

THEORETICAL CONSIDERATIONS REGARDING APPLICATIONS OF ENERGY HARVESTING IN AIRPLANES

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Abstract: *The integration of energy harvesting systems to power wireless sensor networks in modern aviation, replaces the need for batteries which has implications in decreasing weight, maintenance costs and even reducing air pollution. In this paper, we propose to analyze the theoretical methods of obtaining low quantities of energy from harvesting sources, such as solar, thermic, piezoelectric, and radiofrequency, but sufficient for powering low-power sensors displayed inside airplanes. Additionally, we discuss the possibility of placing sensors in hard-to-reach areas as a result of the fact that they can be powered by collecting residual energy. Thus, we discovered that these sensors could be used for flight tests, for systems that ensure comfort during transport, or as backup systems, when the basic one becomes dysfunctional. The wireless sensor networks would not yet be recommended to be used for critical systems of airplanes such as the integrity of the airplane without relying on the aircraft's power supply.*

Keywords: *energy harvesting, solar, thermoelectric generator (TEG), low-power sensor, airplane*

1. INTRODUCTION

Aviation, both civil and military, is one of the biggest consumers of energy from fossil sources and implicitly one of the most polluting means of transportation. Therefore, in the last decade, the transition to green energy has become a priority. Photovoltaic parks are already a viable solution for the generation of large amounts of green energy for aviation management, from the ground, but, regarding the energy consumption of airplanes, during flights, research is still being done.

In August 2007, The Brookings Foreign Policy presented in the document Department of Defense Energy Strategy - Teaching an Old Dog New Tricks, a diagram of fuel consumption by the American government, where we observe that the Department of Defence consumes 93% of the total U.S. government fuel consumed, and the Air Force 52%, Fig. 1 [1].

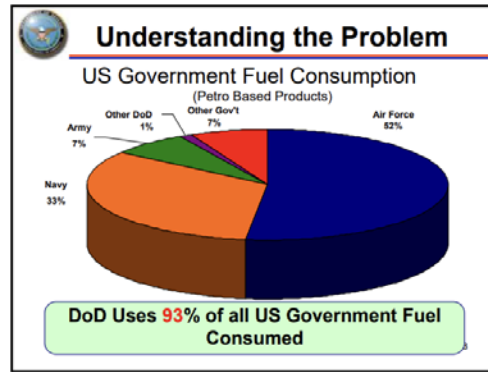


FIG. 1 U.S. government fuel (petro based products) consumption in 2007 [1]

Also, the Air Force made an analysis of energy consumption and found that 84% of energy is used by aviation, and 16% by ground facilities, vehicles and equipment, as we can see in Fig. 2 [2].

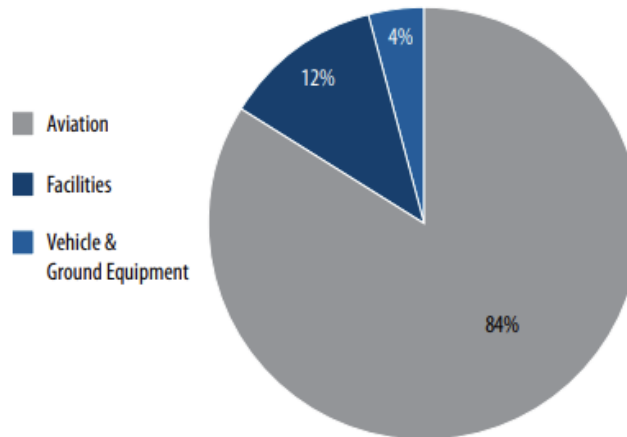


FIG. 2 U.S. Air Force utilization [2]

Therefore, they drew up the Air Force Plan, which aims to reduce the greenhouse gases produced as a result of aviation activities, through a series of measures that will be implemented until 2030.

Thus, in the short and medium term, they took measures to reduce fuel consumption and to use, especially JP-8 fuel, which, although still oil-based, “is therefore less flammable and less likely to ignite accidentally (Zeiger and Smith 1998); and it has a lower vapor pressure than wide-cut jet fuels, so less fuel is lost to evaporation (Makris 1994).” [3] The consumption of 16% of the total energy for powering air bases, vehicles and ground equipment was planned to be provided gradually from renewable sources, such as photovoltaic parks.

In the medium and long term, they proposed the development of light materials that can be used both by ground and in-flight equipment, the development and certification of biofuels, as well as the maintenance of international cooperation in the field of research.

The mission to find solutions to ensure the energy consumption of the Air Force from renewable sources was assumed by the Air Force Research Laboratory. Here, research is done on:

- advanced engine concepts developing technology for next-generation turbine engines
- weight and power reduction
- advanced or alternative fuels
- batteries.[4]

The US Air Force is not the only one that has taken measures for more than a decade to reduce the greenhouse effect by ensuring energy management from renewable sources.

Also, the Aviation Initiative for Renewable Energy in Germany, an institution that has developed collaborations with other international organizations in the field, promotes the production of fuel for airplanes, from sustainable, renewable sources. [5]

As can be seen, the main orientation of military research is to find solutions for supplying renewable energy to large consumers (engines, air bases, etc.). But other researchers have also focused their attention on energy production from renewable sources, especially from ambient sources of small energy consumers, such as low power sensors.

Therefore, in this paper we propose to analyze the possibility of using low-power sensors powered by harvesting energy in aviation.

The paper is structured as follows: general aspects about energy harvesting are presented in the second section, wireless sensors network used in aviation powered with energy harvesting are described in the third, and the conclusions and the future work are presented in section four.

2. GENERAL ASPECTS ABOUT ENERGY HARVESTING

Energy harvesting systems refer to systems that generate small amounts of electrical energy, as a result of the conversion of ambient energy.

We can classify ambient energy into two types, as follows:

1. primary ambient energy, is the energy coming directly from the sun (solar energy and thermal energy) and electromagnetic waves;
2. secondary ambient energy is the residual energy, arising as a result of the operation of other systems, such as the energy generated by artificial light, the thermal energy that can be generated by engines or human body or other systems and the energy arising as a result of the production of mechanical kinetic and/or potential energy.

Technologies used in energy harvesting systems:

A. Photovoltaic cell

The photovoltaic cell works based on the photovoltaic effect applied in different combinations of junctions. It converts solar energy into electricity. The current-voltage characteristic is used to analyze the photovoltaic cell, Fig. 3. The main parameters are determined, such as: short circuit current, open circuit voltage, the filling factor, maximum power, and photovoltaic cell efficiency.

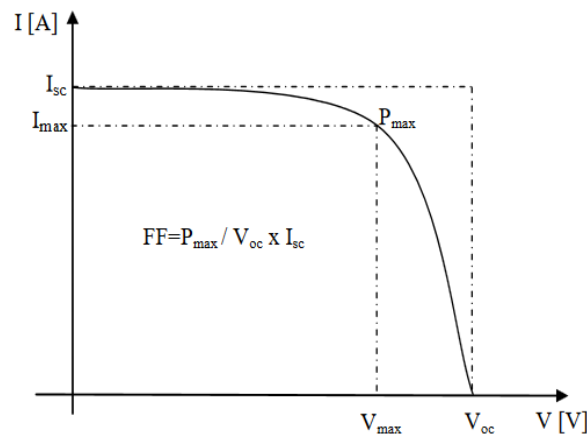


FIG. 3 I-U characteristic for a photovoltaic cell [6]

The efficiency of photovoltaic cells is calculated as follows:

$$\eta = \frac{P_{max}}{A * I_T} \quad (1)$$

where P_{max} represents maximum power, A represents area of the cell, I_T represents irradiance. [6]

Photovoltaic cells can generate enough energy to supply low-power sensors from remote areas from airplanes, but it is not available 24/7. That is why it is recommended either to combine the system's power source with batteries or supercapacitors or to use hybrid systems, such as photovoltaic/thermal or photovoltaic/piezoelectric or photovoltaic/radiofrequency systems.

B. Thermoelectric effect

The thermoelectric effect, also known as Seebeck effect consists of the production of electrical energy when there is a temperature difference between the hot and the cold sides.

The ensemble consisting of a number n thermoelectric elements (called legs) made of a pair of P and N type thermoelements which are positioned between two ceramic plates is named thermoelectric generator (TEG). The thermoelectric elements are connected thermally in parallel and electrically in series, using a thin copper plate. As we can see in figure 4, the load resistance is connected in series with the TEG.

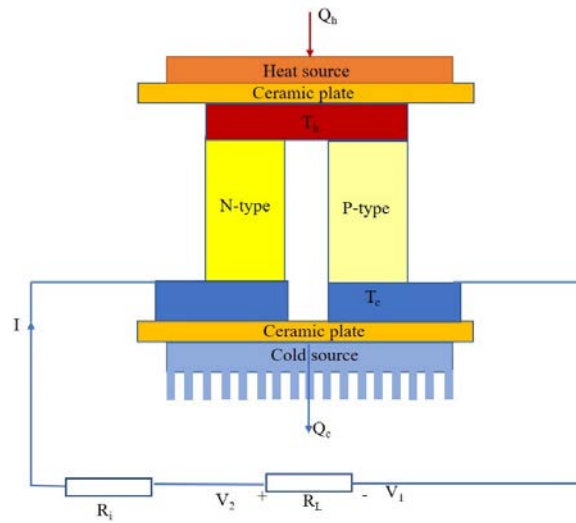


FIG. 4 The structure of TEG with a single thermoelectric element [7]

One of the most important parameter is power generated:

$$P = IV = R_L \frac{\alpha^2 (T_h - T_c)^2}{(R_i + R_L)^2} \quad (2)$$

where α represents the Seebeck effect, R_i represents the internal resistance and R_L represents the load resistance of the TEG, T_h represents the temperature of the thermoelectric element's hot side and T_c represents the temperature of the thermoelectric element's cold side.

The power generated by the thermoelectric generator is directly proportional to the temperature gradient, so in airplanes, it could be relatively small, but continuous, sustainable, and suitable for powering low-power sensors in remote areas.

Photovoltaic/thermal hybrid could be a solution for powering wireless sensor networks from airplanes.

C. Piezoelectric effect

The piezoelectric effect refers to the characteristics of crystals to generate voltage when is applied mechanical stress. [8]

In order to be able to use the piezoelectric effect for harvesting residual energy from airplanes, it is necessary to know the amplitude and frequency of the mechanical stress. For example, a typical rotor speed has the frequency around range 10 Hz - 80 Hz and the frequency produced by the jet engine is in the range 20 Hz - 500 Hz [8].

D. Radiofrequency energy

The radio frequency waves that are around us permanently, in larger or smaller quantities, can also be harvested and converted into electrical energy. Ambient radio frequency sources consist of: AM, FM, TV, GSM, CDMA, 3G, 4G, ISM, and WiFi. [9]

The most important parameters that we must keep in mind when harvesting energy from radio frequency sources are: source power, antenna gain, and energy conversion efficiency.

Generally this systems produce small quantities of electrical energy, but there are permanent available. This systems can be used in hybrid system, such as photovoltaic-radiofrequency harvesting systems or TEG-radiofrequency systems.

Each ambient source has its principles of operation and requirements regarding the conditions under which they can be harvested and transformed into electrical energy in quantities either of the order of nW or of the order of mW, as can be seen in Table 1:

Table 1. Characteristics of ambient sources [9]

Ambient sources	Output power [9]	Conditions requirements
Solar indoor	621 μ W	Non-continuous, light from the sun or from artificial sources
Solar outdoor	1350 mW	Non-continuous, light from the sun
Thermal mechanic	3 mW-50 mW	When residual heat heats one part of the TEG and cooling the other part to obtain the temperature gradient
Vibration human	0,84 μ W-4,13 mW	During any form of human motion
Vibration mechanic	200 μ W-40 mW	During any form of mechanical motion
RF GSM station	1 mW	Continuous at line of sight 0-100 m
RF WiFi	10 nW-0,1 μ W	Continuous at line of sight 0-10 m
RF TV	16 μ W-54 μ W	Continuous at line of sight 0-4 km

3. WIRELESS SENSORS NETWORK USED IN AVIATION POWERED WITH ENERGY HARVESTING

Wireless Sensors Network (WSN) are sensors (temperature, sound, humidity, wind, etc.) connected by WiFi protocols, placed either on large surfaces or in narrow, closed, hard-to-access spaces, to collect and record data about the state of the environment in which they are placed.

Characteristics of WSN are:

- they can be placed in hard-to-reach areas or in difficult ambient spaces;
- for communication, they use the IEEE 802.15 standard;
- requires the use of protocols such as Zigbee, ISA 100.11a, MiWi, Thread and others;
- ensure a very low error rate;
- the network contains a diversity of sensor types;
- the supply is based on batteries or through energy harvesting technologies.

In Fig. 5, we present the basic block diagram of a sensor powered by energy harvesting methods.

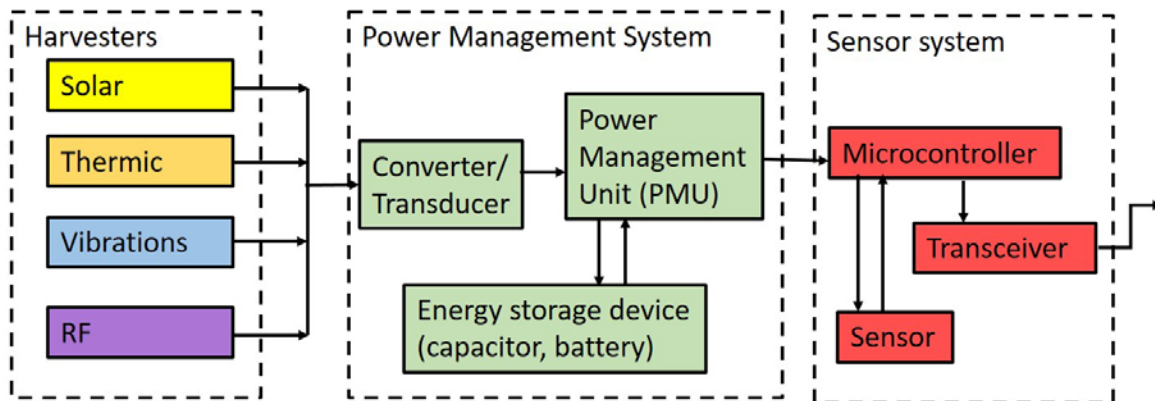


FIG. 5 The block diagram of sensor powered by energy harvesting methods

WSNs are used both in industry and agriculture, as well as in the military field, for monitoring the battlefield or for monitoring and controlling narrow spaces such as airplanes.

Due to their location in hard-to-reach areas that make it difficult to replace the batteries, the use of power systems from ambient sources has become a viable solution.

Also, in airplanes, WSNs are used in applications related to flight tests, Structural Health Monitoring or airplane logistics and safety.

Some studies integrate the energy harvesting technology from the vibrations produced by the jet engine to feed the sensors monitoring the engine condition. Y.Wang et al. present a self-powered sensor system based on a piezoelectric energy harvester in order to monitor in real-time the rotational components of a jet engine. They built the HC-PEH prototypes which have 78,87 mW maximum output power. [11]

J.M. Dilhac et al. describe some practical experiences regarding the implementation of TEG in airlines. They consider TEGs to be suitable for permanent usage because of their robustness, reliability, and power generated when TEG is placed in areas with high-temperature gradients. [10]

However, WSNs are not recommended in airplanes for situations where it should be transmitted large amounts of data or when data should be transmitted in real-time to make quick decisions.

4. CONCLUSIONS

If the possibility of placing sensors in hard-to-reach areas and the transmission of data through wireless communications represents the main advantages of using WSN, these characteristics also represent a challenge for finding innovative solutions when they are used in airplanes, whose metal structure can behave like a Faraday cage. That is why these networks are not recommended for critical systems, where delays or lack of timely data transmission could have serious consequences.

Also, the amount of residual energy produced by airplanes during flights is considerable and can be transformed into electrical energy with the help of energy-harvesting technologies. Thus, photovoltaic cells can be used wherever light is, TEGs can be used near engines, and piezoelectric generators could be used on rotor blades or in the wing structure.

Energy harvesting can be used in unitary or hybrid systems, but for greater effectiveness it is recommended to use hybrid systems for harvesting energy from environmental or residual sources.

Therefore, the harvesting technologies of electricity supply generate sufficient quantities to power the Wireless Networks Sensors, constituting at the same time, a viable and sustainable solution to reduce air pollution by airplanes.

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