

Chapter 1

Introduction



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The aerospace industry is aiming for a cleaner means of transport. One way to achieve this is by making transportation lighter, thus directly improving fuel efficiency and reducing environmental impact. A further aim, of the industry, is to reduce maintenance time to lessen operating costs, which can result in a reduction of air transport costs, benefitting both passenger and freight services. Current developments to support these aims include using advanced materials, with the current generation of aerospace structures being 50% composite materials. These materials offer a weight reduction whilst maintaining adequate stiffness; however, their damage mechanics are very complex and less deterministic than those of metals. This results in an overall reduced benefit. Structures are manufactured thicker using additional material to accommodate unknown or unpredictable failure modes, which cannot be easily detected during maintenance. A way to overcome these issues is the adoption of a structural health monitoring (SHM) inspection system.

Structural health monitoring (SHM) is understood to be the continuous or periodic and automated method for determining and monitoring the condition of a monitored object within condition monitoring (according to DIN ISO 17359). This is conducted through measurements with permanently installed or integrated transducers and the analysis of the measurement data. Its purpose is to detect damage, for example, cracks or deformations, at an early stage to initiate countermeasures. A frequently quoted example for SHM is the human skin, whose pain receptors provide

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spatially resolved and timely information about both physical stress and state of health.

An SHM system comprises the monitoring object with transducers, signal acquisition and transfer units and data storage devices, the data processing system and the (automated) diagnostic system. The determination of the status of the monitored object can be conducted in various degrees of detail. This can include the current recording of the stress (e.g. as a result of an acting load or environmental influences), damage detection and the determination of the type of damage up to the assessment of the effects (the integrity of the monitored object, stability and load-bearing capacity). Objects to be monitored are primarily structures with load-bearing properties and/or frequently statically supported structures.

In the case of aerospace applications, these structures are landing gears, wing boxes, tails, struts and other load-bearing primary structures of the aircraft. For helicopters, rotor blades and their attachment structures, as well as the life cell of the helicopter, are the primary targets for SHM applications.

The knowledge about the existence of critical internal defects stems from their relevance during the operation of aerospace structures. Usually, tests of components are conducted according to fixed times in intervals regulated by flight safety standards. The inspection intervals must be selected in such a way that damage is detected with a given certainty before total failure of the structure occurs.

In contrast to this (classical) approach, the SHM method provides characteristic values at any time, which results in information on whether or not the damage is present. Airlines expect to save up to 40% in maintenance time through this determination alone. Additionally, to the sole knowledge about the damage, the second step is to determine the location and size of the damage, so that in the third step, a statement can be made as to what influence the damage has on the properties of the structure and whether or not it is necessary to replace the component immediately.

Acoustic emission (AE) and acousto-ultrasonics (AU) (10–1000 kHz) based SHM systems that utilize energy harvesting for power generation and wireless sensor networks for communication are being increasingly demonstrated to be effective in monitoring damage in simple plates and aerospace components in a laboratory setting. AE is a passive system that detects and locates stress waves as a structure undergoes damage. AU is an active system that sends out waves and monitors, periodically, for changes in the received wave to identify structural damage. Batteries are currently not allowed within aerospace structures, and the addition of cables to power a system or transfer data adds increased weight to the aircraft, removing any benefit. Hence, energy harvesting and wireless communication are essential for any aerospace SHM system as schematically outlined in Fig. 1.1. Furthermore, the large data sets produced need reliable analysis to deliver prognosis and methods of interpretation that non-specialists can understand. Additionally, vibration-based monitoring methods have been developed with a certain degree of maturity for civil engineering applications. The transfer of the established approaches to aerospace structures has been demonstrated on the lab scale and seems promising for SHM in aerospace structures as well. Finally, the use of strain

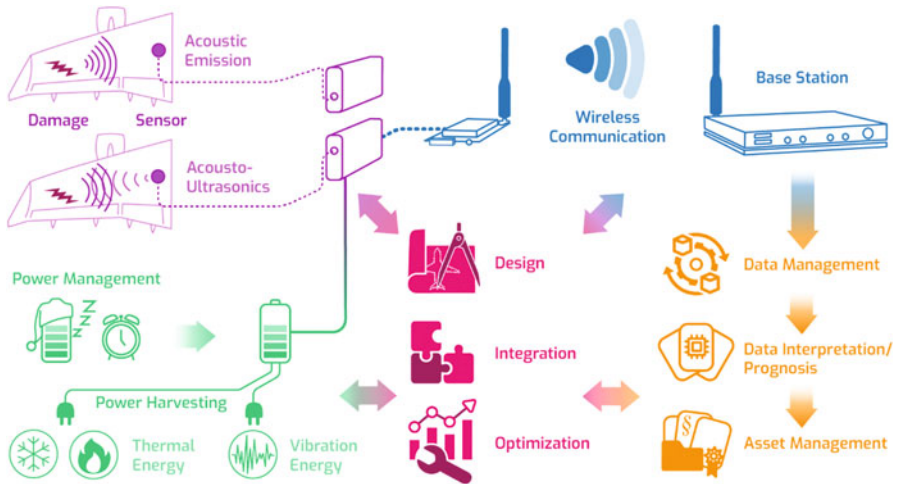


Fig. 1.1 Schematic for the operation of SHM system in aerospace applications

measurement systems in aerospace structures is existent for decades. Modern methods using optical fiber system are emerging in this field and provide an interesting portfolio of applications exceeding the performance and drawbacks of the classical strain gage-based monitoring methods.

COST action ‘Optimizing design for inspection’ (ODIN) CA18203 brought together experts in the fields of NDE/SHM, energy harvesting and wireless sensor networks to integrate these in an aircraft structure, designed and optimized for the implementation. This COST action aims to advance Europe’s position of strength in the aerospace industry through the development of optimized intelligent structures integrated at the design inception phase. The objective of this action is to develop an integrated framework for optimized self-sensing structures capable to diagnose damage as envisioned in Fig. 1.2. The idea is to develop in-service, continuous monitoring of critical aerospace structures by integrating non-destructive evaluation, energy harvesting and wireless sensor technologies at the design phase. This should improve the maintenance effectiveness, by reducing operating costs and, at the same time, increasing safety. To achieve the main objective, the state of the art of the SHM damage detection systems, including sensing technologies, reliability/durability and data acquisition, must be reviewed; methods for delivering the improvement of damage detection need to be identified. Furthermore, the state of the art of the current signal processing techniques must be evaluated. Signal processing techniques, which can identify/classify damage characteristics and parameters, need to be determined.

Within this publication, this network of experts compiled the current status of SHM systems as existent in 2020. Subsequent to this introduction, Chap. 2 will provide an overview of the typical targets of SHM applications in aerospace alongside a definition of its understanding throughout this work. Chapter 3 will

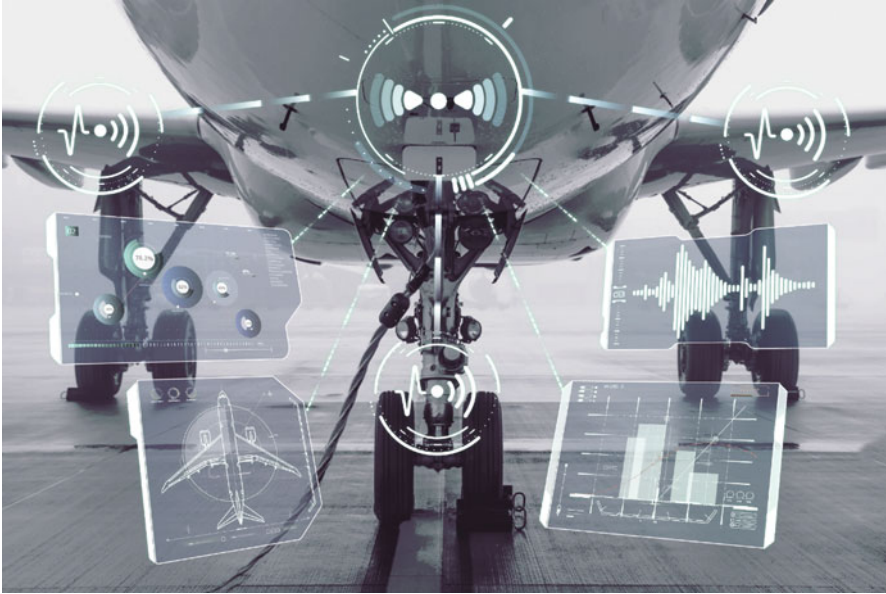


Fig. 1.2 Vision of SHM integration in future aircraft solutions

introduce the typical defects encountered in the materials that are used for primary aerospace structures. Chapter 4 will then set the aerospace requirements for the implementation, operation and reliability of SHM systems. Various techniques that are currently applied in aerospace applications are introduced and elaborated throughout Chaps. 5 to 8. Chapter 9 has its focus on the use data reduction strategies and the use of wireless sensing systems in this context. The work closes with a conclusion in Chap. 10 on the current state of the art of SHM systems to provide an up-to-date reference for future developments.

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