1. UAV - the origin and development of the concept

Searching the origin of the term drone brings us, with the help of Imperial War Museum (UK), to the military origin of the term: the first unmanned vehicles were employed at the end of WW I as both assault weapons for and targets of anti-aircraft gunnery. A large number of radio-controlled target aircrafts by the name of DH.82B Queen Bee was manufactured in the UK during 1930s, and it is believed that the term drone developed in relation to the name Queen Bee, since it signifies a male honeybee.

The term drone emerged into wider media in the 1990s, when the US started to use them as assault weapons in the warfare in the Middle East. Since then drone carries an unpleasant connotation for ordinary people and the Russian conquest war in Ukraine that started in 2022, where drone attacks are an everyday, has only deepened such attitudes.

Contemporary scientific literature uses the following abbreviations for unmanned aerial vehicles:

(s)UAV small unmanned aerial vehicle

UAS unmanned aerial system

RPAS remotely piloted aerial system (i.e. in aviation)

MÕS Mehitamata õhusõiduk (unmanned aerial vehicle) is used by the Estonian Transport Administration.

From the above, UAS has the broadest meaning. This acronym stands for a set of hardware and software (different sensors included) that is fully integrated with the aircraft and used for data collection and operation of the aircraft. Other abbreviations rather denote the unmanned aerial vehicles per se.

In addition to the flying unmanned aerial vehicles, there are also unmanned ground vehicles (UGV), unmanned surface vehicles (USV) and unmanned underwater vehicles (UUV). A comprehensive overview of the aforementioned vehicles can be found in Balestrier et al. (2021), that also addresses the cooperation possibilities of the different types of vehicles.

An interesting development has occurred among the hybrid drones that can move between different environments such as air-water-air (see Li et al., 2022) or air-ground-air (see EL H2020 HUUVER project) (see Image 2 for examples). Another recent development is a swarm of drones where several drones act as a synchronized swarm that coordinates the tasks and gathers information on the environment (Zhou et al., 2022). Such swarms have been presented to the wider public on fanciful drone shows where hundreds of drones move and change colours synchronously (see Image 2).

The present guidebook has employed the term drone, since in Estonian it commonly stands for unmanned aerial vehicles.

Image 2. Left, UGV and UAV hybrid Terra Drone Tilt Ranger; Right, light show consisting of 100 Intel drones.

In Estonia, Tallinn University of Technology (TalTech) works on the technical development of drones and cooperates with Threod Systems, the main manufacturer of (military) UAVs in Estonia. According to the present author, such Estonian companies as ELI (military UAVs and accessories), Skycorp (hydrogen drones), Hepta Airborne (power-line inspection and other UAV surveillance), and Krattworks (application of real-time machine learning, development of drones) also work on the development and construction of UAVs and related systems. Estonian Aviation Academy has developed several study courses that teach handling unmanned aerial vehicles and what is more, in cooperation with **Estonian Air Navigation Services Ltd** they are responsible for managing U-Space, an environment designed to regulate our common airspace.

The most well-known company dealing with UAVs in our neighbourhood, Latvia, is SPH Engineering, a leading UAV flight planning and controlling software developer (UgCS), who integrates UAVs with different sensors such as ground-penetrating radars and sonars. The most well-known Latvian drone manufacturer is UAV Factory (*Penguin* drones) that has been operating since 2022 under the name Edge Autonomy. Finland, our Nordic neighbour, has its own large UAV development centre FUAVE (Finnish UAV Ecosystem) and a relatively new LIFT Future Aerospace Centre, created in the autumn of 2022 as a cooperation project between universities and private companies. Finland is, no doubt, at the forefront regarding UAV based forestry surveys, as well as the development and manufacturing of hyperspectral cameras (Specim, Senop Ricola).

1.1. Types of drones – multirotors

UAVs are generally divided into three categories based on their movement- and thrust mechanisms: multirotors, aircrafts and their hybrids (Hassanalian and Abdelkefi, 2017). There are also other possibilities for movement such as using jet engines or flying wings, but these are not very common, at least not in the civil sector.

Multirotor drones derive their lift solely with the help of thrust generated by spinning blades. One of the greatest advantages of multirotors is the ability to hover in a stationary position. What is more, such UAVs have an excellent manoeuvrability that allows the multirotors to be used in confined spaces. Unfortunately, such UAVs consume relatively much energy, a fact that reduces the flight time of the multirotors. For instance, a regular battery powered multirotor is able to fly for 30–40 minutes, whereby its flight time depends on the weight of the payload. We must not forget that manufacturers often advertise flight time of the drone determined by its 'empty' weight.

Multirotors are the most universal contemporary drones that can be used for mapping different areas (suitable for areas ca <50 ha), on-site observations (E.g. monitoring bird nests), or for just taking pictures or filming interesting locations. Using the so-called computer vision and/or ultrasonic sensors, the newest multirotors have an automatic ability to avoid obstacles and even a beginner pilot can fly them indoors. Still, as it currently stands, for the computer vision to work efficiently, it needs clear contrast pattern images. For example, the so-called computer vision does not to work in case of fresh white snow, and ultrasonic sensors do not detect very small objects (E.g. cables). The collision avoidance system that is still quite robust today together with real-time spatial perception of the surroundings are most certainly the precondition of that in the future, our airspace can simultaneously and safely be navigated by both manned and unmanned aerial vehicles. For a good introduction to anti-collision systems used in UAVs see Yasin *et al.* (2020).

Multirotors are commonly classified according to the number of rotors: **birotor** has two engines, **hexarotor** six, etc. (Image 4). With some reservations this category also contains helicopters with one single rotating blade and tail rotor, vehicles that can also be unmanned (Kaňuk, Gallay, Eck, Zgraggen, & Dvorný, 2018). The most common among multirotors are the ones with 4, 6 and 8 engines. In UAV construction opposing parameters such as complexity, thrust, flight time, weight, redundancy, etc. must be considered. This way, as a rule, the most simple, light and cheap multirotors have four engines and versions with greater capacity have six or eight engines respectively. A greater number of engines enables the drone to fly even in the case of breakdown, or at least land in a controlled manner.

Generally, a four-engine drone will fall down like a stone if one of the engines malfunctions. However, by now the more expensive four-engine drones produced for example by DJI (E.g. M300), can have a controlled landing even with one stopped engine. The choice of a hexarotor among professionals was for years justified by the fact that it could have a controlled landing even if one of the engine fails; octarotor, however, maintains the ability of safe and controlled landing even when two engines malfunction.

The manoeuvring of multirotors happens with relative acceleration of some of the engines. For forward movement the rotation speed of the rear engines is increased, the UAV tilts and with the help of horizontal components of propulsion the vehicle starts moving in the direction of the tilt. Such manoeuvring method must be reckoned with when we wish to attach a sensor on or under the drone, since in case of an inflexible attachment, the angle of the sensor changes in relation to the ground. University of Berkley, USA, has developed a quadrotor configuration QUaRTM that only tilts the engines in forward flight (Tang, Jain, & Mueller, 2022).

Engines can be placed differently on the drone frame, a symmetrical configuration being the most common one: E.g. a typical hexarotor has six equally spaced arms and propellers with *alternating rotation* direction (*CW – clockwise; CCW – counter-clockwise*). Engines can be configured coaxially, i.e. one arm having two rotors that spin in opposite directions. Coaxial configuration enables us to make considerably smaller drones and use longer propeller blades. This way, with the coaxial configuration of engines, it is possible to achieve a more powerful thrust in vehicles with frames of similar size than with a regular single configuration of engines. One of the drawbacks of coaxial configuration is a noticeable increase of the noise of the propellers and the decrease of flight time, since turbulence created by the engines reduces their efficiency.

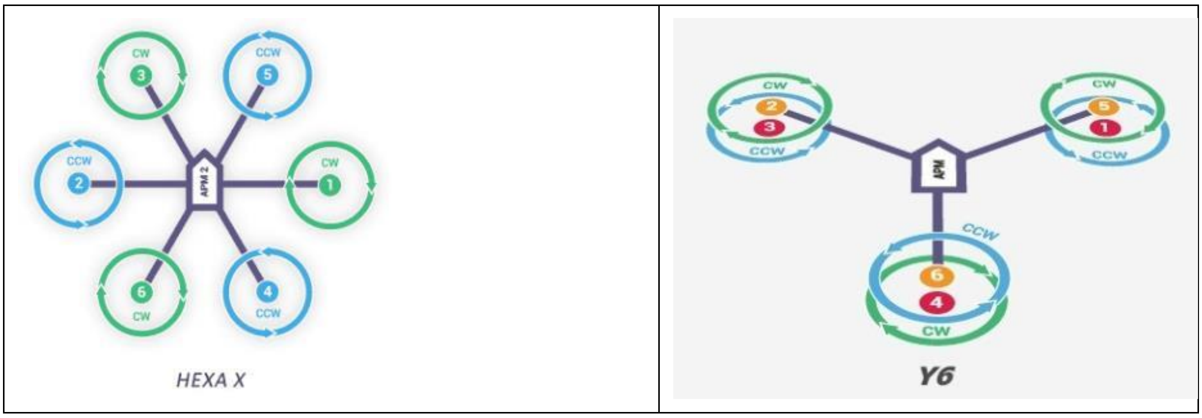

Image 4. Two most common hexarotor engine configurations: left, single and right, coaxial configuration.

The configuration of engines determines the maximum propeller diameter. Larger propellers are more efficient (= longer flight time), yet, at the same time, this results in a reduced UAV manoeuvrability since higher inertia does not allow a quick change in rotation speed. For instance, vehicles built specially for mapping do have larger propellers, for it is of foremost importance to lengthen flight time and thus extend the possible area covered. In such cases, the precise and fast manoeuvring ability is not a priority. On the other hand, the ability to manoeuvre might become more important in comparison to flight time for example in film industry or in aerobatic flights – UAVs performing such tasks have smaller propellers.

The most common multirotor communication solutions between the drone and its ground station use either 2.4 GHz or 5.8 GHz radio frequencies. It must be borne in mind that communication frequency ranges given in product description are reliable only in case of *line-of-sight* (LoS) and in spaces relatively empty of other communicators. As 2.4 GHz is a regular *wifi* frequency, disruptions foremost occur in city environments, but often also near radio masts and towers. In practical terms, this means that flying a drone on a forest path where the dense forest separates the operator from the drone, the 7–8 km frequency range promised by the manufacturer in reality shrinks to approx. 1 km range. Contemporary drones are able to identify less occupied communication frequencies i.e. channels and hop from one frequency to another without breaking the connection (*frequency hopping*); what is more, communication can also be encrypted if necessary.

Communication range can be increased considerably by directional antennas; for example, DJI, a well-known multirotor manufacturer, offers such accessories for their UAVs that are also available in retail. Nevertheless, communication range is usually not a problem in multirotors, since their relatively short flight time does not support long distance flights anyway. Various vendors offer drone control command accessories that work using mobile networks (E.g. Sky Drone 4G upgrade module for Yuneec H520 drone).

Multirotors can be purchased with integrated cameras, changeable integrated cameras, or as platforms for the user to configure a customised load.

Considering the above:

1. Because of the **ease of use** and **price**, UAVs with one integrated camera, the so-called foldable drones can be rated as best (E.g. DJI Mavic series, Autel Evo series, Parrot ANAFI);

2. Because of **ease of use** and **capacity**, UAVs with a combination of changeable integrated cameras are the best (E.g. DJI Matrice series, Yuneec H520);

3. The **greatest freedom** is provided by a standard platform, that can be supplied with necessary accessories, i.e. sensors etc., either by the manufacturer or the consumer (E.g. Acecore Zoe, Vulcan D series, DJI Matrice 200 series) (see also Image 4).

In case of the two first options, the consumer is quite clearly tied to one manufacturer and one product series (i.e. when switching to a new version the consumer needs to change the batteries, controller, cameras, etc.). In case of the third option, you can update the drone modularly by just changing the communication system, or replacing an old sensor for a newer and more powerful one. This freedom does require more work hours that are spent for creating a ‘communication’ capacity between the drone platform and its sensors.

Image 1. Images of some of the multirotors mentioned in the chapter; images from the manufacturers' or vendors' websites.

1.2. Drone planes

Janno Berg-Jürgens, who defended his MA at Estonian University of Life Sciences has compiled a comprehensive overview of UAVs in Estonian (see Berg-Jürgens, 2015).

In case of planes, thrust is created by pressure difference caused by the airfoil shape of the fixed wings. For a sufficient lift, the plane needs minimum stall speed that is necessary for the plain to sustain altitude. What is important is that it is the relative speed of the wing and its surrounding air mass – thus, in case of a strong wind, for example, flying downwind the ground speed of the airplane must be considerably higher: the stall speed of the plane plus wind velocity. At the same time, flying headwind lower speed is enough: stall speed minus wind velocity. Therefore, a drone plane needs a special air flow velocity sensor i.e. *Pitot* tube (Image 6) that measures the airspeed of the aircraft in relation to the surrounding air masses. The *Pitot* tube is of critical importance for airplanes and it needs uninhibited air flow for its functioning. It is therefore extra sensitive to clogging (dust, ice, etc.) and needs to be covered during transportation. At the same time, it is of critical importance to remove the protective cover of the tube during the flight!

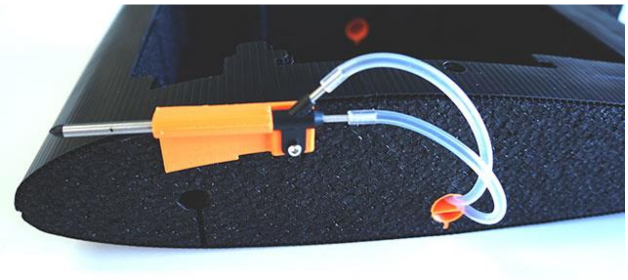

Image 2. Engine and rod for moving flight control surface.

Since the thrust of an aircraft derives from the movement of the wing in relation to air, UAVs need relatively high speed for flying (typically >10 m/s) or a very large wing area (tiiva pindala). Therefore, drone planes are not suitable for mapping small objects and manoeuvring in constrained spaces. At the same time, in comparison to multirotors, drone planes are considerably more effective in regard to energy use. Flight time of plane drones equipped with LiPo batteries can extend to 1 to 3 hours, and their speed allows to cover an extensive area during flight time. Drone planes are substantially more sensitive to balance shifts and therefor need re-balancing after the exchange of load. During the flight the plane moves by changing the shape of the wing and/or tail, using a special rod to move flight control surfaces (Image 7). In cheaper equipment, the driving engine and connecting rods are located outside the frame of the plane and can therefore get loose during the flight etc. Check the control system before the flight!

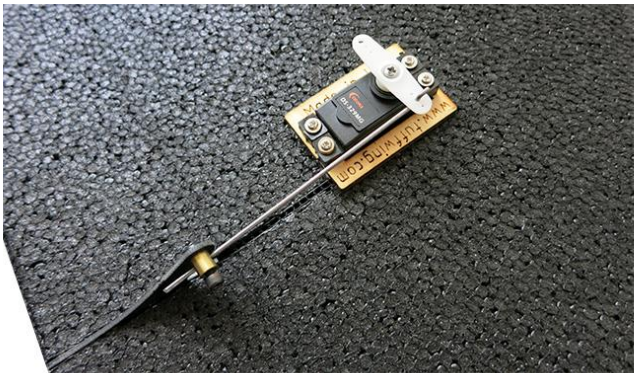

Image 3. Engine and rod used to move the support surface.

Take-off speed is given to the plane upon launch by either throwing the plane, using a specific catapult, or accelerating the plane on the runaway. Taking off and landing are the most dangerous parts of the flight for unmanned (actually, for all aerial) vehicles, since the drone plane has to accelerate or lose speed in a very short time. Thus, any failure in these phases of flight can have catastrophic results. It is reasonable to use wind direction: start-off and landing should always take place downwind. Upon landing, some drone planes turn themselves (semi) automatically downwind, for this helps to minimise the risks of touching the ground with the tip of the wing upon breaking, a practice that will generally not end well.

A typical drone plane needs at least around 100 metres long and about twenty metres wide runaway, finding it on a terrain might be a serious problem. A wider flight range of a drone plane can solve this issue: a suitable landing place can be located on a distance from the object to be mapped.

To ease the landing several additional solutions have been offered:

- **Circle to land** procedure, during which most of the speed and latitude is lost circling the landing area, descending at the same time. Landing, however, is completed by flying straight forward. The radius of the circle can be quite large, since plains are unable to make abrupt turns and therefore need enough space in every direction and altitude around the landing area.

- **Autoland landing**, operated by a navigation computer. In order for this procedure to work, an aircraft needs a *Pitot* tube and proximity sensor (usually either a laser range finder or ultrasonic sensor). Most contemporary flight controllers (E.g. Pixhawk) are able to help the drone plane land efficiently and consistently. However, drone plains still need a fairly long and wide runway.

- **Parachute landing** is landing aided by a parachute attached to the drone plane that can be opened at a pre-programmed point of impact or by radio communication. Parachute can be used for emergency landing, for example, when the plane has lost control etc. Parachute efficiently solves the issue of large landing area, but after the parachute is opened the plane becomes completely uncontrollable and may hit treetops, bodies of water, etc. What is more, landing cannot be stopped once the parachute is opened. Parachutes are installed in more expensive UAVs to soften the emergency landing.

- **Braking with propellers**. In order to make the plane lose speed fast immediately prior to touchdown, the pitch of the propeller blades is changed for a moment providing thus reverse thrust (E.g. AgEagle Ebee series drone planes).

Just before landing, the engines are turned off, the fuselage is kept lined up with the landing surface and the plane glides to the ground. Smaller drone planes usually land directly on their ‘belly’, larger planes have landing gear and wheels similar to manned airplanes. To avoid rapid wear of the airframe during frequent landings, grass fields are the most suitable landing surfaces for smaller drone planes. This also reduces the risk for camera damages.

In case of operational flight control surfaces it is possible to land the drone plane despite of (the main) engine malfunction. However, the plane will lose control if something happens to the flight surface control mechanism.

The wider flight range of drone planes needs communication systems with wider range for which purpose, apart from 2.4 and 5.8 GHz frequency already familiar from multirotors, also lower frequencies that travel further are used. Frequencies used are 1.2–1.3 GHz, 0.87 GHz or 0.43 GHz. Frequencies affect the speed of data transmission. For instance, in real time, a drone is able to transmit an image with reasonably good resolution on 1.2 GHz frequency; the bandwidth of even lower frequencies is only capable of transmitting telemetrics (location, speed, distance and altitude of the drone).

Mapping an area with the help of a UAV does not usually require the transmission of images in real time, since the gathered data is recorded on a SD card or hard drive. At the same time, real time data transmission is necessary for search and rescue purposes. To increase the communication range several accessories are used. One of the most common ones is a directional antenna (E.g. *Yagi* type antenna) along with antenna tracker that keeps it directed at the drone. In addition to that, several manufacturers have started to offer integrated communication solutions compatible with 4G networks that at least in theory offer unlimited communication range within the mobile network. It will definitely gain wider use in the future, but presently an inhibiting factor is the fact that G4 network is currently optimized for terrestrial use (meaning the antennas are pointed at the ground), thus the reception might be poor at about 100 m above ground.

Obstacle avoidance system has become common in multirotors, but despite their descriptions in scientific literature (E.g. see Lin *et al*., 2018), according to the present author, these are not available for drone planes. However, drone planes and other drones can be equipped with transponders (*ADS-B out*) or at least with a passive transponder transmitter (*ADS-B in*) that allows air traffic controllers to follow them, or at least spot a vehicle equipped with a transponder approaching. Larger, < 250 g drones manufactured by DJI, have the inbuilt capability (*AirSense*) since 2020. Some models require turning it on from the menu, following what the remote starts transmitting a warning when a nearby UAV with a switched-on transponder that moves on a potential collision course is spotted.

A particular characteristic of drone planes is that payload needs to be placed completely inside the plane, since all the 'protrusions' are not good for flight dynamics and decrease flight time considerably. The fields of military and search- and rescue use sensor balls that can be moved in/out of the fuselage if necessary. There is generally not enough space inside the fuselage, and, what is more, the entire set needs to be balanced, for what reason drone planes are often designed for carrying one specific battery and camera that cannot be easily exchanged without seriously affecting flight characteristics.

According to the present author, from drone planes only AgEagle Ebee X field-ready solutions that are equipped with both regular as well as multispectral cameras are sold in Estonia, drone planes that are probably the most common also elsewhere in the world. Some of other most common models include Trimble UX5, Delair UX11, Honecomb AgDrone and a C-Astral Bramor or Delair DT26 series that already belong to the top league of drone planes (Image 3). Parrot Disco is a good drone plane for the beginners to start practicing with. In conclusion, it must be mentioned that the importance of drone planes has definitely diminished, since they have been replaced by hybrid-drones that combine the best qualities of drone planes and multirotors.

See the comparison of multirotors and drone planes in the following table (source: www.dronedeploy.com):

Summary Comparison

Maneuverability	✓	✗
Price	✓	✗
Size / Portability	✓	✗
Ease-of-use	✓	✗
Range	✗	✓
Stability	✗	✓
Payload Capacity	✓	✗
Safer Recovery from Motor Power Loss	✗	✓
Takeoff / Landing Area Required	✓	✗
Efficiency for Area Mapping	✓	✗

Trimble UX5

DataHawk

Ebee

Lancaster 5

Sentera PHX

AGdrone

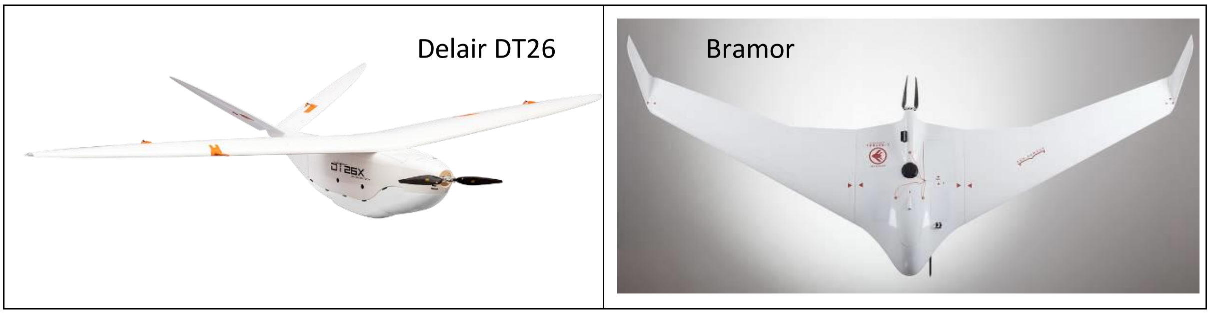

Image 3. Some images of the drone planes mentioned in the chapter.

1.3. Hybrid drones

In order to combine the best qualities of multirotors and drone planes, several hybrid versions have been constructed, generally known as hybrid or VTOL drones (***v****ertical* ***t****ake-***o****ff and* ***l****anding*). The main goal of such hybrids is to make use of the vertical and slower take-off and touch-down inherent to multirotors in combination with fast and effective flight characteristics of drone planes. Nevertheless, there are numerous different solutions an overview of which together with pictures can be found in Saeed *et al.* (2018). What follows is a brief overview of some of the most common and available hybrid solutions.

The simplest and most common hybrid drone is the so-called *quadplane* drone, that is basically a plane mounted on multirotor 'frame'. Both parts have their own engines and propellers optimized to cover a specific flight phase. The multirotor part of the hybrid operates an active take-off and landing as well as acceleration. Drone plane characteristics dominate in the main and stable flight phase. The assortment of such hybrid drones on the market is possibly the widest (E.g. Vertical Technologies DeltaQuad or C-Astral SQA) (Image 4).

Other solutions used in hybrid drones are as follows:

- Tilt-rotor drones (Autel Dragonfish or ARACE GriffinPRO);
- Tilt-wing drones, the use of which is not that wide spread any longer;
- Tail-sitter drones, the entire plane takes off/lands in a vertical position (WingtraOne GEN II or HG Robotics Vetal);

Nowadays, hybrid drones are quickly claiming the part of the capabilities and market that was previously covered by drone planes. Hybrids need less space to complete the tasks and the risks of damaging the drone (or something else) in take-off/touch-down are considerably smaller. Furthermore, hybrid drones can 'stand still' and move vertically, if necessary.

Nevertheless, in comparison with drone planes certain negative characteristics can be brought out – hybrids are technically more complex, that means they are also more expensive, and their flight range and -time is somewhat more limited than in drone planes.

Hybrids' communication and mobility solutions are basically a combination of what was already introduced in the sections about multirotors and drone planes.

DeltaQuad

C-Astral SQA

WingtraONE GEN II

ARACE GriffinPRO

Image 4. Some images of the hybrid drones mentioned in the chapter, photos taken from the manufacturers’ websites.

1.4. Energy source for drones – lithium batteries

The flight time of UAV is dependent on the technology of the battery (capacity) and the weight of the aircraft. In addition to that, flight time is significantly affected by the manner of flying, primarily acceleration time, and the weather (for more detail see chapter on flight planning).

It can be said that battery is one of the most expensive components in UAVs and at the same time it counts as consumables, since during the cycles of discharging-charging the battery gradually loses in its operational ability. Today, UAVs used in the civil sector operate predominantly on lithium polymer batteries (LiPo), drone planes use lithium-ion batteries as well (Image 3).

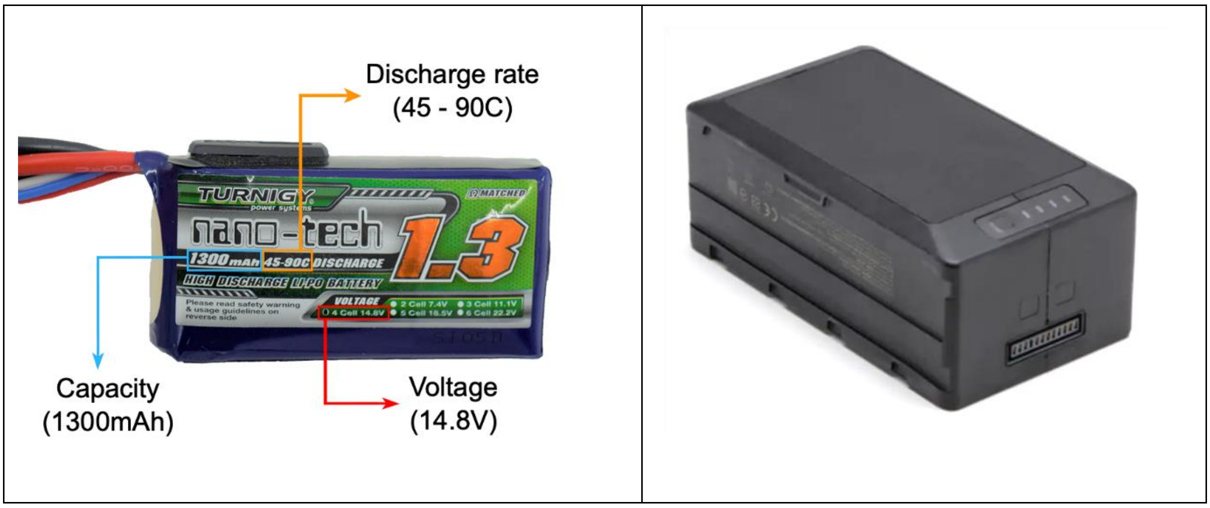

Image 3. Left, a regular LiPo battery along with the explanation; Right, a 'smart' LiPo battery DJI TB60.

In addition to the regular LiPo battery technology, first solutions based on hydrogen fuel cell technology are being implemented. In Estonia such technology is developed by Skycorp, who promises approx. two to three times increase in flight time with batteries that can be charged in a couple of minutes.

Military sector uses hybrid technologies combining internal combustion engines, generators and batteries that enable to increase the flight time of multirotors for 3 and up to 5 hours (see Eg. Foxtec Thea). There are also tethered or cable UAVs, in which case the UAV is not powered by a battery but via a cable by a generator on the ground; optical cable is also used to send data to the checkpoint on the ground. In such a case, the flight time of the UAV is relatively unlimited; however, the mobility of the drone is minimal. The best-known vendor of such solutions is Elistair.

Batteries kept in good condition and used according to the instructions can last for 200 to 300 charge/discharge cycles. The number of cycles decreases considerably if certain simple rules are not followed (see the Checklist below). However, risk management includes closely following fire safety regulations. LiPo batteries contain an organic flammable solvent and shorting the battery on any reason might bring along uncontrollable fires.

For fire safety reasons, and to lengthen the life of the batteries, the so-called smart batteries have become increasingly more used that in addition to the LiPo battery elements contain a range of electronic components that measure and monitor for example the temperature of the battery, its internal resistance, number of charging cycles, and a series of other parameters. In addition, if not used for an extended period, most so-called smart batteries can charge/discharge itself to storage voltage. This means that when you have charged the battery for example a month ago, you might discover during fieldwork that the UAV only has 40–50% out of the planned flight time left.

Some UAV batteries for professional use, such as DJI TB60, feature an integrated heater that allows the batteries to be used with up to -20 °C. Naturally, this feature uses extra energy and thus shortens flight time. As a rule, cheaper consumer drones' batteries do not have such preheating possibility and using them in temperatures not recommended by the manufacturer can result in damaging the drone.

Technological improvements with the help of the so-called self-analysis has made the use of LiPos not completely risk-free, but considerably safer.

The most recent development is the establishment of automatic charging stations, drone docking stations and landing pads that enable the UAV to land and recharge after returning from the mission. Such solutions are especially suitable for industrial areas with fixed perimeter or for routine pipeline checks. Evidently, such solutions are good in areas that need permanent monitoring and that are located in fast-changing environments (E.g. landslides, volcanoes, etc.). Several companies already offer such solutions, the largest manufacturer DJI offers docks integrated with DJI M30 drones.

An interesting development concerns aircraft drones such as Airbus Zephy that boast a combination of solar panels and batteries, a solution that lengthens the flight time practically indefinitely (in 2022 it flew continuously for 64 days)

Checklist:

- Do not charge/discharge damaged, incl. 'bloated', batteries!
- Damaged LiPo batteries or the ones that have reached the end of service life are considered hazardous waste that must be deposited separately from other household waste.
- Charge/discharge batteries with a reputable and well-balanced LiPo charger!
- Use a fireproof LiPo bag (costs ca 10 EUR) or a metal container (E.g. ammunition box) for charging and storage of batteries.
- Batteries must be charged under supervision only! Batteries self-ignite very seldom, but when it happens, the fire progresses rapidly and is very difficult to extinguish.
- Do not overcharge LiPo batteries (4.2V/cell; LiHV batteries 4.35V), nor must they be completely discharged (below 3.2V/cell). Overcharging may cause an explosion, and excessive discharge will considerably shorten the life/capacity of the battery.
- When storing batteries for longer periods (longer than 3–5 days), the recommended storage state-of-charge is 40–50%, since storing fully charged batteries for lengthy periods decreases their life/capacity and increases their flammability.
- When charging the battery taken from storage, it is recommended to discharge the battery (to 10–15%) for a moment, and only then charge it to the full. In case the capacity of the battery is not fully used during the flight, it is advisable to repeat this procedure after about 50 flight cycles or every three months.
- Heat can shorten the service life of the battery (> 40–50 °C). Do not charge the battery that has just been used and is still warm, since charging also increases the temperature!
- Never leave the battery in a car on a hot day!

- The capacity of the battery decreases considerably when its temperature drops below 5–7 °C. With temperatures below zero you need to pre-warm the battery.
- When the temperature of the battery has dropped below zero, you need to pre-warm it before charging, since charging such a battery will damage it permanently!
- When flying a drone you need to leave a reserve of ca 20–25% from its general energy capacity. When the temperature drops below 0°C, it is reasonable to avoid abrupt accelerations of the drone and reserve 30–40% of the total energy capacity of the battery.

1.5. Positioning

In order for the information collected with UAVs to be used, it has to be positioned in space. The data is also necessary to locate the drone. For this, GNSS (*Global Navigation Satellite System*) is used that combines satellite systems such as GPS, GLOSNASS, BEIDOU, GALILEO, which are developed and maintained by different countries. Generally, the accuracy of geopositioning technology used on UAVs remains within the range of 2–5 m, a range similar to smartphones. Such accuracy is usually not enough for example for (repeated) mapping, which requires aligning ortophotos taken at different points in time with the precision of one pixel – typically < 10 cm.

The most common way to achieve and later check the necessary accuracy is using reference points on the ground. Reference points are divided into tie- and checkpoints (see chapter xxx) and their coordinates are calculated with devices allowing necessary accuracy, generally with a high-accuracy GNSS receiver. Tie points are used for a more precise georeferencing of the data, E.g. ortophotos, and checkpoints for error characterization. Basically, reference points need to be marked on the terrain so that they are clearly recognisable – for example, for photos colour marking is used, for LiDAR work markers with a specific shape, for thermal work aluminium markers that reflect the sky, etc. To get a good result such points need to be located evenly throughout the area to be mapped and their number depends on the degree of accuracy of the concrete task. It must be kept in mind that in addition to the horizontal coverage, we must also consider the even vertical distribution of reference points. In case of ortophotos, it is advisable to mark one reference point per 1– 10 million pixels (Singh and Frazier, 2018). Often the marking and measuring of checkpoints is the most time-consuming part of UAV mapping.

More accurate GNSS devices for drones are available on the market since 2018. These have accuracy (1–5 cm horizontally, <10 cm vertically) that is already enough in most cases for the *direct georeferencing* of data, allowing accurate georeferencing of single photos taken by the drone or data points in case of laser scanners, and the number of ground tie points drops significantly or the necessity disappears altogether. Independent check points are still necessary for the accuracy check, but as accuracy evaluation goes now already along with every photo, a couple of checkpoints should suffice.

Mostly two precision GNSS solutions are used: **PPK** (*Post Processed Kinematic*) and **RTK** (*Real Time Kinematic*). In both cases two simultaneous GNSS sensors are needed, whereby one is attached to the drone and the other is an immobile or static base station located somewhere nearby. The two devices must be located as close as possible to each other for them to receive signals from the same satellites, and for the atmosphere conditions to be the same. The *baseline* of the two GNSS devices determines the absolute accuracy of georeferencing: for example, in RTK module accuracy is characterised by „1.5 cm + 1 ppm“. In which case „1.5 cm“ is an error anyway, but „+1 ppm“ means that for each ten kilometres of distance between the drone and the base station, the error margin increases one centimetre.

The static base station on the ground can be another GNSS receiver, or data from a more distant fixed reference station is used, from which a GNSS correction is received over mobile data transmission, or the data are available for a later download from the network. Networks have been created from fixed reference stations (CORS - *Continuously Operating Reference Station*) in most of the European countries. Such a network provides an opportunity to set up virtual reference stations (VRS) between the base stations to decrease the distance between the UAV and the base station in comparison to the actual base station. Estonia has a network comprised of 27 fixed base stations offering GNSS correction sharing services (ESTPOS). In addition, there are several privately owned and managed networks of fixed stations in Estonia (E.g. Trimble, Hades, etc.).

In case of PPK solution, the calculation of accurate coordinates takes place after the flight, in case of RTK, however, in real time. Thus, when using RTK, a constant bilateral communication between the UAV and ground controller and the network of fixed stations is inevitable. The communication between the UAV and the controller is conducted via a communication channel meant for telemetry. However, guaranteeing constant communication during the flight can be complicated in some cases. In case of PPK solutions, both GNSS's data is saved simultaneously and the correction of coordinates takes place later in the computer. This enables the user to choose the calculation schemas more flexibly and analyse the errors more accurately. PPK systems are thus considered to be more reliable, but in comparison with RTK they are more labour intensive. However, one does not exclude the other: RTK by default allows recording GNSS data and, if necessary, conduct PPK processing later.

Both PPK and RTK solutions have been compared to the method of ground referencing points. Experiments show, that the more accurate location of photos (Stöcker *et al.* 2017; Turner *et al.* 2014) along with the calibration of the camera (Carbonneau and Dietrich, 2017) allow achieving the necessary accuracy (almost) without the time-consuming marking of reference points. By 2022, virtually all the UAVs for professional use possess either RTK and/or PPK capabilities; what is more, PPK additional modules can be added to older UAVs (E.g. Emlid Reach or Topodrone products). Both high precision GNSS solutions the precise moment of taking the photo must be recorded – for that, an accessory fitted to the *hotshoe* is generally used.

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