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Design and Optimization of Combustion Chamber for Unmanned Aerial Vehicle through Thermoelectric Power Generation

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Abstract

The efficient fueling process of unmanned aerial vehicles (UAVs) under various environments is an important key to expanding their application regarding flight range and stability. In order to improve the fueling system of UAVs, a simple and scale-adaptive method using thermoelectric generators (TEGs) was examined. Firstly, the ideal thrust-to-weight ratio was determined to optimize the flight of the aircraft. Secondly, a gas-powered heating source was considered for the fueling system, and maximum power output using a single TEG was measured. In this study, two combustion chamber models with 3D modeling were designed and integrated with TEGs to test electrical power output. This power output will be the basis for determining if this approach to powering flight would be able to sustain flight.

Keywords: Machine learning, Automated text scoring, Text embeddings

1. Introduction

The current development of unmanned aerial vehicles (UAVs) is mainly focused on the design of fuel efficiency or flexible structures to adapt and perform in various environments. Recently, the idea of a small and deployable UAVs has emerged due to a wide range of flight and potential applications along with an effective fueling system. In addition, a light-weight material with high-strength can be considered at a lower density to achieve such a fuel efficiency goal (Park & Kim, 2013; Dornfield, 2014). In this regard, the cost and energy-efficient source, such as solar or wind energy, may take advantage in the development of fuel systems (Teng, 2018). Furthermore, the demand for renewable energy has been constantly expanding over the years.

Solid-state energy conversion of heat into electricity can be observed with thermoelectric materials in combination of thermal, electrical, or semiconducting properties (Bell, 2008). Therefore, these thermoelectric materials have been developed and used for cost-efficiency and advanced implementation in system architecture. Recently, thermoelectric generators (TEGs) have been widely applied in providing power to convert heat into additional electrical power via the Seebeck effect, for example, remote distance sensing in offshore platforms or micro self-powered wireless platforms (Jaziri, 2020). The Seebeck effect is a thermoelectric phenomenon that generates an electric voltage via a temperature difference across two dissimilar materials (Mahan, 2005). A previous study demonstrated that several prototype or early working design harvester units efficiently generated electricity from the thermal energy of tree trunks (Le, 2024). The study reported that the thermoelectric harvesters, a future concept to capture and convert energy from the environment to usable electrical power, were integrated into tree trunks to induce the Seebeck effect, and the temperature difference between the internal tree material and ambient air produced a small yield of power across their volumes. Compared to prior research on thermoelectric conversion for cooling, heating, and waste heat recovery (Bell, 2008), these prototype harvesters illustrate a novel application of the same principles, extending the technology from industrial-scale systems to natural, small-scale environments. This new design development for electric power generation not only minimizes the maintenance of batteries independently of recharging but also reduces the toxicity with the disposal of batteries.

This study mainly focuses on the optimal temperature and design consideration of thermoelectric power generation through a combustion chamber to power flight in UAVs. A combustion chamber, in the context of this experiment, is an insulated chamber that allows for the safe and controlled burning of a fuel source. This heat source is then converted to electrical power by the TEG arrays lining the walls of the chamber. In line with this, TEGs were tested in the application for a streamlined and simple conversion from a fuel to electric power for the application of UAV propulsion (Fig. 1).

Figure 1. Study scheme.

The method of converting energy stored in fuel to power has many advantages over traditional methods, such as internal combustion or turbine engines. For instance, one of the biggest advantages is that the small amount of moving parts results in less service requirement and minimal areas for failure. Therefore, the goal of this study is to design the combustion chamber models with material properties using TEGs and to optimize them by evaluating how voltage was generated and changed while the temperature differentiated over time within the system.

2. Experimental Procedure

2.1 The flow of study scheme

TEGs have been utilized in many applications where electricity generation is required with minimized movement of subcomponents in complex systems (Wang, 2020). For this study, TEGs were integrated in possible combustion chambers using a 3D printer to generate electric power and were tested for maximum power generation induced by temperature difference. A better-designed chamber model will be optimized to establish the harvester (Fig. 2).

The maximum voltage and amperage from a single TEG were measured in order to determine the capacity of TEGs without a combustion chamber (Fig. 3). The experimental measurement of maximum voltage out was 2.14mV and temperature difference was 43.1 °C.

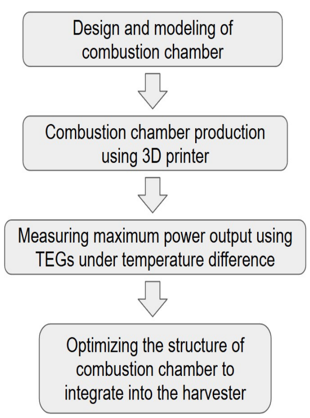

Figure 2. Study workflow.

TEGs used in this project are relatively small, with dimensions of just under 1 square inch with a thickness of 0.12 inches. A total of 12 TEGs were integrated in each chamber model. The combustion chambers were initially designed to utilize aluminum with a series of TEGs. However, it was evidently noticeable that heat was escaping from inside the chamber through the walls. Instead of using aluminum, a thermal insulating foam board was used to trap the heat inside. A rod was also attached inside the chamber to disperse the heat through the series of TEGs (Fig. 4 and Fig. 5).

These TEGs generate power from a heat gradient across the device. In this case of the combustion chamber, the hotter side of this gradient would come from the controlled combustion of a fuel. For this experiment, an electric hot air blower was used to mimic the heat that would be put out by a flame. In addition, the difference in temperature between the ambient environment and the internal chamber was measured. We measured the amount of voltage produced at three different temperature gradients inside the chamber (55°C, 62°C, and 80°C) with four different resistance levels at each temperature (0 Ω, 220 Ω, 470 Ω, and infinite resistance). On the colder side of the chamber and the TEGs - the outside - the temperature was ideally maintained by directing cool air from the outside of the UAV to the outside of the combustion


Figure 3. An experimental setting from a single TEG. TEG was placed between hot plate and metal plate, and then wired with a thermometer and multimeter to measure the temperature and voltage respectively.

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chamber. This was simulated using electric air blowers. To determine whether flight could be achieved using the power generated by the chamber, the chamber's final sustained output was compared with the power-to-weight ratios of other similar aircraft or at varying scales.

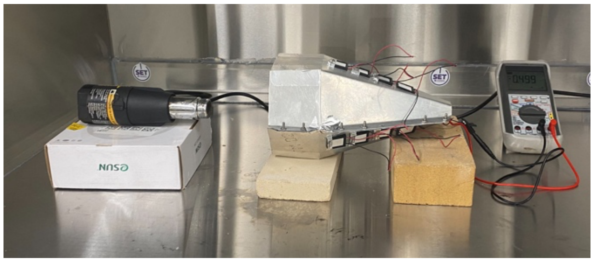

Figure 4. Maximum output test result from the first prototype chamber model (aluminum).

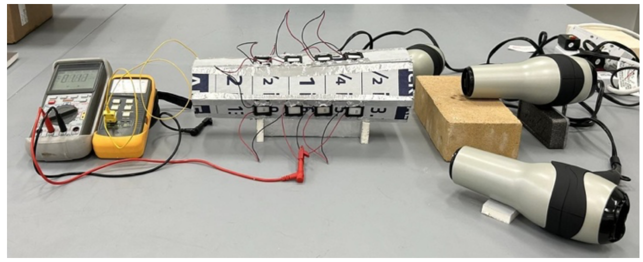

Figure 5. Maximum output test result from the second prototype chamber model (foam board).

3. Design

The combustion chambers were both designed using Dassault Systèmes SolidWorks. The first design of the initial prototype was a rough model, as the manufacturing method of cutting and bending 6061 Aluminum had not yet been decided on. The model resembled a hexagonal cone made from ⅛” 6061 aluminum sheet with a smaller diameter at one end and on the other with an overall length of 14 inches. On 3 of the 6 sides, there are 4 square 1” by 1” holes. These holes would accept the TEG mounts 3D printed from PTEG. All wires were connected in series, and the chamber would then be tested. The second prototype - fully modeled on Solidworks - was made from 1” polyisocyanurate insulation (R-value of 6.0 at 1”) board. Each side of the chamber was cut with the reflective side of the foam board facing the inside of the chamber to reduce heat loss through the walls of the chamber. The final prototype was then assembled with aluminum tape in an effort to reduce radiant heat loss further.

4. Results

For the first trial model, an approximately 0.02-inch-thick aluminum sheet was stamped and folded into the shape with TEGs. Nevertheless, the result showed the chamber body held too much heat through the area of heat loss (not through TEGs), and it appeared the shape of the chamber induced the exhaustion of hot air, which resulted in the waste of energy. Next, the enhanced chamber model with a foam board (0.5 inch) was tested. This model represented lighter for more efficient flight and greater isolation between hot and cold sides of TEGs. The chamber body was supposed to absorb less heat (or less heat loss) and further internally diffuse direct hot air flow to TEGs. The open-circuit voltage from TEGs was measured over time, and the greatest total of 560mV and 1.085 mA at the temperature of 80 °C and at infinite resistance was observed. The max power was selected as the point on the linear fit that would create the largest Voltage output (Fig. 6 and Fig. 7). However, the model showed the lack of cold air flow to the outside (cold side) of TEG and similar waste of energy due to the chamber shape with the previous model.

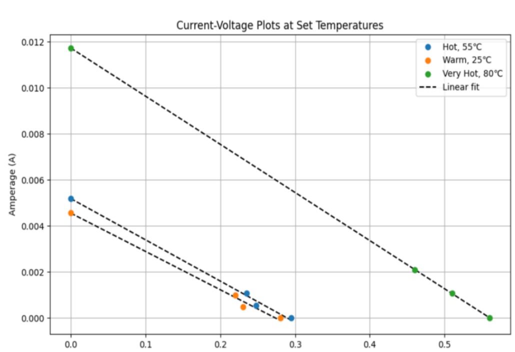

Figure 6. Graph of the relationship between the Current (A) and Voltage(V) at set temperature gradients.

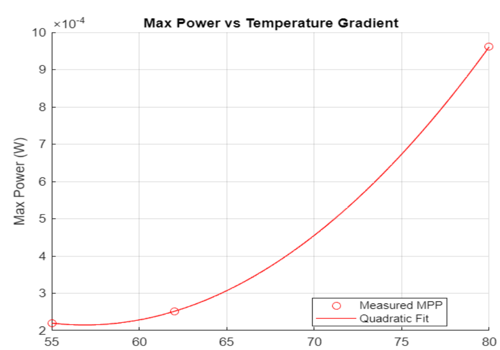

Figure 7. Plotted the maximum power (W) at set temperature gradients.

5. Proposal of Powering an UAV

To explore a simplified and scalable method for powering a UAV, this study proposes the integration of thermoelectric generators (TEGs) within a combustion chamber to convert thermal energy into electrical power for flight. Two combustion chamber prototypes were designed and built together using different materials to optimize thermal insulation and heat distribution across the TEG surfaces. The system operates by establishing a temperature gradient between the internal heat source, simulated with a control flow of hot air, and external cooling, representing ambient airflow during flight. This temperature difference induces an open-circuit voltage across each TEG, enabling electrical energy generation without moving parts. The chambers were tested with multiple resistance loads and varying internal temperatures to determine optimal operating conditions for maximum power output. The resulting data were evaluated against thrust-to-weight ratios of comparable UAV systems to assess the feasibility of sustained flight. This approach demonstrates the potential of TEG-based power systems as compact, low-maintenance alternatives to the traditional propulsion methods, particularly for small-scale UAVs operating in remote environments.

6. Discussion

The development of the combustion chamber model is a relevant technical task to improve the efficiency of energy transfer and generate power using the temperature difference. High reliability and power output were also required for such model development. Therefore, the maximum voltage generation was the main issue.

The current design of the combustion chamber is still in work-in-progress, which means lots of properties or specifics are expected to change for its enhancement for the stability of maximum voltage. Further experiments would analyze the change of voltage under various conditions of differential temperature in order to identify the potential capacity of the combustion chamber.

Limitations of this study include the thermoelectric generators used, which limit the maximum temperature gradient to 80°C. The time frame of the project was also limited, and such a focus on quick design iterations with large effects on performance was prioritized. Further prototypes would have smaller performance effects on the chamber output; therefore, more extensive and repeatable tests would be necessary.

7. Conclusion

In this study, we measured a significant but not substantial electrical power output in an operating model of a thermoelectric-based UAV power plant that burns gas fuel. With this model, we propose that TEGs can serve as a valuable substitute for power generation by replacing the toxicity of disposable batteries. With less toxicity from disposable batteries, our environment can be protected for the long term, as there would be lower amounts of pollution, paving the way for an alternative energy source. With further development, this power-harvesting combustion chamber design would also extend the range of UAVs by providing a lighter and more efficient power plant compared to traditional power generation systems. As our output wasn’t as much as we expected it to be, the output can be improved through many more iterations of the project, with a focus on material selection and combustion chamber geometry.

Acknowledgement

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