Alternative aircraft fuels and their effect on the combustion chamber

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Today the fossil fuel is the most important energy carrier of the humanity, although the extractable amount continuously decreases, and using this material pollutes the environment. Human civilization has started realizing how much harm they have already caused to the environment; and when it comes to take a stand against these environmental problems, the focus shifts to the use of alternative energy sources. It is a difficult and expensive process, but it is necessary.
Like most types of transport, the aviation industry depends on fossil fuels. As air transport demand grows, performance must also continue improving, which is why the aviation industry is determined to achieve carbon neutral growth by 2020 and to cut CO_2 emissions in half by 2050 when compared to 2005 levels. Thanks to the intense researches wide range of potential alternative energy sources are available in aviation The most important task of the scientist to choose the best material, what will replace the kerosene and aviation gasoline. The other task to decrease the harmful emission. Much has been accomplished over the last decade to validate the qualification, production, and usage of lower net carbon fuels. Some versions of these fuels are on the cusp of commercialization. However, many research, development, demonstration, and deployment challenges remain in moving these fuels to significant production and mainstream usage.
Appearance of the alternative fuels have to face with many problems what we must solve. After the solution, we can use it on the airplanes. One of them is the effect of the new fuel on the aircraft fuel system. In this paper I will focus on the effect of the alternative aircraft fuels on the combustion process in the combustion chamber. First of all I think the most important is to present some alternative aircraft fuel. I will write about the bio- and synthetic fuel, hydrogen, and electric energy as the alternative fuel of the aircrafts. Most of them reach significant achievement what I will also introduce. I will introduce also the conventional fuel, but it is not the main subject of my paper.

At the end of the document I will summarise the achievements of the researches. In my opinion changing conventional fuel to alternative propellant is necessary. There are several causes of this, decrease the harmful emission is one of them. On the other hand, using conventional fuel will be more expensive in the future so there are also economic reasons to change them.

This is one of the most important problem of the world what we must solve. I hope that in the next decades, there will be many researches with this topic.

Key words: alternative fuel, combustion chamber, green energy

1. Introduction

Today the fossil fuel is the most important energy carrier of the humanity, although the extractable amount continuously decreases, and using this material large amount of emission pollutes the environment. Human civilization has started realizing how much harm they have already caused to the environment; and when it comes to take a stand against these environmental problems, the focus shifts to the use of alternative energy sources. It is a difficult and expensive process, but it is necessary.
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2. Introduction of aircraft fuels

The structural and maintenance materials are fundamental part of the aircraft operation. We can see one of the classification of them at the Table 1 [1].

aircraft structural and operational materials		
metals	**non metals**	**fuels and other special liquids and gases**
• steels • cast iron • coloured metals and their alloys • light metals and their alloys	• plastics • rubbers • fabrics • composites • sealing materials • paints	• fuels • lubricants • hydraulic fluids • coolants • deicing fluid • compressed gases

1. Table Fuels in the classification of aircraft structural and operational materials[1]

We can see that the fuels have important role in the aircraft operating systems. In the next chapter I will introduce the conventional and alternative fuels what can be used as airplane propellant.

2.1. Conventional fuels

When we speak about the conventional fuels we know that they are fossil derivative material. In the aviation, it has to meet a lot of requirements. We cannot create ideal fuel, but we must be close to it. The safety issue is the most important issue in aviation.

The properties of the ideal fuel are the following:

- Proper ignition temperature (independent from the pressure);
- It should possess high calorific value[2];
- It should not produce much ash during the combustion;
- Gel point[3] must be as low as possible;

[1] Edited by the author (MS Word) by reference [1].
[2] **Calorific value**: the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon or other organic molecule reacting with oxygen to form carbon dioxide and water and release heat. [1].
[3] **Gel point:** low enough temperature whereby enough wax crystals have formed to prevent any movement of fuel [1].

- It should have low viscosity and density;
- It mustn’t contain any water;
- It should not cause corrosion;
- It must have safety handle, storage, transport and uploading.

Aviation fuel is divided into two basic categories: Aviation gasoline and Jet Fuel. Jet Fuel has two forms also: wide-cut and kerosene. Although these fuels differ in things such as volatility and freezing points, their energy density, or heat content, is just about the same. Energy density is defined as the amount of energy per mass or it is the heat released when a known amount of fuel is burned under very specific conditions. In International Metric Units (SI), energy density is measured in MJ/kg (or MJ/L) The energy density of aviation fuel is generally between 43 and 48 MJ/kg.

Aviation gasoline, or Avgas, is the fuel used in aircraft powered by reciprocating, rather than turbo-jet or turbo-prop engines. Avgas is similar to conventional motor gasoline; however, there are several important differences. Avgas is generally less volatile and has a lower freezing point and higher octane number[4] than conventional gasoline. Common additives to Avgas include alkyl-lead anti-knock additives, metal deactivators, colour dyes, oxidation inhibitors, corrosion inhibitors, icing inhibitors, and static dissipaters.

Common types of aviation gasoline: [1]

- B-91/115;
- B-100/130;
- AVGAS-100;
- RB-100.

Grades 100 and 100LL Avgas has octane ratings of 100 and are the most widely available. These grades contain about 1.0 and 0.5 grams per litre of tetra ethyl lead, respectively, considerably more than automotive gasolines currently in use. The first number indicates the octane rating of the fuel tested to "aviation lean" standards, which is similar to the anti-knock index or "pump rating" given to automotive gasoline in the US. The second number indicates the octane rating of the fuel tested to the "aviation rich" standard, which tries to simulate a supercharged condition with a rich mixture, elevated temperatures, and a high manifold pressure. For example, **100/130** avgas has an octane rating of 100 at the lean settings usually used for cruising and 130 at the rich settings used for take-off and other full-power conditions. The use of different aviation gasoline is aircraft specific, which means for any aircraft the type of aviation gasoline is prescribed by aircraft operating manual.

In contrast with the reciprocating engines, the gas turbine engines use kerosene. Illuminating kerosene, produced for wick lamps, was used to fuel the first turbine engines. Since the engines were thought to be relatively insensitive to fuel properties, kerosene was chosen mainly because

[4] **Octane number**: a standard measure of the performance of a fuel. The higher the octane number, the more compression the fuel can withstand before detonating (igniting). A certain rating does not mean that the gasoline contains just iso-octane and heptane in these proportions but that it has the same detonation resistance properties like that mixture of iso-octane and heptane.

of availability; the war effort required every drop of gasoline. After World War II, the U.S.Air Force started using “wide-cut” fuel, which, essentially, is a hydrocarbon mixture spanning the gasoline and kerosene boiling ranges. Again, the choice was driven by considerations of availability: It was assumed that a wide-cut fuel would be available in larger volumes than either gasoline or kerosene alone, especially in time of war. However, compared to a kerosene-type fuel, wide-cut jet fuel was found to have operational disadvantages due to its higher volatility. When the commercial jet industry was developing in the 1950s, kerosene-type fuel was chosen as having the best combinations of properties. Although, wide-cut jet fuel (JetB) still is used in some parts of Canada and Alaska.

Regardless of crude oil source or processing history, kerosene's major components are branched and straight chain alkanes and naphthenes (cycloalkanes), which normally account for at least 70% by volume. Aromatic hydrocarbons in this boiling range, such as alkylbenzenes (single ring) and alkylnaphthalenes (double ring), do not normally exceed 25% by volume of kerosene streams. Olefins are usually not present at more than 5% by volume.
Important criteria of the gas turbine fuels still the low viscosity, providing proper function of pump system. It shouldn’t cause corrosion meanwhile it has high calorific value which is essential for the perfect work of propulsion system.

CHEMICAL AND PHYSICAL REQUIREMENTS FOR JP-4, JP-5, AND JP-8			
Issuing Agency: **Grade Designation:** **Fuel Type:**	**USAF** **JP-4 (NATO F-40)** **Wide-cut, gasoline type**	**USAF** **JP-5 (NATO F-44)** **Kerosene type**	**USAF** **JP-8 (NATO F-34/F-35) Kerosene type**
Composition Maximums:			
Acidity, Total (mg KOH/g)	0.015	0.015	0.015
Aromatics (vol. %)	25.0	25.0	25.0
Sulfur, Mercaptan (wt. %)	0.002	0.002	0.002
Sulfur, Total (wt. %)	0.40	0.40	0.30
Volatility:			
Flash Point (°C) min		60	38
Density range (kg/l, 15°C)	-	0.788 - 0.845	0.755 - 0.840
V. P. at 37.8°C, kPa	0.751-0.802	-	-
	14-21		
Fluidity:			
Freezing Point °C, max.	-58	-46	-47
Viscosity @ -20 °C, max.	-	8.5 centistokes	8.0 centistokes
Contaminant Maximums:			
Existent Gum (mg/100 ml)	7.0	7.0	7.0
Particulate Matter (mg/l)	1.0	1.0	1.0
Additives:			
Icing Inhibitor (vol. %)	0.10-0.15	0.15-0.20	0.10-0.15 (F-35 opt.)
Antioxidant (mg/l)	24.0 max.	17.2 min.-24.0 max.	17.2 min.-24.0 max.
Corrosion Inhibitor	Per MIL-I-25017 and QPL-25017	Per MIL-I-25017 and QPL-25017	Per MIL-I-25017 and QPL-25017 (F-35 opt.)
Metal Deactivator (mg/l)	5.8 max.	5.8 max.	5.8 max.
Static Dissipator	to within range	-	to within range
Other:		**-**	
Elec. Conductivity (pico Siemens per meter [pS/m])	150-600		150-600 (F-34) 50-450 (F-35)

2. Table Chemical and physical properties of some military gas turbine fuels

Some other mainly commercial gas turbine fuels: [1]

- JET A/A-1 (kerosene)
- JET B (wide-cut)
- T-1
- TSZ-1

Just like the aviation gasoline the different types of kerosene also have different properties. some of them are presented in Table 2.

The conventional fuels extremely pollute the environment. In addition, scientists say that it will completely run out after some decades (maybe in 2050). Because of this problem the price of the crude oil increases. All in all, we have to change our fossil energy carrier, and must search for a new alternative energy.

2.2.Alternative fuels

Today the researchers make enormous efforts finding renewable energy sources. In the aviation there are several reasons to change the airplanes conventional fuel but it is a hard task to achieve that, because using any kind of fuel in aviation has much more complex requirements than using it in ground transport due to the higher safety considerations. Additionally, burning alternative fuels can cause lot of problems for example in the aircraft fuel system. Later I will introduce these effects in the combustion chamber. Sure, that the concepts of newly designed aircraft will also change with the new alternative fuels.

The new fuel also has to meet with several requirements. These are the following: [2][3]

- high calorific value;
- cost-effective, satisfying the fuel needs for long period;
- production and application should not require large-scale technology realignment;
- It has to perform high safety standards;
- It should be environmentally friendly.

We can group the alternative energy sources according to their derivation:

• Bio- and synthetic fuel • Cryogenic gases	Possibilities to decrease or leave the traditional aviation fuels.
• Solar energy • Fuel cell	electric engine powering

The energy sources I listed above are just partly renewable energy sources. Some of them are available in large quantities, so we can use it for many years and they can replace the crude oil for a time.

2.2.1. Bio– and synthetic fuels

Flying with synthetic fuel were almost the first attempts with alternative solution in the aviation. It has lot of advantages, for example it is liquid so it does not require large technology realignment. It is created from carbon and hydrogen compounds (natural gas, methane etc.). One hand it is good for us, because we can provide high energy with this material, on the other hand it is bad, because it is not considered for alternative energy. Certainly, it is an unexploited energy source we can use for many years instead of conventional fuel [4] [5] [6].

We have to speak about the disadvantages of the synthetic fuels. It has lower viscosity, what can cause problems for the fuel system of the aircrafts, because some device of the fuel system (fuel pumps) are lubricated by fuel flowing through them. Last but not least, it is not an environmentally friendly propellant [4] [5] [6].

Another alternative propellant can be the biofuel. We can get bio-fuel from different materials, for example vegetable oil, urban garbage, fish oil, suet, algae. New researches try to find solution can create bio-fuel from atmospheric carbon-dioxide [4].

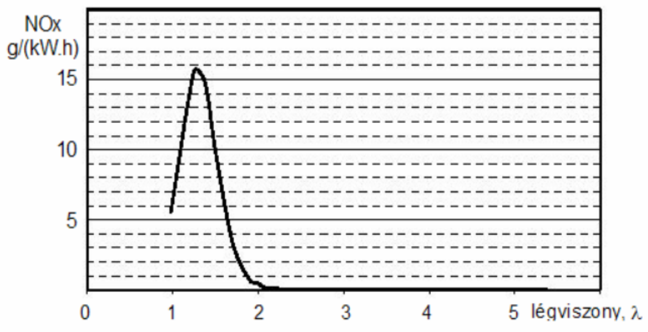
The biofuels have several negative properties, that prevent the spread of this alternative fuel in the aviation. Firstly, we need huge agricultural area for the production/cultivation for the vegetables. Naturally, it has a negative effect on the food industry. In addition, mainly the first-generation bio-fuels have unstable composition, which causes problems with the development of efficient methods to protect them from ageing processes. To avoid this, we should mix biofuel with maximum 20% of gasoline [4].

It has to mention that despite the difficulties the use of the alternative fuels in aviation has started. On November 7, 2011 United Airlines flew the world's first commercial aviation flight on a microbially derived biofuel using Solajet™, Solazyme's algae-derived renewable jet fuel. The Eco-skies Boeing 737-800 plane was fueled with 40 percent Solajet and 60 percent petroleum-derived jet fuel. The hydrogen and cryogenic (liquefied) gases.

The formula of the fuel	Kerosene JET A	Hydrogen H_2	Methane CH_4	Ethan C_2H_6	Propane C_3H_8	Butane C_4H_{10}
Melting [°C]	*< -60*	*-261,9*	*-182,5*	*-183,3*	*-187,7*	*-138,3*
Boiling [°C]	*136-227*	*-252,8*	*-161,7*	*-88,6*	*-42,1*	*-0,5*
$\Delta t_{liquefied}$ [°C]	*196-287*	*≈9*	*≈21*	*≈95*	*≈145*	*≈138*
Critical attribution						
Temperature [°C]	*374*	*-240*	*-82,6*	*32,3*	*96,8*	*152*
Pressure [MPa]	*242*	*1,3*	*4,6*	*4,9*	*4,3*	*3,8*
Fuel density [kg/m^3]						
when melting	*775-785*	*71,07*	*424,4*	*546,4*	*582*	*601,5*
when boiling	*835 (-60 °C)*	*77,15*	*453,4*	*650,7*	*733,1*	*736,4*
Calorific value (at 20 °C) [kJ/kg]						
Maximum	*46470*	*135380*	*56290*	*51910*	*50380*	*49535*
Minimum	*43290*	*114485*	*49930*	*47515*	*46390*	*45745*

3. Table Some attribution of the cryogenic fuels

If we would like to find the proper alternative fuel, we should deal with gases, too. The 3. table introduce for us what kind of alternative gases as energy source can we meet. It also shows us their most important properties comparing to kerosene [7].
It is clear from the Table 3, that the hydrogen has better calorific value than the kerosene. If we burn about 0.36 kg hydrogen it will provide us the same energy like burning 1 kg kerosene. Unfortunately, it has also several disadvantages. The storage of the hydrogen is not solved still on the aircraft [2][8].
The product of hydrogen combustion is mostly water, so it does not pollute the environment, however the effect of water vapour is still not cleared in high atmosphere. In some cases, we can get NOx, too shown in Figure 1 [9].



1. Figure NOx production versus air-hydrogen ratio [9]

In the aviation, there was some experimental flying with propane and butane as cryogenic propellant. Before that, they had to transform the combustion chamber using these materials. Question is whether flying with this alternative fuels can increase the range of airplanes or not?

2.2.2. Electric energy- the solar energy and the fuel cells

In the modern world there is high potential in this type of alternative solution. Using electric power there is no combustion, so we do not need combustion chamber. But on the board of the aircraft limited amount of electric power can be produced. We can speak about two main research direction: solar energy and fuel cells.

Using solar energy is one of the greenest energy, because we do not emit any pollutants. Of course, it has also disadvantages. On one hand, the configuration of solar cells is expensive and the surface area is relatively small. On the other hand, it is hard to store the accumulated energy because the storage is limited by the capacity of the accumulators not to mention of the weight of them.

Applying fuel cell is more widespread. It appeared in aviation too. It is also environment-friendly propellant. In addition, it has minimum noise emission [10].

We have to speak about the harmful effects of using fuel cells. As the solar energy, it is also expensive, not just the configuration but the maintenance, too. Despite the disadvantages, the development of fuel cell technology is one of the most promising and developed at the highest rate [10].

Several airplanes (Solar Impulse, Helios, Zephyr, HY4) proved that electricity has place in the aviation. If we can solve the storage of this energy (maybe developing the accumulators) it will be the perfect alternative energy source for a long period.

3. The effect of the alternative fuels on the combustion chamber

The combustion chamber is one of the most important part of the propulsion system, because the combustion is a very complex process. The designers of gas turbine combustors have to face numerous hardships to meet the multiple requirements a combustor have to perform. The most important of them are bellow.

- Complete combustion to avoid the waste of fuel and to provide high burner efficiency;
- Minimal total pressure loss;
- The combustion must take place in turbine and never in turbine;
- The deposit creation on the liner must be avoided, because it can cause further pressure loss, hot spots, and they are signs of insufficient burning;
- Easy ignition and relight;
- Long lives, without any cracks and failure, because it can cause fatal accident;
- The exit temperature must be uniform both in space and time avoiding the heat stress;
- Stable flame in any operating conditions, air mass flow rate, flow speed and pressure;
- The flame in the combustor shouldn't be prone to flame out;
- Minimal weight and volume.

The different alternative fuels have different effects on the combustion chamber. They can change the heat load of the combustor and with it its life cycle.

If we use biofuel, we do not have to create serious modification in the combustion chamber. In addition, it can be advantageous, because during combustion less carbon-dioxides are emitted into the air. Of course, there are some effects that can cause problem in this part of the engine. When we burn biomass, the exhaust gas is full of little components, what can damage the wall of combustion chamber. During construction and maintenance, we have to pay special attention for this phenomenon [11].

Using of hydrogen as alternative fuel is not a new thing. There was researches with it in early 1800s. Nowadays, because of the mentioned problem with fossil energy carrier, the scientists started to consider it again as alternative energy source. We saw, that it has high calorific value in the Table 3. It can reach 120 MJ/kg. This fact claims serious considerations concerning the combustor structure [9].

The burning of hydrogen is much faster than the conventional fuels or the methane and butane. In addition, it has a high burning temperature what can badly damage the structural elements of the combustion chamber and in some cases the turbine blades. There are solutions, but there is a question: does it worth to build special equipment to stop this negative effect? It means that we will have excess weight, what can cause negative effect on engine performance [12].

On the other hand, the air-hydrogen mixture is very flammable. Partly, it is good, because it has less chance of flame extinction during it combustion. On the other hand, it is bad for us. Any leakage of hydrogen mixing with air can cause huge explosion and fatal accident [9].

4. Conclusion

It is well known, that creating lot of greenhouse gases can cause the greenhouse effect on the Earth. Partly it is created by the traffic specially by the air traffic If we want to maintain a sustainable development, we have to change our attitude concerning the energy consumption.

One way is to decrease our footprint by lessen the energy consumption in every field and every level of our life. Considering the aviation, it is a very successful, but never ending process from the beginning of gas turbine age. The other way is using less pollutant alternative fuels, most of them in aviation. It is a much younger process and the World has just entered in this new and hopefully promising era.

I introduced several new alternative energy sources. Of course, there are lot of obstacles what we have to overcome. First of all, I presented their effect on the combustion chamber. We can realize, that there are big differences using different type of alternative fuel. Due to the limited size of my paper I could just touch this important issue, but the consequence is clear, that changing conventional to alternative fuel is necessary. In the next decades, there will be many researches in this field and sure we are only at the beginning of a long way.

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