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DRONE TECHNOLOGY FOR HOBBY OR RECREATIONAL PURPOSES

DRONY/ BEZPILOTNÍ LETOUNY POUŽÍVANÉ V OBLASTI ZÁJMOVÉ A REKREAČNÍ

BACHELOR’S THESIS
BAKALÁŘSKÁ PRÁCE

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Drone Technology for Hobby or Recreational Purposes

INSTRUCTION:

Make an overview of different types of drones (Unmanned Aerial Vehicles). Describe the technology and the specific areas in which they are used. Focus especially on the description of specific types of drones used for recreational purposes (e.g. FPV / First Person View drones).

RECOMMENDED LITERATURE:

DeFrangesco, R. & DeFrangesco, S. (2022). The Big Book of Drones. Boca Raton: CRC Press. Taylor & Frances Group, LLC

Austin, R. (2010). Unmanned Aircraft Systems: UAVs Design, Development and Deployment. Chichester: John Wiley & Sons, Ltd.

Juniper, A. (2018). The Complete Guide to Drones. Extended 2nd Edition. London: Octopus Publishing Group

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Abstract

This bachelor's thesis provides a list of drone technology used today and its main aim is to introduce drones for leisure activities. The first chapter divides drones according to their design, size and type of propulsion. The further chapter focuses on hobby and recreational drones, specifically the aircraft of the technology company DJI, FPV drones and the entertainment industry. Subsequently, the thesis mentions the areas where drones are used, such as the military, agriculture and building inspections. Finally, it goes through European drone legislation and is concluded with a chapter about drone accidents and ways to prevent them.

Keywords

UAVs, Drones for recreational purposes, RC aircraft, Drone classification, FPV

Abstrakt

Tato bakalářská práce nabízí přehled všech dronů používaných v současnosti, hlavním cílem je ovšem představit drony pro volnočasové aktivity. První kapitola dělí letouny podle jejich konstrukce, velikosti a typu pohonu. Dále se práce zaměřuje na drony hobby a rekreační, konkrétně na stroje technologické společnosti DJI, FPV letouny a na zábavní průmysl. Následně jsou zmíněny oblasti, ve kterých jsou drony využívány, například armáda, zemědělství nebo revize budov. Poté pojednává o evropské legislativě související s drony a práci uzavírá kapitola o nehodách dronů a možnostech, jak jim předejít.

Klíčová slova

Bezpilotní letouny, drony používané v rekreační oblasti, RC modely, dělení dronů, FPV

Rozšířený abstrakt

Tato bakalářská práce nabízí přehled všech dronů používaných v současnosti, hlavním cílem je ovšem představit drony pro volnočasové aktivity. Použití dronů je pro lidstvo přínosné v mnoha směrech, nahrazuje člověka v různých rizikových situacích a povoláních, šetří čas ve specifických zaměstnáních a poskytuje aktivní odpočinek pro všechny věkové kategorie.

První kapitola dělí bezpilotní letouny do tří základních skupin. V první skupině jsou drony tříděné podle technologie využívané k pohybu, lze se v ní dozvědět bližší informace o jedno a více rotorových dronech a jejich principu fungování. Navazuje odstavec o dronech konstruovaných s pevným křídlem, které mohou na první pohled připomínat letadlo. Toto křídlo slouží především k prodloužení délky doletu. Obsahem třetí skupiny jsou drony kombinující obě zmíněné technologie a to, jak je proces letu zajištěn.

Následující podkapitola srovnává rozměry a hmotnosti dronů, společně s nejvyšší možnou vzdáleností doletu a maximální nosností. Podkapitola je rozdělena na čtyři úseky podle parametrů bezpilotních letounů, leč určité nekonvenční stroje vyrobené na zakázku by mohly spadat pod více z těchto kategorií zároveň. Práce uvádí příklady dronů užívaných v praxi armádou, laiky, či profesionálními fotografy. Klasifikaci doplňuje členění dle druhu pohonu. Převážnou část trhu zastupují drony s elektromotory, tedy poháněné bateriemi. Pro dlouhý dolet jsou využívány neekologické spalovací motory. O aktuální problematiku fosilních paliv se zajímají už také vývojáři dronů a firmy z celého světa soupeří v přivedení dronů poháněných vodíkem a fotovoltaikou k dokonalosti.

Druhá kapitola se zabývá drony pro hobby, rekreaci a zábavní průmysl. Toto je stěžejní část celé práce, zahrnuje tedy nejvíce informací, detailů a novinek ze světa dronů. V první sekci jsou uvedeny drony určené pro fotografování a video. Lídrem je čínská společnost DJI, která má s drony mnohaletou zkušenost a v průběhu let vyvinula mnoho revolučních funkcí a senzorů, které u hobby dronů převládají dodnes. Kromě DJI jsou zde i bezpilotní letouny jiných společností, které dokáží čínskému gigantovi se svými modely konkurovat.

Následně se práce zaměřuje na specifika FPV hobby dronů a používaného příslušenství. Jedná se o RC ovladač a brýle s virtuální realitou pro přenos obrazu z kamery dronu v reálném čase. Nejznámější FPV brýle vyrábí firma FATSHARK, ale existují i jiné

alternativy. FPV brýle jsou taky schopny nahrávat obraz, který pilot vidí. Důležitým hlediskem, které definuje parametry dronů, je jejich využití. Jiné požadavky jsou kladeny na freestyle drony a drony kinematografické. Zatímco první musejí být rychlé a obratné, kinematografické slouží k natáčení obzvlášť stabilních záběrů, z tohoto důvodu je tolerována vyšší hmotnost a omezená flexibilita.

Část o zábavním průmyslu je věnována světelným show dronů, jež jsou šetrné k životnímu prostředí a tiché v porovnání s tradičními ohňostroji. Dokáží vyobrazit cokoliv a za použití libovolných barev. Netradiční záběry pro fanoušky poskytují drony i v oblasti sportu. Dron plní funkci přídavné kamery, která je schopna v aktuálním čase přesně kopírovat pohyb sportovce při výkonu. Na sportovních a kulturních akcích zajišťují bezpečnost, pomáhají záchranářům a pořadatelům rychle reagovat na krizové situace. Atraktivní závody dronů mají mnoho příznivců. Láká je různorodost tratí, překážek a pravidel. Ta jsou vysvětlena s odkazem na organizátora závodů DCL. Drony jsou též používány k rybaření a pozorování mořské fauny nebo průzkumu dna.

Značná část uživatelů nachází seberealizaci nejen v létaní s drony, ale zejména v samotném navrhování a kompletaci vlastních dronů ze zakoupených dílů. Podkapitola DIY nejprve udává jaké dovednosti je třeba mít k sestrojení dronu, představuje jednotlivé komponenty, ze kterých se dron skládá. Vysvětluje jejich funkci, prezentuje parametry nejběžněji používaných komponentů a doporučuje, čím se při výběru řídit. Text doprovází vyobrazení podstatných součástí, mezi kterými je i popis bezkartáčových stejnosměrných elektromotorů společně s jejich vnitřní stavbou. Na ně navazuje popis sestavení dronu krok za krokem, až po konečnou instalaci softwaru a samotné spárování s příslušenstvím, po kterém je možné s dronem poprvé vzlétnout.

Třetí kapitola se věnuje dalším oblastem, ve kterých se drony uplatňují, počínaje armádou a zemědělstvím konče. Zprvu pojednává o armádních dronech, které byly původně určené pouze ke sledování, ale průběhem času se začaly vyzbrojovat raketami a podobnou municí pro plnění bojových úkolů a misí. Také jsou zde zmíněny příklady konkrétních letounů využívaných v současné době a příslušenství pro drony představující moderní senzory a radary. Následně je objasněna důležitost dronů v zemědělství a jak mohou člověku ulehčit práci. Podkapitola rozebírá, jak díky moderním technologiím monitorovat zdraví plodin pomocí vegetačního indexu.

Následuje využití dronů k inzerci v realitním byznysu nebo leteckém 3D mapování, ke kterému se často používají letouny s takzvaným pevným křídlem. Mimo jiné, drony jsou též excelentním zařízením pro inspekci a údržbu průmyslových staveb. Tyto objekty jsou špatně dostupné a kontrola je obvykle prováděna ve výškách několika metrů. Se sondou mohou drony jednoduše vystoupat do potřebné výšky a usnadnit nutné úkony testování funkčnosti a zajištění bezpečnosti. Existují společnosti nabízející doručovaní zboží dronem až k zákazníkovi domů, zásilka je dodána do třiceti minut po vytvoření objednávky. Obdobné společnosti letecky doručují například léky do nemocnic.

Čtvrtá kapitola shrnuje platná nařízení a zákony vydané Agenturou Evropské unie pro bezpečnost letectví EASA, hobby drony jsou zařazeny do jedné z podskupin A1, A2 nebo A3. Každá z nich zákonem určuje, jak mohou piloti s daným dronem zacházet a co je nutné provést k jejich legálnímu provozu na území EU. Nadto kapitola informuje o připravovaných změnách s účinností od prvního ledna roku 2024. Drony budou muset být označeny štítkem nesoucí název kategorie, do které patří. Kategorie jsou značeny C0 až C4 a jsou určeny rozměry a hmotností daného letounu. Na konci této části je věnován prostor také povinnosti registrace a zónám v České republice, ve kterých je bez povolení zakázáno drony provozovat. Odstavec doplňuje názorná mapa.

Celou práci uzavírá kapitola nazvaná Havárie dronů. Vysvětluje, jak u volnočasových dronů dochází k častým haváriím v důsledku rušení signálu. Je zde objasněno, proč je signál dronů rušen a čeho by se měli uživatelé vyvarovat, aby těmto nežádoucím vlivům zamezili. Příklad hovoří o nehodě z roku 2015, kdy dron ztratil signál a havaroval na pozemku Bílého domu. Běžný je také střet s dravci. Predátoři často vidí drony jako svoji kořist a útočí na ně, jindy pilot špatně vyhodnotí situaci a vlétne mezi hejno ptáků. V obou případech je doporučeno zkontrolovat okolí ještě před tím, než dron vzlétne. Mnohdy je důvodem havárie i vybití baterií, kdy dron ztrácí schopnost letu a je zapotřebí reagovat rychle, aby nedošlo k pádu a fatálním škodám. Lze tomu předejít průběžnou kontrolou stavu baterie během letu. Závěrem je uvedeno, na jaké instituce je potřeba se obrátit v případě vážného incidentu dronu. Pod kapitolou je v tabulce uveden přehled četnosti havárií a typů úrazů po střetu dronu s člověkem. Data se vztahují k letům 2015 až 2020.

ŠIBOR, Vojtěch. *Drony/bezpilotní letouny používané v oblasti zájmové a rekreační.* Brno, 2023. Dostupné také z: https://www.vutbr.cz/studenti/zav-prace/detail/151493. Bakalářská práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav jazyků. Vedoucí práce Mgr. Šárka Rujbrová.

Prohlášení

Prohlašuji, že svou bakalářskou práci na téma *Drony/bezpilotní letouny používané v oblasti zájmové a rekreační* jsem vypracoval samostatně pod vedením vedoucí bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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V Brně dne …………   …………..………………

Vojtěch Šibor

Poděkování

Děkuji paní magistře Šárce Rujbrové za laskavé vedení bakalářské práce, současně oceňuji vstřícnost v plánování konzultací a pomoc i mimo vyučovací dny.

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Introduction

In recent years, the use of drones is at rapid growth. They are sufficient for tasks that are too risky for people in terms of height, temperature and environment, such as radiation. Apart from sparing people's lives, drones help to save money and time since the preparation and operation of a drone usually does not require more than two employees and it can fly rapidly long distances. The term "drone" can be understood as a vehicle that does not need an aircrew to be controlled. That is why drones are often referred to as UAVs. Drones are mainly controlled remotely. Even though, in some cases, they are pre-programmed to perform a specific task.

Drones have been in use since the last century. Nevertheless, their design was different from what we are used to now, mainly in the form of balloons. As can be assumed, the first ideas were implemented in the military, but the public was unaware of it because research and testing started in secrecy. The army frequently aims to invent weapons. Nonetheless, the drones' purpose was to map enemy territory, oversee and spy. After that, there was a tendency for remote control. The experiments included the use of technology by famous inventors of the time. Since then, drones have become far more sophisticated. Nowadays, drones dispose of radio control with negligible latency, GPS and thermal cameras. This equipment used to be too expensive to be owned by services and businesses.

However, as electrical circuits cost less to produce and offer higher performance, companies can now afford to use drones in their field. In the end, purchasing a drone and energizing batteries is less expensive than employing people. Employees can be replaced in agriculture, transport and monitoring gas leakage or radiation. The most significant representation of the commercial sector is the area of cinematography. In the last decade, drones started to be affordable to the point where even the public uses them for entertainment and recreational purposes, for example, drones with and without a camera, racing and drone swarm light shows, which are further precisely discussed in this thesis.

1 Aircraft Classification

Every field has a diverse approach to what a drone should be able to achieve. Therefore, vehicles have characteristic properties for different purposes. Among the available sources, one can find various categories into which drones are divided. This chapter contains the three most important of them: types of design, size classification and sources of power.

1.1 Types of Drones

Drone technology has been under research for the last century. Thus, many concepts of drones were invented. The word “type” can be understood as how propellers are attached to it and whether it has a wing. This description of an aircraft is essential because it determines how a drone takes off or its maneuverability in the air.

1.1.1 Rotary Blade

Rotary blade type splits into two groups: multi-rotor and single-rotor. It determines the complexity, drone’s power consumption and its final cost. As a result, each group has fields of use where their design is beneficial. Even though the realization of multi-rotor was not possible until processors were invented, both technologies are nowadays considerably developed.

1.1.1.1 Single-rotor

Vehicles such as helicopters have one propeller on the top and a smaller one on its tail, which does not count for this category since its function is to prevent the helicopter from spinning. The propeller comprises wings that are called blades. The proportion of blades is equal to the strength of the lifting power. However, it consumes more fuel. Although full-sized helicopters can have up to seven blades, drones are equipped with two or three blades because they tend to be lightweight; additional power is not needed and the production cost is reasonable.

As Harris & Homer (2022) explain, the assembly of rotating blades is called the main rotor and individual blades are connected to a swash plate. A helicopter has to stand on a flat platform while taking off and spin the main rotor. At the same time, the swash plate is necessary for direct, backward or sideway flight. Leaning the swash plate tilts the blades, lifting the helicopter and simultaneously creating a thrust into the desired direction—as illustrated in Figure 1. Drones for commercial applications use the same principle as ordinary helicopters. In contrast, toy drones have such inexpensive parts that two pairs of bi-blade propellers are used instead. The upper pair determines the direction and the bottom pair alters altitude or maintains the drone in the air.

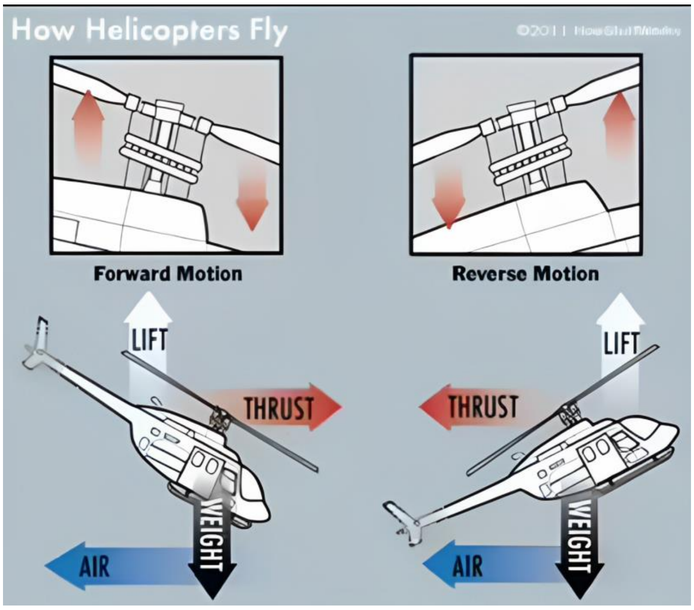

Figure 1. Movement of swash plate for flight direction change. Reprinted from Harris & Homer (2022).

1.1.1.2 Multi-rotor

The technology of three, four or more rotors used by a copter is what many people associate with the word “drone.” Starting with a quadcopter—out of the four motors, two spin clockwise and the other two counter-clockwise. The pairs are assigned to diagonal axes, as shown in Figure 2. Propellers have from two to six blades that can be fixed or foldable. It is difficult to synchronize all the motors to make an aircraft nearly stable in the air. The main parts of its operation are the flight controller and electronic speed controller. The flight controller is an electronic circuit that functions as a processor, determining the motors’ speed. The system of control is indirect because the flight controller sends data. These data are collected by a speed controller that individually applies suitable voltage to the motors.

The electronic speed controller can be on one board or each motor has its speed controller. Speed controller as one part has many advantages unless defects occur. As a result, the whole board has to be replaced. Furthermore, the speed precision is significant for tilting the drone into a direction, as previously mentioned in the subchapter about single-rotor vehicles. The difference is that multiple-rotor UAVs can tilt themselves by raising the speed of two motors—the pair on the opposite side of the direction of flight. Concerning the rotors, drones use brushless or brushed motors.

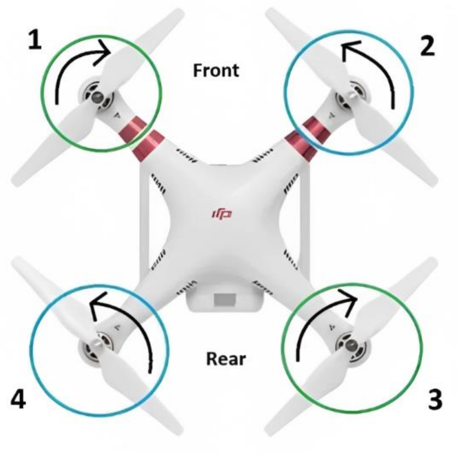

Figure 2. Example of propeller rotation. Reprinted from Corrigan (2020).

1.1.2 Fixed-wing

Wings allow UAVs to fly with lower energy consumption; consequently, they can reach longer distances than the rotary blade type. Another difference is that fixed-wing drones tend to be larger. Although size brings advantages, the drone and spare parts prices are higher. It also requires a runway to take off. As for the construction, the most common design is a drone with one propeller at the back of its tail, facing the opposite way of the flight, thus pushing the vehicle forward. The other type of technology resembles airplanes. These drones have propellers facing forward, which are attached to wings. Due to the structure, turning must be fluent, yet there are many forms of utilization in the military and commercial sector (Kreps, 2016).

1.1.3 Hybrid Drones

This technology combines the two previous types, which means it has all the advantages mentioned. Hybrids do not require runways, can hover precisely in one place and can fly long distances due to their wings. The difficulty for the engineers, which has to be addressed, is the transition from vertical take-off to direct flight with the assistance of wings. The same applies to the landing of the aircraft. Austin (2010) uses the terms "hover flight" and "cruise flight" to differentiate the two distinctive ways of flying. As he describes, there are four approaches to the design of hybrid drones. Tilt rotor and tilt wing designs are both based on the same idea. At the take-off, rotors face up and then reposition to face forward. As for the tilt-rotor, only the motor is the part that moves ninety degrees, whereas the second design moves the whole wing, as can be seen in Figure 3. Regarding functionality, the tilt-rotor performs better in hover flight and the tilt-wing is more effective in cruise flight.

The following design is tilt-wing-body aircraft; this one has the slightest application probability because its function depends on tilting the vehicle. It requires high precision of lift loading ratio, which expresses the transition between hover and cruise flight. Additionally, it demands more engine power, increasing the cost. The last one is ducted fan technology, which is also challenging to implement. Each fan needs two contra-rotating elements to minimize the body's rotation. Unlike the other designs, ducted fans point to the ground because they create lift, which drives the drone. This mechanism is also depicted in Figure 3.

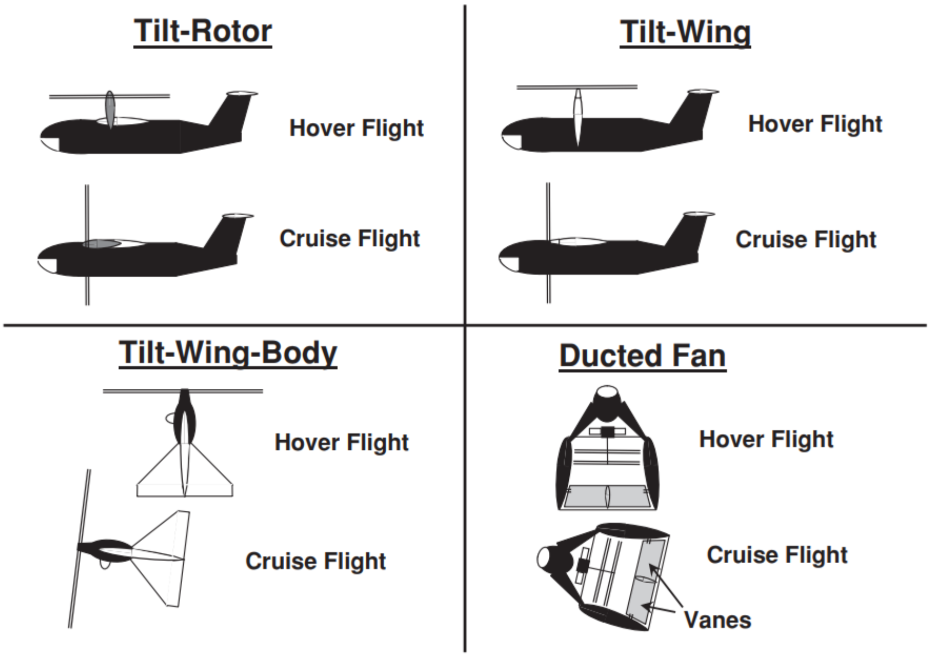

Figure 3. Hybrid aircraft configurations. Reprinted from Austin (2010).

1.2 Size Category

Dimensions of the aircraft determine where it can fly, how much load it can withstand and the ability to manage long-range flights. This subchapter splits UAVs into four groups, even though some drones are made for unconventional purposes and may overlap the groups.

1.2.1 Nano Drones

The size of nano drones is measured in dozens of centimetres; as a general rule, this category of drones can fit into a palm since their maximum length is 15 cm. According to Um (2019), these drones use significantly reduced frameworks and some designs utilize insect flight methods. That type of UAVs is called a robotic insect and can include the ability to crawl on walls or ceilings. They are portable and their flight time is between five to ten minutes at an altitude of 30 meters. For example, Um mentions Dragonfly, Hummingbird and Roachbot. Nano drones are also widely used in the military, specifically the Black Hornet, which excels in surveillance and observation. Black Hornet weighs 33 grams, Vojáček (2022) says. The setup includes a docking station, a touchscreen controller and two drones. They are equipped with two standard cameras and one thermal camera. Thanks to their convenient small and silent design, military units do not have to worry about revealing themselves. Even transportation is undemanding as drones fit in a backpack. Currently, Ukrainian infantry uses these UAVs to scout an area up to two kilometres without risking soldiers’ lives.

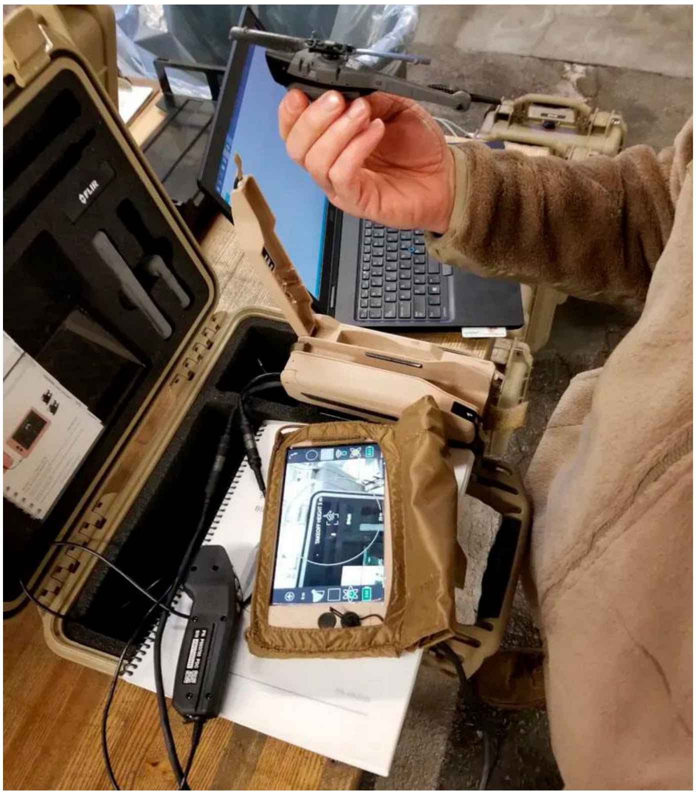

Figure 4. Black Hornet and additional equipment. Reprinted from Trevithick (2020).

1.2.2 Small Drones

According to JOUAV (2022), the diameter is up to 300 mm, the weight is between 200-1000 grams and the flight time is up to one hour. The more robust models can carry payloads ranging from 150 to 270 grams. Small drones traditionally include entertainment drones, such as DJI (brand popular in photography), FPV and drones used in sports. Nesnídal (2017) interprets that these sports drones use autonomous control technology, as the name implies: they can follow, for example, a skier going down a slope or a cyclist without the help of a human. They can also fly around a person and take selfies.

1.2.3 Medium-size Drones

Their length is 300-1200 mm and they weigh up to 20 kg. Drones modified for use in agriculture, such as JOYANCE 16 and DJI Agras T16, can hold 16 liters of pesticide liquid. Surveillance drones of this type do not have the capabilities to carry heavy loads. On the other hand, their flight range is up to six hours, for instance, drone CGT50-VTOL (JOUAV, 2022). The last large group to be mentioned are drones used in filmmaking, the main advantage being that they can get the same video recording as a helicopter but for a more reasonable price. DJI Matrice 600 Pro can be loaded with six kilograms, enough to carry a high-quality cinema camera and additionally, it can reach a speed of 40 mph (Belgrave & De Groot, 2022).

1.2.4 Large Drones

JOUAV (2022) states that large drones are considered aircraft with lengths over 1200 mm and weight of more than 160 kg. Their payload is more than 1000 kg and specific models can fly more than 664 km while their flight time is over 24 hours. Areas of use are weather tracking, geographic mapping and surveillance. Global Hawk and MQ-1 Predator are well-known long-range UAVs used in the military. Such aircraft are accustomed to carrying a heavy payload over long distances; apart from carrying the cargo, it also has to withstand the weight of fuel, which is the reason for the large, fixed wings. Large meteorological drones, particularly FVR-55, can fly at high altitudes and have forecasting abilities for civil use.

1.3 Power Sources

Advancements in the industry allowed the usage of various power sources, such as batteries, gasoline, hydrogen cells and photovoltaic power. Still, companies are competing to bring innovations to the market. Batteries are the best option for most uses since they are affordable. However, NASA and the military have a budget that enables them to challenge the idea of alternative power sources.

1.3.1 Batteries

The technology is mainly used for drones due to its convenient combination of light weight and fast acceleration. As explained by Juniper (2018), UAVs use Lithium-Ion Polymer (also known as "LiPo") batteries. Each battery pack consists of one or more "cells"; every cell produces nominal 3.7 volts of power and can be charged up to 4.2 volts, but if the battery is in bad condition, it might be risky. If the pack has more than one cell, four cells, for example, it will produce 14.8 volts (3.7 x 4). Such a battery is called a "4S" and its scheme is depicted in Figure 5. The amount of power that a LiPo can contain is measured in mAh (milliamp hours).

The power density also rises with the weight. Therefore, while designing a drone, the aim is to use a battery of the highest capacity that is still relatively light for a particular drone. Further, Juniper highlights the discharge rate; it is the speed of the current that can flow from the battery. Two numbers on the battery specified by the manufacturer give this parameter. For example, for values 25C/35C, the lower number indicates the constant flow rate, whereas the higher number states the "bust rate," thus high power output, which can be sustained for just a few seconds (usually used during take-off). LiPos containing more than one cell need to be charged by a balance charger because it monitors the state of each cell. This type of connection is referred to as a "balance plug" or "balance tap." Batteries should always be charged in ventilated and non-flammable places and stored half-charged to keep them functional for longer.

LiPo batteries can be charged with a higher voltage than is specified by the manufacturer, although the customer takes responsibility for any accidents. When the batteries are in perfect condition, they can be charged with two to three times the specified current. It is also advised to keep the batteries in line of sight and not let them be unattended. Even slightly damaged LiPos can catch on fire while charging with increased current. Company DJI has a solution for unsafe charging. Their products are shipped with a charger that does not have adjustable current output. Also, batteries have an easy-to-use case with a built-in power meter, automatically draining the battery to the safest possible level after two weeks. Regarding the military, electric-powered drones used nowadays are Desert Hawk and Skylight.

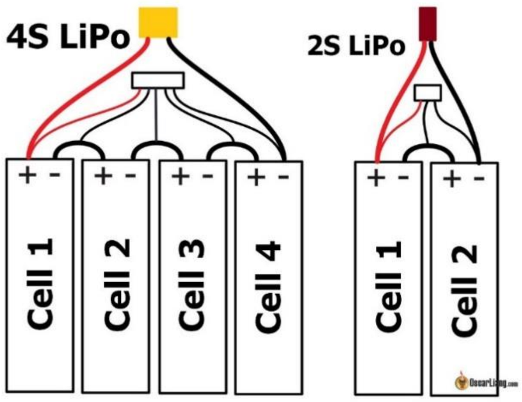

Figure 5. Battery Cell Count. Reprinted from Liang (2019).

1.3.2 Gasoline

Petrol, Kerosene, Methanol, Ethanol and LPG Propane can power a UAV. They can provide over 20 hours of flight time and the drone becomes lighter as the fuel is depleted, increasing its range. Compared with LiPos, gasoline has 48x the mass density and 13x the volumetric density (Team DRONEII, 2017). As Jiya, et al. (2020) explain, combustion engines compose of a combustion chamber, pistons, fuel injectors, intake valve and exhaust valve. A two-stroke engine uses four stages: intake, compression, power and exhaust. Diesel can also be used as a fuel for drones; its difference from petrol is that it does not need spark plugs since it is self-igniting under high pressure. On the other hand, diesel has to be heated up during cold weather before being injected into the combustion chamber.

Another way of using gasoline is a rotary engine. The stator is a crankshaft; the engine housing and the cylinders create a rotor, where the cylinders are constructed in a radial configuration, as shown in Figure 6. The fuel is mixed with air and then dispensed by a crankshaft through cylinder slots or valves in cylinder heads, while cooling allows high pressure (Cwojdziński & Adamski, 2014). This technology used to be unreliable in the past, but now it is becoming more acceptable, Austin (2010) argues. Initially, there were problems with casing breaking down; for example, Canadair UAV used a rotary engine, though it was eventually replaced with a turbo-shaft engine. Currently, rotary engines are used by Israeli Hermes 180 and Hermes 450 UAV.

The last type to be addressed is a Gas-turbine engine. Free-power turbines (FPT) are primarily used, where a shaft of the compressor/turbine set (which generates the power) is separated from the output shaft. This connection prevents the compressor from slowing down when output demand increases; therefore, fuel injection results in rapid acceleration. Another technology is a turbo-fan unit, a combination of turbo-jet and turbo-shaft engines. Part of the energy generated is extracted as a jet and the rest is converted to mechanical energy to drive a fan. The turbo-jet engine is adequate for higher-speed aircraft, a turbo-fan is beneficial for intermediate-speed aircraft and a turbo-shaft is most appropriate for slower aircraft. For this reason, the Global Hawk HALE UAV uses a turbo-fan and the Predator B MALE UAV uses a turbo-shaft engine driving a propeller (Austin, 2010).

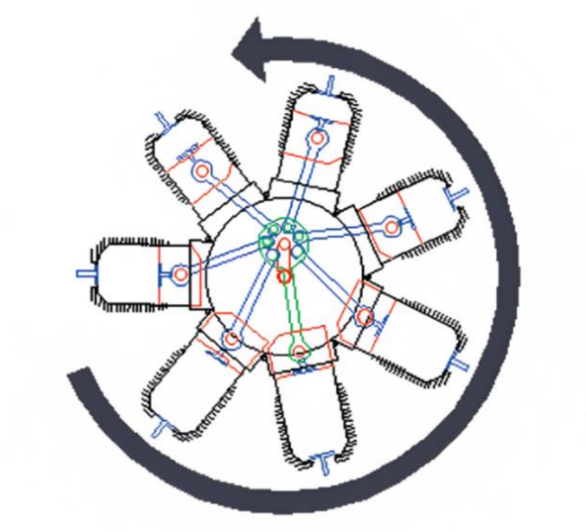

Figure 6. Radial-type engine. Reprinted from Cwojdziński & Adamski (2014).

1.3.3 Hydrogen

This technology works based on catalysis, separating electrons and protons of hydrogen as they go from anode to cathode, forcing them to create an electronic circuit before they can combine with oxygen (Austin, 2010). The downside of hydrogen fuel cells is that the production is expensive. Moreover, hydrogen has to be stored cryogenically as a liquid. Apart from these two disadvantages, it is an impressive power source due to its energy density, no direct pollution, silent operation and efficiency better than combustion engines. In 2019, South Korean company MetaVista recorded the longest-ever multirotor flight, for over 12 hours of hovering in the air, using a 6-liter liquid hydrogen cylinder (Blain, 2020).

1.3.4 Photovoltaic Cells

As for history, NASA (in 2001) achieved an unofficial world-record altitude of 96,864 feet and flight for more than 40 minutes above 96,000 feet with the Helios Prototype flying wing, shown in Figure 7 (Gibbs, 2017). Photovoltaic cells can reach a power ratio of about 175W/m^2. Power from the sun is a clean source of energy and since these drones are equipped with lightweight batteries that are charged by daylight, they can fly even at night. Zephyr S, a photovoltaic hybrid system, could fly for more than 25 days in 2018. Nevertheless, photovoltaic drones are highly dependent on the weather since overcast weather may cause problems with charging (Shearwater, 2019).

Figure 7. Helios Prototype flying wing. Reprinted from Gibbs (2017).

2 Hobby, Recreation and Entertainment

This chapter aims to clarify the significance of UAVs in the modern world and provide a comprehensive list of applications in entertainment. Besides that, specific examples describe its properties, design and functions. Although these drones are primarily lightweight and small-scale, this group has substantial safety precautions since children and non-professionals use them. Although, in some cases, one can encounter difficulties with battery charging or damage being done by propellers when the handling does not comply with the manufacturer's recommendations.

2.1 Photography

All drones in the photography are very similar to each other. The pilot only needs a drone, controller and a phone, which is used as a display. Nowadays, drones have automatic stabilization, hence flying is simple and can be learned in half an hour. The remote control is the same for small and medium-size aircraft. What makes the drastic difference in cost is the quality of a camera, engine performance and, in some cases, features such as sensors of surroundings.

2.1.1 DJI Drones

Undeniably, the Chinese company DJI came up with most of the innovations and shaped the entertainment drones as they are known now. In 2013, was launched the first drone of the Phantom series. According to Smith (2016), it was capable of approximately 10 minutes of flight with a GoPro camera fixed to it; far from the technology used now, but back then, it was revolutionary. Many improved models followed that until Phantom 3 Professional, which offered improved camera stabilization with a three-axis gimbal for smooth footage and 4K video recording. It was something new on the market. Additionally, it had downward-facing sensors and navigation from Glonass satellites allowing one to see the image on the phone via the Go app. Finally, Phantom 4 (and its enhanced models) had more powerful motors, forward-facing sensors and object avoidance feature.

In 2016, DJI also introduced another series of their drones. The focus of these drones was to make them more compact and space-saving; Phantoms were bulky, whereas the new DJI Mavic Pro had foldable arms and even foldable propellers, making it portable and easy to take anywhere. Successors DJI Mavic 2 Pro, DJI Mavic 2 Zoom and DJI Mavic 3 are upgraded models with better camera sensors, lower noise and better resolution. DJI Spark is smaller, with non-foldable arms and camera recording in full HD. The intention was to manufacture an affordable and quality drone. One of the ideas was to control the drone only using a phone, though customers did not find it properly functional and rather bought the package with the controller included for a higher price. Some enthusiasts liked it. Nonetheless, two years after its release, production was stopped and DJI has never came back to this concept. Instead, DJI returned to completely foldable drones. DJI Mavic Air of medium size and DJI Mavic Mini of small size are both copying the parameters of the regular Mavic Series (O'Hare International Aviation, 2020).

2.1.2 Other Drones for Photography

Although DJI has been in the market for the longest, has a lot of experience and budget for development, there are other drones to be mentioned, which are better in terms of price/performance than DJI. Autel EVO Lite + is in a price range of DJI's Air 2 S, though half of its parameters are comparable to Mavic 3, which is one-third more expensive. Jeven Dovey (2022) tested all three drones and concluded that Autel EVO Lite + could fly 6 minutes (34 minutes in total) longer than the other two competitors. Additionally, it can film in 6K resolution, a one-inch sensor and lossless zoom. Its disadvantages are that controller does not charge the phone, video transmission is darker on screen than actual recorded footage and there is no LOG profile (video has strong contrast, which is hard to color grade).

Moreover, Parrot Anafi 4K HDR drone is another powerful aircraft. Despite being in the lower-budget category, it has features like higher-priced DJI drones: lossless zoom, 4K video recording in HDR, 25 minutes of flight and 100 Mbps bitrate. The camera is mounted on two axis gimbal and can move 90 degrees upwards, making a distinctive filming style possible. The package comes with the quadcopter, case, controller, spare parts, charger, battery and 16 GB micro SD card. It is considerably more silent than the Mavic series from DJI and due to its unique design, the vehicle is portable (Posea, 2019).

2.2 FPV Hobby

The abbreviation stands for First Person View since FPV drones have a video transmitter broadcasting a signal to goggles, allowing the person flying the drone to see the surroundings in real-time as the person was piloting the drone from a cockpit. This hobby is for everyone because there are options for beginners, intermediate and advanced RC pilots. Goggles are not the only difference from the other drones. What distinguishes FPV is the acro mode (acrobatic mode). The RC pilot can disable automatic stabilization systems that prevent drones from tilting too much, allowing them to do 360° rotations (as illustrated in Figure 8). Due to this mobility, controlling drones is demanding and requires much practice. However, people are willing to undergo this slow learning phase since freedom of flight and acrobatic tricks are very rewarding.

A combination of maneuvering abilities, FPV goggles and the small size of the drones enable the RC pilots to fly through narrow places where a human would not even fit. That is the reason why is flying in abandoned buildings a popular activity. The small-scale drone can explore everywhere and without risking the owner's life. Apart from acro quads (drones flown in acrobatic mode), there are cinematic FPV drones, basically the same drones but less often flown in acro mode. They also use an enclosed frame to protect the propellers.

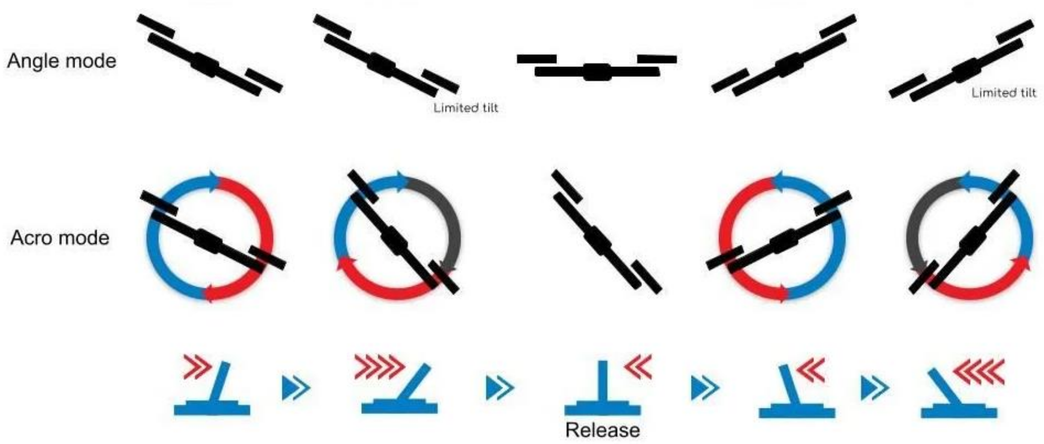

Figure 8. Angle and acro mode differences. Reprinted from https://myracingdrone.com/betaflight-a-guide-to-useful-modes/

2.2.1 FPV Drones

For beginners, it is convenient to buy a starter set. It will include a micro drone, box goggles, RC transmitter, batteries, charger, spare parts (propellers and prop removal tool) and a portable storage bag. These micro drones are called "tiny whoops." They are suitable for flying indoors because their frame is stretched around propellers, making crashes cause no harm to people or furniture. As a power source, tiny whoops use 1S and 2S batteries and the motor can develop high speed because drones are lightweight, yet motors are too weak to cause any damage. Recommendable companies with quality starter sets are BetaFPV and Emax.

For intermediate and advanced RC pilots, there are various options to choose from. Generally, hobbyists have one pair of goggles and one RC transmitter that can connect to numerous aircraft they own. Therefore, FPV drones are often sold individually. Some pilots get the most enjoyment from just flying the drone. They often buy ready-to-fly (RTF) drones that allow them to charge the batteries and go flying. The disadvantage of these drones is that if they crash, drone has to be repaired in a service or replaced by a new one. On the other hand, most FPV pilots choose PNP (complete drone without batteries, charger and additional equipment), BNF (the same as PNP but without RC receiver) or build the entire drone themselves from components that suit their preferences.

Furthermore, two technologies of video transmission are available—analog and digital. Both have their pros and cons. Thus, they are used in different situations. Analog tends to be inexpensive, but selecting a high-performance goggle with powerful antennas and other accessories may substantially increase the price. The quality of the image is not the best and as the signal decreases, the screen turns noisy. The main advantage is the transmission's low latency, which is why drone racers prefer them. As for digital technology, the video image is excellent. The video transmitter has to send a large amount of data to show video on the screen, raising the latency.

As previously mentioned, FPV drones are either cinematic or acro quads. Further, they are classified based on a battery's capacity and propellers' size. Battery capacity is the more critical parameter since it determines the quad's power, ranging from 1S to 6S. The more cells in the battery, the more power they can output. However, power is one of many parameters FPV enthusiasts aim to achieve. A properly optimized and light enough FPV drone can accomplish significant performance even with a 4S battery. Besides this, propellers are measured in inches, starting from 1.6 inches up to 13 inches. The most common combination is a 5-inch aircraft powered by a 4S or 6S battery because it provides the best ratio between power and agility. Figure 9 depicts drones lined up based on propeller size. The smallest drone (on the left) is a 2-inch and the largest is a 10-inch drone (on the right).

Figure 9. Sizes of FPV drones. Reprinted from Liang (2020).

2.2.2 FPV Goggles

As mentioned in the previous subchapter, there are two types of video transmission. Company FATSHARK is widely known for making analogue goggles, they have been in the market for the longest and many RC pilots would not buy goggles from any other brand. Several years ago, DJI decided to manufacture digital FPV goggles that would be affordable. Since then, other companies have come up with their designs for digital gear. All the goggles are excellent, but electronic devices enhance rapidly, hence there are new and better products every year.

Goggles have buttons and switches that change the settings. The most frequently changed parameter is the channel to which goggles are connected. It has to match the channel of the drone to display the video (multiple goggles can be connected to one drone at the same time). Other buttons change the focus of the lenses, turn up/down the volume or turn on the front camera. Another helpful feature is a digital video recorder (DVR) that records flight on an SD card and can help to find a drone after a crash. DVRs are built into most goggles, but it is possible to buy them separately and attach them to the goggles.

The last essential components are antennas. Inexpensive goggles, usually “box goggles” (a type with only one big screen in the middle, which keeps the price low but makes the spatial orientation harder), use only one antenna, thus having short range. High-priced goggles use “true diversity,” which means that the video image is taken from the antenna that receives the stronger signal. Therefore, it makes sense to use omnidirectional and patch antennas. The omnidirectional antenna has sufficient coverage in all directions around the RC pilot. However, in the extended range, the signal breaks quickly. Patch antennas have excellent coverage in long range, but only within a narrow area they are facing. That is the reason for use of two antennas that can automatically switch depending on the strength of the signal.

2.3 Drones in Public Events

Besides capturing unforgettable moments and taking incredible shots for television broadcasts, drones suit many other purposes. UAVs bring joy, help and prevent crowd violence. Further subchapters present light shows, racing and sports where drones are used.

2.3.1 Drone Light Shows

As company VERGE, INC. (2023) represents their drone shows, they are a better version of fireworks. It is because drones are not polluting, loud and wasteful while causing no harm to the environment and wildlife. Events are usually accompanied by music and in comparison, with fireworks, drones can display a 3D picture of anything instead of a couple of simple effects repeated several times. For example, American artist Travis Scott had light drones form a QR code of his new song at his concert. While organizing an event, a team of designers draws up a storyboard timeline showing the images. Then, images are converted through software to drone paths of flight and transmitted to the drones. Now, they are preprogrammed to fly in desired patterns with the help of navigation by GPS and external influences such as wind are suppressed in real time by active sensors. At the time of the event, a pilot operates and oversees them all simultaneously from a ground control station.

Although drone light shows are well-known worldwide, one may seldom see them. The reason is mainly the drone's cost. Transportation of the equipment and accommodation for the crew is also expensive. Additionally, drones have to be insured and regulatory approval is needed. Companies that have been on the market for a long time mostly offer 50 to 1,000 drones for a light show. According to Crumley (2022), the current record holder of the most significant event is a Chinese HighGreat manufacturer with 5,164 UAVs in the air at once that were able to perform for 26 minutes and 26 seconds straight (shown in Figure 10).

Figure 10. Drone Light Show in China. Reprinted form HighGreat Drone Show (2021).

2.3.2 Drones in Sports

Apart from drone light shows like opening ceremonies at the Olympics or halftime entertainment, there are other opportunities for the involvement of drones in sports. The most significant is broadcasting from drones, which offers an unusual view from above. For rally cars, drones provide fans with a third-person view of the racing cars, improving the experience while keeping the audience safe and away from the racetrack. Safety could also be assured by drone crowd control, immediate help in emergencies and fast reaction when violent behaviour occurs. Further application of drones is in refereeing. Footage helps to judge and make adequate decisions. For the coaches, drones bring better angles of view for analytics, making easier strategy planning and enhancing team cooperation.

2.3.3 Drone Racing

It is a relatively new sport where drone pilots compete and can win prizes and money, just like in any other sport. What sets drone racing apart from other sports is that the race takes place in the air. Pilots use FPV goggles, which were covered in the previous subchapter, allowing them to fly the drone like they were sitting in a cabin of a real aircraft. The track is often situated in a stadium with gates placed on the ground, elevated or even in tunnels of the stadium. Another obstacle that pilots can encounter are flags, which have to be flown around. Drone pilots have to fly through every gate to complete one lap.

Drones’ speed can reach about 160 km/h, hence competitors have to react swiftly. To achieve the necessary skills, racers train on PC simulators (games adapted for learning to fly rapidly in a small environment). As for the competition itself, pilots show up to make their qualifying attempts and afterward, they are sorted based on their times. Groups of four or eight are created and again eliminated until eight of them remain, then they race in the finals. Mostly, competitors make their racing drones themselves, which requires soldering skills and often programming skills as well (Hughes, 2022).

The most famous organizer of drone racing is DRL (Drone Racing League), established in 2015, which has held events worldwide ever since. The events are streamed on the internet and allure fans of drone technology. However, there are more options to get into racing. Most cities have local racing clubs or groups that can be joined via a Facebook community. Clubs usually have their arena with obstacles, where members can race for an annual fee.

As for the rules in general, whenever a pilot misses a gate (or another obstacle), they have to go back and fly through it before progressing, DCL (2020) explains. Mid-air collisions are not penalized if they were unintentional. Further, competitors must maintain an altitude of five meters and pilots who take off before a signal are issued a red card. As stated by MultiGP (2018), the hardware of the racing drones is often regulated to some extent (except for the open racing category). The competition’s organizer creates a list of components, such as frames, motors and propellers, from which pilots can select. Conversely, there are no requirements for cameras, transmitters and flight controllers. The track is surrounded by protection netting. Also, declared No-Fly zones ensure safety, keeping the drones more than 22 meters away from the audience.

2.4 Fishing and Underwater Drones

Drone fishing, as simple as it sounds, is a use of a drone with a fishing line attached to it. Drones can cast the bait more than 500 meters away. As the bait reaches a sufficient distance, the line detaches and the drone returns using GPS or manually operated by the pilot. Then everything is set. Fishers wait for a fish to bite and pull it naturally with a fishing rod. Apart from the shore, drones can take off from a boat, but landing back on the boat can be complicated. Drones do not necessarily need to be waterproof, though it is better to pay slightly more and keep the drone from drowning. Since drones generally drain batteries fast, it is advised to turn the aircraft off between casts or to buy spare batteries (Cast, 2020).

For those who do not own a diving license yet still want to explore marine life, underwater drones are the perfect tool. Drones also make investigating shipwrecks safe. The necessary feature is a bright light since sunlight hardly penetrates the water. According to Underwater Team (2020), the best underwater UAV for non-commercial use is the FIFISH V6 drone. It comes with VR goggles and additional equipment like a robotic arm that can grasp objects. Six thrusters on the drone's body enable movement in tight spaces. Its 4K Ultra HD camera has a 166° angle of view and combined with 2000 lumens LED lights, it takes outstanding images. The drone can be attached to a rope to ensure the recommended maximum depth of 100 meters and prevent the drone's loss if the battery discharges.

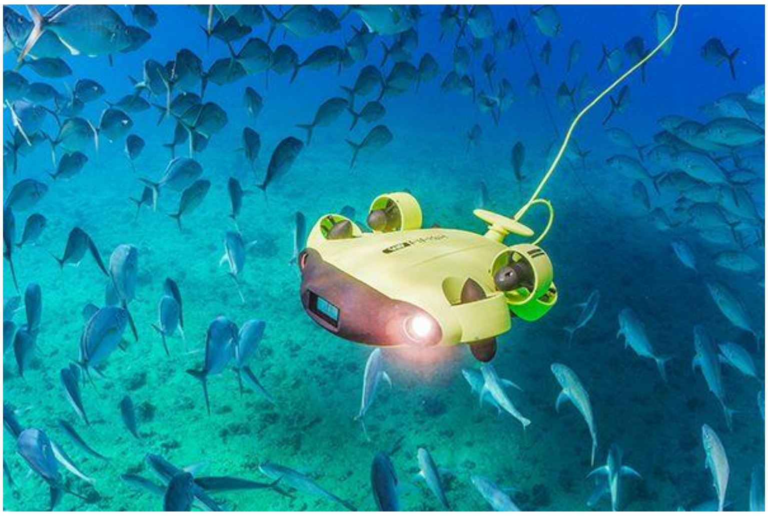

Figure 11. FIFISH V6 Underwater Drone. Reprinted from https://www.qysea.com/store/products/fifish-v6/

2.5 DIY

DIY drones can be divided into two categories, quadcopter kits and creating drones from scratch. Quadcopter kits are less demanding since professionals designed all the components to work together perfectly; shops ship these sets of components and customers put the parts together themselves. It is the less creative option and was already mentioned in the previous subchapter FPV Hobby. Therefore, this section will be devoted to custom-made drones made from zero.

Before listing the individual components, it is essential to state that building a drone is not only about designing it in a way that all the components work correctly. It requires manual dexterity, soldering skills and the basics of electrical engineering. Even if one does not want to create a code themselves to avoid programming, drones still have to be connected to a computer and already existing code has to be uploaded into their memory. This subchapter will first introduce the main parts drones are made of and then a straightforward process of building a drone will be described.

2.5.1 Frame

The first thing to decide is whether the drone will be used for freestyle or cinematic video shooting and to choose the appropriate size. Small drones are not powerful but can sustain crashes and fly indoors, whereas large drones can fly in worse weather conditions and are more stable. Then, it is necessary to select a frame that can fit all the components. The frame can be made of any material like wood, for example. Nevertheless, mainly used is carbon fibre since it offers durability and is lightweight at the same time. In terms of price, plastic is inexpensive and often used as well. The last two variables are colour and shape, which specifies flight properties. Additionally, it should be considered if some details are needed, like sockets for the camera mount.

2.5.2 Motors

The size of the motors is already partly based on a chosen frame, but there is more to determine. To pick the suitable motor, Wales (2023) highlights a rule that all four motors must have enough power to carry at least twice the drone's weight. Thus, if the drone weighs 250 grams, motors must have enough thrust to carry above 500 grams to ensure adequate capabilities. Nowadays, freestyle drones commonly have eight times the power needed to carry the weight of a drone. Drones use brushless DC motors that operate efficiently for more than 1000 hours. They comprise the rotor, stator, windings, shaft, bearings, magnets and poles.

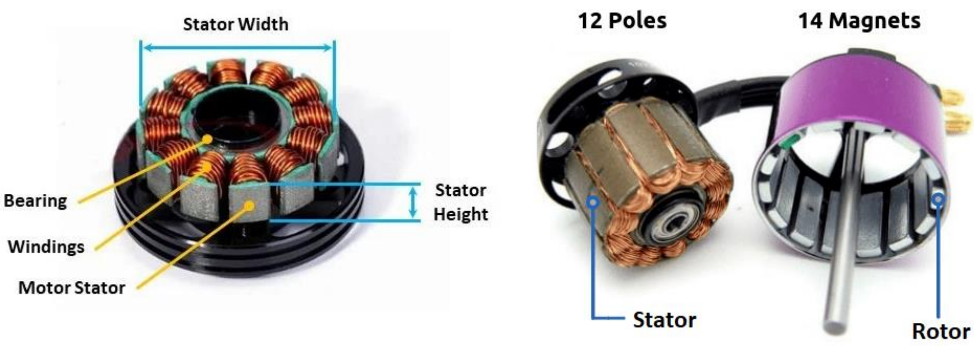

Figure 12. Structure of a motor. Reprinted from https://www.flyrobo.in/blog/different-drone-motors

2.5.3 Speed and Flight Controllers

An electronic speed controller (ESC) is connected straight to each motor with three conductors and manages the motor's speed. After the desirable motor is known, the key parameter for choosing ESC is the current rating, consequently, how much current the motor draws. Using ESC with enough capacity is necessary to prevent overheating (Nagel, 2022). On the other hand, the flight controller processes commands from the pilot. As Mishra (2021) explains, it is the most important part of the drone since it assures stability. The flight controller directs how much power ESC should provide to the motor. Besides that, it can have various useful features like GPS location, though each enhancement increases the price.

Figure 13. ESC and flight controller. Reprinted from https://robu.in/how-to-choose-esc-for-your-quadcopter/

2.5.4 Control and Transmission

Most drones will be equipped with a camera to see the drone's view in real time. The camera does not affect the performance apart from making the UAV heavier. Therefore, the aim is to achieve the best picture quality for the smallest amount of weight. However, the camera itself is not enough. Drones need a video transmitter with an antenna to send the data to a display device. According to Corrigan (2019), the technology uses polarized antennas that operate at a frequency of 5.8 GHz with a 40-channel video transmitter. The main parameter of the antenna is gain, which determines its reach. Another pair is an antenna with a receiver that receives the signal from the radio controller. It is crucial that both the receiver and controller use the same frequency. Widely used are frequencies 900Mhz and 2.4GHz. Different manufacturers (like FrSky or Spectrum) use various protocols for radio transmission. This means that both components have to match the manufacturer or a module is needed; thus, the devices can communicate (Liang, 2021).

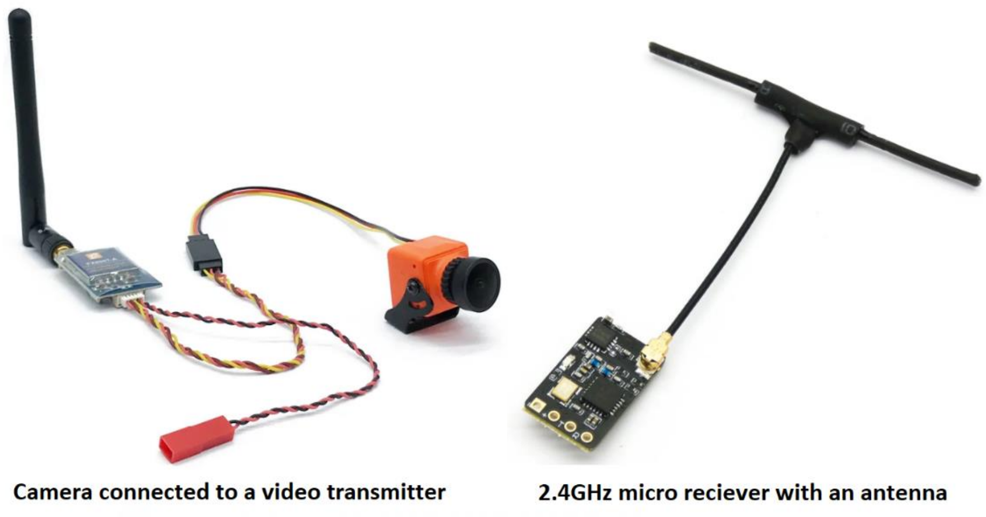

Figure 14. Transmitter and receiver with an antenna. Reprinted from https://speedyfpv.com/

2.5.5 Drone Assembly

First, the flight controller, ESCs and motors must be screwed on the bottom part of the frame. In the following steps, mounted components have to be connected accordingly by soldering conductors. An electronic speed controller powers the whole drone. For that reason, there has to be soldered a battery connector and capacitor to reduce voltage spikes (Liang, 2023). Furthermore, the transmitter and receiver must be connected to the flight controller and camera attached to the drone's front side. All the components should hold firmly to the frame. At that point, the upper part of the frame is fixed. Finally, the drone has to be connected to a computer to upload software into the flight controller, calibrate it and configure the settings. The last step before flying it is to install propellers and pair the drone with an RC transmitter.

3 Other Uses of Drones

Entertainment drones were covered in the previous chapter. In contrast, this chapter provides information about military, commercial and industrial UAVs. Subchapters are focused on present solutions and partly on the development of the future of technology. It is mainly focused on the military and agriculture. Further are mentioned drones used in advertisement, industrial areas and delivery.

3.1 Military

As Gusterson (2017) interprets, drones have been involved in combat territory since World War I. However, their use was to act as bait, obtain information or find a target for manned planes. It was not until late 2001 that the American army equipped Predator drones with Hellfire missiles for operations in Afghanistan. UAV Mojave and Gray Eagle are combat drones developed by General Atomics, America's leading drone supplier. Both are capable of carrying Hellfire missiles and sensors of several types. General Atomics Aeronautical Systems (2021) claim that Gray Eagle features an automatic takeoff and landing system, thus it can be launched and recovered autonomously.

For the military, it is crucial to reveal enemies' positions. The main mission of surveillance drones is to fly in high altitudes for long periods of time and to capture high-resolution imagery of enemy territory in any weather conditions. As an example of the large-scale category, RQ-4 Global Hawk is a remotely piloted, high-altitude, long-endurance aircraft. According to the official website of the U.S. Air Force (2014), Global Hawk was first deployed in November 2001. More compact is a drone called V-BAT constructed by Shield AI. This defence technology company decided to use a ducted fan to power their UAV. The ducted fan allows it for launch and recovery without a runway or any equipment. In the future, these drones are planned to be flown in swarms with the expectation of penetrating integrated air defence systems (Shield AI, 2022). Surveillance drones' key apparatus are electro-optical/infrared (EO/IR) detectors, synthetic aperture radars (SAR) and high and low band SIGINT sensors.

3.2 Agriculture

UAVs are beneficial for agriculture in several ways. They help to keep track of the plant's health, irrigation and development. Further, drones make farming less strenuous and save time. Aircraft can also help with replanting after a natural disaster occurs. Nowadays, drones are used for crop health monitoring, they are equipped with RGB and thermal cameras. The health of plants is determined using software that compares the RGB colours of the images. According to the "normalized difference vegetation index," software differentiates whether a plant is healthy or not. The simplified evaluation of the software is illustrated in Figure 15. Images taken by drones also help to spot gaps between crops after planting, thus they can be replanted (Croptracker, 2022).

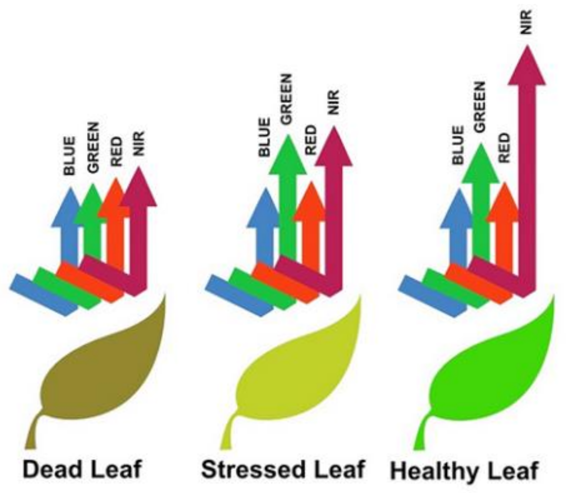

Figure 15. Simplified evaluation of plants' health. Reprinted from Croptracker (2022).

3.3 Advertisement

For the most part, these drones advertise the interior by making short cinematic shots of houses, offices and mansions for real estate agencies. However, open-minded entrepreneurs began advertising their businesses similarly in recent years. One can see drone tours of restaurants, bowling alleys, gyms, amusement parks, cultural centers, and hotels on any website. This kind of advertising is affordable and introduces every part of the complex in 30 seconds.

3.4 Drone Mapping

Any aircraft with a good camera can be used for mapping. Frequently DJI drones are used since they are affordable while providing high-quality camera images. On the other hand, fixed-winged drones are commonly used in large areas due to their ability to glide, allowing them to fly for an hour on a single battery cycle. Wawrzyn (2022) points out that the result depends on the mapping software used. Photogrammetry is the technology that obtains information from two-dimensional photos. By combining overlapping, geotagged images from different angles, the software generates a 3D map that shows topographic surfaces. Drone mapping is used in land surveying, quarries, constructions and large mining sites.

3.5 Inspections and Ultrasonic Testing

Every part of the industry has to be regularly checked. Nonetheless, structures like transmission lines and offshore constructions are challenging to inspect. Skygauge (2023) developed a drone that can accurately measure the thickness of walls in heights and hardly accessible environments. It uses an ultrasonic probe pressed against the wall, emitting ultrasound into the measured body. Then, software processes obtained data, displaying the result on a screen. Moreover, there might be a better solution for duties that are less demanding. As Duncan (2022) suggests, autonomous drones and AI algorithms are the future. These drones would prevent accidents, minimize outage time and inspection teams would not be exposed to any danger. Figure 16 shows corrosion areas and cracks in the concrete of a chimney inspected by a drone.

Figure 16. Cracks in a chimney. Reprinted from https://forcetechnology.com/en/articles/inspection-using-drone-technology

3.6 Drone Delivery

Transportation by drones, as unbelievable as it sounds, is already used in some parts of the world. Walmart, an American corporation that operates a chain of hypermarkets, cooperates with three companies: DroneUp, Zipline and Flytrex, which provide them with drone services. Alund (2023) claims that Walmart currently delivers in Texas, Florida, Arizona, Arkansas, Virginia, Utah and North Carolina. Drones deliver groceries within a 17 km radius of the store. The order has to be less than 4.5 kilograms and will be delivered in 30 minutes. Zipline sends packages with a parachute attached to them, whereas DroneUp UAVs use a solution of rope that slowly lowers the load. Both ways, the package safely lands in the customer's yard. This new way of transportation also means a major change for medicine. Hospital in Kansas uses the services of Spright UAS to order deliveries of medicaments. The main advantage is that drones do not get stuck in traffic (Spright UAS, 2022).

4 Regulations

This chapter focuses on laws concerning recreational and hobby drones in Europe. Where they can be flown, what guidelines pilots have to obey and how to register. UAVs are divided into three subcategories based on the drone’s parameters. The following text is not only about the present situation but also includes planned changes in the near future. Furthermore, there is a brief clarification of laws that apply to commercial drones and the last topic is devoted to flying zones in the Czech Republic.

4.1 European Laws

EASA (European Union Aviation Safety Agency) regulates the laws in Europe. As can be found at the official EASA (2023) website, entertainment drones belong to the “open” category of civil drones, which is then divided into three subchapters. The “open” category covers UAVs that have a maximum take-off mass smaller than 25 kilograms, the aircraft not allowed to fly over assemblies of people, carry dangerous objects or drop any material.

4.1.1 Subcategory A1

It is the first subchapter of the “open” category and is further divided by maximum weight. For drones weighing less than 250 grams applies: Operational restrictions are that flight over uninvolved people should be minimized and flight over assemblies of people is forbidden. The drone’s operator has to be registered only if the UAV has a camera or other sensor able to detect personal data and it is not intended as a toy. It does not require any training and there is no age limit. Whereas drones weighing less than 500 grams have to meet the same operational restrictions, but the operator has to be registered regardless of the camera. A pilot has to be at least sixteen years old and pass the exam and training for the A1 subcategory (EASA, 2023). It is the subcategory where small drones from the brand DJI belong, for example, the series Mavic Mini, Spark and Air.

4.1.2 Subcategory A2

This subcategory concerns aircraft of a maximum weight of less than 2 kilograms. A pilot has to avoid flying over uninvolved people altogether and keep a horizontal distance of fifty meters from them. The pilot has to be sixteen years of age or above, has to be registered and has to pass the A2 category exam and training (EASA, 2023). This subchapter involves DJI Phantom models, Autel Lite/Evo/Evo 2, Parrot Anfai USA and similar aircraft.

4.1.3 Subcategory A3

UAVs weighing up to 25 kilograms must not fly near and over people in general and must abide distance of 150 meters from commercial, residential and industrial areas. Similarly to the previous paragraph, a pilot has to reach the age of sixteen, register themselves and pass the A3 exam and training (EASA, 2023). This subcategory covers high-definition drones like DJI Inspire, DJI Matrice and Yuneec H520, mainly designed for photography. All three subcategories are valid until December 31, 2023. Additionally, states can lower the age limit to 12 (this new limit will apply only within the area of the certain state that changed it).

4.2 Upcoming Laws for European Union

Since January 1, 2024, the law will slightly change. Mainly, manufacturers will have to add identification labels to their drones. The labels are C0, C1, C2, C3 and C4. For the first one, C0 is the same as subcategory A1 under 250 grams. For C1, it will be the same as for the second part of A1, except that the limitation is increased to 900 grams. C2 is similar to A2, but the minimum weight is increased to four kilograms. C3 is equivalent to A3 and C4 is also like A3, but the pilot may fly over uninvolved people. Drones categorized by these labels should be available on the market by the end of 2022.

Furthermore, drones bought or built before January 1, 2024, without the label, will be assigned to either group under 250 grams (the same rules as C0, but there is no age limitation) or to a group under 25 kilograms (equivalent to C4). European states can lower the age limit to 12, where the limit applies only to the area of the state that has changed it (EASA, 2023).

4.3 Civil Drones

To give a brief overview, “civil drones” have two more categories. The first of them is the “specific” category. It includes drones representing greater risk than the “open” category of UAVs. For example, drones that are flown beyond visual line of sight, with a maximum take-off mass bigger than 25 kilograms, flown higher than 120 meters. All the pilots have to be registered and obtain operational authorization from the National Aviation Authority (NAA) of the state of registration. Even if the intention is to operate the drone in another member state, the pilot applies for authorization in the state of their registration. An operational authorization is not limited to any number of flights or times unless stated otherwise by the NAA.

The second one is the “certified” category. It is the category with the highest level of risk, drones that can transport passengers belong to this category. For that reason, the operator needs approval issued by the competent authority and has to have a pilot license. There are three groups into which this category is divided. “Operations type #1”, international cargo drones in airspace classes A-C. “Operations type #2” is drone operations in urban or rural environments with pre-defined routes that operate autonomously. “Operations type #3” is the same as type #2 but conducted with an aircraft piloted remotely (EASA, 2023).

4.4 Registration of Drone Operator

All pilots must be registered unless their drone is intended as a toy (or does not have a camera or other sensor able to detect personal data) while weighing less than 250 grams. Pilots have to register themselves in a member state of the EU, where their place of residence is. Third-country operators must register in the first EASA member state where they want to fly drones. Every pilot can register only once, regardless of how many drones they own. Registration is valid for the period stated by the National Aviation Authority of the member state where the pilot was registered (then it has to be renewed). Each pilot receives their original “drone operator registration number” that has to be displayed on all of the drones owned by the operator, including privately built aircraft (EASA, 2023).

4.5 Laws in the Czech Republic

Since it is a part of the European Union, pilots must behave in accordance with the rules set by EASA. Licensing and permits are handled by the Civil Aviation Authority (UAV Coach, 2022). Figure 17 depicts a map of forbidden zones for flying drones in the Czech Republic. The zones are mainly areas of cities and towns. Additionally, there are planned routes for officially registered drone flights. The map featuring the present flights can be found on the dronview.rlp.cz website.

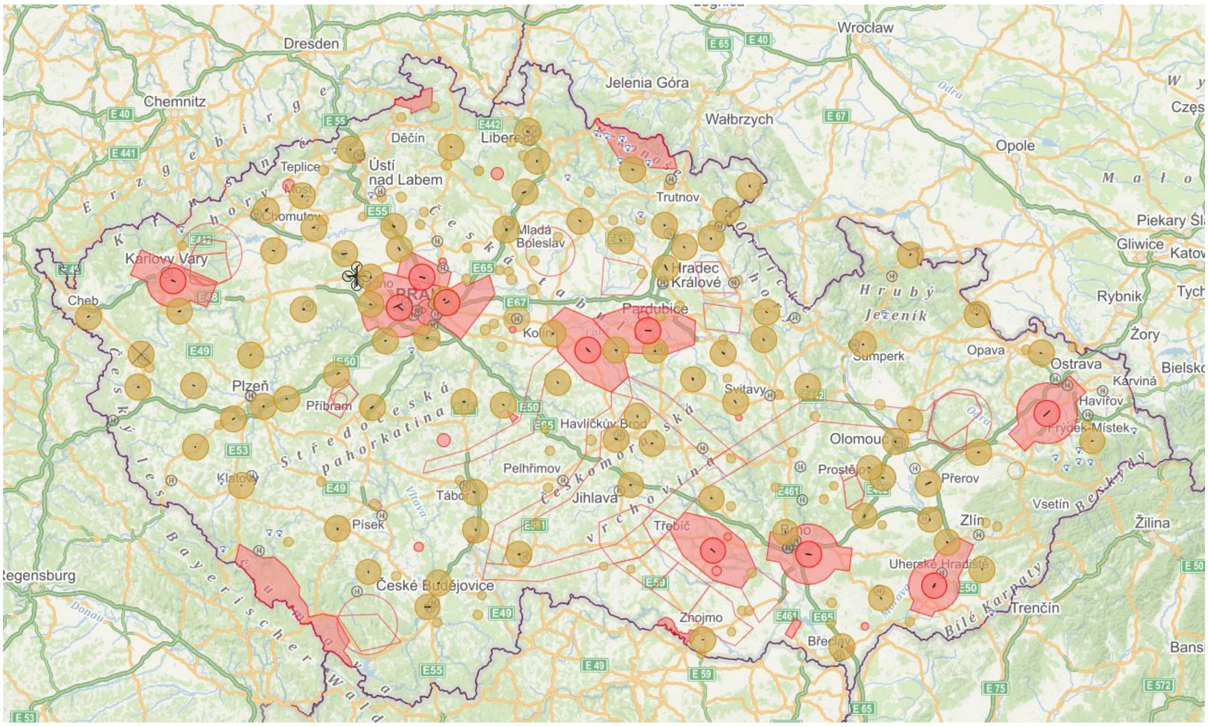

Figure 17. Map of forbidden flying zones in the Czech Republic. Reprinted from https://dronview.rlp.cz/

5 Drone Accidents

This part of the thesis presents the causes of drone accidents. Their main issue is interference, how it arises and its prevention can be found in the following subchapter. Further discussed are natural influences, human errors and battery failures. Examples are related to the hobby and recreational drones. The last subchapter describes where accidents in different countries should be reported.

5.1 RF Interference

As explained by Elliott (2020), there are areas that drone pilots should be aware of or avoid altogether while flying. It is due to electromagnetic interference. Drones operate in the following frequency bands 2.4GHz, 5.8GHz, 433MHz and 915MHz. Firstly, cell towers and phones generally operate at 1.9 GHz. Nevertheless, the drone's transmission might interfere. The undesirable effects are caused by intermodulation. This phenomenon, as described by Shure Performance & Production (2015), is comparable to playing two notes on a piano simultaneously. Apart from the harmonics of the two notes, there is another sound. It is because a combination of the previous two notes creates the sound of a new note. Something similar happens to the radio frequencies. Each device produces a fundamental frequency and multiples of this frequency. When there are two or more devices, they interact with each other creating new frequencies. Some of the newly created frequencies might overlap with the frequencies used by drones, causing interference.

Secondly, Elliott further says that flying near high-voltage power lines is not advisable for various reasons. The interference is caused by a high amount of electricity running through the power lines, called "broadband electromagnetic interference." Although many drones have some type of shielding built in, the power lines can still interfere with communication between the drone and the controller or mess with the voltage output of the electronic speed controller (the main circuit that controls the speed of the motors). Power line cables are also hard to see from a distance. Thus, these places are generally adverse for flying drones.

Thirdly, Wi-Fi networks and buildings can cause interference in some cases as well. The Wi-Fi interference is called "narrowband interference" and occurs when two frequencies are too close and mutually cancel each other out. Fortunately, it is easier to solve than the broadband interference, which was discussed previously. Especially for DJI drones because their frequency band of video transmission can be changed in a smartphone application. Concerning buildings, thick walls or metal structures can reflect electromagnetic waves. It may cause difficulties while calibrating a drone or even flying it. Pilots do not have to avoid flying near buildings and structures alike but should keep in mind that it might negatively affect transmission (Elliott, 2020).

Finally, there is an example of a drone crash near the White House. According to Miller (2015), in 2015, shortly after 3 a.m. drone crashed on the grounds of the White House and triggered a lockdown. Officials rushed to the drone to verify it did not pose a threat. It was a DJI Phantom 3, available on the market as a drone for photography and recreational purposes. At the time, former president Barack Obama and Michelle Obama were in India. Nonetheless, it was another misconduct of the Secret Service and Obama asked the agency's director to step aside. Forrest (2018) writes that the aircraft's owner was Shawn Usman. He was not charged because the drone was not under his control during the crash.

Figure 18. Photo of the crashed DJI Phantom 3. Reprinted from Miller (2015).

5.2 Wildlife Hazard

Fortunately, collisions with birds are not that frequent. There are two types of them: a pilot misreads the situation and flies into a flock of birds, or predatory birds attack the drone because they see it as prey. Both can be avoided by an awareness of where the drone is flying and checking the sky before taking off. For example, here are two incidents: A red-tailed hawk was hit by a drone in a park in Massachusetts. The drone recorded the accident on camera and the video went viral online. Whereas in Norway, UAV was caught and taken away by a golden eagle. The eagle might have seen it as a rival bird (Forrest, 2018).

5.3 Poor Flight Planning and Nescience

Beginners often fail to read or understand the manual and instructions. On the other hand, even experienced pilots sometimes underestimate weather conditions, drone payload or gear preparedness. Another difficulty arises from a lack of spatial awareness. That was most likely the reason for the following accident: As Kesteloo (2022) reports, a drone crashed into a helicopter during the King of the Hammer in California. It was an off-road race in the desert, where five helicopters and four drone pilots were hired to record the competition, says Kesteloo. Apart from some scratches, the helicopter was completely functional, whereas the drone lost its arm during the process and collapsed to the ground. The drone operator was using a casual drone for hobby photography DJI Mavic 2 Pro, hence the monetary loss was insignificant, though it did not positively affect the pilot's reputation either.

5.4 Battery Failures

Although batteries have a limited number of cycles, customers usually do not respect it. They bought the product expecting it to last a couple of years. Especially people, who buy hobby and recreational drones and are not that knowledgeable about electronics. Moreover, they tend to overcharge the batteries, unintentionally damaging them. A battery failure caused an accident during the Henley Royal Regatta in 2022. As described on the website Henley Herald (2023), the drone's operator wanted to record every second of the 80 races that day. From the pilot's experience, batteries should be replaced after every third flight. At the time of the 21st flight, a low battery warning was triggered on his display. The operator directed the drone away from the river and started descending. Despite reacting fast, the pilot saw that the battery was depleted and the crash was inevitable. At an altitude of 50 meters, the controlled flight was lost and the aircraft fell on a Celtic Queen boat. Nobody was injured. Just slight damage was caused to the boat and the drone sank into the river.

5.5 Reporting of a Drone Accident

In Europe, incidents or accidents that a pilot witnesses or is involved in must be reported to the NAA (National Aviation Authority) of the country where the accident happened (EASA, 2023). In the United Kingdom, all accidents must be announced to AAIB (Air Accident Investigation Branch). According to FFA (2023), in the US, accidents have to be reported within ten days if a severe injury to a person was caused or damage to another's property exceeded 500 dollars. To summarize the drone accidents, a graph in Figure 19 shows statistics of injury rates and the most frequently injured body parts.

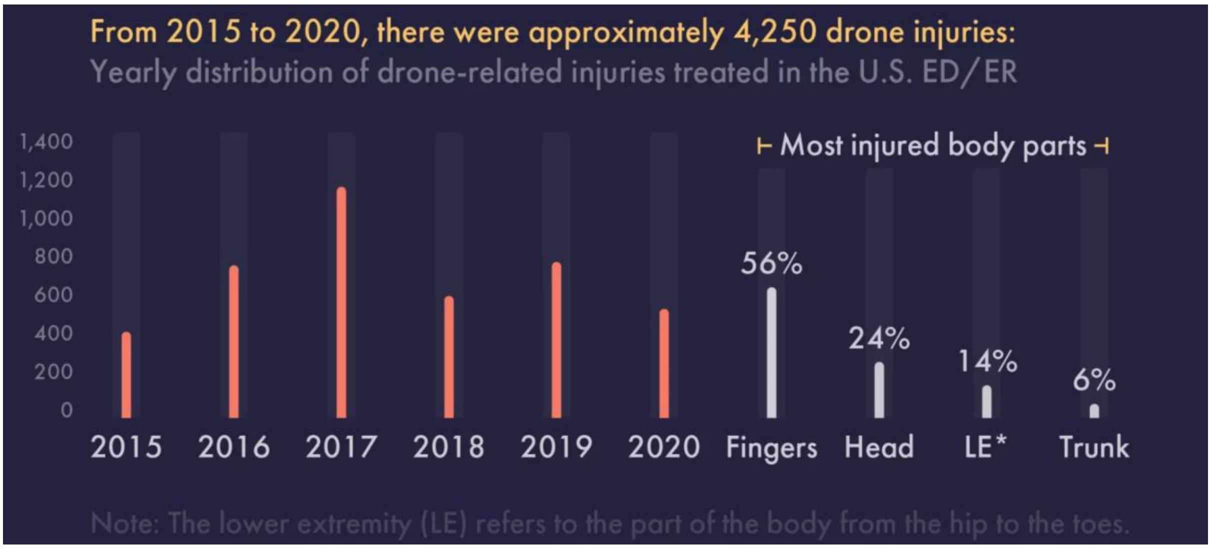

Figure 19. Graph showing drone-related injuries. Reprinted from Chase (2021).

6 Conclusion

It is challenging to keep the information up to date with the advancements in modern technology. That especially applies to drones since the military makes most of the progress. Regrettably, research is classified or extensively restricted. It is resulting in most of the available documents being several years old. It is suitable for raising awareness or extending knowledge. Nevertheless, it does not truly reflect what humankind is capable of. Concerning entertainment, it is the exact opposite. Businesses try to get in the lead by presenting new technology their company offers.

To sum up, technology is being enhanced. As a result, various methods of flight were developed. The main difference is how the motors are used and whether the aircraft uses a wing to extend its flight range. Additionally, UAV classification is based on its dimensions that state their abilities like payload, swiftness and other capabilities crucial for numerous real-world applications. At the same time, the drone’s important factor is the propulsion system. Widely used are batteries due to their reasonable price, power output and weight. Their disadvantage is the length of time they can provide power. It is solved by the use of diesel engines or photovoltaic panels that currently suffer from impractical energy storage and dependence on weather conditions.

This thesis shows that hobby and entertainment drones have achieved significant growth in the last decade. This expansion of popularity was expected because of the interest they have always attracted. Recreational photography drones went hand in hand with the progress of digital cameras and the reduction of their size. Since 2013, company DJI has been coming to the drone market yearly with revolutionary features. The Chinese company surely has competition, though customers still tend to buy DJI due to their established marketing and wide range of aircraft.

Further, drone enthusiasts capable of soldering and programming gladly assemble drones themselves. These drones are mostly equipped with an FPV camera and video transmitter that sends the image of the UAV’s view to virtual reality goggles in real-time. Aircraft of this kind is used for cinematic shoots, freestyle tricks and, most importantly, drone racing. Competitions take place in many states and are watched by fans worldwide. Other ways of recreation are concentrated on rather relaxing activities like fishing, exploration of marine life and drone light shows.

Undoubtedly, aircraft are used in many other areas. Drones represent a valuable part of equipment in the military. UAVs have irreplaceable abilities for surveillance and combat. Likewise, the utilization of drones in agriculture is quite dramatic since they can replace humans in physically demanding work. Moreover, inspections of buildings, infrastructure and machines are now done by drones. Not only is it less expensive, but it also keeps people away from dangerous environments.

Finally, it should be noted that laws are necessary to regulate such fast and small aircraft. European Union Aviation Safety Agency dictates where drones can be used according to their size to prevent airplane collisions. Nonetheless, there are more and more injuries and accidents due to several faults that can occur. The ideal future would be to employ autonomous drones with a variety of sensors ensuring safe operation. Besides this, the biggest progress that will certainly be seen in the coming years will be achieved in the area of parcel delivery. Further, UAVs will be flown in swarms by the military, with the expectation of penetrating integrated air defence systems. These innovations, some facilitating work for humankind and others capable of provoking a war, are a part of today’s world. Thus, shaping the future depends entirely on the present generation.

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List of Abbreviations

AAIB - Air Accident Investigation Branch

BNF - Bind and Fly

DC - Direct Current

DIY - Do It Yourself

DLR - Drone Racing League

DVR - Digital Video Recorder

EASA - European Union Aviation Safety Agency

EO/IR - Electro-Optical/Infrared

ESC - Electric Speed Controller

FAA - Federal Aviation Administration

FPV - First-Person View

GPS - Global Positioning System

HALE - High Altitude Long Endurance

HDR - High Dynamic Range

LiPo - Lithium-Ion Polymer

MALE - Medium Altitude Long Endurance

NAA - National Aviation Authority

NASA - National Aeronautics and Space Administration

PNP - Plug and Play

RC - Remote Control

RTF - Ready to Fly

SAR - Synthetic Aperture Radar

SIGINT - Signals Intelligence

STOL - Short Takeoff and Landing

UAV - Unmanned Aerial Vehicle

VR - Virtual Reality

WAS - Wide Area Search