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SHM AND NDT FOR COMPOSITE AIRCRAFT STRUCTURES

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Summary: SHM and NDT share a common objective, to detect local damages before they may affect the structural integrity of the structures; sometimes it is heard that SHM may supersede NDT technologies, which is far to be truth. SHM is understood as "the process of acquiring and analyzing data from on-board sensors to evaluate the health of a structure"; whatever technologies are used, it always works by comparing acquired signals obtained after service, respective to the signals obtained from the pristine structure. As such, it will never be able to do 'first inspection', looking for material discontinuities, which can be done with conventional NDT techniques.

Other main differences between SHM and NDT are:

- For conventional NDT techniques, an operator periodically evaluates the structural integrity with the help of external probes and equipments, like ultrasound, X-ray, or many other systems. It requires very often that structural parts need to be disassembled for inspection. That means usually a labour intensive activity, and drives to a time-based maintenance approach, looking to ensure that defects or flaws remain below a pre-established threshold, to apply damage tolerance design criteria.

- The key concept for SHM is that sensors are permanently attached to the structure, consequently, the parts do not need to be disassembled, inspections can be done on-line, even during flights, or during the overnight stops. The inspection can be automated, even the evaluation of results may be done without human intervention; the inspections can be done as frequent as requested, leading to the concept of condition-based maintenance. Because of it, significant savings are expected in the maintenance tasks, while keeping the same level of safety.

The underlying physical phenomena for NDT were known from the beginning of 20 century, but NDT methods started to be developed after World War II, as the emerging industry required more and more flawless components. First method coming to industrial application was radiography, and it was soon complemented by dye penetrate testing, Eddy currents, magnetic particles. Composite materials have pushed the development of ultrasonic inspection, and more recently, some contactless techniques, as infrared thermography, shearography and accousto-ultrasonics. NDT technologies are fully matured, it will not be discussed here, and it has been brought only to clarify the differences with SHM, and to highlight its potential.

The concept of attaching sensors to detect failures in mechanical systems was applied with great success during the '90s to the power transmission mechanism of the main and tail rotor helicopter, significantly reducing the number of incidents and accidents. Clearly the helicopter drive train is a complex system operating in highly variable and adverse conditions; any imperfections in gears and bearings are quickly amplified, threatening the safety of the helicopter. But it was enough to place accelerometers at the bearing supports, and to perform the FFT of the acquired signals, to obtain a reliable early warning system. The signal is very intense at the rotation frequency, any imperfection is manifested as a distortion of the frequency spectrum; Thresholds have to be set to warn for the anomaly before it becomes a threat. The same concept works equally well in any other rotating machines, such as power plants, wind turbine power plants, etc, and is a mature technology widely applied, known as ' Condition Monitoring '. SHM is its counterpart for static structures.

Every SHM system includes three key elements: 1) a network of sensors, permanently attached to the structure; as it was said, this aspect is a main differentiation with conventional NDT procedures. 2) On-board data handling and computing facilities, only available since the eighties. 3) Algorithms that collect data from sensors, clean data from environmental effects, compare to former data from the pristine structure and inform about occurrence, localization and damage type.

As sensor system to be built within the structure, three main types have been explored and their technology is now matured: Piezoelectric wafers, fibre optic sensors, formerly Bragg gratings and now distributed sensors, accelerometers and MEMS.

Accelerometers were the first sensors to be used, in combination with Damage Detection algorithms based on Modal Analysis, or vibration techniques. They afford information on damage happening anywhere in the whole structure, but resolution is low, damage size need to be large enough to influence the global vibration modes.

Several piezoelectrics (PZTs) can be easily bonded/embedded into the structure, with the desired array. From these points, they may launch/receive elastic waves, existing three basic interrogation approaches (algorithms): Acoustic emission, electromechanical impedance, Active sensing diagnosis system (pitch-catch method). The range of inspection is very local, just around the sensors, for the first two techniques, and limited to the emitter-receiver path for the active interrogation. The biggest obstacle for a wider application of these technologies into aircraft structures lies in the waviness nature of the excitation, which propagates quite well in plates of uniform thickness, but suffer complex reflection and refraction phenomena at each thickness changes; the elastic waves can hardy jump over stringers and reinforcements, thus requiring PZTs are located at each bay.

Optical fibres are very good strain sensors, but again, its ability to detect a damage happening somewhere else from the sensor position is limited. A local crack may be the failure initiation point, but its influence on the far-field strains is very small. Some algorithms based on pattern recognition and artificial Neural Networks are currently being developed.