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ALTERNATIVE MOTORS IN AVIATION

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Abstract. The increasing demand for air travel leads to more pollution produced by air transport. At the same time the fuel prices are constantly rising. Therefore, it becomes necessary to find alternative energy sources for aircraft (alternative fuel, motors). In this article alternative propulsion systems (fuel) that can be used in aviation, their advantages and disadvantages are reviewed.

Keywords: aviation, pollution, emissions, aircraft, hybrid motors, electric motors, natural gas.

1. Introduction

Aircraft emit gases and particles which alter the atmospheric concentration of greenhouse gases, trigger the formation of condensation trails and may increase cirrus cloudiness, all of which contribute to climate change. They are estimated to contribute about 3.5 percent of the total radiative forcing (a measure of change in climate) caused by all human activities and it has been projected that this percentage, which excludes the effects of possible changes in cirrus clouds, will grow (International… 2013).

Aircraft contribute to air pollution, which is the main problem for those who live in the vicinity of large airports. Light sport aircraft (LSA) and very light aircraft (VLA) which are used for training and sport flights fly nearby airports, so they contribute to the pollution in airports more than passenger aircraft that fly at high altitudes. Such aircraft represent a significant proportion of general aviation and this portion will be growing further. The advantages of these aircraft include relatively low operation costs and relatively flexible rules for their construction and operation, which can facilitate the usage of alternative propulsion systems.

These airplane categories use piston engines that operate on avgas (aviation gasoline), the prices of which continue to rise, and account for a significant portion of the total cost of flight training, which can be one of the causes of decreasing interest in flight training.

2. Emission

The main emissions produced by aviation fuel include:

a) carbon dioxide (CO_2), a colorless, odorless, non-flammable and slightly acidic liquefied gas, which contributes to the formation of photochemical smog;
b) carbon monoxide (CO), one of the greenhouse gases that causes global warming;
c) nitrous oxide (N_2O) and nitrogen oxides (NO_x), causing the most significant effect on the ozone

layer, as nitrogen oxides destroy ozone molecules according the following equations:

$NO + O_3 \rightarrow NO_2 + O_2$

$NO_2 + O \rightarrow NO + O_2$.

This allows more ultraviolet radiation to reach the earth's surface:

a) methane (CH_4) (Rypdal 2013);
b) sulfur dioxide (SO_2), which causes acid rain that leads to a change in the chemical composition of soil and damages plants;
c) volatile organic compounds, VOC;
d) soot, which contains carbon, sulphate, nitrogen, water and other unidentified ingredients. Long-term exposure to urban air pollution containing soot increases the risk of coronary heart disease.

3. Reducing aircraft emission

Emission produced by a small aircraft with a piston engine can be reduced by using a catalytic converter, using alternative fuel such as natural gas or ethanol, or by using a completely alternative propulsion system.

3.1. Using a catalytic convertor

A catalyst is thin layers of precious metals, e.g. palladium, platinum and rhodium, applied on the grid of a catalyst which induce and speed up the reaction of imperfect product combustion and their decomposition to less dangerous products (Hromádko *et al.* 2011; Adamec *et al.* 2001).

Tow-way catalysts (oxidation catalysts) are able to reduce emissions of HC and CO, three- way catalysts (oxidation-reduction) reduce emissions of HC, CO and NO_x. Oxidation catalysts are not used in modern petrol engines.

In order for the three-way catalyst to work properly, there must be enough oxygen in the emission. These catalysts work during combustion of exact stoichiometric mixture of fuel-air, (1kg fuel + 14.8 kg air) when excess air coefficient = 1.

The optimum working temperature inside the catalyst is 250–800 °C. Until the temperature reaches 250 °C the catalyst is ineffective. More specifically, it is ineffective when the catalyst is in the status of cold start shortly after start in the period of 30–60 seconds. At lower temperatures (to 600 °C, clogging is recognized in the active area of catalysts, with slow thermal aging. At a 600–800 °C temperature range the clogging of the catalyst reduces, but the thermal aging increases.

Aircraft supplied with a catalytic converter produce less greenhouse emission of HC and NO_x, in the case when optimum excess air coefficient and working temperature in catalyst are achieved. However, we must notice that a catalyst significantly degrades engine power.

It is important to note, that the use of a catalyst must be combined with the use of unleaded fuel, because it deactivates the main catalyst element, platinum.

3.2. Alternative fuel

Alternative fuels are a good solution in aviation because they produce less toxic emissions than traditional aviation fuel; however, they still have less energy content than jet fuel and avgas (Tab.).

Table. Energy content of all types of fuel

Fuel	Energy content [Btu/gallon]	Energy content [MJ/dm^3]
Jet fuel	125800	35.04
Biodiesel	117000–120000	32.58÷33.42
Avgas	112500	31.33
LPG	≈84000	23.39
Ethanol	≈80000	22.28
CNG(@ 3000 psi)	33000–38000	9.19÷10.58

3.2.1. Natural gas

3.2.1.1. Liquefied petroleum gas, LPG

LPG is a mixture of petroleum and natural gases that exist in a liquid state at ambient temperatures under moderate pressures (less than 1.5 MPa or 200 psi). The common interchanging of the two terms is explained by the fact that in the U.S. and Canada LPG consists primarily of propane. In many European countries, however, the propane content in LPG can be as low as 50% or less, while its octane rate is 101–111.

The advantage of using LPG is that it is more efficient because motors working on LPG have better specific fuel consumption and better performance.

Its disadvantage is the fact that LPG is obtained from petroleum, so there will always be a problem of using it as alternative fuel because of the constant dependence on fuel price.

3.2.1.2. Compressed natural gas, CNG:

CNG is made by compressing natural gas which is mainly composed of methane, CH_4. It is stored in hard containers at a pressure of around 200 bars, while its octane rating is 128.

Advantages:

a) CNG is cheaper than LPG;
b) it does not produce carbon or particular matter when burns;
c) due to the high octane number it can be used at a high compression ration which leads to more efficient combustion;
d) when a leakage of gas occurs it will dissipate immediately, because it is lighter than air, and that reduces the risk of fire and explosion.

Disadvantages:

a) CNG is stored at high pressure and this means that robust and heavy tanks and vehicles are needed;
b) it has lower energy content than other fuel.

3.2.2. Biodiesel

Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant grease for use in diesel vehicles. Biodiesel's physical properties are similar to those of petroleum diesel, but its burning process is clean. The use biodiesel instead of petroleum diesel reduces emissions (Dvorský 2011).

Advantages:

a) does not require special storage conditions;
b) pure biodiesel is not toxic; it is biodegradable and does not contain any aromatics or sulfurs.

3.3. Alternative motors

3.3.1. Electric motors

There are two possibilities of using electric motors in aviation:

– Electric motors that work on batteries.
– Electric motors that work on fuel cells.

Electric motors working on hydrogen fuel cells:

The fuel cell contains an anode and a cathode with an electrolyte sandwiched between them, separating the two. Hydrogen is supplied into the anode and oxygen into the cathode. The two gases want to join but are prevented from doing so by the electrolyte which causes the hydrogen to split into a proton and an electron. The proton passes freely through the electrolyte while the electron is forced to take a different route around it, creating an electric current before re-combining with the proton to form hydrogen again and combining with oxygen through a catalyst, creating a molecule of water (Jones 2010).

There are several different types of fuel cells that work on this principle, each using a different material for the electrolyte (alkaline, phosphoric acid, molten carbonate, solid oxide and solid polymer or proton exchange membrane), and each of them operates at different temperature ranges.

The aircraft fuel cell system consists of a fuel storage system (fuel tank, compressor), fuel cells, electric motor, radiator, controller of the electric motor, propeller, and a splitter for voltage balancing.

Advantages of a hydrogen cell (Conserve… 2013):

a) hydrogen is abundant and readily available;
b) hydrogen is a non-toxic gas and does not produce any toxic emission;
c) hydrogen energy is efficient; it produces more energy per pound of fuel than any other fuel.

Disadvantages:

a) hydrogen gas is expensive and time-consuming to produce;
b) it is difficult to store and transport;
c) though hydrogen energy is renewable and its environmental impacts are minimal, it still needs other non-renewable sources like coal, oil and natural gas to separate it from oxygen;
d) hydrogen cells produce a great amount of heat, so a radiator is always required in fuel cell system.

Electric motors working on batteries:

The first aircraft with an electric motor which obtained an airworthiness certificate were the Antares 20E and 23E. They are electric gliders with a 42kW motor and a lithium-ion battery.

Batteries used in aircraft can be lithium-ion batteries or Lithium-polymer batteries (Li-Pol) (Šplíchal 2012).

Lithium-ion batteries:

Advantages:

a) they have high energy density due to volume;
b) lithium-ion batteries need less maintenance;
c) they have almost no self-discharging.

Disadvantages:

a) the final voltages must not be exceeded during charging and discharging;
b) these batteries lose their maximum capacity whether it is used or not. The speed of aging increases with higher temperature and higher charging current (load). Therefore they are not suitable for using at high intensity;
c) the production of this battery type is rather expensive.

Lithium-polymer batteries (Li-Pol):

Their advantage is the fact that they are 10–15% lighter in comparison with the type Li-Ion at the same capacity.

Disadvantages:

a) when any damage is done to the battery, explosive and flammable gases will expand, so security packages are needed for storing, transporting and charging these batteries;
b) battery cells are covered with a metal foil which has less mechanical resistance.

3.3.2. Hybrid motors:

A hybrid motor is a combination of piston and electric motor which can be connected either parallel or serial of each other.

In a series system, the electric motor is the only means of providing power. The motor receives electric power from either the battery pack or from a generator run by a gasoline engine. A computer determines how much of the power comes from the battery or the engine/generator set. Both the engine/generator and regenerative braking recharge the battery pack. The engine is typically smaller in a series drive system because it only has to meet average driving power demands. The battery pack is generally more powerful than the one in a parallel hybrid in order to provide remaining peak driving power needs. A larger battery and motor, along with the generator add to the cost, which makes a series hybrid more expensive than a parallel hybrid (Union… 2013).

The Parallel Hybrid system consists of a diesel motor and an electric motor, each capable of driving the propeller individually or at the same time. The advantage of this system is the redundancy of having two different motors capable of driving the same propeller. A parallel hybrid can use a smaller battery pack and therefore rely mainly on regenerative braking to keep it recharged. However, when power demands are low, the parallel hybrid also utilizes the drive motor as a generator for supplemental recharging, much like an alternator in conventional gasoline motors.

The Siemens DA36 E-Star is an example of a hybrid aircraft (Fig.). It is a modified version of the two-seat glider HK36 Super Dimonad, equipped with a serial hybrid drive system. It has an electric motor (70 kW), which provides energy for battery and generator, and it is driven by a 40 kW Wankle engine. The airplane operates on an electric motor during take-off and climb, then on a gasoline engine during climb, which also recharges the battery. This aircraft has achieved two hours of flying during a flight test.

Advantages of hybrid motors:

a) the use of an electric motor for propulsion in low speed environments and the technology that allows a HE system to turn off the combustion engine when idling greatly reduces emissions;
b) HE motors increase fuel efficiency;
c) they use smaller engines than conventional motors and have less moving parts that are prone to wearing out and creating waste;
d) hybrid electric motors are significantly quieter that traditional motors.

Disadvantages:

a) hybrid motors cost more than a non-hybrid version of the same propulsion system;
b) the battery for a hybrid motor adds more weight to the system;
c) a hybrid propulsion system requires more parts and components than a traditional one; these extra steps may cause more pollution during the manufacturing process.

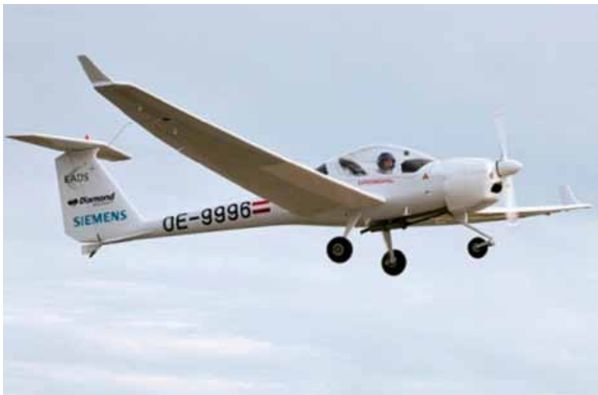

Fig. Siemens DA36 E-Star (Trout 2011)

4. Conclusions

Although it might seem that using hybrid or electric motors is the ideal solution from an environmental point of view, sometimes it may not be economically feasible.

Small aircraft used for flight training fly for short and frequent periods, so it seems that it is more efficient to use electric motors that have no emissions and can be charged easily. However, for aircraft that fly for longer periods both hybrid motors and traditional piston motors with natural gas or biodiesel can be used, but a combination of natural gas and an electric motor seems to be the optimal solution. Using an electric motor during start and take-off will reduce the gases emitted in airport to zero, as well as operation of the system on an alternative fuel will decrease emission during the flight.

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