# PhD in Aerospace Engineering

## Research Title: New health monitoring techniques using FBG sensors applied to aerospace systems

<table>
<thead>
<tr>
<th><strong>Funded by</strong></th>
<th>Inter-departmental Center Photonext</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supervisor</strong></td>
<td>Paolo Maggiore, Davide Janner e Matteo Dalla Vedova</td>
</tr>
<tr>
<td><strong>Contact</strong></td>
<td><a href="http://www.photonext.polito.it/">http://www.photonext.polito.it/</a></td>
</tr>
</tbody>
</table>

### Context of the research activity

Aerospace systems have to withstand a variety of mechanical and environmental loads during their life resulting in what is described as fatigue, wear, corrosion or any other type of degradation. A traditional way of designing engineering structures has been to consider a principle entitled ‘safe life’. In many of the cases a damage once being initiated will slowly grow. In the aerospace systems there is an absolute necessity to identify unexpected changes (faults) in the system before they lead to a functional breakdown (failure). Fault detection, isolation, and recovery (FDIR) is a subset of control engineering which concerns itself with monitoring a system, identifying when a fault has occurred, and underlining the type of fault and its location. Two approaches can be distinguished: a) direct pattern recognition of sensor readings that indicate a fault, and 2) analysis of the discrepancy between the sensor readings and expected values, derived from some model. In the latter case, it is typical that a fault is said to be detected if the discrepancy or residual goes above a certain threshold. It is then the task of fault isolation to categorize the type of fault and its location in the machinery. Fault detection and isolation (FDI) techniques can be broadly classified into two categories. These include model-based FDI and signal processing based FDI. Classically, hardware redundancy (multiple sensors with the same function) and thresholding were used to address fault detection. There is, therefore, the need to call upon analytical redundancy, i.e. to exploit mathematical relations between measured or estimated variables in order to detect possible dysfunctions. The resulting set of methods is commonly called model-based, where the last one should be understood as a
knowledge based dynamical model (usually a set of differential equations in state-space form). Many methods have been proposed to address model-based fault diagnosis. Moreover, aerospace operators are faced with increasing requirements to extend the service life of aerospace systems beyond their designed life cycles, resulting in heavy maintenance and inspection burdens as well as economic pressure.

System health monitoring (SHM) based on advanced sensor technology is potentially a cost-effective approach to meet operational requirements, and to reduce maintenance costs. Fiber optic sensor technology is being developed to provide existing and future aerospace systems with SHM capability due to its unique superior characteristics. To continue to meet safety, airworthiness and availability requirements, aggressive inspection and maintenance regimes are expected to be imposed, resulting in added costs of maintenance and support. Although conventional schedule-based inspections contribute greatly to the safety and reliability of these platforms, they are also the main contributors to the high operation costs. Additionally, these periodic on-ground inspections might require the disassembly and reassembly of inspected components, further increasing the potential for introducing damage and degradation of structures and auxiliary systems, such as electrical wiring and hydraulic lines. The concept of SHM stands to reduce the complexity and the costs associated with these traditional approaches, and the exploitation and implementation of SHM tools are expected to replace schedule-based inspections by the on-board and real-time monitoring to reduce platform life cycle cost, improve safety and reliability, and extend operational life cycle. A wide range of embedded and attached sensors have been studied for SHM applications, including strain gauges, accelerometers, fiber optic sensors, active ultrasonic sensors, passive acoustic sensors, wireless sensors, etc. Among them, fiber optic sensor has been emerging as an increasingly important tool for SHM due to their unique advantages in sensitivity, small size, quick response time, electromagnetic field immunity and multiplexing capability. Over several decades, a wide range of fiber optic sensor approaches have been intensively studied and widely implemented. Among these advanced candidates for the development of structural health monitoring systems, fiber Bragg gratings (FBG) have received the wider visibility and acceptance in both R&D and field applications. The recent trends in FBG-sensor based SHM for aerospace applications include the in-situ detection of strain, the hybrid use of FBG sensors and acoustic inspections designed for the damage detection inside components, and the highly multiplexed FBG sensor system for other related parameters detection.
The objectives of the research are summarized in the following points.

- The first step of the research program is focused on the definition of special algorithms in order to implement model-based FDI and signal processing based FDI, with special reference to BLDC and PMSM motors, hydraulic servo-valves and, more in general, servomechanisms.
- Then, a special study will involve the sensor packaging; packaging has the highest importance in terms of measure quality and reliability and easiness of the sensor integration. Materials of the substrate and techniques of bonding and agents will be defined and tested.
- The third step of the research will consider the integration of different types of sensors to increase the effectiveness FDI signal processing to achieve a more precise diagnosis. In this field techniques of sensor fusion will be applied, including virtual sensors and augmented reality tools.
- The final step will consider the testing of the solutions proposed, in terms of algorithms and sensors integration, for their validation. Some real application cases will be considered in the field of aeronautical and space engineering. The validation process will follow some aerospace qualified standards during both laboratory and on board in-flight testing. In particular, a flight test campaign on large flying models and general aviation aircraft will be arranged and conducted. Moreover, a laboratory experiments campaign in space qualified facilities will be performed as well as a tentative design of a payload for the in orbit testing will be conducted.

Skills and competencies for the development of the activity

Matlab programming, Simulink, Basics of CAD, CFD and FEM techniques. Basics of system engineering, electronics and lab testing.