Thermogeneration harvesting in an aeronautical application, from specification to realization

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***Abstract*— In this paper, we present results related to a thermoelectric harvesting system developed for powering a SHM datalogger installed in an Airbus A380 closed to the engine.**

Keywords*— *thermogenerator, energy harvesting, structural health monitoring, aeronautical.

I. INTRODUCTION

Aircraft manufacturers and more precisely their R&D department are very interested in the development of wireless solutions for Structural Health Monitoring (SHM) applications. For safety reasons and due to extreme temperatures (high or low), batteries are prohibited in favor of supercapacitors for the storage stage. An energy harvester must be added to balance the energy budget and compensate the SHM datalogger energy consumption. In this work, a solution using a thermogenerator is presented. The SHM sensors are located in the Aft Pylon Fairing (APF) of the A380 aircraft; the pylon holds the engine to the wing (fig.1). The TEG is attached to the pylon primary structure; this structure is heated by the engine at temperature T_H. However, the ambient air temperature in the pylon T_c is lower than those of the primary structure giving a thermal gradient estimated between 100 and 200C during flight (cruise)

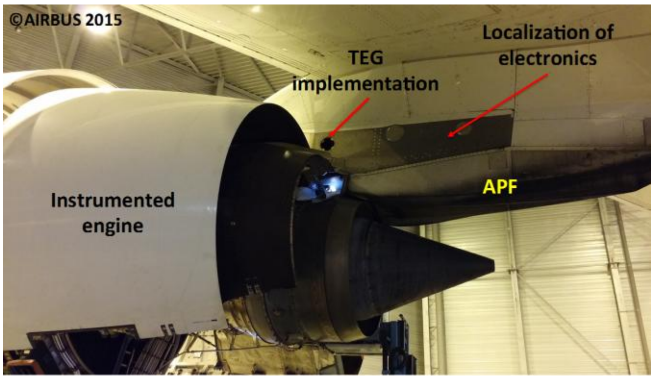

FIGURE 1. Localization of the thermogenerator (TEG) and the associated electronic device (HMEC). Electronics is deported in a cooler zone next to SHM dataloggers.

In a previous paper [1], specifications have been presented. We summarize hereafter the main requirements: temperature (up to 300°C), strong vibrations (12g), lightning protection and no destruction in case of engine fire (1100°C) according to DO160-G Standard. More details can be found in [2].

II. TEG

Very few commercial TEGs are able to handle 300°C. We chose a $50x50x4.4mm^3$ Kelk thermogenerator. The TEG assembly with its heatsink has been previously presented in [1]. The TEG is installed (fig.2) in the pylon primary structure. Ambient air and aircraft skin temperature sensors are implemented close to the TEG.

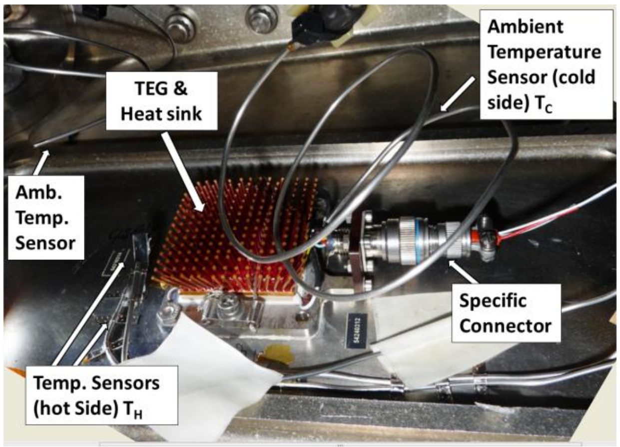

FIGURE 2. TEG and its copper heatsink installed into the A380.

The TEG (standalone and with its heatsink) has been tested, characterized and modeled before flight in laboratory under expected thermal conditions ($\Delta T = T_H - T_C$ between 100 and 200°C). Results are summarized in Table 1. We must notice, the gradient (ΔT_{TEG}) across the TEG is smaller than ΔT and in laboratory conditions we get $\Delta T_{TEG} \approx 1/10.\Delta T$. As shown in fig. 3, to maximize energy transfer, we simply chose a fixed working point (see LT3105 working principle) at 0.35V leading to harvest always more than 30 mW if $\Delta T > 80°C$ at ambient pressure.

III. HMEC BOARD

Distant from the TEG, the management circuit called HMEC (Health Monitoring Energy Converter), previously described in [1], is installed in a less hot zone. Its main components are listed hereafter. It includes an input common mode filter to serve as an EMI protection against lightning risks and a LTC3105 circuit (harvesting function, storage voltage regulation). A LDO allows powering the output enabling comparator. The storage tank is composed of two in-series supercapacitors Maxwell BCAP0003 3.3F, 2.3V (equivalent capacitance 1.65F with 4.6V maximum voltage). A low power LT6700 comparator circuit is used to enable the boost stage when storage voltage is high enough. A LTC3539 boost performs output 5V regulation. We added an output protection circuit LTC4362 in order to increase the HMEC reliability.

The HMEC operates successfully between -50°C and 125°C.

TABLE 1. TEG PARAMETERS

TEG	R	(Ω)	3.7
	S	(V/°C)	0.063
	Rth_TEG	(°C/W)	2.9
HeatSink	Rth_HS	(°C/W)	25

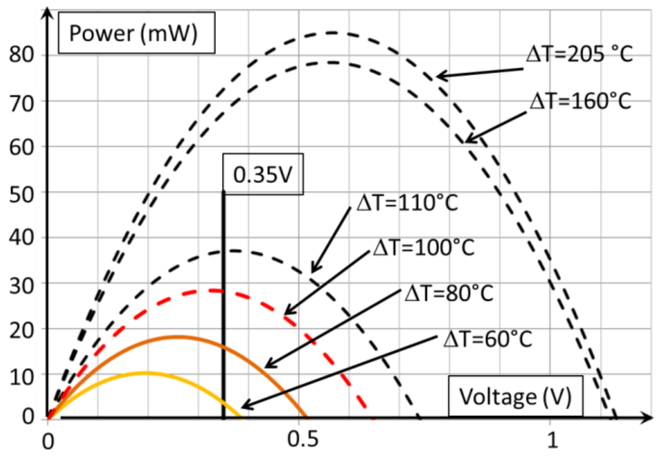

FIGURE 3. Power vs Voltage of the TEG. Experimental characterization (dotted lines) and simulations results (colored lines).

IV. RESULTS

Both components (TEG and HMEC) have been correctly operating in flight for 1 year. The SHM datalogger is powered by a local power network or by the harvester as soon as the supercapacitor voltage reaches 4.4V and until it drops down to 1.5V. Unfortunately, the datalogger consumption initially supposed to be around 2.4 mW is in practice 10 times higher at 25 mW. So the harvester cannot power permanently the datalogger as seen on fig.4 (supercapacitor voltage decreases when the harvester supplies the datalogger as the harvested power cannot compensate the consumption). On this figure, the TEG output power is around 12mW and the harvested power in supercapacitor is around 6 mW: LT3105 efficiency is around 44%. The datalogger is powered by the harvester 15% of the time.

The flight analysis allowed highlighting the main influence of the altitude in the convection phenomenon (fig. 5). In fact despite a high temperature gradient (around 100°C), the harvested power in supercapacitor drops to 0 mW if P < 200 hPa. As a consequence, the supercapacitor voltage decreases because of the self-consumption of the enable electronic circuit (≈ 90µW as Vsupercap < 2.4V). Pressure effect is well seen too on fig.6. On this figure, ΔT is always between 65 and 80°C.

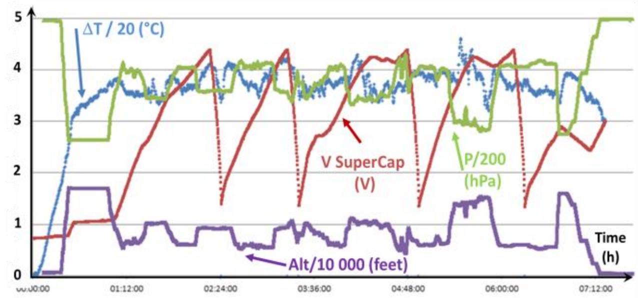

FIGURE 4. Flight 1134 Altitude, pressure, temperature gradient vs time during a low altitude flight.

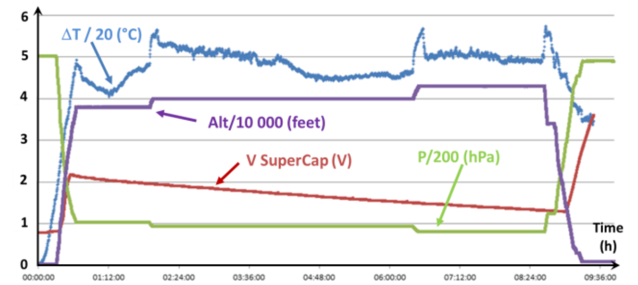

FIGURE 5. Flight at high altitude. The small pressure temporarily inhibits the convection phenomenon which cancels the harvested power. The self-consumption (90µW) of the electronic circuit discharges the storage unit.

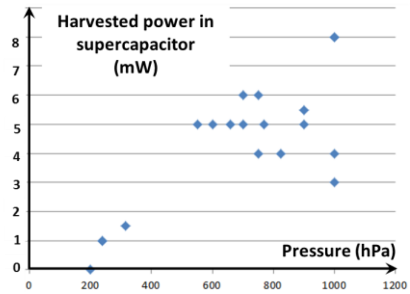

FIGURE 6. Harvested power stored vs flight pressure under different gradients of temperature. Il manque la valeur des ΔT

V. CONCLUSION

The designed energy harvester module is robust and operates properly although temperatures and vibrations are significant which is a good result. Unfortunately, due to imprecise starting specifications and false environmental data it could not power the load all the time long despite the implemented safety margin in the design. At high altitude, convection reduction must be taken into account when ventilation is limited.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCE

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[2]. Energy Autonomy of Batteryless and Wireless Embedded Systems – Aeronautical Applications, J-M. Dilhac, V. Boitier, Elsevier ISTE Press, 2016.