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Heavy fuel engines (HFE)

The principle of work and chosen examples of construction of SI engines assigned to feeding with aviation fuel (Heavy Fuel Engines – HFE) have been presented in article. Contemporary solutions of HFE combustion system constitute the development of patent of Australian firm Orbital working on two-stroke SI engines. Engines of HF type, characterized by low weight and low value of specific fuel consumption are applied among the others to propulsion of drones (Unmanned Aerial Vehicles – UAV), where essential parameters are range and endurance. That is also a practical realization of military logistical concept of "single fuel in the battlefield".

Key words: *drones, Unmanned Aerial Vehicle, aviation kerosene, SI engine, Jet A, JP-5, JP-8, heavy fuel engines, HFE*

Silniki ZI zasilane paliwem lotniczym

W artykule przedstawiono zasadę działania i wybrane przykłady konstrukcji silników z zapłonem iskrowym przewidzianych do zasilania paliwem lotniczym na bazie nafty, tzw. HFE (Heavy Fuel Engines). Współczesne rozwiązania systemu spalania HFE stanowią rozwinięcie patentu znanej australijskiej firmy Orbital zajmującej się silnikami dwusuwowymi ZI. Silniki tego typu charakteryzujące się małą masą i małą wartością jednostkowego zużycia paliwa stosowane są między innymi do napędu współczesnych dronów, gdzie istotnymi parametrami są zasięg i długotrwałość lotu. Jest to również praktyczna realizacja wojskowej logistycznej koncepcji wykorzystania jednego typu paliwa do wszystkich pojazdów.

Słowa kluczowe: *drony, nafta lotnicza, Jet A, JP-5, JP-8, silnik ZI*

1. Introduction

The development of small Unmanned Aerial Vehicles (UAVs, drones) caused the demand of lightweight, efficient and reliable engines that burn "heavy fuel" i.e. kerosene-based fuel like JP-5, JP-8 or Jet-A1. The reason is striving for support the Army's "single fuel in the battlefield" concept. That idea concerned with logistics and safety is not new but nowadays the technical conditions enable practical application of such solution. The name Heavy Fuel Engines (HFE) relates contemporary to the spark ignited (SI) engines assigned to feeding with aviation fuel, mainly of JP-8 or Jet-A1 type. Usually HF engines are multi-fuel ones working on wide range of fuels from petrol to Jet-A1 or diesel. The choice of two-stroke SI engines as the propulsion source of small UAVs results from its simple construction and low weight enabling the good power to weight ratio what is essential for aircraft. Unfortunately, application of the HF combustion system to mentioned above engines leads to much more complicated design. The fuel unification concept is, however the most important matter for the military.

Combustion systems of particular HF engines are generally based on the Australian firm Orbital patent what has been developing for many years and known nowadays as the Air Assisted Direct Injection (AADI). Orbital works essentially on two-stroke engines combustion system but recently on four-stroke engines too.

The specialized engines for propulsion of drones (UAVs) are manufactured usually by firms that have experience in aircraft model-making or recreational aviation and well known to modellers or experimental aviation enthusiasts.

The principle of work of HFE combustion system and chosen examples of application of that idea to engines for small drones propulsion are presented below.

2. Orbital's Air Assisted Direct Fuel Injection (AADI)

Orbital developed and patented the two-stroke and recently also four-stroke AADI engines combustion system. This technology is utilized among the others in the outboard engines by the Orbital licence holders, such as Mercury Marine, Tohatsu or Aprilia. There are also known many applications of that patent to water or snow scooters. In these cases AADI applications are all done exclusively within the area gasoline two-stroke engines. Orbital however, applied that system to the family of own developed FlexDI engines that enable to burn different fuels including aviation kerosene-based fuel, LPG or CNG.

The schematic diagram of AADI system is presented in figure 1. There are two main circuits in that system: fuel supply and air supply. Fuel is pumped from a tank by a pump providing the pressure of about 6 bar. The air compressed to the similar value 6 bar is delivered by a mechanically driven piston compressor. Both mediums meet in the air-fuel injector unit, what is the essential part of the system. The entire device together with ignition system is controlled by use of ECU. The cross section of Orbital Air Assisted Direct Fuel Injector of I generation is shown in the figure 2.

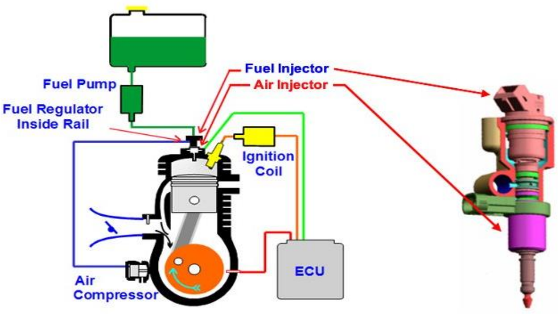

Fig. 1. Schematic diagram of Air Assisted Direct Injection (AADI) system [1]
Rys. 1. Schemat pneumatycznego systemu bezpośredniego wtrysku paliwa (AADI) [1]

Fig.2. Orbital I generation Air Assisted Direct Fuel Injector - cross section [2]
Rys.2. Przekrój wtryskiwacza I generacji systemu AADI [2]

The conventional fuel injector taken from petrol MPI system is used to meter precisely the defined dose of fuel into the interface chamber between the metering injector and the direct injector. The interface chamber links the compressed fuel circuit and the compressed air circuit. A mixture of air and fuel is then injected directly into the combustion chamber with use of direct injector. This injector, presented in the figure 3, is described by patent authors as a charge injector [2], [3].

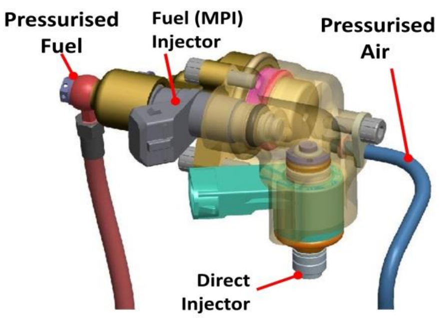

Fig. 3. Contemporary air-fuel mixture injector unit of AADI system [3]
Rys. 3. Współczesny zespół wtryskiwacza systemu bezpośredniego wtrysku paliwa AADI [3]

The injected air-fuel mixture ignites from the spark afterwards providing possibility of stratified charge combustion [4]. The scheme of injection process is presented in the figure 4.

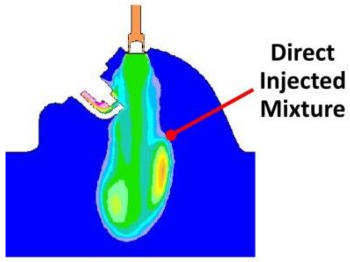

Fig. 4. Scheme of air-fuel mixture injection process implemented by AADI system [4]
Rys. 4. Schemat wtrysku mieszanki paliwowo-powietrznej realizowanego przez system AADI [4]

AADI system enables fuel to atomize perfectly preparing it for the combustion process. This air-assist injection atomizes the heavy fuel droplets down to 5-7 micron SMD, which is the result comparable to the gasoline spray characteristics and effects in possibility of efficient combustion of both kinds of fuels in SI engines equipped with the AADI system. The air pressure of the injection system is usually about 0,5 to 0,65 MPa. The fuel pressure is controlled with use of a pressure regulator with a reference relative to the air pressure, maintaining a constant pressure difference between 0,1 to 0,25 MPa.

The droplet size for a diesel fuel spray equals 6,8 micron SMD and for gasoline equals 5,7 micron SMD [5]. The comparison of spray shape of diesel and petrol fuels obtained with use of AADI system is shown in figure 4.

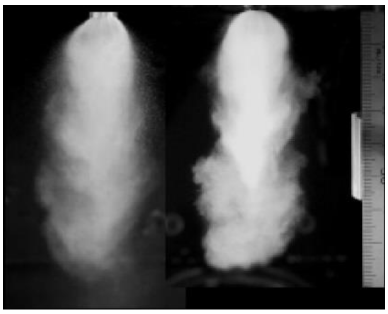

Fig. 5. Comparison of spray shape of diesel fuel (left) and petrol (right) obtained with use of AADI system [5]
Rys. 5. Porównanie kształtu strugi rozpylonego oleju napędowego (po lewej) i benzyny (po prawej) uzyskanego przy zastosowaniu systemu AADI [5]

Examples of the typical construction of cylinder head of ADDI system engine are presented in the figure 5. A possibility of arrangement of air-mixture direct injector inside a combustion chamber (cylinder head) is obtained due to the "compact" design of that injector. Even for the cases of four-stroke engines fitted with two and four valves there is usually enough space to place the direct injector in [5].

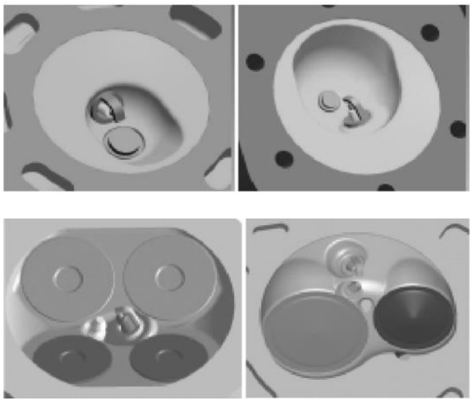

Fig. 6. Examples of the typical construction of cylinder head of ADDI system engine:
2-stroke (top), 4-stroke (bottom) [5]
Rys. 6. Przykłady typowej konstrukcji głowicy silnika z systemem AADI:
2-suwowego (u góry), 4-suwowego (u dołu) [5]

The example of practical realisation of AADI system in one of Orbital's FlexDI two-cylinder, two-stroke HFE engine is presented in the figure 7.

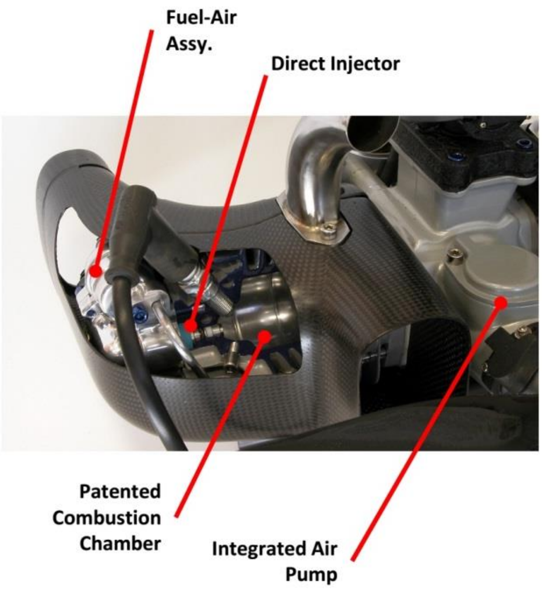

Fig. 7. AADI system components of Orbital FlexDI family engine [6]
Rys. 7. Elementy systemu AADI typoszeregu silników FlexDI firmy Orbital [6]

3. Sonex two-Stroke HFE technology

The American firm Sonex Research, Inc. developed own heavy fuel engine (HFE) technology and applied it to the conversion of single and multi-cylinder, lightweight, gasoline engines. This technical solution leads to the similar results of air-fuel making as Orbital's AADI system, but obtained in a thermal-chemical way.

Elaborated and patented Sonex Combustion System (SCS) is applied among the others to engines propelling the Scan Eagle UAV being in service for U.S. Navy and Australian Army.

Sonex Combustion System (SCS) together with also patented Cold Starting System (CSS) enable converted engines to start reliably in low temperature and work excellent, fed with heavy fuel (JP-5, JP-8, Jet-A1 or diesel). CSS consists of a heated fuel vaporizer and a combustion chamber insert performing a role of control module.

The SCS heavy fuel conversion of petrol engine maintains the original factory made systems, that is: intake and exhaust systems, fuel injection (or carburettor) system and spark ignition system. Lubrication principle remains the same – lubricant additive to all fuels. No modifications are made to the moving parts, including the piston what results in the retaining of original SI engine compression ratio. SI engines converted to HF feeding operate with knock-free combustion after ignition timing adjustment, producing no visible smoke.

The Sonex Combustion System components are presented in figure 8 [7]. The SCS consists of a cylinder head with combustion chamber insert (“combustion ring”) containing the proprietary SCS technology and a glow plug heating-starting system. Glow plug heater together with the combustion chamber insert (with patented micro-chambers) enables control of fuel vaporization at the end of the compression stroke in such a way that a portion of the heavy fuel is vaporized in the vicinity of the spark plug. This results in excellent preparation and then combustion of air-fuel mixture.

Fig. 8. SCS two-stoke HFE system components: combustion chamber insert (left), cylinder head with glow plug heater (middle), original factory made cylinder body (right) [7]
Rys. 8. Elementy systemu spalania Sonex dwusuwowego silnika HF: wkładka komory spalania (po lewej), głowica silnika ze świecą żarową (w środku), cylinder silnika (po prawej) [7]

The example of SCS applied to 3W240 HF engine is shown also in figure 9 where the combustion chamber ring insert (R) is visible.

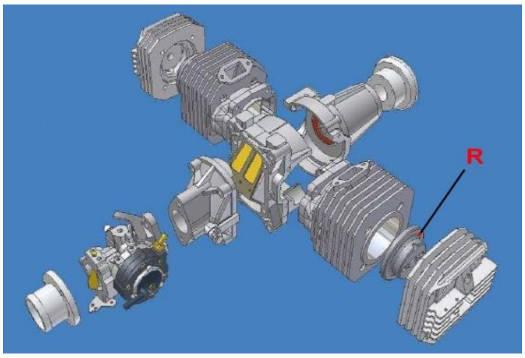

Fig. 9. SCS 3W240 HFE Assembly;
R — combustion chamber ring insert [8]
Rys. 9. Elementy uładu SCS silnika 3W240 HFE;
R — pierścieniowa wkładka komory spalania [8]

4. Examples of HFE technology application

4.1. Orbital UAV FlexDI

The example of Orbital two-stroke HF engines is presented in the figure 10. That is the representative of FlexDI 2-stroke boxer UAV engines family fitted with AADI system. The general specifications of these engines are shown in the table 1.

Fig. 10. Example of Orbital FlexDI two-stroke family engine [9]
Rys. 10. Przykład rodziny silników FlexDI firmy Orbital [9]

Table 1. Orbital FlexDI 2-stroke UAV engines family specifications [6]
Tabela 1. Specyfikacja rodziny dwusuwowych silników Orbital FlexDI przeznaczonych do napędu dronów [6]

Configuration	Single cylinder	2- cylinder boxer
Cooling system	air	air
Capacity range	35–85 cm3	70–500 cm3
Power range	1,8–3,7 kW	3,3–23 kW
Specific performance	0,62–0,92 kW/kg	0,60–1,61 kW/kg
SFC at cruise	330–310 g/kWh	340–300 g/kWh
TBO	250–500 h	300–500 h

4.2. Hirth-Orbital HF engines

The German firm Hirth is the manufacturer of among the others HF engines for UAVs. Hirth is the licensee of Orbital's Air Assisted Direct Fuel Injection (AADI) and uses this technology into its new engines. The U.S. distributor for Hirth aircraft engines RecPower together with Orbital's U.S. Representative are the suppliers of engines for propulsion of Northrop Grumman Bat UAV.

The interesting solution developed by Hirth for heavy fuel engines is the use of carbon (graphite) pistons applied to S1200HF and 3503HF engines. These pistons have practically zero thermal expansion that allow piston-to-cylinder wall clearances of 0.0005 compared with a typical 0.005 for aluminium pistons. The composite pistons are equipped with only two piston rings, being utilized for centring purposes only. Hirth carbon piston used in 3503 HF engine is presented in the figure 11.

Fig. 11. Carbon piston of Hirth S1200 HF and 3503 HF engines [10]
Rys. 11. Grafitowy tłok silników Hirth S1200 HF oraz 3503 HF [10]

Fig. 12. Hirth 3503 HF engine with 2 kW generator for UAV application — right side view [11]
Rys. 12. Silnik Hirth 3503 HF — widok z prawej strony [11]

Fig. 13. Hirth 3503 HF engine with 2 kW generator for UAV application — left side view [10]
Rys. 13. Silnik Hirth 3503 HF z generatorem o mocy 2 kW przeznaczony do napędu dronu — widok z lewej strony [10]

Table 2. Hirth 3503 HF engine specifications [11]
Tabela 2. Specyfikacja silnika Hirth 3503 HF zasilanego naftą lotniczą [11]

Type	Two-cylinder, two-stroke
Displacement	625 cm^3
Stroke	69 mm
Bore	76 mm
Max. Power	45 kW at 6500 rpm
Max. Torque	67,5 Nm at 6000 rpm
Mixture formation	AADI (Orbital system)
Ignition system	CDI programmable
Generator	2500 W, 20 amp, 12 volts
Cooling	Liquid cooling
Lubrication	Oil injection
Weight	30 kg with exhaust and coolant
Start device	Recoil starter
Direction	Counter clockwise, view to output shaft
Fuel	JP-5 / JP-8 / Jet-A1

Hirth S1200 HF engine is a two-stroke, two-cylinder-opposed engine, air-cooled, with air assisted direct fuel injection (AADI) system. For the more precise control of charge interchange a reed valve is applied. The engine is equipped, like the majority of engines of that type, with altitude and temperature compensation. That feature enables efficient work at an altitude above 5000 m and the reliable starting in a temperature range of -40 to +50°C.

That engine is destined for reconnaissance air vehicles and all other propeller driven UAVs. The example of S1200HF engine application as a propulsion unit of mentioned above Bat STUAV (Small Tactical Unmanned Aerial Vehicle), manufactured by Northrop Grumman.

The S1200 HF engine is presented in the figure 14, and its basic specifications are shown in the table 3.

Fig. 14. Hirth S1200 HF engine with AADI system [12]
Rys. 14. Silnik Hirth S1200 HF wyposażony w układ wtrysku paliwa AADI [12]

Table 3. Hirth S1200 HF engine specifications[12]
Tabela 3. Specyfikacja silnika Hirth S1200 HF zasilanego naftą lotniczą [12]

Type	Two cylinder two-stroke boxer
Displacement	130 cm^3
Stroke	37 mm
Bore	47 mm
Max. Power	10 kW at 6500 rpm
Control	Reed valve
Mixture formation	AADI (Orbital system), altitude and temperature compensation
Ignition system	CDI programmable
Cooling	Air cooling
Weight	4,5 kg with exhaust system
Length	145 mm
Width	240 mm
Direction	Clockwise, view to output shaft
Speed range	1800 – 6500 1/min
Fuel	JP-5 / JP-8 / Jet-A1
Lubrication	Oil injection

4.3. Ricardo Wolverine 3 HFE

Wolverine 3 HF engine is designed by Ricardo for lightweight UAVs. It is a 2,3 kW power, two-cylinder, two-stroke, air-cooled engine with spark ignition and direct fuel injection system elaborated by Ricardo. Lubrication is provided with use of oil injection. The pistons geometry with a proprietary crown shape, one-piece connecting rods with rolling-element big-end bearings and Nikasil-coated cylinder liners are the examples of high technology applied to that engine [14], [15].

The integrated 500W motor-generator is adapted by Ricardo from a medical-robotics application. It provides supplemental power to UAV and also enables the hybrid-electric aircraft to operate quietly in all-electric mode with use of batteries charged during former flight.

The front and rear view of Wolverine 3 are presented in figures 15 and 16. The engine was used for propulsion of Nightwind 2 UAV what is a blended-wing design with a 2-m wingspan, built by Unmanned Aerial Systems of Las Vegas [13]. The engine drives the pushing propeller directly without gear reduction at 6000 crankshaft rpm.

Basic specifications of the Wolverine 3 engine are presented in the table 4.

Fig. 15. Ricardo Wolverine 3 HF engine — front view [16]
Rys. 15. Silnik Ricardo Wolverine 3 HF — widok z przodu [16]

Fig. 16. Ricardo Wolverine 3 HF engine — rear view [17]
Rys. 16. Silnik Ricardo Wolverine 3 HF — widok z tyłu [17]

Table 4. Specifications of the Wolverine 3 HF engine [15]
Tabela 4. Specyfikacja silnika Wolverine 3 HF [15]

Type	Two-cylinder, Two-stroke
Cooling	Air
Power	2,3 kW (3,1 HP)
Displacement	88 cm^3
Max. Speed	6000 rpm
Ignition	Spark
Fuel Injection	Direct (Ricardo system)
Starting device	Starter/Generator 500W
Width	267 mm
Height	175 mm
Length	193 mm

4.4. XRDi Multiple Fuel Engines

XRD*i* firm working on light-weight, fuel efficient, low emission propulsion systems, developed the Multiple Fuel Engines (MFE) where the patented own technology of air-fuel mixture building (MCDI) has been applied [18]. This system results in the similar operation abilities of engine fed with heavy fuel as AADI, hence, MFE name is the equivalent of HFE name.

The spark ignited XRD*i* MFE can be fed with petrol or kerosene-based fuels as well as bio-diesel and ethanol.

The Mechanical Compression Direct Injection (MCDI) is the XRDi technology which provides a perfect atomization and high level of fuel charge stratification in the main combustion chamber.

The MCDI system makes use of a small compressor that is attached to each cylinder (one compressor to one cylinder) and injects the air-fuel mixture into the combustion chamber through a delivery valve. The excellent atomization of the fuel, including low evaporation (heavy) types of fuels, enables its reliable ignition and combustion at low ambient temperature. Besides, the MCDI system making a stratified charge by use of delivery valve mechanism eliminates a detonation phenomenon [x].

The examples of XRDi Multiple Fuel Engines are presented in figures 17 to 21 and the chosen corresponded specifications of engines in the tables 5 and 6.

Fig. 17. XRDi 75 cm^3 HF engine [19]
Rys. 17. Silnik XRDi 75 cm^3 HF [19]

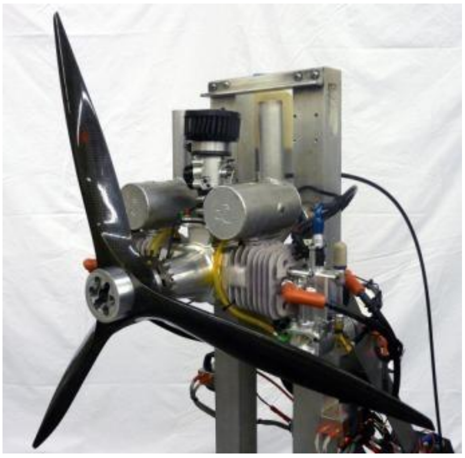

Fig. 18. XRDi 150 cm^3 HF engine on test stand [20]
Rys. 18. Silnik XRDi 150 cm^3 HF na stanowisku badawczym [20]

Fig. 19. XRDi 400 cm^3 HF engine [21]
Rys. 19. Silnik XRDi 400 cm^3 HF [21]

Fig. 20. XRDi 530 cm^3 HF engine [22]
Rys. 20. Silnik XRDi 530 cm^3 HF [22]

Table 5. XRDi 75 cm^3 engine specifications [19]
Tabela 5. Specyfikacja silnika XRDi 75 cm^3 [19]

Engine	75 cm^3
Type	Single cylinder
Displacement	75 cm³
Mixture Control	MCDI
Bore	49 mm
Stroke	40 mm
Power	4,4 kW
Ignition	Dual Plug ECU controlled
Cooling	Air or Liquid
Weight	2,86 kg
Speed Range	3000-7000 rpm
Fuel	Any US military grade fuel
Lubrication	Oil injection
Temperature Range	-30 °C to + 55 °C
Maturity Level	Available
Expected TBO	>150 hours

Table 6. XRDi 400 cm^3 engine specifications [21]
Tabela 6. Specyfikacja silnika XRDi 400 cm^3 [21]

Engine	400 cm^3
Type	Twin Cylinder
Displacement	400 cm³
Mixture Control	MCDI
Bore	65,15 mm
Stroke	60 mm
Power	25,7 kW at 7000 rpm
Ignition	Dual Plug ECU Controlled
Cooling	Liquid or Air
Weight	15 kg (with electronics)
Speed Range	4000-8000 rpm
Fuel	Any US military grade fuel
Lubrication	Oil injection
Temperature Range	-30 °C to + 55 °C
Maturity Level	Over 33 tested
Expected TBO	TBD

4.5. NW-44 EFI HFE engine

The NWUAV firm (Northwest UAV) was established in 2005 [23] to meet the growing demand for companies that utilize propulsion systems and components required in unmanned vehicles. The particular field of NWUAV interest is nowadays the development of HF engines fulfilling the mentioned army requirement of "single fuel on battlefield".

The NW-44 EFI HFE presented in the figures 21 to 23 is manufactured entirely in the USA to ensure the engine availability in the future what is a military logistic demand. That engine is dedicated to HALE (High Altitude Long Endurance) UAVs of weight less than 25 kg.

NWUAV developed and applied a patented Electronic Fuel Injection System to the NW-44 engine as well as the variable pitch propeller system what enables the UAV equipped with NW-44 EFI/HFE to enhance substantially its endurance. The NW-44 EFI HF engine with variable pitch propeller is presented in the figure 22.

Construction details are not available yet, however from the factory brochure one can find out the general information. The engine speed is controlled by use of a direct drive servo mounted to the throttle body. The air-fuel mixture is made by a micro atomizing fuel injector mounted inside the throttle body enabling heavy fuel operation with use of twin spark plugs fired by dual 25kV ignition coil. The ECU utilizes data from MAP, barometric, cylinder head and intake air temperature sensors. NW-44 EFI/HFE is also equipped with heavy fuel cold start system. The proprietary lightweight silencer (fig. 23) allows obtaining very low level of noise and hence small acoustic trace of UAV.

Table 7. NW-44 EFI/HFE engine specifications[26]
Tabela 7. Specyfikacja silnika NW-44 EFI/HFE [26]

Engine Core Weight	1,02 kg
Complete System Weight	~4,3 kg
Displacement	43.6 cm^3
Bore	38.99 mm
Stroke	36.53 mm
Max Power at 8150 RPM	3 kW
Max Torque	3,8 Nm
Max Generator Power at 4500 RPM	250 W
Configurable Generator Outputs	6 / 12 / 28 VDC
Fuel System	Electronic Fuel Injection
Fuel Type	Petrol / JP-5 / JP-8 / JetA1
Ignition	Twin 25kV CDI
Cooling / ServoTemp. Controlled	Air
TBO	up to 500 h

Fig. 21. NW-44 EFI HFE engine; basic configuration [27]
Rys. 21. Silnik NW-44 EFI HFE; wersja podstawowa [27]

Fig. 22. NW-44 EFI HFE engine with variable pitch propeller system [24]
Rys. 22. Silnik NW-44 EFI HFE z układem regulacji skoku śmigła [24]

Fig. 23. NW-44 EFI HFE engine; configuration with special silencer[25]
Rys. 23. Silnik NW-44 EFI HFE; wersja ze specjalnym tłumikiem wydechu [25]

4.6. Rotron HF rotary engines

The British firm Rotron Power Ltd [27] established in 2008 is a manufacturer of series of types of SI advanced rotary propulsion systems for Unmanned Aerial Vehicles, both petrol and heavy fuel fed. The Rotron light-weight HF rotary (Wankel) engines utilise special fuel supply techniques to achieve reliable starting under the different operating conditions (temperature). Application of rotary engine concept enables to obtain a high power to weight ratio and relatively low fuel consumption what is the basic demand of the military drones market.

Rotron offers two models of rotary heavy fuel engines: single rotor RT300 HFE (presented in fig. 24) and twin rotor RT600 HFE (presented in fig. 25) what differ in a displacement and consequent performance [28]. Specifications of these engines are presented in tables 8 and 9. All manufactured engines might be "custom tailored" and equipped optionally with onboard starter system.

Fig. 24. Rotron RT300 HFE rotary engine [29]
Rys. 24. Silnik Rotron RT300 HFE (Wankel) [29]

Table 8. Rotron RT300 HFE specifications [29]
Tabela 8. Specyfikacja silnika Rotron RT300 HFE [29]

Engine type	Single rotor, SI
Max. power	22,8 kW at 7500 rpm
Max. cont. power	20,6 kW at 6500 rpm
Max. torque	30,6 Nm at 6500 rpm
Power/weight ratio	1,84 kW/kg
Displacement	300 cm^3
Block weight	12,3 kg (core block only)
Starting device	External / Onboard[1)]
Compression ratio	8,5:1
Cooling	Liquid
Fuel type	JP-5 / JP-8 / Jet A1
Fuel consumption	353 g/kWh at 6000 rpm cruise
Min/max ambient temp.	-20 to 50 ^oC
Generator	300W / Starter generator[1)]
Additional features	ECU altitude compensation

[1)] Onboard starter (1kW to 5kW) optional

Fig. 25. Rotron RT600 HFE rotary engine [30]
Rys. 25. Silnik Rotron RT600 HFE (Wankel) [30]

Table 9. Rotron RT600 HFE specifications [30]
Tabela 9. Specyfikacja silnika Rotron RT600 HFE [30]

Engine type	Twin rotor, SI
Max. power	41,2 kW at 7500 rpm
Max. cont. power	38,3 kW at 6500 rpm
Max. torque	56,9 Nm at 6500 rpm
Power/weight Ratio	1,91 kW/kg
Displacement	600 cm^3
Block weight	21,2 kg (core block only)
Starting Device	External / Onboard[1)]
Compression Ratio	8,5:1
Cooling	Liquid
Fuel Type	JP-5 / JP-8 / Jet-A1
Fuel Consumption	408 g/kWh (at 6000 rpm cruise)
Min/max ambient temp.	-20 to 50 ^{o}C
Generator	300W / Starter generator[1)]
Additional Features	ECU Altitude compensation

[1)] Onboard starter (1kW to 5kW) optional

5. Conclusions

In recent years, drones have proven their value, not only due to their military but also civil applications in many areas of everyday life. That is a reason why aviation industry is more and more interested in the high efficiency sources of drones' propulsion. It is assessed that nowadays the current global UAV expenditure is more than 6 milliards of dollars per year with permanent growing tendency.

Special interest of contemporary drones' designers is paid to the HF SI engines. Despite of former prediction of jet engines as the only propulsion units, the piston engines seem to revive once again. This time their development is caused by two requirements: military demand of single fuel on battlefield and aspiration to achieve a better efficiency effecting in UAV's flight endurance.

Nomenclature / *Skróty i oznaczenia*

UAV Unmanned Aerial Vehicle / *bezzałogowy pojazd powietrzny*
HALE High Altitude Long Endurance / *długotrwały (lot) na dużej wysokości*
HFE Heavy Fuel Engine / *silnik zasilany paliwem naftopochodnym („ciężkim”)*
AADI Air Assisted Direct Injection / *pneumatyczny wtrysk bezpośredni*
SMD Sauter Mean Diameter / *średnia średnica Sautera*
SFC Specific Fuel Consumption / *jednostkowe zużycie paliwa*
SCS Sonex Combustion System / *system spalania Sonex*
CSS Cold Starting System / *układ zimnego rozruchu*
MFE Multiple Fuel Engines / *silniki wielopaliwowe*
MCDI Mechanically Compressed Direct Injection / mechaniczny wtrysk paliwa
TBO Time Between Overhauls / okres miedzynaprawczy (resurs)

Bibliography/*Literatura*

[1] Lightweight Heavy Fuel Engines. Hirth-Orbital brochure, 2013.
[2] Schmidt B., Lightweight Heavy Fuel Engine Technology. Orbital Presentation, 2014.
[3] Innovative UAV Heavy Fuel Engine Technology. Orbital Brochure, 2013.
[4] Orbital Heavy Fuel Engine Technology. Orbital Brochure, 2013.
[5] Cathcart G., Dickson G., Ahern S., The application of Air-Assist Direct Injection for Spark-ignited Heavy Fuel 2-Stroke and 4-Stroke Engines. SAE Japan, no. 2005-32-0065

[6] www.orbitalcorp.com.au/369-orbitals-suas-engines-and-technologies/file.html. (accessed 10-03-2015)

[7] www.sonexresearch.com/2-Stroke.htm. (accessed 26-02-2015)

[8] Pouring A., Heavy Fuel Engines for Small UAVs, NMIA UAS Conference, San Diego 2008. Sonex Research, Inc.

[9] www.unmannedsystemstechnology.com/company/orbital-corporation (accessed 08-03-2015)

[10] www.eaa.org/experimenter/articles/2009-12_fuel.asp. (accessed 16-04-2014)

[11] www.hirth-engines.de, Hirth 3503 HF engine Brochure. (accessed 19-02-2014)

[12] www.hirth-engines.de, Information S1200 Heavy Fuel. (accessed 16-04-2014)

[13] Brooke. L., Secrets of Ricardo's new UAV engine may spawn range-extender for EVs. articles.sae.org/8424/ (accessed 20-02-2015)

[14] www.ricardo.com/en-GB/News-Media/Press-releases/News-releases1/2010/Ricardo-announces-new-Wolverine-family-of-engines-for-Unmanned-Aerial-Vehicles-UAVs. (accessed 10-03-2015)

[15] www.aviationweek.com/UserProfile.aspx?newspaperUserId=163197 (accessed 06-02-2014)

[16] www.ricardo.com/Global/IA/News/Press%20Release%20Listing%20images/2010%20download%20images/Wolverine%203%20UAV%20engine/Ricardo%20Wolverine%203%20UAV%20engine_front.jpg. (accessed 10-04-2015)

[17] www.ricardo.com/Global/IA/News/Press%20Release%20Listing%20images/2010%20download%20images/Wolverine%203%20UAV%20engine/Ricardo%20Wolverine%203%20UAV%20engine_back.jpg. (accessed 10-04-2015)

[18] www.xrdi.com. (accessed 06-03-2015)

[19] www.xrdi.com/75_hp_Engine.html. (accessed 10-03-2015)

[20] www.xrdi.com/12_hp_Engine.html. (accessed 10-03-2015)

[21] www.xrdi.com/35_hp_Engine.html. (accessed 10-03-2015)

[22] www.xrdi.com/105_hp_Engine.php. (accessed 10-03-2015)

[23] www.nwuav.com. (accessed 07-03-2015)

[24] www.nwuav.com/images/uav-engines/BilletEngine-219.jpg. (accessed 07-03-2015)

[25] www.nwuav.com/images/uav-engines/NW44-EFI-HFE-6690.jpg. (accessed 07-03-2015)

[26] Northwest UAV Introduces the COTS 44cc EFI/HFE at AUVSI 2013. The NW-44 EFI/HFE, Press Release, 2013.

[27] www.rotronuav.com. (accessed 15-03-2015)

[28] www.rotronuav.com/press/release/rotron-to-launch-heavy-fuel-engines-at-farnborough-2014. (accessed 15-03-2015)

[29] www.rotronuav.com/engines/rt-300hfe. (accessed 11-03-2015)

[30] www.rotronuav.com/engines/rt-600hfe. (accessed 11-03-2015)

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