INTRODUCTION

Over a hundred years ago, in a year of 1903, 17th of December, at 10:35 AM, at North Carolina’s Kitty Hawk beach, Wright brothers managed to perform a first in the world, fully controlled flight of the heavier than air machine. In a year of 1906, 22nd of May, Wright brothers received patent, numbered 821 393, for their flying airplane, and after their patent notification, placed in the year of 1903, 23rd of March. The first flight was only of 12 seconds duration, and Flyer airplane, known lately as Flyer 1 or Kitty Hawk, piloted by Orville Wright, has flown for a distance of 120 feet (36 meters). Following flights were piloted by Wilbur brother, and took 12 seconds, with distance of 120 feet (36 meters), followed by next Orville flight, 15 seconds, 200 feet. In the last and the longest fourth flight, Wilbur reached duration of 59 seconds and flown for a distance of 852 feet (255, 6 m). Airplane was powered by carbureted, 4 cylinder gasoline engine, with 201 cubic inches (3,294 liters) capacity, cylinder bore and piston stroke was equal to 4 inches and compression ratio was of 4.4 value, four stroke and water cooled design reached power of 12 HP by 1000 rpm. It was the Wright brothers own design, based on contemporary automobile engines and manufactured in their bicycle workshop, very light in those days, weighing only 179 pounds (91 kilograms). Wright brothers had send earlier ten offer requests to the various engine manufacturers with four precise requirements for engine, needed by them: engine weight less than 200 pounds, output of 10 horsepower, automobile gasoline fuelled and vibration free. No one has answered them, so they build their lighter engine in 8 weeks (!), using helping hand of employed mechanic, Charles Taylor. It was a very simple engine and it worked only at the nominal output. Engine speed was controlled by change of the ignition timing. Engine output rose finally to the value of 16 horsepower, approx. Fuel mixture was supplied by downdraught carburetor, fuelled with automobile gasoline, supplied by Standard Oil firm, fuel with value of octane number equal to 38 (estimated by contemporary standards). Fuel tank has capacity of 1,5 gallons. In preliminary tests engine worked for a period of 12 hours between overhauls. After the last flight, wind gusset and resulting ground contact damaged the airplane, only a few original parts and incomplete technical drawings remained to our times. (We can add a technical curiosity here, Wilbur Wright has read a propeller theory presented by well known polish scientist and inventor – Stefan Drzewiecki, but finally we don’t know if he understands it and applied it, because he sent the paper back after lecture. Soon, the world changed much more, than we usually presume, especially in military and fuel areas, leading in fast pace to invention of a new, Ethyl gasoline, main component of the new, modern engine development, and for the other side, environment protection problems, including discovery of the Freon refrigerants and related ozone layer problems– as it was recently discovered. Going farther, consecutive engine versions were improved by exchange of many elements and improvement of the fuel supply, lubrication and cooling systems – Wright brothers manufactured over two hundred engine types in total, design of all of them was closely related to the original first engine. Airplane fuels were also changed. Their octane number raised and reached value of 58 in a year of 1910. From the beginning, American Army and French Army took a great
interest in airplanes, according to information from the Smithsonian Institution, National Air and Space Museum, Washington, D.C. Rapid development of airplane engines started, power output increased, accelerated by the First World War. True, normalized airplane fuels appeared soon, like Red Crown Aviation Gasoline in 1918, produced by Californian Standard Oil Co. Lead Tetrathyl additive was introduced to aviation fuels in a year of 1921, increasing fuels resistance to detonation combustion. Demand for production of aviation gasoline increased significantly. The key circumstance was standardization work performed by Cooperative Fuel Research Center Committee created by representatives of petroleum and engine industries. Charles Lindberg has flown his transatlantic flight in a year of 1927 on such standardized gasoline. In a year of 1932, a special engine for designating gasoline octane number, designed by H.L. Horning of Waukesha Motor Company, has found a general acceptance. In a year of 1934, Standard No. X3575 for aviation gasoline Avgas 100/130 with octane number 100/130 appeared. Creation of this gasoline and deliveries of that fuel to the Great Britain helped to win famous Battle of the Great Britain Gasoline properties are characterized by its anti-knocking attributes, like motor octane number for lean mixtures / motor octane number for rich mixtures, designated according to proper methodology. The latest methodology, ASTM D 909 – “Standard Test Method for Knock Characteristics of Aviation Gasoline by the Supercharge Method” was implemented in a year of 1958! Gasoline assortments manufactured in different countries were reduced to a few grades, and were interchangeable between them. In Poland, in December of the year 1918, just after restoration of the independence, Scientific – Technical Department in Airborne Section of Ministry of Warfare was created. In a year of 1922, first laboratories of Military Central for Aeronautical Research, led by eng. H. Zaliński, started their work. Laboratories were located in buildings, at the address of Puławska 2a, Warsaw, Poland. Testing and measurements methods were not different from the contemporary world standards. Thanks to the work of this laboratory, in the Technical Institute of Aviation (later transferred to the periphery of the Okęcie airport, to the Zbąrz fort) a high octane BAB aviation fuel was developed to Polish Military Aviation Forces and LOT airlines by doc. Mielnikowa, undepend on Poland from delivery of German fuels (a word of mouth information from doc. Tadeusz Kostia). Function of the Test Laboratory Manager was held by eng. Jan Tuszyński, which performed research work on the CFR engine. After the Second World War, aviators have chance to met with soviet aviation gasoline fuels, produced according to GOST 1012-72 standard, types B-70, B-91/115, B-95/130 and B-100/130, and also gasoline SB-78 (mixture of previously mentioned gasoline types in proper proportions) and gasoline BA (115/160, approx.). As curiosity, one can mention, that aircraft fuel for piston engines with the highest parameters was the 115/145 OCTANE aviation gasoline, equivalent to the soviet BA gasoline. It was used on the C124E Globemaster airplane during Cold War era.

Beyond Otto Thermodynamic Cycle engine, used in the Wright brother’s airplane, a Diesel Thermodynamic Cycle engines were also used in the first years of the aviation history. The first aviation Diesel engine was four cylinder MO-3 engine, build by Dr. Junkers in a year of 1913. Fully developed design of Junkers F03 engine with 830 HP @ 1200 rpm amazed aviation world in a year of 1926 and specifically, from this moment, interesting career of high compression engines in aviation begun. Following Junkers designs followed, known as Junkers Juno 4 (770 HP @ 1800 rpm), Juno 205 (880 HP @ 3000 rpm), Juno 206 (1200 HP) and Juno 207 (1000 HP @ 3000 rpm). All that types were designed as twin crankshaft, opposed twin piston in single cylinder two stroke engines with very low unitary mass coefficient, lowered from 0.95 kg/HP to 0.64 kg/HP in turbocharged versions. Junkers found quickly followers in Germany and abroad, they also sold a number of engine design licenses. Together with Deutsche Lufthansa, Junkers Company defined requirements for aviation Diesel fuel. Cetane number, which defines fuel compression ignition properties, was investigated on CFR variable compression engine, manufactured by Waukesha Motor Co, together with proper engine equipment. At that time, aircraft engine fuels had cetane number in range of 45-60, and point of cold filter block reached temperature of −20°C. In Germany, aircraft Diesel engines were building by Bayerische Motoren Werke and Daimler Benz, the later one build engines, which were installed in famous Graf Zeppelin airship. Designs of airplane Diesel engines appeared also in France, England, Italy, and Soviet Union and even in our southern neighbor, Czechoslovakia (ZOD 260B engine). Diesel engines were also build in USA. The first one, 9 cylinder, 225 horsepower Packard engine was tested in 1929. Two years later, this engine mounted on Bellanca „Pacemaker” aircraft, broke the long endurance record, and hold it until year 1986. Successful type of aircraft engine, which revolutionized both military and civil aviation, was gas turbine jet engine, on which development was held in two countries, Germany and England. In England research was performed by Frank Whittle, who patented jet engine in a year of 1930, over passing dr Hans von Ohain from Germany, who patented his design in 1936. In a year’s 1931-1932, in Poland, not knowing nothing about developments in England and Germany, eng. Jan Oderfeld (next, professor in Warsaw’s University of Technology). It was later proved, that engine prototype designed by them was similar to the V1 flying bomb engine. V1 engine was designed to the single use, and our aim was to use engines designed by us to propel airplanes, e.g. to haul post quickly in „CUAV” – civil unmanned air vehicles. Our invention was rather civil in its character, not military like V1 – professor Oderfeld says. Research engine model, designed by: Jan Oderfeld, Władysław Bernardzikiewicz and Józef Sachs worked non-continuously, by pulse principle. Beyond that, modern initial compressor and harmoniously working cylinders were used. First engine trials were successfully completed in a year 1933 in State Engineering Enterprise Research Workshop. But airplane-building stage was never reached. Airplane gasoline BAB (Benzol-alcohol-gasoline) was used as fuel and was delivered by doc. Mielnikowa (private author talks with professor Jan Oderfeld). The first jet-powered airplane flight was performed by Germans in a year of 1939, in Heinkel HE 178 airplane, outfitting Britons, who repeated this achievement two years later, 15th of May, 1941 on Gloster Meteor airplane from Gloster Aircraft Company powered by W1-Pionier engine. As fuels for the first flight – gasoline
was used in Heinkel HE 178 and kerosene in W1-Pionier. Use of gasoline as jet fuel resulted in fact, that Germans does not widened development of the jet engine program in its beginning phase. Several fuel mixtures were tested, including gasoline - fuel oil mixture, searching for the best solution. Interesting is the fuel oil usage (several authors refer to multi fuel usage, and are probably correct, considering fuel shortage at the war’s end) in first jet fighter airplanes, type Me 262, which arrived at combat theater in last phase of war, from July of 1944. However, they used plenty of fuel, supply of which lasted only for 40 minutes of flight. Engines were very prone to malfunctions. Shortly after the war, the first jet fuel JP-1 (jet propellant) with good properties for jet engines arrived at the market. Successive events in fuel and engine development revolutionized world aviation. Arms Race has started. New fuels arrived, as: JP-1, JP-2, JP-3 till JP-8 and their Russian counterparts, as: TS-1 and RT, according to GOST 102227. Currently, turbine jet engines and special fuels for them dominate in aviation. Demand for them raised explosively at the beginning of the sixties decade. Piston engines were passed to the general aviation niche at this moment. Fuel quality stabilized at the fuel market, but it is disrupted by still rising world jet fuel consumption, reaching 4% yearly increase. Inevitably, fuel crisis arrives, and new fuel era arrives with him.

**FUELS FOR PISTON ENGINES**

Currently, basic fuel assortment for spark ignition aviation engines includes 3 grades of gasoline, determined in trade by color, respectively:
- Leadless 80 (Avgas 80) color red
- Lowlead 100LL (Avgas 100 LL) color blue
- Lead – 100 (Avgas 100) color green

Basic gasoline properties and normative documents are stated in table below:

<table>
<thead>
<tr>
<th>Properties</th>
<th>Aviation gasoline grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80</td>
</tr>
<tr>
<td>RON octane number, minimum</td>
<td>80</td>
</tr>
<tr>
<td>Antiknock property for rich mixture</td>
<td>87</td>
</tr>
<tr>
<td>Tetra-ethyl lead in g Pb/liter</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Requirements
- **Poland** NO-91-A235
- **USA** ASTM D910
- **France** AIR 340/1
- **Great Britain (Joint Service Designations)**: AVGAS 80, AVGAS 100LL, AVGAS 100
- **NATO Code** F18

In Poland, aviation gasoline 100LL is used, produced in OBR Płock or imported by the Total firm. Usage of F 44 fuel in the limited range is performed. Use of F 44 fuel in the limited range is anticipated.

**FUELS FOR TURBINE ENGINES**

For jet turbine engines, fuels are classified according to:
- Civil aviation fuels, according to IATA: JetA-1, Jet A, Jet B
- Military aviation fuels, according to NATO and Stanag 3747 Codes, respectively: F-35, F-34 (JP8), F 40, F44

Jet A fuel is used mainly in USA, replacing Jet A-1 fuel. It differs by crystallization temperature (-40°C), similarly to Jet B fuel, used mainly in USA and Canada, instead of Jet A/Jet A-1 fuels. In Poland, fuels Jet A-1, F 35, F 34 are used, produced in Plock and Gdansk Refineries or offered by TOTAL firm. Usage of F 44 fuel in the limited range is anticipated.

Basic fuel properties are given in the table below.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Fuel grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density kg/m³</td>
<td>Jet A-1, F 35, F 34, F 44</td>
</tr>
<tr>
<td>Heating value MJ/kg</td>
<td>775 - 840, 788 - 845</td>
</tr>
<tr>
<td>Heating value MJ/kg</td>
<td>&gt;42,8, 42,5</td>
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<tr>
<td>Aromatic content % mass</td>
<td>&lt;25,0</td>
</tr>
<tr>
<td>Olefin content % mass</td>
<td>&lt;5,8</td>
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<tr>
<td>Sulphur content % mass</td>
<td>&lt;0,3</td>
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<tr>
<td>Merkaptan sulphur content %</td>
<td>&lt;0,003</td>
</tr>
<tr>
<td>Gum, existent, max mg/100 ml</td>
<td>&lt;7,0</td>
</tr>
<tr>
<td>Freezing point °C</td>
<td>-47, -46</td>
</tr>
</tbody>
</table>

**THE SEARCH FOR NEW FUELS**

Future of the aviation fuels was used to be defined according to the two strategies:
- **Evolutionary**
- **Revolutionary**

Those two strategies exist, in principle, from the beginning of the aviation engine era, in dependence from the long range trend, which is based on the fuel production sources. It should be remembered, that Otto-cycle engine started as gas fueled engine, and Diesel engine started as biofuel engine using peanut oil fuel. Cheaper and cheaper and also handier fuels distilled from the crude oil created unbelievable development of these fuels.

Currently, no one questions that a World resources for cheap oil are diminishing. Fuel usage rises about 2.9% yearly. Maximum of world oil mining is predicted for a year 2020. Dependence from oil import of two most important world economies: USA and Europe is rising, too. In a year of 2002 ENS from 11.09.2002 estimated USA dependence for 50% and Europe for 70%. It should be expected that this value will rise in 2020 to 90% as Loyola de Pallacio, EU Commissioner for Energy and Transport prognosticated. QinetiQ firm estimated respective dependency for fuel import on 65% for USA and 75% for Europe. It may be added, that there is a constant dependency for oil import equal 100% for Japan and 95% for Poland. Whole World demand for various energy carriers is increasing – according to the International Energy Outlook 2002 in a year’s 1999-2020 it will reach value of 60%. Crude oil meets currently 40% of world demand for fuel, coal drops from 28% to 20%. Rise of natural gas consumption from 23% to 29% in 2020 is expected. Nuclear energy production is stabilized. Demand for renewable energy carriers rises rapidly – it is estimated that it will rise by 53% till year 2020. Pessimistic scenario assumes end of the cheap oil in a year of 2010, optimistic scenario assumes year 2040. Because of that, one searches for synthetic fuels and biofuels whether new glance at fuels of biological origin – biofuels excite great expectations. USA lead’s the way in implementation of biofuels in national economy, because fuel sovereignty is seen from...
strategic reasons. 25th of April 2002 Senate approved so called Senate Energy Bill, containing several parliamentary initiatives, referring to wide promotion of biofuels. Information’s about various biofuel applications as energy source in aviation engines are coming mainly from USA. In eighties decade of the XX century, Bellanca 8KCAB Decathlon airplane, fuelled by ethanol with 10% water contents flew for the first time transcontinental to Brazil. In Baylor University Centre of Renewable Fuels Development modification of the Lycoming O–235 aviation engine for ethanol E95 with 5% water content fuelling and meeting all FAA requirements was made, as a result of 13 year long research program. Also Cessna 152 airplane was prepared for certification with this engine. Mixtures of gasoline with 10% ethanol were also tested on 5 airplanes. Certification requirements are included in Federal Air Regulations, Part 33. Underscoring possibilities of safe usage of biofuel in aviation, 25th of September 1989 the first transatlantic flight, fuelled with pure ethanol was made, starting in Waco, Texas and ending in Paris. Popular „Velocity” composite structure airplane was prepared for this flight with Lycoming HIO-360 engine in which compression ratio was raised, according to ethanol requirements. Dr Max Shauck, head of the Centre for the Development of the Aviation Renewable Fuels at Baylor University was the pilot, and he was awarded for that flight with fourth successive prestigious aviation award: „Harmon Trophy”, the first award in history went to Charles Lindbergh! Interesting is the fact, that fuel cost for a whole transatlantic flight was equal to $160. If the gasoline was used instead, fuel cost will be $230. During engine tests, engine time between overhauls – TBO was lengthened almost twice, was notified. Version of the same engine, but fuelled with classic leaded aviation fuel (so called Avgas) is used on composite airplane I-23 „Manager”, developed at Institute of Aviation. In case of HIO 360 engine, contact was made with Lycoming firm and Dr. Max Shauck. Dr Max Shauck (called also Mad Max) visited Institute of Aviation. Research performed at Baylor University also considered use of biofuels in turbine engines. This research considered esters received from rape or soy oil (Biodiesel B100), ETBE ether and ethanol (in low percentage) mixed with aviation Jet-A fuel. Biodiesel 5, 10, 15, 20 and 25 % mixes were used. In exhaust, CO₂, CO, O₂, HC, NOx and SO₂ percentage was measured. Drop of NOx emissions from 90 to 60 PPMV in cruise speed conditions and drop of HC emissions from 330 PPMV to 260 PPMV during idle was measured. Solid particle emissions were not measured. (Actual aviation rules do not regulate maximum rates of engine exhaust toxic emissions). It was found (considering cost of biofuels), that greatest benefits occur with JetA fuel and 20% Biodiesel additive. Beechcraft King Air 90 flight-tests with 20/80-fuel blend does not disclosed pilots perceptible differences (performance, fuel consumption!). Lack of the smoke marks on upper wing surfaces behind PT6 engine exhaust can be seen! Also preliminary tests of B100 mixtures with ethanol and ETBE were performed, material problems were notified. Because of the quantity of aviation fuel burned in turbine engines, and in near future in aviation Diesel engines, Baylor University considers that this fact will have significant meaning for biofuels production. In 6 Framework Programme of EU Aeronet network was involved in that issue, and in those tasks Institute of Aviation was also involved. In Europe, research on synthetic fuels aiming at the leaded fuel elimination was performed in Sweden, by HjemeCo. firm.

In a year of 2003 it encloses grades Avgas 91/96 UL, Avgas 80/87 UL and Avgas 82 UL. The first two grades meet aviation fuel requirements; the third one is a re-certificated grade of automotive fuel. Avgas 91/96 UL has minimum octane number equal 96 with rich mixture and 91 with lean mixture, not containing tetra-ethyl lead. It is made in unique production process from proper grade of crude oil with synthetic, nontoxic tetra-ethyl lead substitution additive. Those fuels are used only in Sweden and are suitable to use for about 70% of all piston engines, mainly in engines with power not exceeding 350HP power. First engine of such power (Lycoming TIO 540-J2BD) with computerized ignition system PRISM is barely tested. In USA leadless fuel Grade 82 UL exists, according to D 6227, Standard Specification for grade 82 Unleaded Aviation Gasoline, but it is not available for sale. Aviation fuels type MOGAS (modified leadless automotive fuels) may be used on several types of airplane engines, not stressed and with power output not exceeding 150 HP. They received certificates, called Supplemental Type Certification for 11 engine types and 16 airplane structures. In Germany, those certificates embrace 57% of airplane types. On whole world, 57000 airplanes use this type of fuel. In Europe 600 certificates STC were issued, including such countries as Switzerland, Austria, Germany, Greece, Netherland and Lithuania. TOTAL firm limits ethanol content in MOGAS fuel to 1% level, ROTAX firm accepts 5% ethanol in fuel, according to European Norm EN 228 and minimum octane number 93.

Contemporary aviation does not demise compression ignition engines, however Jet A-1 fuel is proposed for them. Several various designs were developed in Europe and in USA. Americans predict in their AGATE program that those engines will help them to dominate contemporary aviation market. Well known Continental firm has great success here, together with a new Delta Hawk firm, newly created especially for Diesel engine production, visited on site by author of this paper during his short stay in USA. Those engines are not certified yet, although airplanes with Diesel engines performed their first flights. Recently, American Continental firm contacted Japanese Honda firm to develop jointly a new generation of Diesel engines for aviation. In Europe, automotive engine designs were adopted and modified to aviation compression ignition engine standards (several Thielert firm designs using Mercedes engine parts and Morane Renault, based on Renault F1 race designs). Other aviation fuel and engine concepts are based on fuel cell hydrogen combustion producing electricity to power an electric engine or direct hydrogen combustion in aircraft turbine engines. Boeing firm is the most advanced organization in fuel cells aviation applications, acting globally and entering mostly retarded Europe through Madrid’s Research and Technology Centre is testing in flight small composite single engine airplane, called Low Emission Air Vehicle. Other American research groups joined in Advanced Technology Products are working on fuel cells at American Gihles Aircraft of Dijon on E-Plane airplane, build on the basis of DynAero Lafayette III airplane. It is predicted that future fuel cells will be powered with methanol, ethanol or even esters.
Several consortia’s are working at hydrogen as aviation fuel. It seems that although unsurpassed hydrogen successes as automotive fuel, for using hydrogen in aviation much more engineering efforts should be spent. First work was performed in USA at the year 1937 by Pratt & Whitney, next wave of interest come in 1956-1958 (Pratt & Whitney J57 engine) 1957 (Boeing, B57) 1970 (General Electric and NASA), 1988 (TU-154), 1990 (Airbus, APU engine A321) and 2000 (EC-project CRYOPLANE). It seems, that traditional aviation fuels will be dominating till 2050 year, supplemented by biofuels and synthetic fuels, also developed from vegetable sources and other, not previously utilized sources like wood, heavy oils and oil shale. It refers both to the light fuels for spark ignition internal combustion engines (alcohols, esters) and to the heavy fuels for compression ignition engines (vegetable oil esters). Problem is still open in turbine engines, they are multifuel in principle. Leading world engine manufacturers are performing intensive and outspread research, they are considering JP 11 as the fuel of the future (names JP-9 and JP-10 are reserved for air launched cruise missiles fuels). Important property of this fuel is the very high thermal stability. Mach 4 and higher airplanes demand endothermic fuels, calming fuel degradation reactions when fuel absorbs heat coming from aerodynamic friction and wing surface (being simultaneously integral fuel tank surface) reaches temperature of 400 degrees centigrade. Future of fuel modifications for specified tasks turbine engines will be decided by modification costs, engine performance changes, exploitation properties and fuel stability.

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Zbigniew Pagowski
PALIWA W SILNIKACH LOTNICZYCH

Streszczenie
Artykuł przedstawia zakres problemów dotyczących rozwoju paliw lotniczych. Rys historyczny paliw lotniczych, począwszy od pierwszego lotu braci Wright w 1903 roku, poprzez czasy pierwszej i drugiej wojen światowych wpływają nas w czasy współczesne samolotów tłokowych i turbinowych wymagających paliw o wysokich osiągach. Autor przedstawia skład i osiągi współczesnych paliw, przeходząc w ostatniej części artykułu do możliwości rozwoju paliw lotniczych w XXI wieku, zarówno ze względu na rozwój napędów lotniczych i ze względu na wzrost zainteresowania odnawialnymi źródłami energii i ich wykorzystaniu w lotnictwie.

Zбігніве Понговски
ТОПЛИВА АВІАЦІЙНИХ ДВИГАТЕЛЕЙ

Резюме
В стате представлены проблемы касающиеся развития авиационных топлив. Описывается история развития авиационных топлив от первого полета братьев Райт в 1903 г, периода первой и второй мировой войны до современных поршневых и реактивных самолетов требующих топлив с высокими характеристиками. Автор описывает состав и характеристики современных топлив, представляет возможности развития авиационных топлив в XXI в., так с точки зрения развития авиационных двигателей как и роста заинтересованности обнавляемыми источниками энергии и их использованием в авиации.