Journal of KONES Powertrain and Transport, Vol. 21, No. 4 2014

ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1130487
DOI: 10.5604/12314005.1130487

PROSPECTIVE ALTERNATIVE PROPULSION SYSTEMS FOR UNMANNED AERIAL VEHICLES

Marek Orkisz, Tomasz Wołoszyn, Piotr Wygonik

Rzeszow University of Technology
Department of Aircraft and Aircraft Engines
Powstancow Warszawy Av. 8, 35-959 Rzeszow, Poland
tel.:+48 17 8651450, +48 17 8652347, +48 17 8651241
e-mail: mareko@prz.edu.pl, tomekw@prz.edu.pl, piowyg@prz.edu.pl

Abstract

The paper presents selected issues concerning alternative power sources and propulsion systems meant for unmanned aerial vehicles (UAVs). The implementation of new propulsions in aviation is a laborious and long-term process, mostly due to safety and economical restrictions and requirements. Broadly, exploited solutions known from automotive industry may serve as a basis for development in aerospace technology, but cannot be applied without considering specific technical aspects (related to aircraft technology and flying objects physics). These aspects are mentioned in the text and some issues concerning suitability of types of aircraft are described. The paper presented contains a review of research on non-conventional propulsion systems for UAVs, conducted in Rzeszow University of Technology. Selected results of the research – the fuel cell and the solar-cell UAVs and the aerial hybrid-electric drive test stand are shown in adequate pictures. The small-unmanned flying objects seem to be an accurate basis for such research. They allow reducing costs and improving safety in comparison to full-scale manned aircraft. They are also much quicker in manufacturing and easier to maintain and repair. Moreover, due to their various applications they may comprise the target market for this kind of propulsions. In particular, the issues of parallel hybrid-electric propulsions, fuel cell and solar-cell-assisted systems with appropriate examples are mentioned in the paper.

Keywords: *alternative energy sources, hybrid-electric propulsion systems, fuel cells, solar cells, unmanned aerial vehicles*

1. Introduction

Aviation has always been one of the most conservative branches of industry when considering new technical solutions implementation. The main problem with using flying objects, as testing platforms for new technology are the limitations arising from safety issues. The systems applied in aviation have to be proved failure-free and error-resistant. Such requirements imply in increasing expanses of new applications. In such case, taking an advantage of other industry branches experience may be a worth-considering conception.

Last year brought an intensive development of alternative energy sources and propulsion systems. Particularly, this growth is maintained by automotive industry, which is the major petroleum fuels consumer. Therefore, the need of finding a substitute for conventional hydrocarbon fuels grows significantly. Not only the diminishing crude oil reserves but also some ecological aspects (like limiting exhaust gases emission) are the crucial issues [1, 6].

Undoubtedly, the road vehicles industry experiences in the matter of alternative propulsions are invaluable; however, they have to be confronted with requirements adequate for aviation. Taking safety precautions and economic issues into account, the unmanned aerial vehicles (UAVs) seem to be appropriate (in comparison to full-scale manned aircraft) testing platform for unconventional propulsion systems applications.

A brief summary of currently utilized UAVs propulsions may help to define potential areas of alternative solutions implementation. There are two main groups of propulsion systems for the UAVs – combustion engines and electric drives. Within the first group, we may distinguish piston engines (both two – and four-stroke, spark or glow ignited, coupled with a propeller) and jet engines (in most cases turbine engines but in narrow area rocket engines may be applied). The other group consists of conventional electric drives based on electric motors, powered by electrochemical batteries. Among many various types of electric motors, recently the brushless permanent magnets synchronous motors became very popular in small aviation and model making. Due to their properties (high efficiency and power-to-weight ratio), they rival with piston engines. The significant disadvantage of this solution is limited electrical-capacity-to-weight ratio of the galvanic batteries (resulting in low energy density and low specific power).

Although, there are many different types of alternative propulsion systems, some of them seem to be more suitable for aircraft applications than others ones. These are pure electric propulsions powered by unconventional electrical energy sources – like fuel cells, photovoltaic (solar) cells and also hybrid-electric propulsion systems (similar to the ones used in automotive applications). Further chapters of this paper present some research conducted by Rzeszow University of Technology on selected alternative propulsion systems meant for the UAVs.

2. Hybrid-electric propulsion systems (HEPS)

In general, terms, the hybrid drive is a system composed of at least two different conventional drive units, coupled in specified way. This type of drives is developed mostly by motor industry to counteract diminishing of fossil fuel reserves. Typical automotive hybrid-electric propulsion system consists of the piston engine and one (or more) electric motor/generator. Each drive unit is equipped with an individual supply system, globally controlled to achieve desired performances.
Compiling the energy management and distribution with hybrid drive architecture, we may distinguish three main types of HEPS: a series one, a parallel one and mixed (series-parallel) one [one, 6].

Each configuration has some advantages over the others. The series hybrid drive is the simplest one when considering energy flow and conversion. It is also relatively easy to control. However, it has limited operation modes capabilities and its architecture results in low overall efficiency and increased mass of the system. Hence, this variant is not suitable for UAVs applications. The mixed hybrid drive enables high flexibility in changing the operation mode but its control and structural complexity (increasing mass) excludes this type of drive from aerial applications.

A parallel hybrid propulsion system (Fig. 1.) includes single piston engine and single electric motor. Both units are mechanically coupled, and the coupling node may serve as a reduction gear (e.g. planetary gear). Thus, the number of components within the system is reduced, resulting decreased mass. Such a configuration enables various states of operation, allowing better matching to power requirements. This type of the hybrid drive offers most advantages to be considered as potential propulsion for the aircraft [2, 4].

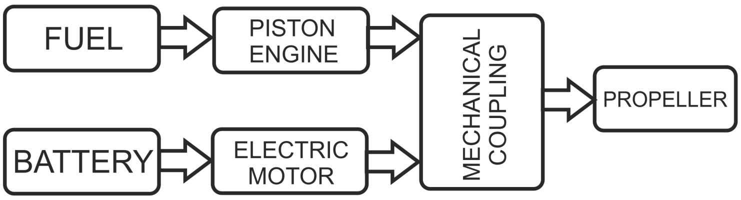

Fig. 1. Aerial parallel hybrid-electric propulsion system (own source)

The general idea of the parallel hybrid drive operation in UAV application is presented in Fig. 2. The total power is a sum of both units power. It allows obtaining an operation point at higher rotational speed resulting in generating the higher thrust. The piston engine does not need to provide maximal demanded power, thus its size (and correspondingly its mass) may be reduced. The electric motor operates as an auxiliary unit and supplements the power requirements. Due to this fact, the piston engine may operate close to the point of its highest efficiency.

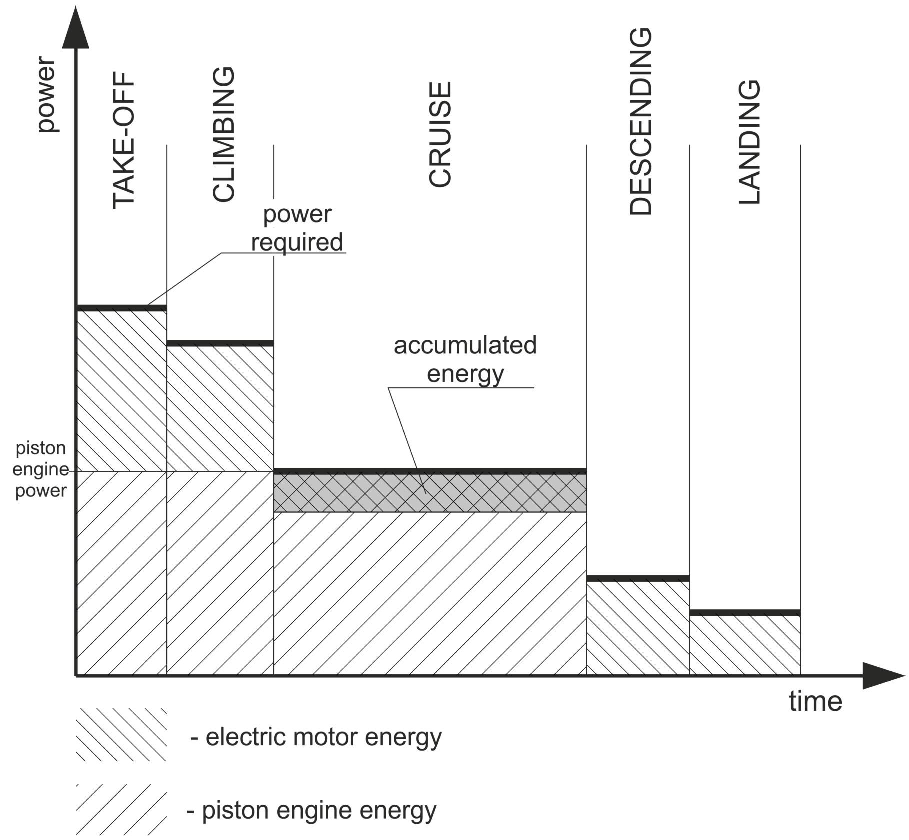

Fig. 2. Operation modes of parallel HEPS in main phases of flight (own source)

Reversing the operating mode of the motor to electric energy generation during the cruise allows to recharge the main battery and thus to provide power that may be needed for next phases of flight (e.g. landing or manoeuvres resulting from performed mission). The amount of energy stored in the battery is an integral of charging current over the charging time, with respect to the charging process efficiency. Due to relatively long charging time, the generator current is low thus; an additional loading of the piston engine in charging mode is reduced to minimum.

As a partial result of research on aerial HEPS conducted in Department of Aircraft and Aircraft Engines of Rzeszow University of Technology, a test stand of parallel hybrid drive has been designed and assembled. It was depicted in Fig. 3. A spatial arrangement of the test stand is not optimized for mounting within UAV fuselage yet and it serves as on-ground testing equipment only.

3. Photovoltaic-cell propulsion systems

Global pro-ecological trends focus on developing and utilizing so-called renewable energy sources. That includes photovoltaic cells (also called solar cells). The technology is developed mainly by civil and power engineering; hence, the applications are usually stationary. However, the improvement of the overall efficiency of the solar cells, and introducing elastic cells allowed attempts to implement these devices to moving objects like road vehicles, aircraft or special vehicles (space probes, satellites, etc.).

Although there are few examples of applying solar cells, technology to the flying objects (mostly UAVs), there is a crucial problem of low energetic efficiency – the amount of power attainable from cell surface is insufficient to maintain flight of standard-form aircraft. Thus, the gross area of an aircraft powered purely by photovoltaic cells has to be much greater than the one resulting from required lift force [5]. It seems that the best configuration to match this requirement have objects with great aspect ratio (long wings) or flying wing aircraft. The former type suffers from low wing structure stiffness; therefore, they are suitable only for long steady flights without

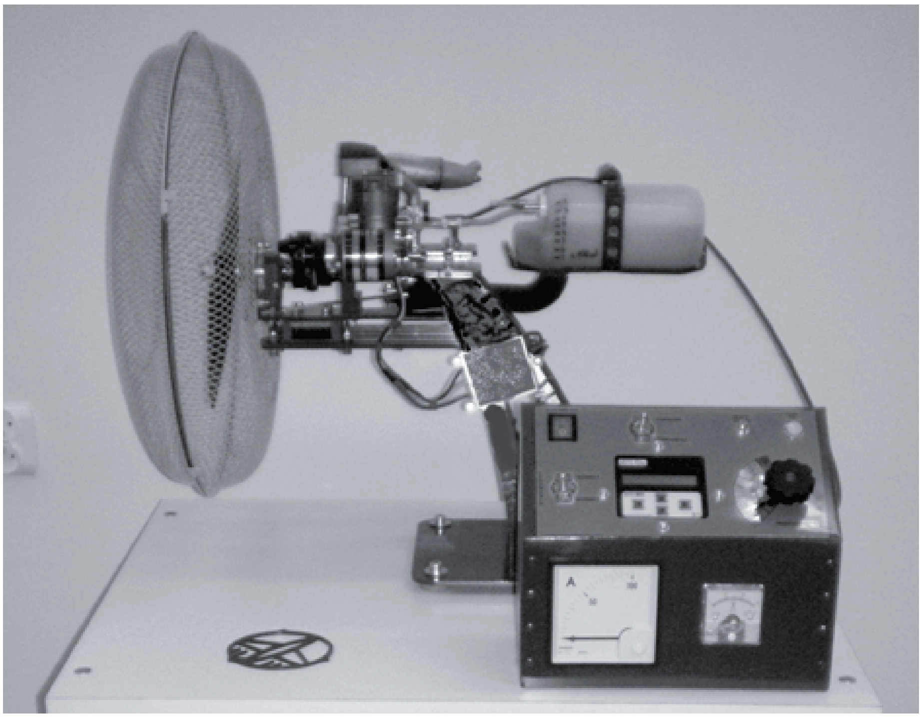

Fig. 3. Test stand of the aerial parallel hybrid propulsion system (own source)

rapid manoeuvres and blasts of wind (high altitudes above clouds tip). The latter type is more resistant to unsteady flight but its gross area is usually smaller than the former one. Another problem is resistance to changing intensity of solar radiation. The aircraft has to have capability of maintaining flight in conditions of limited or faded exposition to sun rays; hence, it should be equipped with additional source of energy (e.g. electrochemical battery).

An example of the UAV with solar cell panels assembled on lift surface is the aircraft built in cooperation of Rzeszow University of Technology and Trigger Composites Company depicted in Fig. 4. Although it reveals features appropriate for flying wing type objects, it is easy to distinguish main parts like fuselage, wing, tail. Applying the round wing allowed to obtain sufficient lift surface and made entire structure rigid. An electrochemical battery mounted inside the fuselage is aided by solar panels attached to upper wing surface.

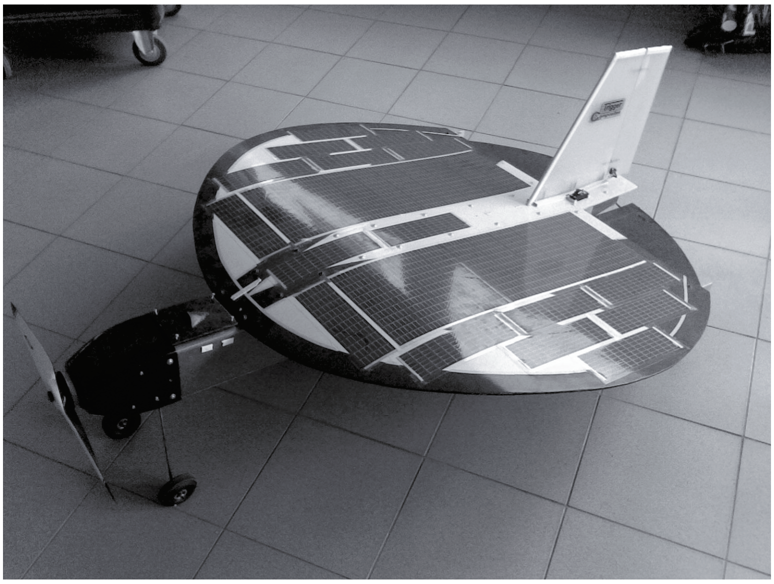

Fig.4. The flying wing UAV with solar cell panels

4. Fuel-cell propulsion systems

Conventional electric drives, powered by electrochemical batteries, suffer from the lack of efficiency and capacity of the energy source. Even the most efficient batteries based on lithium-ion or lithium-polymer cells cannot compete with specific energy capabilities offered by hydrocarbon fuels. Thus, the mass balance is unfavourable in case of using galvanic cells.

As an alternative, fuel cells may be considered an energy source for the electric motor. The fuel cells operate similarly to the electrochemical cells – an exchange of the ions between electrodes (enabled by presence of an electrolyte) is the principle of their operation. Main difference is the necessity of supplying the cell with fuel (hydrogen). The hydrogen is oxidized within the cell, which causes passage of electrons, providing current. There are many types of fuel cells; nevertheless not all of them may serve as a potential power source for the aerial vehicles. Taking the operation temperature along with performances in consideration, the proton-exchange membrane (PEM) cells seem to match the requirements [3].

One of the few examples of the commercial application of the PEM cells is the Aeropak system, manufactured by Horizon Energy Systems Company. It in an integrated stack of the cells equipped with an electronic control system and hydrogen supply system. The device is adapted to be mounted on board the aircraft. Technical specification of the system is presented in Tab. 1.

Tab. 1. Specification of the Horizon fuel cell system [7]

Fuel cell type	PEM
Number of cells in stack	35
Maximal current	10 Amps (at 21 V)
Output power (continuous)	200 W
Output power (momentary)	600 W
Stack voltage range	21-32 V
Operation time	500 h
Device mass	470 g
Operational temperature range	0-35˚C
Efficiency	50%

The complete device with the hydrogen supply container is shown in Fig. 5. As one can see from the Tab. 1, once set working, the device continuously produces electric energy for several hundred hours what is unachievable by any conventional energy sources like galvanic batteries or capacitors. That may prove it ideal solution for long lasting aerial missions like environmental monitoring or atmospheric measurements.

Fig. 5. Aeropak fuel-cell system [7]

This solution may provide real alternative for piston-engine-based propulsion systems. Additional benefits of using fuel cells are relatively simple maintenance, zero emission of toxic gases (water as a product of the reaction) and almost noiseless operation. The device also solves a problem of hydrogen storage because the gas is produced currently and continuously from a granulated chemical compound that is far more easy and safe to store than liquid hydrogen itself.

As a result of the research conducted at Rzeszow University of Technology, the fuel-cell powered unmanned aerial vehicle has been built. The Aeropak system supplies a brushless permanent magnet synchronous motor with electric energy. The aircraft during the test flight is shown in Fig. 6. For testing purposes, the propulsion system has been adapted to supply with compressed hydrogen stored in composite tank instead of original container for the granulated chemical compound. Such a solution allows conducting short-term tests with many on/off operations.

Fig. 6. Test flight of the fuel-cell powered UAV (own source)

5. Conclusions

An intensive development of the alternative propulsion systems is possible due to the progress in materials technology, fabrication techniques and growth of the ecological tendencies. The great credits in this development have to be claimed to the automotive industry and civil engineering. Although the applications of the alternative propulsions in aircraft technology still seem to be considered as a scientific research problem, they may prove worthy of broader interest in the near future. In addition, a growing market of unmanned flying objects allows wider experimenting with new propulsion systems and energy sources.

The paper presents only selected issues of the problem and points out potential directions of development.

References

[1] Ehsani, M., Gao, Y., Gay, S. E., Emadi, A., *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, Fundamentals, Theory, and Design*, CRC Press, 2005.

[2] Glassock, R., Hung, J. Y., Walker, R. A., Gonzales, L., *Design modelling and measure of hybrid powerplant for unmanned aerial systems (UAS)*, Proceedings of the 5th Australasian Conference on Applied Mechanics, Brisbane, Australia 2007.

[3] Hoogers, G., *Fuel cell technology handbook*, CRC Press, 2003.

[4] Hung, J. Y., Gonzalez, L. F., *On parallel hybrid-electric propulsion system for unmanned aerial vehicles,* Progress in Aerospace Sciences, Vol. 51, pp. 1-17, 2012.

[5] Noth, A., *Design of Solar Powered Airplanes for Continuous Flight*, ETH, Zurich 2008.

[6] Xu, J., *Hybrid Electric Vehicle – Overview.*

[7] *AEROPAK fuel cell power system*, Operation & maintenance guide, 2010.