

Smart Monitoring System for Aircraft Structures

TRIADE is a European Union project that focuses on the development of technological building blocks for Structure Health Monitoring (SHM) sensing devices in aeronautics. It is funded under the 7th framework program. In terms of objectives, the TRIADE project focuses on providing these technological building blocks and fully integrated prototypes in order to achieve power generation, power conservation, energy management and embedded powerful intelligence for data processing and storage for SHM sensing devices.

The principal technological building blocks that the TRIADE project will provide are: – A low profile battery with high energy density which will be able to function in a harsh environment, – An energy harvester from vibration and electromagnetic RF, – Ultra low power sensors which will be designed in SOI technology, and – A neural network for data recording and damage assessment.

The smart tag will be the size of a credit card (dimension 85x55x4 mm) and will support remote sensors. It will be embedded under the last composite layer or attached on the structure of the aircraft. It will be autonomous as all the power needed will be provided by the onboard rechargeable battery. It is wireless and the data stored will be transferred to the base station by using the RFID communication protocols through an RFID reader. It will record temperature, relative humidity, pressure, strain, vibration and acoustic emissions whenever the flight domain is overrun.

The structure health monitoring capability that the TRIADE project offers is planned to be applied in 2 application domains: on helicopters with Eurocopter and PZL Swidnik as end-users, and on airplanes with EADS Deutschland GmbH and Dassault Aviation as end-users. The different requirements from each end-user have been unified on the smart tag with minimal compromises to accommodate of.

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INTRODUCTION

Structural Health Monitoring (SHM) is very important for Aeronautics [1, 2, 3]. It shows a great potential in terms of cost savings coming from the benefits it would have on inspections [4]. For that reason, the

maintenance of engineering structures should be minimized without compromising safety, reliability and sustainability.

Monitoring structures is a major issue which leads to the emergence of numerous technologies including sensors, low power electronics, smart microprocessing, wireless communication... All these technologies are entering the SHM to improve the knowledge of the behaviour of the aircraft structure to allow the extension of the inspection intervals and to optimise the return on investment. This new monitoring trend leads to the European FP7 project named Triade [5] which is based on several technological bricks which are essential to smart monitoring systems dedicated to SHM for aeronautics.

CONTEXT

Historically, in aeronautics, the maintenance is conducted according to time-based inspections. The schedule is planned according to the number of flying hours, whatever the operating life of the aircraft could have been. For this reason and because the environments and the loads are different from one aircraft to another, important margins are defined.

To reduce these margins, to optimize the maintenance and the availability of the aircrafts, a condition-based maintenance for all aircraft components is under investigation. This suggests the implementation of health-monitoring sensors to parts and change the way scheduled inspections are done by allowing maintenance organizations to test for fatigue cracks in airframes using new non-destructive methods, monitoring component anomalies such as cracks or delamination in real-time.

With such a monitoring system, the inspection frequencies could be reduced by a factor of two (e.g. from 5,000 hr. to 10,000 hr for wing stringers [6]), even envisioning maintenance-free aircraft. However, it is supposed that the operators will still make manual checks in parallel with this monitoring technology, for a while, to demonstrate its credibility. Nonetheless, end-users will have to decide to integrate real-time data management from the aircraft health monitoring systems and choose the data management method which is the best adapted for them.

Aircrafts can be exposed to numerous kinds of environments, sometimes very harsh. The knowledge of these environments allows identifying the different loads which can exceed the normal flight domain (e.g. lightning, storm, very cold or very hot temperature, bird strike...). This is the role of the monitoring system to record and even identify overloads in such a way that the maintenance plan can be adapted for each aircraft.

THE HEALTH MONITORING SYSTEM

The needs (Fig.1) concerning a “fix and forget” monitoring system are numerous. It has to be wireless in order to be placed everywhere, small, autonomous and reliable (at least more than the part under monitoring).

However, these needs rapidly lead to contradictory parameters between the size of the power source to reach a minimum autonomy, the size of the antenna for wireless communication, the size of the electronics, the energy harvesting capability and the maximum miniaturisation for an easy integration (Fig.3).

Within the Triade project, the trade-off leads the consortium to a smart monitoring system with the following dimensions $85 \times 55 \times 4 \text{ mm}^3$, near the size of a credit card (Fig.4). The aim is thus to be able to stick the system above or near the area to monitor, but also to have the opportunity to integrate it directly inside the structure (e.g., in the last layer of a composite structure).

The different technology blocks developed within the project focus on the optimization of such a monitoring system:

- Very thin battery withstanding aeronautical constraints,

End user requirements	Dassault Aviation requirements	Eurocopter requirements	EADS-D requirements	PZL requirements	Final requirements
Temperature	-50°C to 95°C	-40 to 95°C	-54°C to 80°C	-50°C to 90°C	-40°C to 95°C
Humidity	0% to 100% RH	0% to 100% RH			0% to 100% RH
Pressure	0 to 1 bar			0 to 1 bar	0 to 1 bar
Vibration Acceleration	10 to 2000 Hz	±20g	±20g	±20g	10 to 2000 Hz ±20g
Strain		5000 µε		1000 µε	5000 µε
Ultrasonic			1000 kHz		1000 kHz

Figure 1. Measurement requirements

Sensors	Measurement range	Operating temperature
Temperature	-40°C to 120°C	-40°C to 125°C
Humidity	0% to 100% RH	
Pressure	0.01 to 1.1 bar	-40°C to 125°C
Vibration	2 to 6000 Hz	-40°C to 125°C
Strain	50000 µε	-70°C to 200°C
Ultrasonic	175 to 1000kHz	-65°C to 177°C

Figure 2. Implemented sensors

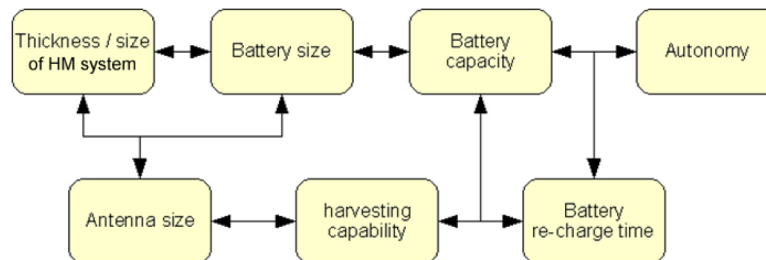


Figure 3. Smart health monitoring system trade-offs, considering an electromagnetic coupling for energy harvesting

- Energy harvesting for electromagnetic coupling and vibrations,
- Silicon On Insulation (SOI) technology to decrease the power consumption,
- Neural network to be able to have processing power to discriminate between normal and abnormal behaviour.

Battery

The battery targeted in this project is very challenging since it has to be implemented with a very low profile (less than 1.5 mm) protected by a metallic can, have a high energy capacity and withstand aeronautical environment and in particular low and high temperatures. Since the Triade project considers aeronautic applications, the safety aspects dictated the choice of the Li-ion technology. Thus, the LiFePO₄ / graphite technology was selected for a nominal voltage of 3.2V. The capacity of the battery has been estimated above 200mA. Nonetheless, studies on electrolyte for low temperature are still conducted.