-friendly designs is an ingenious concept that can described as tackling the problem in early stages of production. This can be done by incorporating environmental impact considerations to reduce potential negative impacts. One way to achieve this goal is through reduction of materials in products. Another possible way optimizing the design and selection of materials, which would, in turn, decrease waste amounts. For production, processes that are energy efficient and generate less scrap can be selected [5]. Another way is including disposal options for any part created that allow it to be recycled or reused. An example of this is Ras Abu Aboud stadium in Doha, which was created and designed with the objective of it each component in the stadium being recyclable. It is important for designers to be mindful of these factors
when designing products; however, their choices might not significantly influence the decisions of big corporations.

**Packaging material from fungi**

Plastic is currently the most common packaging material because it improves product durability and handling convenience. A new alternative that has been researched lately is a mushroom-based packaging material. Ecovative Design, a company that is leading research on this topic, creates a packaging material that is fully natural and compostable. This packaging material can decompose in approximately 30 days in the proper conditions, but it can also be reused if kept dry. The way this company manufactures packages is by compressing agriculture by-products such as oat hulls, hemp, and cotton burrs into the desired shape. After forming, the packaging materials are seeded with mushroom spores and sealed away for a few days. The mushroom spores sprout a root structure that threads quickly through the desired object, binding it together. The final step is to treat the object with heat to prevent further fungal growth. This new technique of creating packaging uses 12% less energy and produces around 90% less carbon emissions than plastic production [8]. This alternative to plastic production is both innovative and ecofriendly, and its only drawback is how durable this material is in different environments. This material is being heavily worked on and could be the future of packaging. IKEA has already jumped on the movement of using this new packaging material for some of their items.

In conclusion, the research shows that increased plastic production is generating additional plastic waste every year. This plastic pollution is increasingly causing a negative impact on nature preserves, the oceans, and wildlife. It has also been observed that even though high-income countries have very good waste management practices, they still generate the greatest amount of plastic waste per person. Nevertheless, mismanagement of waste is the main problem driving ideas on the risks of plastic pollution. Therefore, it is critical to find solutions for this mismanagement to preserve nature. In addition,
plastic has unique properties. Plastic is versatile, light, resistant, and cheap, which makes it valuable for a multitude of operations. One solution that has been presented is using recyclable plastic to repave roads, which carries multiple benefits for road quality as well as the environmental benefits of reusing plastic waste. Moreover, for the massive amount of plastic production each year, there should be guidelines for ecological designs. This would reduce the amount of waste to be managed. There are many other solutions to this enormous problem that could be considered. Steps must be taken urgently as projections of current plastic waste trends are only increasing.
III.2 Solid Waste Incineration
By Aisha Hussain

Waste management is one of the most urgent issues that countries are trying to manage. City governments provide solid waste management for citizens, which might be one of the most essential municipal duties. Mismanagement of waste in cities is a global issue as it affects the health of citizens, animals, and the environment. Sanitary landfills, incineration, gasification, pyrolysis, and anaerobic digestion are some of the waste management methods cities opt for [1]. These methods have varying degrees of service levels, environmental impacts, and costs. In addition, these methods can also be classified as waste-to-energy technologies. Recycling and recovery are also waste disposal methods, but they do not generate energy. More of the human population is migrating to cities, and as a consequence, the percentage of the total population that lives in urban areas has increased from 30% in 1950 to 55% today. This percentage is expected to increase to 68% by 2050 [2]. This population increase means there is more waste to be disposed of and efficiently managed. An important and noticeable by-product of an urban lifestyle is municipal solid waste, which is growing even faster than urban populations [3]. In 2002, 2.9 billion urban residents generated approximately 0.64 kg of solid waste per person per day, amounting to 0.68 billion tons of waste per year. In 2012, approximately 3 billion residents generated an estimated 1.2 kg per person per day, which is 1.3 billion tons per year. It has been projected that by 2025, 4.3 billion urban residents will generate approximately 1.42 kg of solid waste per person per day, for a total of 2.2 billion tons per year [3]. Hence, an efficient waste management method is crucial for the future of cities. This research investigates incineration as a solid waste management method, and discusses energy efficiency, thermodynamic cycles, advantages and disadvantages, frequency of use, carbon emissions, and steps that are taken to mitigate the toxins released by the process.
Definition of an incinerator

In an incinerator, solid waste is treated by the combustion of organic materials in the waste at high temperatures, turning the waste into ash, flue gas, and heat [4]. The incineration method falls under the umbrella term of thermal treatment, in which waste is treated at high temperatures. If energy from combustion is recovered, this process is referred to as incineration with energy recovery.

Processes and components

Figure III.2.1 shows a diagram of a typical waste incineration facility [5]. Collected waste is added into the waste storage and then fed into the feed preparation department. The waste then enters the combustion phase, where the waste burns and produces gases, ash, and heat. Waste residue then enters the gas temperature reduction chamber where heat is recovered using a special type of generator. The cooled gas and other residue enter the air pollution control chamber where pollutants are removed, and solid residues are separated. The remaining solid waste is then disposed in a landfill and the treated gas is released to the atmosphere through the emission stack with the help of a fan.

Figure III.2.1. Typical waste incineration facility with energy recovery [5]
Figure III.2.2 shows a typical waste incineration facility that uses a steam generator as an energy recovery system. In this facility, the collected waste is added into the waste storage pit, after which it is carried by a crane and dropped into the furnace. In the furnace, the waste enters the combustion phase, where it burns and produces gases, ash, and heat. The heat is then recovered through a boiler system in which water is boiled to become steam that is used to power a generator that produces electricity. The incinerator reduces the waste mass by 75% and its volume is decreased by 90% [6]. The exact values of these decreases depend on the composition of the trash and the degree of material recovery for recycling.

The ash and other residues are collected through the ash collection system and then shipped to a landfill. Ash formed by inorganic materials form particulates that are carried by the flue gas. The flue gas thus is toxic and must be cleaned of gaseous and particulate pollutants before human exposure or before being released into the atmosphere. The cooled flue gas and other residues enter the scrubber and filter where air pollutants are removed. Lastly, the treated gas is released to the atmosphere through the emission stack with the help of a fan.

Figure III.2.2. Waste incineration facility with a boiler system for energy recovery [7]
Process energy efficiency and carbon dioxide emissions

In this research, Dr. Eriksson examined the differences in the energy sources that the waste incinerator substitutes [8]. The waste incinerator was compared to coal, oil, wind power, and natural gas. He also studied the energy recovery methods used such as the heat only boiler (HOB), combined heat and power (CHP), and condensed power (CP). These energy recovery methods are defined in Table III.1.1. Note that even if the CHP process can generate both heat and electricity, the process will experience losses.

Table III.1.1. Energy recovery methods

<table>
<thead>
<tr>
<th>Type of energy recovery</th>
<th>Processes involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOB</td>
<td>Heat from the combustion process boils water in the boiler to steam, which is used only for heating.</td>
</tr>
<tr>
<td>CP</td>
<td>This type of generator only extracts electricity from the incinerator.</td>
</tr>
<tr>
<td>CHP</td>
<td>This type of generator extracts both electricity and heat from the incinerator.</td>
</tr>
</tbody>
</table>

Three types of efficiency were used to weigh the benefits of different combinations of energy recovery and generation. The overall efficiency, or energy-to-fuel ratio, was determined using Equation III.2.1, the power-to-fuel ratio was determined using Equation III.2.2, and the power-to-heat ratio was determined using Equation III.2.3.

\[ \eta = \frac{\text{electricity} + \text{heat}}{\text{fuel}} \]

Equation III.2.1. Overall efficiency (energy-to-fuel ratio)

\[ \alpha_2 = \frac{\text{electricity}}{\text{fuel}} \]

Equation III.2.2. Power-to-fuel ratio
\[ \alpha_1 = \frac{\text{electricity}}{\text{heat}} \]

Equation III.2.3. Power-to-heat ratio

Table III.2.2 shows the minimum and maximum energy-to-fuel and power-to-fuel ratios of different types of plant designs. HOB does not have a power-to-fuel ratio because it does not produce electricity. Furthermore, the energy-to-fuel and power-to-fuel ratios are the same for CP because heat is not accounted for in this process. CP has the lowest efficiency of all the heat recovery systems for the waste incinerator, especially because the energy generation is heat based. In contrast, HOB has a very high energy-to-fuel ratio, and CHP is the highest as it utilizes both heat and electricity. For this reason, newer incinerators opt for CHP rather than the previously popular HOB. When comparing it to other energy sources, CP of the waste incinerator is the least efficient and that of the natural gas combined cycle (NGCC) is the most efficient. On the other hand, the CHP of the waste incinerator is more efficient than the CHP of natural gas.

Table III.2.2. Maximum and minimum energy-to-fuel and power-to-fuel ratios of different plant designs [8]

<table>
<thead>
<tr>
<th>Plant design</th>
<th>Energy-to-fuel ratio</th>
<th>Power-to-fuel ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Incineration of waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOB</td>
<td>0.869</td>
<td>0.696</td>
</tr>
<tr>
<td>CP</td>
<td>0.288</td>
<td>0.006</td>
</tr>
<tr>
<td>CHP</td>
<td>0.941</td>
<td>0.526</td>
</tr>
<tr>
<td>Oil (HOB)</td>
<td>0.91</td>
<td>0.85</td>
</tr>
<tr>
<td>Coal (CP)</td>
<td>0.45</td>
<td>0.35</td>
</tr>
<tr>
<td>Wind power (CP)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>NGCC (CP)</td>
<td>0.58</td>
<td>0.58</td>
</tr>
<tr>
<td>Natural gas (CHP)</td>
<td>0.91</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Table III.2.3 shows the minimum (e.g., HOB2) and maximum (e.g., HOB2) energy-to-fuel, power-to-fuel, and power-to-heat ratios of different types of waste incineration plants. HOB does not have power-to-heat or power-to-fuel ratios as it does not produce electricity. CP does not have a power-to-heat ratio because heat is not accounted for. Although the CHP of waste incinerators has a high overall efficiency, the power-to-fuel ratio is still very low. This shows that an incinerator produces more heat than electricity.

Table III.2.3. Minimum and maximum energy-to-fuel, power-to-fuel, and power-to-heat ratios of different types of waste incineration plants [8]

<table>
<thead>
<tr>
<th>Plant</th>
<th>η</th>
<th>α₁</th>
<th>α₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOB1</td>
<td>0.869</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>HOB2</td>
<td>0.696</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>CP1</td>
<td>0.288</td>
<td>NA</td>
<td>0.288</td>
</tr>
<tr>
<td>CP2</td>
<td>0.006</td>
<td>NA</td>
<td>0.006</td>
</tr>
<tr>
<td>CHP1</td>
<td>0.941</td>
<td>0.24</td>
<td>0.184</td>
</tr>
<tr>
<td>CHP2</td>
<td>0.526</td>
<td>0.08</td>
<td>0.039</td>
</tr>
</tbody>
</table>

Table III.2.4 shows the CO₂ emissions of different plant designs. The table can help in determining the amount of CO₂ emitted by the waste incinerator relative to other heat generation systems. HOB combined with the waste incinerator has lower emissions than other energy sources.

Table III.2.4. CO₂ emissions of different plant designs [8]

<table>
<thead>
<tr>
<th>Plant design</th>
<th>Specific CO₂ emission (g/kWh fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incineration of waste</td>
<td></td>
</tr>
<tr>
<td>HOB</td>
<td>100</td>
</tr>
<tr>
<td>CP</td>
<td>100</td>
</tr>
<tr>
<td>CHP</td>
<td>100</td>
</tr>
<tr>
<td>Oil (HOB)</td>
<td>274</td>
</tr>
<tr>
<td>Coal (CP)</td>
<td>335</td>
</tr>
<tr>
<td>Wind power (CP)</td>
<td>0</td>
</tr>
<tr>
<td>NGCC (CP)</td>
<td>203</td>
</tr>
<tr>
<td>Natural gas (CHP)</td>
<td>212</td>
</tr>
</tbody>
</table>
Important improvements and facts

Communities surrounding incineration plants and experts are still concerned about the environmental and health effects of incinerators. A heavily criticized factor of the incineration process is that some of its by-products, such as dioxin (polychlorinated dibenzo-para-dioxins) and furan (polychlorinated dibenzofurans), are toxic, thus their emissions are harmful for surrounding communities and the environment [9]. Emissions of these deleterious gases have been reduced by allowing these by-products to fully combust and performing catalytic filtration. For instance, in 1990, one third of all dioxin emissions in Germany could be traced to incineration plants. As of 2000, less than 1% of the dioxin and furan emissions in Germany were from incinerators [10].

Another improvement made to waste incinerators is the material separation phase [11]. In the absence of such a phase, hazardous, bulky, and recyclable materials cannot be separated before combustion. Hence, plant workers and the environment can be harmed. In addition, modern incinerators opt for CHP rather than the previously popular HOB energy recovery system as the former is more energy efficient [8].

Although incineration cannot completely replace landfill waste management, the process reduces the volume of waste considerably before it is sent to a landfill [4]. An advantage to the incineration process is that medical wastes containing harmful pathogens and toxins and toxic chemical waste can be effectively eliminated under high temperatures. Individuals, municipalities, and even institutions use this method to get rid of waste; however, waste incineration on an individual level is discouraged. This is because fumes are usually not filtered on an individual level, which can be bad for the individual and their neighbors [12].

Waste management through combustion is popular in countries where land is a scarce resource, such as the United Kingdom and Japan [13].
Incinerators also tend to be useful in colder regions as they are the best option for heating purposes. The methods of waste removal used from 1960 to 2010 in the United States and the increase in the amount of waste [5] show that the total amount of waste to be disposed has increased throughout the years, with most of it discarded in landfills. The amount of waste disposed through incineration remains almost the same in 2010 as it was in 1960. However, it is important to note that some environmentally friendly alternatives to waste disposal, such as recycling and composting, which started in the 1980s, have increased.

This research provides an overview of waste incineration with energy recovery and provides details about the processes involved, its efficiencies, and CO\textsubscript{2} emissions compared to other energy generation methods. The process involves the input of waste, feed separation, combustion, heat recovery, ash removal, and air filtration. In terms of energy recovery and CO\textsubscript{2} emissions, incineration is a better option than coal and natural gas. CHP in waste incinerator plants has the best efficiency compared to CP and HOB. This research also provides several advantages, disadvantages, and improvements that have been made to the incinerators to overcome the disadvantages. Incineration creates the perception that making waste is beneficial for the city; however, using an incinerator and making more waste is harmful for the environment. Dioxin and furan are toxic emissions that incinerators produce, but these have been mitigated by filtering the polluted air. Material separation has also enabled more recycling and fewer health hazards. The incineration process significantly reduces the mass and volume of waste that is sent to landfills and is effective in eliminating most medical and chemical waste due to its high temperatures. It is mostly useful in colder regions where heating is necessary, as the power-to-heat ratio is low. Lastly, although there has been an increase in the total quantity of trash, the use of incineration as a disposal method has barely increased.
III.3 Social, Economic, and Environmental Sustainability

By Mohamed Hazem Hussein

Engineering and engineering design have come a long way, and the list of core components and basics of good engineering practices are ever-expanding. From risk-reward measures and time management to healthy attitudes and other engineering disciplines, it is hard to argue which core component within the scope of common engineering practices is the most important [1]. However, many can agree that sustainability is currently one of the most critical components.

Definition

In general, sustainability is merely consuming resources in a manner that does not negatively affect the environment or deplete potential future resources. Recycling is only a minimalistic example of one of the forms of sustainability.

Within the engineering scope, sustainability is about managing a system in such a way that resource consumption and products such as pollution, toxins, or waste are minimized. In addition, there must be a focus on maximizing system efficiency, as well as integrating a dependency on renewable resources [2]. Sustainability is a manner of ensuring that the final product of an engineering process is economically, socially, and environmentally acceptable, as shown in Figure III.3.1.
Environmental sustainability

Environmental sustainability is the ability to improve the quality of human life without exceeding or overloading the ecosystem’s ability to sustain its inhabitants, given the available resources and other necessities. It is the act of not taking from nature, but rather working alongside it. A good example would be sustainable agriculture systems. In conventional agriculture, repetitive cultivation of the same crop in the same location leads to degradation of soil quality and overall land fertility. Furthermore, to counter such effects, humans have resorted to using chemical fertilizers and other inorganic by-products to maintain consistent crop quality, which counterproductively can lead to crop contamination and sometimes even negative human health impacts.

In contrast, sustainable agriculture involves integrating the animal production and plant cultivation processes to achieve independence...
from non-renewable resources and inorganic products. In addition, it minimizes environmental impact while maximizing crop productivity. Such practices involve using manure and other organic waste from animals in the cultivation process and crop rotation to maintain consistent soil quality [4]. Some industries have also resorted to vertical farming, where crops are planted in planters stacked vertically with parallel water access from the same source to maximize the efficiency of available space [4].

**Economic sustainability**

Economic sustainability is the use and maintenance of resources, both human and non-human alike, and optimizing their use to prolong their availability. Methods of optimizing resource usage include recycling, recovery, and conservation of finite resources in a way that neither negatively affects the environment nor compromises the other two fronts of sustainability [5]. Within the engineering scope, economic sustainability can be practiced by calculating the costs of running a system or chain of production and comparing those costs to the benefits or revenue produced, both monetary and non-monetary.

**Social sustainability**

Social sustainability is an often-overlooked step of achieving sustainability. Social sustainability involves ensuring that a system promotes human wellbeing to create healthy and livable social communities [6]. Within the engineering scope, this means that the system caters to a specific need that was left unmet before the system was introduced to the environment or community. An example of a sustainable system that does not ignore social sustainability would be the introduction of wind turbines to provide electricity in remote areas with enough wind for power generation. This serves to supply power to residential areas, as well as provide decorative roadside centerpieces or prestige for university institutions and companies.
Examples of unbalanced sustainability

Now more than ever, the world is moving at an incredibly fast pace. Whether it is stock prices, social media trends, or technological advances, nothing seems to last more than a few days at a time. To keep up with this ever-changing world and to stay relevant and competitive, companies, especially those in the private sector, tend to overlook most of the three sustainability cores, prioritizing economic sustainability over social and environmental sustainability.

A good example would be the CO₂ emissions involved in the production chain of some everyday items such as mobile devices and laptops. Both devices meet two pillars of sustainability, social demand and economic profit; however, production of a mobile device releases 30 kg of CO₂ emissions and production of a laptop releases 250 kg of CO₂, hence completely ignoring environmental sustainability. To put this in perspective, if a mobile device is used every day for about eight years, its use would equal the same amount of CO₂ released during its production. Similarly, a laptop requires about three years of use [7]. As a result, CO₂ levels around the world are at an all-time high, and the ozone layer is more damaged than ever.

Unfortunately, manufacturers would rather invest their capital into researching advances that would increase their revenue or appeal to a broader audience than into how they can reduce on the resultant wastes or by-products of their production chain [8].

Issues with sustaining sustainability

However, despite our best efforts to ensure sustainability and combat dependency on inorganic and toxic manufactured chemicals and tools, certain issues cannot be prevented through greener alternatives or by adopting recycling policies. The most significant threat to maintaining sustainability is the continued increase of the human population. The major problem with this ever-growing world population and its resultant increase in demand and consumption for resources has
several repercussions, each of which contribute to today’s major world crises. Some of these include, but are not limited to, climate change, loss of biodiversity and collapsing ecosystems, stress on water resources and food production, and pollution.

For example, high population density around the world causes a high demand for food, which causes soil erosion and toxic agricultural practices that leave land barren over time and wipe out the possibility of future generations reusing fertile land.

Similarly, air, land, water, and chemical pollution are all occurring on astronomically large scales around the world because large industries need to provide resources for more people than ever before. In fact, since the Second Industrial Revolution during the 1970s, which capitalized on animal mass-breeding, product testing, and using water bodies as waste dumps, humanity has wiped out about 60% of the world’s animal population [9].

To prove this, we can look at pollution around the world and compare it to population density. The link between population and pollution, climate change, food crises, and so on becomes undeniable, which was further supported by research on air pollution done by NASA that correlates pollution with population size, as seen in Figure III.3.2. Although one can argue that the pollution of these resources is unavoidable to a certain extent, the havoc wreaked on the planet and the backlash it has on often fragile and irreplaceable ecosystems is comparatively exponential.
Figure III.3.2. NASA research on pollution resulting from population [9]
Balance as a solution

Many industries have started investing more into greener and sustainable research to acknowledge this issue [11]. Although it has a minimal effect for now, many everyday objects are slowly being switched out and replaced by greener and more sustainable alternatives. Some examples include paper straws instead of plastic ones, denim-textured cotton in place of actual denim, reusable cloth and paper bags instead of plastic bags, and even regular A4 paper made from bamboo, which is more readily sustainable than trees [12].

Another aspect that seems to be generating traction in the engineering industry are green buildings. Green buildings are made to be more sustainable by regulating waste management, using building materials that are free of toxins, installing water-efficient plumbing systems, and integrating green energy cycles into the system through the use of eco-friendly technologies such as hydroelectric or solar power, all at an affordable price.

Traditionally, to maintain sustainability in a system from within the engineering perspective, the entire system is considered rather than a single object or process. As opposed to focusing on technical issues to solve an immediate problem, engineering sustainability considers both technical and non-technical issues simultaneously. In addition, it attempts to prevent the issue from resurfacing. In addition to considering the global context rather than just the local context, engineering sustainability also acknowledges the importance of field professionals in disciplines that are related and unrelated to the issue [14].

Figure III.3.3 shows a more in-depth classification of sustainable engineering principles in terms of social, environmental, and economic criteria.
Figure III.3.3. Classification of sustainable engineering principles with respect to environmental, social, and economic criteria [13]

Solutions that put all factors to simultaneous use are present in the middle of the large triangle. These include using engineering system analysis and integrating environmental impact assessment tools, respecting local subsidiaries and cultures, and internalizing all costs within the values of the provided goods and services. A good example of an engineering field that has harnessed a balance between all three pillars of sustainability would be green power generation and consumption.

Wind turbines, for example, have been integrated into farmland windmills for multifunction purposes, giving a rustic countryside look that fits in with the surrounding theme, assisting farmers with their work, and generating more power than it requires for upkeep. Solar panels have also been integrated almost flawlessly into modern day society. In fact, solar panels on the roof has become a trademark in the
construction of modern-style housing [15]. **Figure III.3.4** shows a house with a roof completely covered in solar panels.

![Solar panels on the roof of a house](image)

**Figure III.3.4. Solar panels on the roof of a house [15]**

The recent appearance of smart/electric cars that roam the streets of Europe and the United States are another efficient solution. These cars run on an electric battery (charged at specialized stations around the country) and produce little to no waste relative to their gasoline consuming counterparts. Other countries have even integrated this electric power consumption method into their public transport system, which is much greener and more efficient in terms of transporting the public and waste production.
Work sustainability reflection
February 2, 2020
Dr. Sami G. Al-Ghamdi gave a presentation on the topic of sustainable work environments and infrastructure research development. This section contains the opinions students had about the topic.
Sustainable Built Environment

- As engineering students, we should find solutions to make the Texas A&M at Qatar building green.
- It is our mission as engineers to contribute to healthier and long-lasting solutions for our generation and those to come.
- Qatar’s consumption of electricity and water raises red flags on how we currently function.
- A sustainable solution can be extremely effective in one country and a waste of time and money in another.
- Some sustainable solutions are just for show and good public opinion.
- Environmentally sustainable is not the most economically sustainable.
- It’s frustrating how the negligence of just one consumer can damage batches of reusable material.
- 80% of generated electricity in Qatar goes for cooling systems in buildings. Therefore, finding new engineering solutions for cooling systems is essential.
- I’m proud of Qatar for finding sustainable solutions for the preparations of FIFA World Cup 2022.
- Sustainable built environment can be good for profit as it prioritizes efficiency.
- If businesses chose to be environmentally sustainable, they can attract a new audience that prioritize being eco friendly.
Chapter IV
ENERGY
Simply put, without energy there will be no life at all on our planet. Energy runs in everything that we have around us. Our bodies, our foods, and our actions are all forms of energy that we use daily. The main source of energy for our planet is the sun. From the very beginning of life on Earth, the sun provided warmth and light for the early organisms. The food chain always leads back to plants, which require solar energy to grow and thrive by fueling photosynthesis.

Early on, our ancestors (*Homo sapiens*) discovered that we must learn how to master energy if we wanted to improve our lifestyle. Early humans learned how to use their natural internal energy to forge tools that improve their chances of survival. From spear heads to bows and arrows, more efficient hunting became possible. Humans soon hit a limit on what they could produce using only their internal energy, so when fire was discovered, a new level of development began. New, stronger, and more efficient tools were forged from metal, and this discovery improved human lifestyles and ability to survive against harsh nature.

Jumping forward a few centuries to the industrial era, fossil fuel was discovered, first in the form of coal, then as oil, and finally as natural gas. With each discovery and mastery of a new energy resource, humans advanced and conquered more land, higher skies, and deeper oceans. At a certain point human started to venture into space, the moon, and very recently Mars. However, what seemed like an unlimited expansion finally hit a thick wall. In the last few decades scientists started raising an alarming flag against climate change. Humans have unlocked CO$_2$ and other greenhouse gases (GHG) in a matter of less than two centuries. These GHGs were stored in the form of fossil fuels for millions of years. These emissions are deemed to be the main reason for the climate change challenge that threatens the survival of life on our planet today.
Fossil fuels are not the only source of energy in the world today, but they are by far the dominant source of energy that has enabled humanity to reach where it is today. All the important essential daily activities are powered by either electricity (which can be sourced from fossil fuels, nuclear power, or renewable energy) or by fuel (which can be derived from fossil fuels or biological sources). World leaders are taking many important steps toward carbon neutrality, which basically means that we will continue to enjoy our current lifestyle, but in a responsible way. Humans will have to manage GHG emissions to ensure the sustainability of our planet for future generations.

When it comes to renewable energy resources available today, we find that solar and wind energy are at the top of the list, followed by hydro power and bioenergy. Solar and wind are readily available worldwide; however, hydro power and bioenergy are more challenging and differ in availability from region to region. Geothermal, wave, and tidal energy are also considered potential sources of renewable energy, but there are limitations to accessing them and difficulties in managing them. All renewable energy solutions face a single main challenge. They are out of our control, meaning that the only way we can make them available at our convenience is to pair them with energy storage facilities, a technology that has not yet been fully mastered.

For the sake of the survival of our planet and our future generations, we must continue to take more serious steps toward carbon neutrality and sustainability. More investments are needed that are dedicated toward developing environmentally friendly solutions that will ensure we will continue to enjoy our lifestyle without destroying our planet. Humans have faced many challenges in the past and have overcome them successfully, and the challenge of building a reasonably balanced and carbon neutral energy mix will be the key solution to the climate crisis we face today.
IV.1 Energy Sector Outlook Review

By Ian Greener

This research discusses the benefits of, drawbacks to, and innovations in different means of creating energy and provides a prediction of what the energy market will look like in 20 years. Even though this research primarily discusses renewable energy sources, this does not imply that they are preferred over fossil fuels. The focus on renewable energy is mainly due to it having a high projected growth of unsure magnitude [10]. The global demand for energy is increasing with coal, oil, and natural gas making up most of the energy market. However, some predict that electricity coming from renewable sources is on the rise due to innovation and implementation of renewable energy technology. Figure IV.1.1 shows the annual share of total U.S. electricity generation by source from 1950 to 2016.

Figure IV.1.1. Annual share of electricity generation by source (1950–2016) [10]

Of the three primary fossil fuels, natural gas is the most popular because of its abundance, ease of transport, and economical value, and it has the least harmful effects. Coal, on the other hand, emits almost double the amount of greenhouse gases (GHG) as natural gas [11]. The ability to produce and utilize natural gas already exists, which makes it easy to incorporate it into systems around the world.
Natural gas is flammable, which makes working with it very dangerous. It is also a non-renewable resource and the fear of running out of non-renewables is a catalyst for the movement toward renewable options like hydro power, wind, and solar energy. The largest problem facing fossil fuels is that they release GHGs, which will hurt the earth in the long run. GHGs are gases that absorb and emit radiant energy. These gases trap the sun’s energy in the atmosphere, which results in the heating of the earth, a phenomenon known as the greenhouse effect.

Large companies have made drastic changes to decrease their emissions. These changes helped develop technologies such as hydraulic fracturing, which caused CO$_2$ emissions to be at a 25-year low [7]. The work required to make natural gas a more viable solution is a continual process that is on the right track due to the Environmental Partnership, a coalition of oil and gas companies committed to improving the industries’ environmental performance. However, despite these advancements, there is still an immediate need to find sustainable alternatives.

**Hydro energy**

The first type of renewable energy discussed is one of the oldest forms, hydro power. Hydro power started out with small wheels on the sides of rivers that rotated and provided mechanical work. Today, hydro power consists of full-size dams with electric-generating turbines. A great benefit from hydro power generation is that once the upfront cost is covered, it has cheap maintenance, making it a viable long-term solution. In addition, there are many rivers that can be dammed to provide energy, and some existing dams only need additional supplies become a hydro dam. This could result in cheap means to capture much unused energy. The generation of hydroelectricity has been increasing over the past century.
However, dams can prevent fish from going back and forth, which interrupts the crucial patterns fish require to prosper. Many fish could die because of dams, which would hurt the ecosystem tremendously. Also, the initial amount of capital needed to set up a hydroelectric dam is $1 million per megawatt on average, and large dams can have initial costs of as much as $450 million. When a river has a dam installed, a lake is formed, which can result in water flooding residential areas close to the river. Thus the relocation of people near the project must be considered. Looking to the future, new technology continues to improve the efficiency of the systems in dams. A new idea of adding generation technology into existing dams is on the rise. This innovation would be a cheap method to maximize the available energy that is currently not utilized.

**Wind energy**

Like hydro power, wind energy has quite a history. Windmills started appearing in the United States in the mid-19th century and have been evolving ever since. The use of windmills does not generate any pollution and does not require any destructive chemicals. New wind turbines are great means of generating renewable electricity. It is also free energy, so people can be independent of an energy company if they have the right equipment. Wind turbines are relatively inexpensive and can help power a few homes in a windy location. The use of wind turbines has increased over the past century, as shown in Figure IV.1.2.
One of the drawbacks to wind energy is that wind is not always present, making it an inconsistent supply of energy. Thus, a good energy storage method or alternative energy source is required for such times. The movement of turbine blades can also hit birds flying nearby, possibly resulting in the death of many birds and damage to turbine blades. Wind turbine blades are also so large that anything nearby would be destroyed if they fell. Wind turbines are being improved each year by finding ways to reduce costs and improve the reliability of the components. One of the new trends that is making this happen is the ability to inspect windmills using drones [5]. There are new sensors that help with relaying the condition of the blades to experts, so they can quickly solve any problem that arises from damage. This new technology will help expand the innovation of taking wind turbines offshore.

Companies like Siemens Gamesa Renewable Energy (SGRE) are developing blade robots for monitoring and basic servicing of wind turbines [5]. These robots will climb around the blades using a vacuum pump. This will help reduce labor costs by automating the technician’s basic jobs and make wind turbine maintenance safer by
eliminating the human element. The most fascinating advancement is that an inspector robot has a new microwave scanner that determines the structural integrity of the blades. This allows them to predict when and if a turbine blade is likely to fail [5].

**Solar energy**

An essential form of renewable energy, especially in deserts, is solar energy. Energy from the sun can be transformed into electricity and is widely available. Like other energy alternatives, solar energy does not create pollution, and most solar power systems do not require much maintenance, needing to be cleaned twice per year in normal conditions. Although the initial cost of solar energy is rather high at $3 per watt, the long-term cost proves cheaper and governments can help by providing subsidies. The exponential growth in solar energy industry capacity is shown in [Figure IV.1.3](#).

![Figure IV.1.3. Cumulative installed solar photovoltaic capacity (in MW) [3]](image)

One drawback is the lack of energy storage systems. There have been many advancements in batteries and energy storage, with electric car innovations resulting in more efficient batteries for less money. However, the new advancements in batteries have their own downsides that are mainly due to the materials used. When dust accumulates on solar panels, the system’s efficiency decreases. This
requires a monthly cleaning of the panels to maintain the highest efficiency rating in areas with lots of dust. Additionally, some types of solar cells need materials that are expensive and rare. The use of these cells can work to deplete those finite resources. To maximize the opportunities of getting free energy, there are many new attempts at acquiring solar energy.

One new idea is solar paint, which is applied the same way as conventional paint and requires minimum work to become fully functional [2]. Even though it can currently only reach an efficiency of 3–8% (compared to the 18% efficiency of the average solar panel), solar paint is likely to become commercially sustainable in a couple more years [2]. Another innovation is solar windows that convert sunlight to electricity when the light passes through. Although solar windows can never reach the same efficiency as traditional solar panels, they can still help solve the energy problem. Another very popular new advancement in solar energy is solar cars. Currently most transportation is run by fossil fuels. These new cars will charge themselves using the sun’s rays. This innovation has already been attempted by a Dutch start-up called Lightyear [2] that recently came out with their first solar electric car known as Lightyear One. In addition, there is also an initiative to design solar roads that make use of the land covered by roads. The first attempt was done in 2016 in Sandpoint, Idaho [2]. The goal is to maximize the available real estate that the roads provide.

Nuclear energy

The final source of energy is sometimes known as the non-renewable renewable energy. This is because nuclear energy can be misconstrued as having aspects of both types of energy. Nuclear energy does not release GHGs, but it does have a finite amount of fuel that can be used. Like the other alternatives, once a facility is built and running, it is relatively inexpensive to operate. Additionally, the fuel source, uranium, is relatively cheap and has a long lifetime. The overall cost of power distributed across the lifetime of a reactor is relatively low,
and reactors are primarily dependent on the availability of uranium. Nuclear energy is considered reliable because, at the current rate of use, there is enough uranium to last almost 80 more years. Nuclear energy is dependable because it will work despite changing external conditions. On the downside, because of its radiation, spent fuel waste can harm the surrounding environment if it is not properly handled. In the event of a disaster, radiation can be released, harming those who encounter it. Despite two large public disasters, nuclear energy has consistently been on the rise as shown in Figure IV.1.4.

**Figure IV.1.4.** Nuclear energy production worldwide [8]

Nuclear energy has been undergoing innovation in small practical ways that could have a large impact. New reactors are being produced that rely on advanced manufacturing through the use of 3D printing technology. The ability to 3D print reactors saves time and money by being able to easily prototype and test new designs. As a result, new solutions can be brought to the market faster [8]. Overall, despite its
finite characteristic, nuclear energy can be a viable alternative to fossil fuels.

**Outlook for energy**

In late 2019, ExxonMobil released a report titled “Outlook for Energy: A Perspective to 2040.” This report explains where the energy market is presently and where it is expected to be in the future. In so doing, they investigated the technology acquired, consumer preferences, and possible policies implemented in the next 20 years. They recognize the significant growth of solar and wind energy systems globally by 2040 as shown in **Figure IV.1.5**.

![Figure IV.1.5. Share of renewables in different region. ExxonMobil “Outlook for Energy” (2019) [9]](image)

ExxonMobil predicts an increase in every sector except for coal. Oil and gas stay at the top of the distribution, but in comparison, renewables stand to gain good percentage of the market.

Overall, ExxonMobil expects technological improvements throughout the 20 twenty years that will help attain higher efficiency for resources used and will lower emissions for all forms of power systems. Most of
the energy sectors will increase in magnitude to meet the rising demand for power, and renewables will rise at the greatest pace. In comparison, the Energy Information Administration released a similar report showing their expectations for the future energy market.

Every alternative energy discussed is expected to innovate and grow significantly in the next 20 years, with most of the growth and innovation in wind and solar power. Contrary to popular belief, oil and gas are also predicted to grow in significant magnitude due to increased demand. This growth is expected despite government interventions, because of oil and gas industry innovations that now make their total GHG emissions account for less than one percent of total emissions [7]. Across the board, power systems are being made more efficient and less harmful. In conclusion, the energy market will look very similar to today with the exception of the growth of renewables and the stagnation of coal.
IV.2 Geothermal Energy Consumption

By Hessa Al-Mansoori

Geothermal energy is a natural energy source that exists beneath Earth’s surface. It is generated under extremely high temperature and pressure and is only generated in the Earth’s core. Geothermal energy is a renewable, clean, and cost-effective energy source. This type of energy comes in various natural forms such as hot springs, hot rocks, volcanoes, and magma plumes. However, geothermal energy is less popular than coal, oil, and gas. For centuries, coal was one of the few known sources of energy and it was widely used around the world. It was extensively used in the 19th century during the Industrial Revolution to power steam engines in locomotives, and is still used in steel production and electricity generation. There are a few technologies currently dependent on geothermal energy, such as flash steam, dry steam, and binary cycle power plants. According to the U.S. Energy Information Administration, total global energy generation consists of 36.5% from oil, 30.6% from natural gas, and 0.2% from geothermal energy [1]. Geothermal energy is not only renewable and a great alternative to current energy sources, it is also sustainable and eco-friendly as it is does not emit CO₂ and only emits water vapor [2]. This lack of CO₂ emissions makes geothermal energy an interesting alternative to fossil fuels and other sources of energy.

Energy Formation

Earth consists of several layers that cover the core. The uppermost and thinnest layer is the crust, which consists of oceanic and continental crusts. Oceanic crust is found at the bottom of the ocean and it is 5–7 km thick. In contrast, continental crust can be up to 40 km thick. The next layer down is the upper mantle, which is approximately 410 km thick, after which is the lower mantle, which is approximately 2890 km thick and is thus considered Earth’s thickest layer [3]. The final layer is Earth’s core, which is divided into an outer core and an inner...
core. The temperature in the inner core is estimated to be around 5,200°C, and the outer core’s temperature is estimated to be about 4500°C [4].

The extreme conditions of high pressure and temperature within Earth’s core can cause hot steam or magma to find its way through the mantle and crust as shown in Figure IV.2.1. Hot steam and magma are geothermal energy sources that can be harnessed through power plants. Volcanos and hot springs are unmanaged geothermal energy sources that are unpredictable, and eruptions can be harmful to nearby human life. Current active volcanos such as Mount St. Helens in Washington and the hot springs of Yellowstone National Park, Wyoming, are examples of uncontrolled geothermal energy sources.

Hotspots or countries with potential geothermal energy sources

Iceland, Hawaii, and Yellowstone National Park are some locations known as geothermal hotspots. These locations are geothermal energy hotspots due to their geographical position. For instance, Iceland lies
over a mid-oceanic ridge that can be seen on land as well. This ridge was caused by two tectonic plates drifting away from each other. The movement of these two major plates created a mantle plume, an upwelling of abnormally hot rock within the Earth's mantle. As the heads of mantle plumes can partially melt when they reach shallow depths, they are thought to be the cause of volcanic centers known as hotspots. This caused volcanic activity through the crust to the surface as seen in Figure IV.2.2, thus becoming the Icelandic geothermal source of energy. Because Iceland lies over a hotspot, the abundant geothermal energy is harnessed and should be managed. The country has five geothermal power plants that harness this energy and provide the country with heat and electric power. In fact, Iceland relies highly on geothermal energy, with about 26.2% of the country’s electricity and about 85% of its heating and hot water coming from geothermal energy [7].

Furthermore, Iceland is extending its research in this field, encompassing all the aspects of containing geothermal energy, including the magma power source. The Icelandic Deep Drilling Project (IDDP) that started in 2009 involved drilling a well and pumping water into the volcanic substratum that interacts with the liquid magma to produce high-pressure steam. This steam travels through a turbine to generate electric power using geothermal energy.
In addition, the scientists of the IDDP have been studying Reykjanes Peninsula as it is a high potential area that has volcanic activity few kilometers below the surface. The IDDP started drilling in 2016 and drilled a well 4.8 km deep. This well did not directly contact the magma; however, the temperature at that depth was measured to be around 427°C [8].

A difficulty faced in this case was that the deeper they drilled the well, the greater the chances of the site turning into an active volcanic spot. This can make it difficult to harness the energy. This case of geothermal energy extraction from volcanic magma relies on heat energy from supercritical water according to the IDDP [8]. Supercritical water is a special state of water that occurs when water reaches an extremely high temperature that changes its state, causing it to be neither liquid nor gas. This state of water can conduct much more energy than regular geothermal steam [8]. IDDP researchers in Iceland suggest that this method of using geothermal wells can generate more energy with lower impact on the environment. They stated, “If deep supercritical wells, here and elsewhere in the world, can produce more power than conventional geothermal wells, fewer wells would be needed to produce the same power output, leading to less environmental impact and improved economics” [9].

**Technologies and cost**

Geothermal energy can only be managed and harnessed through power plants and an important part of a geothermal power plant is the well. Wells are the only way to reach geothermal energy sources deep in the crust. A well generally reaches 1–4 km below the surface of, and the depth of the well depends on where heat energy can be harnessed properly. The deeper the well, the more it will cost. For example, drilling a 4 km well can cost $5 million dollars. Yet, if the heat source is deeper, say 10 km, well drilling can cost around $20 million [10]. On the other hand, a geothermal power plant itself costs much less, as it is capital-intensive and easy to run.
There are a few technologies used to control this type of energy, specifically to generate heat and electricity. There are three types of geothermal power plants: dry steam, flash steam, and binary cycle power plants. Each power plant has a different and unique way of using geothermal energy and converting it to heat or electricity.

**Dry steam power plant**

This type of power plant is the most common and easy to install according to the Save On Energy report. A dry steam power plant uses direct pipes drilled into the crust as shown in Figure IV.2.3. Hydrothermal fluids that are initially steam go through the pipes of the production well and directly to the turbine to generate electricity. Wastewater, which is rich in minerals but not harmful to the environment, is injected through the injection well [12].

![Cross-sectional diagram of a dry steam power plant system](image)

*Figure IV.2.3. Cross-sectional diagram of a dry steam power plant system [13]*

**Flash steam power plant**

This system uses hot water from production well pipes that is first pumped into a cooling tank known as a cooling temperature flash tank. The term “flash” comes from the sudden change in water pressure. This results in a high-pressure steam that goes through the turbine to power the electric generator as shown in Figure IV.2.4 [14].
Binary cycle power plant

This type of system relies on two fluids, a hot geothermal fluid and a cold fluid. During operation, the geothermal fluid rises through the production well up to the surface and evaporates the cold liquid, which results in a high-pressure steam that goes through the turbine and powers the generator to produce electricity as seen in Figure IV.2.5. A binary cycle power plant is a closed loop system and emits only water vapor to the atmosphere [14].

Figure IV.2.4. Cross-sectional diagram of a flash steam power plant system [13]

Figure IV.2.5. Cross-sectional binary power plant system [13]
Is geothermal energy eco-friendly?

Geothermal energy can be compared to fossil fuels like coal, natural gas, and oil by the amount of CO₂ emitted in the electric power generation process. Each energy source has different emissions when used for electric power generation and heat generation. Figure IV.2.6 shows CO₂ emissions in grams per kWh of electricity produced by geothermal and different fossil fuels. As shown in the figure, fossil fuels all have higher CO₂ emissions than geothermal energy.

![ELECTRIC POWER GENERATION](image)

*Figure IV.2.6. CO₂ emissions due to electric power generation according to IGA 2002.*

Figure IV.2.7 Error! Reference source not found. shows CO₂ emissions caused by generating heat from different energy sources such as oil and coal. Similar trends, such as coal emitting the highest amount of CO₂ and geothermal emitting the least, are observed in heat generation. Although harnessing geothermal energy for heat generation emits a negligible amount of CO₂, geothermal electricity generation produces a small amount. In general, geothermal energy
emits 99% less CO$_2$ and 97% less sulfur dioxide and nitrogen oxides, which are compounds responsible for acid rain, than oil [6].

![HEAT GENERATION](image)

*Figure IV.2.7. CO$_2$ emissions due to heat generation from different energy sources*

In conclusion, the geothermal energy is a renewable and abundant energy source that is currently being minimally utilized. However, it has the potential to become more efficient, providing an eco-friendly energy source and satisfying the increasing energy demands of the future. Currently, scientists and engineers can harness this energy without direct contact with the magma, extracting enough energy to produce electricity and heat for a whole country. Also, it is important to know that geothermal energy is eco-friendly when extracted through power plants. This type of energy is currently valuable while the rest of the world is relying on fossil fuels with high CO$_2$ emissions that threaten environmental and ecological systems.
Online education impacts different majors differently

Refines online learning by locally supplying educational resources

Enables customizable degrees

Some cons to online education are:
- Negative effect on social and communication skills
- Removes important skills required in the workplace
- Lack of professional physical interaction
- Lack of hands-on experience and peer help
- Student focus is negatively affected
- Distance education doesn’t allow for education and community to interlink

And its pros are:
- Provides international equal learning opportunity
- Less staff needed, benefits university business
- Accessible recorded lectures
- Distance learning provides the opportunity to partake in multiple commitments
April 12, 2020
Dr. Marwan Khraisheh gave a presentation on the topic of digital learning and education. This section contains the opinions the students had about the topic. Note that these opinions could have been influenced by the sudden change to online education that students had to face.
Introduction: Automotive Aerodynamics and Fuel Economy
Dr. Ibrahim G. Hassan

In general, the discipline of aerodynamics describes the way objects such as cars, airplanes, and rockets move through air. It is a sub-field of fluid dynamics and gas dynamics and primarily deals with the lift and drag forces affected by the motion of air around solid bodies. Automotive aerodynamics is the study of the aerodynamics of road vehicles. This is essential for designing fuel-efficient vehicles as smoother airflow over a car yields lower drag, resulting in lower fuel consumption at a specific speed. Because of this, automotive aerodynamics is considered a significant factor in overall vehicle energy consumption.

The automotive industry has been interested in aerodynamics since the introduction of the Chrysler Airflow car in 1934. A moving vehicle must move air out of the way, which requires consumption of fuel. About half of the mechanical work of a car’s engine is used to overcome wind resistance and the rolling resistance of the tires, and at higher speeds, more air obstruction is faced. For instance, aerodynamic drag contributes more than 50% of the resistive force at speeds greater than 40 mph (64 kph). Wind resistance can be quantified by a factor known as the drag coefficient (Cd). A vehicle with a low Cd vehicle is more aerodynamic, meaning it needs less energy to overcome wind resistance.

The aerodynamic drag of a vehicle is determined by its shape and size, which is defined as the frontal area. A car with a streamlined (smooth) shape and a relatively low frontal area with limited openings in the body would have improved aerodynamic performance. An ideal aerodynamic vehicle would be a low-slung, teardrop-shaped, absolutely smooth vehicle that is not much wider than its driver. This car would be ideal for setting new fuel economy records; however, such a design is not practical. Instead, engineers must work with realities such as cabin volume, ground clearance, and engine cooling spaces. Also,
aerodynamic features on sports cars such as spoilers, hatchbacks, and side skirts have been introduced to control airflow (i.e., reduce drag) and to boost downforce (i.e., reduce lift). Overall, aerodynamic drag is proportional to the square of the vehicle’s speed; therefore, the power needed to overcome drag is directly proportional to the cube of the vehicle’s speed. This means that a significant relationship exists between vehicle speed and the proportion of fuel used to overcome drag.

To accomplish optimum fuel economy, vehicle manufacturers investigate and incorporate many aerodynamic models for efficient vehicle design. This is a relatively cost-effective approach for automakers to increase vehicle efficiency through aerodynamics compared to expensive engine technologies or costly weight savings. Moreover, the lower fuel consumption resulting from efficient designs also preserves environmental sustainability by reducing harmful exhaust emissions.
V.1 Effect of Aerodynamics on Performance and Fuel Economy

By Mohammad J. Shehabi

When the first road vehicle was invented, engineers did not consider the effects of aerodynamics. However, as early as 1920, the automotive industry started to incorporate specific design features into the bodywork of vehicles based not only on aesthetics, but also on aerodynamic considerations. Nowadays, every car design comes from the factory with labels of its aerodynamic properties.

Automotive aerodynamics is a special topic of flow over immersed bodies that studies the aerodynamic stability of road vehicles at high speeds and their performance in the presence of drag and unwanted lift forces. Later, engineers started to apply economic analysis on how enhancing vehicle aerodynamics can observably increase fuel efficiency, especially at high speeds. High speeds are specified because aerodynamic forces are directly proportional to the square of the flow speed.

Very early designs of vehicles, as shown in Figure V.1.1, had vertical windshields and very short hoods. This design resulted in very high drag forces acting on the vehicle, affecting its performance. For example, even if a vehicle were designed to accelerate to 50 km/h, it would not be able to reach that speed. The conclusion reached from this outcome was that drag force plays an important role.
As the automotive industry revolutionized, the design of cars became a priority. In fact, automotive aerodynamics became a crucial aspect of engineering. In cases like Formula 1 cars, aerodynamics became one of the eminent factors to consider, if not the most important one. This realization is still shaping our cars today. Figure V.1.2 shows a modern, streamlined car that is considered very aerodynamically efficient based on current standards.

In the period between the production of the two cars shown above, many car designs were developed. As a result, many new terms,
concepts, and testing methods were introduced into this industry. The concepts of coefficient of drag, computational fluid dynamics (CFD), wind tunnel testing, pressure drag, friction drag, and much more have been helping engineers make strong automotive designs. These methods were at the core of the revolution in automotive aerodynamics.

**Research and analysis methods**

Engineers in this field have been utilizing the competition between companies and their race for the first place in the market. This supplied them with the resources necessary to develop their testing and analytical methods. This development revolutionized the industry and helped take it to new levels. A brief description of some of these key concepts and methods will follow.

**Computational fluid dynamics**

CFD is a branch of fluid mechanics in which computers are used to simulate the fluid flow in both free-stream and boundary flow regions. It is known that differential equations such as the Navier-Stokes equation do not have known analytical solutions except in special cases. In short, the Navier-Stokes equation is a relation between the temperature, pressure, viscosity, velocity, and density of a moving fluid. **Equation V.1.1** is the x-momentum part of the Navier-Stokes equation.

\[
\frac{\partial (\rho u)}{\partial t} + \frac{\partial (\rho u^2)}{\partial x} + \frac{\partial (\rho uv)}{\partial y} + \frac{\partial (\rho uw)}{\partial z} = -\frac{\partial \rho}{\partial x} + \frac{1}{Re} \left( \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} \right)
\]

**Equation V.1.1.** The x-momentum part of the Navier-Stokes equation

Here, \( \rho \) is the density of the fluid; \( u, v, \text{ and } w \) are the velocity components in the \( x, y, \text{ and } z \) directions, respectively; \( p \) is the pressure; \( Re \) is the Reynolds number; and \( \tau \) is the shear stress exerted
on a fluid element in a specific plane. This equation, along with its extensions to the y and z components, are the fundamentals of CFD.

After the body is designed using computer aided design, CFD takes this body and simulates different scenarios as desired. This field heavily relies on discretization as it provides good approximations to fluid flow problems. With the aid of supercomputers, the uncertainty of these approximations has decreased drastically as more computational power and speed are involved. Figure V.1.3 shows a visualization of a pressure heat map produced using this method.

![CFD simulation of a race car](image)

**Figure V.1.3. CFD simulation of a race car [6]**

**Lift and drag coefficients**

The aerodynamics of vehicles are described by the coefficient of drag $C_D$ and the coefficient of lift $C_L$. The question here is how these coefficients relate to the actual values of aerodynamic forces. The answer is simple and is given by Equation V.1.2 [5].
Here, \( \rho \) is the density of the fluid, \( U \) is the velocity of the fluid, and \( A \) is the frontal/projected area of the immersed object. \( C_L \) is similarly given by Equation V.1.3 [5].

\[
C_L = \frac{Lift \ Force}{\frac{1}{2} \rho U^2 A}
\]

Equation V.1.3. Equation for \( C_L \)

These coefficients are dimensionless and are constant for a given shape or geometry. A vehicle’s aerodynamics are often related to the vehicle’s coefficient of drag.

Wind tunnels are very useful in experimentally determining the values of those coefficients. The total aerodynamic force can be found as an integration of pressure over the whole surface area. Drag force is the horizontal component of this force and the vertical component corresponds to lift force. Equations V.1.2 and V.1.3 are thus applied based on the given flow conditions. Table V.1.1 shows how the drag coefficient of vehicles has changed over the years. Drag coefficients were large in the 1980s and then started to decrease and are expected to decrease even more in the future.

Table V.1.1. Evolution of coefficient of drag through the years [8]

<table>
<thead>
<tr>
<th>Automobile</th>
<th>Calendar Year</th>
<th>( C_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mazda Miata</td>
<td>1998</td>
<td>0.38</td>
</tr>
<tr>
<td>BMW 7 Series</td>
<td>2009</td>
<td>0.31</td>
</tr>
<tr>
<td>Tesla Model X</td>
<td>2018</td>
<td>0.25</td>
</tr>
<tr>
<td>Porsche Taycan Turbo</td>
<td>2019</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Engineers in the automotive industry are enhancing designs to avoid unwanted aerodynamic forces. The factor that has contributed the most to this reduction in $C_D$ is the decrease in frontal area. Even though the relation between frontal area and $C_D$ is linear, frontal area is considered the most controllable factor in cars [9].

A car at typical urban speeds (usually 0–50 km) will have its fuel consumption mainly affected by frictional drag and rolling resistance. Rolling resistance, or rolling friction, is essentially the force acting against the motion of a body rolling on a surface. As for frictional drag, this is caused by the friction between a body and moving fluid, and boundary layer effects are also considered here. However, at higher speeds, drag pressure is the most prominent force working against the motion of the car. In extension, the faster the vehicle goes, the more fuel it needs to overcome the force of drag and push through it.

A larger $C_L$ means a higher lift force. This is desirable for airplanes, but not for road vehicles. Road vehicles, especially light ones, usually need downforce to increase traction between the wheels and the road or track. In some race cars, downforce contributes more to traction than the actual weight of the car.

**Enhancing aerodynamics**

Many aspects related to car design have changed since aerodynamics gained more attention, with the most noticeable changes being those related to the hood and front windshield. Flow separation happens around the end of the hood. This allows the detached flow to follow the curvature of the windshield, consequently creating a smaller wake area behind the vehicle. The wake area is an area behind a moving object that is characterized by low pressure. This reduced wake area contributes to smaller pressure difference between the stagnant air hitting the front of the vehicle and the air behind the vehicle. The difference in pressure is the pillar of aerodynamic drag. As discussed earlier, friction drag is considerable at urban speeds. So, engineers
must always optimize their design to find a middle ground between reducing pressure drag and not significantly increasing the friction drag. This is where the optimization process comes in.

As for the windshield, reducing its projected area to the front has remarkably helped to reduce $C_D$; however, like any optimization problem, there are some unavoidable constraints. One of the main constraints is the angle of the windshield. The windshield should not be close to horizontal as it is needed to guide the airflow smoothly. Otherwise, the boundary layer would extend, and the airflow would not reattach at high speeds, leading to extremely high drag forces.

Other enhancements to the design are carried out by adding or removing parts of the car’s body. Some of the most common modifications include [11]:

- Removing sharp edges that may cause turbulence and unwanted drag. Round edges are optimal in such cases.
- Removing/adding rear spoilers. Rear spoilers are inverted airfoils at the rear of the vehicle that increase downforce, and thus traction. However, this comes with a cost of drag. So, spoilers are to be kept if better handling is desired; however, if less drag (i.e., more speed) is wanted, spoilers should be removed.
- Adding an under tray, which can reduce turbulence in the flow under the car and possibly reduce drag.
- Using a boattail design that narrows at the rear of the car. This approach reduces drag considerably.
- Adding diffusers to decelerate the flow of air under the car and decrease drag and turbulence.
- Adding roof flaps like NASCAR race cars. These work as emergency spoilers on the top of the car to prevent the car from lifting off the ground.

Many more methods are being experimented on daily to contribute to improving road vehicle aerodynamics. Figure V.1.4 shows a car with an aerodynamic body kit installed.
Effect on performance

Vehicle handling and directional stabilities are the most important car performance criteria. The effect of lift is more prominent in this area than in fuel economy. Optimization is not about decreasing $C_L$ per se, but rather about making use of available lift force to increase downforce at the rear end of the car. As discussed previously, this increases traction, which improves handling on slippery surfaces. Other concepts that car performance heavily relies on are yaw, pitch, and roll. Yaw is the freedom to rotate about the vertical axis, pitch is the angle between the car and the horizontal axis, and roll is the freedom to rotate about the lateral axis. Figure V.1.5 illustrates the directions of aerodynamic forces that work on a car.
During high winds, the yaw moment induced on a car can be significant, which can sometimes cause the car to lose its stability. The drag coefficients of the other sides of the car are a point of interest for these situations. Like lift and drag, the coefficients for these aerodynamic forces were developed and take the usual form (a function of the square of velocity, density, area, and characteristic length). This section lacks statistical evidence; however, the interest in this field is increasing daily.

The center of pressure is crucial when it comes to aerodynamics. Aerodynamic forces are the integration of pressure over the area of the car, thus, the closer the center of pressure is to the center of gravity, the fewer moments act on the car due to aerodynamic forces. This heavily relies on the design of the car, with developers being interested in all sides of the car, not just the front and rear.
Effect on fuel economy

Fuel consumption correlates with power consumption. Reducing a car’s drag coefficient reduces the drag force acting on it; hence, less force is required to overcome drag and accelerate the vehicle to the desired speed. Therefore, a smaller $C_D$ means fuel consumed. Old cars, despite designers not having tools to approximate $C_D$, were estimated to $C_D$ values ranging 0.4–0.7, which is relatively large. However, some modern automobiles, like trucks and sport utility vehicles (SUVs), have coefficients greater than 0.5.

Recent research provided an approximate equation showing that a 10% reduction in drag force on a vehicle yields a 5% increase in fuel economy [14]. In principle, power is the energy consumed/supplied per unit time. It can also be represented as the product of force and velocity. In this case, we are only interested in the power needed to generate a thrust that overcomes drag, which would eventually yield Equation V.1.4 [5].

$$P = Drag\ Force \times U = C_D \frac{1}{2} \rho U^3 A$$

Equation V.1.4. Thrust generated to overcome drag

This equation is a simple proof that the power needed to overcome drag is directly proportional to the drag force itself. Because power is directly related to the burning of fuel, this validates the findings of the research. Figure V.1.6 shows the energy consumed at various speeds due to air resistance and rolling resistance.
Exceptions

It is widely known that SUVs major contributors to emissions. This is because their bulky masses and inefficient aerodynamics lead to very high fuel demand. This is the reason why SUV designers are becoming more concerned with the luxury aspects of the vehicle, often focusing on other issues. For example, Mercedes’ G63 and G65 AMG off-roaders are a perfect example of a non-aerodynamic, boxy design. Despite the latest turbo-technology developed in the making of both vehicles, their performance figures are poor compared to other cars [16]. Even though the G65 is considered the most powerful SUV, its fuel economy, as anyone can predict, is inefficient.

Such cars only offer luxury to the drivers. Optimizing the aerodynamics of such vehicles has proven difficult but is still feasible. A lot of research is looking into making SUVs more eco-friendly and increasing their performance. However, this is a significant change that will probably take some time. This slow progress demonstrates a
weak response to global invitations for automotive companies to abandon making SUVs. Whether these calls come through or not, a change for the better is bound to happen in this field.

In conclusion, aerodynamic forces play a major role in dictating vehicle fuel economy and performance, especially at high speeds. When a car’s coefficient of drag is reduced, performance (reaching higher speeds) and fuel economy (fuel consumption) both improve. It is possible to add or remove specific body parts to enhance a car’s aerodynamics. It has also been discovered that lift and drag are not the only aerodynamic forces acting on a moving vehicle. Yawing, pitch, and rolling moments also hold significance and are directly linked to performance, especially in extreme weather conditions. The field of automotive aerodynamics seems to be reaching its pinnacle, but this does not necessarily mean that the rate of advancement will start to decrease. Optimization is always a busy task in all companies, and engineers always manage to find new issues to fix and ways to improve their designs.
Wind tunnels, like most engineering designs, were inspired by nature. Scientists in the 18th century observed and attempted to understand how birds fly and their airborne characteristics. However, they could not get far as they lacked knowledge about how air flows over surfaces and its relations to fluid dynamics. This prompted scientists to create and explore many innovative versions of wind machines. Some of these designs mounted basic models of flying machines on windswept ridges, or even relied on makeshift aeronautical centrifuges called whirling arms. The challenge was making sure that the test subject would fly in a constant and controllable air stream, unlike the turbulent air that primitive wind tunnels created. This led to the development of the first wind tunnel in 1871 by the Aeronautical Society of Great Britain. This wind tunnel consisted of a horizontal 18 inch by 18 inch square tunnel 12 feet long that was driven by a fan blower steam engine. The generic definition of a wind tunnel is a device that produces a controlled stream of air to study the effects of air movement or air resistance on a subject. Wind tunnels are also meant to replicate and visualize the actions of an object in flight or moving along the ground [1]. Over the years, wind tunnels grew and air speeds increased and have been used to test new technologies like supersonic aircraft, missiles, and faster cars, and to create stronger, safer buildings. For instance, wind tunnels are important in testing the safety of buildings against natural disasters by measuring airflow and ensuring proper ventilation. This primarily helps in calibrating wind gauges, which in turn helps measure wind flow. Hence, aerodynamic research has expanded into several other fields such as architecture, education, automotive industry, and the environment among others.

**How wind tunnels work**

The general structure of a wind tunnel is quite simple, consisting of a long tube made of plastic, metal, or glass. **Figure V.2.1** shows a basic design of an open-circuit wind tunnel.
The settling chamber uses the panels with honeycomb-shaped holes or a mesh screen to settle and straighten chaotic and swirling air. Air then enters the contraction cone where the radius of the tube decreases and airflow velocity increases. Test models are scaled to a suitable size and are placed in the test section. Sensors are placed in the test section to record data and scientists make visual observations through a window on one of the walls. Next, the air flows into a conical diffuser, with a widening radius and air velocity decreases smoothly. Throughout the wind tunnel, the walls are carefully kept smooth to prevent turbulence. The axial fan that creates high-speed airflow is in the drive-section. This fan is placed at the end of the tunnel, as the fan pulls air, resulting in a smooth stream. If the fan was located at the entrance of the wind tunnel, the fan would have to push air, resulting in a choppier airflow [3].

Wind tunnels vary in size from as small as coffee tables to as large as warehouses; however, most are small enough to fit into a university
science lab. Therefore, test objects must be scaled down to fit into the tunnel and precisely made, which can be expensive. An alternative is that only parts of the test subject are tested [3].

Furthermore, wind tunnels have various settings to test different objects and recalibrate wind gauges at different wind speeds. This is crucial as it keeps test objects and wind gauges from being ruined during experiments, ensuring that the wind gauge will provide precise and accurate measurements [12]. There are typically sensors and instruments inside wind tunnels that help scientists collect data on an object’s interaction with wind. With these obtained data, researchers can then address various engineering factors and variables of aerodynamics such as pressure, velocity, temperature, and density. Researchers assess the lift, drag, shockwaves, and other conditions that affect planes and other vehicles [2].

**Flow visualizations**

The transparency of air makes it difficult to perceive air movement. Thus, scientists developed several different qualitative and quantitative flow visualization methods that aid in the tests performed using wind tunnels. Qualitative methods, such as that shown in Figure V.2.2, include fluorescent mini tufts that are attached to a wing of the Kirsten Wind Tunnel. These tufts show the direction of air flow and separation.

![Figure V.2.2. Qualitative method [8]](UW1655_RUN_2_R0027P014.JPG)
There are also several specifications present for each set of data such as angle of attack (degrees) and speed (mph). Other qualitative methods include smoke, oil, fog, and evaporating suspensions [8]. As for quantitative methods, a famous technique called pressure sensitive paint is used. As shown in Figure V.2.3, this technique consists of coating the model with a type of paint that reacts to variations in pressure by changing color.

![Pressure sensitive paint technique](image)

*Figure V.2.3. Pressure sensitive paint technique*

High-speed cameras are also placed within wind tunnels to photograph objects under controlled wind. Images from these cameras can then be used to create a complete distribution of the external factors and pressures acting on the object. Other quantitative methods include particle image velocimetry, particle tracking velocimetry, laser speckle velocimetry, and model deformation measurement (MDM) [9].

**Classifications**

Several different types of wind tunnels have been developed over the past several decades. They are classified by the range of wind speeds that the device is able to produce and include subsonic and transonic wind tunnels, supersonic wind tunnels, and hypersonic wind tunnels.
Subsonic wind tunnels have wind speeds lower than the speed of sound and transonic tunnels have speeds that are almost equal to the speed of sound. The supersonic and hypersonic tunnels are even more impressive as some can reach wind speeds of more than five times the speed of sound [1].

**Wind tunnel flow simulation**

An important subtopic within this field is atmospheric boundary layer flows and wind tunnel flow simulation. The atmospheric boundary layer is the lowest part of the atmosphere, and the effects of surface roughness, temperature, and other properties are transmitted by turbulent movement within this layer. Different similarity theories have been projected for various atmospheric stability conditions. **Equation V.2.1** is the Prandtl logarithmic law equation, which can be used to perform similarity studies in the case of a neutral boundary layer where \( U \) is the mean velocity, \( z_0 \) is roughness height, \( z_d \) is the zero-plane displacement for a very rough surface, and \( u^* \) is the friction velocity. This definition is a crucial one in the science of wind tunnels as it is used to characterize the atmospheric flow simulations of air flows in wind tunnels [12].

\[
\frac{U(z)}{u^*} = \frac{1}{0.4} \ln \left( \frac{z - z_d}{z_0} \right)
\]

**Equation V.2.1.** Prandtl logarithmic law

**CFD simulations and 3-D printing**

Computational fluid dynamics (CFD) and wind tunnels are often used together in an interdependent process for the same project. Wind tunnels simulate the movement of a test object through air and measure various forces acting on it. Meanwhile, CFD uses computers to simulate fluid flow over digital models as shown in **Figure V.2.4.** The general analysis technique can simulate this flow over virtual models without the need for physical models. However, this may lead people to falsely believe that CFDs are more useful and less costly, and hence a replacement, for physical wind tunnels. In fact, CFD only
makes assumptions and approximations when solving flow equations, which can reduce the overall accuracy of CFD results. Therefore, despite CFD being a great scientific and engineering breakthrough, it is wrong to assume that it overpowers wind tunnel simulations. Nevertheless, CFD results make it relatively easy to visualize flow features throughout a model and extract different data. This demonstrates that CFD goes hand-in-hand with wind tunnels. Hence, wind tunnels will provide more accurate, real-life results from physical testing and CFD can be used for data extraction as it is much cheaper than wind tunnels. On another note, 3D printing has been an even bigger breakthrough, as it can print scale models for testing. Wind tunnel models are commonly made using composite materials, and this can be a very time-consuming process. However, CAD plays an important role in the production process today and can reduce the model production time frame significantly [10].

![Figure V.2.4. CFD Visual [11]](image)

**Applications**

As previously mentioned, the main aim of a wind tunnel is to calibrate and test wind gauges. These wind gauges are used to measure the wind forces both indoors and outdoors, in factories and even in ductwork in office buildings. These devices help keep track of the pressure, and with the help of other devices, ductwork pressure can be
controlled. However, in recent years, the most popular use of wind tunnels has been to measure the aerodynamics of various objects, vehicles, and systems, especially in the aerospace industry. Planes and cars are tested in wind tunnels prior to being manufactured commercially. This test certifies that the vehicle has the required aerodynamic properties and will perform safely on the road or in the sky. Some of the biggest organizations like NASA and Boeing test aircraft and plane engines in company-owned wind tunnels to ensure aircraft safety and efficiency [12]. Figure V.2.5 shows an airplane being tested in a wind tunnel.

Wind tunnels are integral in the primary research on the boundary layer, which is the layer of air parallel to any surface exposed to air. Ultimately, such tunnels help engineers determine how the wind interacts with stationary or moving objects and find ways to make them sturdier and safer.

The two main wind tunnel tests used to classify and measure other parameters, are the static stability test and the pressure test. These tests are crucial as they determine the aerodynamic properties of a vehicle.
The static stability test measures the moments caused by forces such as normal, axial, rolling, and pitching forces due to external factors. The pressure test accurately determines pressures acting on the object being tested. The data obtained from both tests are combined to yield a model and information about how the total wind load is distributed [1].

**Economic analysis**

Overall, aerodynamic studies in wind tunnels have proven to be highly profitable over the past decade due to their accuracy in solving design problems for all kinds of vehicles and structures. Because reducing costs has become progressively more important, new design methods such as concurrent engineering have helped take wind tunnel simulations to the next step economically [7]. Concurrent engineering is a method for designing and developing products, in which the different stages run simultaneously rather than consecutively. This has also led to many improvements such as shortening the overall time required to bring products to market. Most importantly, this has reduced defect rates with lower product and life-cycle costs. Wind tunnels remain an important part of the development process in the aerospace industry. In fact, Boeing 777 airplanes spend almost 2,000 hours in wind tunnels as this can predict powered flight over a staggering 32 years [7]. Companies have started capitalizing on the increasing potential of experimental economics as a decision-making tool. This field requires modern research in economics that has become strictly dependent on high-performance computers that are tricky to involve at low costs.

As the world gets more populated and saturated with infrastructure, scientists will need wind tunnels to ensure structural integrity. They test various important pieces of infrastructure like buildings, planes, and tunnels, and wind tunnels also help solve pre-existing problems. Wind tunnels also pave the way for engineers to account for public safety before a final product is constructed. Thus, wind tunnels are crucial to making any engineering design process successful.
Furthermore, scientists and engineers are constantly reaching out for more developments and achievements using wind tunnels due to their numerous benefits. Researchers are attempting to create wind tunnels that are smaller, more practical, environmentally friendly, technologically advanced, and less expensive to operate. Ultimately, with the invention, creation, and constant advancement of wind tunnels, the cost of designing and testing aircraft and structures has been reduced, which is a vital step for public safety. Without such inventions, there is little to no way for engineers and scientists to predict what will happen with their creations.
March 22, 2020
Dr. Fawaz Saeed Al-Qahtani gave a presentation on the role of researchers in innovation and IP commercialization. This section contains the opinions students had about the topic.
The Role of Researchers in Innovation & IP Commercialization

- IP is not addressed enough in university student research
- Capitalism in this context links research and innovation to profit and greed
- It pays to pay specialists
- It's not a question of morality when choosing to patent before sharing an idea
- Ideally companies should be held accountable regardless of copyrights
- IP cultivates innovation
- Focus on both quality and financial outcome
- Potential and timing are crucial for investment
- Positive impact on national industries and economy
- Inventors gain motivation to create more due to recognition
- Adds a layer of governmental order and organization
- A cycle of research in institutions and innovation is integral in bringing important products in the market
References

I.1 3D Printed Prosthetics by Dana Alyafei


I.2 Compliant Mechanism by Fatima Al-Khuzaei


### 1.3 Self-Cleaning Materials by Seham Al-Baker


I.4 Virtual Reality by Abdo Harami


II.1 Recreational Quadcopters Drones by Maryam AlMulla


II.2 Simulation, Production, and Analysis of Tower Cranes by Reem Elhadi


II.3 Stealth Aircraft by Ahmad Issa


III.1 Plastic and Environment Sustainability by Hadear Hassan


Conferences and Computers and Information in Engineering Conference (Vol. 42854, pp. 901-909).


III.2 Solid Waste Management: Incineration by Aisha Hussain


III.3 Social, Economic, and Environmental Sustainability by Mohamed Hussein


IV.1 Energy Sector Outlook by Ian Greener


IV.2 Geothermal Energy Consumption by Hessa Al-Mansoori


V.1 Effect of Aerodynamics on performance and fuel economy by Mohammad Shehabi


V.2 Wind Tunnel by Nilufer Kizilgun


Introduction References
