An Overview of Engines for Small Unmanned Aerial Vehicles

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Abstract: - One of the most important inventions of humanity, which is also one of the most complex constructions, is the flying vehicles and their engines. In this study, we will present the main types and applications of aircraft motors, examining the various types of internal combustion engines and the principles of operation of heat engines. More specifically, the main components of gas turbines and their basic characteristics will be discussed. The scope of discussion is the choice of motors for the rapid prototyping of small unmanned aerial vehicles, suitable for military and civilian operations.

Key-Words: - Unmanned Aerial Vehicles, UAV, aircraft engine, internal combustion engine, external combustion engine, turbine, electric motor.

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1 Introduction

The international interest in the use of unmanned aerial vehicles (UAVs) for both civilian and military applications has increased rapidly nowadays, focusing on the optimization of their design and manufacturing features [1].

A key part of aircraft is the propulsion system. The movement of airplanes is due to the mechanical work produced by the engines. Due to the action of the engine, the air masses move with force backwards and this is done either due to the rotation of a propeller or the movement they acquire through the engine itself. The propeller during its rotation sucks and pushes the air masses backwards. This process is achieved because the propeller exerts a force on the air and the air exerts an equal force on the propeller. Due to this force, the propeller-driven airplane is propelled.

In all flying vehicles to date, two of the most widespread types of engines are: Electric motors and turbojets. Electric propulsion systems have an even lower power density than turbojets, but with the technological development of superconducting electric motors, it seems that an equalization of power density performance will be achieved. However, in small UAVs (SUAVs), other small aerial vehicles (MAVs) and remote-controlled model airplanes, electric motors are a widespread propulsion system, due to the low power density they need for a successful flight.

This paper attempts a description of the types of engines for SUAVs, their properties and capabilities, in order to facilitate the selection of technical solutions for the rapid development of prototypes, in military and civil applications.

2 Principles

Thrust is a reaction force. It is measured in kp or pounds or lbf. According to Newton’s second law, it depends on the acceleration of the mass of the gas. The greater the amount of air produced, the greater the thrust. In addition, the pressure difference of the exhaust gases produced to the atmospheric pressure is also responsible for creating thrust. The factors that affect thrust are proportional to the operating characteristics of the engine and proportional to the conditions of the flight environment.

The operating factors for combustion engines are the following: air intake, aircraft speed, engine speed, fuel flow, engine cooling by water intake, exhaust gas inlet temperature to the turbine and reduction of thrust produced by reducing compressed air. The environmental factors are the following: the pressure and the ambient air temperature.

Another equally interesting topic is the principles of thermodynamics and how they apply to internal combustion engines. Topics such as temperature, heat and its transfer, heat engine efficiency, heat conversion into work, cyclic changes of states, the first and second laws of thermodynamics and the concept of entropy are some of those that are of great importance for the operation of combustion engines.

3 Aircraft Engines

The most common types of engines used by aircraft are: Propeller engines, jet engines, electric motors, rocket engines, ramjets and scramjets (e.g., see [2]).

3.1 Propeller engines

The older and smaller propeller-driven aircrafts used reciprocating engines or piston engines to turn the propeller and create thrust (Fig. 1). The amount of thrust a propeller produces depends on the area over which its blades rotate. If this area is too small, the efficiency is not sufficient, while if the area is large, the propeller must rotate at a sufficiently low speed to avoid the possibility of supersonic motion and creating more noise than thrust. Because of this, propellers are mainly used for airplanes that travel at speeds below Mach 0.5, while jets are a better choice for speeds above this limit.

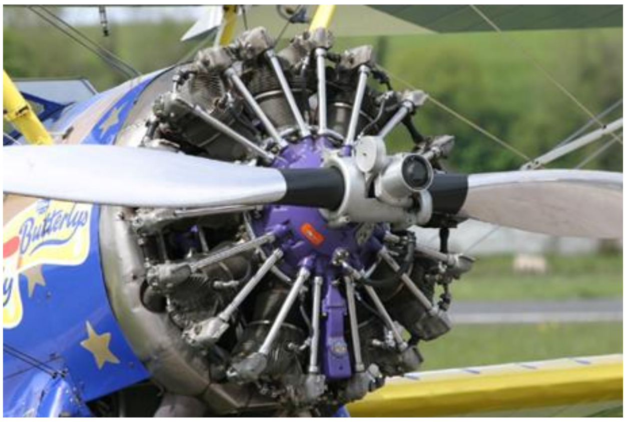

Figure 1. A propeller aircraft engine [3].

Propeller-driven engines may be quieter than jet engines and may be less expensive to purchase and maintain for light general aviation aircrafts. Larger propeller-driven aircraft use a jet engine to drive the propeller, primarily because an equivalently powered piston engine would be larger and more complex.

3.2 Jet engines

The propulsion of jet aircrafts by jet engines is used because of the aerodynamic limitations of propellers, which does not apply to jet propulsion. These engines are more powerful than a reciprocating engine for a given weight or size and are considerably quieter and operate better at higher altitudes (Fig. 2).

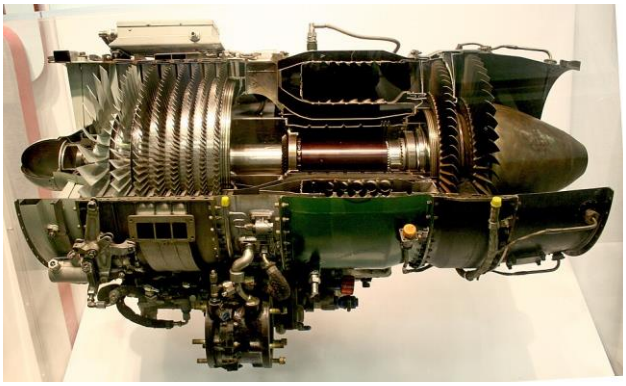

Figure 2. A J85-GE-17A turbojet engine [4].

Most modern jet aircraft use turbojet engines, which balance the advantages of a propeller with the power of a jet. This is essentially a propeller in a duct attached to a jet engine, much like a turboprop, but of a smaller diameter, and is effective as long as it remains in subsonic flight, that is, below the speed of sound. Fighter jets and other supersonic aircraft, which do not remain supersonic for long periods of time, often use turbine engines, but to operate they require air intake into the duct to slow the air down, so that it is subsonic by the time it reaches the front of the turbine. As the air passes through the engine, it is accelerated again to supersonic speeds. To further increase the power output, fuel is injected into the exhaust stream, where it is ignited. This is called afterburning and is used in both jet and turboprop aircraft, although it is normally only used in fighter aircraft because of the amount of fuel consumed, and even then, only for short periods. Supersonic passenger aircraft (such as the Concorde) are not widely used, as supersonic flight creates a sonic boom, which is prohibited in densely populated areas, and because of the higher fuel consumption required for supersonic flight.

Jet aircraft achieve high cruising speeds of 700 to 900 km/h (430 to 560 mph) and high takeoff and landing speeds of 150 to 250 km/h (93 to 155 mph). Because of the speed required for takeoff and landing, jet aircraft use flaps and leading-edge devices to control lift and speed. Furthermore, many jet aircrafts use thrust reversers to reduce the aircraft's speed during landing.

3.3 Electric engines

An electric aircraft uses electric motors instead of internal combustion engines, with the electricity coming from fuel cells, solar cells, electric double-layer capacitors, power radiation or batteries. At present, electric aircraft flights are limited to small manned and unmanned aircrafts (Fig. 3).

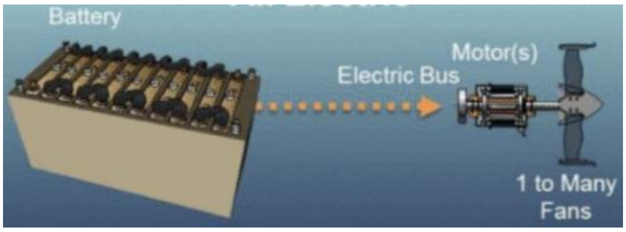

Figure 3. Electric engine schematic [5].

3.4 Rocket engines

Rocket-powered aircrafts use rocket engines (Fig. 4). In World War II, the Germans used rocket-powered aircrafts, such as the Me-163 Komet. The first aircraft to break the sound barrier was a rocket plane, the Bell X-1. The later North American X-15 broke other speed and altitude records and laid the foundation for later aircraft and spacecraft designs. Rocket aircrafts are no longer in use, although there are military aircraft that take off with the help of rockets. Recent rocket aircrafts include the SpaceShipOne and the XCOR EZ-Rocket.

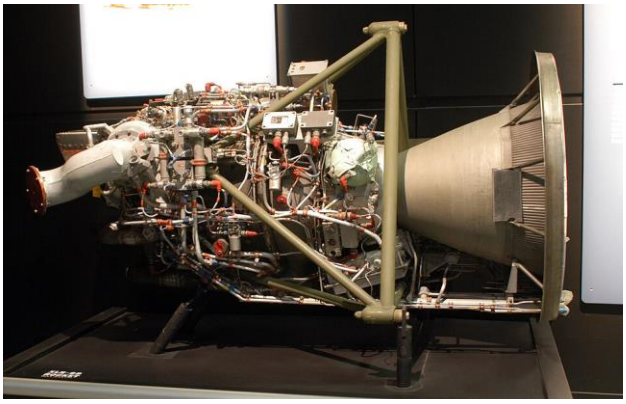

Figure 4. The XLR-99 rocket engine [6].

3.5 Ramjet and scramjet engines

A ramjet engine is a type of jet engine that contains no major moving parts and is useful in certain applications that require a small and simple engine for use at high speeds, such as missiles (Fig. 5 upper). Ramjets require forward motion before they can generate thrust and are often used in conjunction with other forms of propulsion or external means to achieve sufficient speed. The Lockheed D-21 was a Mach 3+ ramjet-powered reconnaissance drone, launched from a parent aircraft. A ramjet uses the forward motion of the vehicle to force air through the engine, without resorting to turbines or vanes. Fuel is added and burned, which then heats and expands the air to provide thrust.

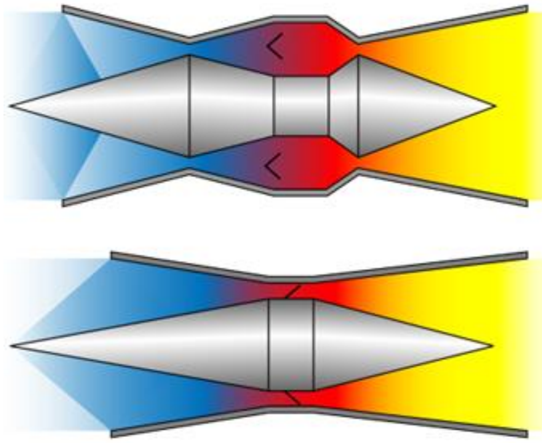

Figure 5. Schematics of a ramjet (upper) and a scramjet (lower) sections [7].

A scramjet is a supersonic ramjet, and apart from the differences in how the internal supersonic airflow works, it operates like a conventional ramjet (Fig. 5 lower). This type of engine requires a very high initial speed to operate. The NASA X-43, an experimental unmanned scramjet, set the world record for a jet aircraft in 2004 at Mach 9.7, approximately 12,100 km/h (7,500 mph).

4 Unmanned Aerial Vehicles

Drones are UAVs that are controlled either by a remote operator or autonomously, following a predetermined flight plan. They can be multicopters (tricopters, quadcopters, hexacopters, etc.) or even airplanes.

Many refer to the term drones as any unmanned vehicle controlled remotely or by a predetermined plan, regardless of where it operates:

- land – unmanned ground vehicles (UGV);
- sea – unmanned marine vehicles and (UMV);
- air – unmanned aerial vehicles (UAV).

Others do not use the term drone for UAVs, because they believe that the name drone refers to military missions, which was in effect years ago. But the situation has changed and now most people when they refer to drones have multicopters (multirotors) in mind.

The quadcopter drone, in order to move, increases or decreases the speed of its engines, depending on the command given. For example, to move forward, it increases the speed of the 2 engines located on the back and reduces the speed of the front ones.

Hybrid SUAVs combine the advantages of multicopters with those of fixed wings. They take off and land vertically, but they fly like airplanes, saving energy [8].

5 Internal Combustion Engines

The first attempts to create aircraft engines were based on the operating principles of heat engines. A heat engine is defined as an engine that can convert heat into mechanical energy. Heat comes from various sources, such as coal, oil, liquified petrol gas (LPG), but also from alternative energy sources, such as the sun or from nuclear reactions.

In combustion, the chemical energy of the fuel is converted into heat and subsequently into mechanical energy: through a piston in a piston engine, or through a turbine in a gas turbine engine. The heat engine that uses fuel is characterized depending on whether the working medium is the same as the combustion product or whether it is different from it. In the case of internal combustion engines, or otherwise ICE, the fuel is burned with the appropriate percentage of air inside the engine. The working medium is the exhaust gas itself. In external combustion engines, the fuel is burned in the boiler, that is, outside the heat engine. In this case, the working medium is not the same but different from the exhaust gas.

According to the way in which thermal energy is converted into mechanical work, fuel heat engines are distinguished into: reciprocating (piston) and rotary (turbine). In piston engines, the exhaust gases produced by the combustion of fuel and air give the necessary movement to pistons, which are connected to appropriate mechanisms, so that the reciprocating movement performed by them is converted into rotary movement. In this simple way, the aircraft propeller rotates. Rotary engines have exclusively rotating parts (gas turbines). Wankel engines are a hybrid category, as they operate with a rotating "piston" [9].

5.1 Piston engines

The criteria by which piston engines are distinguished are mainly constructional and functional (Fig. 6). Thus, we have the following types which arise depending on:

- The ignition method: (a) spark plug engines, gasoline engines or Otto engines; (b) compression ignition engines, petrol engines or diesel engines.
- The number of operating times (two-stroke, four-stroke).
- The method of cooling the cylinders (liquid-cooled, air-cooled).
- The number of cylinders (single-cylinder, twin-cylinder, four-cylinder, etc.).
- The arrangement of the cylinders (in-line single or twin, radial or star-shaped, opposed piston, V or W type, polygonal type – in the case where the cylinders are arranged in the shape of a triangle, square, etc. - double piston, Wankel).
- The speed of rotation of the shaft (low-speed, medium-speed, high-speed).
- The process of introducing the air to be mixed with the fuel (introduction and use of only air, drawn directly from the atmosphere, or use of air from supercharging).

Figure 6. The Rolls-Royce Merlin piston engine [10].

5.2 Gas turbine engines

A jet engine produces propulsive force or thrust in a specific direction, forcing a mass of gas to move in the opposite direction. In other words, it applies Newton's third law, which was mentioned above. We consider the action to be the force exerted on a mass of exhaust gases towards the rear of the aircraft engine. As a reaction to the exit of the mass, a force (thrust) towards the front of the engine and of the aircraft is taken.

Because of this, propellers are mainly used for airplanes that travel at speeds below Mach 0.5, while jets are a better choice for speeds above this limit. Propeller-driven engines may be quieter than jet engines and may be less expensive to purchase and maintain for light general aviation aircrafts. Larger propeller-driven aircraft use a jet engine to drive the propeller, primarily because an equivalently powered piston engine would be larger and more complex.

The magnitude of this force depends on the amount of mass of gas entering the engine and how much acceleration the exiting gases will acquire. To better and more easily understand the concept of jet propulsion, we will mention the example of a balloon. By inflating a balloon with air and holding its mouth closed with our hand, the air inside presses on the walls of the balloon. When we let go, the air is released with force and the balloon is launched towards the opposite side of its mouth.

A jet engine works similarly to our example. The balloon's flight is short, because the drop-in air pressure on its walls is very fast. If we use a bicycle pump for continuous and constant pressure on the walls of the balloon, we will achieve better thrust production. Now, replacing the pump with a compressor, we can achieve even greater performance.

This compressor needs a specific device to rotate. The connection is made, through a shaft, to a turbine. This requires fuel to make it rotate. The air that comes out of the compressor is mixed with fuel and the exhaust gases that are produced will begin to rotate the turbine. By increasing the compressed air, an increase in the thrust produced is also achieved.

All that has been said previously leads to the conclusion that in a jet engine the exhaust gases are pushed towards the exhaust (action) and they exert a thrust (reaction) from the opposite direction, towards the engine and the aircraft. It is a misconception that the exhaust gases, in order to move the aircraft in the opposite direction, push the air behind the engine. The thrust comes from the forces exerted by the exhaust gases inside the engine. They press on the adjacent walls and at the same time the front of the engine. No force can be exerted on the rear of the engine. Just as in a balloon, the engine moves in the direction of the force where it is not balanced.

The main factors that affect the operation and performance of an air turbine are: the inlet temperature of the exhaust gases, the inlet diameter, the pressure ratio of the compressor, the efficiency of each section, and the atmospheric conditions.

There are two types of gas turbine operation: operation at constant volume or with a combustion system at constant pressure. In the first case, the construction difficulties are very great and this is because the addition of heat at a constant volume makes it necessary to use valves to isolate the combustion chamber from the compressor and the turbine. This means that they cannot have continuous engine operation. This was the reason why they rejected this system. In the second case, on the other hand, this operation was accepted due to the following advantages: combustion is continuous and so we do not need valves; the ability to operate with enormous masses, which gives us the ability to have engines with high power; the processes take place inside the engine but also each process separately in each section.

The main advantages of the gas turbine are the following:

- Continuous flow ICE with absence of reciprocating motions and minimization of frictional parts.
- Degree of thermal efficiency (it is in the order of 32-45%).
- Fuels can be either liquid or gaseous.
- Low efficiency in partial load operating conditions.
- Operation is significantly affected by environmental conditions, while this influence becomes more significant when used in aircraft.
- Higher specific fuel consumption, compared to technologically advanced internal combustion piston engines.
- High development/construction cost and time.

The main parts/components of an air turbine are the following: the intake section, the compressor, the combustion chamber, the turbine, the exhaust section, the casing and the heat exchangers [9].

5.2.1 Intake section

A special air duct is responsible for the air intake. This air duct consists of the aircraft section and not the engine. Its purpose is to direct the air towards the compressor, with as few losses as possible and with a uniform flow, as well as to operate at all speeds and flight conditions. They are used to reduce the sound waves that come from the compressor, as it rotates at a very high speed. In addition, they serve to prevent foreign bodies from being sucked into the engine. For this reason, filters are used at the inlet of the air duct.

In front of the compressor, the flow must be slowed down in order to increase the static pressure. The position and shape of the air duct depends on the type of aircraft. Sometimes special blades are placed in order to smooth the intake air flow, before it enters the compressor. The jet engine works in such a way as to match the amount of incoming air with the production of thrust required for flight. The appropriate amount of air is provided by the compressor.

5.2.2 Compressor
The compressor compresses the incoming air so that when it comes out of it, it has a much higher density. Because of this, the engine will produce a lot of thrust, since it will handle large amounts of air, compared to its small volume. The compressor also provides air for cooling the turbine, for the operation of the anti-icing system and for the needs of the crew or passenger cabin.

The air that is compressed and its quantity, as well as the increase in pressure, depend on how fast the engine rotates. As the engine speed increases, the greater the compression is achieved. However, the increase in pressure also depends on the inlet air temperature. The lower it is, the greater the compression.

There are also types of compressors that are used in air turbines and they are the following: Centrifugal Flow, Axial Flow, Axial and Centrifugal Flow. According to the direction of the air flow, each type receives its name. The last type is a combination of the other two and combines their characteristics. The centrifugal consists of one or two stages at most, performs in a rotation range of 20,000-90,000 rpm, is simple, light, compact and therefore resistant in case of suction of foreign bodies, cheap to acquire and easy to start.

5.2.3 Combustion chamber
The efficiency of the combustion of air and fuel determines the engine performance, the operating cost of the entire aircraft, and the environmental impact. The most important goal of the combustion chamber is to achieve the combustion of a specific amount of air-fuel. The thermal energy of the exhaust gases produced is due to the turbine located after the combustion chamber. Combustion takes place in the very small space of the combustion chamber and must be done with the lowest possible pressure loss.

The most common way of combustion is to spray fuel droplets into the air that passes through. The smaller the spray cross-section of the fuel droplets, the more efficient the combustion. The air for combustion passes through holes in a metal diaphragm. The fuel flows in pipes that have a small cross-section and one end of which is parallel to the air flow. The air in these tubes is mixed with the fuel. The two are heated and vaporized in the combustion chamber. The remaining air is used for cooling.

5.2.4 Turbine
The purpose of the turbine is to produce the power needed to rotate the compressor. It absorbs energy from the current produced by the hot exhaust gases as they exit the combustion chamber and converts it into mechanical energy to produce power.

A turbine consists of a casing, stator, ring and rotor. The stator and rotor are enclosed by the casing. It has flanges at both ends to connect the turbine to the combustion chamber and the exhaust nozzle. On the side, where the combustion chamber is located, is the stator, where it receives the exhaust gases that exit. They are fixed blades in the shape of an airfoil. The blades are narrowed so that the exhaust gases pass through at high speed to be strong enough when they reach the blades.

On the other hand, the blades now give the appropriate direction to the exhaust gases to maximize the turbine's performance. The ring is located on both the outer and inner sides of the stator blades. The rotor functions as a diffuser. This converts the incoming air into pressure. Because the cross-section of the movable blades decreases towards the point of escape, the flow of the exhaust gases accelerates. In this way, there is a reduction in temperature and pressure, which makes the conditions for work production favorable.

5.2.5 Exhaust system
This system releases the exhaust gases into the atmosphere. The exhaust gases, after passing through the turbine, have a fairly high pressure and low speed. In a gas turbine, the production of thrust and the increase in the speed of the exhaust gases, released into the atmosphere, are essential. Therefore, the exhaust system aims to maximize the kinetic energy of the exhaust gases during the exit, and reduce the pressure according to the atmospheric.

The performance of the engine depends on the exhaust gas exhaust. The size and shape of the exhaust affect the temperature of the exhaust gases entering the turbine, the air entering the engine, and the speed and pressure of the exhaust gases exiting into the atmosphere. The thrust produced depends to a small extent on how the exhaust gases are extracted. The exhaust system is made from where the turbines end until the end of the exhaust gases in the atmosphere. The basic assemblies of an exhaust system are: the cone, the duct and the nozzle.

When the exhaust pressure is high, the converging-diverging nozzle is used after the turbine. In this case, the nozzle has a cross section that increases and one that decreases. Hence the name converging-diverging. In its first section, the flow is achieved at subsonic speeds and the pressure decreases. In the smallest cross section of the nozzle, the speed is equal to the speed of sound. The speed takes on supersonic values and the diverging part reduces the pressure. Due to the high speed of the exhaust gases, they also have a higher thrust.

There are cases where the exit cross section is changed. In this way, the flow acceleration is controlled in the nozzle. Of course, their complexity is great, which burdens the design of the engine in aircraft that fly at speeds that reach supersonic values. Civilian aircraft have engines with a different exhaust system, but their operation follows the same principle as that of a fighter aircraft. The difference is the type of turbine they use.

5.2.6 Heat exchangers

Heat exchangers have different forms, depending on their position in the thermodynamic cycle. The best-known types are the classic, the regenerative, the intercooler and the replacement of the combustion chamber in closed-cycle gas turbines. They are generally of the gas-liquid or gas-gas type. Their efficiency ranges from 0.75-0.90 and they are of various technologies, such as cross-flow and counterflow.

5.3 Classification of Gas Turbines and Basic Features

Gas turbines are classified based on:

- The recirculation or not of the working medium in: (a) Open cycle (continuous suction of atmospheric air from the inlet to its discharge into the atmosphere); (b) Closed cycle (the same amount of gas remains in the engine, recirculates and repeats the thermodynamic cycle).
- The number of shafts (Single shaft, Double shaft, Triple shaft, Use of free power turbine).
- The use of heat exchangers or additional combustion chamber (with preheating, intercooling, with reheating or afterburning, with a combination of the above).
- Depending on their application (Turbo-reactor, Propeller Turbine, Axial Turbine, Turbofan, Turbo-Atomic Turbine, Rocket Turbine).

The main types of gas-turbines, depending on their application, will be analyzed in some detail below [11].

5.3.1 Turbojet

The turbojet is the simplest form of gas turbine engine (Fig. 2). The exhaust gas flow is used to form the exhaust nozzle for the movement of the aircraft and is the only means of producing thrust. A characteristic parameter of it is the compression ratio or engine pressure ratio (EPR). The ratio of exhaust gas pressure is due to the turbine to the pressure of the air entering the engine. Its value is an indication of the thrust produced for a specific power output.

A disadvantage of the turbojet is the low thrust produced at low flight speeds. This is due to the fact that a fairly high air intake pressure is required in the compressor, and therefore a high speed. For this reason, a turbojet engine needs a large takeoff runway, in order to sufficiently increase the intake pressure, and therefore the thrust during takeoff of the aircraft. In addition, the high fuel consumption is a significant and characteristic disadvantage of the turbojet engine. Finally, the turbojet engine achieves lower efficiency at flight speeds below 750 km/h, compared to the propeller engine. Because the efficiency of the propeller with the cooperation of the propeller engine decreases at flight speeds above 550 km/h, new types of gas turbines were created for more efficient operation in this specific flight speed range.

5.3.2 Turboprop

This engine has a wide range of applications. It is similar to a turbojet except that a gear system is used to reduce the speed and transmit the power to a propeller (Fig. 7). The thrust is very low because in a turboprop, almost all of the exhaust energy is used to drive the propeller.

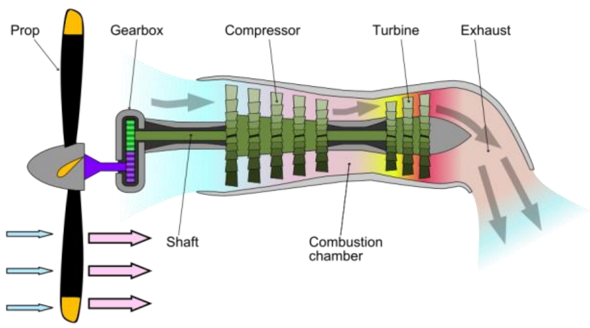

Figure 7. Schematics of a turboprop engine [12].

In more detail, up to 90% of the exhaust energy of a turboprop engine is transferred as power to the shaft that drives the propeller. The remaining 10% of the exhaust energy is provided for thrust. In some turboprops, a different turbine is used to drive the propeller. The name of this turbine is a free turbine and it is connected to a separate shaft with a speed reducer. The function of providing high-energy exhaust gases to rotate the turbine is due to the parts of the engine where the compressor, the combustion chamber and the exhaust turbine are located. The movement of the propeller is achieved by exploiting part of the energy of the exhaust gases, which are expanded in a turbine that also drives the compressor.

The most important advantage of the turboprop engine is that it makes the best fuel consumption, compared to other engines of other types. The propeller allows the acceleration of large air masses at low speeds. The thrust produced is high and the aircraft has satisfactory characteristics in take-off and climb. It also performs at high flight altitudes.

The advantages mentioned above decrease when the speed increases, mainly above 650 km/h, and the flight altitude above 7,000 m. An additional disadvantage of the turboprop engine is that its construction is quite complex and sometimes there are problems with its maintenance. Finally, it is heavier than a turbojet with comparable thrust.

5.3.3 Turboshaft

In turboshaft engines, the power is located entirely on its axis, as it is very small; it is the creation of thrust (Fig. 8).

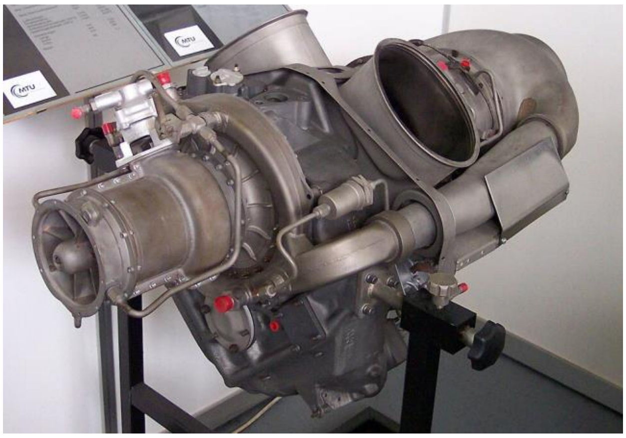

Figure 8. The Allison (MTU) 250 C20B turboshaft engine [13].

The common features with the turboprop (Fig. 7) are many. When the aircraft propeller does not have contact with the turbine of the turboprop engine, the shaft turbine is created. In order to have a different means of power supply, the engine is used in aircraft. The free turbine has the ability to connect to the rotor shaft of a ship, car or electric generator. The output of the turboshaft engine is defined by the axial power of the free turbine.

5.3.4 Turbofan

One of the most important technical developments of the air turbine is the turbofan, which is a variant of the turbojet (Fig. 9). Their technical characteristics are linked to each other. The turbofan accelerates a smaller mass of air than the turboprop, but a larger one than the turbojet. It does not require a large runway for takeoff and at the same time has a high flight speed, even at high altitudes. In addition, the limitation of the flight speed of the turboprop to values from 550 to 650 km/h does not apply. In order not to be greatly affected by the developing speed of the aircraft, the fan blades are appropriately designed. Additional advantages are the increased power output per unit weight, good fuel consumption and reduced noise during landing and takeoff. To be precise, it is a turboprop with the propeller inside the engine.

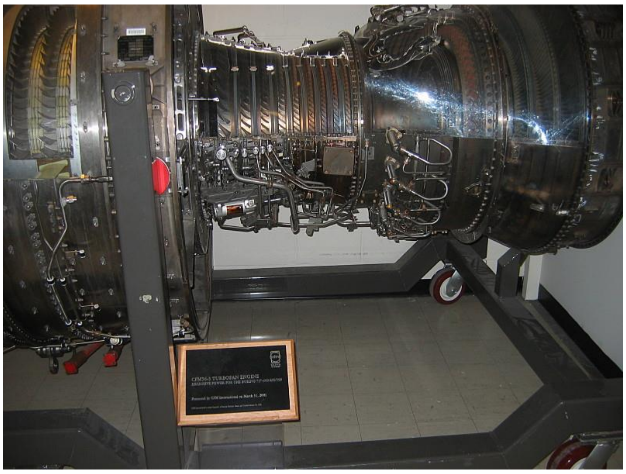

Figure 9. A turbofan engine [14].

The fan is located at the front or rear of the engine. The hot and cold are two streams into which the air flow enters. The hot stream passes through the engine. The cold stream passes peripherally of the engine, at the same axial speed. This stream helps produce 80% of the engine's thrust. The fan accelerates cold air towards the rear of the engine, without it mixing with fuel and burning. Thus, thrust is produced where it is added to the total thrust of the engine.

A characteristic of the turbofan is the bypass ratio, that is, the ratio of the cold to the hot stream. A turbofan is characterized as having a low or high bypass ratio, with values ranging from 2:1 to 10:12. In the main body of the engine, the bypass air is discharged through a special duct. The length of the duct is long, when the duct extends the entire length of the engine or in the possibility of using a fan with a large diameter. More than one turbine is used to drive the fan alone. Nowadays, turbofans are considered the most remarkable types of jet engines used by large aircraft.

5.3.5 Rocket turbine

It is an alternative solution that transports oxygen in liquid form, which is placed in cylinders for combustion, so it does not use atmospheric air. The engine consists of a multi-stage turbine, which drives a low-pressure compressor. The turbine is driven by the exhaust gases of the combustion of kerosene and liquid oxygen in a combustion chamber like in rockets. One of the most important advantages of the rocket turbine is that it has a small volume but also a low weight. Of course, it has a particularly high specific fuel consumption. It is used when a flight is required that is short in duration but high in altitude, so that it does not require the consumption of a very large amount of propellant, like in rockets.

6 Discussion

UAVs may differ in size from the length of a palm [2] to 20m wingspan [15]. Usually, the large UAVs are still used for military operations/missions, while the MAVs are mostly experimental. The medium/small size categories are used for all kind of applications, both military and civilian. Therefore, the research on their features and capabilities is intensive, internationally. Although there is a more-or-less formal taxonomy on their size, conventionally herein SUAVs are regarded as being from around 1 to 5 meters, in overall length/wing span (e.g., see [16]).

Because of the significance of SUAVs in modern applications and usage, the related research concerns their shape, as being: multicopters [17], helicopters [18], conventionally designed airplanes, multi-wing morphs [19], tandem-wing aircrafts [20], tilt-rotor and tilt-wing configurations [21], deployable and telescopic wing and fuselage designs [22], etc. All these shapes are studied, often having particular kind of missions in mind. The relevant research is not, of course, confined in their shape, but also includes their overall performance (speed, operational altitude and range, payload, fuel consumption, runway demands, etc.), and the proper type of engines to achieve whatever is expected by SUAVs.

Regarding their engines, larger UAVs may have all types of conventional engines, yet rarely electric motors that are predominantly used in MAVs. Because of their size and usage, SUAVs are suitable for having installed a variety of engines, depending on their desired operational results. Accordingly, electric motors have very low noise of function, they are easy to purchase and install. Yet, their construction requires nowadays rare-earth materials, like neodymium, its global sources being restricted to few countries [23], which is an important strategic disadvantage. In addition, they have limited range, mainly due to the weight of the required batteries. Indicatively, Heurobotics UAV has a flight endurance of 25 minutes, when equipped with electric motors, while 4.75 hours, when equipped with conventional gasoline ICE [24]. To overcome the disadvantages of electric motors, as well as to reduce carbon dioxide emission aspects, hybrid configurations are inquired that consist of coupling electric motors with other types of motors, in what is referred to as “Turbo Electric Hybrid Architecture” [25].

ICEs are also widely used. There are turbines of the size of a palm [2] and piston engines. Both have the advantages and disadvantages of their type, as mentioned previously herein. The calculation of their performance depends on a variety of factors that include: thrust, fuel-air ratio, thrust-to-weight ratio, specific fuel consumption, endurance, specific efficiency of compressor and turbine, temperatures of devices, etc. Several mathematical formulas are available for this purpose [26]. An interesting feature of piston engines is that they may run on a variety of fuels, such as gasoline, petrol, hydrogen and hydroxy [27], even compressed air [28]. This ability may cover not only environmental concerns and specifications [29], but also logistic ones, regarding the availability of fuels.

Two unconventional choices, presented lately, are external combustion Stirling engines [30] and bladeless engines [31]. The former may run on practically any kind of fuel (i.e., anything that burns), while the latter is based on the Coanda Effect [32]. Both have extremely low noise levels. Consequently, engineers have a variety of alternatives to choose, in order to meet the desired operational requirements.

Finally, issues of construction/manufacturing ate also considered intensively, with the usage of additive manufacturing. This relatively recent technology involves the entire spectrum of construction needs, including large-scale metal additive manufacturing for aerospace applications [33] to very small size turbomachinery applications [34].

7 Conclusion

The international interest in the performance and usage of SUAVs is expressed intensively, nowadays, both for civilian and military operations. SUAVs may undertake a large variety of missions, and therefore, their design is carefully studied. Their ability to have an equally large variety of engines installed gives to their designers/constructors the ability to choose the proper configuration for the intended application. Moreover, the international interest on SUAVs is also intense because of 3D printing technologies that allow easy manufacturing, customized to the users' requirements, and available world-wide to even less industrialized countries. Therefore, their future is extremely promising.

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

During the preparation of this work the authors used Google Translate services in order to improve the readability and language of their manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Christos Papakitsos wrote the English text and assessed the mechanical engineering aspects.
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Evangelos Papakitsos and Nikolaos Laskaris structured the report and assessed the research methodology.
Ilias Panagiotopoulos assessed the aerodynamics aspects.
Dionysios E. Mouzakis set the research directions, assessed the research methodology and supervised the project.

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