SAFE DRONES OVER SAFE ENVIRONMENT

HANDBOOK

DRONE - Unmanned Aerial Vehicle (UAV)

2020-2023 SAFE DRONES OVER SAFE ENVIRONMENT

Tempus Foundation Erasmus + 2020-1-RS01-KA202-065370

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Preface

The Erasmus+ project "Safe drones over safe environment" (2020-1-RS01-KA202-065370) presents cooperation for technological innovations and environmental performance Improvement which are the most important needs of the industry. This strategic partnership links the four aviation VET schools:

- Aksu Ucak Bakim Teknolojisi Meslek Ve Teknik Anadolulisesi, Antalya, Turkey,
- Istituto Tecnico Commerciale"G.P. Chironi", Nuoro, Italy,
- Asociacion Centro Benefico Ada Avenida Turia, Sevilla, Spain,
- Aviation Academy (Vazduhoplovna akademija), Belgrade, Serbia.

The project gave chance to share experiences, exchange good practices and cooperate to transfer our schools to a higher level expanding and internationalizing the educational and technical activities of the institutions and participants.

The handbook, as a compilation of all researches, analysis and conclusions during the project duration, is a guideline comprising all the researches that have been done throughout the project. The handbook is published as final version online and will be available for free to all other aviation students and teachers, not only in participating schools but all other stakeholders. The publication will be published in English, and translated in mother tongue of participating schools. A4 format teaching materials allows for easy copying and use of the material in class. The use of handbook (translated into mother tongue) has been integrated into curriculum of each school and covers topics of the subject approved / updated by Ministry of Education / VET centers. The handbook can be used in total or partially as didactic and educational resource in aviation schools around the Europe, or as a starting point for advanced researches and improvements of designed drone and environmental data collections. This output will be of great importance to all the teachers being involved in secondary aviation schools all around the Europe and it may be used as a primary or secondary teaching resource, depending on the curriculum of every school. This compilation of teaching materials, being published as the first version, may be expanded in future after the project is over, depending on further innovative contribution of aviation teachers and forthcoming cooperation that is expected among many European aviation schools.

This handbook was produced within the project "Safe drones over safe environment", (2020-1-RS01-KA202-065370), which was financed by the Erasmus+ program of the European Union.

1 Introduction

The Unmanned Aerial Vehicle (UAV) does not have a flight crew. It is controlled by a navigator (pilot), remote transmission of signals from the ground, vessels on the water or from the airspace, and most often from the control station. It depends on the category, purpose and specific mission of the UAV. The flight can also be autonomous, according to a programmed trajectory. Most often, the unmanned aerial vehicle is operated in a combined manner, by conducting signal transmission from the operator, and certain parts of the trajectory take place autonomously. In autonomous flight, the data for a certain state vector corresponding to that part of the trajectory is previously stored. This independent segment of flight exclusively supports and controls the autopilot. Unmanned flying is gaining more and more importance in all aviation branches of use and the entire human activity, especially in countries of great technical and material potential. This is primarily due to the rapid shifting of the boundaries of technology development: propulsion, microelectronics, the development of powerful sophisticated sensors for automation, artificial intelligence, robotics, etc. UAV for military application paves the way with the largest investment in the development of advanced technologies, which primarily serves to compete in achieving combat prestige over a potential adversary. That competition is provided by high and favored military budgets. With the cessation of the exclusivity of these technologies in the military, they gain the status of wide application. In the first level of development, UAVs were used as targets in the airspace, to check and train the operators of the air defense system (Air Defense).

Previously, older aircraft, retired from operational use, were used for this purpose, which the pilot balanced (trimmed), in the last flight and left, just before the shooting, in a part of safe and free airspace. There are disposable UAV solutions - “suicide bombers.” They are full of explosives and are used to destroy particularly important targets, similar to cruise missiles.

The purpose of UAV has expanded significantly, except for military use it is widely used in sports, economy, and unfortunately in terrorism as well. With the further advancement of technology, the range and scope of their purpose is expanding. Abuse is becoming increasingly difficult to control, making it a global problem.

UAV is primarily intended for multiple use and it is defined according to all rules of the profession the same as other aircraft and, if necessary, it is remotely controlled by the operator. The flight of the cruising missile takes place autonomously, using the chosen principle of self-guidance and target recognition.

It differs from the piloted aircraft in that it does not have a cabin and other necessary conditions for the presence and work of the flight crew (pilot) are not provided.

The technique and principle of take-off and landing are often identical to an aircraft with a pilot, and there are also solutions with catapulting and parachute landing. They take off from land, ships, and recently from transport aircraft as well. For the aerodynamic and constructive scheme of the UAV, airplane standards are more often used rather than helicopter standards. Simple, non-standard flying platforms are also increasingly used.

Figure 1: Yugoslav People's Army (YPA) air defense training aircraft with radio control (RC)

The most widespread use of UAV is in the military. Gradually, military UAVs were trained for increasingly demanding tasks. In the early period of development, they were exclusively reconnaissance and spy, and later they were also used for complex air-to-ground and air-to-air combat tasks. The US Air Force plans to have a huge increase in the UAV fleet in operational use by 2047, and other armies around the world have similar plans.

It is quite certain that the sixth-generation fighter planes will be unmanned, with the alternative possibility of using crew. It is realistic to expect that the seventh generation planes will primarily be unmanned. The distinction between UAV, in relation to unmanned fighter jets and other aircraft (with remote control), is still not clear. Experts do not yet have a clear opinion on this issue.

There is a wide range of projects and applications of unmanned aerial vehicles. There is an even greater range of their sizes, which vary between two extremes, from the imitation of insects to the dimensions of flying fuel tanks, and up to the mass of combat UAVs of several tens of tons.

Figure 2: Lighting system for UAV.

2 History

A historical consideration of the development of unmanned aerial vehicle technology leads to the conclusion that it is based on the principle of transmitting commands by radio signal, the "child" of the genius Nikola Tesla. Nikola Tesla patented this ingenious invention of his under number 613,809. It has become the basis of unmanned aerial vehicle technology, known as radio control (RC), on which modern robotics is based. Nikola Tesla first demonstrated remote control of vehicle movement at the end of the nineteenth century. He demonstrated remote control on a model of ship using a radio signal on the lake in Madison Square Garden in 1898. This is the first such application of radio waves in history, with which Nikola Tesla indebted the world a lot and even deserved great recognition. With his invention, Tesla laid the foundation and pointed out the potential for further development of unmanned aerial vehicles, as well as for other advanced technologies. That fact is mostly unjustly kept silent.

More concrete approaches and the development of UAV date back to the beginning of the twentieth century. At that time, they were primarily thinking about their application on the object as a target in the airspace for the training of anti-aircraft defense (AAD) artillery crew. The development of unmanned aerial vehicles continued during the First World War. Then, the Dayton-Wright airline developed a flying torpedo, without a pilot, which was pre-set to explode at a certain time.

Significant progress followed after the First and during the Second World War, in the leading armies of developed countries. Nazi Germany also produced and used various UAVs during that period. In World War II, the military used flying airplane models to train anti-aircraft artillery operators to track moving targets in the airspace. The exercise was reduced to an angular tracking of a moving target, which flies in the air, by turning the barrel of the weapon and hitting it in the field of view, with a radio signal, in 1898. The analogy used here is that the angular velocity of rotation of the weapon barrel is the same both for the case of the target movement at high speed and at high altitude as well as at low speed and at low altitude. It is a credible weapon aiming exercise for a soldier, who operates on the cannon, and thus the basic conditions for that level of training were met. The Yugoslav People's Army (YPA) also used this method of training its air defense artillery battery crew. After the Second World War, with the introduction of jet engines for aircraft propulsion, significant development and operational use of UAV for military purposes began. UAVs were widely used in the Vietnam War in the tasks of reconnaissance, laser marking of targets and guiding manned aircraft to more important targets.

The American Air Force, being worried about the great losses of pilots over enemy territory, began to plan the deployment and use of unmanned aerial vehicles in 1959. Planning accelerated after the Soviet Union overthrew their reconnaissance U-2 aircraft in 1960. A highly sophisticated UAV development program, codenamed "Red Wagon", was soon launched. The military conflict in the Gulf of Tonka between the units of the American and North Vietnamese navies in August 1964 intensified the combat use of American drones in the Vietnam War.

When the Government of the People's Republic of China showed photos of downed American drones, official America was left "without comment". However, later, in 1973, they confirmed that they used UAV in Southeast Asia (Vietnam).

More than 5,000 American airmen were killed in that war, and over 1,000 were missing or captured. The 100th Strategic Reconnaissance Wing of the USAF carried out 3,435 drone missions during that war, losing 554 units. General George S, Brown, the commander of the air force, stated in 1972: "*The only reason for using the UAV is that we do not want to unnecessarily risk the lives of people in the cockpits of airplanes*." Later that year, General John C. Meyer, Commander-in-Chief of the Strategic Air Command, said: "*We leave a high degree of risk to drones, their losses are high, but we are ready to bear them and thus save the lives of pilots*."

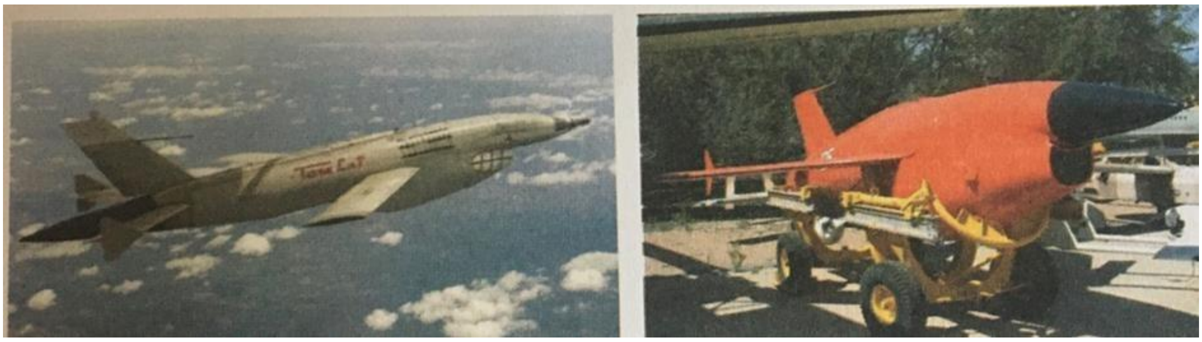

Figure 3 left: UAV Ryan 147, right: Ryan Firebee is one in a series of developed UAVs; it flew in 1951.

In the Yom Kippur War of 1973, Israel used drones as bait to challenge enemy forces to launch and consume as many expensive anti-aircraft missiles as possible. After this war, several key team members, who developed these early cheap UAVs, joined a small company that began developing them as a commercial product. In the end, that became the basis for the development of the first significant Israeli military UAV.

Figure 4 Israel's first tactical UAV Madiran Mastiff, launched in 1975

During the 1973 war, Soviet surface-to-air missile batteries in Egypt and Syria inflicted heavy losses on Israeli fighter aircraft. Based on that experience, Israel developed the first UAV with remote control and real-time field recording. Photographs and radar data from these UAVs helped Israel fully locate and later neutralize the Syrian air defenses, at the beginning of the Lebanese war in 1982, The concept of super-maneuvering flight control was practically proved for the first time in Israel in 1987, even after the "break" of the aircraft's lift (when the tail efficiency ceased). This was realized on the basis of the application of advanced technologies of three-dimensional control of the thrust vector of the propulsion jet engine on the UAV. This is realized in a very demanding research and development task. The first generations of the UAV were primarily used to perform reconnaissance tasks, and later, after a large number of surveillance missions and experience gained during the aggression on the FRY, the US Air Force was equipped with MQ-1 predator drones and armed air-to-ground missiles.

Figure 5. US Predator МК-1, launches rocket air to ground АГМ-114 Hellfire

With the improvement and miniaturization of applicable technologies at the end of the twentieth century, the interest in the UAV at the top of the American army grew. In the 1990s, a mutual cooperation agreement was concluded with the Israeli companies AAI and Malat. The US Navy purchased the AAI Pioneer UAV, developed and manufactured by AAI and Malat.

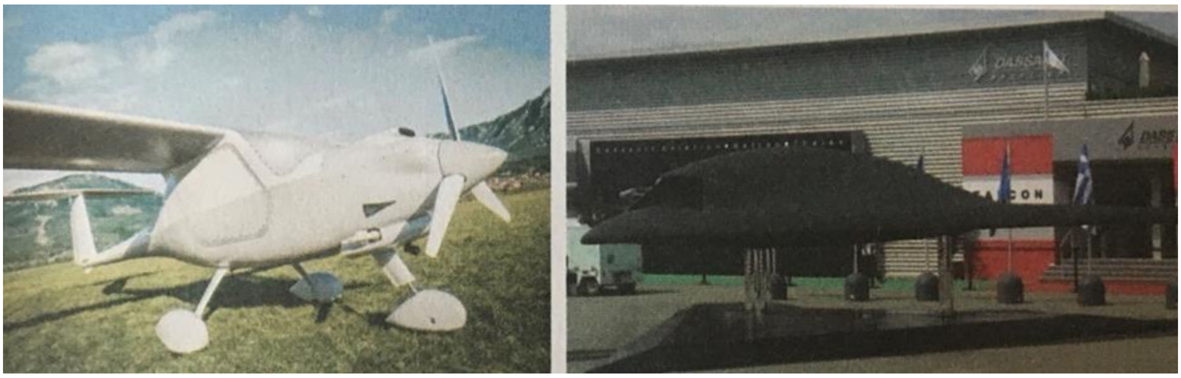

Figure 6 left: One of the many realized configurations of the UAV, right model of the most famous European UAV Nero.

Many of these drones were put into operational use in the 1991 Gulf War. They showed efficiency and a high ratio between the price of the performed task and their costs, without exposing themselves to the risk of the pilot's life. In 2012, the US Air Force had 7,494 UAVs in operational use. That is almost a third of the total number of aircraft of all types, the US Air Force. That number is growing every year. The Central Intelligence Agency (CIA) also owns UAVs and uses them in its operational tasks.

The UAV Neuron (stylized as nEUROn) is a European experimental UAV. Visibility is reduced, on the principle of the "flying wing" aerodynamic scheme, similar to the well-known American V2 spirit bomber. The carrier of the development of this aircraft is the French company Marcel Daso.

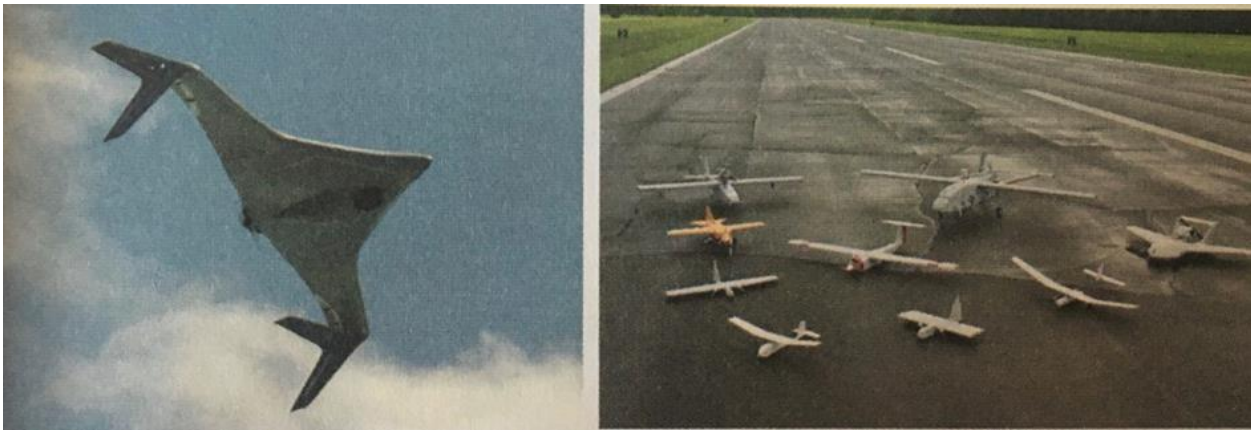

Figure 7 left: Gruman 's UAV carries EO / IR and SAR sensors, laser rangefinder, laser marker and infrared (IR) cameras, right: exhibition of American UAVs in 2005.

3 Main parts UAV

Drones are unmanned aerial vehicles that can be controlled with remote control, can be instructed, and can record video and images. It consists of a combination of components such as a drone, propeller, engine, fuselage, and flight control card. A drone consists of a frame (hull), landing gear, engines, propellers, Esc (Electronic Speed Controller), flight controller (Flight Controller- Autopilot) and GPS receiver, remoter and receiver, image transfer system (FPV), and it has batteries as well.

The difference in body formation is that a drone does not have a cockpit compartment from aircraft such as a helicopter or airplane. Drones have more than one rotor on them. Unlike helicopters, the number of rotors ranges from 4 to 8. Drones can perform the balancing process on helicopters thanks to rotor connections. Their biggest advantage is that they are unmanned aerial vehicles.

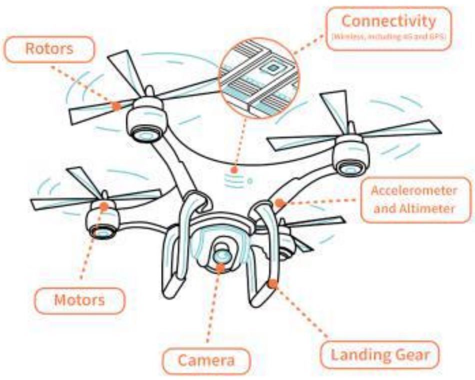

Figure 8. The parts of UAV

There are various sensors on the drone. These sensors issue flight commands based on the data collected.The magnetometer, gyroscope, and accelerometer signal the drone's direction vector, stability, and acceleration information. In order to be able to take off and land at the desired level, to make an autonomous flight, the engines create various operating modes according to a certain algorithm.

3.1 Drone Structure Material

⌘ Fiberglass drone kit

Fiberglass drone kit is mostly used in small and medium-sized UAVs. Compared with metal materials, fiberglass composite materials are lighter in weight. Figure 42.

Figure 9. Fiberglass UAV

⌘ Aluminum drone frame

Among metal materials, aluminum alloys are relatively low cost and light, meeting light weight requirements but the aluminum alloy frame is prone to bending deformation when subjected to external forces that will cause instability in flight.

Figure 10. Aluminum UAV

⌘ Engineering plastic drone kit

Engineering plastics are also lightweight materials that are more suitable for small drone frame manufacture, but actually air resistance can be clearly felt during flight.

Figure 11. Plastic UAV

⌘ Carbon fiber drone frame

Carbon fiber composite materials are preferred by many UAV manufacturers due to their excellent mechanical properties and weight reduction advantages. Applying carbon fiber composite materials to the frame can reduce weight.

Figure 12. Carbon fiber UAV

3.2 Drone Body Types

⌘ Quadcopter

It is the most popular used type of drone. It has two motors moving clockwise and the other two motors moving counterclockwise. This resets the angular momentum of the drone. It has a structure suitable for many flight control profits.Quadcopters have 3 different models.

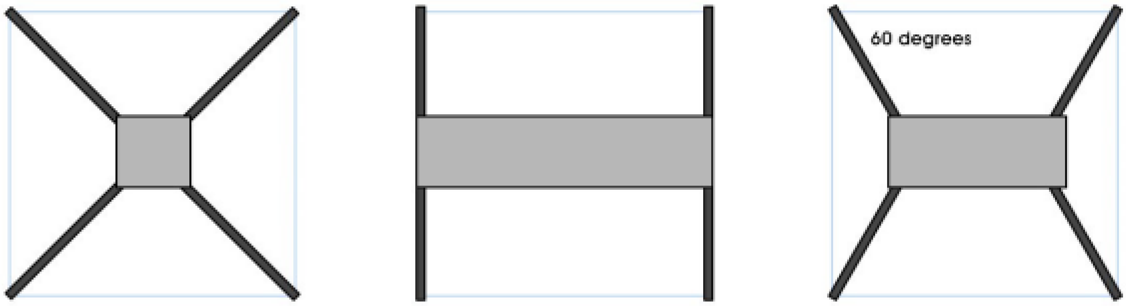

Figure 13. Quadcopter

⌘ X Body

It is easier to make as a DIY than other types of frames. Its arms are longer due to its smaller body size compared to other quadcopter types.

Figure 14. X body

⌘ H Body

Among the quadcopters, the drone with the most body area is the variety. Through this excess area the battery can be used, image transmission equipment, communication systems, flight computer and camera are included. The most important advantage of the H hull: it allows the camera to be directly on the midbody rather than the landing gear.

Figure 15. H body

⌘ Hybrid X Body

Adjusting the arms to 60 degrees allows the body to be shortened by 60% compared to the H body. Assuming both are made of the same material, it has a body that is 60% lighter than H body. Compared to an X body of the same size, its arms are 16% shorter. The camera is located inside the H body.

Figure 16. Hybrid X body

Drones are used in most parts of civil aviation and military aviation. The health sector, agricultural and cultivation applications, photography and cinema sector, mapping, cargo, traffic, and security can be given as examples of used areas of drones.

3.3 Body of an UAV

The primary difference in cabin layout between a manned aircraft and the same UAV scheme is that the UAVs are without a cockpit and windows. The UAV project scheme that is often applied is one with several helicopter rotors (rotary wings), usually four or eight. Aircraft without tail surfaces are: Crewed aircraft, known as helicopters, having one or two rotors, and one smaller tail to balance the deflection moment generated by the propulsion rotors.

The design scheme with four helicopter rotors (square) has become popular primarily for small UAVs, although this scheme is rarely used in manned aircraft.

Due to its advantages in wide application is the quadrotor (four motors with rotors) that gradually suppresses other conceptual schemes of the UAV project. Also, there are eight drive kits. Such UAVs are flying platforms that are capable of flying efficiently and for a long time autonomously by wireless communication. They can float in place for a long time, without changing their position, monitoring the environment and collecting information on natural disasters, weather and other conditions. The UAV project planning program consists of priority tasks related to: communications, sensors, flight commands and management of collected data. Wireless transceivers use signals sent by micro commands to quadrotor control units. The accelerometer, gyroscope and magnetometer deliver signals of the acceleration, stabilization and direction vector of the aircraft. In order to achieve the flight of the quadrotor in the desired phases of angular inclination, ascent, hovering or lowering, the engines change the operating modes to achieve certain forces according to the appropriate algorithm. Weather sensors collect information according to a certain pattern, and this data is further processed. The useful purpose of the quadrotor is to monitor the territory and monitor the weather conditions, in conditions where human participation is difficult. Quadrotor is a UAV that uses four rotary engines to change altitude and flight speed, control and stabilization. Unlike classic aircraft, the quadrotor can achieve and sustain vertical flight and hovering for a long time without changing altitude.

Figure 17: UAV with eight helicopter rotors

It is not burdened by the need for a constructive solution for the compensation of the turning moment caused by the rotation of the propulsion rotors, as in the case of helicopters, where a smaller tail rotor must be added for that. Moreover, the overall realization of the project is simpler and it is cheaper to maintain it in operation, than classic aircraft configurations. As technology becomes more advanced and affordable, many engineers and researchers have begun to design and implement squares for a variety of more ambitious purposes, realizing them on a larger scale. The same goes for UAVs with twice the number of rotor engines (eight). Professional groups, such as the military, engineers, researchers and hobbyists expand the range of using quadrotor in many areas. Therefore a large number of projects have been launched. This is due to the great possibilities of adapting the quadrotor to meet different, and often contradictory tactical - technical requirements. In this respect, they are ahead of most other UAV conceptual schemes.

However, there is another solution that also combines the characteristics of a biplane and a helicopter, using only one propulsion group (engine and propeller). The exit parts, all four half-wings, are also the contact parts with the ground during take-off and landing.

This design scheme enables vertical take-off, landing and hovering, with the possibility of rapid transformation into an airplane, relatively fast up to 110 km/h. It is a simple and very practical concept, which has the perspective of more mass application in UAV design. Also, it does not require a runway for its application, just like a square.

3.4 Propulsion

The performance of drones mostly depends on the propulsion system. When choosing a propulsion system, one should pay attention to the purpose of the aircraft itself, because it is the key factor for its selection. For example, certain military drones require significantly more powerful engines that do not have to be light and meet the environmental requirements, although these two requirements should also be met. Choosing the propulsion system itself is not an easy job because there is no perfect choice.

The right choice implies a compromise. It is extremely important to be aware of the requirements and their importance in order to know where greater deviations from the ideal can be made. One should also be familiar with different types of propulsion systems, as well as their characteristics.

The various types of propulsion systems used for drones, their characteristics, as well as how to choose the correct system will be described further in this paper. The goal is to create a clear picture of the options available and how to handle them.

3.4.1 Types of Propulsion in Aviation

Piston, rocket, electric, Wankel and jet engines are used in aviation.

- Reciprocating engines

Reciprocating (piston) engines are one of the oldest types of engines and when they appeared they revolutionized the world. Energy was used with minimal losses, and issues that diminish the value of the reciprocating engine today, such as the issue of maintaining the environment, were not asked.

Piston engines consist of a cylinder inside which there is a piston which is connected to the crankshaft by a connecting rod, which drives the propeller. Inside the cylinder, on the upper side of the piston, there are both intake and exhaust valves. The intake valves are connected to the fuel and air supply, and the exhaust valve to the exhaust system. Between these valves inside the cylinder is a spark plug whose role is to ignite a mixture of air and fuel.

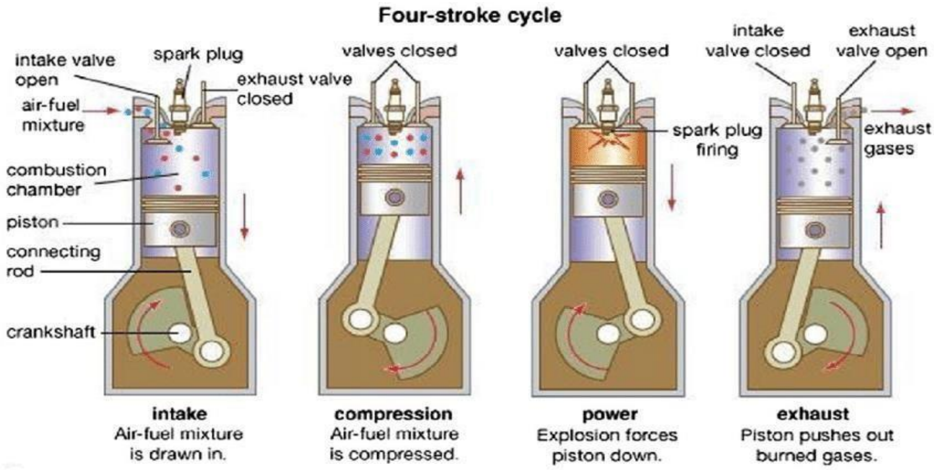

Figure 18: Four stroke cylinder

There are two-stroke and four-stroke piston engines.

With four-stroke engines, a mixture of air and fuel is sucked in in the first stroke. In the second stoke, the piston moves upwards and compresses this mixture. As a consequence of this compaction, a rise in temperature also occurs, which prepares this mixture for the next cycle. The third stroke starts throwing a spark from the spark plug, ignites the mixture of air and fuel and pushes the piston down. This is the operating stroke of the piston engine, i.e. it creates energy that can be used. The fourth stroke involves moving the piston upwards, which results in the pushing of exhaust gases from the piston into the exhaust system.

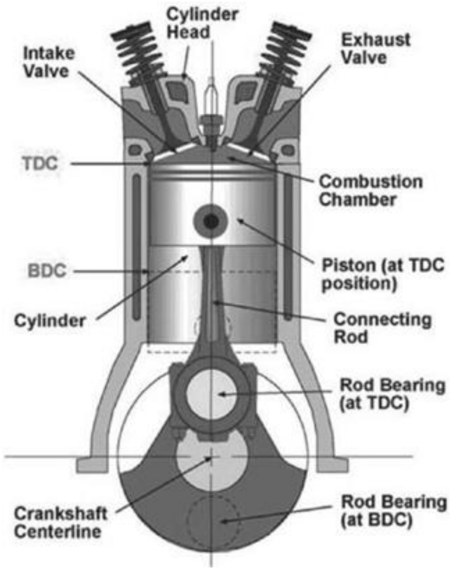

Figure 19. Cross-section of a reciprocating engine cylinder

In two-stroke engines, the first and fourth strokes occur simultaneously, as do the third and second. This loses engine efficiency.

This type of engine is used almost everywhere around us. We can find it in cars, power generators, airplanes, etc.

They are also found in aviation everywhere: in airplanes, in airport equipment (towing tractors, fire trucks, ground generators, etc.) and in other devices and equipment used in.

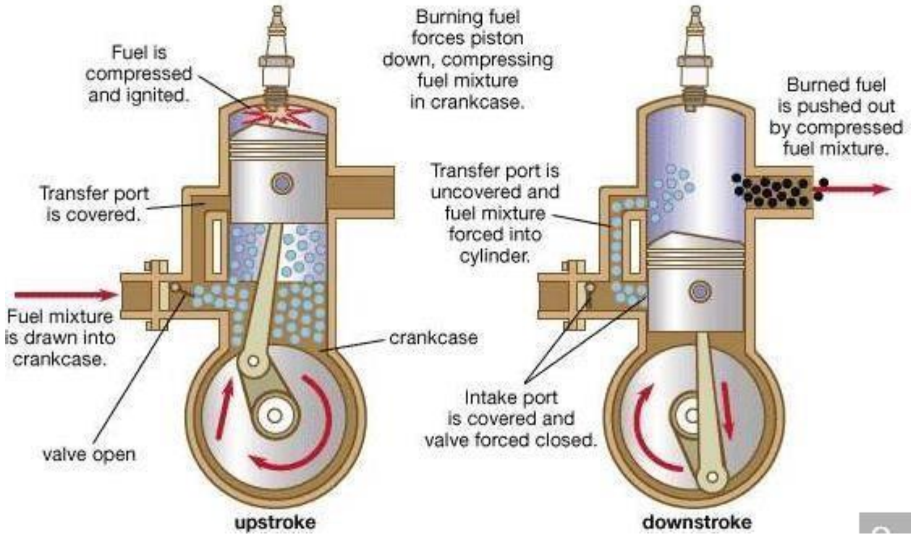

Figure 20: Two stroke cylinder

⌘ Rocket Engines

There are two basic types of rocket engines. These are rocket engines with liquid fuel and rocket engines with solid fuel. In liquid rocket engines, the fuel is mixed with an oxidizing agent before combustion. Fuel is stored in tanks located above the engine itself.

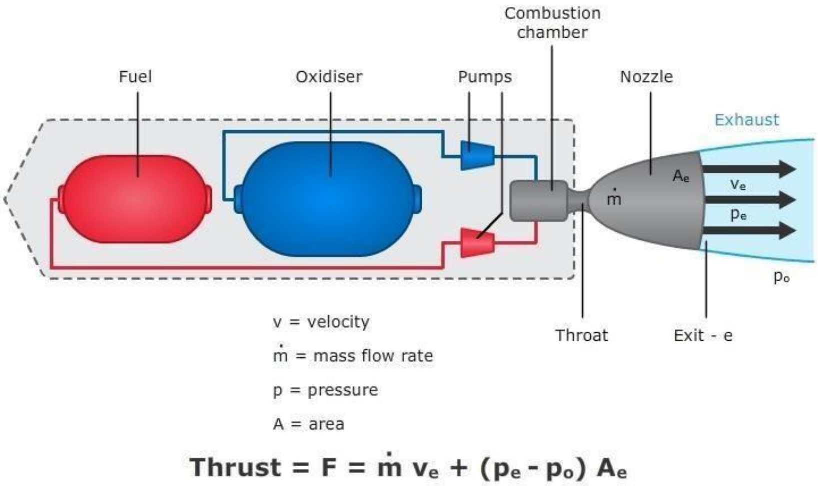

Figure 21. Cross-section rocket engine

These tanks are connected by a pipeline to the combustion chamber. The combustion chamber is designed so that the fuel mixes as efficiently as possible with the oxidizing agent.

The oxidizing agent must be present in rocket engines because a very large amount of fuel burns in a very short time, and the air from the outside environment is not enough to maintain this reaction. The fuel and oxidizing agent are injected into the combustion chamber by means of two pumps driven by a turbine. This turbine gets energy for its work from the part of the burned mass that is ejected from the exhaust.

Volume openings are able to create huge amounts of thrust in a relatively short time. Their disadvantage is short working time, very high prices of their production and use, and being often unusable after one use.

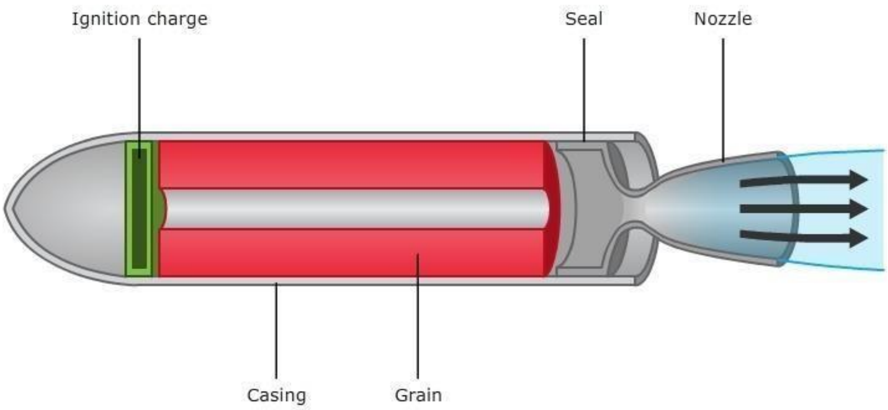

Figure 22. Elements of rocket engines

In solid rocket engines, the fuel and oxidizing agent are mixed before the engine itself is made. These engines are significantly simpler and only the engine ignition system is required for their operation. These engines have an even shorter operating time than those with liquid fuel. It is impossible to stop them after starting, while with the previous type, the supply of fuel or agent can be interrupted.Rocket engines are primarily used to launch rockets and maneuver them in space. In addition to this, these engines have a huge application in the military industry, for the production of missiles and missile weapons. In aeronautics, these engines can also be used as an additional source of thrust to take off from very short runways.

⌘ Electric Engines

Electric motors are devices that convert electricity into mechanical energy using the principle of electrical induction. They primarily consist of rotors and stators.

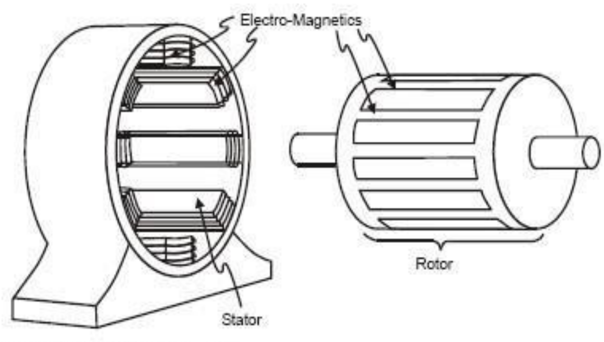

Figure 23. Stator and rotor

Electricity passes through one of these two components, and the other is a permanent magnet. When electricity passes through a conductor, a magnetic field is created. It is the movement of magnetic fields inside the electric motor that causes it to rotate or work. There are two basic types of electric motors used. Motors that use direct current and motors that use alternating current.

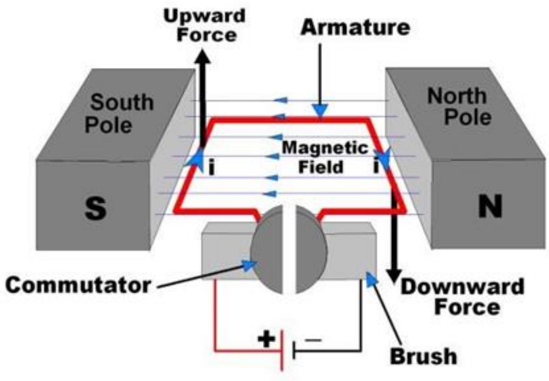

Figure 24. DC Engine diagram

Direct current motors are powered from sources such as batteries or converters from alternating current to direct current.

The rotor of these motors is armature, and the stator is a permanent magnet. They are made with brushes and commutators. These two components tear over time and must be changed over a period of time, which is not a cheap process. Also, this type of motor is less efficient in converting electricity into mechanical energy than electric motors that work on alternating current.

The speed of these motors is controlled by changing the flow of current through the threads. No mechanism is required to start the motor with direct current. All direct current motors are single-phase.

For many, electric motors represent the future, given that environmental pollution is significantly less with them than with internal combustion engines.

The main problem when using these engines are the batteries. Electricity storage technology is advancing and more efficient batteries are being created. Therefore, the future of these engines in many spheres of life, as well as in aviation, is almost certain.

Engines of this type are used for many things in aerospace. For example, starting the engine, starting the control surfaces, moving the vehicles used inside the buildings, or as the primary engine on certain aircraft.

⌘ Wankel Engines

This type of engine consists of the following basic components: front and rear bulkhead, rotor bulkhead, rotor and insulating tires, crankshafts, spark plugs and fuel and air injectors and exhaust vent. This engine works on the same principles as the piston engine, but the strokes are realized differently. The only moving parts of this engine are the rotor and the crankshaft.

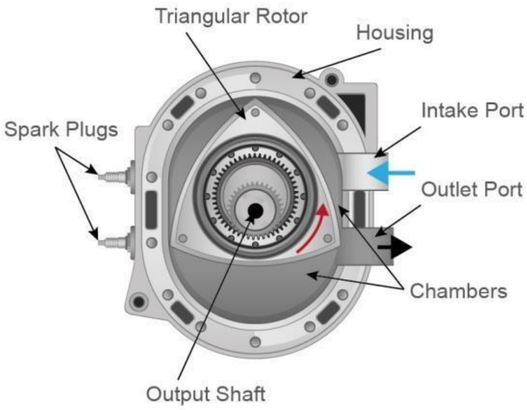

Figure 25. Wankel Engines

Therefore, it is possible to achieve much higher engine speeds than with reciprocating engines, where many components must be synchronized to ensure their operation. For the same reason it has significantly reduced vibrations during its operation. The disadvantages of these engines are unreliable insulating rubbers, which often break down, which causes difficult starting of the engine, incomplete compression and combustion. To ensure good sealing of these tires, it is necessary to constantly supply lubricant to the engine, which leads to environmental pollution and high consumption of lubricant. Also, in case there is not enough lubricant, the engine will "stall".

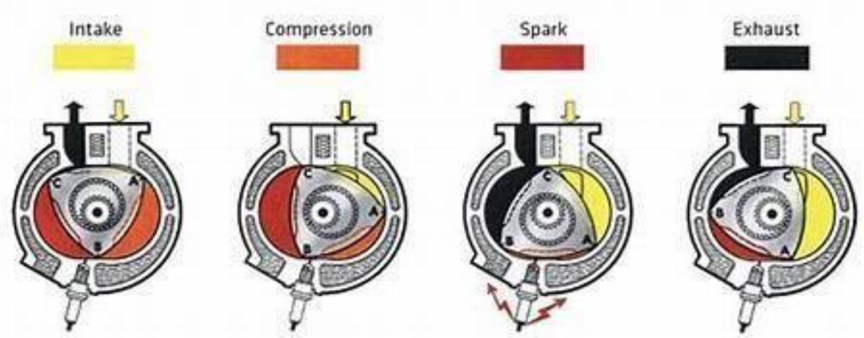

Figure 26. Work cycle of Wankel Engines

With their appearance, these engines made a real mess in the world of aviation. NASA was especially interested in researching engines of this type because it had a fantastic ratio of weight and power and almost did not produce vibrations. At the time it appeared, its efficiency was also far greater than that of gasoline or diesel engines. Over time, due to the problems that this type of engine has in most cases, its production has dropped significantly, but they are still used, most often in unmanned aerial vehicles.

⌘ Jet Engines

The last type of aircraft that we will consider is also the most important engine for modern aviation: jet engine. There are many subtypes of jet engines, such as:

- ⌘ Turbojet
- ⌘ Turboprop
- ⌘ Turbofan
- ⌘ Ramjet
- ⌘ Similar subvariants of the above

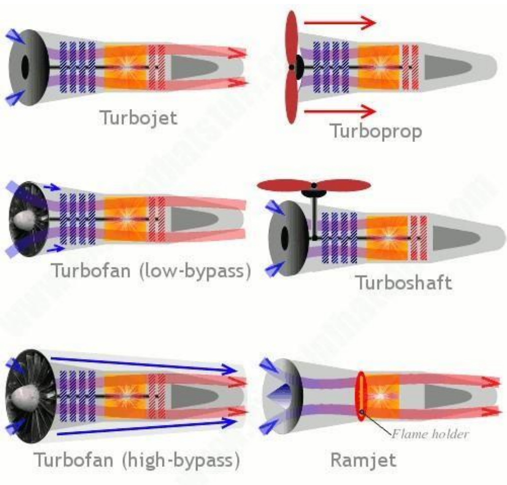

Figure 27. Work cycle of Jet Engines

In these engines, the air passes through the suction cup and enters the low-pressure compressor, which compresses the air and conducts it to the high-pressure compressor, further compresses it and, thus, raises its temperature. This air is brought to the combustion chamber where fuel is added. The mixture is ignited. Ignition leads to the expansion of mixture of gases and drives high and low-pressure turbines that are connected to high and pressure compressors. After that these gases the engine through the exhaust.

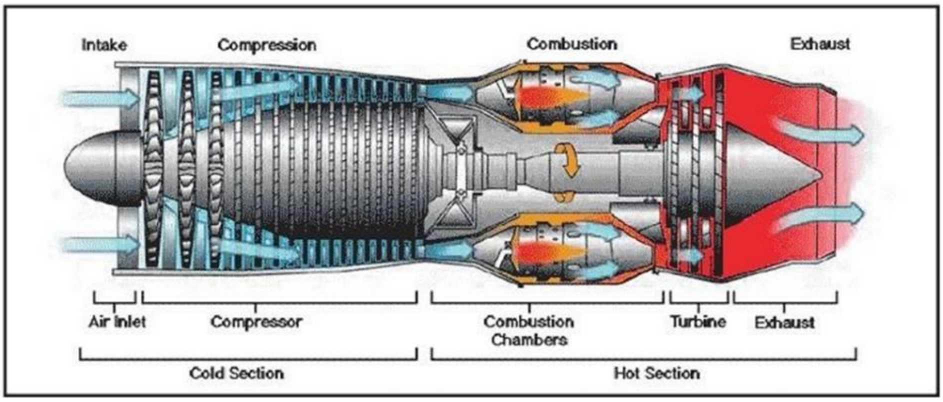

Figure 28. The parts of jet engine

This type of engine is used in all major modern passenger aircraft, almost all military aircraft, certain drones, and even medium-sized drones. Figure 59|: Jet engine spare parts

3.4.2 Types of Drone Propulsion

Economy is one of the most important factors to consider in aviation, in addition to safety. It is most often achieved by reducing the weight of the aircraft, implying that the aircraft is already aerodynamically well made.

The problem of weight is especially emphasized in drones. They must have as less weight as possible, and as much lifting capacity and strength as possible.

When choosing a propulsion system for a drone, attention must be paid to its desired range. It is not possible to use electric motors for large ranges because we still do not have batteries of large enough capacity, and small enough mass and volume to be used. Therefore, in this case, some of the other engine types will be used, for example the Wankel engine.

⌘ Reciprocating Engines

Reciprocating engines are used for larger drones. These are engines with one or two cylinders. Their weight varies from one to a few kilograms and their power is up to 25kW

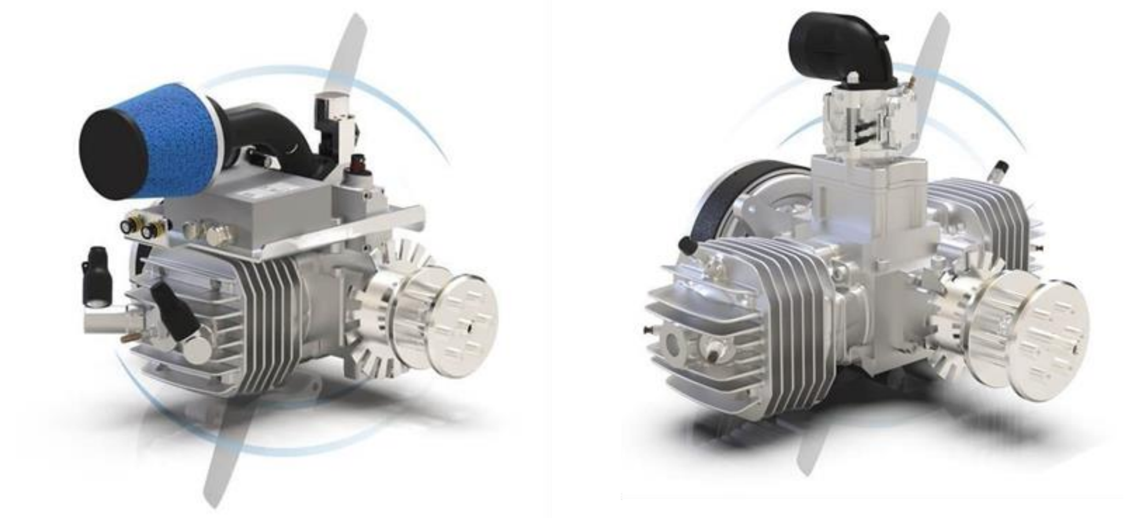

Figure 29: Basic small engine

⌘ Rocket Engines

Due to their price and mode of operation, rocket engines have not been used in drones.

⌘ Electric Engines

When someone thinks of a drone, almost every time it is an electronically powered drone. They have an autonomy of a few minutes to a little over half an hour. They do not pollute the environment, they are quiet and light, and they are the primary choice for 90% of drones in use. Due to their weight, they can be used in places where people are, although new security systems are needed. These are most often DC motors and brushless DC engines, although AC engines can also be seen.

Figure 29: Electric engine

⌘ Wankel Engines

Wankel engines are very convenient to use on large drones due to their low weight and great power. Moreover, the problems due to which this engine did not come to life have significantly decreased. The weight of these engines vary from 5-10 kilograms, with a power of about 22 kilowatts.

Figure 30: Wankel basic engine.

⌘ Jet Engines

Jet engines are used in many military UAVs, but are rarely used for drones. However, there are also cases where they are used. Such drones are real heavyweights in all matters. Their masses and strengths are significantly greater than their competitors. All this power results in high speed and flight ceilings. They can lift up to 18 kilograms of cargo, and the engines have a power output of up to 150kW.

In order to correctly choose the type of propulsion system, it is necessary to precisely define the requirements that the drone will have to meet.

As there is no perfect propulsion system, a compromise is inevitable, therefore it is very important that in addition to defining the requirements, to also arrange them in order of importance.

After that, it is necessary to determine the price range in which the drone can be found and to find the best representatives of various types of engines. The next step is to compare the performance and characteristics of the propulsion system with the list of requirements. The propulsion system that meets the most important requirements is the best choice for the drone.

Questions to be answered:

- What is the maximum permissible mass of the propulsion system?
- What is the minimum power-to-weight ratio of the propulsion system?
- What is the mass of the drone without the propulsion system?
- How much payload must the drone have as a whole?
- What environmental requirements must the drone meet?
- What noise requirements must the drone meet?
- What must be its maximum speed and how steerable must it be?

Figure 32: Drone propulsion system

Choosing a propulsion system may seem to be a complicated task, especially because of the number of options that are presented to us, but by following the simple steps it is possible to correctly determine which propulsion system to choose in a short time. It is desirable to have as much knowledge as possible of different types of engines, so it is always useful to further explore the characteristics of propulsion systems that have been shortlisted, as well as the reliability of the manufacturer from whom it was purchased.

3.5 Types of Aviation Fuel - Propellants

3.5.1 Basic Properties of Fuel

Every drone, depending on what they are used for, requires special propulsion system. Bigger vehicles need more power to stay in the air and therefore more powerful batteries are used.

- Lithium Polymer battery;
- Lithium Polymer batteries ("LiPo" batteries), are a type of battery used nowadays in many consumer electronics devices.
- Differences between LiPo batteries and their Nickel-Cadmium and Nickel-Metal Hydride counterparts:

	LiPo Batteries	NiMH Batteries
Advantages:	⌘ Much lighter weight, and can be made in almost any size or shape; ⌘ Much higher capacities, allowing them to hold much more power; ⌘ Much higher discharge rates, meaning they pack more punch;	⌘ Longer lifespan than LiPo, usually into the 1,000 cycles range; ⌘ Much less sensitive, and usually without posing a fire risk; ⌘ Simpler chargers and routines required for use.
Disadvantages:	⌘ Much shorter lifespan; LiPo average only 150–250 cycles; ⌘ The sensitive chemistry can lead to fire if the battery gets punctured; ⌘ Need special care for charging, discharging, and storage;	⌘ Much heavier, and limited on size; ⌘ Lower average capacity, and less efficient overall; ⌘ Lower discharge rates; they lack tremendous punch;

LiPo battery is used for drones because of its weight and ability to be made in various shapes and sizes, its high capacities and energy and capability to be rechargeable. The problem is that it can be dangerous because it is capable of catching fire if not used properly.

Figure 33. Battery

3.5.2 Hydrogen Fuel Cells

A hydrogen fuel cell converts chemical energy stored by hydrogen fuel into electricity. Hydrogen on its own is not a source of energy. It must be kept in a suitable container until it is ready to be used in a fuel cell to produce electricity.

When hydrogen is combined with oxygen within the fuel cell, and the byproduct water is removed, the fuel cell can generate electricity. Hydrogen is very difficult to handle—it must be separated from other elements, compressed and stored in a stable environment, or otherwise explodes. Another characteristic of hydrogen fuel cells is that they involve a significant amount of heat. Considering that plastic is a dominant component of most drones, the generation of heat could melt some of the drone hardware.

Benefits for hydrogen fuel cells:

- Hydrogen is a clean energy source - colorless, odorless, and nontoxic gas, the entire product is water;
- Hydrogen is the most common resource on Earth;
- Hydrogen fuel cells have a higher energy density over batteries and enable longer flight times;
- Hydrogen fuel cells refuel quickly;
- Hydrogen-fueled drones function in low temperatures;
- BVLOS flights are more attainable with hydrogen-fueled drones.

3.5.3 Solar Energy as a Propellant

Extending the endurance of electric unmanned aerial vehicles (Drones, UAV, UAS, RPAS) is an important consideration for many drones. While this can be achieved by adding batteries, the extra weight and space often make this counterproductive. Developments in solar power technology have made photovoltaic (PV) technology a possible alternative for powering UAVs, drones and other unmanned aircraft.

Drones generally do not have enough usable space on the aircraft to place solar panels. They are less efficient at generating lift than fixed-wing aircraft, which means increasing the size of the drone presents a significant design challenge

Figure 34. Solar panels on aircraft

3.5.4 Types of Fuel Cells and Method of Selection

As for now, the most sufficient propulsions are considered to be the following:

Battery

The relation between battery capacity Ebatt and weight mbatt can be calculated from eq. (1) using the specific energy εS:

$$Ebatt = \varepsilon S \cdot mbatt \cdot \eta DOD$$

Where the specific energy relates to the battery chemistry and ηDOD, the depth of discharge of the battery, affects the cycle life.

3.5.5 Fuel Cell Hybrid System

The hybrid system is characterized by the degree of hybridization βbatt, as calculated by Eq. (2). This is the relative average power distribution between the fuel cell and the battery. It ranges from 0 to 1, where 0 is only fuel cell power, and 1 is only battery power.

$$\beta Batt = \frac{Pbatt}{PFC + Pbatt}$$

The total energy of a fuel cell hybrid system EFCHS is the sum of the effective energy available from the FC system and hybrid battery:

$$EFCHS = EFC + Eh.batt$$

And the mass of the fuel cell hybrid system mFCHS includes the mass of the fuel cell stack with plant balancing control electronics mFC, the hybrid battery mh.batt, and the hydrogen cylinder with regulator and hose $mH2$. The mass of hydrogen is only about 5% of the pressure vessel mass, and thus can be neglected:

$$mFCHS = mFC + mH2 + mh.batt$$

In order to get a realistic comparison of power sources, it is important to include all mass contributions associated with the system. The mass and power specifications of a fuel cell system is governed by what is commercially available.

3.5.6 Hydrogen Energy

The effective electric energy from a fuel cell system EFC depends on the efficiency of the fuel cell and the amount of stored hydrogen. As a function of pressure and cylinder volume, it is:

$$EFC(p,Vcyl) = \rho_{H2}(p) \cdot Vcyl \cdot h_{H2} \cdot \eta FC \cdot \eta_{H2}$$

where the density of hydrogen ρ$H2$ and the cylinder volume Vcyl gives the hydrogen mass. The specific enthalpy of hydrogen at the Lower Heating Value (LHV) is $hH2$= 33.6Wh·g-1. By multiplying this with the hydrogen mass, the theoretical energy stored in the system is obtained. The fuel cell efficiency ηFC is related to the cell voltage and can be assumed to be 50%. The last factor is the fuel utilization factor $\eta H2$, representing the fact that not all hydrogen is used in the chemical reaction and its typical value is around 0.95.
The cylinder volume and associated mass is given by commercially available options. A range of Class IV cylinders, carbon fiber wound vessels with a polymer liner, rated for 300bar are listed in Table 1. The specifications may vary between different manufacturers, and more lightweight cylinders are available. These might, however, have lower safety factors and a limited number of fill cycles.

Table 1 Properties for a series of lightweight Class IV cylinders from CTS. They are certified to store 300bar hydrogen according to EN 12245 (CEN, 2002). A fuel cell efficiency of 50% is assumed for the energy estimates.

Volume [L]	Cylinder Mass [kg]	H_2 mass [g]	Storrage effect [%]	Energy [Wh]	Specific Enegry $[Wh \cdot kg{-}1$
2.0	1.2	41.7	3.5	700	584
3.0	1.4	62.5	4.5	1050	750
6.0	2.5	125.0	5.0	2101	840
6.8	2.7	141.7	5.2	2381	882
7.2	2.8	150.0	5.4	2521	900
9.0	3.8	187.6	4.9	3151	829

3.5.7 Hybrid Battery

The energy capacity of the hybrid battery as a function of the primary power source, the fuel cell system energy, can be calculated according to:

$$Eh.batt(EFC)= \frac{\beta batt \cdot EFC+(temc\cdot PFCHS)}{1-\beta batt}$$

where emergency power backup is calculated from the average power consumption PFCHS and the time required for an emergency landing temc. By modifying Eq. (1), the mass of the hybrid battery mh.batt can be calculated according to:

$$m_h.batt= \frac{Eh\cdot}{\varepsilon S\cdot \eta DOD}$$

The allowed depth of discharge must be considered to ensure that the required energy is available. Also, the calculated energy and mass are minimum values. In practice, a commercially available option that can provide the required energy and power (discharge rate) must be selected. Eq. (8) can be used to convert to the much used mAh battery definition. Unom is the nominal battery voltage:

$$CmAh= \frac{Eh.\quad \cdot 103}{\eta DOD\cdot Unom}$$

3.6 Computer and Electronic Systems

The application of computers in UAV projects follows the general progress of computer technology, starting with analogue, micro-digital and integrated systems on a chip (System-on-Chip, SOC), all on one board (single-board computer, SBC).

The rapid development of computer technology is very noticeable, but the fact is that computer technology is still a limiting factor for the speed of development of unmanned aerial vehicles, especially autonomous ones.

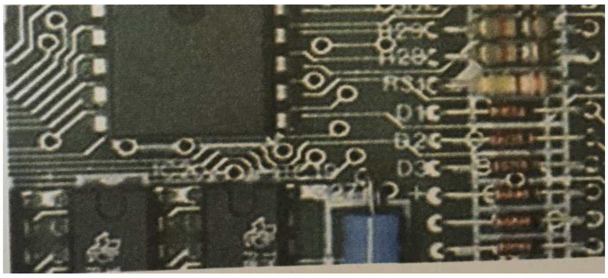

Figure 65: Part of a computer printed circuit board

The system hardware for small UAV, practically comes down to flight commands (Single-board computer, SBC), Flight Control Board (FCB) and autopilot.

The electronic hardware assembly consists of individual electronic components, resistors, transistors, capacitors, inductors and diodes, interconnected by conductors or in printed circuit boards, through which electric current flows (Figure 15). In order for a circuit to be called electronic and not electrical, there must generally be at least one active component in it. The combination of components and conductors allows you to perform various simple and complex operations: signal amplification, computer processes and data transfer from one place to another.

Circuits can be realized from discrete components connected by individual conductors, but it is much more common to interconnect in printed circuit boards and connect components by soldering into a single whole, in order to obtain the necessary integrated circuit. In such a circuit, the components and interconnections are formed on the same substrate, usually semiconductors. A chip system (SOC) is an integrated circuit in which all components of a computer or other electronic system are integrated. These components typically (but not always) include the central processing unit, memory, input/output ports, and secondary memory. Everything is integrated on one chip, of small size (microchip). They may contain functions of digital, analogue and mixed signals, and often radio frequency processing them, depending on the application. As they are integrated on a small basis, SOCs consume far less energy and take up significantly less space in a multi-chip design, retaining their functions. That is why SOCs are very often used on computers, as well as on mobile devices (such as smartphones).

Stronger integrated computer systems improve performance and reduce power consumption, as well as the surface area of the semiconductor arrays required for a suitable project composed of discrete modules. The level of component interchangeability is reduced.

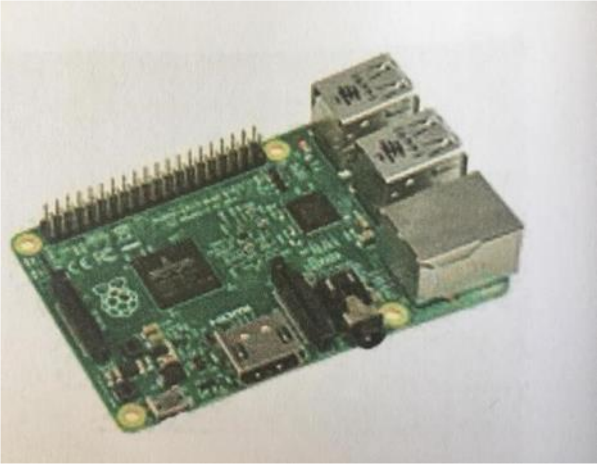

Figure 36: This system on a chip (SOC) does not include any data storage, which is characteristic of a microprocessor chip

By definition, SOCs are structures fully or partially integrated through different component modules. For these reasons, the general trend is towards greater component integration in the computer hardware industry. That lesson was learned and adopted thanks to the impact of SOCs in the relentlessly competitive mobile phone and computer markets. Systems on a chip can be seen as part of significant advances in computer development and hardware improvement.

3.6.1 Sensors

Information on the parameters of UAV movement, according to the number of degrees of freedom, depends on the number and quality of sensors on the aircraft: for 6 degrees of freedom gyroscopes and accelerometers around and along three basic axes are necessary (Fig. 17 Typical inertial platform), 9 degrees of freedom requires an inertial platform plus a compass, 10 degrees of freedom additionally requires barometric altitude measurement, and 11 degrees of freedom additionally requires a receiver for the Global Positioning System (GPS).

Figure 37. View of the freedoms of movement along and rotation about the three axes of the aircraft

Position and motion sensors provide information on the condition of the aircraft. Proprioceptive sensors are intended to provide data on external information such as measuring distances, light intensities, sound amplitudes, while exteroceptive sensors interconnect internal and external states.

Non-operational encoders are able to automatically detect targets and obstacles, so they are used for security, avoiding collisions with obstacles, monitoring the terrain configuration and for guiding lethal means in combat. Radar and optoelectronic transmitters are important, especially when all that information is combined.

3.6.2 Accelerometer

An "open circuit" accelerometer consists of a body of a certain mass attached to a spring and a damper. These three components are in the same direction of displacement, caused by acceleration. In accordance with the characteristics of the spring stiffness, the body has limited movement. The acceleration of the body due to the force of inertia is forced to lag behind by the opposition of the spring. The acceleration intensity of the movable body and the entire assembly of the aircraft is derived from the value of the deflection of the spring, that is, from the length of the movement of the moving body. The constant characteristic of the acceleration measure is obtained by adjusting the size of the body mass and the stiffness of the spring. The system is damped by a built-in damper, in order to avoid oscillations of that assembly.

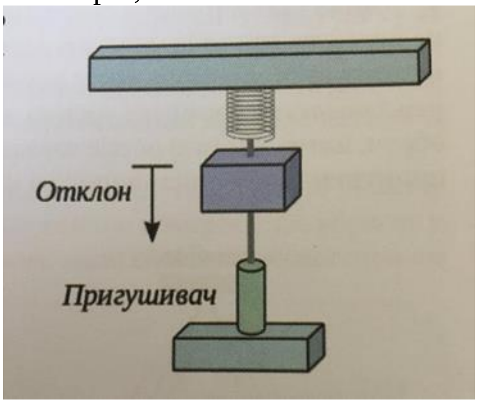

Figure 38. Schematic representation of the basic principle of operation of a mechanical accelerometer

When the spacecraft is at rest on the Earth's surface, the accelerometer will measure the acceleration equal to the gravitational constant $g \approx 9.81 \ m/s^2$.

High-sensitivity accelerometers are important components of inertial navigation systems, which are used for navigation in UAV. They are used to determine the position and direction, as well as the UAV flight stability. They also sense the multiple motion parameters of the UAV, that is, the corresponding current components of the aircraft state vector.

Modern accelerometers are small micro-electro-mechanical systems MEMS (Micro Electro Mechanical Systems). These are the simplest inertial devices for drone use. They significantly reduce the problems of increasing vibrations caused by the moving parts of the powerplant assemblies.

3.6.3 Gyroscope

There are two basic types of gyroscopes:

- Mechanical
- Optical (laser) gyroscope

Application:

- Angular speed meter;
- Encoder to maintain the direction of movement.

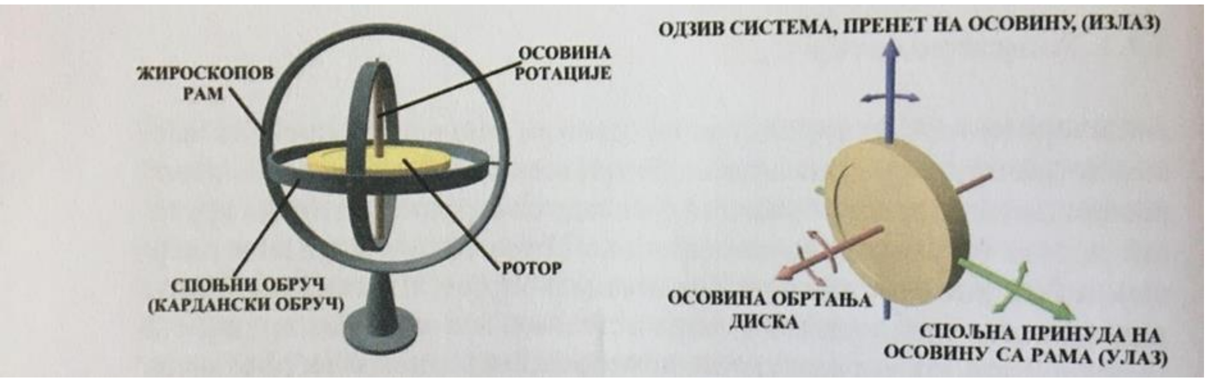

Figure 39. left: Working principle of a mechanical gyroscope with a cardan mechanism, with three free rings; right: The principle of the response of the gyroscope mechanism to external coercion

Any change in the position of the gyroscope axis due to the action of external coercion is much smaller than it would be without a large angular moment of opposition, due to the rotation of its disk. Due to the minimization of the consequences of forcing the device by transferring the force into the gimbal, its position remains almost fixed, regardless of any forced movement of the platform on which the device is placed.

The measured level of that moment opposing the rotation of the axis direction is in a proportional relation to the level of the aircraft deviation from the previous flight direction and in that effect is the essence of the purpose of the gyroscope. The intensity of this opposition is converted into a transmission signal of proportional intensity to the corresponding systems. There are also gyroscopes based on other principles of operation, such as MEMS gyroscopes in a package with microchips that are in electronic devices, then a laser gyroscope with an active ring, fiber-optic gyroscopes and extremely sensitive quantum gyroscopes.

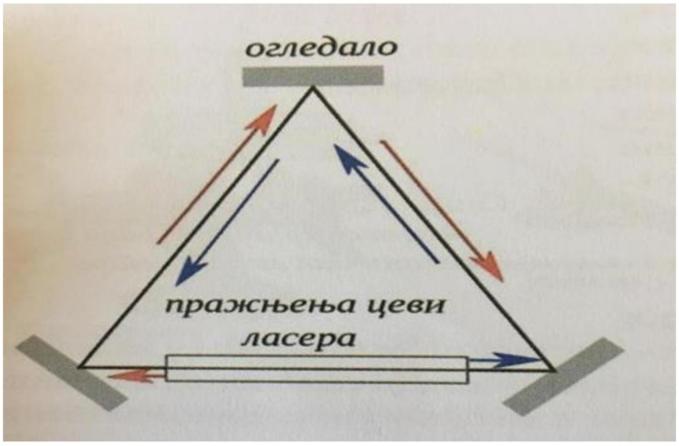

Figure 40. The working principle of a gyroscope with laser operation

Accelerometers and gyroscopes are very important subsystems of the UAV inertial navigation system.

The Inertial Navigation System (INS) uses angular velocity and acceleration data as a function of calculating relative position over time. Since INS provides a relative position in relation to the initial state, the integration process quickly loses its initial values, i.e. its real position in relation to the external reference comparison, due to the accumulation of errors in that process. Its correction support is the Global Navigation Satellite System (GPS) which gives it information about the initial reference data and provides it with data to correct the error during integration.

3.6.4 Sensor Integration and Signal Fusion

The fusion of the UAV sensor signal and the obtained measurement results are combined with a special algorithm, providing the best performance, reducing the risk of losing the ratio of the aircraft state vector data to external references. By combining GPS and INS techniques, the correction data is improved relative to the reference values.

Inertial measuring units in combination with GPS are crucial for maintaining the direction and accuracy of the flight trajectory. Since flight autonomy is the key regime for drones, it is important to provide them with conditions for compliance with international flight rules and air traffic control.

Attitude and Heading Reference System (AHRS), in addition to the accelerometer and gyroscope, use multi-axis magnetometers, which are basically small compasses with a high degree of accuracy. They detect changes in direction, about which they enter data into the CPU, which ultimately indicates the direction, orientation and flight speed of the UAV.

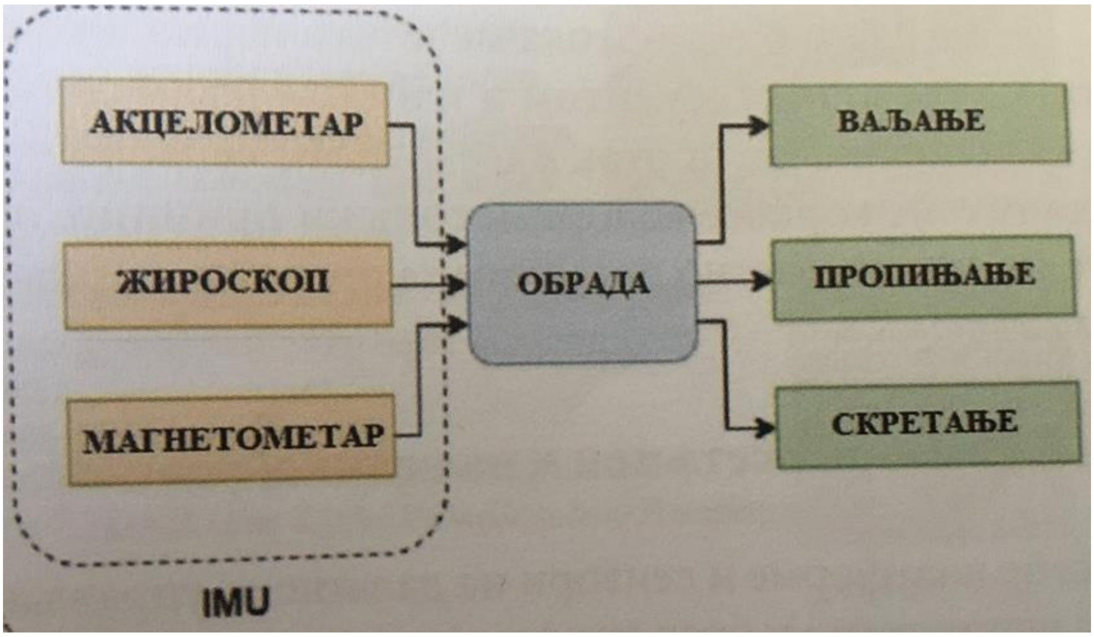

Figure 41. AHRS

Accelerometers and gyroscopes in combination provide input data on the inclination around all three axes in the flight command system in the function of maintaining a safe and quality flight of UAV. This is particularly important for changes in which flight stability is important, such as surveillance missions and the transfer of sensitive goods.

These sensors detect small variations in movement (oscillations). The measured characteristics of these oscillations are of great importance in the designs of moving objects to compensate for the quality of their movement, by providing adequate damping. In this way, the dynamic stability of the aircraft during flight is improved.

In the case of unmanned aerial vehicles, the consumption and use of electricity is important. Current sensors can be used to monitor and optimize power consumption, safely charge internal batteries, and cover engine and other system components (Figure 17, right). They measure the characteristics of the electricity and control the insulation to avoid losses and prevent the possibility of electric shock, which is a risk of injury to the user or damage to the system. These are sensors with fast response time (low time constant) and high accuracy, they optimize battery operation and even aircraft performance.

In UAV, electronic compasses provide critical directional information to inertial navigation and guidance systems. Anisotropic magneto-resistive (AMR) and permalonic sensors have superior accuracy and response time characteristics, while consuming significantly less energy than alternative technologies, and are suitable for UAV use. They enable manufacturers to provide quality data recording in a compact package.

Flow sensors can be used to effectively monitor airflow in small gas engines used to power some types of UAVs. They help the engines determine the correct ratio of fuel and air in the mixture for a given operating mode, resulting in improved power, efficiency and reduced exhaust emissions.

Many gas mass flow sensors use a calorimetric head with a heated element and at least one temperature sensor to quantify the mass flow. MEMS hot air flow sensors also use the calorimetric principle, but on a micro scale, which makes them extremely suitable for applications in conditions of priority mass reduction.

3.6.5 Sensors Sensitive Even at a Great Distance

Stressed platforms and remote-control sensors are technologies that are constantly and rapidly advancing, with a constant increase in IT infrastructure. The range and potential of sensors performance in terms of spatial, spectral and temporal capabilities has expanded far beyond the traditional limits of remote use, resulting in significantly improved observing capabilities.

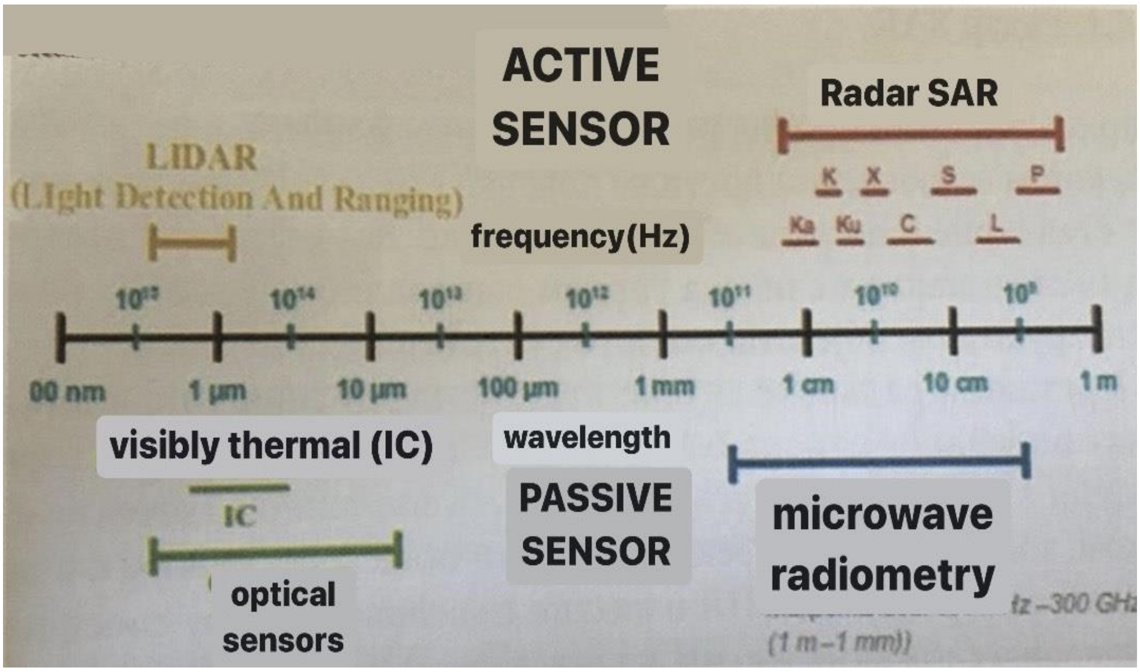

Figure 42. Classification of remote sensors

The development of platforms with new satellite installations of remote sensors in the function of operational use of UAV is intensive.

Solutions for the application of sensors in support of the global navigation infrastructure, which enables remote sensing technology, are constantly being researched and developed. Figure 22 schematically shows an overview of groups of active and passive remote sensors of different wavelengths, and Figure 23 shows their possible effective performance globally.

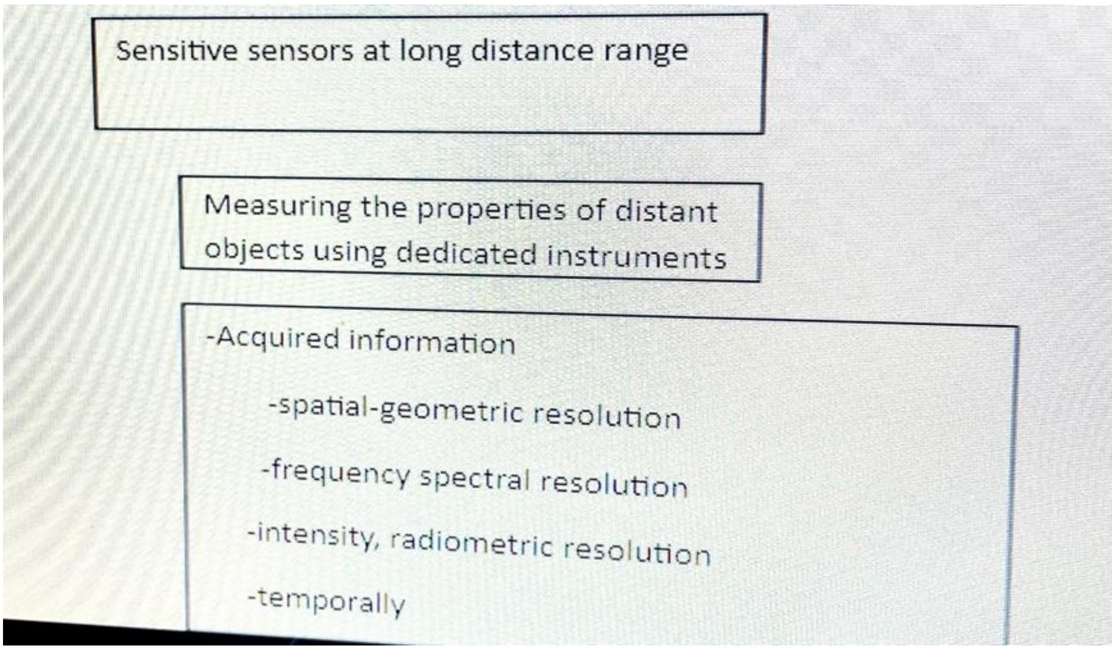

Figure 43. General information about sensors for capturing scenes at long distances

3.6.6 Radar SAR

Radar with a synthetic aperture (Synthetic Aperture Radar SAR) artificially achieves an increased effect compared to the possibility of a standard phased array antenna. It is used to create two-dimensional images, and three-dimensional ones are obtained from the reconstruction of objects, such as buildings and landscapes. By moving the radar antenna over the target area, the effect of increased aperture was obtained, as well as the image of finer spatial resolutions in relation to classic radars with phased array antenna, due to the obtained effect of artificially increased aperture.

SARs are built into UAVs and significantly increase their ability to perform complex missions for demanding purposes. An advanced side looking airborne radar (SLAR) has been developed.

The path that the SAR device travels over the target in the time it takes for the radar pulses to return to the antenna artificially creates the effect of an increased aperture relative to the physical antenna. This allows SAR to create high-resolution images with relatively small physical antennas. This property of SAR is especially useful for capturing more distant objects as it allows for consistent spatial resolution over a distant and larger range of observations.

To create a SAR image, successful radio wave pulses are transmitted to the target scene and illuminated, and the echo of each pulse is received and recorded. The pulses are transmitted and their echoes are received by a single antenna forming a beam of wavelengths from a meter to a few millimeters. As the SAR device on the aircraft accelerates, the antenna moves identically relative to the target, as a function of time.

The signal processing of successfully recorded radar echoes allows a combination of images from multiple changed antenna positions. This procedure artificially creates the effect of an enlarged antenna aperture and allows the creation of images of higher resolution than would otherwise be possible with a physical antenna, with an actual aperture. Since 2010, airspace systems have provided a resolution of about 10 cm, and ultra-wideband systems provide resolutions of several millimeters.

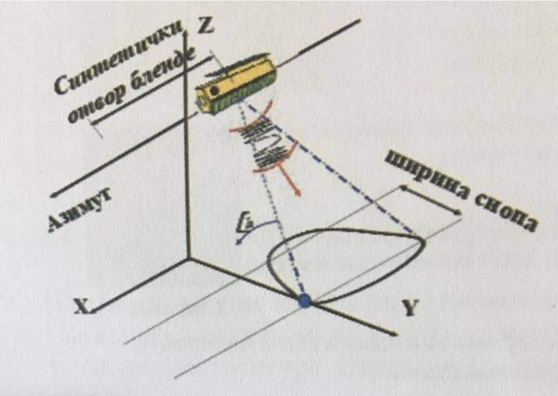

Figure 44. Illustration of a part of the SAR operating principle

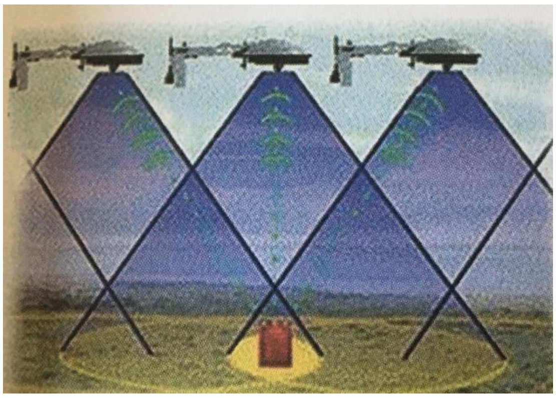

Figure 45. The SAR scheme when sending a radio wave pulse to the target, "illuminates" it, and the echo of each pulse is received and recorded

Since SAR is an active sensor and uses a microwave band in a wide radio spectrum it has the ability to record day and night with great penetration ability. To some extent, it can also record in the rain The L and R microwave band have a relatively large depth of penetration into vegetation and soil, which enables obtaining information about the interior of the targets. Due to these characteristics, SAR will be used in various fields of research, from oceanography to archeology.

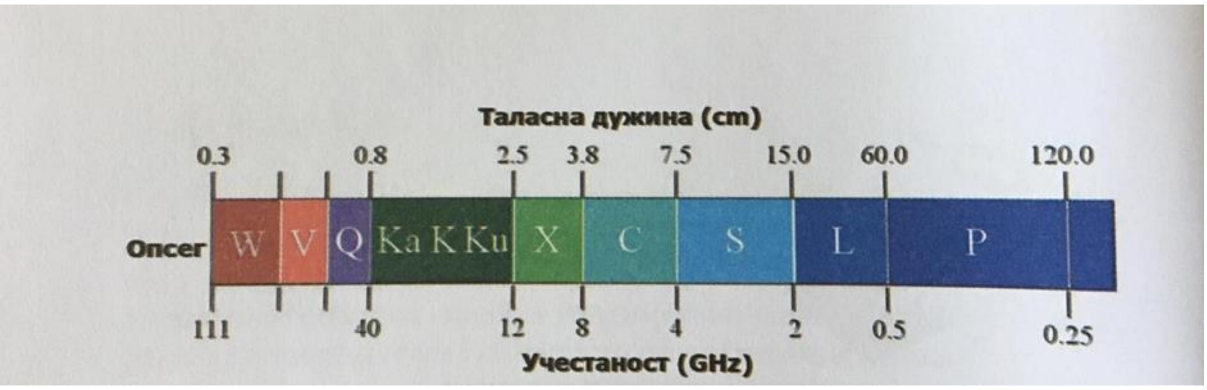

Figure 46. Active SAR sensor using microwave range in the wide radio spectrum

SAR is used on unmanned aerial vehicles for long-term observation from the airspace. This is effective in typical missions that take a long time. SAR is often used in difficult weather conditions, military surveillance and environmental monitoring.

SAR images are widely used in the remote control of UAV flight and ground surface mapping. SAR is used in topography, oceanography, geology (for example, to discriminate the terrain and record the depths of land and buildings), and in forestry (including altitude, biomass and clearing). Differential interferometry is used to monitor volcanic activity and earthquakes. The SAR is also used to monitor the stability of civilian infrastructure and the environment, such as bridges, to monitor the environment, oil spills, floods, urban sprawl, and global change. Military surveillance includes strategic and tactical assessment of adversary intentions. SAR can also be applied inversely, observing a moving target over a significant period of time, in the status of a stationary antenna (when UAV is hovering).

SAR is a pad for shooting comic images, it is installed on a moving platform (aircraft). The emitted electromagnetic waves are transmitted sequentially, echoes are collected, digitized by electronic systems and stored for further processing. As transmission and reception occur at different times, they are mapped to different positions. A well-arranged combination of received feedback signals creates a virtual aperture that is much longer than the physical width of the antenna. This process of obtaining the properties of photographic radar is the basis for the introduction of the name "artificial aperture".

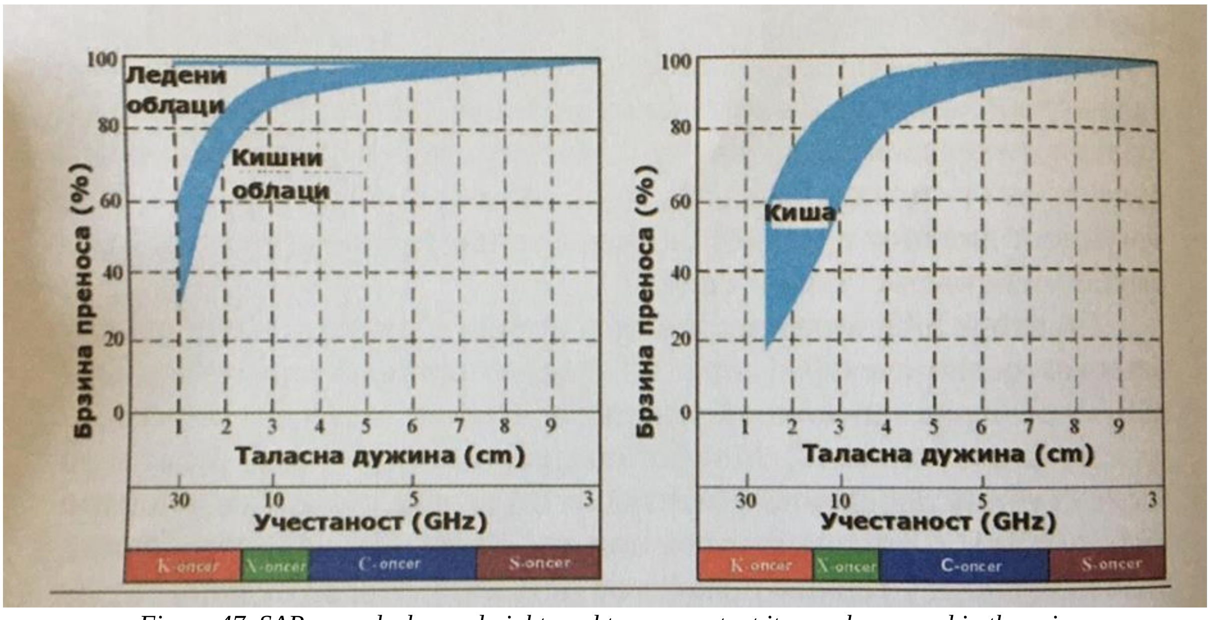

Figure 47. SAR records day and night, and to some extent it can also record in the rain

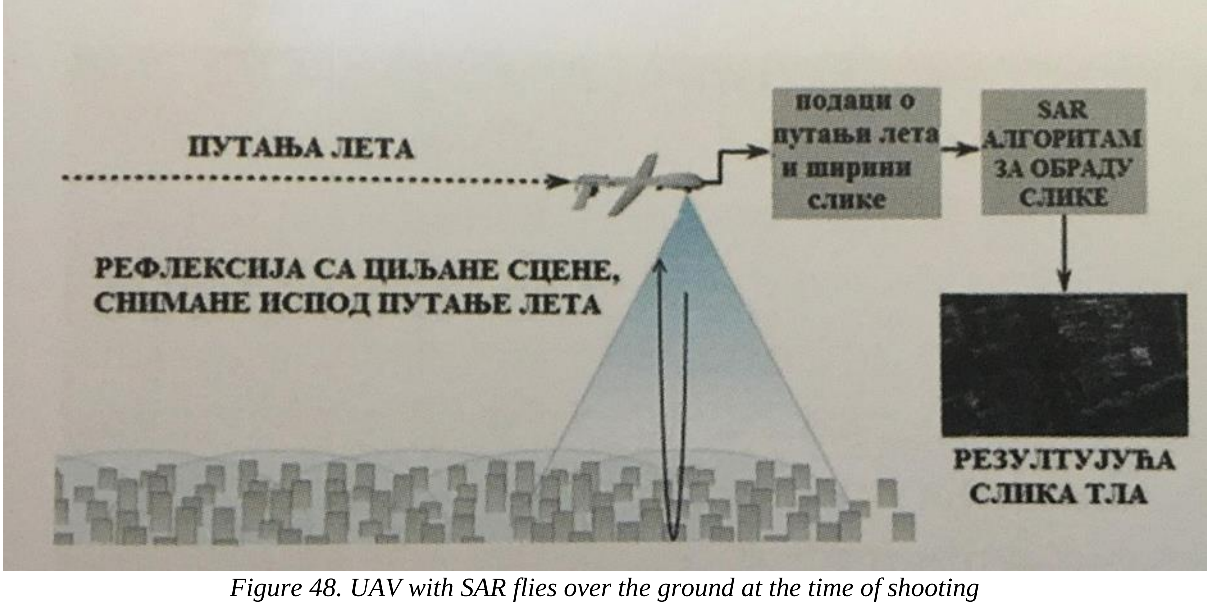

Figure 48. UAV with SAR flies over the ground at the time of shooting

The direction of the recording range is parallel to the flight trajectory and it is perpendicular to the azimuth direction, which is also known as the longitudinal direction, because it is in line with the positions of the objects within the field of view of the antenna.

Three-dimensional (3D) processing is performed in two phases. Azimuth and range directions are focused on generating high-resolution 2D images (azimuth range), after which a digital elevation model (DEM) is used to measure the phase differences between complex images, which are determined from different viewing angles for different height information. The obtained altitude data, together with the azimuth coordinate range provided by the SAR's focus on 2D, gives a third dimension and that is altitude. The first step requires only standard processing algorithms. As for the second step, additional pretreatment such as co-registration and phase calibration of the image is used.

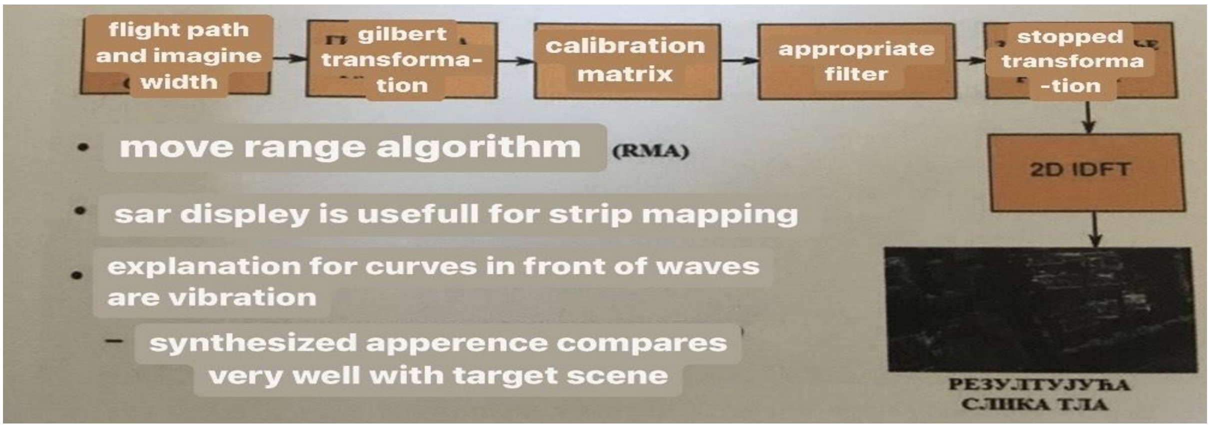

Figure 49. Block diagram of the SAR function in image processing of the target scene.

Multiple baselines can be used to extend 3D recording in the time dimension..

SAR falls within the X-band and has a moving target tracking and recording mode (GMTI) with a minimum speed of 2 m/s. The SAR sensor has the ability to produce images with a resolution of 1 meter in search mode and a resolution of 0.3 meters in point mode. The maximum shooting range is 200 km. Data are processed in the aircraft and transmitted as uncompressed images (8 bpp) or compressed (2 bpp). Algorithms (Joint Photographic Express Group, JPEG) are used for compression. Images are uploaded in the NITFS format (National Imagery Transmission Format Standard) with self-defined ethnicity (SDE). SAR Wide Area Airborne Surveillance (WAAS) images are segmented. Data (moving target tracking and recording mode, GMTI) is transmitted as a text product that offers location and range speed.

There are two modes of operation. Mode 1 provides a map of images without a reference point (location). It is the movement of the center of the map in relation to the movement of the aircraft. Mode 2 is the classic tape mapping mode. Mapping regardless takes place over a predetermined centerline of the scene, at the movement of the aircraft.

Figure 50. The image is the result of SAR recording in the X-band

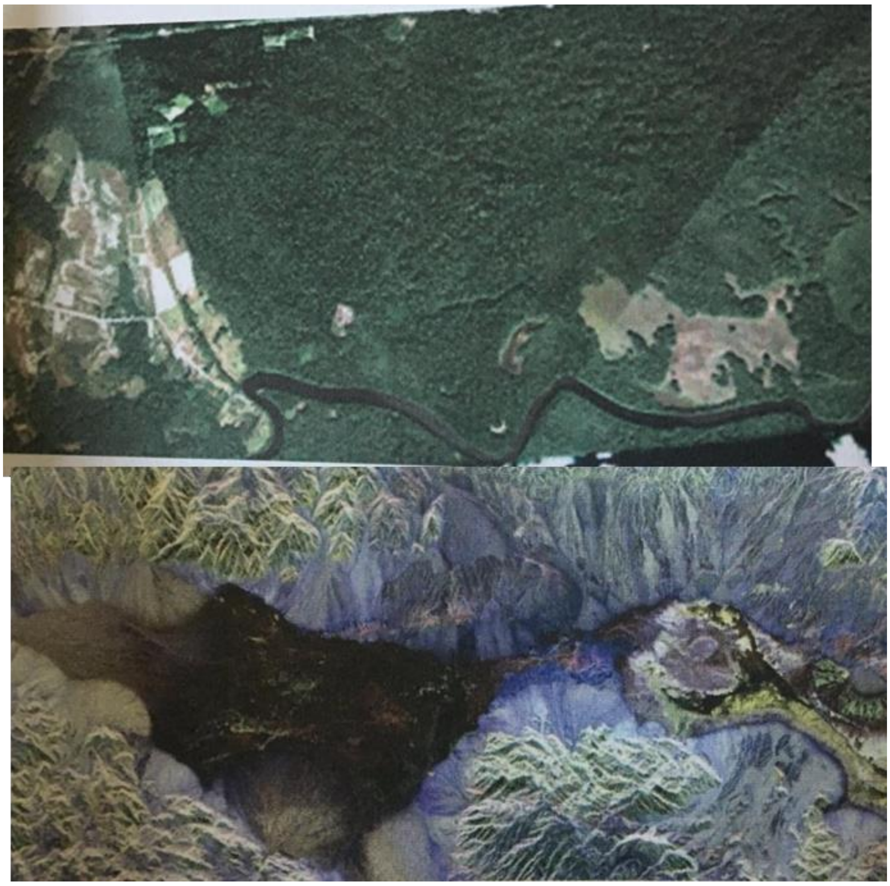

Figure 51. The study area is Parakou, French Guiana, which is an important experimental site for tropical rainforests;
Death Valley, recorded by SAR using polarimetry

The SAR is designed to map at an angle of up to 45 degrees to the direction of the flight speed vector of UAV. At a ground speed of 25-35 m/s, the bandwidth of the images is 800 meters. At speeds greater than 35 m/s, the width decreases in proportion to the increase in speed relative to the ground. The Tactical Endurance Synthetic Aperture Radar (TESAR) subsystem operates autonomously by executing a series of pre-planned mission commands loaded before operations, which can change mission profiles during flight.

Compressed and continuous SAR images are not available in Duty / Ultra High Frequency (LOS / UHF) modes. The results are transmitted via a broadband connection of 1.5 Mb/sec by satellite relay to the ground control station, for decompression and display.

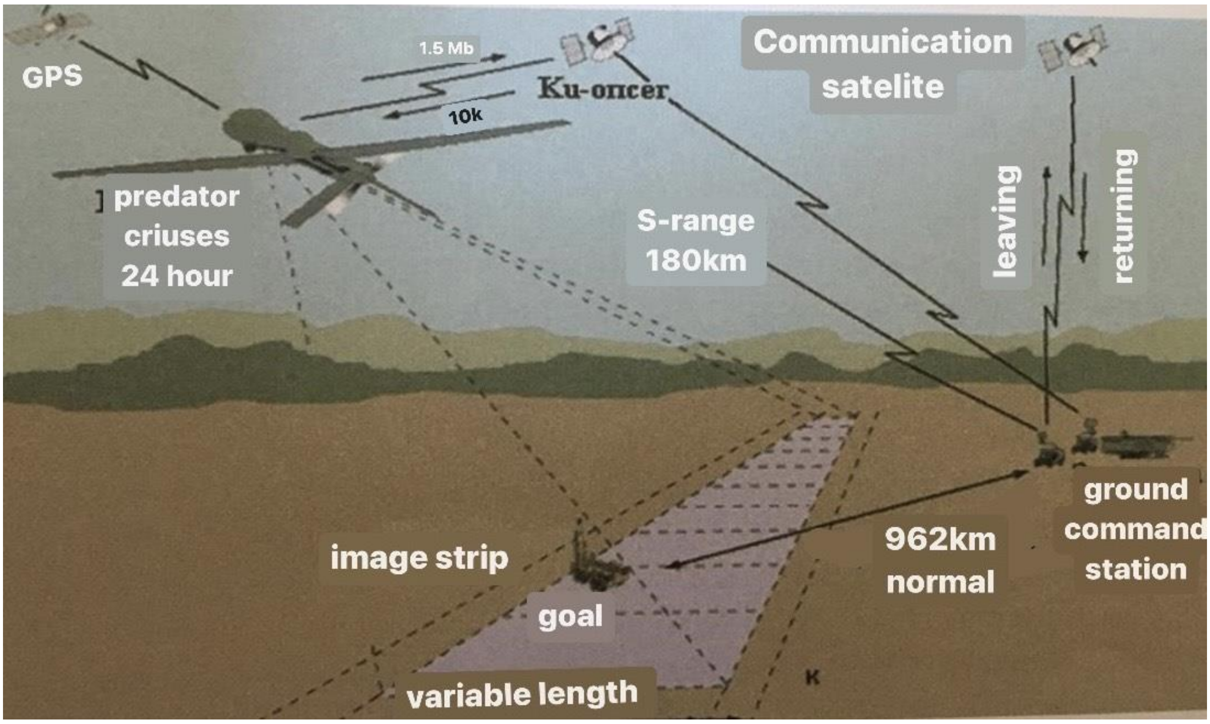

Figure 52. Mapping and transmission system to command station with UAV Predator

The SAR continuously provides 0.3 meter images. The desired image is formed in the UAV, compressed and sent to the ground command station via the Ku range of the data link. Images are adjusted and displayed in SAR mode on the command station screens. As the images move, the operator has the ability to select its segments (approximately 800 m x 800 m) for use at the command station. Images are also recorded continuously on (Digital Linear Tare, DTL) tapes. The subsystem operates autonomously, executing pre-planned mission commands loaded before the operation, which can be changed during the mission profile, during the flight.

In most cases, the initial design of the SAR and the aircraft are carried out independently, and by learning about the specific application, its appropriate variant is designed for a specific UAV or the UAV is adjusted to a specific SAR. This process certainly leads to a limited range of choices to achieve a particular desired goal and does not provide the system designer with complete choice and compromise. It is most advantageous when integrated approaches to the project are developed by optimal integration of the SAR and the aircraft project. This approach allows for wider application of a specific SAR for a specific UAV. There are several mutual influences between SAR and aircraft on their efficiency, and even conditionality in their final definition and integration. For example, the strength of the radar reflection is affected by the size of the antenna, but the size of the aircraft limits its size, even the azimuth resolution.

The speed of the aircraft affects almost all characteristics, including SAR and azimuth resolution. For applications that shift the SARs of small UAVs, it is important to keep in mind that the propulsion of the branch aircraft must power both

Figure 53. The light system

3.6.7 Lidar system

The LIDAR system (Light Detection and Ranging, LIDAR), uses laser to illuminate and capture the area by detection in its range in order to collect geometric and other information relevant to civilian and military use By applying this technology, a large number of points with precise coordinates are obtained, and thus the high quality of image details of the target object. Areas of application of the LIDAR system are important and useful in many ways.

Spatial data on the elements of traffic and industrial infrastructure, watercourses, oil pipelines, gas pipelines as well as the deployment of military forces and equipment for military tactical development and usage in decision-making are collected.

LIDAR technology works based on light laser pulses, by measuring the time of their reflection from the target shooting area to the position of the study site. The time is recorded with the help of sensors. Therefore, the key is the time difference between the moment of directing the laser beam and the reflected feedback signal. This time interval is then converted to distance data. Knowing the position and orientation of the sensors, three-dimensional coordinates of surface points are obtained, which enables the creation of digital terrain maps.

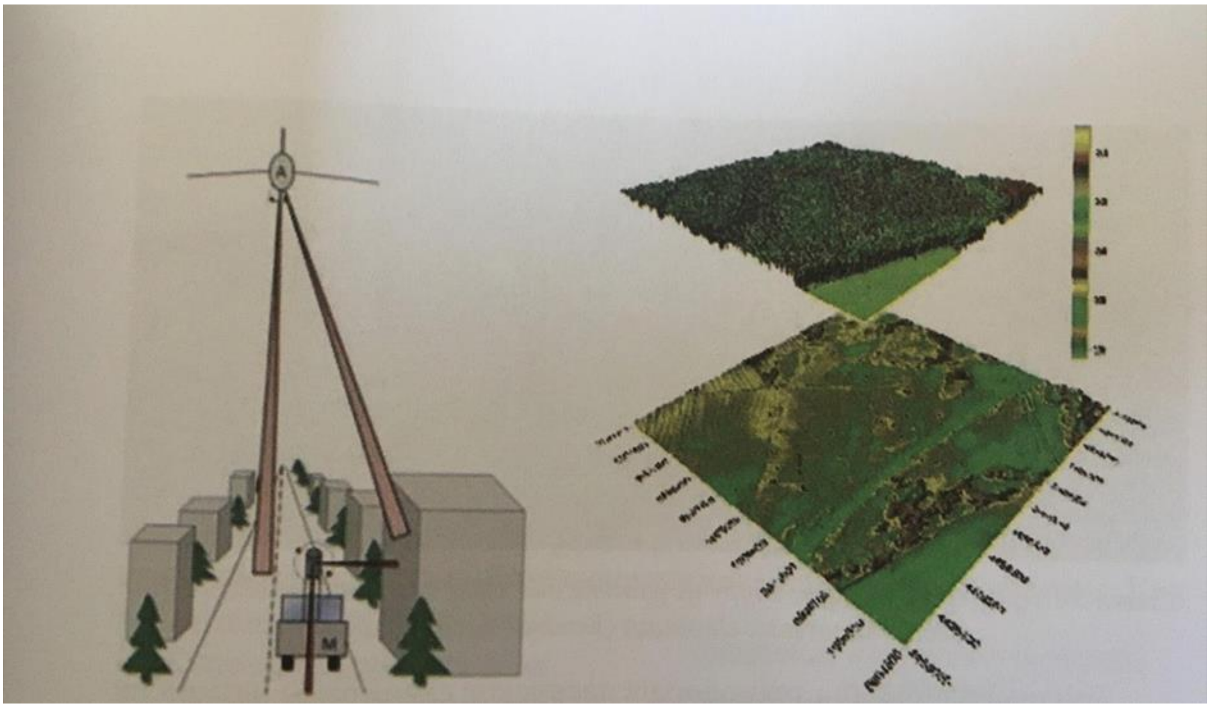

Figure 54. left: Illustration of scanning with the LIDAR system from the airspace; right: Digital display of the recorded terrain with a clear indication of vegetation types and shapes

The LIDAR system implements the recording of a large number of points with high precision and speed (up to 500,000 points per second). The accuracy of laser points is (+/-) 10 cm in position and height. In addition to lasers, which can be of different wavelengths, scanners, optical systems and photodetectors, navigation systems for navigation and positioning are an integral part of LIDAR technology. In that sense, the Global Positioning System (GPS) is used, which is crucial for accurate information about the position of the sensor, as well as the inertial navigation system, which provides information about its orientation in relation to a given location.

Figure 55. Image processed digitally in 3D. The height of the trees is clear

Three-dimensional laser scanning technology dates back to the 1960s, and was originally used to detect submarines from airspace. It was widely used after the development of GPS technology, which enabled the positioning of the sensor itself and obtaining precise geometric information. Since the 1990s (when operational use began), LIDAR technology has developed intensively in both speed and recording quality, as well as in data processing methods.

Figure 56. Example of 3D model, area about 1000m long and about 100m wide, around railway tracks (Kokemaki, Finland)

The advantage of the LIDAR system compared to classical methods is that it has faster, more efficient and economical data collection with the possibility of creating digital terrain models (DMT) of high accuracy. On the other hand, with the help of a laser beam of smaller wavelength, LIDAR enables the detection of small objects, which gives it an advantage over radar or sonar technology, which are based on similar principles of reflection. Experientially, LIDAR system is the most efficient to use for surveying larger terrain with a drone.

LIDAR is applied as a basic sensor on autonomous mini-buses (driverless) used experimentally in urban traffic, in several U.S. cities.

3.6.8 Software

UAV control software is the programmed logic, flight command control laws, including autopilot. UAVs are systems whose flight is controlled in real time.

Safe and accurate UAV flight requires a quick response to changes in sensor data (encoders) for regulation (correction) of flight according to the desired and set parameters of the state vector, as well as changing that desire (command-RC) from the operator. There are several systems in use. One of them is Henomal.

The aerodynamic asymmetric problem plays a critical role in the realization of safe and stable UAV flight due to technical errors in production, which is often influenced by limitations in the choice of materials, especially when flying in turbulent atmospheres. This problem is especially emphasized in small (light) drones. By applying adequate control algorithms, undesirable effects of aerodynamic asymmetry are suppressed and stable flight of the aircraft is achieved. UAVs often have small masses and are very sensitive to all errors and disturbances. Their unstable flight must be prevented by special measures. For conditions of major aircraft disturbances, the design and stability project contains applied techniques of nonlinear systems. In case of larger disorders, linear techniques of system analysis and synthesis are not applicable, but much more complex techniques.

3.6.9 Navigation System

The output of the navigation function is the input to the flight control system, which executively controls the appropriate correction of the position of the control surfaces and the engine operating mode in order to establish the desired trajectory and flight mode.

Figure 57. Anti-collision light

3.6.10 Inertial Navigation System (INS)

Inertial navigation depends on inputs from sensors located directly on the body of the aircraft and which do not relate to an external artificial input (e.g. GPS). In this way, it is not subject to unauthorized adjustment or interference from the outside.

The goal of inertial navigation is the independent processing of signals from built-in sensors to determine the speed and position of the UAV. The key components of INS are sensors and it is very important that they are set up and adjusted correctly. Their purpose is to collect data for determining the current UAV state vector in order to determine the deviation from the reference state within the selected coordinate system. The Inertial Measure Unit (IMU) is able to measure position (pitch, roll and yaw), velocity, height change and the inertial force acting on the UAV. The navigation function is part of the flight guidance, navigation and control system. It contains parameters for calculating the location and speed of the aircraft, as well as its orientation or position (known as the state vector). Navigation relies on input from multiple sensors and subsystems:

- Accelerometers;
- Gyroscope;
- Magnetometers.

The IMU intelligently compensates for the shortcomings of some sensors by providing input from others less provoked, resulting in output with reduced interference and less deviation (errors). The main problem with IMU is that it naturally accumulates errors over time during the angular and linear velocity integration process.

The air data system measures the atmospheric conditions in the environment. It may contain sensors:

- The barometer measures static pressure, and from these results the altitude of the aircraft is calculated.
- The static-pitot system contains a pitot tube and measures the total air pressure that makes up the sum of static and dynamic. This system is used to determine the flight speed.
- The thermometer measures the temperature and its construction can be performed on several principles. Temperature is necessary to estimate the density of the surrounding air. Density is used to calculate the flight speed from dynamic pressure data.

The state of the UAV in relation to the reference system (Attitude and Heading Reference System, AHRS) is determined on the basis of information from sensors: gyroscope, accelerometer and magnetometer. The determined difference is processed and systematically reduced to zero, via flight commands in which the autopilot is integrated. The inertial navigation system INS (Figure 39) is intended for measuring the navigation parameters of an object in space, using sensors, and their delivered data is processed by a computer. Changes in vector of the aircraft state in space are detected by measuring the translational motion with accelerometers, whereas the rotation with gyroscopes.

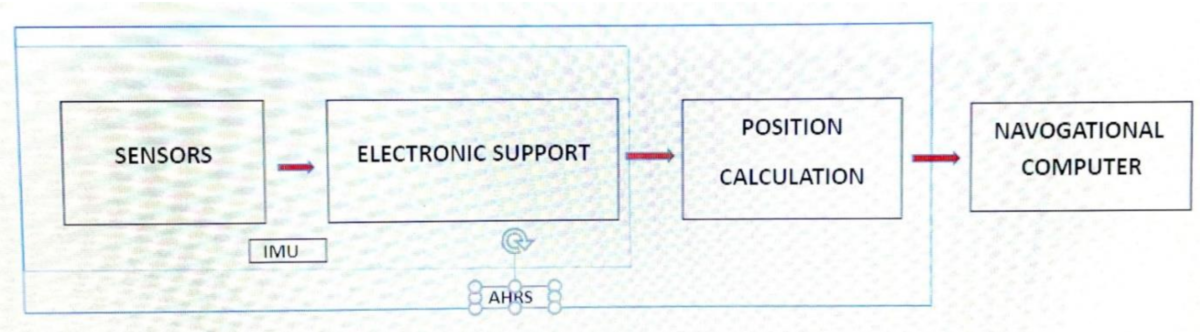

Figure 58. Inertial Navigation System

Inertial navigation system (INS) continuously takes the received signals from the sensors, calculates the navigation parameters based on them and compares the obtained results, in relation to the reference state (initially, in the fictitious state of the rest of the aircraft) or to a newly downloaded one. In this way, the orientation and speed of the UAV are determined in real time.

The UAV motion parameters in space are determined without the need for a constant reference comparison in relation to the external environment. The INS functions according to the movement of the UAV by measuring the kinematic parameters for six degrees of freedom, three translations (along three axes) and three rotations (around them) without the need to rely on external references.

The concept of the inertial navigation principle is based on the measurement of acceleration in translational motion along axes and angular velocities, rotation about the axes. Based on the known mass and the measured force of inertia, the computer determines the acceleration and the angular velocity based on the precession force. A major disadvantage of INS is the deviations in measurement with available sensors. In practice, this is overcome with a combination of INS and other navigation systems. For example, in combination with the GPS system, absolute position data is obtained every second, while the INS itself interpolates the mean values. By using the Kalman filter, in the appropriate control loop, INS measurement errors are minimized. For the inertial navigation system, the terms are related: inertial reference platform, inertial instrument and inertial unit of measurement.

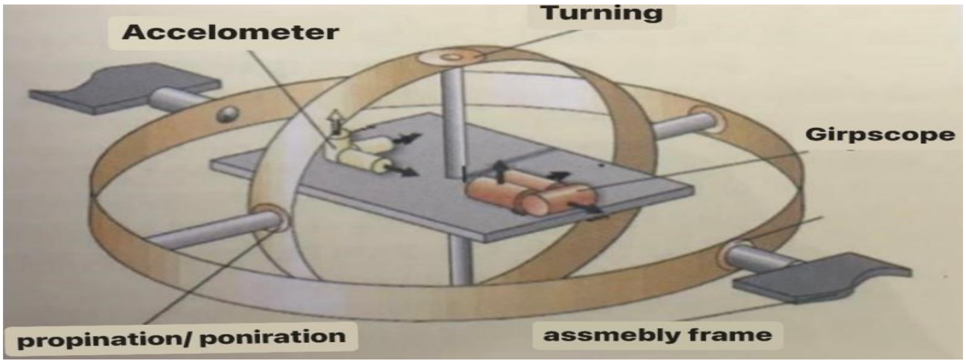

Figure 59. Inertial instrument and inertial unit of measurement inertial instrument and inertial forms

Elementally, this process, represented by mathematical equations, is based on Newton's laws of mechanics.:

$$m \cdot \ddot{s}(t) = m \cdot \frac{d^2 s(t)}{dt^2} = m \cdot a(t) = \sum_I F^I$$

Calculations of the total acceleration of the aircraft (including the gravitational constant) can be performed in a direct way:

$$\frac{ds}{dt} = v \quad \longmapsto \quad \frac{dv}{dt} = g + a_T$$

From the initial speed and starting position of the aircraft (or any other reference object) follows the integration over time, between the two-time moments of receiving sensor data. It is the same for the angular velocities that can be converted by determining the angular precession of the sensor (gyroscope) with simple integration over time into the angle of inclination in global space. INS gives a total simultaneous measurement of six variables in three mutually orthogonal directions in space. They are refer to as three translational degrees of freedom with three accelerations and three rotations with their own angular velocities.

In the last equations (t), the position of the spacecraft is determined. Velocity vector v, with respect to the inertial reference frame.The acceleration vector is defined as a consequence of the difference between the thrust and the resistance of the aircraft. The vector of total acceleration is the sum of a and g.

A simple calculation of the position and speed of the spacecraft is based on the equations of first-order differences that have the form:

$$\Delta \mathrm{v}_a(t_n) = \mathrm{v}_a(t_n) - \mathrm{v}_a(t_{n-1})$$

$$\mathrm{s}(t_n) = \mathrm{s}(t_{n-1}) + \mathrm{v}(t_{n-1}) \cdot \Delta_t + \frac{1}{2} \cdot \mathrm{g}_{n-1} \cdot (\Delta \mathrm{t})^2 + \frac{1}{2} \cdot \Delta \mathrm{v}_a(t_n) \cdot \Delta \mathrm{t}$$

The vector v_a is obtained by the integration process without considering the influence of the force component from the gravitational acceleration. The gravitational vector g_n, is a function of position in time t_n. Since the velocity is updated using the average gravity value in one time step interval, this method is called the "*average g method*".

Careful analysis of the spacecraft's errors in Earth's orbit showed that this algorithm gives an error of 100 m, and a speed of 0.2 m/s for a flight period of 35 minutes, using a two-second integration time step. Compared to a typical accelerometer error, the error of a computer algorithm is smaller by several orders of magnitude..

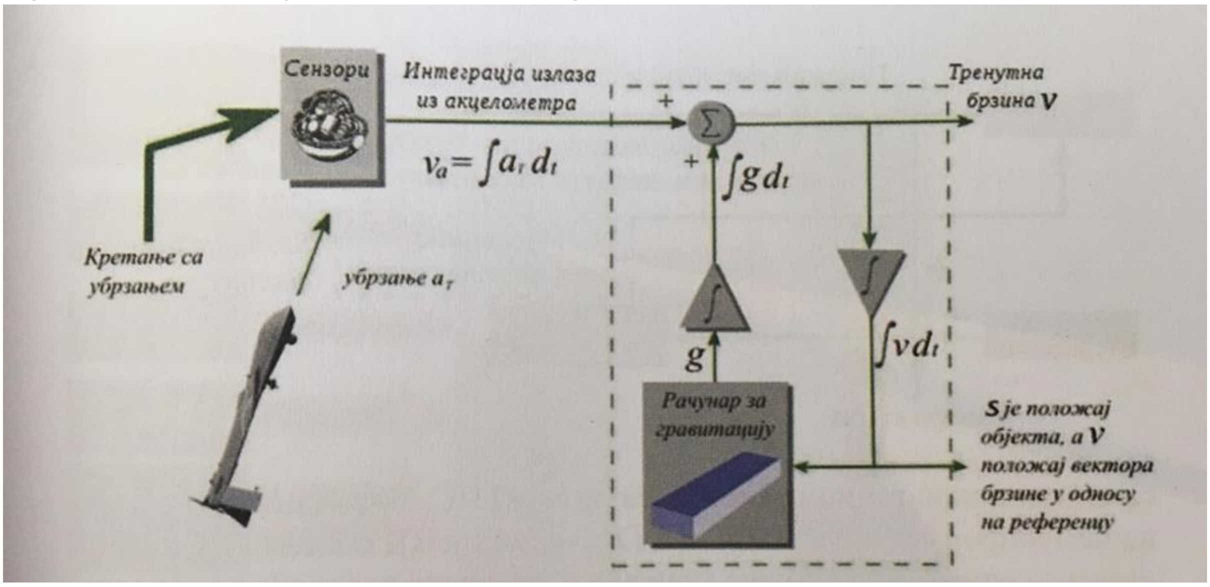

Figure 60. The principle of INS functions schematically shown

All inertial navigation systems tend to deviate from the accurate results. Small errors in measuring acceleration and angular velocity are integrated into the progressive magnification of the navigation parameter error. The applied principle of determining the new position in relation to the previous one, calculated in measurement steps and with calculations based on the currently received signal on translational acceleration and angular velocity, in relation to all three axes of the coordinate system, constantly adds system error to the final result.

Errors increase cumulatively relative to the initial state, at the same rate as the measurement and calculation process is renewed. Due to this characteristic, it is necessary to periodically correct the displayed position with reference data from another navigation system, usually from GPS. The deviation from the exact position of the object, with navigation with INS, in the resulting amount is on average less in the travelling distance of 1.1 km, and in the change of direction about ten degrees per hour of system operation.

Accordingly, an inertial navigation system is usually used in combination with another system, thus providing a higher degree of accuracy than it is possible with the use of any system alone. For example, if the inertial speed is monitored in field use, it is periodically updated to zero with the object moving (on the ground), the position will remain accurate for a long time. This so-called zero update rate is often used.

General control theory, especially Kalman filtering, provides a theoretical framework for combining information from sensors of various types. One of the most common alternative sensors is a global satellite navigation system such as GPS. By correctly combining information from INS and GPS, a GPS / INS system is obtained, which eliminates the occurrence of errors in the position of location and in the speed of the moving object. In addition, INS can be used the same as short term asset while GPS signals are not available, for example when a vehicle passes through a tunnel in isolation.

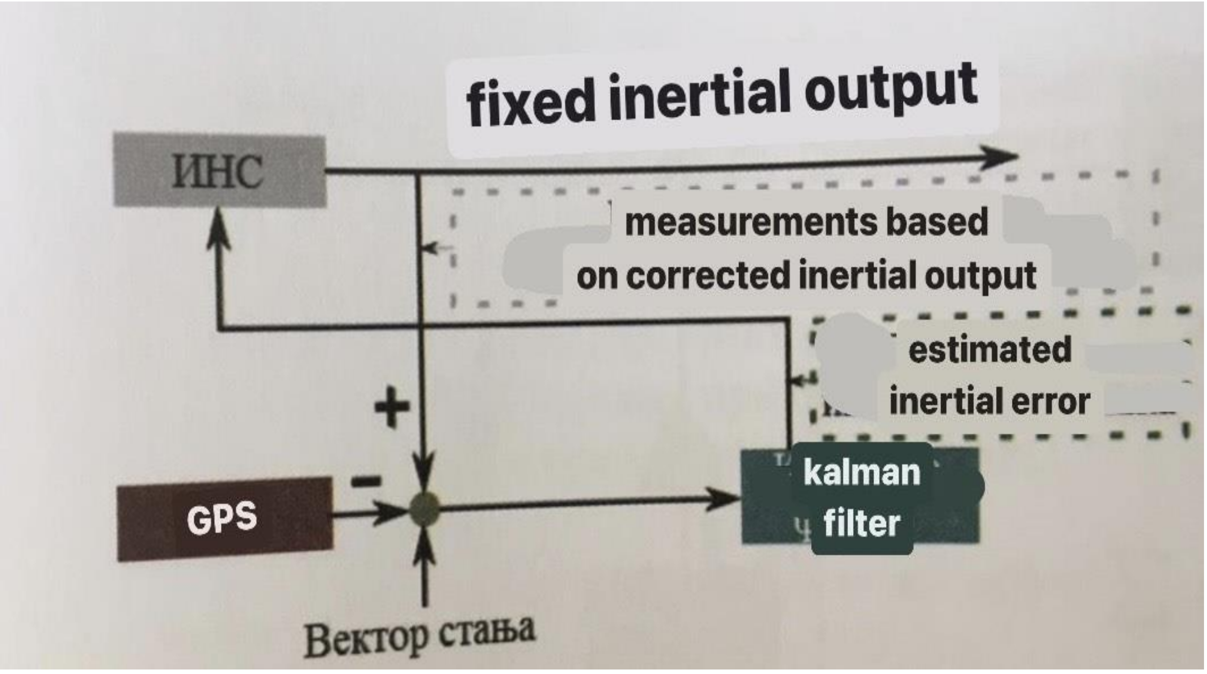

Figure 61. ИНС shema with loop GPS and Kalman filtter

The Kalman filter (KF) is a very effective stochastic estimator (judge) in navigation. It is the optimal combination, in terms of minimizing variations in deviations, between the values of the previous parameters and the current ones. It is extremely efficient and versatile in the procedure of combining noisy sensor signals, for assessing the state of systems with uncertain dynamics. The noise signals (outputs) of the sensor also include the outputs from the GPS and INS.

The position of the system can include the position, speed and overall dynamics of the aircraft. Uncertain dynamics also include unpredictable disturbances in sensor signal parameters or pilot-induced disturbances or external disturbances (such as wind gusts).

The Kalman filter is used to estimate the error introduced into the system due to gyroscope and accelerometer errors.These errors are in the format of the state vector hk, in relation to the measured values using GPS, form z. Errors tend to have zero values, with the help of the GPS system in the coupling-forward control loop, with the Kalman filter in it.

Figure 62. Drone T300 for lighting system

3.7 Flight Commands, Management and Stability

Linear and nonlinear modeling techniques are used in the design, analysis, and synthesis of UAV control and stability. It depends on the configuration and aerodynamic scheme of the aircraft and the flight conditions it can withstand.

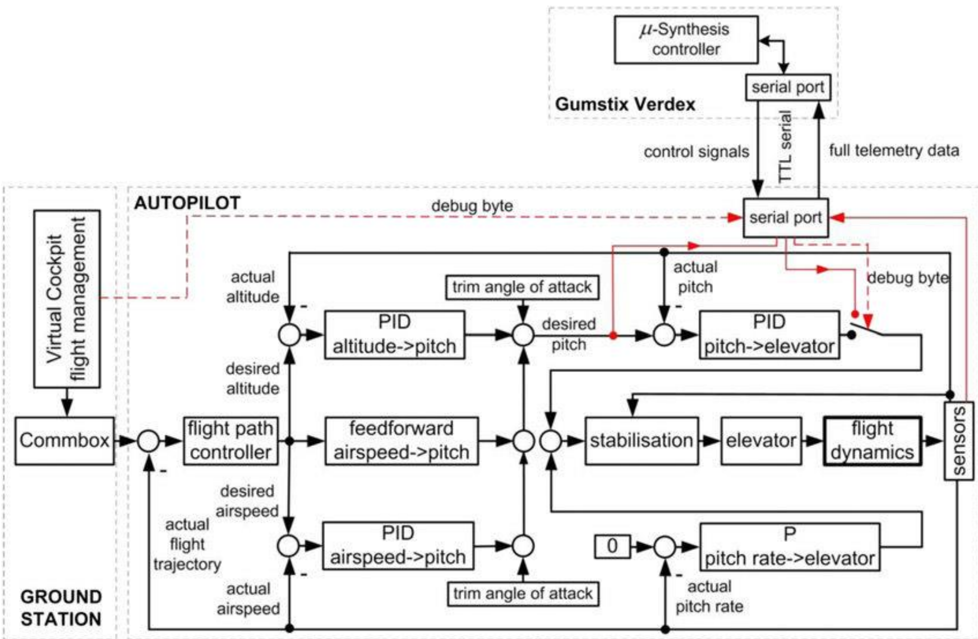

Figure 63. Integration of UAV flight systems and their mutual exchange of information

In general, UAVs have different types of management modes that can be chosen depending on the needs of the operation. There are three management modes that are most common and known by different names. Open, closed and hybrid architectures are used:

- The open circuit gives a direct control signal (to move faster, slower, left, right, up, down), without including feedback from the sensor data, via feedback loops.
- The closed circuit includes sensor feedback via feedback loops and comparator to regulate the behavior of the aircraft. The error (difference) between the desired value and the currently realized parameters of the state vector is forcibly reduced to zero. This system works efficiently in the linear domain of regulation of the mutual deviation achieved from the given (desired), by reducing the difference to zero.
- These two architectures are most often combined in more demanding projects.

In general, these control modes are used on all types of UAVs. However, professionals have more advanced and sophisticated autopilots. They are required to have more complex and high-quality characteristics of stability and control, as well as increasingly autonomous flight. Semi-automatic and manual control modes have both UAV pilot training and coaching. This is useful because some operations require special forms of flight, depending on the requirements of the competent aviation authority.

The autopilot mode would be the usual autopilot control mode that can be deactivated at any time during the flight so that the pilot can manually operate the drone.

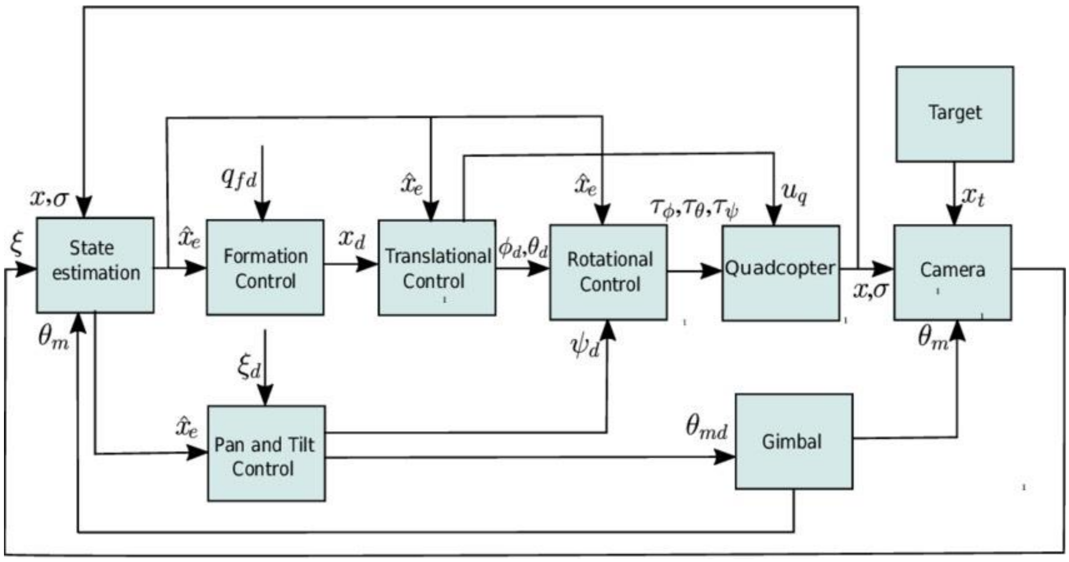

Figure 64 Global drone control scheme

In manual control mode (MC), the pilot fully controls the drone by dictating the positions of the control surfaces via the joystick, which results in the appropriate movement of the servo actuators of the control surfaces and the "throttle" (potentiometer, for electric motors). The pilot must be sufficiently skilled and trained in this mode of direct control as he is alone, without assistance and correction by the autopilot.

The semi-automatic mode is equivalent to manual mode, but autopilot helps. In this case, the pilot commands via autopilot which receives its signals communicated via the joystick, automatically stabilized command signals are transmitted to the control surfaces and, "throttle" via the servo. Essentially, a person without prior knowledge of piloting can manually operate the drone in this way.

The autopilot controls the position of the aircraft, while the pilot manually controls the altitude, speed or other reference parameters of the flight. Among other things, an algorithm is applied to adjust the rudder outside the control network, assuming that asymmetry of UAV production is present. Simulations show that the method of linear regulation improves the safety of continuous and stable UAV flight.

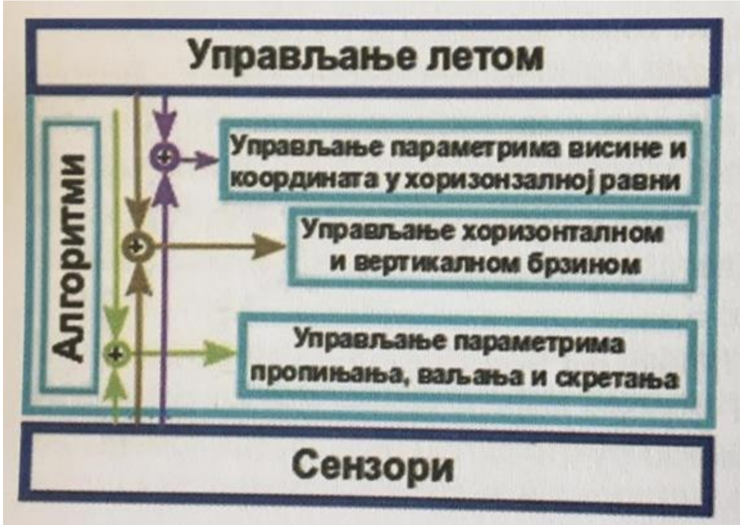

Figure 65. Typical scheme of UAV autopilot flight control

The engineering feasibility of this management is very important. Having that in mind, this method has great application in practical engineering.

Modern drone flight controls originate from the principle of radio guidance (RC), whose roots are in the patent of the genius Nikola Tesla. Historically, in the beginning, the pilot exclusively operated the aircraft directly by radio (RC).

Today's flight control systems have a large selection of sensors at their disposal, such as GPS, barometric pressure sensors, speed sensors and many others that preserve their wide list. Main contribution to the budget flight parameters are still gyroscopes combined with accelerometers.As the name suggests, accelerometers measure acceleration-induced by inertia, sharp maneuver n*g, or stopping force, but that is not enough. The intensity of the maneuver "confuses" the system, which should function exclusively on the accelerometer data. This is solved by turning on the gyroscope. Measuring the intensity of rotation around the axis, the results obtained from the gyroscope are the basis for determining the angles of inclination around its axes..

The helicopter drone uses a tail rotor to prevent the active influence of the main rotor torque on the reactive rotation of the entire aircraft.

The active moment of rotation of the rotor generates a reactive one, which is transmitted and forcibly acts on the rotation of the whole body of the helicopter.It all works great once the balance is fine-tuned, but it can still be a problem, especially for novice pilots.

Figure 66 UAV Flight Crew at the Common Base (LSA Anaconda), Iraq, April 20, 2005

This problem was solved by introducing a gyroscope. Its brass rotating element of a large mass, tilts in response to the helicopter's rotation. The effect of this inclination is sent by the sensor in the form of a signal-command to the rear rotor to prevent the rotation of the helicopter body. Mechanical gyroscopes have been replaced by solid micro-electro-mechanical systems, gyroscopes - microcontrollers (Micro Electro-Mechanical Systems, MEMS). Microcontrollers came into widespread use and enabled the development of advanced projects.

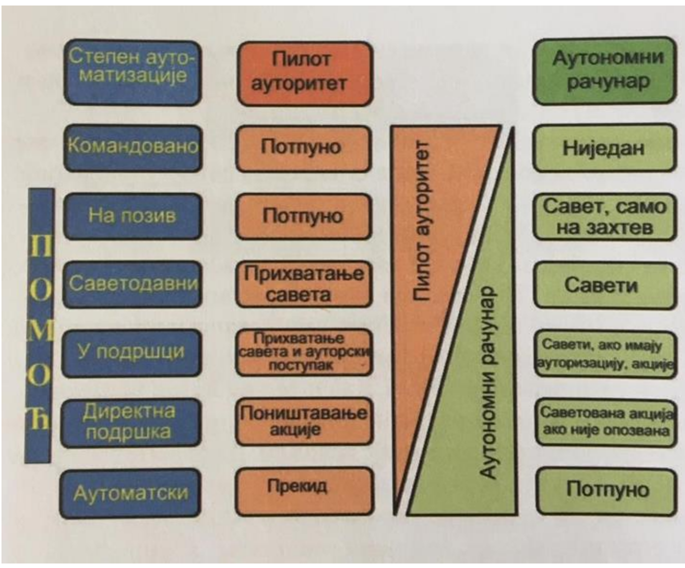

Figure 67. Automate UAV

3.8 Flight Autonomy

The aircraft condition measurement systems receive and process the recorded signals from the sensors and establish their fusion with special algorithms in order to achieve the desired flight mode faster and continuously. This is a key task for the efficiency of the formed control schemes with appropriate loops of autonomous control. The UN special agency (International Civil Aviation Organization, ICAO) has classified UAV into remotely operated and fully autonomous. In practical application, UAVs are with combined management and belong to the group of medium degree of autonomy. For example, remote-controlled aircraft can in most cases have an autonomous return to base.

The basis of autonomy is based on the use of sensors to measure values within the complete system. However, advanced autonomy additionally requires situational awareness, knowledge of the environment around the aircraft provided by sensors of advanced technology, with the fusion of all signals and integrated information obtained.

Autonomous control is achieved by means of multi-layer control loops, which is the principle in all hierarchical control systems.

Since 2016, flight control applications include low-level loops that pulse as much as 32,000 times per second, while higher-level loops can pulse once per second. The principle is to change the behavior of the aircraft with control commands more reliably and easily, during known transient processes. The most common control mechanism used in these layers is the proportional integral derivative (PID) regulator, which can be used to achieve quadrotor hovering using data from the Inertial Measure Unit (IMU), with precise calculation of inputs for electronic speed regulators and engine operating modes.

Executors of UAV task hierarchy plans use methods such as general state searches or genetic algorithms.

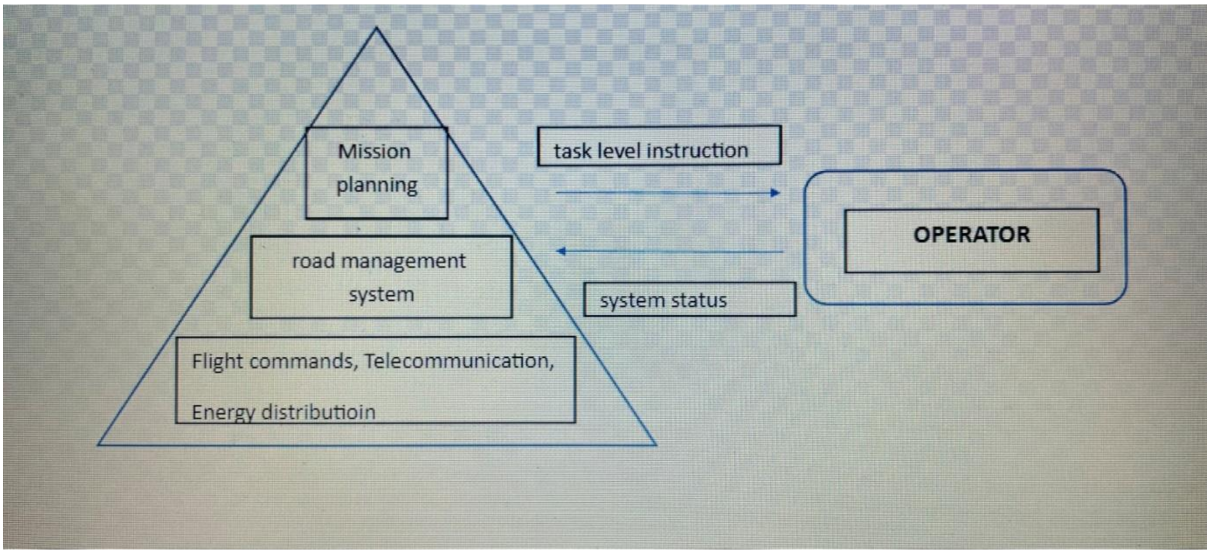

Figure 68. basics of automatic control UAV

Examples of middle layer algorithms:

- Planning the route, its optimal determination, on which the aircraft must move in compliance with the objectives and adhering to the limitations of the mission, such as the obstacles or the provision of necessary fuel;
- Route design (movement planning), determining control maneuvers to follow a particular flight trajectory, from one location to another;
- Trajectory control, limiting the aircraft within the permitted deviations on the trajectory.

UAV manufacturers provide special autonomous operations, such as:

- Self-adjustment, condition stabilization to terrain conditions and axis rotation;
- Maintaining altitude — the aircraft maintains flight altitude using barometer or ground sensors;
- Maintaining position, maintaining pitch angle, transverse tilt and turn, flight stability and altitude, while maintaining position using satellite navigation;
- Special mode, tilt control in relation to the pilot's position and not in relation to the aircraft axes;
- Carefree, automatic control of rolling and turning during horizontal flight;
- Take-off and landing using various aeronautical or ground-based sensors and systems;
- Safety in case of error, automatic landing return to base after loss of control signal;
- Return home by returning to the take-off location (often the flight altitude is increased first to avoid possible obstacles due to the ground configuration below the flight trajectory);
- Adherence to the procedure - a relative position is maintained before the reference object, using satellite navigation, image recognition or a native signal;
- GPS navigation, by checking checkpoints on the flight trajectory: the use of satellite navigation to navigate to the middle location on the trajectory;
- The orbit around the spacecraft is continuously orbiting the target (слике 49 и 50);
- Pre-programmed flying figures, such as rolling and loops.

Today's UAVs combine remote control, artificial intelligence and computer automation, integrally into autonomous flight.

More modern versions may have built-in flight controls with remote control and auxiliary automation systems to assist the pilot in steering in lower-level operations such as speed maintenance, trajectory stabilization and certain navigation functions for a given trajectory. It is wrong to call such sophisticated systems a "drone", on the contrary, they are "smart" aircraft, especially since they can take off most of their trajectory without human intervention, and even choose and make certain decisions. These possibilities increase intensively with the development of advanced technologies.

It turns out that the older drones were not autonomous at all. The area of autonomy of the UAV is a newer concept and it is in constant development, whose financing is largely driven by military priority needs for prestige in efficiency. In relation to the production of UAV hardware, the market for autonomy technology is quite immature and underdeveloped. Therefore, autonomy will continue to be a bottleneck in the development of future UAVs. This area is under technological and economic secrecy, and it is even more protected in the military segment.

The automatic control mode allows the UAV to perform options completely independently without the participation of pilots, which allows one pilot (operator) to control multiple instances simultaneously. In this case, the autopilot, supported by specific software, performs various phases of flight that allow the pilot to monitor the operation. These phases consist of tracking the waypoints of the route in a predetermined direction and direction of flight for taking off and landing, maneuvering hovering, cruising and many other possibilities.

Sometimes, during a preset path operation, additional specific interest in a change may arise based on new gathered ongoing information and unplanned needs. At that point, the system may warn of this possibility and suggest switching to camera control in guidance mode after monitoring the events in the video. Through this mode, UAV control is taken intuitively, targeting the camera according to the operator's decision and allowing the autopilot to adjust (coordinate) the flight, keeping it stable and controlling it directly in the direction indicated by the camera. This method of management is particularly useful for application in vehicle tracking, border surveillance and other similar missions.

In perspective, there is a video transmission of the camera from the aircraft in real time, remote recording using HD TV (high resolution), with the daytime color of the current time and black-gray-white at night, in the light of stars. Terrain recording is supported by additional built-in electronics. Movement and climb functions are enabled by systems for automatic terrain tracking and trajectory recording. One of the latest inclusions in advanced autopilot management modes is "follow my path". With this new management mode, instead of following a moving target, the UAV follows the path that that target follows, so that if it follows the same proven track, it avoids collisions with the same fixed obstacles. Simply put, a UAV with such an autopilot avoids collisions with obstacles on the path in the same way as a moving target in front of it is following, since it has already avoided them, by moving ahead.

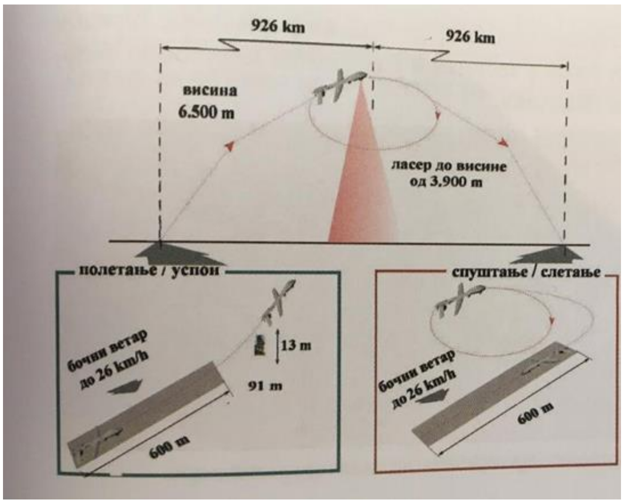

Figure 69. Laud system fo UAV

When using autopilot, no human intervention is required to internally adjust the mission parameters. Typical autopilot functions include: take-off, climb, flight maneuver methods and types, trajectory tracking between waypoints, navigation, descent, landing, sensor analysis, telemetry, decision-making, and mission behavior via onboard flight computer software. Mapping to and from the Internet via the onboard flight computer IMU can be displayed using Google Maps and a mobile phone with the Android system. Reporting with photos and pictures includes: finding points of interest and tracking moving goals.

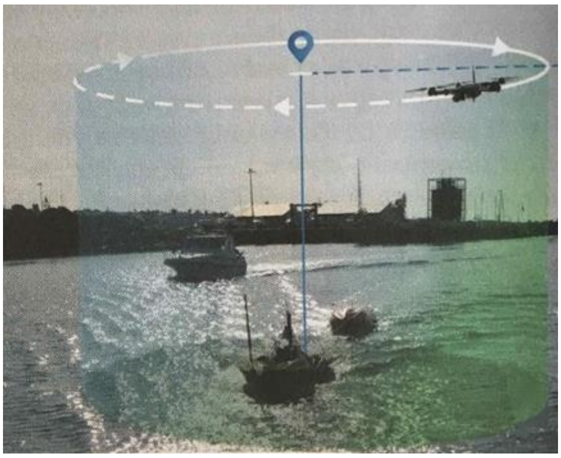

Figure 70. Rolling auto-pilot

By fusion and integration of sensor information, the obtained data are automatically combined, according to priority for the needs of the drone system. Communication is the management of the transfer of information, commands and coordination between multiple participants and in conditions of mutually incomplete and imperfect data.

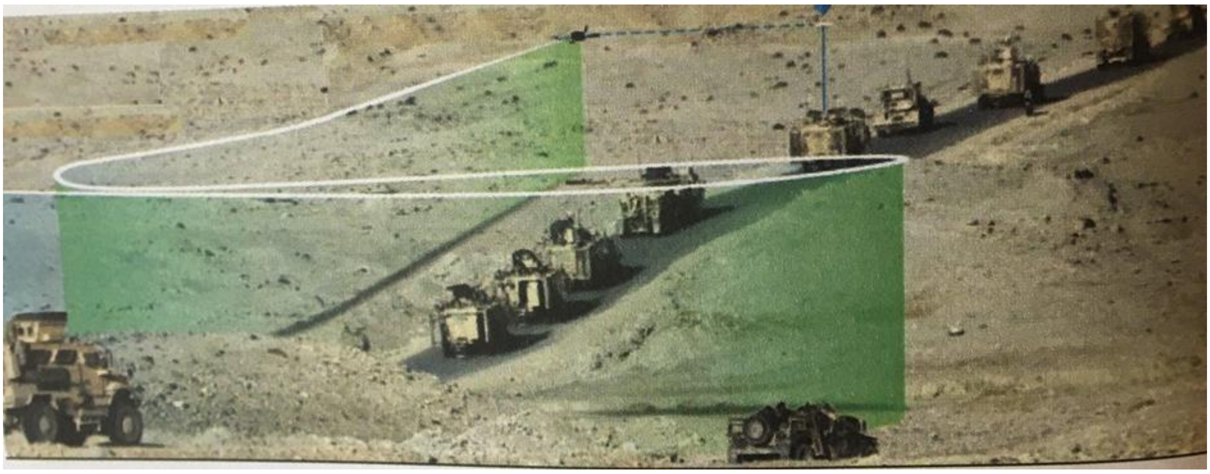

Figure 71. Long-distance surveillance control

Determining the flight trajectory is the choice of the selection of the optimal flight path for the UAV during a defined mission, while avoiding encounters with certain spikes and respecting restrictions during it, such as physical obstacles or the amount of fuel.

Trajectory control generation is the determining the optimal control for the desired maneuver to follow a given trajectory or an optimal flight from one location to another. The trajectory movement standard is a specific requirement of the control strategy with the limitation of the deviation of the unmanned aerial vehicle, within the prescribed size on the path (permitted deviation from the given one).

The distribution of tasks is their optimal division among the participants within the group, conditioned by the time and limitations of the available equipment.

Joint Tactics is the selection of optimal tactical sequences and spatial arrangement of activities among the participants with the aim of increasing the overall effectiveness and results within the entire mission.

In a general sense, autonomy is usually defined as the ability to make decisions without human intervention. In that sense, the goal of autonomy is for the UAV to "learn" to be "smart" and to behave as similarly as when it is controlled by a man. This feature can be related to the development of the field of artificial intelligence, expert systems, neural networks, machine learning, robotics and vision.

However, the path of technological development in the field of autonomy has mostly been followed by a bottom-up approach, such as hierarchical management systems.Recent results are largely based on experience in the field of control theory (automation), and less so in the computer profession. Accordingly, autonomy will continue to develop further primarily through the theory of control, automation, robotics and artificial intelligence.

The development of UAV autonomy technologies strives to replace the human pilot as an obligatory participant in aircraft control as much as possible. It remains to be seen whether the future development of autonomy technology may be constrained by the political climate surrounding its use in certain UAV applications.

The result is that artificial vision for piloting is not capable of reaching the level of a human pilot. It can only get closer to that of a human pilot. NASA used synthetic visions on the HiMAT program in the early 1980s. The introduction of UAV flight autonomy, a higher level autopilot, significantly reduces the use of artificial visionThe introduction of UAV flight autonomy, a higher level autopilot, significantly reduces the use of artificial vision.

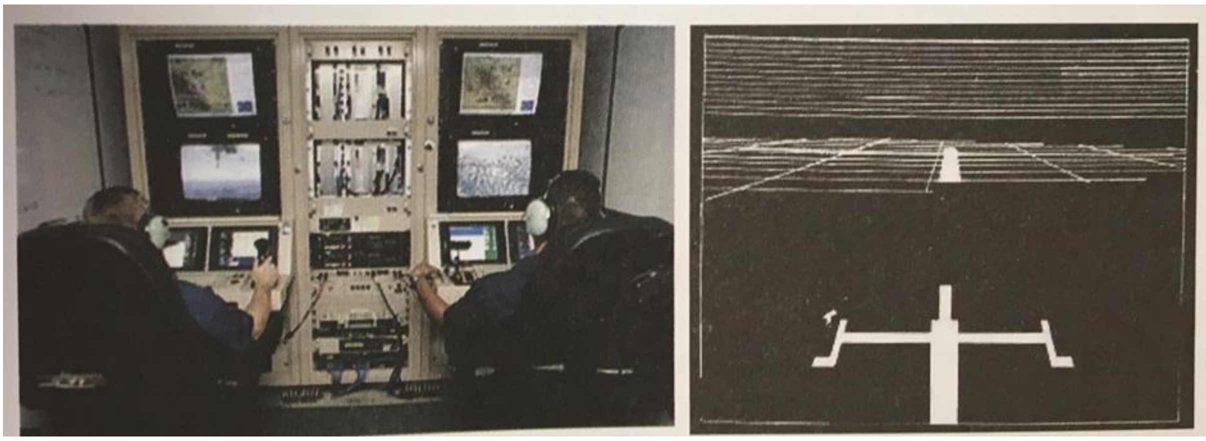

Figure 72. left: UAV control station; right: Display screens and remote synthetic cabin of the HiMAT aircraft

3.9 UAV Autonomous Flight Research and Development Project

One autopilot project for autonomous unmanned aerial vehicles was developed at the Czech University in Prague. This development is motivated by the desire to bring this demanding technology closer to interested users.

Networked hierarchically distributed control systems are presented and their hardware and software structure is described in more detail.A mathematical model of a small UAV is presented, and a methodology for identifying and estimating the condition using a Kalman filter is considered. Control algorithms have been proposed, based on the approach of proportional integral control (PI), quantum gravity in the loop (Loop Quantum Gravity LQG) and numerical solution of the Ricati equation (state-dependent Ricatti equation SDRE). focused on UAV, including a complex hierarchical autopilot project. These blocks (or nodes) of the entire content of the flight command are interconnected by an electrical network (Controller Area Network, CAN). Actual data measured during experimental UAV testing are presented.

In addition to wide military application, UAVs are present in many economy branches, and they are very interesting for academic research because they can be used for various purposes, as flying laboratories, objects for control algorithms or as a tool for education and student exercises.As a result, there is a growing demand for UAV control systems and many relevant projects, for both commercial and scientific purposes, with the aim of developing the most perfect UAV autopilots possible. Many impressive results have already been achieved, and many UAVs are already more or less autonomous. They use various scenarios of solo flight mode.

From the autopilot project point of view, UAV is a great challenge. It is a very complex multidisciplinary process that includes disciplines from hardware design, sensors, measurement, networking programming, etc. to mathematical modeling and control theory, artificial intelligence, robotics, image and signal processing. That is why this process is very interesting for researchers from various fields, and there is still a lot of room for improvement and new approaches, since this is a relatively new field, fresh and still insufficiently researched and developed.

Wi-Fi communication is not critical with the UAV, as it is only used for telemetry and remote system monitoring. Autopilot commands (automatic/manual switching of operating mode and desired values for commands) are sent via the model RC system, which is much more reliable and has a much wider range. In the future, a Wi-Fi connection will be replaced by a better system. It is consciously used only temporarily, in order to accelerate the development process. The control input data, such as the current position of the spacecraft, is provided by a navigation block containing an inertia unit (IMU) and a global positioning system (GPS Currently, the system is being expanded with a triple magnetometer to simplify the determination of direction and heading.

So far the angles of the aircraft inclination were determined by measuring the acceleration. Acceleration caused by inertial loads can be decomposed into three components, parallel to the axis of the aircraft. These components are measured with an accelerometer, and the angular value is determined by integrating the angular velocity. The disadvantage of this method is that it is not only the acceleration of the aircraft that the accelerometers measure but also the gravitational acceleration g. These obtained values are superimposed on each other. Aircraft accelerations can be extracted using a low-pass filter, but this introduces a system process delay, i.e. it increases the system response delay to the command signal.

For the initial mathematical modeling, the flight controller designations are sufficient, according to the chosen well-known model of the state vector components: [u, v, w, p, q, r, Θ, φ, β1c, β1s], where u, v, w are the velocity components aircraft, r, q, r are the angular velocities around the axes, [β1c, β1s] parameters related to the drive rotors (if the variant is with them).

Figure 73. Block diagram of the autonomous control system

3.10 UAV Classic Aerodynamic Schemes

UAV classical aerodynamic schemes are basically naturally stable. These are aircraft with lifting surfaces, a fixed wing and most often with horizontal and vertical tail surfaces that stabilize them longitudinally and laterally. On these stabilizing lifting surfaces, the rotating surfaces of the flight control controls are placed around all three axes of the coordinate system. They primarily use linear techniques for the analysis and synthesis of control loops, which has been proven satisfactory by experience. The content of the system state vector is of the same shape as in piloted aircraft (same or similar aerodynamic schemes). Advanced fighter UAVs are being developed according to similar criteria as fifth-generation manned fighter jets. Their priority is to minimize visibility. This is achieved by introducing advanced technologies:

- By applying composite materials that do not reflect radar rays;
- By minimizing the radiant reflection of "wetted" surfaces, their optimal shaping by complex computational algorithms;
- Concealed air intake, engine exhaust and weapons (in "bunkers" in the hull).

For these requirements, the so-called aerodynamic scheme is most often used. "Flying wing", modeled on the American low-visibility bomber B-2 spirit (Northrop Grumman B-2 Spirit).

Typical examples of these conceptual solutions are the European experimental UAV Neuron and the Russian Ohotnik, which are presented in a separate chapter of this book. These solutions with an aerodynamic "flying wing" scheme are recognizable by the fact that they are without tail surfaces, with a hidden suction cup on the back of the fuselage (in place of the cockpit of a piloted plane), hidden exhaust of engine jets and hidden weapons in "bunkers" in the fuselage.

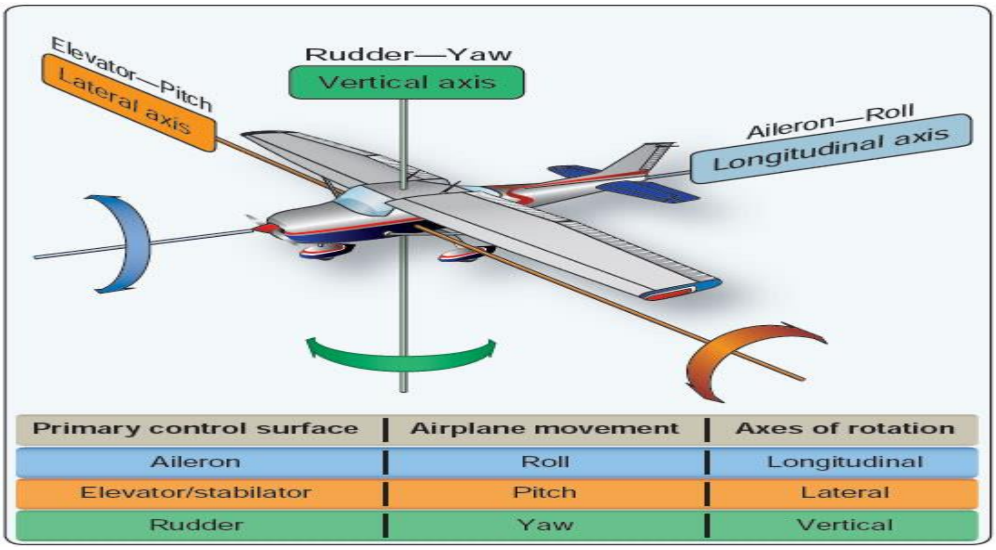

Figure 74. Control axis

Apart from the fact that the "flying wing" configuration enables efficient integral optimization of the design of "wetted" surfaces for minimal radar reflection (minimum radar cross-sectional area), it also has other advantages in the project. It facilitates the construction of the stressed structure, having less mass for the required strength and rigidity.

It also facilitates more efficient application of composite materials technology for the construction of the supporting structure (simpler tools) and larger internal space for storing fuel and weapons.

In the "flying wing" configuration, the local chords of the aircraft wing are longer, which contributes to less aerodynamic wave resistance in supersonic flight.

The hidden intake at the place where the cockpit is installed, prevents the thermal infrared sensors from "seeing" the heating of the engine parts and the structure around it, from the front through the UAV intake duct.

The use of composite materials to make the structure of the aircraft that absorb radar waves has reduced the area of the radar section. In addition to the efficient application of carbon fiber-based composites, more efficient nanocomposites have been used recently. With them, the structure is much lighter for the same strength and rigidity. The F-35 Lightning II is the first aircraft whose many parts of the structure are made of nanocomposites. It is understood that this technology will be applied to advanced UAVs as well.

3.11 UAV with Four Rotors (Quadrotor)

The quadrotor is a specific aerodynamic and constructive configuration, which is completely different from the manned aircraft. It is traditionally used for small and light UAVs, but recently more often for UAVs of larger dimensions. It has a wide range of application possibilities in all areas of human activity. It is more flexible and has more diverse possibilities than classic aircraft configurations. Despite the fact that it is not possible to provide natural stability to this configuration, it is successfully achieved artificially, with the help of relatively cheap consumer devices.

The quadrotor configuration provides the ability to move forward, backward, right, left, up, down and hover for a long time, according to the signal that the user sends as desired. These demanding operations are performed with a more appropriate concept of flight commands and a stabilization system, through programmed mutual combinations of the operating modes of four engines with rotors, according to special sophisticated algorithms.

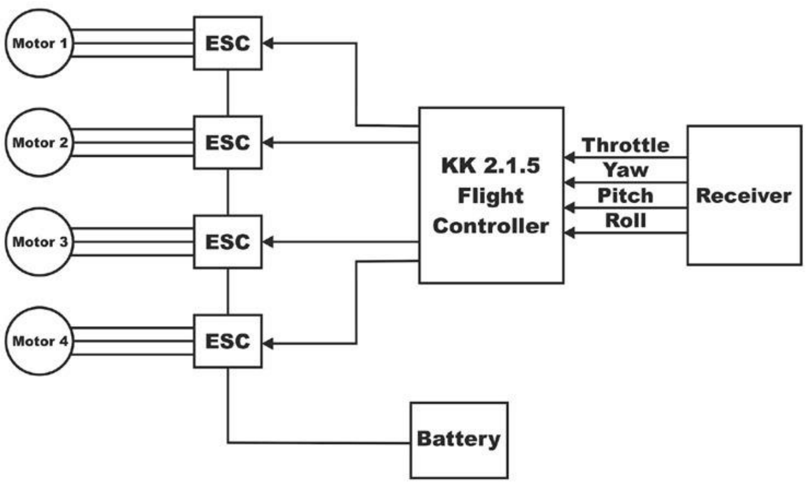

Figure 75. Flight control algorithms

The frame (specific hull) is strong enough so that it remains undamaged in the event of a collision or inappropriate (rough) landing.

Four engines with rotors, symmetrically distributed around the perimeter of the body frame (hull), drive the quadrotor, as shown in Figures 55 and 56. In the following illustrations, the rotors are shown as circular surfaces, and the direction of their rotation by arched arrows. The engines marked with the number one and three turn the rotors clockwise (top view). Engines two and four, with rotors, rotate counterclockwise (Figures. 57, 58, 60 and 61). Each engine, in conjunction with the rotor, produces thrust (lifting force), and with its algorithmic redistribution, individual intensity. Due to the symmetrically opposite direction of rotation of the paired engines, in conjunction with the rotors (2 + 2), their total torque, produced around the Z axis, is canceled. This eliminates the need to introduce an additional solution to cancel the induced torque, due to the rotation of the rotor, transmitted to the body of the aircraft. In a classic helicopter, this moment is canceled by a smaller tail rotor.

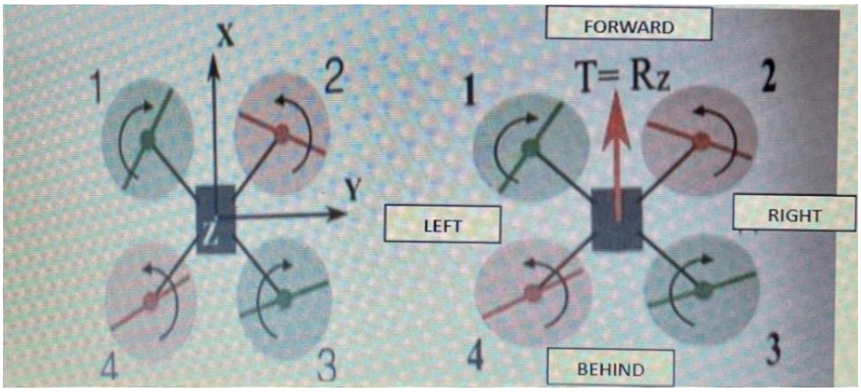

Figure 76. Direction of movement UAV

The vertical lifting force is created by a coordinated increase in the speed of rotation of all engines with rotors in the identical operating mode. When the total lifting force exceeds the gravitational forces, the quadrotor leaves the ground and climbs to the desired (commanded) height.

This is achieved by increasing the rotation speed of the rotor 3 and 4 (rear, green) and by reducing the rotation speed 1 and 2 (front, pink). The total lifting force, the sum of the redistributed individual ones, equals the weight of the aircraft, so that the quadrotor extends the flight without changing the altitude.

One of the rear rotors rotates clockwise, and the other counterclockwise. The individually increased torques are in the opposite direction around the Z axis, and with the same increase in the rotation of both rotors, they will still remain identical to each other and are canceled. The same goes for the UAV front rotors. The flight (forward movement) takes place on the basis of the obtained drag force component due to the forward inclination of the rotor, because of the higher total thrust force of the rear UAV rotors than the total on the front rotors. In this way, the total thrust force gets the lift component and the drag force component to move the UAV forward. With this longitudinal tilt, the UAV flies in a straight line without changing the direction (the turning angle ψ does not change), and with unchanged total lift and without changing the height.

On all rotors, the thrust is automatically adjusted individually so that the total vertical lifting force remains equal to the weight of the UAV for the commanded horizontal flight condition, while maintaining the initial condition of equal thrust of the paired rotors.

In this flight mode the following conditions are met:

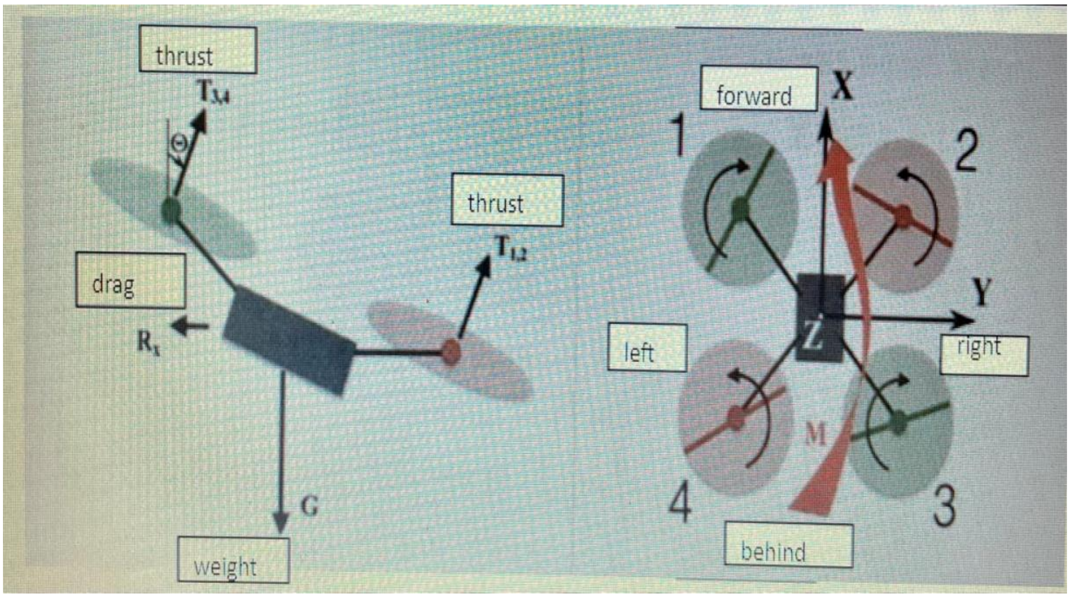

Figure 77. Direction of movement UAV

- ⌘ Ψ=0 -> T3=T4 и T1= T2
- ⌘ ɵ=const -> (T3+T4)>(T2+T1)
- ⌘ G=Rz
- ⌘ Rz=(T1+T2+T3+T4)cos ɵ • Rx=(T1+T2+T3+T4)sin ɵ

The achieved longitudinal moment of climbing/diving M causes the inclination of the quadrotor along the longitudinal axis X (around the axis Y), by an angle Ө. This is indicated by a red arc longitudinal arrow.

Condition for the transverse slope of the quadrotor at the angle f: (T1 + T4) > (T2+ T3).

The right engines decelerate and the left ones accelerate, the difference in total lifting forces generated by the rotors on the left motors (1 and 4) and the right engines (2 and 3) create a rolling moment L. This moment causes the quadrotor to tilt to the right, indicated by a red arc arrow (Fig. 61). In this way, a transverse inclination of the quadrotor around the longitudinal X axis for the angle φ is achieved. The total lift for the UAV horizontal flight remains the same as for the fulfillment of hovering conditions: G = T1 + T2 + TZ + T4.Most helicopters have only one main rotor and then torque is caused which must be reversed. In the case of helicopters, this is solved by a small tail rotor placed laterally on a sufficient arm from the center of gravity of the aircraft (tail part).

Figure 78. M210 system UAV speaker

In the case of quadrotor, this problem of annulment of the induced moment acting on the body of the aircraft is systematically solved by a combination of paired engines with rotors of opposite direction of rotation (2 + 2). This technique is also used to control the quadrotor in the direction by deliberately establishing the imbalance of these moments, by establishing different speeds of rotation of the rotor. Rotors that rotate faster cause a greater moment transmitted to the body of the aircraft, which causes a moment N around the Z axis, which turns the quadrotor by angle Ψ. The rotation of the quadrotor by the angle Ψ is in the direction of rotation of thepaired rotors of higher speed. This is achieved by increasing/decreasing the speed of the two paired rotors (1 with 3) and adequately reducing/increasing the other two engines with rotors (2 with 4). Such a change in the rotor speed results in a turn of the quadrotor to the right/left (Figure 62). The same figure shows the moments N about the Z axis. The moment caused by rotors 1 and 3 is marked in green, and the moment caused by rotors 2 and 4 is marked in red. When these moments are equalized, there is no deflection; when the green rotors rotate faster, a higher torque is caused which causes the quadrotor to turn to the right, and when the other pair of rotors rotate faster (2 and 4), the quadrotor turns to the left.

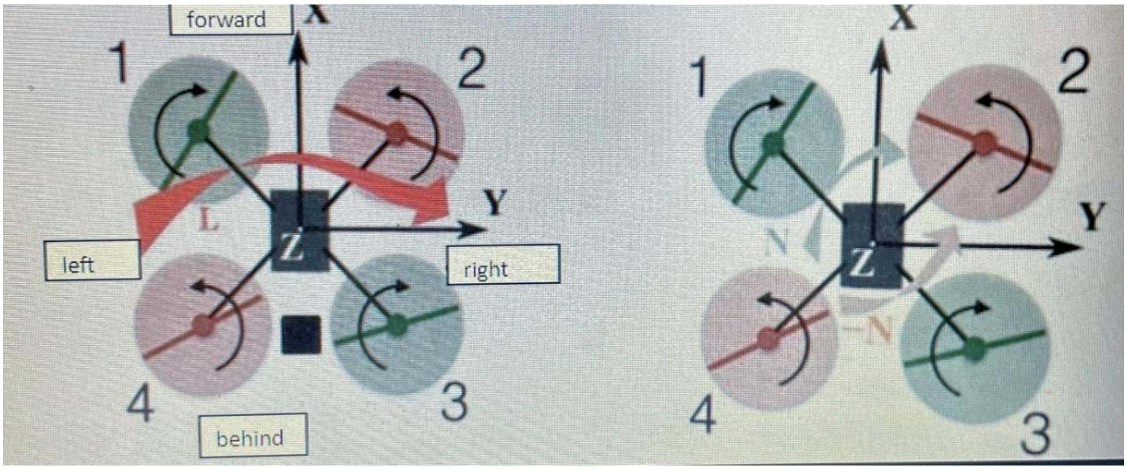

Figure 79. Transverse torque (rolling), Turning moment

The flapping dynamics of the rotor arm and the preservation of the moment around the shafts at the flapping angle can be approximately determined using Fourier series. The flapping angle is determined by the balance between the aerodynamic and centrifugal moment and the instantaneous stiffness. In addition, the flapping dynamics can be considered in an acceptable approximation, simplified using expressions for its constant values. Then the whole object needs to be considered with a total of all counter-rotating rotors (without the influence of soil). Stabilization is enhanced by the tilt phenomenon of the rotor discs. This phenomenon occurs so that during the forward flight, the arms of the front rotors rotate more than the rear ones.

Transmitter architecture for selection of different shapes and phases of flight (hovering, taking off, landing, progressive flight. By default, ie. when the user does not touch the screen of his control device, the UAV enters the hovering flight mode, where the altitude is kept constant, there is no change in the position of the aircraft and its angular velocity is stabilized at zero. The aircraft is switched to landing mode by double-clicking on the screen, setpoints for speed increase/decrease and angular speed of turn are determined (the screen is touch sensitive).

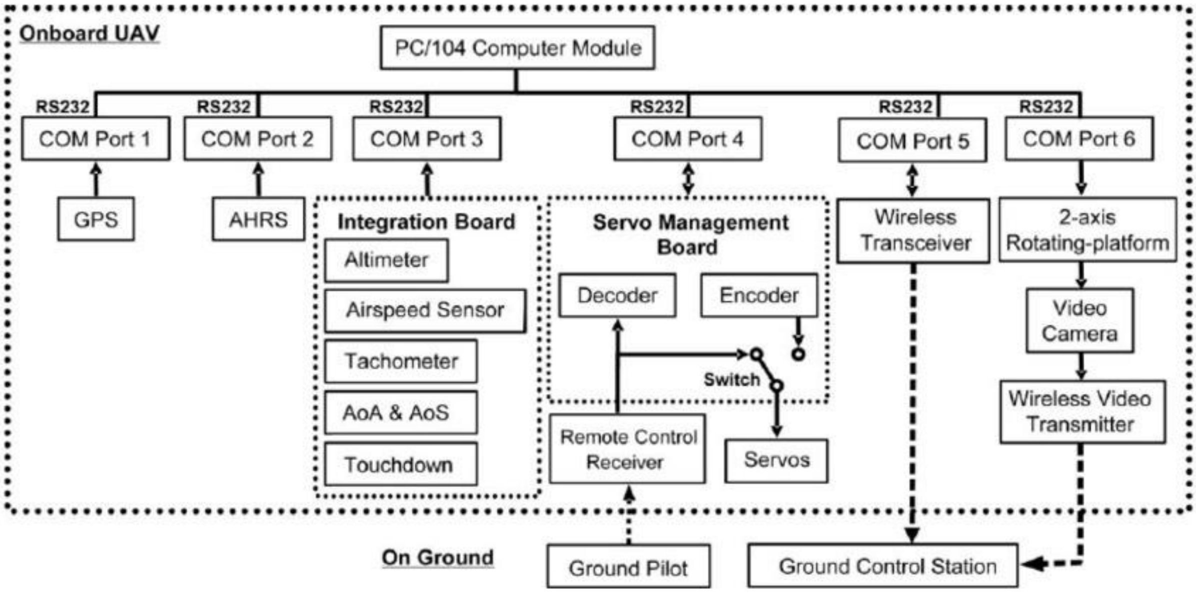

Figure 80. Ground operator

The control takes place via closed loops with the travel speed, height and angular speed. The loops determine the difference between the set and realized values and reduce it to zero. When canceling the difference, the flight mode requested by the user is established. Angular velocity is monitored by proportional integral control (PI).

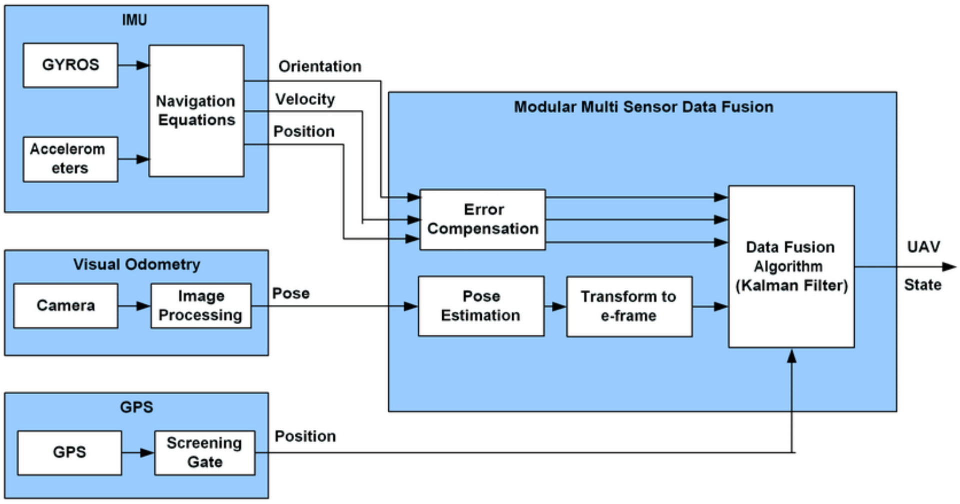

Figure 81. Data fusion and UAV management architecture, quadrotor

In flight mode, the pilot (operator) sets the position value. When hovering, the set state value is zero, but the transition from flying mode to hovering is realized by setting the state with zero speed, zero altitude change and maintaining that state of the drone, which automatically maintains and provides the control loop in hovering mode. Planning for a mode change starts from the current state of the quadrotor speed, when the pilot leaves the progressive mode or some other current flight mode. The technique of generating transient modes has been carefully designed, so that the mode of zero speed and unchanged position is interrupted for a short time (without excessive actions), and in case of stopping the control of forward motion, it is accompanied by inversion.

Concentrating on the longitudinal velocity and the corresponding angle of inclination ϴ, the reference signal ϴref (t), the inversion of the dynamics u = -g * ϴ-Sxu is calculated, where Sx, the coefficient of aerodynamic drag, is a second-order filter resulting from closed loop identification.

$$\frac{\theta(s)}{\theta_{ref}(s)} = \frac{K}{\frac{s^2}{w_0^2} + \frac{2\xi s}{w_0} + 1}$$

Approach speed	Open fuselage	Closed fuselage
U0<3m s^{-1}	1,5s	1,5s
3<U0<6m s^{-1}	1.0s	2,2s
$U_{0>}$6m s^{-1}	1,5s	2,4 s

Figure 82. Stop time for different previous (initial) speeds

Aircraft without lift and stabilization aerodynamic surfaces with a rotor are versatile. They are capable of vertical take-off, landing, hovering, flying within very low altitudes with the performance of complicated maneuvers.

These properties make them suitable for a variety of applications such as surveillance, ship patrol, search and rescue, etc. On the other hand, their nonlinearities and dynamic coupling pose a challenge to the designers of their flight controls and stability solutions, which attracts great interest from experts. Many control techniques have been applied to provide autonomous flight for this category of aircraft. Recently, the model predictive control (MPC) method has been recognized as a potential application method for unmanned aerial vehicles.

The prediction feature of MPC is a suitable strategy for UAV applications, especially in trajectory tracking where a future reference value can be considered for improving management performance. Essentially, the procedure in the application of MRC algorithms is to solve the formulation of optimization problems. For a nonlinear system, the MPC technique generally requires that the optimization problem be numerically repeated very often. Data samples are often taken over time, which makes it difficult to implement in real time due to the high workload and reduced bandwidth of the computer. The resulting reduced computer throughput and increased delay make it difficult to meet the high requirements for operating systems with extremely high dynamics, such as rotorcraft without fixed lift and stabilization surfaces. Only a few management applications have been reported where the high-level IAS principle has been applied to solve monitoring problems based on local linear feedback (coupling) of regulators. Solving the formulated nonlinear optimization problem requires the mandatory application of an additional secondary more powerful flight computer.

The analytical solution of nonlinearity by the MPC method can also be found in the application of a consequent closed-loop regulator, which can be formulated without Internet optimization. The advantage of this use of the MRC algorithm is not only the elimination of network optimization and extension of resources, but also the greater width of the control field, which is very important for the flight of this category of aircraft. From an engineering point of view, there are practical questions about the issue of autonomous flying of small UAVs of this category. It is known that MPC-based control performance is highly dependent on quality mathematical modeling. However, high precision modeling of small aircraft of this category is difficult to achieve, especially due to the complicated aerodynamic nature of the rotor system. On the other hand, due to the small mass of the structure, the small dimensions of the aircraft, they are very sensitive to any disturbance, especially to wind gusts. The answer lies in the domain of large disturbances, which is not easy to model mathematically. Unlike larger aircraft, these are very sensitive to changes in payload and its distribution in the fuselage. Additional load and power consumption is a very tangible problem for small UAVs.

4 Classification, purpose and use UAV

Based on the altitude, the following UAV classifications have been used at industry events such as Parc Aberporth Unmanned Systems.

- Hand-held = 2,000 ft (600 m) altitude, about 2 km range
- Close = 5,000 ft (1,500 m) altitude, up to 10 km range
- NATO type =10,000 ft (3,000 m) altitude, up to 50 km range
- Tactical = 18,000 ft (5,500 m) altitude, about 160 km range
- MALE (medium altitude, long endurance) = up to 30,000 ft (9,000 m) and range over 200 km
- HALE (high altitude, long endurance) =over 30,000 ft (9,100 m) and indefinite range
- Hypersonic high-speed, supersonic = (Mach 1–5) or hypersonic (Mach 5+) 50,000 ft (15,200 m) or suborbital altitude, range over 200 km
- Orbit =l low Earth orbit (Mach 25+)
- CIS = Lunar Earth-Moon transfer
- Computer Assisted Carrier Guidance System (CACGS) for UAVs

The basic division of the UAV is into groups for military and civilian use.

Regardless of the fact that it is assumed that for military purposes they are equipped with systems based on the currently most modern existing technologies, the simplest civilian UAVs can be used in military missions, even those intended for hobby use.

NATO UAS CLASSIFICATION

Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Primary Supported Commander	Example Platform
Class III (> 600 kg)	Strike/ Combat*	Strategic/National	Up to 65,000 ft	Unlimited (BLOS)	Theatre	Reaper
	HALE	Strategic/National	Up to 65,000 ft	Unlimited (BLOS)	Theatre	Global Hawk
	MALE	Operational/Theatre	Up to 45,000 ft MSL	Unlimited (BLOS)	JTF	Heron
Class II (150 kg - 600 kg)	Tactical	Tactical Formation	Up to 18,000 ft AGL	200 km (LOS)	Brigade	Hermes 450
Class I (< 150 kg)	Small (>15 kg)	Tactical Unit	Up to 5,000 ft AGL	50 km (LOS)	Battalion, Regiment	Scan Eagle
	Mini (<15 kg)	Tactical Subunit (manual or hand launch)	Up to 3,000 ft AGL	Up to 25 km (LOS)	Company, Platoon, Squad	Skylark
	Micro** (<66 J)	Tactical Subunit (manual or hand launch)	Up to 200 ft AGL	Up to 5 km (LOS)	Platoon, Squad	Black Widow

Figure 83. UAV categories

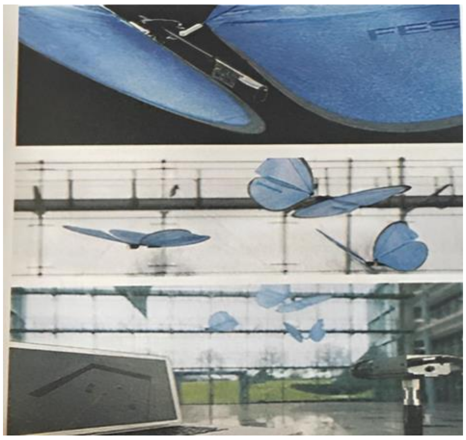

Figure 84. Micro UAV

Class	Category	Alti-tude (ft)	Mission radius (km)	Civil Category	Sample Platforn
Class I 150kg>	Micro (<2 kg)	<200 (AGL)	5 (LOS)	weight class group 1 small UAV (<20kg)	Black Widow
	Mini (2-20 kg)	<3.000 (AGL)	25 (LOS)		Bayraktar, Scan Eagle
	Small (>20 kg)	<5.000 (AGL)	50 (LOS)	weight class group 2 slight UAV (20-150 kg)	Hermes 90
Class II 150-600kg	tactic	<10.000 (AGL)	200 (LOS)	weight class group 3 >150 kg	Bayraktar, Aerostar
Class III 600kg <	Medium altitude long endurance (MALE)	<45.000 (MSL)	Unlimited (BLOS)		Heron,Predator, Reaper
	High Altitude Long Endurance (HALE)	<65.000	Unlimited (BLOS)		Global Hawk
	Attack	<65.000	Unlimited (BLOS)		X-47B,Phantom Ray

Figure 85. class UAV

The classification of UAV by categories based on several key characteristics is shown in 7. However, this classification is not quite possible according to the exact criteria.This is, in fact, a classification made for easier communication in the process of planning their use in specific missions. The UAV classification system is used by U.S. military operatives, because of their designation in the overall plan of use in their aviation, military and civilian missions.

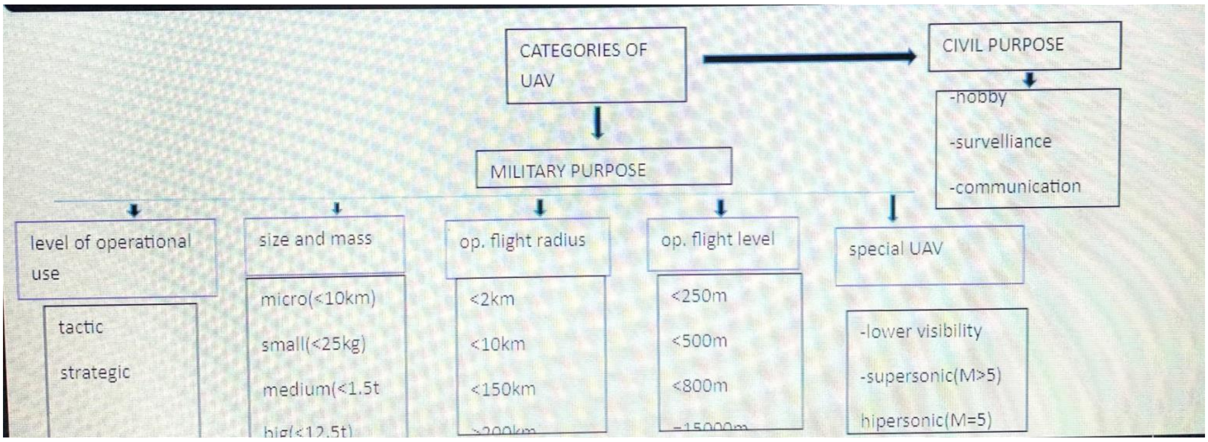

Figure 86. Scheme of global classification of UAV by categories

4.1 UAV Categories According to Range and Flight Altitude

- Flight altitude up to 600 m, and range about 2 km.
- Limited space within an altitude of up to 1,500 m and a range of up to 10 km.
- NATO type, flight altitude up to 3,000 m and range up to 50 km.
- Tactical UAV, flight altitude up to 5,500 m and range up to 160 km.
- Medium-altitude long-endurance (MALE), flight altitude up to 9,000 m and range over 200 km.
- High altitude (over 10,000 m), high-altitude long-endurance (HALE) and unlimited range.
- Supersonic UAV (Mach number is 1-5), hypersonic (Mach number is 5+), and flight altitude 15,000 m, or suborbital altitude, range over 200 km.
- Orbital low-earth (Mach number is 25).
- Earth-Moon Transporter.
- Computer Assisted Carrier Guidance System (CACGS).

Other categories include:

- Medium military and commercial UAV.
- Large Special Military UAV.
- Combat UAV, reduced stealth.
- Alternative options with and without piloting belong to unclassified aircraft.

Hobby UAV, that can be further classified into:

- Flying, but commercially unavailable;
- Usable various platforms, with minimal flight knowledge;
- With its own design and training for flying - great knowledge is required for successful implementation;
- With bare frame - requires extensive knowledge and own installation parts and flying skills.

The classifications of UAV by weight are quite simple:

- Micro UAV - can be lighter, even 10 g. These UAVs mimic insects, the next order of bird size.
- Miniature UAVs weigh up to approximately 25 kg;
- Heavy UAVs have up to several tens of tons.

groups	categories	Maximum Take off Weight (kg)	Flight celling (m)	fight autonomy (h)	Signal range	Examples	
						Missions	Aircraft
Micro/Mini	Micro	0,10	250	1	<10	contact, cause, observation inside the building	Black widow, Microstar, Microbat, Fan copter, Quatro-copter
	Mini	<30	150-300	<2	<10	film and emoting industry, agriculture, pollution measurements, surveillance inside the building, communication	Micado, Aladin, Tracker, Dragoney, Reven, Poenter, Carolo C40/P50, Scorpio, Maxmend,R-50, Robocopter, YH-300SL
Tactic	Closed range	150	3000	2-4	10-30	RSTA, detection of mine, search and rescue, EW	Observer 1,Fantom, Micado, Robocopter 300, Poenter, Cemocopter, Airijel, Agricultural RMax
	Short range	200	3000	3-6	30-70	BDA, RSTA, EW, detection of mine	Scorpi 6/30, Luna, silver Fox, I-vujv,Firebird,R-Max, agro-photography, Hornet
	Medium range	150-300	3000-5000	6-10	70-200	BDA, RSTA, EW, detection of mine, NBC	Hunter B, Muki, Aerostar, Snajper, Falko, Armor X7, Smatr UAV,UCAR, Igl aj=alis, Extender
	Big range	-	5000	6-13	200-500	RSTA,BDA, communication relay	Hunter, Vigilant 502
	Big authority	500-1500	5000-8000	12-24	>500	BDA, RSTA, EW, communication relay, NBC	Aerosonde, Vulture II Her, Shadow 600, Searcher II, Hermes 450S/450T/700

	Medium height, big authority	1000-1500	5000-8000	24-48	>500	BDA, RSTA, EW, communication relay, NBC, delivery of weapon	Skyfond, hermes 1500, Heron TP, MQ-1, Predator-IT, Igl-1/2, Darkstar, E-hunter, Dominator
Strategic	Big ceiling and authority	2500-12500				BDA, RSTA, EW, communication relay, stimulation of the phase of interception of aircraft, global security of airport	Global houk, Raptor, Kondor, Desus, Helios, PredatorB/C, Libelule, Eurohouk, Mercator, Sensorcraft, Global observer, Patfinder plus
special	Deadly	250				anti-radar; anti-ship; anti-aircraft; anti-infrastructure	Mali, harpur, Lark, Marula
	Bait	250				Deception in air and at the sea	Flerd, MALD, Nulka,ITALD,Shuker
	For stratosphere	-				-	Pegas
	Eco-stratosphere	-				-	Mars flyer, MAC-1

Fgure 87. Examples for UAV landing categories in 2006

Micro UAVs deserve special attention, and those that are an incredible imitation of birds and insects. Knowledge of biomechanics is a priority when designing these UAVs.

Experts are very interested and motivated by the unknown resistance of birds and most insects to strong winds, during which they fly successfully. They fly in such conditions, even though they are very small. Passenger planes, incomparably larger masses, are forced to land in such weather conditions.

These observations encouraged experts, and in 2015, they approached the study of this phenomenon in an organized and institutional manner, in a specific scientific field called biomechanics. Special UAVs were built for that purpose, for the needs of researching the life and specific flight of birds and insects.

The design of one of these UAVs was inspired by the flying of dragonfly. The dragonfly has four wings, which make it steady in flight and in strong winds that would otherwise prevent the existing standard miniature spy UAV from flying.

The secret project was a great challenge, due to the unusual use of fluttering wings for propulsion and buoyancy of the micro UAV. Although the wings are more efficient than the propeller and they can provide hovering in strong wind gusts, it is almost impossible for engineers to artificially, with constructive solutions, achieve the function of a dragonfly's wing.

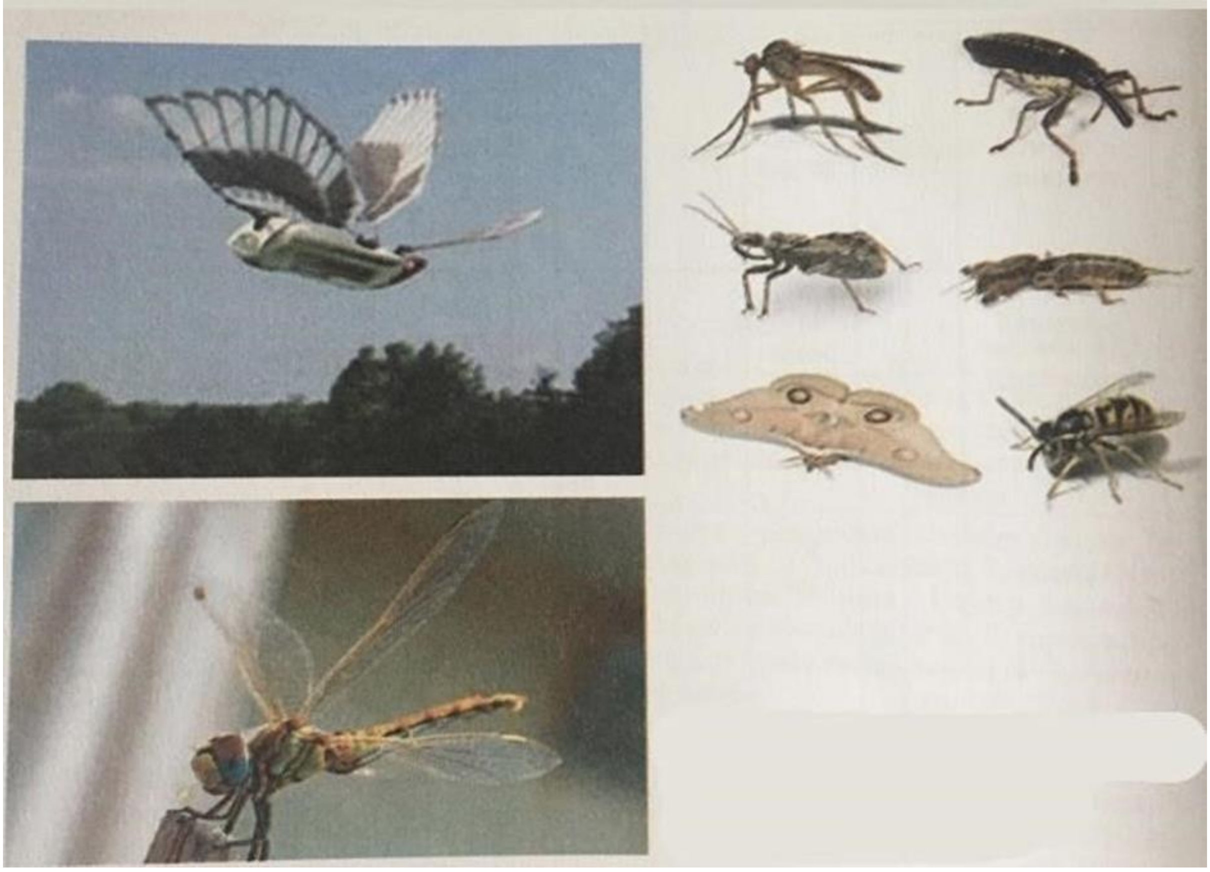

Figure 88. Micro UAVs are often in the form of birds and various insects

However, they succeeded in the realization of such micro-aircraft, which can withstand stronger winds. They are used by soldiers to spy on enemy positions.

A micro UAV was realized, which can float at a wind speed of 10 m/s, carry a camera and communication systems. It is 8 cm long, and its further development is primarily focused on reducing the size.

The acquired knowledge was applied to biomechanical butterflies (Figure 9). By combining the ultra-light construction of artificial insects and the acquired knowledge in the domain of the problem of mutual coordination, their flight was realized in a flock, indoors.

Coordinated flying, indoors, is achieved using GPS and infrared cameras. Ten cameras installed in the hall record butterflies using their infrared markers. The cameras transmit data about their individual position to a central computer, which coordinates the flight of each butterfly individually (Figure 29). The intelligent networking system creates a guidance and monitoring system, which could be used in networked monitoring and management in future factories.

In order to imitate the natural pattern, as authentically as possible, artificial butterflies are characterized by highly integrated built-in electronics. They can individually precisely activate the wings, and quickly change the shape and speed of movement. Waving the wings creates aerodynamic buoyancy, thanks to the imitation of the specific aerodynamics of a natural butterfly.

In that way, highly integrated research flying platforms were achieved, with minimal use of materials. Another step has been achieved in the field of miniaturization, light construction and functional integration. These aircraft impress with a smart system used, the least possible sources of power and units in a limited space. With the minimal use of materials flight was achieved based on the real flight of a natural butterfly.

4.2 Division of Drones According to Areas of Application

"A drone is a remote-controlled unmanned aerial vehicle (UAV) or missile." – definition by Oxford American Dictionary

Civil drones consist of:

- Remotely operated aircraft;
- Human element;
- Take-off and landing;
- Payload;
- Command and control;
- Communication link for data transmission.

Drones, like other aircraft, were originally used for military purposes (bombing actions from a safe distance, logistical assistance, surveillance actions).

Today, drones are used in various fields. In addition to military applications, drones are also used for civilian purposes - search and rescue operations, road traffic surveillance, border surveillance, agriculture, service activities, and entertainment.

4.2.1 Use of drones for military purposes

Drones are useful to the military because they can replace a man in jobs where a man's life is in danger. UAVs are categorized in the military based on their weight, speed and specific capabilities.

Classification based on specific roles intended in certain military operations:

- Drones used as bait or target (used to monitor the ground and for air attacks on enemy targets);
- Reconnaissance drones (used to provide information on the battlefield);
- Combat drones (used to attack in risky situations);
- Drones for research and development (used to develop technologies that can be added to the existing drone system).

Possibilities of using drones for military purposes:

- mine detection;
- detection of chemical and nuclear weapons;
- radar interference;
- target lighting;
- carrying combat cargo.

Figure 89. The largest military drone The Global Hawk used for surveillance

The effect of the military use of drones is vividly outlined by the Portuguese author, with her introductory quote in the article Classification of UAVs:

Imagine yourself in the middle of a battlefield with only one truly convincing goal to maneuver and act from one point to another and carry out your mission - with the reward of your own survival. One eye focuses on constant threats and the other on spatial orientation! Tension and deep fear grab you, you are in mortal danger, and you have to overcome it and confront it. This is your priority and your chance to survive! With the UAV, a directional antenna, can you safely do more than you could directly on the battlefield without being life-threatening?

MARIA DE FATIMA BENTO

Unmanned aerial vehicles quickly evolved from light surveillance devices to heavily armed unmanned aerial vehicles and thus became a favored weapon for conducting a modified form of warfare.

The vast majority of thousands of military drones are used for surveillance, and military experts predict that this will continue intensively.

Military analysts estimate that more than 80,000 surveillance drones and nearly 2,000 armed combat vehicles will be purchased worldwide in the next 10 years. Armed drones are not cheap. Experts claim that the initial unit price of that technology is around 15 million dollars, and for additional needs and equipment, that is significantly increased. In addition to maintenance and training of the crew, professional teams are needed to service them.

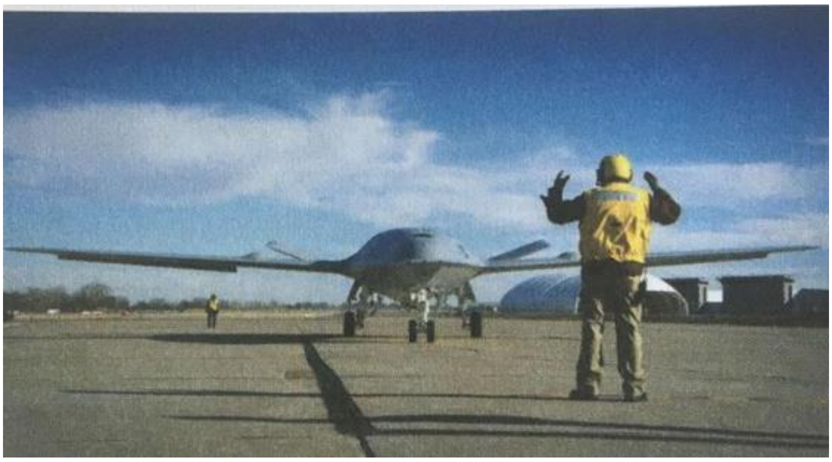

Figure 90. Boeing's MQ-25A is the first unmanned aircraft to refuel aircraft during flight

Unmanned aerial vehicles have become part of standard military equipment and this has caused the expansion of the network of appropriate formation operational units, bases, test stations, repair workshops, appropriate infrastructure and maintenance systems in the armies of the world.

A study by the Center for Strategic and Budget Assessments in Washington, D.C., recommends reforming the formations of U.S. air regiments into a composition of only 20 manned fighter jets and 24 drones, equipped for electronic warfare and missile defense. This was published by the well-known magazine Air and Space.

Figure 91. Predator for military purpose

Well-known American aviation experts and analysts seriously claim that jet piloted aircraft are coming to an end. They are rapidly being replaced by more rational unmanned aerial vehicles.

The conversion of the US Navy's fuel tanker aircraft into unmanned ones are already under way, and new ones whose purpose is to fill cargo planes with fuel in flight are being built. On the battlefields of Libya, Ukraine, Syria and Yemen, as well as in zones of geopolitical conflicts, such as the Persian Gulf and the East China Sea, the crowds from the deployment and use of UAVs of different sizes and levels of sophistication have increased. Whether UAVs are used to gather intelligence, to attack enemy air forces, to fight for supremacy in the airspace, to correct artillery fire, or for electronic warfare, their use will significantly change the character of warfare. The trend of their application in armed, subversive and other actions continued intensively, compared to the earlier application, during the aggression and disintegration of the SFRY, and many other countries, as well as the Arab part of the world. Drone warfare is atypical, irregular, without necessarily recognizable opposing sides in it. This is affected by the fact that weapons are easily accessible at relatively low prices. Conventional warfare includes causes, opposing states, individual soldiers participating in each of the opposing sides. With the development of unmanned technology, the nature of war has changed a lot, it has become unprecedentedly complex for several reasons.

First, the use of military drones leads to the undefined status of drone operators. Are they fighters? They are not exposed to two essential factors in their daily participation in the classic battles of soldiers: fear and the risk of death. It is paradoxical that the great exposure of people as a target grows drastically, and thus the risk that they will suffer. Due to these facts, the last indicator of the war chivalry of soldiers is deleted. In conventional warfare, fighters on both sides are exposed to physical risk. In the absence of a distinction between dying and murder, war is less special.

Second, the absence of unilateral physical risk spills over into the political sphere. In a war zone like Libya, when Turkey and Qatar deploy the UAVs, it is less likely to cause dissatisfaction among the people compared to the deployment of fighter jets.

In other words, the use of military drones reduces the nuances of the logical connection of events on the battlefield. In Libya, the frequency of drone strikes has increased significantly after the crimes in April 2019, confirming the negative correlation between ease of manipulation and refraining from action.

Unmanned aerial vehicle operators, in the range of their competencies, perform four actions: watch, aim, decide and fire. This happens in every drone attack, transforming the battlefield into an action game in which the player watches the virtual field for hours, and then uses the joystick to shoot when the target appears. This loop, which involves man and machine, suggests that the battlefield is depersonalized. As accountability mechanisms become blurred, killing becomes easier and possible from a greater distance.

The Portuguese MARIA DE FATIMA BENTO in her author's article Classification of UAVs (previously quoted) certainly did not have in mind these aspects of the nature of war in which UAV participates. The study on military drones contains issues in several aspects. There are specialized UAV armed groups in the world in 101 countries, in seven regions: Asia, Oceania, Eurasia, Europe, Latin America, the Middle East, North Africa, North America and Sub-Saharan Africa. Currently, more than 170 types of military drones are used in the world. The capabilities of each country's military drone are assessed in six areas: inventory and active acquisition contents, personnel and training programs, infrastructure, operational experience, research and development programs of the respective technologies and exports.

Unmanned aerial vehicles for military purposes can be classified into three groups:

- Medium-sized combat and commercial drones that are not available to individuals due to costs or demanding infrastructure needs. However, these systems can be sold or transferred to foreign armies and private users;
- Great wars, specially armed drones. They need more significant military infrastructure for operational use. They are generally not available for free purchase. They are used only by professional army formations.
- Stealth drones contain very sophisticated technologies, and in addition, their visibility is reduced in the operation of their systems. These technologies are not available to manufacturers outside of military and security control. Several countries are developing these combat drones. Currently, they are only owned and operated by the United States.

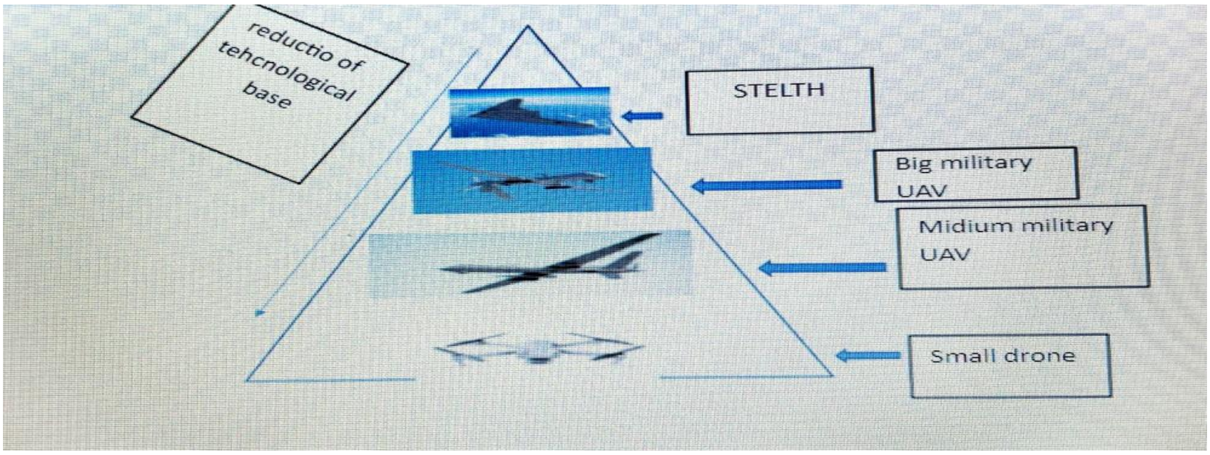

Figure 92. Schematic representation of the pyramidal relationship of applied technology, mass production and application of UAV

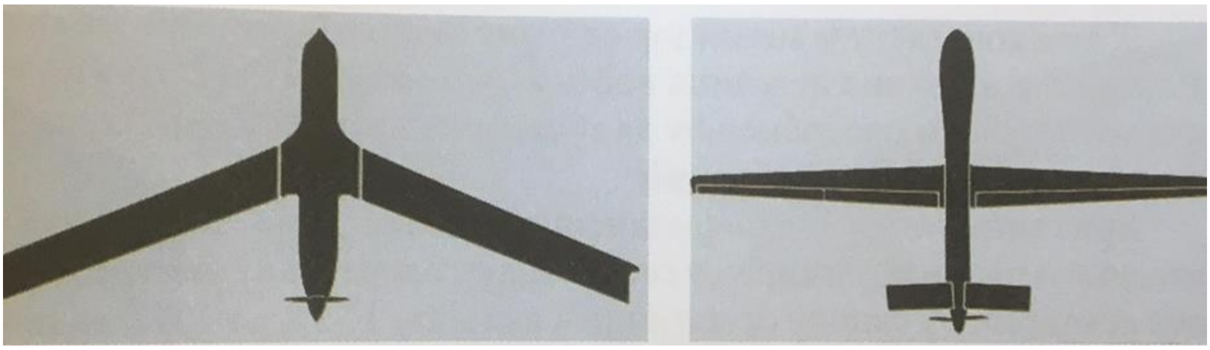

Figure 93. Military and commercial medium-sized UAV, Large military UAV of special size

The effectiveness of the new tactics of UAVs combat use is intensively considered and examined. The approach consists in the flight of a larger group of cheaper UAVs in a group that is similar to a swarm of bees, and in the center of that "swarm" is a fifth generation aircraft with maximum advanced weapons (as a "queen").

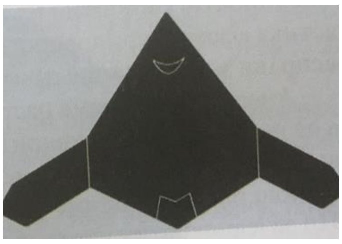

Figure 94. New tehnology UAV

Anti-aircraft defense systems are not able to single out the parent plane, as a target through this "swarm" of cheap drones, and it easily breaks through with its weapons to the target area and it can easily realize the planned task of its mission.

Figure 95. Bettle versus UAV stelt

In that context, the Minister of Defense of Great Britain stated: "*Swarms of drones led by F-35 planes will defeat the enemies with their ability to confuse and overcome the enemy's air defense*.".

The British are intensively financing the development of a "swarm" of unmanned aerial vehicles and plan to be the first in the world to put their squadron into operational use, as part of the F35 parent aircraft, by 2022. The Americans also claim that Britain will be the first to succeed in integrating "swarms" of drones into military operations, provided that their officials continue to support that program.

It is obvious that what military experts have been saying for years is being confirmed: "Technology that enables synchronized "swarms" of drones is a perspective". Battle leaders are beginning to accept the idea and incorporate it into their combat operations plans.

Peter Singer, a senior fellow at the New America Foundation who studies future warfare, said: "*This idea, which was once science fiction and then heresy, is now present in professional and scientific debate and is increasingly accepted*.".

According to available sources in the literature, the Americans claim that they will also develop squadrons of "swarms" of drones during their three-year program.

A disposable UAV research and development program has been running since 2006. These are miniature UAVs that should be deployed in large numbers in critical areas. These aircraft have small electronic sensors and they could provide the grouping system with military surveillance of risky areas without sending pilots - people over enemy territory.

The experimental program also investigates the method of launching small drones from the fuselage of the S-130 transport aircraft, and after performing that part of the task, their return to the fuselage of the same aircraft. In this way, individual transport aircraft want to be efficiently converted into UAV flying carriers.

In 2016, an experiment of autonomous systems was realized, which the Pentagon called one of the most important examinations of the Ministry of Defense. The system refers to a larger "swarm" of 100 micro UAVs, dropped from the fuselages of F/A-18 super hornet fighter planes. This "swarm" is described as a "collective organism" that divides one distributed brain for decision-making and mutual adaptation to each other, like a swarm of bees in nature.

At least one well-known U.S. defense system manufacturer is investing in UAVs that should be used in combat operations in cooperation with aircraft.

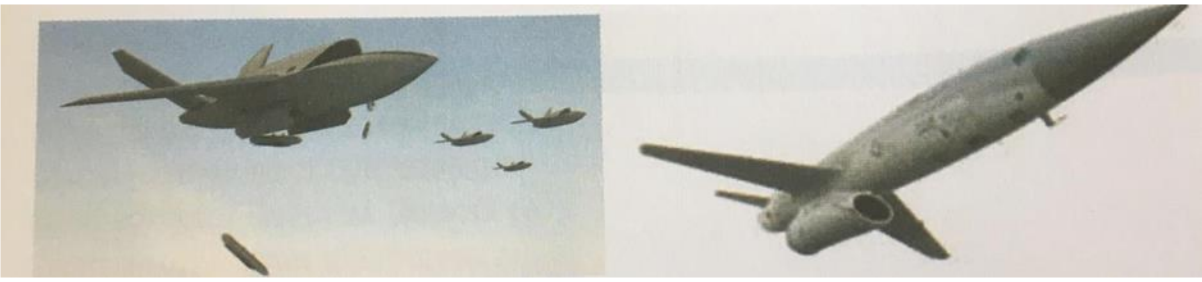

Figure 96. XQ-222 Valkyries and UTAP-22 Mako

The San Diego-based company produces two classes of drones, the UTAR-22 Mako and the XQ-222 Valkyries, which are said to have been built just for that purpose. The company received funding for dedicated research from the relevant Pentagon institutions.

U.S. military experts underline the fact that every use of a weapon that uses artificial intelligence will have to be questioned. This means that combat robots (UAV) will be able to decide for themselves on the movement and selection of targets, but that man will always decide on "pulling the trigger".

Nevertheless, experts studying the future of the war say that some drones within the "swarm" should be partially or completely autonomous.

The essence of the idea of a "swarm" is not only in the large number of copies of the UAV, but also in the fact that this multitude works in a coordinated manner, exchanging information with each other. Although the U.S. Air Force has extensive experience in piloting drones (predators and rippers), the use of "swarms" of drones is a new experience. They need to understand how one person can control the mass of robots and have full control over them all the time, and at the same time their complete mission. That is disputable, the officials do not completely agree on that issue. In recent years, Russia has seriously focused on research and development, production and operational activities within UAV technologies, of all categories. The UAV variants that Russia plans to introduce are different from the Western ones. In their plans there is the categories variation of light, medium and UAV "monsters" weighing up to about 20 tons.

In Moscow, on Victory Day, during the parade in May 2018, the Russian army showed its first combat drones put into operational use. Before that, they owned UAVs only for reconnaissance purposes.

Russian UAVs are diverse with a classic aerodynamic scheme and with rotors (without aerodynamic lift surfaces), squares. They are armed with "smart" and classic weapons, even intended for the destruction of armored combat vehicles on land and at sea.

Figure 97. Russian UAV Orion E

Within these programs is the UAV Altair middle category. Its development began in 2011. It is an expensive flying platform for carrying and launching advanced guided air-to-ground missiles. It is protected from modern and efficient enemy air defense systems, using advanced technology to minimize visibility (stealth technology).

It is intended for reconnaissance and air-to-ground operations. It has the possibility of a long flight, and its weight is about 5000 kg. Ohotnik is the largest UAV developed by the Russian military-industrial complex, weighing 20 tons. It is designed as an open configuration system so that it can be further developed continuously. The project will significantly push Russia forward in the race of prestige in drone technologies. The details published about that project are scant, and what was presented is not reliable. The real data is still kept secret. The first flight was performed on August 3, 2019. At that time, Ohotnik flew for about 20 minutes, at an altitude of 600 meters, above the state experimental center. During the development of Ohotnik, a fifth-generation Su-57 fighter was used as a "laboratory plane". Sophisticated systems and the latest technological solutions were tested on it. It is planned that, with the cooperation of that fifth-generation Su-57 fighter plane, Ohotnik will successfully penetrate the enemy's airspace and air defense. There are some differences in the new tactics of combat use of UAV of Western countries in cooperation with UAV in a group similar to the swarm of bees with the "mother" aircraft of the fifth generation F-35 and the cooperation of the Russian aircraft of the same generation Su-57 with UAV Ohotnik. "With the F-35 plane, the tactics of penetrating the enemy's airspace are obvious, and with the Russians, the increase in efficiency is the preservation of dominance in airspace.

Figure 98. Russian UAV Altai

In contrast to the previously held fairs, the "Army" in 2020 had a significantly higher presence of Russian drones of various categories. A complete line of unmanned aerial vehicles for various purposes is shown: Helios, Sirius and Grom. All these types of UAVs, in addition to their basic function, also have combat capabilities and enviable characteristics.

UAV type helicopter was shown for the first time. The new Russian unmanned helicopter has a really huge space for potential application.It can perform a much wider range of tasks than the standard primary search and rescue missions for which it was initially intended. In its further evolution, a reconnaissance-combat version armed with high-precision weapons and other combat systems can be expected. The unmanned helicopter has a flight ceiling of 1,500 meters and an autonomy of two hours. It is a multi-purpose flying platform. It can be equipped with various types of sensors, including a multispectral camera, then a gamma radiation dosimeter, a miniature radar and a magnetometric system. It has a searchlight, sound equipment and a container for transporting rescue equipment for the use in rescue operations.

The entire range of systems for combating enemy UAVs at medium distances (Bastion-automation), then a modernized system for short-range interference (Kupol-PRO) and a mobile automated system for combating long-distance (Rubež-automation) were also presented at the fair.

A version of the UAV Attack anti-system is also shown. This UAV system can independently, without the participation of the operator, locate and identify the enemy drone according to the principle of encrypted recognition of "own/alien", as well as to automatically electronically prevent it from further penetrating its airspace.

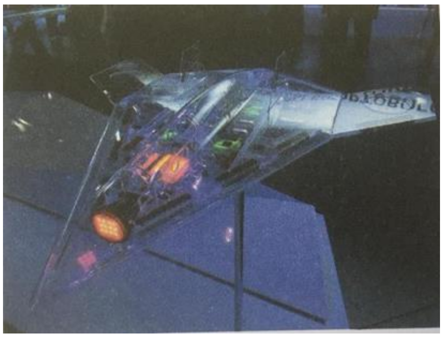

Figure 99. Illustration of the contents of the UAV Hunter

Figure 100. The first Russian unmanned helicopter

The time of the system transition from duty to combat mode is not longer than five minutes. The system is able to cover a radius of 1,000 meters and to block in that airspace zone all control channels and the total frequency range of radio waves commonly used by control points with operators (from 2-6 GHz). This type of aircraft can be successfully used for surveillance and transport operations of various cargo. With its characteristics, UAV Attack can be used to neutralize the effectiveness of tactics of using "swarm" UAV in cooperation with the "parent" aircraft F-35.

The oldest, and probably the most controversial, is certainly the use of drones for military purposes. The British and American armies started using some basic forms of drones to spy on the enemy in the early 1940s. However, today's drones are, of course, far more advanced than these forms. They can be equipped with thermal imaging cameras, laser distance meters, as well as devices for performing air attacks.

One of the most famous models is the MQ-9 Reaper, which is 11m long, it can remain undetected up to 15km high and it is equipped with a combination of missiles and intelligence gathering equipment.

Figure 101. MQ-9 Reaper

The MQ-9 Reaper is an armed, multi-mission drone, with medium-altitude flight and long flight duration, which is primarily used to eliminate dynamic targets, and then as a means of gathering intelligence. Due to the fact that it is able to fly in a circle for hours before finding a target (loitering time), that it is equipped with wide-range sensors, multimode communication system, as well as precision weapons, this drone provides a unique ability to perform attacks, coordination and reconnaissance of unstable and time-sensitive goals. The Reaper may also perform the following missions and tasks: information, surveillance, reconnaissance, close air support, combat search and rescue, precision attack, convoy or raid surveillance, as well as terminal air guidance.

General characteristics of the drone MQ-9 Reaper:

- Length - 11m;
- Height - 3.8 m;
- Wing span - 20.1m;
- Weight - 2,223kg (empty);
- Maximum weight at takeoff - 4,760kg;
- Load capacity - 1,701 kg;
- Speed - 200 knots;
- Range - 1000 nautical miles;
- Vertical range - 15km;
- Thrust - 900 horsepower;
- Honeywell TPE331-10GD turbo-propeller engine;
- Weapons - a combination of four air-to-surface missiles - AGM-114 Hellfire, two laser-guided bombs - GBU-12 Paveway II, while air-to-air missiles - AIM-92 Stinger - are being tested;.

4.2.2 Use of Drones in Agriculture

The practical application of drones in various areas of the economy is increasingly represented and records significant development.

Agriculture is the most important branch of the industry for the survival of humanity on the planet.

There are various types of drones for this purpose, but some of the tasks are:

- Crop inspection;
- Irrigation;
- Review of crop irrigation;
- Spraying the crop with appropriate products;
- Planting;
- Plant health assessment.

Drones are a safer, more efficient way to maintain the field - they reduce costs and time. Unmanned aerial vehicles provide farmers with information to detect possible problems and reduce them. Drones intended for agricultural purposes can withstand even more adverse weather conditions. Drones have certain sensors that have the ability to collect a large amount of information (detect the quality of plants and early detection of disease).

Figure 102. Agriculture UAV

Unmanned aerial vehicles are a cheaper and more efficient alternative for preserving the wild world. Tracking the population of wildlife is almost impossible from the ground up, so a bird's eye view allows wildlife conservation scientists to track different groups of animals, from orangutans in Borneo to bison in the Great Plains in the central North America to gain a better idea of the health of their species and ecosystems. Drones for the protection of the wild world are also the perfect tool in the fight against poaching in Asia and Africa. On the other hand, drones are often used to reforest areas previously affected by fires, dropping containers of seeds, fertilizer and nutrients. Since 1990, almost 300 million hectares of land have been reforested in this way.

Figure 103. UAV in the protection of the animal world

At the University of Technology in Queensland, researchers have developed an innovative method for detecting koala populations using drones and infrared imaging, which is a more reliable and less invasive technique comparing to traditional animal population tracking techniques.

In a study published in the journal Scientific Reports, the scientists described in detail a technique that includes an algorithm for locating koalas using heat-sensing drones. This technique has incredible potential not only when it comes to monitoring the population of koalas, but also other endangered species, as well as for detecting invasive species.

Namely, this system uses infrared imaging to detect koala heat signals, despite being covered by a dense canopy of eucalyptus trees. To maximize the effectiveness of this technique, the researchers examined the area early in the morning during the colder months, when the difference between the body temperature of the koala and the area was probably greater.

After the flight, the data from the drone is analyzed using an algorithm that is designed so that it can distinguish the thermal traces of koalas from the thermal traces of other animals in the same area. This method is certainly faster and cheaper than the traditional analysis of areas from the ground. However, there are areas that are not accessible to drones, and for that reason the role of man cannot be completely excluded.

After the excellent results achieved by the scientists using drones, the goal is to use the drone system in some other areas and to adapt the algorithm, so that some other species of animals can be detected and thus monitor their population in the future.

4.2.3 Delivery

Drone delivery technology is evolving rapidly, but is not yet ready for day-to-day implementation. Amazon, Alphabet, Flirtey have recognized the potential of using this technology for cost-effective purposes.

Amazon has created a patent relating to parachute deliveries, which would reduce the possibility of collisions with "obstacles" in the yard.

These drones could follow the package after being dropped and adjust the direction of delivery in the event of deviations using compressed air, a landing flap or a secondary parachute

Figure 104. Delivery UAV

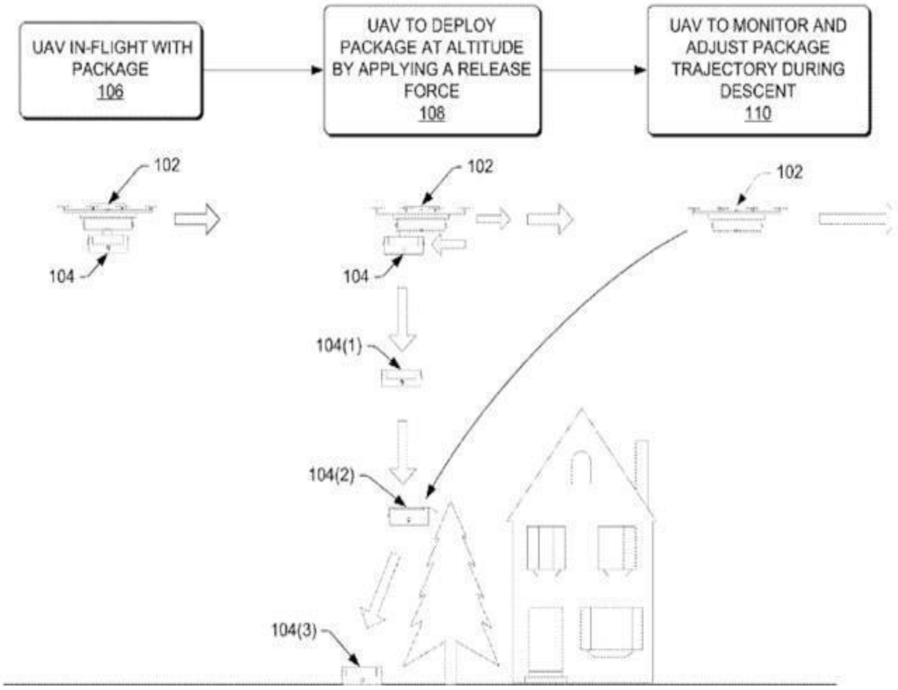

Figure 105. Delivery UAV

The drones used for delivery are usually autonomous unmanned aerial vehicles and are used to transport food, packages and goods to the doorstep. These drones are also known as "last mile" delivery drones, because they are used to deliver items from nearby stores or warehouses. Retail outlets and food chains are increasingly turning to drones as a more efficient delivery alternative. They can carry up to an impressive 55kg of cargo. Walmart, Google, FedEx, UPS and other major brands are currently testing different versions of the drones for the delivery.

Figure 106. Delivery UAV

In 2019, Asian e-commerce giants Rakuten and JD.com, in response to increased demand for online shopping, established cooperation in the field of commercialization of drones that would be used to deliver packages. Namely, the company Rakuten, based in Japan, has set technological innovations as its priority in the last few years, experimenting with autonomous "last mile" deliveries, where the mountainous terrain of Japan and remote islands represent an ideal environment for testing drones.

Rakuten will use a JD.com drone for this purpose, which is 160cm wide, 60cm high and can fly up to 16km. In addition to this unmanned aerial vehicle, Rakuten will also use an unmanned ground vehicle 171cm long, 75cm wide and 160cm high, which has a speed of up to 15 km/h.

4.2.4 Small UAVs

Small UAVs mostly use electric propulsion, with lithium-polymer batteries, while larger ones are powered by aircraft engines. The size and mass of the UAV are the basic conditioning characteristics for the choice of propulsion type.

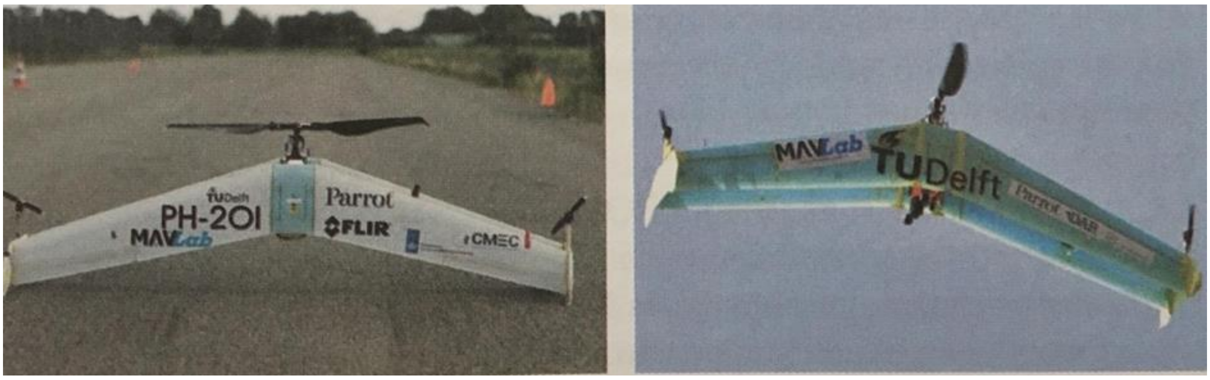

Figure 107. UAV biplane configuration, with one drive propeller

Figure 108. Helios

Currently, the energy concentration in lithium-polymer batteries is significantly lower than that of gasoline. A record UAV range was achieved by flying over the North Atlantic Ocean. The structure of this UAV was made of balsa and leather, and a petrol engine was used for the propulsion.

Electricity is used in a simplified way with fewer simple operations, and the electric motors are quiet. Properly realized relationship between the energy of the propulsion and the mass of the aircraft with an electric or gasoline engine that propels the propeller or rotor can ensure its floating and vertical climbing. The assembly for fitting one battery, by centralizing and distributing energy to all consumers, is realized by a microregulator. This avoids the need to introduce more energy supply networks. This reduces energy loss to unnecessarily heated platform and excess conductors In addition to propulsion with electricity, accumulated in batteries, and aircraft engines, electric propulsion with the conversion of solar energy into electricity is increasingly being researched and improved. A good example of this is the experimental design of an unmanned Helios aircraft, whose batteries are charged during flight with electricity obtained from the solar system.

4.2.5 Civil Purpose

There is an increased focus on monitoring weather changes and informing about safety preparations and preventive protection against them. Weather conditions can be monitored and changes in parameters such as temperature, humidity, light intensity, etc. can be tracked. This data is useful for studying, analyzing, and understanding weather conditions. Quadrotors are very practical aircraft for this purpose. In assessing the damage from natural disasters: storms, fires, floods, earthquakes, etc., UAVs are used professionally to collect relevant data by reconnaissance, real-time image transmission and condition recording. With their practicality and efficiency, they have almost become irreplaceable in that role. Since April 2010, NASA has been working on global atmospheric research using long-stay UAVs in airspace (flight autonomy). For this purpose, UAVs carry additional packages of various sensors that are used to measure a large number of parameters for the needs of scientific research. In August and September 2010, the drones collected numerous information about hurricanes "Earl" and "Frank".

Using photographs taken by UAV in the air, collect useful data are collected for research, analysis and assessment, as well as for obtaining the legality, development and intensity of the wind farm’s effect.

In March 2011, the American UAV Global Hawk Block 30 was used in the operation to assess the damage to the nuclear power plant in Japan from earthquakes and tsunamis.

In December 2011, the Marine Environmental Protection Society established monitoring, control and detection of whaling in Japanese seas using UAV.

The increasing civilian use of UAV is accompanied and encouraged by intensive research. In addition to the application in various services, UAVs are being introduced massively for use in the police, for control and redirection of traffic, tracking the perpetrators of robbery and other criminal acts. The parliaments of some countries dispute their application in the police because there is a risk of compromising privacy. And there are also data protection concerns.

Figure 109. UAV with eight rotors; Commercial UAV (quadcopter, is equipped with a camera product of Chinese by DJI)

In order to train and educate the population in Germany, an experimental organization has been set up that gathers hobbyists for long-range drone flying.

In Germany, a UAV development program is underway that will be able to detect the occurrence of fires in a wide monitoring area. It is planned to monitor the entire territory and gather information, which will drastically reduce the damage and consequences of the fire. Data transmission will be integrated and presented in real time to emergency centers.

In 2014, UAVs were among the most popular Christmas gifts. So popular and massive gifts that the British authorities have warned their recreational users that these toys must be used legally and that violators face huge penalties. Similarly, the U.S. FAA released a video just before the holidays, teaching ambitious drone users how to behave when using them. Increasing number of people are training for the hobby of using UAV, following the rapid growth in the number of their versions. The field of UAV use in various activities is expanding, even among real estate buyers, because aerial images can provide a better insight into the real contents of the offered property.

In addition, hundreds, if not thousands, of users of commercial drones are waiting for legislation to be enacted with defined details on sensory technologies to avoid contact with obstacles and other aircraft. Also, the prescribed rules for application are awaited, which would define the ways of division and use of airspace in relation to manned aircraft.

This trend of rapid development of commercial UAVs is closely monitored and supported by the structures in charge of military implementation. The widespread use of unmanned aerial vehicles for commercial purposes leaves hope that awareness of the importance of their useful peacetime application will increase. It may help to no longer associate them exclusively with the currently overemphasized intent to kill.

In the beginning, the development of drones was exclusively within the framework of military programs, and it was only recently that the civilians began to appear on the scene. It soon became a very profitable commercial product.

The civilian UAV market is dominated by Chinese companies. Their manufacturer DJI had a 75% share of the global civilian market in 2017, with a global sales forecast of $ 11 billion in 2020. It is followed by the French company Parrot with $ 110 million and the American company 3D robotics with $ 21.6 million in 2014.

Since March 2018, more than one million UAVs (878,000 hobbies and 122,000 commercials) have been registered with the U.S. FAA. The civilian UAV market is relatively new compared to the military. Companies appear simultaneously in developed countries and in the countries that are being developed. Many early-stage beginners have received support and funding from investors such as the United States and government agencies, as it is the case in India.

Some universities offer programs or graduation theses for research or training. Private entities also provide online programs and training programs for individuals for both recreational and commercial use of UAV.

Commercial drones are also used by the military around the world, due to their economy. In 2018, the Israeli military began using the UAV Mavic and Matrix types for an easy reconnaissance mission as civilian drones are easier to use and more reliable. Also, commercial unmanned aerial vehicles of the Chinese company DJI were widely used by the American army.

Figure 110. Photograph taken by a drone

The global UAV market will soon reach a turnover of 21.47 billion US dollars, while the Indian market will reach the figure of 885.7 million dollars by 2021.

Unmanned aerial vehicle lighting is beginning to be used for nightly screenings of sports competitions and in art and advertising programs.

4.2.6 Hobby Purpose

UAV models of well-known derived aircraft that visually look like the original, that have autonomous flight characteristics or that are also a simulation of the original are often use for the recreational purposes.In addition to these aircraft models, many hobby aircraft modelers develop original solutions without copying the original aircraft.

The first hobbyist UAVs were simple with radio control signal (RC). One of the first such derivatives is shown in Figure 111.

Hobby drones also include those that are easily available for purchase, mostly up to several thousand dollars, from interested parties for various events, celebrations and parties. These systems can be assembled from parts and components in advance or before use, and do not require formal infrastructure or operator training.

Figure 111. A piston-propeller-powered airplane model controlled by radio signals (RC) ushered in the era of unmanned aerial vehicles

Drones intended for hobbyists allow individuals to take photos that previously could only be taken from airplanes or helicopters. Sensors are of the utmost importance for good photo quality, especially when it comes to aerial photography, so today, in the drone market, the 1-inch sensor appears as the new gold standard used by drones like the new Mavic 2 Pro and the professional Phantom 4 photographic drone Pro V2.0.

Certainly the most powerful professional photography drone is the Inspire 2, which uses a CMOS (Complementary Metal Oxide Semiconductor) sensor, which makes it easy to take high-quality photos in low light.

Good photographic drones are extremely expensive, not only because they provide good image quality and a flight control system, but also because they are equipped with intelligent shooting support functions. Different drones have different characteristics. For example, the Mavic 2 Zoom has a dual optical zoom that gives a closer view of distant subjects, making unique scenes more accessible for remote shooting. The Phantom 4 Pro is equipped with a mechanical shutter to reduce distortion that can occur when shooting fast-moving or high-speed subjects.

Figure 112. Hobby UAV

Most drones today are used for personal use. People use drones for fun, they race and compete with them. Light and small drones are most often used for these purposes.

The most important characteristics of drones for racing

- Strength;
- Speed;
- Maneuvering abilities - agility is scored in competitions;
- Durability - due to high speed it can collide with something, so firm parts of the drone are needed;
- Flight time – which is not so important since most drones fly 5-10 minutes;
- It is much more important to have batteries for fast charging;
- Camera quality - FPV (First Person View) is needed which has the required field of view and good video transmission to transmit the image live.


Figure 113. Racing drone Eachine Wizard X220s

4.2.7 Drones for Emergency Rescue Interventions

It often happens that due to the scale or severity of the disaster, it is simply not safe enough to send people on rescue missions. In these situations, the drone becomes the ideal solution. For example, in the case of overturning a ship or drowning persons, rescuers can send an autonomous underwater vehicle to assist in the rescue. Moreover, if avalanches occur at high altitudes, drones are deployed in search of those who may have remained under the snow. In that sense, it is interesting to note that the aircraft manufacturer Kaman has even developed an unmanned helicopter called K-MAX, which is capable of carrying up to 2700kg of cargo. This type of helicopter is already used in China and Australia to help put out fires.

Display of capabilities of DJI MAVIC 2 ENTERPRISE DUO the property of academy as well as all accessories intended for search and rescue operation.

Figure 114. Thermal picture for SAR drone

Figure 115. UAV for rescue

4.2.8 Drones for Locating Persons Missing in an Avalanche

According to National Geographic statistics, avalanches take the lives of more than 150 people each year, most of them skiers, snowboarders and snowmobile riders.

The manufacturers of drones believe that their drones could contribute to faster locating of avalanche victims, but also enable ski patrols to remotely activate explosives as a preventive measure in order to clear snow from high-risk slopes.

Using drones to dramatically shorten the search time, rescuers are given the opportunity to reach the victims buried under the layers of snow, before it is too late. Namely, more than 90% of people who are buried under the snow survive, if, of course, they are dug out within 15 minutes. However, after 45 minutes, the chances of survival are reduced to only 20%.

The Mountain Rescue Service in the Czech Republic uses Robodrone Kingfisher rescue drones, which are equipped with cameras and their own system for detecting avalanche transceivers or handheld radios that, when activated, emit a low-power pulse signal, which makes it easier to locate people buried under the avalanche. However, for people who do not carry avalanche transceivers, there are special thermal and multispectral systems that are able to detect gases, such as methane and carbon dioxide, and thus detect people buried under snow or even under rubble.

On the other hand, when it comes to drones that help patrol teams launch controlled avalanches using explosives, it happens that their development is currently on hold, especially in America, where the Federal Government does not allow civilian operators to operate armed drones over US soil.

4.2.9 Drone Space Flights

NASA and the U.S. Air Force has been testing unmanned aerial vehicles aimed at space travel for several years now. Namely, the X-37B drone is an ultra-secret drone of the U.S. Air Force that looks like a miniature space shuttle, and which has been circling in low Earth orbit for more than two years, thus setting a record for the longest flight of a drone.

The X-37B is 8.9m long, and has a wingspan of 4.5m, while the maximum takeoff weight is just under 5tons. Because the lower orbit requires greater maneuverability, which means more fuel, this drone uses thrusters, more precisely Hall thrusters, which use "electric and magnetic fields to ionize gases, such as xenon, to create a "jet" of ions that creates thrust. "This technology is much cleaner, safer and more energy efficient than traditional rockets, but its main problem is relatively low thrust and slow acceleration, so it cannot be used for launches from Earth, but only for space travel"..

According to official information, multi-year testing of this model is aimed at testing advanced guidance, navigation and control; testing thermal protection systems and avionics; testing the resistance of structures and seals in high temperature conditions, reusable conformal insulation, lightweight electromechanical flight systems, advanced propulsion systems, advanced materials, as well as autonomous orbital flight, return and landing.

What its tasks will be is probably a closely guarded secret, however reducing large satellites to smaller satellites, equally capable of descending to lower parts of the orbit, makes sense when you need higher resolution images of places, for example launching missiles in North Korea or Chinese operations in disputed areas in the South China Sea.

4.2.10 Drones in Medicine

Today, medical technologies are no longer limited to the use of computers. Around the world, prototypes of drones are being worked on that could be used for various purposes - to deliver medicines and medical equipment to remote and hard-to-reach areas, to transport blood samples from remote hospitals to hospitals in major cities, to reduce delivery time of donated organs to people across the country, as disaster relief, in emergencies.

Researchers from Johns Hopkins University in the state of Maryland, in 2017, successfully transported blood samples by a drone, which managed to fly over 250 km of desert, and thus set a new record when it comes to flight length. The Latitude Engineering HQ-40 spacecraft was used in this study. It is a QuadPlane hybrid drone that has the ability to take off vertically and switch to traditional horizontal flight. The drone proved to be extremely suitable, because it has the possibility of landing in a small space.

Namely, during the three-hour flight, thanks to the built-in temperature control system, optimal conditions were created so that the samples would be ready for further analysis after landing.

The samples were housed in a temperature-controlled chamber designed by the Hopkins team. The chamber uses the aircraft's electricity to store samples at room temperature during hot or cold weather. This device is lighter than the equivalent amount of ice, which is most commonly used today when transporting samples. In addition, the chamber has the ability to heat the samples if the air temperature is low.

This has proven to be the fastest, safest and most efficient option for delivering biological samples, whether in a rural or urban environment, where the biggest enemy was logistical inefficiency, which can now be overcome using drones.

In 2018, Joy Nowai became the first baby to receive the vaccine delivered by a commercial drone, in the island state of Vanuatu in the South Pacific.

The drone then flew almost 40km of mountainous terrain from Dillon Bay, located on the west side of the island, all the way to Cook Bay on the eastern, remote end of the island. Namely, Cook Bay lacks electricity, and therefore there are no health facilities, and to reach this small community, it is necessary to walk over rocky hills or by small local boats, whose departures are often canceled due to unfavorable weather conditions.

According to Henrietta H. Fore, the executive director of UNICEF, this is also the first time on a global level that the government of a country has hired a commercial company for drones to transport vaccines to remote areas. That was the Australian company Swoop Aero and this is a great example of how drone technology could influence change in the future by bridging miles of inaccessible terrain that was almost impossible to cross until now.

Figure 116. Specific drone in medicine

4.2.11 Filming and Sports Events

Lately, drone movies have become popular due to their better effect and easier and faster shooting. Drone cameras can capture scenes from the air, capturing the entire scene on their own with a pre-programmed flight path that captures a specific scene. Camera drones are lightweight and made of durable materials. They are also used for recording weddings, concerts, sports events. They provide a perspective that cannot be captured with fixed cameras.

Figure 117.UAV in filming industry

4.3 Purpose UAV

The purpose of UAV is very wide and is expanding with increasing functionality, which provides a dynamic technological development of applicable technologies. As in other cases, the military invests most in the technological development and operational use of UAVs, using favored budget opportunities to focus on prioritizing a particular advantage over others, for a variety of purposes and missions. With the commercialization of applied technologies, the application is rapidly expanding in many civil activities as well.

Unmanned Aerial Vehicles (UAVs) or drones are designed to perform a variety of tasks, from everyday tasks to extremely dangerous. Originally developed for the military and aerospace industries, drones have entered everyday life over time, thanks to the increased level of safety, but also to the efficiency they bring with them.

Figure 118.Special UAV

Unmanned aerial vehicles are characterized by a certain level of autonomy. This level ranges from remote piloting (man controls the movement of the drone), all the way to advanced autonomy, which means that the drone relies on a sensor system and laser scanning technology LIDAR (Light Detection and Ranging) to calculate the movement. LIDAR technology is one of the fastest growing technologies in the processes of collecting and processing spatial information. Another name for LIDAR is optical radar or laser radar. It works in a similar way to radar and sonar, using laser light waves instead of radio waves or sound waves.

Figure 119.Eqipment UAV

For example, very close-range drones can fly up to 5km and are mostly used by hobbyists. Close-range unmanned aerial vehicles reach almost 50km, while short-range unmanned aerial vehicles reach up to 145km and are most commonly used for espionage and intelligence gathering. Medium-range unmanned aerial vehicles are capable of flying up to 650 km and are used for intelligence gathering, as well as for scientific and meteorological research. The longest-range unmanned aerial vehicles are also called "Endurance" drones and have the ability to travel up to 650 km and fly at an altitude of almost 1 km.

Due to the fact that drones can be operated remotely, as well as being able to fly at different altitudes and achieve different distances, drones are perfect for taking on some of the most difficult jobs in the world.Thus, they can be found when searching for survivors in poorly accessible areas, then, very often, they provide the army and police with a bird's eye view during terrorist activities, but also, which is very important, they advance scientific research in some of the most extreme areas on earth. Drones have over time also found their way to our homes and today, among other things, represent a key tool for photographers around the world.

Figure 120.UAV

- ⌘ Single-rotor helicopters – They look like smaller versions of ordinary helicopters and they can be gas or electric powered. A single propeller blade and the ability to work on gas contribute to its stability and enable it to fly longer distances. These drones are typically used to transport heavier objects, including LIDAR systems for terrain survey, storm research, and mapping erosion caused by global warming.
- ⌘ Multi-rotor drones - Multi-rotor drones are generally one of the smallest and lightest drones on the market. They have limited range, speed and altitude and are the perfect tool for enthusiasts and photographers. These drones can spend about 30 minutes in the air, carrying a light load, such as a camera.
- ⌘ Fixed-wing drones – They look like regular airplanes where lift is provided by wings rather than rotors, making them very efficient. These drones usually use fuel instead of electricity and this allows them to stay in the air for up to 16 hours. Since they are usually much larger than other drones and are designed differently, they need a runway for takeoff and landing, just like the ordinary airplanes. Fixed-wing drones are often used for military operations, used by scientists to transport equipment, but are also used by non-profit organizations to deliver food and other goods to hard-to-reach areas.

4.3.1 Technology of Application UAV

The development and production of UAV around the world is intensive, especially for military purposes. Development costs for military UAVs, as with most military programs, usually exceed initial estimates. The reasons are mainly changes in requirements during development, rapid arrival of more advanced technologies and failures in the rational use of available capacities.

The early use of UAV was during the Vietnam War. After the launch, UAV recorded videos on film tape, in a device on the aircraft. Due to the simple nature of these aircraft, they were called drones.

The aircraft often flew in a straight line or in a pre-set circular path after launch and collected video data until the end of their autonomy, after which they landed. After landing, the film was developed and analyzed.

With the development of radio control systems and appropriate infrastructure, they have become remotely controlled, with a very extended and sophisticated purpose, and even a much more useful effect.

Drone technologies are of paramount importance as they offer great opportunities to facilitate the challenging, risky and dangerous actions of participants in military and civilian operations. This importance justifies their rapid development, with a large investment in the advanced technologies on which drones are based.

NATO initiated the need for consensual standardization with the document STANAG 4586 (Standardization Agreement).

The text was presented which began in the process of ratification in 1992. The goal was to enable the allied nations to easily share information obtained by drones, through common command station language technologies.

The STANAG 4586 standard allows all allies to understand information in standardized message formats in the drone process. Likewise, knowledge gained from other harmonized UAVs can be transferred as specific messages from a seamless interoperability format. This can work with the joint support of that protocol of all allied states.

Amendments to the agreement have been added to the hands-on test, with feedback and comments from industry experts and support expert teams.

There are many systems available that are being developed in accordance with STANAG 4586, including products from interested industry leaders, integrated into large corporations.

UAV autonomy technology was created by integrating mechanical and electronic components such as the frame and sensors for navigation and other purposes, computers and drive. This package of equipment performs functions for autonomous tasks, the reasons for the intervention of the pilot (operator) located at a great distance are minimal.

Embedded components can be grouped into:

- Flight control computer (FCC);
- Navigation sensors;
- Communication module;
- Power supply.

The flight control computer with built-in RS / 104 program is designed with compatible electronic boards due to a higher degree of reliability, compactness and the possibility of capacity expansion (open configuration).

The heart of navigation is a steady inertial navigation system. It consists of a package of firmly integrated inertial sensors, a digital processor and signal transmission via a serial port. The output of the navigation system (Digital Quartz IMU-Navigation Processor DQINP) is a serial solution. It is necessary to periodically update the data supplied by the INS sensor in relation to the position of reliable external benchmarks in order to correct the system error of estimating the UAV position, caused by collecting errors in the process of aggregating the received information. The update is done using GPS.

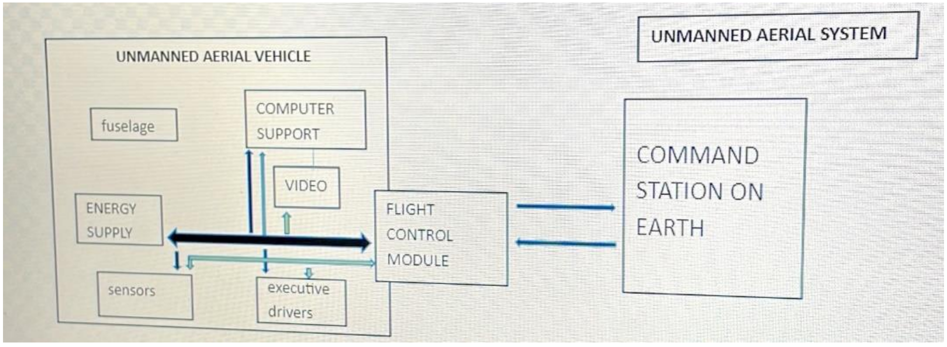

Figure 121. In general, unmanned aerial vehicle components

The Global Positioning System (GPS) used in this control structure has an exceptional accuracy of two centimeters. The DQI-NP flight command computer gets the position and values of the linear and angular velocity of UAV, with high precision. Inverted position estimation messages are transmitted from the GPS package to the DQI-NP computer every second. Based on the obtained navigation data, the flight control computer (FCC) calculates the output for the four control channels: hovering, turning, rolling and engine operating mode. Based on this output signal, the control surface and the "gas" of the engine are driven by actuators that accept signals (Pulse-Width modulation PWm) for 14-21 ms, as reference commands. The delay (time constant) of this process is in the range of 0.8-2.4 ms. To ensure safety, a special circuit is added to the customized reception of the night plate by means of which control can be transferred from FCC to radio transmission (RC) for direct control of the pilot (operator) from the ground command station. Other channels in case of exceeding the capabilities of the basic panel, will show the output of the radio receiver, so that the human pilot takes command of the UAV. This solution proved to be extremely important for the identification and feedback system for assistance and reservation of UAV flight reliability.

The communication module contains two modems with 900 MHz wireless cards and one 2.4 GHz wireless Ethernet card. The type of communication device is selected based on the type of mission. Wireless modems are more useful for long-range missions because their superior range is within 20 to 32 km. Their disadvantage is the relatively slow flow (<11.5 kbps). One wireless modem is used to transmit navigation data and the other to read differential data emitted by GPS. In normal situations, a 2.4 GHz wireless Ethernet card has the advantage of relatively high throughput (up to 11 Mbps), versatility and low power output, and reduced potential interference with sensitive GPS operations. Currently, wireless Ethernet is used as the backbone of multiple participants, in a system consisting of a large number of UAVs.

The earth station has a GPS, a base station and a laptop, intended for communications, then devices for wireless modem or wireless Ethernet. Also, the UAV flight data is monitored and stored from the station, and command signals for navigation are sent from it, in the "language" of management.

Bigger drones are equipped with a built-in vision supported by a processing unit (VPU – vision processing unit) and cameras with zoom on the platform. The VPU can track the target object in specific colors and calculate its coordination based on the navigation data obtained from the FSS computer, via a serial connection. It can be accessed via independent wireless Ethernet for monitoring and debugging processes. The VPU serves the vital role of landing vision, avoiding objects on the ground (bypassing obstacles), detecting and recognizing the image and plan of the relevant building. It is an obvious fact that in the UAV project, the primary sophisticated technologies are digitalization, flight control, navigation, sensors, artificial intelligence, robotics and signal transmission between the aircraft and the base command station. For other areas, proven aeronautical technologies on serial piloted aircraft are primarily used with the application of criteria for minimizing dimensions and costs.

Aircraft of the same type with crew and UAV usually have recognizably similar physical components. The main exceptions are the control system, cockpit, pilot environment and systems necessary for his life and safety.

Some UAVs carry a payload (such as a camera) that is significantly lighter than an adult (pilot). Although they carry a large cargo, the armed military UAVs are smaller in mass than their equivalent aircraft with crew and comparable weapons.

Small civilian UAVs do not have certain protective systems, so they can be made of lighter and cheaper materials of lower strength. Smaller electronic systems, developed for flight control, are used.

The miniaturization of the propulsion of the UAV means that the technology of smaller dimensions, high power is used, which is not feasible for aircraft with crew, larger mass and dimensions. The UAV uses small electric motors and durable modern electric batteries.

UAV command systems are quite different from the solutions on manned aircraft.

The pilot replaces the remote control of the UAV, in the case of a manned aircraft, whereas the cameras and video connections are basically replaced by the cabin windows. Radio-portable digital controls are replaced by mechanical or electrical flight controls, from the cockpit to the aerodynamic control surfaces. Autopilot software is basically similar for piloted aircraft and unmanned aerial vehicles, but they have different content functions.

Figure 122. Lighting system for UAV

4.3.2 Drone Technology

Drones, which are widely used in recent years and offer unlimited opportunities in many areas under different name, unmanned aerial vehicle, are no longer just a hobby. They have become a technology used in many fields such as the military and commercial industry. Drones, which have evolved with the internet and artificial intelligence, are today a cheap and effective way to create various physical and cyber security threats.Its use has become widespread with the use of unmanned aerial vehicles by the US army to fight terrorist organizations. The fact that drones are small, can be operated more easily in dangerous environments, and have less maintenance and operating costs than conventional aircraft is very effective in the widespread use of drones.

Figure 123. US Military Drone

While 878 thousand of registered drones are for hobby purposes, 122 thousand are used for public and commercial purposes. According to a report published by BI Intelligence in 2016, the total sales of drones worldwide was 12 billion dollars. By 2021, according to the estimated figures in the aforementioned report, only three countries in the world are expected to exceed the previous amount.

While there are millions of drones, this number is expected to increase to 17.5 million in 2019 and to 22 million in 2020. According to the “Global Drone Market” report prepared by Aviat Drones in 2017; drone security tools market will exceed $10.5 billion by 2020 . The research firm GrandView Research in 2017 shows that the global market for drone software and services will reach $84.3 billion by 2025.

4.3.3 Drones in Turkey

The increase in the number of registered drone and drone license holders in Turkey shows that the interest in drones has increased. According to 2018 data of the General Directorate of Civil Aviation (SHGM); The number of registered drones in Turkey is 24,866 while the number of people using these tools was 31,194. The number of registered drones in Turkey in a year is about eight. the number of license holders increased fivefold. In order to keep drones under control, even a little, it has been made compulsory to register in our country. UAVs with a maximum take-off weight between 500 grams and 25 kg and their pilots are sent to the SHGM (Civil Aviation General Directorate) in order to register.

Figure 124. Barjaktar

5 The Concept of Regulation and Division According to Areas of Application

5.1 Regulation

Regulation is the legal basis that allows control over certain aspects of life. It consists of legal instruments, such as laws and bylaws. Laws and bylaws serve to point out what is allowed and what is not, and what the legal restrictions and sanctions are.

Unmanned aerial vehicles represent the technology of future, their flight characteristics differ from other aircraft, which requires corrections in the legal regulations that will enable the safe accommodation of unmanned aerial vehicles in the existing airspace. Regulation should be based on safety - it should protect society from the possible bad impact of drones. By expanding the use of drones, potential dangers have been identified. The growth in the number of users and the large number of accidents, pointed out the problem of safety and the need to introduce certain laws in this area.

Each country adopts its own regulations on drones, therefore there are certain differences between them. Of course, there are certain basic rules adopted by international aviation organizations, which all countries should stick to.

5.2 Regulation in Europe

The European area has a large number of organizations that contribute to the development of the aviation industry. These organizations make rules, standards, procedures and regulations. Their goal is to improve the current level of safety, economy and efficiency of air traffic. The two most important organizations in Europe are EASA and EUROCONTROL.

EASA

Figure 125.EASA

EASA (**E**uropean **A**viation **S**afety **A**gency) is the official agency of the European Union in charge of air safety and environmental protection. EASA is headquartered in Cologne, Germany, with 32 member states. The Director of EASA believes that Europe will be the first region in the world with a comprehensive set of rules that ensure safe and sustainable drone operations (both business and leisure activities). Common rules contribute to innovation, the growth of the technology sector that includes drones and the encouragement of investment.

EASA has published a number of documents determining and suggesting the use of drones, the most important of which are:

- Basic regulations (EC) No 216/2008- basic rules in air traffic. Refers to: production, design, performing operations with aeronautical products, parts and devices. It does not apply to the aforementioned products, parts, appliances, personnel and organizations when engaged in police, military, customs or similar services. It was released in February 2008.
- Regulatory framework for the operation of drones NPA 2017-05 (A) and (B)- contains regulations on unmanned aerial vehicles with a maximum take-off mass (MTOM) of less than 150 kilograms. These aircraft are the responsibility of EU Member States, leading to a fragmented regulatory system that hinders the development of the EU single market for drones and their cross-border operations.

The objectives of this document:

- to ensure an operation-centric, proportionate, risk-based and performance-based regulatory;
- framework for all UAS operations conducted in the open and specific category;
- to ensure a high and uniform level of safety for UAS (Unmanned Aircraft Systems);
- to foster the development of the UAS market;
- to contribute to enhancing privacy, data protection, and security.

It was released in May 2017.

Introduction of a regulatory framework for the operation of drones A-NPA 2015-10- maintains the principles set out in the Riga Declaration on Remote Control Devices. Introduces three categories of operations for drones:

- '*Open*' category (low risk): safety is ensured through operational limitations, compliance with industry standards, requirements on certain functionalities, and a minimum set of operational rules. Enforcement shall be ensured by the police.
- '*Specific*' operation' category (medium risk): authorisation by National Aviation Authorities (NAAs), possibly assisted by a Qualified Entity (QE) following a risk assessment performed by the operator. A manual of operations shall list the risk mitigation measures.
- '*Certified*' category (higher risk): requirements comparable to manned aviation requirements. Oversight by NAAs (issue of licences and approval of maintenance, operations, training, Air Traffic Management (ATM)/Air Navigation Services (ANS) and aerodrome organisations) and by EASA (design and approval of foreign organisations).

This regulatory framework encompass European rules for all drones in all weight classes. It was released in September 2015.

EUROCONTROL is the European organization for the safety of air navigation. Founded in 1963, as an international organization whose main goal is the constant development of the European air traffic management system.

EUROCONTROL is headquartered in Brussels. Currently, 41 member countries are included in the organization, including the Republic of Serbia. The largest project of this organization is "Single European Sky". The goal of the project is to erase the state borders and create a single European airspace.

Figure 126. EUROCONTROL

EUROCONTROL divides unmanned aircraft systems into RPAS (Remotely Piloted Aircraft Systems), automated aircraft and DPAS (Driverless Personal Air Vehicles).

The UAS ATM Flight Rules document the problem of the possibility of a drone being piloted by a pilot who is not at all familiar with air traffic rules. The importance of setting new flight rules that are applicable to drones and other aircraft around them is stated. Without the development of Low Flight Rules (LFR) in VFR (Visual Flight Rules) and IFR (Instrumental Flight Rules), full integration will not be possible. It is considered that the best option is to develop flight rules that include VLOS (Visual Line Of Sight) operations in VFR and BVLOS (Beyond Visual Line Of Sight) operations in IFR.

The most important document issued by EUROCONTROL is RPAS ATM CONOPS-describing the concept of drone operations, explaining unmanned systems and types of operations that can be performed by drones. The primary objective is to describe the operational ATM (Air Traffic Management) environment of manned aircraft and drones, which provides a common understanding of the challenge, and aims to create a level playing field for all ATM actors involved. It was released in February 2017.

5.3 US Regulations

FAA (Federal Aviation Administration) is a governmental body of the United States with powers to regulate all aspects of civil aviation in that nation.

One of the main legal frameworks is an official document called Unmanned Aircraft Systems - UAS (Unmanned Aerial Systems). It was released in August 2017 and is marked as document JO 7200.23A - it has eight chapters and four appendices. The purpose of the document is to provide information and guidance on how to legally operate a drone and prescribe planning coordination and services that include drone operations within U.S. airspace.

Since December 2015, all drones have been required to register. The FAA points out that drones between 0.25 and 25 kilograms must be registered. Registration can be done traditionally or online.

If the drone weighs more than 25 kilograms, and is used for non-hobby operations, if the intended operation is outside the United States, the operator must submit a traditional application for registration of the drone.

Conditions for granting registration - the applicant must be a US citizen or must have legal permanent residence and must be over 13 years. Upon completion of the registration, the application will issue an Aircraft Registration Certificate, which will contain a unique identification number (which is also indicated on the drone).

The Part 107 document (FAAs Small UAS Rule) applies to all drone users who have a hobby and users who use drones for commercial purposes.

They must meet the following conditions:

- Obligation to register a drone;
- Possession of a license to operate a drone,
- The maximum take-off mass must not exceed 25 kilograms;
- It is necessary to have visual contact with the drone;
- It is forbidden to fly near other aircraft;
- Maximum flight altitude is 122 meters;
- It is forbidden to fly in the controlled zone of the airport (unless approved by the agency).

5.4 Iceland Regulations

The main regulation of operations in Iceland is contained in the document Regulation 990/2017. It is forbidden to fly at an altitude above 120 meters above ground level without a special permit from the Ministry of Transport of Iceland. It is forbidden to fly a drone within a certain area from the airport border without the approval of the airport. No special approval is required in the event of the drone flying below the height of the tallest structure in the immediate vicinity of the unmanned aerial vehicle path.

Figure 127. Reykjavik airport borders

5.5 Japan Regulations

“A drone is any aircraft that cannot accept passengers, it can be controlled remotely or automatically, excluding aircraft lighter than 200 grams".

In Japan, the Air Traffic Law regulates drone operations. The law prohibits drones from flying over residential areas or areas around airports without permission from the Ministry of Infrastructure and Transport. It is also forbidden to fly drones at night and during sports or other events. In areas where there are no restrictions, drones must fly at altitudes below 150 meters and be at least 30 meters away from people, other vehicles or buildings. It is forbidden to transport dangerous goods by drones.

5.6 Serbia Regulations

The National Aviation Authority in the Republic of Serbia is the Directorate of Civil Aviation. The most important national regulations related to drones are the Law on Air Traffic and the Unmanned aerial vehicle regulations. Article 10 of the Law on Air Traffic (No. 45/2015) states that unmanned aerial vehicles, aircraft models, rockets and other flying objects may be used for economic, scientific, educational, sports and other purposes so as not to endanger air traffic safety. In the Rulebook on drones, Directorate prescribes more detailed conditions for the safe use of drones. Unmanned Aerial Vehicle Regulations

According to the maximum take-off mass (MTOM), unmanned aircraft are classified to the following categories:

- category 1 - includes unmanned aircraft whose maximum take-off mass is less than 0.9 kg;
- category 2 - includes unmanned aircraft whose maximum take-off mass is from 0.9 kg to 4 kg (not including 4 kg);
- category 3 - includes unmanned aircraft whose maximum take-off mass is from 4 kg to 25 kg (not including 25 kg);
- category 4 - includes unmanned aircraft whose maximum take-off mass is from 25 kg to 150 kg.

The following are entered in the Aircraft Register maintained by the Directorate of Civil Aviation of the Republic of Serbia::

- All unmanned aerial vehicles belonging to categories 3 and 4;
- Unmanned aerial vehicles belonging to category 1 or 2 used for: flying at altitudes higher than 100 m, flying near the airport, flying at a horizontal distance of more than 500 m from the drone operator, flying above people, flying near people, flying in a conditionally prohibited zone, flying at night, ejecting liquids or objects or carrying external cargo that is not an element of the structure of the unmanned aerial vehicle.

Entry in the Aircraft Register is made at the request of the owner of the unmanned aircraft. Along with the request for registration of the unmanned aircraft in the Aircraft Register, the following documentation is submitted:

- Proof of paid customs if the aircraft was manufactured abroad, i.e. certified written statement of the owner if the aircraft was manufactured in the Republic of Serbia;
- Manufacturer's instructions for the use of unmanned aircraft, in Serbian or in English;
- A contract on liability insurance for damage caused to third parties by the use of an unmanned aircraft, in accordance with the law governing compulsory traffic insurance.

The maximum permitted flight altitude of an unmanned aircraft is 100 m above the ground, unless the Directorate has previously approved the flight to be performed at a higher altitude and if the airspace has been allocated. The maximum allowable horizontal distance of an unmanned aircraft from an unmanned aircraft operator is 500 m, unless the Directorate has previously approved the flight to be performed at a greater horizontal distance and the applicant has submitted an appropriate risk assessment. The transport of people, animals and dangerous goods by unmanned aircraft is not allowed.

5.7 Duties of a Drone Operator

A drone operator:

- Is obliged to ensure that the flight of the unmanned aircraft does not endanger the life, health and property of people and does not disturb public order and peace.
- Is obliged to use the unmanned aircraft in a way that ensures compliance with flight rules;
- Is responsible that in case the airspace is allocated, the flight of the unmanned aircraft takes place completely within the boundaries of that space, as well as to be available to the competent air traffic control unit for possible interruption of the flight.
- Is obliged to make sure that the drone system is correct before the flight, as well as to check the amount of propellant, i.e. battery status.
- Is obliged to ensure that all equipment of the unmanned aircraft is properly attached
- Is obliged to collect all necessary information for safe performance of the planned flight, to make sure that meteorological and other conditions in the flight area ensure its safe performance, and to check whether the airspace is previously allocated for the needs of other users, or whether there are restrictions for performing the planned flight.
- Is obliged to ensure that the unmanned aircraft is safely removed from obstacles during the flight.
- Must not be under the influence of alcohol or psychoactive substances, nor in such a psychophysical condition that prevents him from safely operating an unmanned aircraft.

6 Flight Safety and preparation

An unmanned aerial vehicle operator is an individual who directly manages the unmanned aerial vehicle system, controls its flight, programs the unmanned aerial vehicle control system and is responsible for its flight.

The operator is responsible and obliged to make sure that the drone is safe to use before take-off. Before each use, the operator is obliged to make sure that all systems are working, that the batteries are charged, that there is a connection with the drone camera. The operator must also check that the light markings are good.

The operator is obliged to check all the components of the drone, because in case of failure or battery drain, the drone must be noticed by people.

Moreover, the operator of the drone is obliged to check the allocated airspace in which the flight will be performed. The operator should take care not to cause damage to other aircraft and facilities, as well as injuries to people.

6.1 Basic Parameters for the Safe Execution of a Drone Flight

Safety actions to be performed before the flight:

- Airspace selection,
- Risk assessment (danger from birds, other traffic, populated areas, etc.);
- Assessment of one's own abilities and competencies (fatigue, stress, alcohol, etc.);
- Drone check (lights, batteries, parts, etc.);
- Checking software components (connection to the controller, security warnings, etc.).

When all these actions are performed, the drone controller is notified that the drone is ready to take off and be used safely.

Safety actions to be performed during the flight:

- Continuous monitoring of drone security status;
- Use of the drone in accordance with its characteristics;
- Respect the airspace,
- Drone range control.

Safety actions to be performed after the flight:

- Safe drone landing;
- Check drone components;
- Safe drone disposal.

6.2 Safety Minimum and Maximum

When it comes to safety minimum - safety minimum in the form of correctness of components is issued by the manufacturer in the form of MMEL - Master Minimum Equipment List. The operator can define its safety minimum on the basis of the manufacturer's MMEL, which must not be less restrictive than the manufacturer's.

Function	Equipment	Use	Picture
Driving	Coreless Motors	Drives the prop in small multi-rotors	 [22]
	Brushless Motors	Drives the prop and controlled by the Electronic speed controller	 [23]
	Electronic speed control (ESC)	Regulates the electrical power supplied to the motors, which is managed by the flight controller	 [24]
Power	LiPo Battery	Provides energy to the driving system, pilot system, and payloads	 [25]
Control & Communi cation	Antennas	Receives commands from the ground station (receiver antenna) and sends telemetry and other data (e.g. video) from the on-board system (transmitter antenna)	 [26]
	Ground Station	Sends operator commands to the UAV and receives real-time flight data	 [27]
Autopilot	Flight Controller	Controls the power of each motor and other systems depending on the data received from the sensors, as well as the commands from the ground station; can be a commercial standard device with open software or something developed for a specific solution	 [28]
	GPS	Establishes the geographic position of the RPAS	 [29]
	Barometer	Determines the distance from the sea level	 [30]
	Inertial measurement unit （IMU）	Integrated accelerometers, gyroscopes, and magnetometers. Determines the current rate of acceleration, changes in rotational attributes and orientation drift	 [31]

Figure 128. MEL UAV

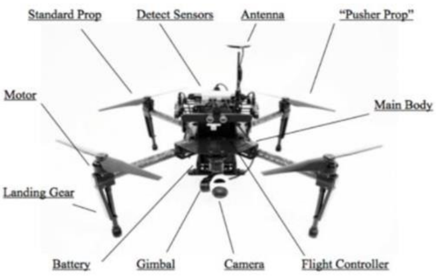

Figure 129. Sensor for drone and basic spare parts

The safety maximum is the set of all hardware and software components of the drone that are used for safe operation. The operator must pay attention to the fact that everything is in a functional state, as well as that all programs are working.

6.3 Methods and Types of Flight Preparation

As mentioned earlier, there are a couple of actions that a drone operator must adhere to. When choosing the airspace, you should pay attention to the forbidden zones, the relief of the terrain, populated places, the proximity of the airport and its zones. After selecting the airspace, it is necessary to perform a risk assessment such as the danger from birds - the operator should pay attention that the drone does not come into contact with birds because it can endanger flight safety; danger from other traffic - the drone should not come near any aircraft, car, train, ship, etc.

Figure 130 An example of unsafe use of a drone

Once the airspace is chosen, an assessment of operator's own abilities and competencies needs to be made. To operate a drone, the operator should not be intoxicated or stressed. The operators should also be rested and aware of their own possibilities.

The check of the correctness of the drone includes any check of the hardware part of the drone, ie. propeller correctness, as well as light, battery, engine, sound signals, pitot-static sensors, camera correctness, angle of attack sensor, etc.

Checking software components includes checking the connection to the controller, checking security warnings.

6.4 Methods of Selecting the Types of Management

The choice of drone control is influenced by the following factors:

- Weather conditions;
- Drone equipment;
- Abilities (training) of the operator;
- Purpose of the flight;
- Distance of the drone from the operator.

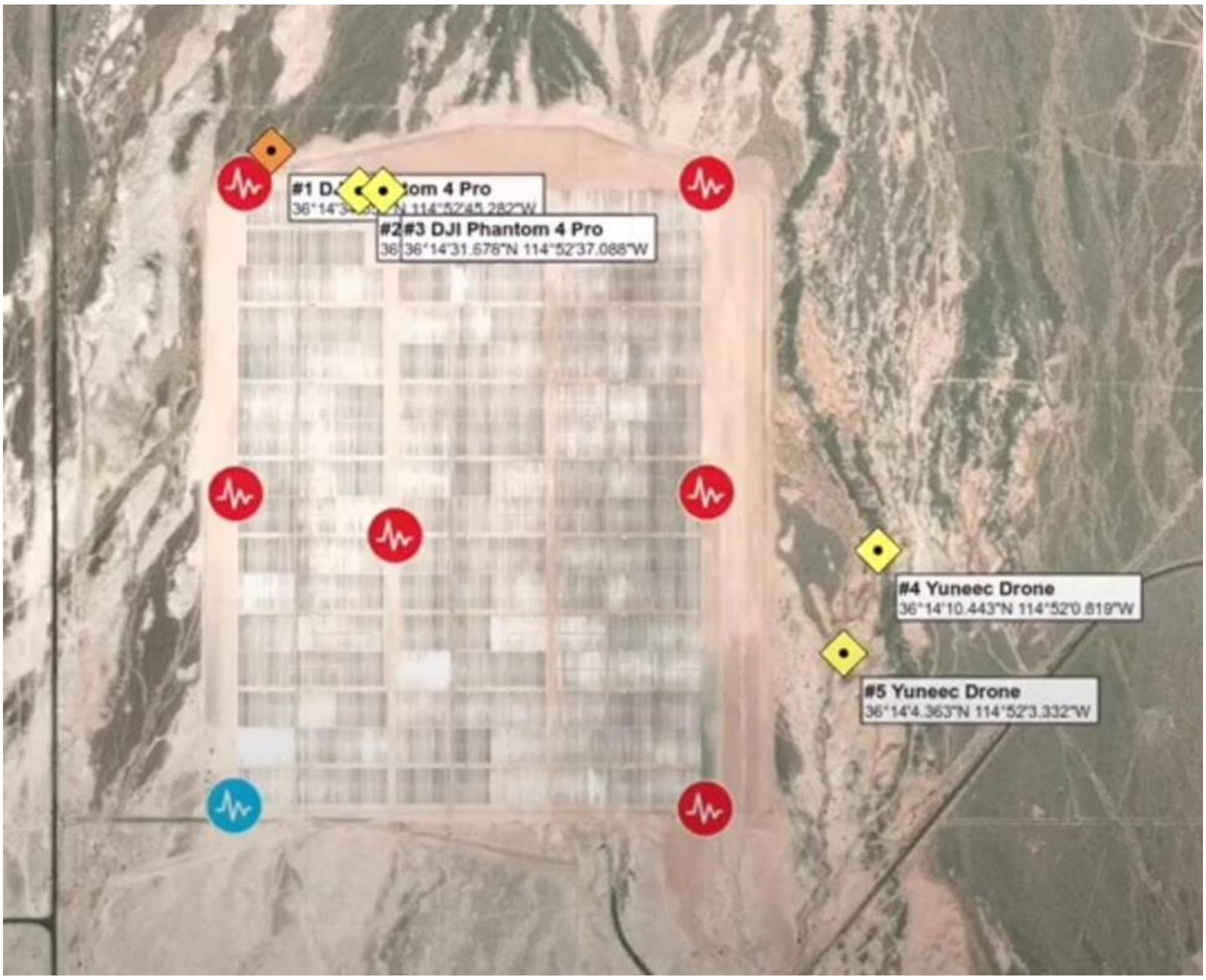

Figure 131 Distance of the drone from the operator

6.5 Automatic Flight at Given Coordinates

When programming the route, the operator is obliged to specify the coordinates of the starting and ending points, and to determine the altitude and ceiling of the flight. The operator should take care that the drone does not endanger the safety of the environment on the path between two set points at a given height. One should also pay attention to the performance of the drone, as well as its maximum range.

If the operator does not take into account the performance and characteristics of the drone, the drone would activate its security system and return to the starting point. This function would enable the drone, when it reaches its maximum, to return safely with the help of programs and already memorized coordinates and land independently at the take-off point.

This function could also be used in situations when drones fly over dangerous zones (approach, departure area, military facilities, power plants, hydroelectric power plants, etc.).

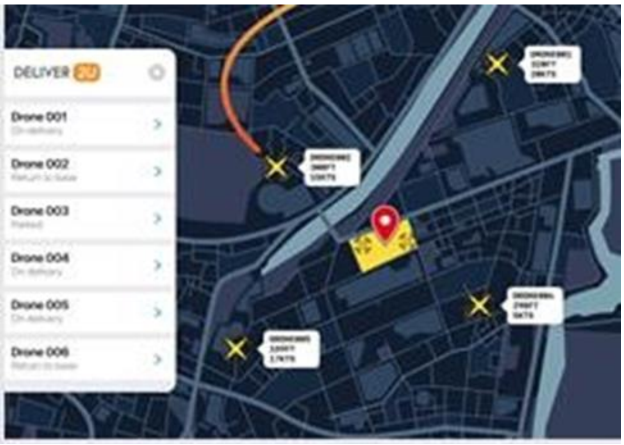

Figure 132 Flight of drone according to the given coordinates

6.6 Free Flight

In free flight, it is important to note that the operator is obliged to have visual contact with the drone at all times, and to respect its performance and range. It is necessary to take into account the safety notices on the steering wheel and check the battery status periodically. The regulation states that the operator is obliged not to move from the place of take-off. It is also forbidden to operate a drone from a moving vehicle.

In the event that the operator loses direct contact with the drone and exceeds its range, or the signal with the drone is lost, the drone should activate its security system, and automatically return to the take-off point at already known and remembered coordinates.

6.6.1 Separation Norms

Separation norms represent vertical and horizontal separation of drones and other traffic participants, people, animals.

Separation norms include.

- Separation between two or more drones;
- Separation between two or more groups of drones;
- Separation of drones from other traffic;
- Separation of drones and humans and animals;
- Separation of drones and objects of high importance;
- Separation of drones from populated areas.

Separation between two or more drones implies vertical and horizontal separation between drones. Drones should be at a sufficient distance, i.e. such as not to interfere with each other's work.

Separation between two or more groups of drones is a vertical and horizontal separation between two or more drone systems, which should not negatively affect each other.

Separation of drones with other traffic is a vertical and horizontal separation between drones and other means of transport (planes, cars, buses, trains, etc.).

The separation of drones and humans and animals represents the vertical and horizontal separation between drones and humans and animals. The regulation determined that the vertical separation is 100ft (30m).

Separation of drones and objects of high importance represents vertical and horizontal separation between drones and objects of high importance. This regulates the ban on access to museums, airports, prisons, banks, military facilities, etc..

Separation of drones from populated areas is a vertical and horizontal separation between drones and populated areas. This implies a ban on flying over densely populated areas.

6.7 Flight Security Software

The software part of the system is complicated. It is based on certain functions that send signals to the drone and with which the drone is actually controlled. In order to improve this system, it is necessary to devise new functions that would help preserve the environment and safety.

The software program would prevent the drone from approaching airport surfaces, and facilities of high importance. The controller would display a "nearby airport" notification. If the operator did not adhere to that notification and continued on the way to the airport, the software would prevent that act and return the drone to the starting point of takeoff.

Notifications to display on the controller:

- Attention! You are approaching a restricted area (if it is an airport or other facility);
- Attention! Aircraft nearby. Move the drone! (if the drone is close to the aircraft)

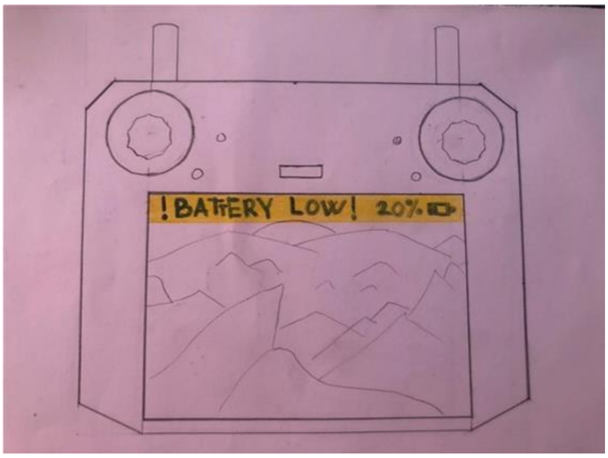

Figure 133 Emergency information

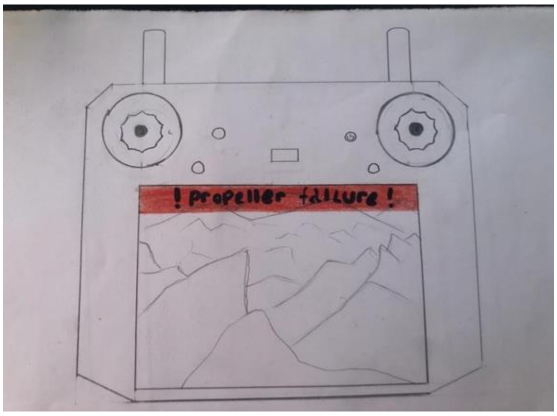

Figure 134 Emergency information

6.8 Selection of Operating Frequencies

When selecting the operating frequencies, one should pay attention not to overlap with the frequencies used for radio navigation devices. Operating frequencies from some devices are:

- NDB (ADF) - operating frequency is 190-1750kHz.
- ILS (Instrument Landing System) - operating frequency is 108-112 MHz
- VOR- operating frequency is 112-118 MHz - VHF communication 118-136MHz
- VHF комуникација 118-136MHz
- DME operating frequency is 960-1000MHz
- GPS operating frequency is 1575MHz

The drone should not operate on any of the frequencies occupied by other radio navigation aids.


Figure 135 Special drone for aviation navigation

6.9 Drone Technology and Its Future Use and Application

Drones are unmanned aerial vehicle. Drones are kind of air vehicle which fly without any actual pilot or crew on board. So, it is often referred as unmanned aircraft.

UAV (Unmanned Aerial Vehicle) are made up of light composite materials which reduce their weight and increase their strength and maneuverability.

Initially drones were only used by military. Now it is used by many professional and individuals.

Drones are used in various fields. Areas in which drones can be used are: construction, defense, photography, marketing, delivery, agriculture, rescue, entertainment, etc.

In these field drones are playing a vital role and making things easier and efficient.

Due to some drone flying restrictions, it is not being used to its full potential.

India has a record of 19,553 drones. While the world will use more than 16 million drones by 2020.

There are various drone technologies used for various purposes.

1. Product Delivery
2. Air Taxi/ Drone Ambulance
3. Disaster Management
4. Search and Rescue
5. Aerial Photography
6. Law Enforcement
7. Weather Forecast
8. Entertainment
9. Wildlife Monitoring

Drone Technologies

Drone comes in a variety of sizes and there are various drone technologies.Few of them are listed as under:

Vertical Take-Off and Landing (VTOL)

Not every drone is capable of vertical take-off and landing. Drones are quadcopters that can take-off, fly, hover, and land vertically. That is why it is called VTOL. There are drones that can be launched from palm of your hand.

Radar Positioning Drone Technology

These drones are equipped with dual navigation technology. It connects to a group of navigation satellites when it is turned on. This satellite constellation gives this drone accurate coordinates of the destination.

Obstacle Detection Drone Technology

This kind of drone is loaded with many detection sensors, such as ultrasonic, vision sensor, infrared, lidar, monocular vision etc. These drones scan surroundings and do the 3D mapping.

Gyro Stabilization Drone Technology

Drones equipped with gyroscope which allows them to fly, rover, and land smoothly against any external force.

Drone Propulsion Technology

These drones have a propulsion system that allows the drone to fly and hover in any direction.

GPS Drone Technology

This type of drone has a GPS system which helps in knowing the real-time location, and improves accuracy.

Drone Transmission Technology

Such drones are used to send and receive real-time data. With the introduction of 5G network the accuracy and speed of transmission of data in such drones have improved manifold.

Live Video Drone Technology

These drones are equipped with high definition cameras that records and transmit real-time video (Live Video) of a location while flying at a height.

Drone Technology Uses and Applications

Drone technologies have great importance in many fields. Areas like construction, defense, aerial photography, marketing, delivery, agriculture, rescue, entertainment have many real-time applications of drones.

Few of them are listed below:

- Product Delivery

For both ecommerce companies and small entrepreneurs, it is expensive to pay a delivery person for a short distance if the efficiency is low. So drone is a better substitute for delivery person to reduce operational cost. Drones with GPS, transmission, and gyro stabilization technology are used to deliver parcels to a short distance. Not only does it save manpower but also shifts unnecessary road traffic to sky. Drones can be used for quick delivery of small packages, medicines, food, etc. over a short distance.

- Air Taxi / Drone Ambulance

Air Taxi and Ambulance are now the demand of time. With growing environmental concerns and road traffic the demand of air taxi is growing.Not only does the Air Taxi reduce the travel time but it also reduces carbon emission, cost incurred, and traffic congestion. Air ambulances help people get medical attention quickly. Specifically in flood affected areas and congested locations drone ambulance can do wonders.

- Disaster Management

Drones can be used to quickly send means to a disaster affected location. Whether it a natural or a manmade disaster drones can reach the earliest, record and send information, navigate other concerned persons, and look for the injured and victims. UAV with cameras and sensors can give a better high definition view of the location, and reach up to a congested place due to its smaller size

- Search and Rescue

Since drones are loaded with thermal sensors, infrared, night vision cameras and transmission devices, they can work as a strong surveillance system. They can send real-time information about location of lost persons, unfortunate victims, culprits even in difficult and high terrains.

- Aerial Photography

Beside giving a detailed view of the location and subject, aerial photography also gives information about the near surroundings at much lower costs. Commercial photographers, cartographers, geologists, etc. are using these drones to get better understanding of the subjects.

- Law Enforcement

In case of large public gathering drones maintain surveillance and ensure safety of the crowd.

⌘ Weather Forecast

Due to its maneuverability, small size, and strength it can be sent to tornados, hurricanes, etc. to send data about them. It can help weather scientists to know the detailed weather parameters. Drones with thermal sensors and gyroscope give insights of the weather trajectory.

⌘ Entertainment

Drone with high-definition cameras can help capture an aerial view of cricket, soccer, and sports matches. Cinematographers use such drones to capture life-pictures and to take aerial shots.

⌘ Wildlife Monitoring

Drones can be used for monitoring forest reserves, wildlife sanctuaries, and zoo. Drones can send information about the poachers. Such UAV with thermal sensors and night vision cameras can monitor such areas during night as well. They can help in observing wild animals without going near them or causing them any harm

The Importance of drone technology is quite evident from the above discussion. The wide range of technologies convey real-time applications of drones. With more weight capacity, robust and advance technologies, longer flight duration and maneuverability, the drones can be much more useful than they are now. Integration of different drone technologies, and wide range of sizes and capacity of such drones is an inevitable asset for businesses. There is huge scope of drones in many other fields such as agriculture, garbage management and sanitation, traffic monitoring, etc. Therefore, the government and businesses should build required infrastructure and create policies for real-time applications of drones. Current issues and problems in the development of unmanned aerial vehicles: there are certain areas in which current UAV research is focused

Cost: Although the operational costs of the UAVs are very low as compared to the manned aircraft, yet the cost of the development of certain UAVs is very high. For example, the "Global Hawk's unit cost is said to be $35 million, a figure that is more than tripled if the development costs are included" (Merle, 2004).

Endurance: Current UAVs have endurance which is much higher than the normal piloted aircraft but that is still considered to be low for a UAV. In 1970s the idea of flying UAVs with the solar energy appeared, and indeed certain UAVs were developed, but they are still unable to increase the endurance as demanded by the military. Recently USAF has launched a program named „Vulture Program‟ („Vulture - The Unmanned Aircraft Able to Stay in the Air for 5 Years‟, 2008) whose purpose is to develop a UAV with endurance of up-to five years. Although the idea sounds like a science fiction novel, yet the development in this direction has happened before that requirement as well as the appearance of the first UAV capable of staying in the air for five years with a payload capacity of about 1000 lbs.

Autonomy: Another issue facing UAVs is autonomy. Researchers are trying to develop UAVs which can perform most of their functions by themselves, and rely less on the "man in the loop". For this purpose increased C4I and advance artificial intelligence feature with more advanced and complex systems on board are being developed. "Autonomy is replacing the human operator in many applications" (Tsourdos, White, & Shanmugavel, 2011)

Lockheed Martin is developing UAVs with advance C4I, which will be autonomous to a larger extent, although the debate is still going on in political circles on how much autonomy should be allowed to UAVs. Tsourdos, White, and Shanmugavel notes, "Advances in avionics, navigation based on GPS (Global Positioning System), flight control techniques and low-cost electronics have further fuelled the use of UAVs in commercial and military applications. Future UAVs will be more autonomous than the remotely piloted reconnaissance platforms in use today." Another related issue is the refusal of the pilots to leave the cockpit duty and join the drawing-room-type control room of a UAV. The culture of service is seriously been affected by the advent of the drones. Very few of these operators of drones "are volunteers, as most have expressed a preference for flying in the cockpit, rather than remotely" (Fulghum, 1998, pp. 61– 62). Although the new generation of pilots, or more precisely drone operators, who are especially trained for the UAVs may have less objection on it, yet the norms of the service have been challenged.

Lack of satellites: Although the United States is developing a big fleet of its UAVs, they cannot be operational at a time because of the limited number of satellites in the orbit. For example the United States might have a fleet of hundred Predators with it, but all of those cannot be operational at one time because of this limitation. (Sirak, 2002). In 2001 and 2002, the USAF had the ability to keep operational only two Predators and one Global Hawk in Afghanistan at one time (Hasik, 2008, p. 42). This capability of the United States has improved significantly in the recent years, yet the challenge still remains.

In-flight refueling: Researchers and developers are trying to develop UAV-UAV refueling in air in an attempt to amalgamate the issues related to autonomy of the UAVs. Northrop Grumman is specifically trying to develop UAV-UAV refueling facility (Bigelow, 2010). A parallel program is the development of the solar-powered UAVs to mitigate the effects of this limitation.

Stealth Technology: Recent target of the developers is to develop "a relatively stealthy, unmanned strike aircraft with an airframe built from nearly 90 percent composite materials" (Sweetman & Cook, 2001, p. 59). U-2s were successful for a considerable period of time in the cold war only because of the inability of the Soviet Union to shoot them down. If they succeed in developing the stealth technology enabled UAVs, the United States will be in a better position to monitor the activities of those states which do not allow the American drones in their airspace – most prominently China.

Greater payload capacity: Currently UAVs can carry payloads that are not considered „enough‟ in the military jargons. So the demand is to either increase the payload capacity of current UAVs or to develop new UAVs with the greater payload capacity. The target is to increase the endurance of UAVs to novel lengths with the nuclear devices on it thus ensuring not only the second-strike capability but also to create a deterring effect on the belligerent..

Ethical Issues: Biggest ethical issue in the use of UAVs is the collateral damage. Criticism is often raised that the operator of a UAV cannot precisely judge the situation on ground while sitting thousands of miles away in a control room. Firing of missiles on the wedding ceremonies in Afghanistan – where the culture of aerial firing at the occasion of happiness is frequent – is just one example of such scenarios. A Brookings study in 2009 concluded that the "number suggests that for every militant killed, 10 or so civilians also died" (Byman, 2009). "Critics have raised the concerns that it is just like „video game scenario‟, and "operators can now safely manipulate battlefield weapons from control rooms half a world away, as if they are playing a video game" (Muhammad Nadeem Mirza, Irfan Hasnain Qaisrani, Lubna Abid Ali, & Ahmad Ali Naqvi, Unmanned Aerial Vehicles: A Revolution in the Making). On the other hand there is no denying the fact that these are the best weapons available in the arsenal to minimize the number of civilian casualties – as compared to the piloted aircraft and the casualties caused by the missiles fired from the aircraft carriers at times stationed hundreds of miles away. Manned fighter jets can pound the positions of the belligerents within an extremely limited time. But in the case of the UAVs, the operator can wait for months while monitoring the activities on the ground, waiting for a suitable time to launch the attack thus ensuring the minimum number of the civilian casualties. A related problem is breaching of the international law. Recasting the terms of sovereignty, being one of the major parts of the Bush Doctrine, entitled the United States to enhance the UAVs operations in many parts of the world. The sovereignty has become a highly relative term in the post 9/11 era especially for the weaker states. Scholars challenge this position on the basis of being a serious threat to the international law and the norms of the international society. Targeted killing without any trials raised too many of ethical and legal issues.

6.10 UAV Development

In China, UAVs have already been operating and used for deliveries and during the pandemic they proved vital as China implemented very strict lockdowns across the country. Companies such as EHang, ZTO Express, and JD.com are now not only improving drone delivery systems across China, including developing larger UAVs to increase the amount they can carry, but regulations are also being developed that will allow experimental passenger UAVs to operate in the near future. New vertical takeoff UAVs are still development and experimentation phase but could be seen operating with passengers in the next few years. Both in the US, EU, and China, regulatory preparation are being considered that will regulate long-distance UAVs and UAVs that operate autonomously.

An area of increasing interest and development will also be UAVs used for first responder purposes, particularly in delivering aid and assistance in remote regions. Similarly, Uber Air, which was recently sold, has been developing the concept of air UAV taxis in the US, although both regulation and infrastructure for this are likely to be some years further away from changes in China. However, given that China has made significant progress in unmanned taxis and delivery systems, the US has recently attempted to catch-up by investing more in technologies and trying to allow regulation to catch-up.

Regulation changes are now beginning to accelerate across many countries in relation to UAVs, especially as the number of UAVs and rapid changes to technology have become evident. For many countries, particularly the US and China, it is also seen as a race that is part of the broader economic battle and competition being developed. For consumers, in the near future it will be likely to see UAVs become more common and applied in tasks such as parcel deliveries or assistance. We are probably a few years away from air passengers taking UAVs but regulatory changes mean that legal preparations are underway in Europe, the US and China to make it a reality in the not-too-distant future.

The technological development that brought us to drones didn't just stop with them. It expanded till drones were used for more than just for military purposes. The latest developments indicate that there is no stop in spreading the drone use to all types of professions. Some of the major drone technology developments include the following.

6.11 Landing Characteristics

The latest drones have better landing characteristics. They are able to give the user greater camera access and better videography and allow the user to better judge the location for landing. This is a great feature for military purposes.

Other than that, this feature allows spreading the drone's legs evenly and quickly without getting stuck into objects that can damage it. A quick landing also makes the drone work more efficiently and shows that the user has better control over the device. Furthermore, better landing characteristics ensure the drone is away from any physical damage near landing places.

6.11.1 Improved Control System

Having a precise control system has always been an issue with the drone technology, but things have changed for the best. These days the Drone Courses by UAV Training allow for better control of the drone and have substantially improved overall control characteristics. Moreover, it is super convenient as well. What is more exciting is that drones can be controlled by anyone from a smartphone or even a tablet. The latest drones can even be controlled by using wristwatches. People who are paranoid that their drone may get into foreign hands can always keep control by using this feature. Also, it keeps the drone from being damaged by random people.

6.11.2 Drones for Kids

As mentioned earlier, drones are not just used for spying or military purposes. Recently, their usage has expanded to almost all spheres of life. It is a new toy for the kids and offers great engagement and motor skills development opportunities. If you get a drone for your child, it will keep them busy and engaged for hours. Children who are interested in photography can make use of a drone and control it by using their smartphones. The efficiency and convenience these advancements provide are unmatchable to any toy the kids have ever used.

6.11.3 Collision Control

Earlier drones had no features that could stop them from crashing into objects. This resulted in a large number of drone damage which cost people and authorities a great deal of money. The introduction of collision control ends this problem altogether. The collision control ensures that a warning is sent to the user when the drone gets too near to an object that it can crash into. This alert system warns the user to change the direction of the drone to keep it away from damage. The alert sent on the latest control devices ensures that no financial or physical damages of any sort occur to the drone.

Figure 136 Landning UAV on hand

7 Aviation meteorological reports

Observations at aviation meteorological stations are carried out 24 hours a day, unless otherwise determined by a special agreement between the authority in charge of meteorological security of air navigation and the aircraft user.

Based on the data obtained from regular monitoring, regular aviation reports are compiled which contain the following information:

- Report type designation;
- Airport location mark;
- Observation time;
- Direction and speed of ground wind;
- Visibility distance;
- Visibility along the runway (if necessary);
- Present tense;
- Quantity and type of clouds (in the form of open text with abbreviations, only cumulonimbus clouds at or near the airport are shown in reports);
- Cloud base height;
- Air temperature and dew point temperature;
- Sea level air pressure value (QNH);
- Airport-level air pressure value (QFE).

Regular observation reports can be submitted to users in the form of codes or in the form of open text with abbreviations.

7.1 METAR Report

The name **METAR** comes from French, from the abbreviated term: **MÉT**éorologique **A**viation **R**égulière ("message d'observation météorologique régulière pour l'aviation"), a regular weather report for aviation.

It was adopted as a world standard in 1996. It is relatively easy to understand, because abbreviated English words are used.

METAR is the term for the regular aviation-meteorological report of the airport, which is compiled and exchanged between airports in the following form.

(Ове теме су снимљене на телевизији и налазе се на каналу РТС ПЛАНЕТА –дуално образовање – ваздухопловна метерологија-метеролошки извештаји и друге лекције под називом врсте облака.)

		METAR	Identification of report typ
		CCCC	Locator of aerodrome
(T’T’/T’dT’d)	Air temperature on RWY	GGgg	Hour and minute of report
	Dew point temperature on RWY	ddd	Wind direction in degrees
		ff	Wind speed in knots
		fmfm	Maximum wind speed
(PhPhPhPh)	Pressure QNH	VVVV	Lowest visiblity
		R	Group indicator
		VrVrVrVr	Visibility on RWY
		DrDr	Direction of RWY to which the visibility refers
		W’W’	Significant time in hour of observation
		Ns	Amount of cloud layer
		CC	Type of cloud layer
		hshshs	Height of cloud layer

7.1.1 Explanation the meaning of groups in the METAR report

- ⌘ CCCC - four-letter indicator of the airport where the METAR report was compiled; the first letter is always L (locator), the second letter is the initial letter of the state expressed in English; the last two letters are taken from the name of the airport (LYBE = Belgrade).

- ⌘ dddff / fmfm - this group usually contains five digits, of which the first three indicate the wind direction in degrees 0˚ to 360˚ (ddd), and the other two wind speed in knots (ff); seven digits in a group are given only when the wind blows on the gusts (fmfm).

- VVVV - group for horizontal visibility at the airport expressed in meters; if this is not the same in all directions, its smallest value is given. 9999 indicates visibility over 10km.

- RVrVrVrVr / DrDr - visibility group along the RWY, where (R) is the letter designation for this group, DrDr means the direction of the RWY extension to which visibility refers (given for airports with more RWYs).

- W'W '- for coding significant phenomena, during the observation at the airport, two-letter markings are used, which mainly represent, the first two letters, phenomena in English.

- NsCCHshshs - cloud group, where Ns indicates the amount of clouds given to this group in the report. CC is a type of cloud, and hshshs is the height of the cloud base. The type of cloud is indicated in the report by the Latin abbreviations for clouds that we already know. CI - cirrus, AC - altocumulus, NS - nimbostratus, CB - cumulonimbus and so on. The height of the clouds is given at equal intervals of 30 m (100 feet). A group of clouds can be repeated several times in case there are more layers of clouds above the airport, then in the report with the cloud group the lowest layer of clouds is given regardless of the amount, the second higher layer is given if its amount is 3/8 or more, and the third higher if its quantity is 5/8 or greater.
- Cb is always encrypted regardless of the quantity.

When the sky is invisible due to fog or other conditions of limited visibility, the cloud group is coded as follows: 9 // 002 = sky invisible; vertical visibility 60m. If there is no data for vertical visibility, the group is encrypted with 9 // xxx.

- T'T '/ T'dT'd - group for air temperature and dew point temperature.

- PhPhPhPh - QNH pressure group given with four or three digits.

When the following meteorological conditions prevail at the airport:

- visibility 10 km or more;
- there are no clouds below 1500 m or below the highest level of sector height (which is determined for each airport);
- no Cb;
- no precipitation, thunder, a thin layer of fog or snow, then, instead of the group VVVV R VrVrVrV / DrDr, W'W', Ns CC hshshs the word "CAVOK" is given which means ceiling and visibility o.k. (cloud base height and visibility fine).

If the word AUTO appears in the METAR report after the time mark when the report was issued, it means that the report was issued by the Automatic Weather Station.

- AUTO - Automatic weather station
- If the report does not have this code, it means that the report was compiled and issued by a man.
- If the AUTO code is replaced by the COR code, it means that a corrected METAR report has been issued for some reason.

Qualifier		**Weather phenomenon**		
Intensity or speed 1	Description 2	Precipitation 3	Shading 4	Other 5
Weak **Moderate (Note 2) + Strong** **WC Nearby** **(note 3)**	**MI Superficial** **PR Partial** **BC Pramen** **SH Pljusak** **TS Storm** **FZ Freezing**	**DZ dew** **RA Rain** **SN Snow** **IR Ice crystals** **GR Grad UP Unknown rainfall**	**BR twilight** **FG Fog** **FU Smoke** **DU Dust** **SA Sand** **HZ Smog**	**PO Swirls of dust or sand** **SQ Whirlwind** **FC Tornado (note 3)** **SS Sandstorm** **DS Dust storm**

Notes:

1. Time groups are constructed in sequence 1-5 from the above table, i.e. Intensity, then Description, then Precipitation, etc. For example, a heavy downpour will be coded as +SHRA.

2. No symbol is used for moderate intensity.

3. A tornado is always coded as +FC.

7.1.2 Example of a regular report

METAR for Belgrade airport METAR LYBE 1630 24015 Kmh 0600 R1000 42 FG 3SC010 17/16 1018 Report in abbreviated open text for Belgrade MET REPORT LYBE 1630 240/15 Kmh VIS 600M RVR 1000M FG 3/8 300M T17 DP16 QNH 1018 Meaning of both reports: Regular report for Belgrade Airport at 1630 UTC; ground wind direction 240 degrees; wind speed 15 km/h; visibility 600 m; RVR 1000 m; fog; 3/8 clouds of the genus Stratocumulus at 300 m; air temperature 17˚C; dew point temperature 16˚C; QNH 1018 hPa.

7.2 SPECI Report

In addition to regular meteorological observations, special meteorological observations are performed at aviation meteorological stations. The obtained special observation data are used for compiling special reports intended for airport air traffic management services.

Reports on the results of special observations can also be used to compile selected special reports in the event of a change in certain meteorological elements, as follows:

- when the direction and speed of the wind change (including wind gusts);
- when the distance of visibility and visibility along the runway reaches certain limits;
- at the beginning, cessation or change of intensity of phenomena such as thunderstorms, hail, snow with rain, cold precipitations, carried drifting snow, dust and sand storms, whirlwinds, tornadoes and water leeches.

SPECI is a special aviation meteorological report. It has the same form as the METAR report, only it is compiled and submitted in the form of a special warning when the height of the cloud base or visibility or wind deteriorates, i.e. improves to certain limits. At airports where meteorological elements and phenomena are observed every half an hour and on the basis of these observations, METAR reports are compiled and submitted; SPECI reports are not compiled.

7.2.1 Example of selected special report

SPECI for Nis airport

METAR LYNI 1115 05025 / 37KT 2500 95TS 7CB005

Report in abbreviated open text:

METAR LYNI 1115 050 / 25KT MAX37 MNM10 VIS 2500M TS 7/8 CB 500FT

Meaning of both reports: Selected special report for Nis airports at 1115 UTC; ground wind direction 50 degrees; wind speed 25 knots with gusts up to 37 knots; visibility 2500 m; thunderstorm; 7/8 cloud of the genus Cumulonimbus at 500 feet

7.3 Meteorological Forecasts in Aviation

In the meteorological security of air traffic, one of the most important tasks is to forecast the phenomena and meteorological elements that occur during the immediate flight of the aircraft. The preparation of significant weather maps for these levels begins with forecasts of meteorological fields obtained from the model. They should include cloud coverage, visibility, freezing level and turbulence. Knowledge of wind and relative humidity values is necessary to calculate vertical and horizontal visibility and cloud base. The freezing level is calculated using the MOS method, using the thickness of the layer of relative topography.

Temperature advection and wind profile are used to predict the occurrence of turbulence, temperature and orographic effects. Short-term or very short-term forecasts of meteorological elements and phenomena are used for flight planning and immediate flight provision for a period of one hour to one day. Aviation weather forecasts are prepared for the airport, the airport area, for landing and take-off, air lines, the flying area.

All these forecasts contain characteristics of clouds (amount, height, lower cloud base), precipitation, significant phenomena, horizontal visibility distance, wind direction and speed, air temperature, isothermal height 0˚C, position and height of tropopause, mountain coverage by clouds, etc.

7.3.1 Take-off forecast

Should be prepared by the meteorological office designated by the meteorological authorities.

The take-off forecast should refer to a specific period of time and it should contain information on expected weather conditions above the RWY with data on the wind on the RWY and its changes, temperature, pressure (QNH) and other elements in accordance with the local agreement.

The meteorological forecast for take-off should be submitted to operators and flight crew members at their request within 3 hours of the scheduled take-off time.

Meteorological offices preparing a take-off forecasts should keep the data up to date and, when necessary, issue appropriate updates immediately. Criteria for issuing amendments to the take-off forecast, for RWY wind, temperature and pressure and other agreed elements, should be agreed between the meteorological authorities and the operators concerned. The criterion should be aligned with the relevant criteria for special reports established for airports in accordance with the relevant issuing provisions.

7.3.2 Forecast for the area and route

It should contain wind at altitude, temperature at altitude, significant weather phenomena on the route with the corresponding clouds that are related. Other elements can be added as required. This information should cover the flight for which it is intended with respect to time, altitude and geographical area..

Meteorological offices that prepare the forecast for the area and the route should constantly monitor the changes and issue supplements as needed.

7.3.3 Forecast for the airport

It is prepared by the meteorological office determined by the meteorological authorities..

The forecast for the airport should be issued at a certain time and contain concise reports on the expected meteorological conditions at the airport for a certain time.

There are two types of airport weather forecast:

- Two-hour weather forecasts that rely on the current weather, following the regular METAR meteorological report. These forecasts are called **trend forecasts.**
- Weather forecasts for an airport with a validity of 9, 18 or 24 hours are given under the name **TAF forecasts**. With these forecasts, there is a certain period of time between the time of issue and the time of the beginning of their usability.

In preparation for compiling the weather forecast for the airport, it is necessary:

- to have the information on the initial meteorological conditions, obtained by measuring or calculating the size of all necessary meteorological elements at the airport and its wider surroundings for the corresponding period of time as well as in the previous time from the date of compiling the forecast;
- To possess the knowledge of the laws and rules that govern certain meteorological elements on a local scale.

The airport forecast and its supplements should be issued in accordance with the template in TAF code form and contain the following information in the order in which they are listed:

- Code name TAF / TAF AMD;
- Location mark;
- Date and place of issuing the forecast;
- An indication of the missing forecast, where applicable;
- Date and period of validity of the forecast;
- Mark of the canceled forecast when possible;
- Wind on the ground floor;
- Visibility;
- Phenomena;
- Cloudiness;
- Expected significant changes in one or more of these elements during the period of validity.

Additional elements will be included in the airport forecast in accordance with regional aviation agreements.

For the analysis of the initial meteorological conditions, a ground map is used, on which a limited number of observed or measured meteorological elements are recorded, and altitude maps, which provide data on the vertical distribution of meteorological parameters.

The meteorological offices that prepare the forecast for the airport are obliged to constantly monitor it and, when necessary, issue appropriate supplements. The length of the meteorological message and the number of changes shown in the forecast should be kept to a minimum.

Airport forecasts and their corrections exchanged between airport aviation meteorological services are given: according to the TAF key prescribed by the World Meteorological Organization (in the form of open text with abbreviations), using teleprinter signs whose meaning is agreed between the interested meteorological authorities.

7.3.4 Landing forecast

Preparation is a meteorological bureau designated by the competent meteorological authority. Such forecasts meet the requirements of local users and aircraft crews located about one hour's flight from the airport.

The landing forecast will be prepared in the form of TREND forecasts, as determined by regional aviation agreements.

The TREND forecast will consist of a summary report of expected significant changes in meteorological conditions at that airport, which is added to the local regular or local special report, METAR or SPECI report. The period of validity of the TREND forecast will be 2 hours from the reporting date (local regular report, local special report, METAR or SPECI) which is part of the landing forecast.

7.3.5 TAF and TREND Forecast

TAF is a coded weather forecast for the airport, and is compiled according to an international key, with the basic letter groups from the METAR report repeated in the TAF forecast. Airports that have an organized forecast service issue TAF forecasts in 9 hours. The TAF airport forecast with the keys for deciphering the icing and turbulence forecast has the following form:

Information	**Airport sign**	**Time**		**Wind**			**Horizontal visibility**	**Occurences**	**Clouds**		
		ОД	ДО	direction	speed	max			quantity	type	height
TAF	CCCC	G_1 G1	G2 G2	ddd	ff	f_m f_m	VVVV	W'W	Ns	C	hshshs

Temperture			**Icing**				**Turbulence**			
indicator	time	temperature	indicator	Intensity of icing	height	thickness	indicator	type	height	thickness
(0	G_f G_f	T_f T_f)	(6	Ic	$h_ih_ih_i$	t_e)	(5	B	$h_bh_bh_b$	t_e)

Key code	**Ic (кључ 1733)**	**B (кључ 0300)**
	Intensity of icing	Type and intensity of turbulence
0	No icing	No turbulence
1	Weak icing	Weak turbulnce
2	Weak icing in cloud	Moderate in the clear, occasional
3	Weak icing in precipitation	Moderate in clear weather, frequent
4	Moderately icing	Moderate in clouds, occasional
5	Moderately icing in cloud	Moderate in clouds, frequent
6	Moderately icing in precipitation	Moderate in the clear, occasional
7	Severe icing	Strong in the clear, frequent
8	Severe icing in cloud	Strong in clouds, occasional
9	Severe icing in precipitation	Strong in clouds, frequent

7.3.6 Examples of an airport forecast

a) TAF in code form

TAF LYBE 0918 13010 9000 6Sc020 GRADU 1316 3000 50DZ 8St006

б) TAF in open text with abbreviations

FCST LYBE 09/18 130/10 KT VIS 9KM 6/8 2000FT GRADU 13/16 VIS 3000M DY 8/8 600FT

Knowledge

TAF: airport forecast

LYBE: airport Belgrade;

0918: the importance of the forecast from 0900 to 1800 hours UTC

13010: ground wind 130˚ 10 knots;

9000: horizontal visibility 9km

6Sc020: 6/8 Sc cloud at 2000 ft (open type omits cloud type)

The airport forecast in the form of open text with abbreviations should be marked with FCST, and its correction with AMD FCST. The order of elements and terminology, units and scales used in airport forecasts in the form of open text with abbreviations, should be the same as those used in aviation scheduled and aviation special weather reports for the same airport.

The TREND landing forecast consists of a regular, special or selected special report for an airport to which is attached a summary of the expected trend of meteorological conditions at that airport. The period of validity of the TREND landing forecast is 2 hours from the time to which the report relates and which forms part of the landing forecast.

TREND landing forecasts indicate changes in one or more elements: ground wind, visibility, significant weather and clouds. Only those elements for which change is expected are included. If no change is expected, this is indicated by the expression NOSIG (No Significant Change), both in the METAR key and in the plain text version.

If a certain change in the value of any of the four quantities is predicted, then this is indicated using the following groups:

TTTTT GG ggHR dddff/fmfm VVVV w'w' NsCCHshshs

- TTTTT - change indicator
- GG ggHR - time group, which is preceded without spaces by one of the letter indicators TT = FM (from), TL (to) or AT (u), is used to indicate the time of beginning (FM) or end (TL) of the predicted phenomenon or the time (AT) when specific prognosis conditions are expected.

Other parts have the same meaning as in the METAR report, including the possibility of using the abbreviation CAVOK.

The BECMG change indicator is used to describe expected changes in meteorological conditions that reach or exceed certain thresholds of the stated criteria, regardless of the mode of change.

Changes in meteorological conditions that reach or exceed certain thresholds of the stated criteria for TREND forecasts are indicated as follows:

- when the change is predicted to start and end completely during the TREND forecast period: using the BECMG change indicator, followed by the letter indicators FM and TL, individually with their associated time groups, to indicate the beginning and end of the change (e.g. for the TREND forecast period from 1000 to 1200 UTC in the form: BECMG FM1030 TL1130);
- when the change is predicted to occur at the beginning of the TREND forecast period and end before the end of that period: using the BECMG change indicator, followed only by the letter indicator TL and its associated time group (letter indicator FM and its associated group is omitted) to indicate the completion of that change (e.g. BECMG TL1100);

- when the change is predicted to start during the TREND forecast period and end at the end of that period: using the BECMG change indicator, followed only by the letter indicator FM and its associated time group (letter indicator TL and its associated time group is omitted.), to indicate the beginning of that change (e.g. BECMG FM1100);
- when it is possible to indicate the time when the change will occur during the TREND forecast period: using the BECMG change indicator, followed by the letter indicator AT and its time group, to indicate the time of that change (e.g. BECMG AT1100);
- when changes are predicted to occur at midnight UTC, the time is indicated by: when combined with FM and AT 2400, when combined with TL.

When the change is predicted to occur at the beginning of the TREND forecast period and to be completed by the end of that period or when the change is predicted to occur during the TREND forecast period but there is no time for that change (perhaps immediately after the start, in the middle or at the end of that period), the change is indicated only by the BECMG change indicator (the letter indicators FM and TL or AT and the associated time groups are omitted).

As an indicator of change, the official abbreviations (GRADU, RAPID, TEMPO, INTER and TREND) are used as follows:

- CITY is used if changes are expected to occur in an approximately constant ratio throughout the entire prognostic period or during a certain part of it.;
- RAPID is used instead of CITY when changes are expected to occur over a period of less than half an hour;
- TEMPO is used when changes are expected to last for a period of less than one hour and changes occur infrequently enough for the prevailing conditions given in this report;
- INTER will be used if changes are expected to occur frequently in short periods of time and conditions will fluctuate continuously between those in the report or those in the previous part of the forecast or those in the forecast;
- TREND will be used if none of the terms CITY, RAPID, TEMPO and INTER is applied. It will not be used if another indicator has already been used in the previous section.

The letter abbreviation NSW (no significant weather) is used to indicate the cessation of significant meteorological phenomena instead of the group W’W’. To indicate a change to "bright", it is used abbreviation SKC (clear sky). When it is predicted that there will be no clouds below 1500m (5000ft) or below the highest minimum sector height, whichever is greater, and clouds of the genus Cumulonimbus are forecast and CAVOK or SKC do not respond, the abbreviation NSC is used (no significant clouds).

The RMK indicator indicates the beginning of the part of the key that contains information that is included in the report based on a decision at the national level and is not intended for international exchange.

Example of a forecast for landing in coded and open text form with abbreviations - TREND forecast provided with the METAR report:

Landing forecast in coded form:

METAR LYBE 1930 05009KT 5000 1023 TEND 3000 10 BR

Landing forecast in the form of open text:

MET REPORT LYBE 1930 050/09 VIS 500M QNH 1023 TENF 3000M BR

This example shows the same forecast only in two different forms, so the meaning will apply to both:

METAR: current weather report;

LYBE: Belgrade Airport;

1930: at 1930 UTC;

05009KT: ground wind 050 ° speed 9 knots;

5000: horizontal visibility 5 km;

1023: air pressure at sea level 1023 hPa;

TEND: development (tendency) of time for the next two hours;

3000 10 BR: horizontal visibility in haze 3000 m.

8 Literature

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