Technical Issues on Constructing Ultralight Drones via Additive Manufacturing

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Abstract: - This study focuses on technical considerations on constructing ultralight drones, using CAD software for their 3D printing. 3D printing technology offers the possibility of using a variety of materials, while at the same time being distinguished by its accuracy and speed. First, an extensive historical review of the development of drones, CAD software, 3D printing, and the basic principles of drone aerodynamics and stability is presented. This is followed by the design suggestions for a drone, using Fusion 360 to draw the 3D models. After designing them, we may proceed to simulations to test if they can endure the forces and heat, generated by their engines. Static stress analysis can be performed, through which we may find whether the model is subject to deformation from the forces generated by the motors. Then, with the help of static analysis, we may eliminate the deformation. After confirming that the drone can endure the mechanical stresses, generated by the thrust of its motors, we may proceed to the thermal analysis that confirms which materials can withstand temperatures up to 70°C, thus ensuring the drone's functionality under typical operating conditions. The combination of certain materials offers high rigidity, impact resistance, and structural flexibility.

Key-Words: - CAD software, drone, quadcopter, simulation, 3D printing, additive manufacturing.

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1 Introduction

A drone can be defined as an unmanned aerial vehicle (UAV), that is, an aircraft without a human pilot inside it. The flight of a UAV can be done either remotely controlled by a human operator, or fully autonomously by a computer inside the vessel. Drones are much more complex devices than simple remote-controlled aircraft, because they incorporate cutting-edge technology and have the ability to be controlled remotely. In addition, with the help of position sensors and controls, they can perform fully autonomous flight. The aircrafts usually referred to as drones today are small, unmanned aerial vehicles that are divided into rotary-wing aircrafts and fixed-wing aircrafts [1].

Historically, a bamboo helicopter was developed in Japan during the period of (710-794 AD), while later Leonardo da Vinci designed a sketch in 1483, which was called an air-screw (Figure 1). His drawings detailed how the propeller would work. Similar to modern helicopters, the propeller was powered by four men, turning a crank to turn the shaft and then the propeller. Da Vinci believed that the rotation would successfully make the propeller hover, but in reality, it was impossible to fly due to its weight [2].

In 1907, the French Breguet brothers developed the first manned helicopter, with the help of Charles Richet. The first Breguet-Richet aircraft was referred to as a quadrocopter, which is the first helicopter with multiple propellers. In 1917, Elmer Sperry began developing an unmanned aircraft with the help of Peter Hewitt. Hewitt was an inventor and wireless communications engineer. This aircraft had no pilot and was stabilized by gyroscope technology, developed by Sperry. The aircraft was a full-scale unmanned aircraft. Subsequent unmanned aerial vehicles were developed by Britain and the United

States. The Queen Bee in 1935 and the Target drone in 1937 respectively. These were used as naval and air force target aircrafts. The FA-61 helicopter is the first full-scale manned helicopter and was created in Germany in 1936. Three years later, in 1939, the VS-300 was manufactured in the USA by Vought-Sikorsky.The FA-61 helicopter had a twin rotor, while the VS-300 had a single rotor and a tail rotor. These two helicopters are exactly the same as manned helicopters today. In Japan in the late 1970s, a remote-controlled helicopter was designed with the intention of being mass-produced worldwide in the early 1980s. In these helicopters, their handling was determined by the skills of their pilot [1], [2].

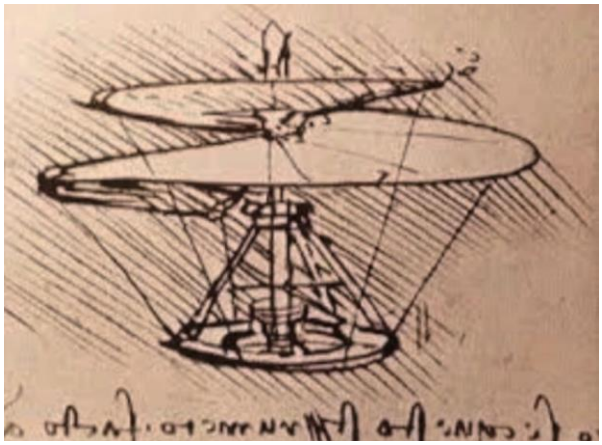


Fig. 1: The air-screw of Da Vinci [2]
Source: created by the authors.

Baghdad-born Abraham Karem became the most famous pioneer of unmanned aircrafts. Abraham co-developed the Albatross in the 1980s. The Albatross was not intended to be an operational drone and was built for a technology demonstration. It was constructed primarily of mahogany plywood, spruce, fiberglass, and urethane foam. The diameter of the fuselage's spherical nose was 11.8 inches. The wings were 15 feet long and were located at the top of the fuselage, midway between the nose and tail. At its rear end was a small vertical stabilizer 18 inches high and half inch width, pointed straight up. The propeller was powered by a two-stroke, single-cylinder McCulloch 101 kart engine. Radio-controlled, the Albatross could take off and land like a regular airplane, using a detachable nose wheel landing gear. It also had a parachute to make an emergency landing in the event of a failure. Specifically, Abraham's drone weighed 105 pounds when completely empty, but could carry 95 pounds of fuel. In addition, it could carry a camera under the nose. From his humble beginnings in a garage in Los Angeles, Abraham has changed the face of military technology. In 1990, Abraham created a new version of the Albatross, the Predator (Figure 2). The Predator was one of the first large fixed-wing aircrafts with a wingspan of 50-100 feet. The payloads of these large UAVs included radar, lasers, cameras and missile systems. The introduction of these aircraft removed pilots from danger and have the ability to remain in the target area for several hours [3].



Fig. 2: The General Atomics MQ-1 Predator [4]
Source: created by the authors.

Over the years, drones have undergone significant changes, due to the rapid development of technology. Technological innovations include the process of designing, simulating and manufacturing a drone, using Fusion 360 and a 3D printer, as well as the software provided by the printer company. Combining these technologies makes it possible to design, simulate and build drones with precision and speed. This study will analyze technical consideration on constructing ultralight drones via additive manufacturing, referring to equipment, materials and their properties.

2 Methodology

Computer-Aided Design (CAD) technology was developed in the 1960s and was revolutionary for its time, as it enabled designers to create, modify and simulate models with greater accuracy. In addition, it is a fact that the progress of additive manufacturing (in terms of 3D printing) is closely related to the development and construction of drones [5].

2.1 Computer-Aided Design

Ivan Sutherland is considered the father of CAD, as in 1963 he developed Sketchpad as part of his doctoral thesis. In Sketchpad, the user interacted with the computer using a light-sensitive pen on a large Cathode Ray Tube (CRT) screen. This technology gave its users the ability to draw graphics in real time directly on the screen, something that had not been

possible until then. In the mid-1960s, the development of the first generation of CAD systems began, which usually concerned two-dimensional design applications. During this decade, Design Automated by Computer (DAC) was developed by General Motors, CADD by McDonnel-Douglas (1966) and PDGS by Ford (1967) [6].

In the mid-1970s, the commercial use of CAD began. In 1975, United Computing released the first Unigraphics system, which designed in two dimensions. In 1979, a new format for exchanging three-dimensional data was created by Boeing, General Electric, and NIST. This technology was called IGES. The 1980s marked the beginning of solid modeling with CAD technology. The first solid modeling system was created in 1981 by Unigraphics, which was called UniSolids. In the same year, the French company Dassault Systemes was created, which in 1982 released CATIA V1. In 1982, Autodesk was founded, and just a year after its founding, AutoCAD was released. AutoCAD costed $1,000 and ran on a personal computer. These features made it much more affordable than other systems that required mainframe computers. In 1984, Apple introduced the first personal computer, the Macintosh 128, and a year later, it created MiniCAD, a CAD software for MAC computers. In the mid-1980s, MACs and PCs had several limitations compared to more powerful UNIX workstations. In 1987, the CAD industry was revolutionized by the Parametric Technology Corporation's release of Pro/Engineer. Pro/Engineer revolutionized CAD by allowing users to create three-dimensional models, using parameters and constraints. It also had an innovative user interface, based on the Windows X operating system, making it more user-friendly [6].

Improvements in operating systems and computing power played a major role in the development of CAD. In 1994, Microsoft released its first 32-bit operating system, Windows NT, which provided stability and better resource management, while being ideal for heavy-duty applications such as CAD. That same year, Intel introduced its first Pentium Pro processor, increasing the processing power of desktop computers. In 1995, another major step forward in CAD was made with the release of the first version of SolidWorks, a three-dimensional CAD program. This program was one of the leading CAD software, designed to run on desktop computers with Windows operating system. Following the example of SolidWorks, Intergraph in 1996 created SolidEdge, a CAD based on the ACIS modeling core. In addition, this program although similar to SolidWorks offered more tools for industrial and construction applications. In the same year, Autodesk released Mechanical Desktop, which quickly became the first selling CAD worldwide. In 1999, Autodesk released Inventor, a 3D CAD based on the ACIS core, as opposed to the AutoCAD-based Mechanical Desktop. This allowed Autodesk users to create models more easily. The ACIS modeling core was acquired by Dassault Systemes in 2000. In the 2000s, CAD developers tried to simplify and make modeling more understandable. In 2007, SpaceClaim, an innovative 3D CAD direct modeling, was released. Reacting to the innovation of SpaceClaim, CAD developers, based on its features, began to incorporate direct modeling into their products. In 2008, SolidEdge incorporated a new tool called Synchronous Technology, while SolidWorks incorporated Instant 3D, which helped in the rapid editing of models, by displaying controls directly in the 3D environment. In 2009, Autodesk introduced Inventor Fusion, a technology that combined the capabilities of direct modeling and parametric modeling. However, in 2013, Inventor Fusion was replaced by Fusion 360, which is still a complete design package today, offering CAD, CAM and CAE capabilities [6], [7].

2.2 Additive Manufacturing

Additive manufacturing is a process in which material is added to create a geometry. One of the most well-known processes is 3D printing. In 3D printing, objects are manufactured by adding successive layers of material under the guidance of electronic instructions, known as gcode. It is a revolutionary technology in terms of how an object is manufactured [8].

In 1984, Charles Hull developed a revolutionary method of reproducing a physical object, which he called stereolithography (SLA). Stereolithography was the first 3D printing technique that made it possible to create objects layer by layer from a liquid polymer, which was solidified by radiation with an ultraviolet laser [8].

Hull founded “3D Systems” company in 1986, which brought the first stereolithography machines to the market, making it a leading force in the world of additive manufacturing. Stereolithography creates an object by solidifying thin layers of polymer, sensitive to ultraviolet radiation, which was emitted by a laser. Thus, with the availability of the first 3D printers on the market, inventors were given the opportunity to explore the new method for making prototypes of designs, without having to invest in manufacturing. These machines provided them with a great advantage, as designers could create an object in a short period of time. That is, a simple idea took on material form within a few minutes, without the need

for intermediaries to secure investments. In parallel with 3D Systems, Helisys Inc. was founded in 1985 and developed LOM, a new method of 3D printing. Recognizing its commercial power, the company in the name of Michael Feygin, inventor of the technology, filed for a patent in 1987. The LOM did not require any human intervention, while at the same time it was capable of operating throughout the day and had the great advantage that objects could be made from a variety of materials [8].

Additive manufacturing encompasses a diverse range of 3D printing technologies, each characterized by distinct functional capabilities and structural advantages. Prominent among these are Fused Filament Fabrication (FFF), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA). FDM and FFF represent two of the most widely deployed techniques for three-dimensional fabrication. Specifically, FFF is distinguished by its cost-effectiveness and prevalent utilization in rapid prototyping. The principal technical distinction between FDM and FFF lies in FDM's enclosed heated chamber, which facilitates the processing of a broader spectrum of materials, including metal, wood, and ceramic composites. Stereolithography (SLA) is an additive process that utilizes a laser source to selectively cure liquid photopolymer resin, a technique renowned for its high dimensional precision and suitability for complex geometry manufacturing. Furthermore, Selective Laser Sintering (SLS) employs a laser beam to sinter powdered material particles into solid entities, making it particularly advantageous for producing components with superior mechanical strength and extended durability [1].

3 Technical Issues

Initially, there are two families of aircrafts, i.e., rotary wing aircraft and fixed wing aircraft. Rotary wing aircraft are capable of hovering in the air and moving vertically, which greatly facilitates takeoffs and landings, especially when space is limited or there are obstacles. A negative element of rotary wing aircraft is that they have lower top speeds and shorter ranges than fixed wing aircrafts. However, they have the ability to take off vertically and remain in the air stably [9].

The subject of this study was the design and construction of an ultralight drone, capable of lifting the following components: a 6s 26v battery, the iFlight XING2 3106 1200KV 6s motors, a Walksnail Avatar HD Micro Camera & VTX Kit V2 32GB, a flight controller Speedybee F405 V3 30X30, and a Happymodel 2.4G ExpressLRS EP1 Dual TCXO RX True Diversity Receiver Module, or similar compatible items. The total weight of the vessel is to be about 150 grams, plus the equipment.

A major advantage of the Fusion 360 software (see subsection 2.1) is that it can simulate various technical aspects, like stresses (Figure 1), deformation, or thermodynamic analysis (see subsection 3.2), without the need for mathematical formalisms and numerical analyses. Therefore, the construction process is significantly simplified and the results readily visible on screen.

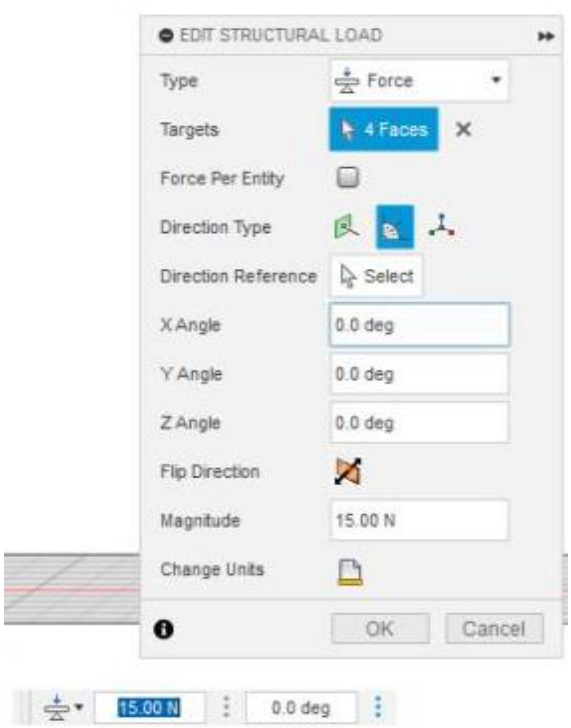


Fig. 1: Regulation of stress [1]
Source: created by the authors.

3.1 Configuration

The model suitable to be designed and built for this magnitude belongs to the rotary wing vehicles. Aircrafts with an even number of rotors do not need additional stabilizing rotors as the torques cancel each other out. There are five categories of drones with rotary wings: bicopters, tricopters, quadcopters, hexacopters and octocopters; and four categories of drones with fixed wings: regular, swept back, swept forward and delta. It should be noted that the more motors the drone has, the greater the load it can lift. In a drone with six engines (i.e., a hexacopter), if due to some fault one of the engines is damaged or stops working, the remaining five continue to work. This means that it can land safely even when one engine is not working. However, this would be impossible to do in a drone with four propellers (i.e., a quadcopter);

yet, a quadcopter has enough propellers to lift a lot of weight and is not characterized by the complexity of hexacopters.

The drone structure includes rotors that are rotatably connected via arms or wings to the drone frame (skeleton). The rotors are located in the same plane, producing thrust, while its geometry is symmetrical. Also, each rotor must be able to produce an equal amount of thrust in terms of torque. Each rotor produces a force during rotation, resulting in an opposing force, according to the principle of Newton's third law: "for every action, there is an equal and opposite reaction". If the propeller has rotated clockwise, the motor that sets it in rotation will tend to rotate in the opposite direction, that is, counterclockwise. This creates a major problem of directional stability. In the case where all rotors rotate in the same direction, the drone frame would rotate in a vortex, which makes it impossible to control the drone. To overcome this disadvantage, there must be an opposing torque, by placing half rotors on the drone in opposite direction, to cancel out the reaction torque, produced by the other half. For example, in a four-rotor drone, two of them will rotate clockwise (CW) while the other two will rotate counterclockwise (CCW), which creates reaction torques in all four rotors that cancel each other out [10].

3.2 Thermal Analysis

Thermal analysis calculates the conduction of energy throughout the geometry of the model. This type of analysis is a process, used to calculate heat transfer within a specified model to understand and control its thermal behavior, allowing accurate predictions of its performance under various conditions. Heat transfer occurs in three main ways: conduction, convection, and radiation. Convection is the transfer of energy between a fluid and a solid, usually the surrounding air. Radiation is considered at high temperatures or low flow conditions, because its intensity increases exponentially under these conditions. Radiation is the transfer of heat between two solid surfaces that exchange electromagnetic energy or radiation, governed by the Stefan-Boltzmann law. Radiation is confined to a specific surface. However, the physical mechanisms of heat transfer are very different from those of convection. Accelerated electrons and protons in a solid emit photons that carry energy. At the same time, photons emitted by one surface strike a second surface and can be absorbed by it. Therefore, a net exchange of energy occurs. In general, modeling radiation is more difficult than conduction and convection.

Heat transfer in a material can occur by radiation, conduction, and convection. Conduction is generally the main mode of heat transfer in solid materials, especially in conductive materials, but also in some insulating materials. In a solid, thermal conductivity is the transfer of vibrational energy through the collision of a particle with neighboring particles. In general, however, the material plays a large role in thermal conductivity, i.e., metals transmit heat much better than plastics, but size and surface area play a large role. For example, a thick material takes longer for heat to reach the other side.

Polymers are divided into two categories, amorphous and semi-crystalline. Thermal behavior differs between crystalline and amorphous. In amorphous polymers, the molecules have a disordered structure, and heat transfer in them occurs sequentially, that is, heat propagates from the atom closest to the heat source to the nearest atom, causing rotations of the polymer atoms in nearby chains. In general, in amorphous polymers, heat transfer occurs more slowly, while in semi-crystalline polymers, heat propagates as a wave due to the arrangement of the molecules. The reason that semi-crystalline polymers have better heat transmission is because they have an ordered molecular arrangement. The thermal properties of composite materials vary depending on the polymer, used in their composition. In general, the thermal properties of synthetic materials differ, depending on the polymer, used for their synthesis [11].

Conducting a thermal analysis simulation (Figure 2), the points where the highest temperature will develop are at the motor bases. We examined a scenario in which the potential temperature development was at 70 °C at the points of interest. We observed that in the 70 °C simulation, the model is able to withstand this temperature, without suffering any deformation.

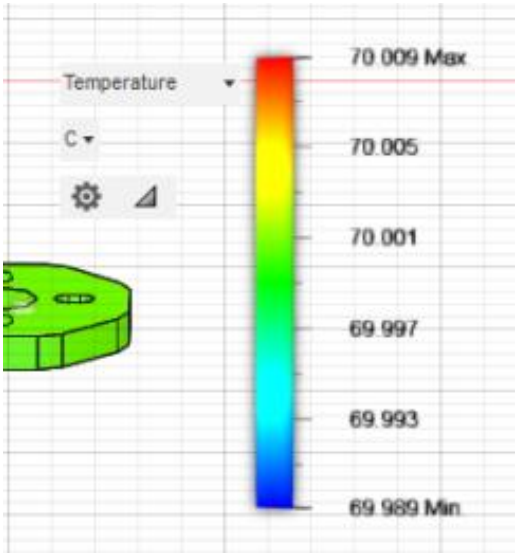


Fig. 2: Thermal analysis [1]
Source: created by the authors.

Furthermore, if we look at the Heat flux (Figure 3), we will see that the temperature is distributed throughout its body.

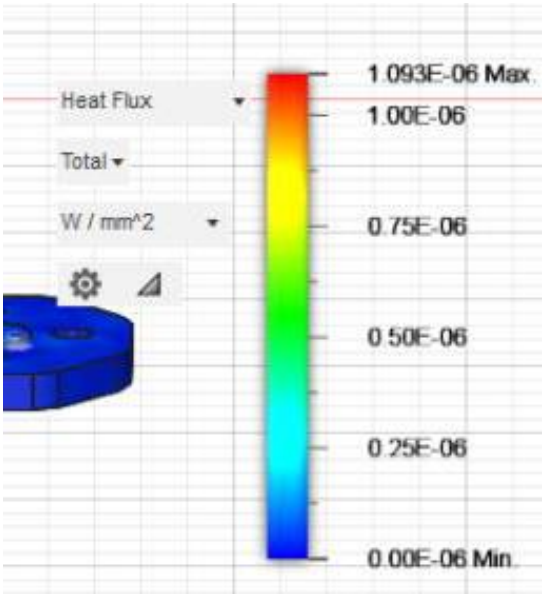


Fig. 3: Heat flux [1]
Source: created by the authors.

3.3 3D-Printing Technologies

There are many 3D-printing technologies, each of which has different characteristics and benefits (see subsection 2.2). Some of them are FFF, FDM, SLS and SLA. FFF and FDM are among the most widespread and widely used technologies for creating objects in three dimensions. FFF technology is characterized by its affordable price and frequent use in prototyping. The biggest difference between FDM and FFF is that FDM has a closed heated chamber, allowing it to use a wider range of materials, including metals, wood, and ceramics. SLS is a 3D-printing technology that uses a laser to fuse powdered materials, resulting in the creation of a 3D entity. The aforementioned technology is often used to produce parts that have strong mechanical characteristics and extended durability. SLA is a 3D-printing technology that uses a liquid, i.e., resin, which is hardened by a laser to build a 3D object. The aforementioned technology has gained a reputation for its extreme precision, making it suitable for producing complex objects.

3.4 Basic 3D-Printing Materials

The materials used in 3D-printing are polymers, because they are flexible, economical and easy to use. Polymer materials consist of materials such as plastics and resins, which are melted and extruded into various shapes. The most widespread method, using polymer materials, is FDM technology. Various types of polymers are used in 3D-printing, each type having its own characteristics. The most commonly used materials are polylactic acid (PLA), polyethylene terephthalate glycol (PETG), thermoplastic polyurethane (TPU) and acrylonitrile-butadiene-styrene (ABS) [12], [13].

3.4.1 Polylactic Acid

PLA is one of the best-known polymer materials and the dominant material in the world of 3D-printing. PLA is a thermoplastic material derived from lactic acid, obtained from starch. This starch is extracted from sugar cane. PLA has a variety of applications in 3D-printing, such as prototyping, biomedical applications, artistic and household objects. Its most important advantages are that it is simple to print, there is a wide variety of colors, it is “biodegradable” and has minimal sensitivity to distortion and shrinkage. However, it also has some disadvantages, such as having relatively weak mechanical properties, being brittle and also not having much resistance to ultraviolet (UV) radiation. The polylactic acid contained in PLA is responsible for its widespread use in FDM technology, due to its lack of toxicity, biocompatibility and low melting point.

3.4.2 Polyethylene Terephthalate Glycol

PETG has become popular. It is a thermoplastic material that is a safe choice for food. PETG is essentially a variant of polyethylene terephthalate (PET), with the difference that PETG also contains glycol. PETG is ideal for mechanical applications and protective parts. This material has the best characteristics of both PLA and ABS. It has good durability and resistance to impact and chemicals, while at the same time, it is flexible and easy to print.

At the same time, it is an ideal choice for outdoor applications, due to its excellent resistance to UV radiation, but it is susceptible to moisture.

3.4.3 Thermoplastic Polyurethane

Thermoplastic polyurethane (TPU), thermoplastic elastomer (TPE) and thermoplastic copolyester (TPC) are flexible polymers, used in 3D-printing. These materials are flexible and durable and have properties similar to those of rubber. They are ideal for use in products such as small automotive parts, phone cases and household appliances that require high flexibility, good wear resistance, chemical resistance and compression. TPU, TPE and TPC are generally very difficult to print without any morphological alteration.

Among them, TPU is one of the most widely used thermoplastic polymers. This material has the elasticity of an elastomer, as well as the rigidity of a plastic. It consists of three main components: polyols, which provide elasticity and flexibility, diisocyanates, which form the bonds that provide structural integrity and strength to the material, and chain agents, which control the hardness and toughness of the polymer. The elasticity of the material, with which it can regain its original shape after deformation, is one of its key properties. This elasticity is due to its chemical structure, which is composed of segments of soft and hard polymer chains. The soft chains provide flexibility and movement, while the hard chains enhance stability and structural integrity. So, with these characteristics we have a material capable of returning to its original form, when the pressure exerted on it is removed. At the same time, TPU is useful for tools that are subject to high stress, such as scratches and other types of damage, due to its durability. In addition, it is resistant to certain chemicals, such as oils, greases, solvents, giving it the ability to be used in applications that come into contact with these substances. Unlike other materials, which at low temperatures lose their elasticity and become hard and brittle, TPU has the ability to maintain its elasticity even at temperatures down to -40 °C. At the same time, it can be colored, but also remain transparent. If we combine its optical clarity and its resistance to damage, we have a material suitable for the production of protective covers.

It is also worth mentioning that in the health sector, TPU has played an important role due to its biocompatibility and resistance to water and humidity. As it is not dangerous to humans, it can be used in applications that come into contact with the human body. Finally, its resistance to water and humidity makes it a useful material for the manufacture of medical instruments, such as tubes [14].

3.4.4 Acrylonitrile-Butadiene-Styrene

A similarly well-known material is ABS that has gained popularity, due to its suitability for applications, such as automotive parts, cable sheaths and phone covers. Thus, it is one of the most widely used thermoplastic polymers, known for its combination of strength and rigidity. The composition of the material consists of three elements: acrylonitrile, butadiene and styrene, each of which provides distinct characteristics to the final product. Acrylonitrile provides chemical resistance and thermal stability, butadiene enhances flexibility and impact resistance, while styrene increases gloss. For example, by increasing the proportion of butadiene in relation to the other components, impact resistance increases. However, this change will also cause a change in other properties. Furthermore, the characteristics of the final product vary, depending on the temperature at which it was molded. That is, if the molding is done at a high temperature, the final product will exhibit better thermal resistance, while conversely, if the molding is done at a low temperature the final product will exhibit better impact resistance. ABS as a thermoplastic polymer has the ability to be heated and reused several times, without losing its properties.

The ability of ABS to be reused makes it a suitable material for mass production, as it facilitates the manufacturing process, such as injection molding and 3D-printing. In addition, one of the main advantages of ABS is its density. This characteristic is useful in applications that require materials that combine durability and reduced weight. A notable example of this is found in the automotive industry, where ABS is used to create lightweight components without sacrificing their durability, thus contributing to reducing vehicle weight, vehicle acceleration and reducing fuel consumption. The durability combined with its density explains why it is widely used to create protective housings, cases and external components of electronic devices. In addition, it is an ideal material for the manufacture of helmets or tools that need protection from abrasion and impacts. Also, acrylonitrile has the ability to heat and cool without deforming, thus providing thermal stability to ABS. This characteristic enables the material to be applied to tools that are subject to heat changes. At the same time, it exhibits excellent chemical resistance to ethanol, alkalis, aqueous acids and vegetable, animal and mineral oils, without deteriorating. ABS does not show high sensitivity to humidity, allowing its use in environments with high humidity levels. For

example, it is used in components intended for use in outdoor environments, such as toys or sports equipment, as well as in structures where contact with water is unavoidable. In addition, it is one of the most economical materials, compared to others that have similar characteristics, such as high performance and durability.

However, ABS has some disadvantages. Among the most important is its sensitivity to ultraviolet radiation, which can cause deterioration of the material over time. In particular, after prolonged exposure to sunlight, the material will discolor and lose its mechanical properties. In addition, although ABS has good thermal stability, it is flammable at high temperatures. In general, it can be used in a temperature range of -20 to 80 °C without losing its mechanical properties. Therefore, ABS is an ideal material for the construction of small drones, because it has the ability to withstand the temperature that can be produced by the motors.

3.4.5 Other Materials

Another Polymer, used in 3D-printing, is polyamide (PA). This material has enormous strength, flexibility and durability, which make it ideal for applications that require durable components, such as tools and mechanical components. However, this material during printing, due to the presence of moisture in the material, can lead to poor adhesion. However, if dried, the mechanical properties can be improved, and the problem with moisture can be eliminated.

Polycarbonate (PC) is one of the most durable polymers, used in 3D-printing. It has enormous temperature resistance, as it can withstand temperatures up to 110 ^{o}C. PC is ideal for applications where durability and strength are essential. The thickness of each layer and the filling parameters for 3D-printing have a great impact on the performance of printed models from this material. For example, models with a smaller layer thickness and a higher density showed greater compression resistance.

High Impact Polystyrene (HIPS) is a material that combines the hardness of polystyrene with the tensile strength of rubber. It is often used as a support material when printing with ABS. HIPS is a reliable filament and is a suitable support material. However, it must be post-processed to be removed.

Another ideal material, used for support, is water-soluble polyvinyl alcohol (PVA). PVA is a suitable support material, although it is sensitive to moisture like PLA and is not easy to process. Despite its negatives, its positives include the fact that it is a biodegradable material and has a low purchase cost.

One of the best-known materials in the automotive industry is acrylonitrile-styrene acrylic acid (ASA). This material has great resistance to environmental conditions. That is, it is resistant to ultraviolet radiation, temperature and is generally characterized by great durability. These characteristics make it an ideal material in various applications, such as components that are exposed to sunlight and extreme weather conditions.

Polypropylene (PP) is durable, flexible and chemically safe for use in food, a property that makes it ideal for food packaging. In addition, PP has strong mechanical properties, high chemical resistance and low friction, properties that make it suitable for objects that must be resistant to chemicals and wear.

Another ideal material for food packaging is called acetal (POM). This material has good resistance to heat and chemicals, but requires a high bed temperature, otherwise the adhesion of the first layer may be disturbed and consequently the printing may fail.

The polycarbonate ABS alloy (PC/ABS) combines the characteristics of ABS and PP, that is, it is a material that is flexible and resistant to high temperatures. However, the PC/ABS alloy is sensitive to moisture and requires high temperatures on the print bed to be printed. In tensile tests, it has been shown that the PC/ABS material has the ability to maintain its shape.

Polymethylmethacrylate (PMMA) is an impact-resistant, transparent and rigid material. It is also known as acrylic or plexiglass. In short, PMMA is brittle, translucent and impact-resistant.

3.5 Construction Stage

To select the appropriate construction materials, they must meet three criteria: to have high impact resistance, to offer durability and to provide elasticity. The material that can be used exclusively for the construction of the frame, arm and legs is ABS. We may choose it because it is used strictly in mechanical processes, but also because of its impact resistance and high rigidity. In addition, the arm protectors must be elastic, flexible and return to their original shape after impact. The material that meets these criteria is TPU. Its high elasticity makes it an excellent material for products that require resistance to deformation. At the same time, it performs well even in difficult conditions, maintaining its elasticity. The ability to absorb shocks makes it an ideal material for tools that are subject to intense mechanical stress, as in our case. For the above reasons, the combination of ABS and TPU offers excellent advantages.

Ultimately, the choice of ABS and TPU materials for printing a small drone is ideal in our case. In particular, ABS offers strength and robustness, without excessively increasing the weight, while TPU offers excellent elasticity and impact resistance. In addition, these materials have the ability to be used in an outdoor environment, since they do not lose their mechanical properties upon contact with water or moisture. In conclusion, the above choice of materials ensures the functionality and durability of a drone.

Regarding printing, we have used Bambu Lab's software to print a drone, as well as its printer, Bambu Lab P1s [15], [16]. Bambu Lab's proprietary software ecosystem (anchored by its open-source slicing application, Bambu Studio, and integrated mobile platforms) exemplifies a highly optimized, project-based workflow designed to streamline additive manufacturing. By combining advanced slicing algorithms, automated calibration profiles, and seamless cloud connectivity, the software minimizes manual user intervention, while maximizing dimensional accuracy, multi-material coordination, and real-time remote telemetry.

The speed of this machine is 500 mm/s and can also print filled materials after upgrades that have been made, such as hardened nozzle and hardened gears. It is also an ideal printer for printing ABS because it has a closed heated printing chamber and a filter, which is necessary for the odors that ABS emits during printing. A 0.4mm nozzle was used to print the frame. No supports were used, only skirts on the four spacers. We chose the printing material to be ABS (Bambu Lab) and the thickness of each layer to be 0.2mm because the thicker the layer, the greater its resistance. It was printed with a 50% infill density, a nozzle temperature of 260 °C for the first layer and 270 °C for the remaining layers, and a Textured PEI plate temperature of 90 °C. We used glue for better adhesion of the spacers.

Arms must be printed with a 0.2mm nozzle, because if a 0.4mm nozzle is used, gaps appear in the structure. However, using a nozzle with a diameter of 0.2mm avoids the appearance of these gaps. We chose ABS (Bambu Lab) as the printing material and the thickness of each layer to be 0.1mm. It was printed with 50% infill density, nozzle temperature in the first layer 260°C and in the remaining layers 270°C, Textured PEI plate temperature at 90 °C. Legs must be printed using supports, because there are surfaces that are in the air. The supports should be tree slim type, as they are easier to detach from a model. These supports will be placed automatically by the program. We choose the nozzle to be 0.4mm, the printing material to be ABS (Bambu Lab) and the thickness of each layer to be 0.2mm. It was printed with a filling density of 50% (infill density), Grid filling pattern, monotonic top surface pattern, nozzle temperature in the first layer 260 °C and in the remaining layers 270 °C, Textured PEI plate temperature at 90 °C. For printing covers, we choose the nozzle to be 0.4mm, the printing material to be TPU 95A (Bambu Lab) and the thickness of each layer to be 0.2mm. They were printed with a filling density of 50% (infill density), Grid filling pattern, monotonic top surface pattern, nozzle temperature 230°C, plate temperature 35°C. We used glue to ensure better adhesion to the first layer.

In total, our modelled drone took 15 hours and 26 minutes to be printed. Its total final weight is 58.01g in ABS, while in TPU it is 25.64g, and the total cost of materials was 3.10 euros.

4 Conclusion

During the development, Fusion 360 helps in the precise design of a drone, while 3D printing facilitates its implementation, with great precision and speed. Through static stress simulation, it can be found that a model may present some deformations, due to the forces exerted by the motors. Then, improvements can be made to the arms, to avoid deformations that could lead to collisions of the propellers with the vessel. After the improvements, it should be checked whether the deformations have been eliminated. With the thermal analysis, it can be confirmed that ABS, a material that is resistant to the temperatures produced by the motors, can be used to build a drone. When choosing the construction materials, ABS and TPU are ideal materials for usage, as they meet the selection criteria. TPU is chosen based on its elasticity, wear resistance, and ability to return to its original shape. At the same time, ABS is chosen for its strength and durability. However, an important role in their selection is also the resistance they demonstrate in the external environment. Finally, it has been confirmed that CAD software and 3D printing represent reliable methods for the design and construction of functional and durable drones.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the

accuracy, integrity, and final content of the publication.

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