ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2834

ELECTRIC ENERGY BALANCE OF THE ROTAX 912 WITH FUEL INJECTION

Krzysztof Skiba, Jacek Czarnigowski

Lublin University of Technology
Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems
Nadbystrzycka Street 36, 20-618 Lublin, Poland
tel.: +48 81 5384764, fax: +48 815384749
e-mail: k.skiba@pollub.pl, j.czarnigowski@pollub.pl

Tomasz Zyska

Lublin University of Technology
Institute of Electronics and Information Technology
Nadbystrzycka Street 38A, 20-618 Lublin, Poland
tel.: +48 81 5384309, fax: +48 81 5384312
e-mail: t.zyska@pollub.pl

Abstract

A majority of ultralight aircraft is powered by the Rotax 912 ULS, which is a four-cylinder carburettor piston SI boxer engine. However, its power-to-power advanced aircraft is insufficient. This article discusses the examination of the Rotax 912 fitted with a modified power system and mechanical charging to increase the power of a base unit by 36%. This engine was developed as a collaborated project of the Lublin University of Technology and the AVIATION ARTUR TRENDAK & SON GmbH, a manufacturer of autogyros. Sources of energy in the Rotax 912 are generated with a generator integrated with an ignition system of a maximum power of 250 W at 5800 rpm and 13.5 V [1]. The technology of fuel injection and charging required us to apply control systems and to measure engine-operating parameters, which resulted in higher electric energy demand. Additionally, a mechanical pump was replaced with a more efficient electric pump, which also changed electric energy balance. The examination was conducted on the test stand of the Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems of the Lublin University of Technology. The measurement system consisted of the Tektronix TCP305 current probes and TCP A300 converters. Signals were recorded with data acquisition cards and the National Instruments Ni CompaktDAQ module. Power consumption was measured for the selected speed ranging from 2000 to 5800 rpm. The current probes were appropriately installed on power cords. The probes recorded respectively the power consumed by the fuel pump, the energy demand of the lambda sensor, and the electricity taken by the ECU. The data obtained was converted with the author's script in LabVIEW. Based on the results, the highest electricity demand shows the fuel pump. Furthermore, increasing engine speed and load results in higher pressure in the fuel system and consequently in the higher power demand of the pump. The pump consumes up to 89% of all energy consumed by the system. In the control system, the highest demand shows lambda sensor BOSCH LSU4.2 [4]. With the increase in speed, the exhaust gas temperature increases, which leads to less power consumed by the heater of the sensor head. The demand of the other measurement systems and actuators is less than 10.6% of total consumption. The investigation shows that the total power demand of this new system ranges from 63 to 73 W, which is from 24 to 70% of the total power output from a generator mounted on the engine.

Keywords: *electric energy balance, air transport, combustion engines, transport*

1. Introduction

Air transport is one of the most universal means and methods to transport people and cargo. It is now one of the most dynamically developing field of transportation. New technologies make flights safer and more economical. The private sector is also increasingly interested in air transport. From year to year, there are more and more civil aircraft in use and aircraft pilot licences issued. The current tendency is safe ultralight aircraft that could be beginner- and inexperienced pilot-friendly. Manufacturers therefore seek to create comfortable and economic structures with advanced aircraft technologies to support the pilot. This solution requires numerous electronic control systems, on-board monitoring during flight and new powertrains.

The basic power unit used in most ultralight aircraft is the Rotax 912 ULS – a four-cylinder spark ignition piston boxer engine with carburettors. Its power is 73.5 kW and torque 128 Nm. This engine shows, however, the inadequate strength-to-propulsion ratio as a new type of aircraft. The collaboration of Lublin University of Technology and Aviation Arthur Trendak Company, the producer of autogyros, focused on the modification of the Rotax 912.

The result of this cooperation is a new system showing increased power of the base unit by 36% by applying a supercharger and replacing a carburettor with a new electronically controlled fuel injection system. The technology of fuel injection and a compressor was applied to replace a mechanical fuel pump with a set of more efficient electric pumps as well as with applying control systems and the measurement of engine parameters. Most of these devices depend on electricity to work. The elements applied in a new system and their electronic specification, provided by the producer, is given in Tab. 1.

Tab. 1. Catalogue of power demanded by the fuel injection system

Fuel injector kit	Electric power [W]
Fuel pump BOSCH 044	120.00
Lambda Sensor LSU 4.2	10.00
Injector Edelbrock Pico Fuel Injector 3583	9.60
Throttle position sensor BEI Duncan 9851	0.15
Hall effect gear tooth sensor Honeywell 1GT101DC	0.12
Air temperature sensor KTY 19-6M	0.12
Coolant temperature sensor KTY 19-6M	0.12
Engine Control Unit ROTAX ECU V01	0.10
Air pressure Honeywell PX2JG2250KA	0.066
Fuel Pressure Sensor Honeywell PX2AG110BAA	0.066
TOTAL	140.342

At the design stage, components that meet design requirements and are energy efficient are considered only in spite of the fact that the theoretical aggregate demand of the new system amounts to 140.342 W. The source of electric energy for the Rotax 912 is a generator integrated with the ignition system of a maximum power of 283 W at a speed of 5,800 rpm. It should be remembered that a glass cockpit, trimmers, a VHF radio, a transponder, a fuel level gauge are powered by this generator. Given the deficit of on-board electric energy, the consumption of electric energy by this new system was studied.

2. Test bench and research results

The research was carried out on an engine test bench at the Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems at Lublin University of Technology – Fig 1. The ATX 200 test bench enables the measurement of engine parameters under steady state and the load conditions.

The measurement system consisted of the Tektronix TCP305 current probes and TCP A300 converters. Signals were recorded with data acquisition cards and the National Instruments NI CompaktDAQ-9184 module (Fig. 2). The data obtained was converted with the author's script in LabVIEW. The fuel injection was being controlled with an electronic driver based on information

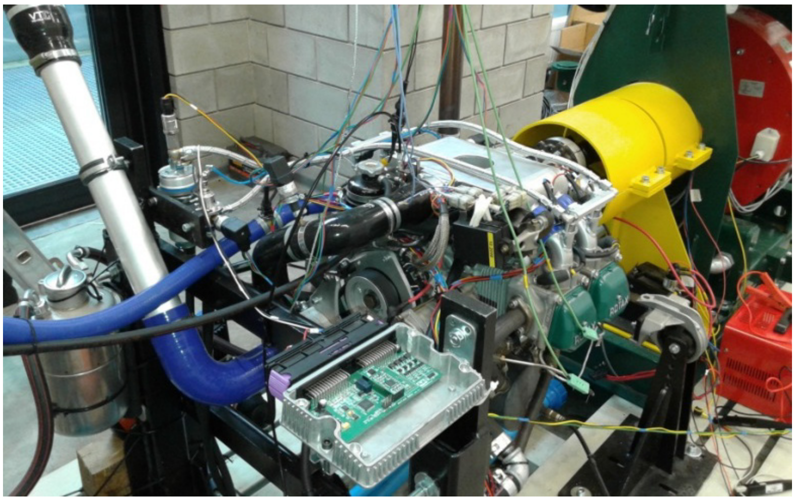

Fig. 1. Test bench to measure electric energy consumption by the Rotax 912

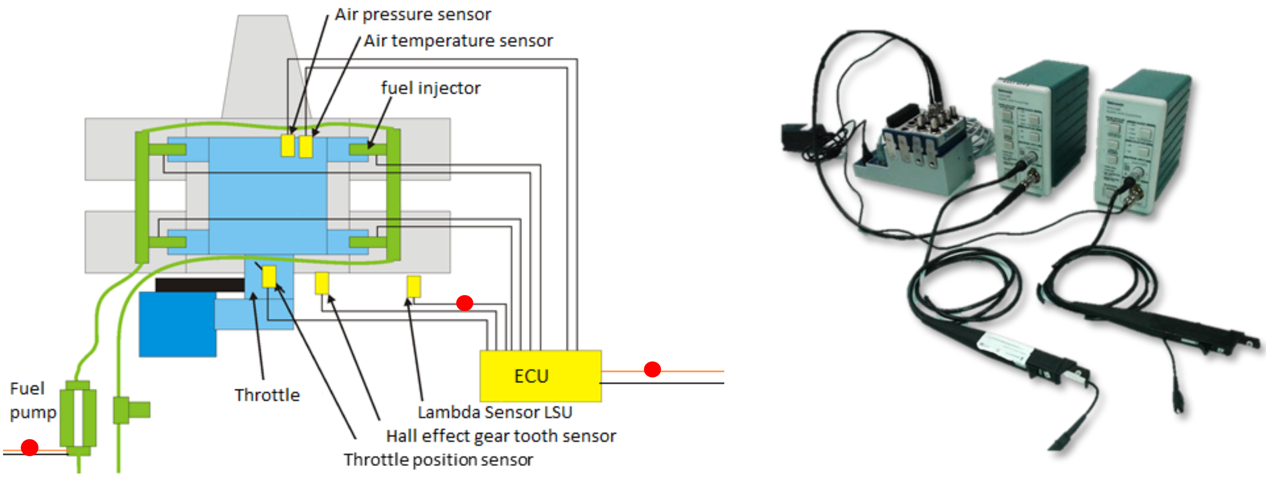

Fig. 2. Schematic of the new fuel injection system and the measuring apparatus

from crankshaft position sensors, a lambda sensor LSU, a throttle position sensor, pressure and air temperature in the intake manifold. The sensors were installed on cords supplying the fuel pump, the lambda sensor and the engine control unit. The red dots mark measuring points.

Energy consumption was measured at points for a set speed at a fixed engine load corresponding to the percentage of throttle opening. Fig. 3 shows the total energy consumption registered by the new system. The results of the measurements show a directly proportional dependence of the energy consumption and the increase in engine power. Demand for electricity reduces with increasing engine speed, which is particularly evident for loads above 50%. The exception is the engine with a load of 10% where the increased speed contributed to higher energy consumption. The highest registered demand amounted to 73.1 W for a speed of 3,188 rpm at full throttle. The lowest demand was 63.4 W at a speed of 5,548 rpm and 30% of throttle opening.

The modified engine is powered by four fuel injectors mounted at the final part of the intake system, directly above the intake duct of the cylinder head. Fuel injection is only possible as a result of pressure difference between centres. This is achieved by keeping a constant pressure of 250 kPa of fuel in the fuel rail in relation to the pressure in the intake system. This is done with a pressure reducer D1 Spec installed at the end of the second fuel rail. A pressure control connection is connected to the engine intake manifold after the throttle valve. Energy demand by the fuel pump (Fig. 4) is the highest share of the total of energy consumption by the new system. The dependence of the power consumption increases directly in proportion with increasing engine speed and load. The highest energy demand shows a pump supplying the engine and running

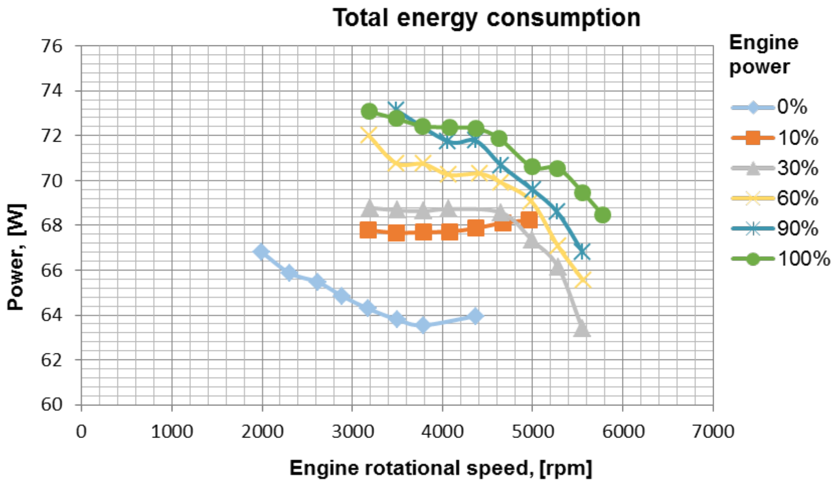

Fig. 3. Total energy consumption of the new system

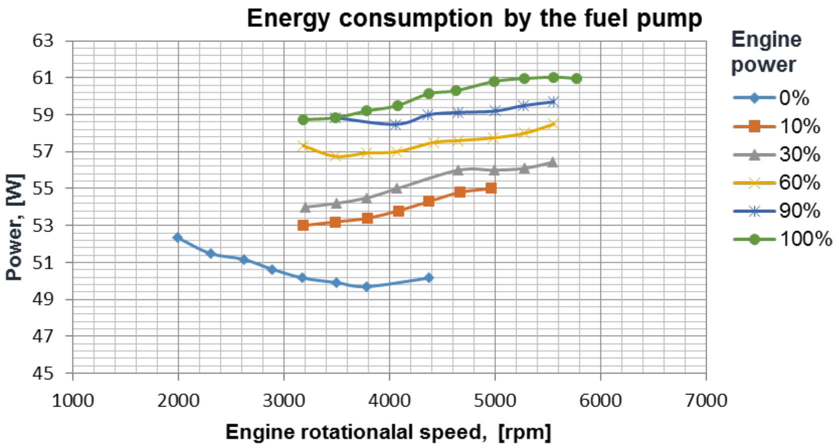

Fig. 4. Energy consumption by the fuel pump

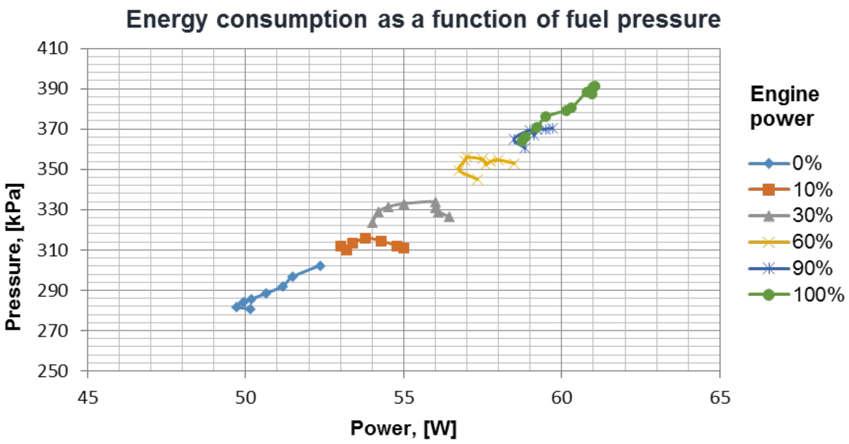

Fig. 5. Energy consumption as a function of fuel pressure

at maximum, throttle opening and speeds of up to 5,800 rpm, which is the permissible (safe) boundary for the Rotax 912 series. The unloaded engine operation at speed ranging from 2,000 to 3,785 rpm is inversely proportional. If speed increases, energy consumption gradually reduces to the value of 49.7 W at a speed of 3,785 rpm, which is the lowest recorded value. The graph shows the change in pressure and energy demand of the pump in relation to the percentage of load of the drive unit while speed and power increase. Pressure increases in the inlet manifold and so the fuel pressure in the fuel system does (Fig. 5). The characteristics of the Bosch 044 pump shows that the dependence of energy consumption increases with increasing pressure [5]. The pump to operate correctly needs an electrical system to generate electric energy ranging from 49.7 W to 61.1 W.

The amount of fuel is dosed according to the amount of oxygen in the exhaust gas. The measurement is made using a Lambda sensor Bosch LSU 4.2 fixed at a muffler exhaust system. A subsequent measurement showed an inverse correlation of energy demand by the Bosch LSU with increasing engine speed. The highest value, i.e. 13.4 W was registered for the lowest speed of 2,000 rpm at a unit in operation without load. The lowest value close to 0.35 W was recorded in the last measurement points for a speed range of 5,500-5,800 rpm and loading more than 30% (Fig. 6). Fig. 7 shows energy consumption as a function of exhaust gas temperature. Reducing energy consumption occurs with increasing exhaust gas temperature. The relationship was established due to the specifications of the Lambda sensor Bosch LSU 4.2 [4] according to which the temperature sensor must be kept above 330ºC. As engine speed and engine, load increase, exhaust gas, temperature increases, too. The increasing temperature in the exhaust system heats the sensor and thus starts a heating system. Power consumption is reduced to the value of the measurement system.

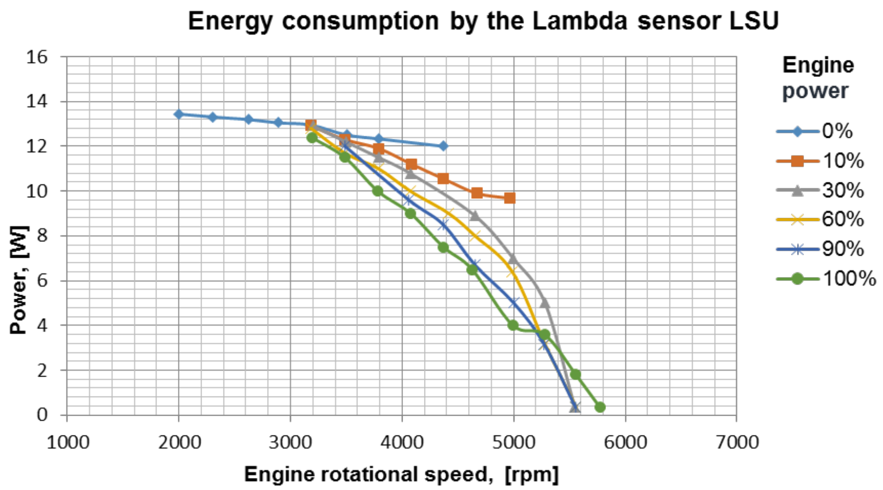

Fig. 6. Energy consumption by the Lambda sensor LSU as a function of engine rotational speed

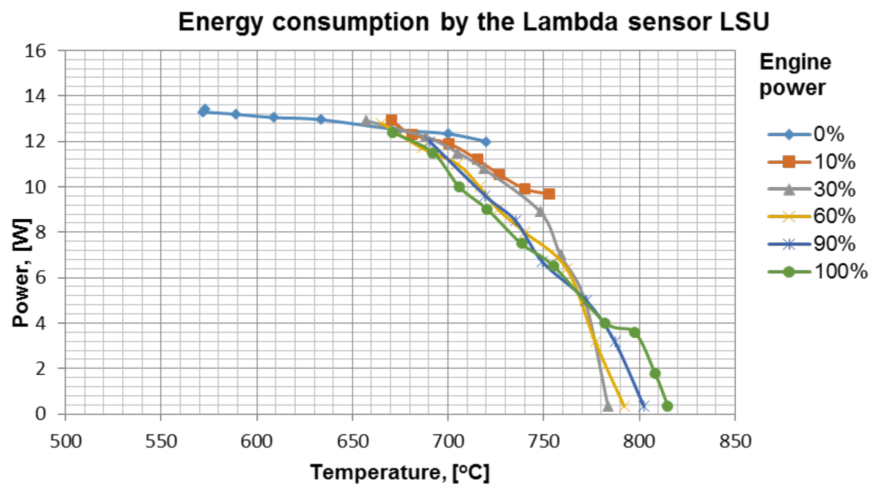

Fig. 7. Energy consumption by the Lambda sensor LSU as a function of temperature

Figure 8 shows the energy demand by the ECU as a function of engine speed. The controller is powered by the following measuring systems: a Hall Effect gear tooth sensor, an air temperature sensor, a coolant temperature sensor, a throttle position sensor, an air and fuel pressure sensor. Fuel injectors controlled and are also powered by the ECU. Tab. 1 describes the systems with their energy demand as shown in a manufacturer's catalogue. Our test results show the increase in energy demand system with increasing speed. The lowest value of 3.38 W is achieved by the controller for an unloaded engine operating at 2,000 rpm. The increase in unit power is accompanied by increased consumption up to a maximum value of 7.25 W at a speed of 5,770 rpm. The main consumer of energy generated by the ECU is a set of four injectors Edelbrock 3583 Pico. The amount of energy depends on the time and frequency of opening of the injector. These values are interrelated and result from a developed engine map. Fig. 9 shows the injection time as a function of engine speed and boost pressure of the engine. The increase in speed increases the frequency of opening of the injector per unit of time. Opening the injector is determined like other parameters by an intake manifold in order to ensure the correct proportions of a fuel mixture. Increasing the angle of the throttle opening affects the pressure increase in the system and increases the amount of fuel injected.

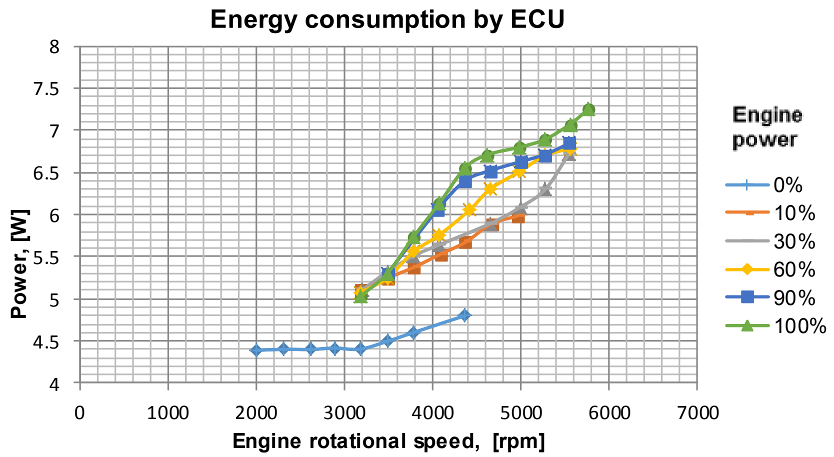

Fig. 8. Energy consumption by the EngineControl Unit

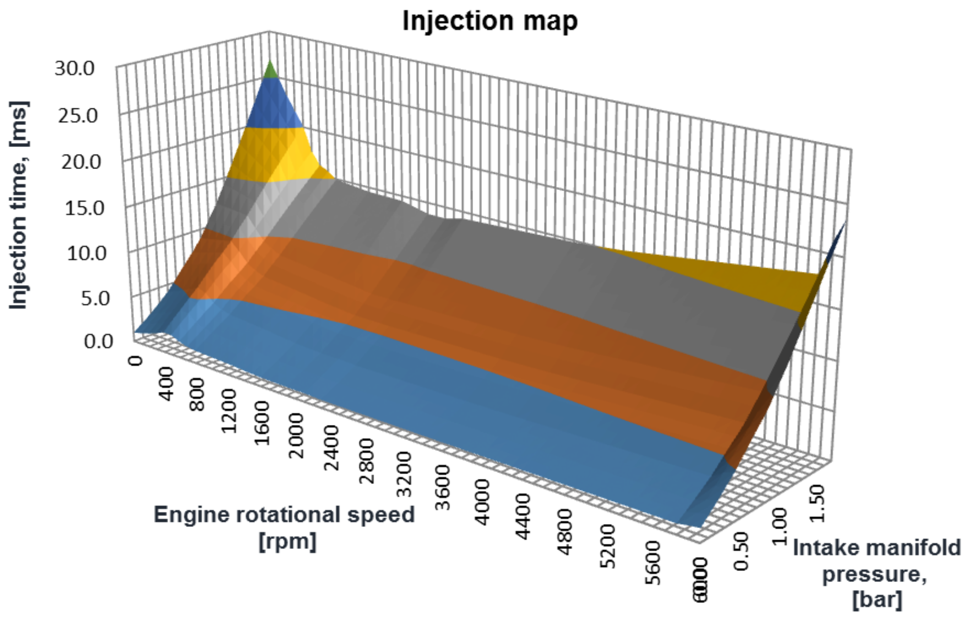

Fig. 9. Mapping of fuel dosing as a function of engine rotational speed and air pressure

3. Conclusions and final remarks

Based on the results, the highest electricity demand shows the fuel pump. Furthermore, increasing engine speed and load results in higher pressure in the fuel system and consequently in the higher power demand of the pump. The pump consumes up to 89% of all energy consumed by the system. In the control system, the highest demand shows the lambda sensor. With the increase in speed, the exhaust gas temperature increases, which leads to less power consumed by the heater of the sensor head. The demand of the other measurement systems and actuators is less than 10.6% of the total consumption. The investigation shows that the total power demand of this new system ranges from 63 to 73 W, which is from 24 to 70% of the total power output from a generator mounted on the engine. Such large power consumption is due to the low efficiency of the generator at low speeds [5]. The increase in speed above 3,000 rpm significantly improves the efficiency of the generator. The engine in autogyros operates during take-off and flight at speeds above 4,500 rpm.

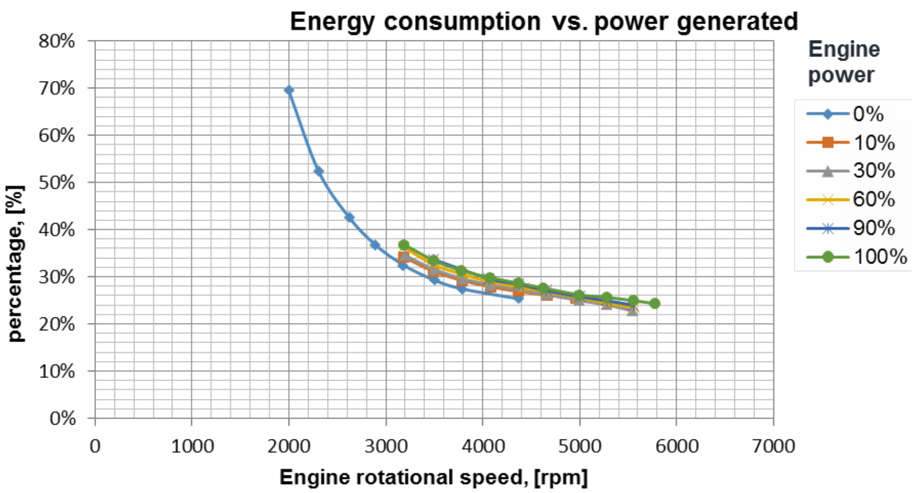

Fig. 10. Energy consumption vs. power generated as a function of engine rotational speed

Conducting this theoretical energy balance of the new system at a design stage has been successful. The energy-saving components in this new system have enabled us to increase the power of the base unit at the cost of 30% of electric energy. The next stage of research will be to balance power on the aircraft after implementing a modified engine autogyro.

References

[1] Akiyama, E., *Electronically-controlled fuel injection system for internal combustion engine*, Patent USA, No. 4941556, 1990.

[2] Wasicek, A., Weimerskirch, A., *Recognizing Manipulated Electronic Control Units*, SAE Technical Paper 2015-01-0202, 2015.

[3] Wendeker, M., *Adaptacyjne sterowanie wtryskiem benzyny w silniku samochodowym*, Wydawnictwo Naukowe PWN, Warszawa 2000.

[4] Bosch GmbH Automotive, *Lambda oxygen sensors catalog 2014/2015,* 2014.

[5] Bosch Motorsport, *Fuel Pump FP catalog 2014/2015,* 2014.

[6] BRP-ROTAX, *Installation Manual for Rotax Engine Type 912 Series*, 2012.