

TFT-FOS
Technobis Fibre Technologies
Fibre Optic Sensing



Successful 2nd Test Flight

TFT-FOS and the Dutch National Aerospace Laboratory (NLR) made their first successful flight test with the Deminsys C interrogator on 24 October 2008.

This first flight was performed with the PH-NLZ test aircraft, a Fairchild Metro II twin turboprop aircraft with pressurized cabin. It demonstrated the initial feasibility of the FBG sensor technology and specifically the Deminsys interrogator for use in an aircraft environment.

After the flight-safety qualification, the second flight test was scheduled and, on 30 December 2010, the Ultra finally made its maiden flight on the PH-LAB test aircraft, a Cessna Citation II jet aircraft with pressurized cabin.

The aim of this flight was to validate the Deminsys Ultra in-flight against a reference data-acquisition system.

Analysis of the in-flight recorded data of both systems demonstrated that the Deminsys successfully reached a Technology Readiness Level of five (TRL5).

Aerospace

A flight approved system for FBG interrogation for Structural Health Monitoring (**SHM**) is developed and tested. The design of the new system is revolutionary (light weight, compact and solid-state).

SHM includes all monitoring aspects which have a direct link to structure integrity. SHM offers reduced cost of ownership through condition-based maintenance, extended service life (Fatigue Life Assessment), and reduced risk of failure. Automated inspection means time savings and a reduction of the Human Factor.

Fibre optical systems are lightweight, small, and easy to integrate into/onto composites and other materials. Due to the fact that many sensors can be integrated into one optical fibre, the sensor network becomes much simpler when compared to electrical sensor networks.

Fibre optical sensors are EMC insensitive and safe. These sensor systems can be used for predictive health monitoring and realtime monitoring during flight.



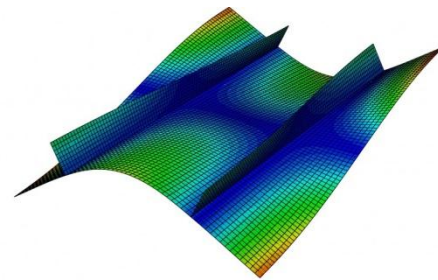
1 DAMAGE IDENTIFICATION WITH OPTICAL FIBRES IN COMPOSITES

During the last year considerable effort has been put in the application of optical fibres with Fibre Bragg Grating sensors for damage identification in composite structures. This is a collaboration between TFT-FOS, the National Aerospace Laboratory (NLR) and the University of Twente.

Aircraft require regular costly inspections to guarantee their safety. This currently mainly relies on manual non-destructive inspection methods. During the last century, a lot of research has been dedicated to more automated systems called Structure Health Monitoring (SHM), which consists of a network of sensors to detect changes in the physical and/or geometric properties of a structure from data gathered at two different states, a reference state, considered as the undamaged state, and the current state. Changes can be caused by damage present in the structure. SHM techniques can be operated on-line during the flight or off-line on the ground and can be focused on global inspection of large surface areas or on local inspection of highly critical areas (hot spots). The main objectives of SHM are to reduce the cost of ownership and to improve the system operational availability.

The objective was to examine vibration-based response characteristics of a structure, such as: natural frequencies, mode shapes, modal strain energy, and determine which of these can serve as a damage indicator in a SHM system based on optical fibres. Several vibration-based damage indicators were evaluated for damage types relevant for aerospace applications such as cracks in aluminium structures and impact damage and stringer debonding for composite structures.

This research focused on the methodology to extract damage information by comparing the measured response signals on the current state of a structure against an initial (undamaged) state of the structure.



In general, four consecutive levels of damage identification can be distinguished of increasing complexity:

1. Determination that damage is **present** in the structure
2. Determination of the **location** of the damage
3. Quantification of the **severity** of the damage
4. Prediction of the **remaining service life** of the structure

Besides optical fibres various other sensors are available. Optical fibres have a number of advantages for application in an aerospace structure, of which the most important are:

- Light weight
- Tolerant for harsh environments, such as temperature and chemical components
- Long term stability and durable
- Completely passive
- No interference with other signals in the aircraft

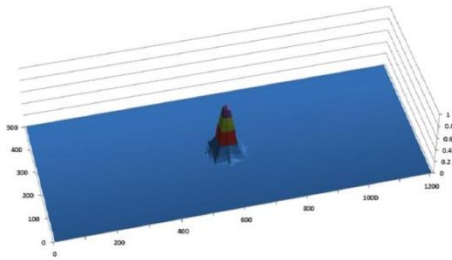
Numerical results obtained for a cracked aluminium plate and a two-stiffener composite plate with impact damage and stringer debonding have demonstrated that the presence of various damage types can be detected and located with a limited number of sensors by means of the change in modal strain energy, yielding a level 2 structural health monitoring system. For a sufficiently large number of sensors the damage size (level 3) can be determined as well.

The experimental investigation has been performed by the University of Twente on a cantilever composite beam structure. Dynamic properties, like natural frequencies and strain mode shapes, were obtained by using a forced vibration set-up including optical fibre Bragg gratings and by applying Operational Modal Analysis. Currently, this work is extended to the two-stiffener composite plate structure.

2 SHM AND IMPACT DETECTION FOR PRIMARY AIRCRAFT STRUCTURES

High-speed, synchronous interrogation using multiple fibre bragg grating sensors enables design and delivery of robust inspection and analysis systems.

The increasing use of thermoplastic carbon fibre-reinforced plastic (CFRP) materials in the aerospace industry for primary aircraft structures, such as wing leading-edge surfaces and fuselage sections, has led to rapid growth in the field of structural health monitoring (SHM). Impact, vibration, and load can all cause failure, such as delamination and matrix cracking, in composite materials. Moreover, the internal material damage can occur without being visible to the human eye, making inspection of and clear insight into structural integrity difficult using currently available evaluation methods.



Here, we describe the detection of impact, its localization, and its potential damaging effects on materials and structures by high-speed interrogation of multiple-fibre bragg grating (FBG) sensors mounted on a composite aircraft component

Working with several knowledge partners within the aerospace industry, we are developing different solutions for monitoring aspects of the structural integrity of aircraft structures and materials. One of these solutions is what we call impact detection: determining impact location and energy to assess potential damaging effects. We compare the impact energy level with the structural strength of the exposed surface, which in turn facilitates decision making regarding next steps in accordance with common condition-based maintenance concepts.

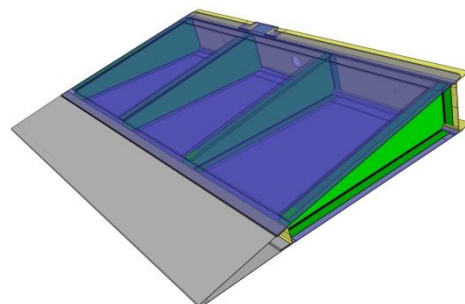
Impacts cause local elastic deformations in the affected material surfaces that propagate through the structure like waves. These local deformations are measured by FBG sensors placed at several locations on an aircraft part. Combining and comparing the information relayed by the sensors enables the system to calculate the location and energy level of the impact.

We designed and built an experimental test setup consisting of a composite aircraft component equipped with an FBG sensor network of four sensors in one optical fiber, our lightweight, small, high-speed Deminsys interrogator, and a data acquisition and processing platform.

The composite aircraft component currently used is a thermoplastic wing-control surface that consists of two skin plates, four ribs, two spars, and a folded plate to cover the trailing edge. The test setup provides real-time feedback on impacts and the condition of the material. We began by carrying out a proof of concept using a flat, homogeneous composite plate as a test specimen.

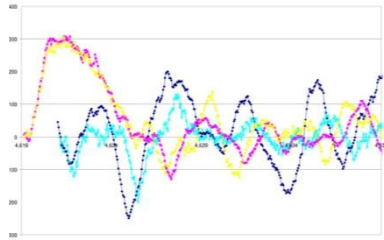
We placed FBG sensors at the outer edges of the long side of a plate. Impacts were generated by striking the specimen with a hammer. The position of the impacts was calculated based on a time differential equation of the sensor signals. The impact intensity level was calculated according to the weighted sensor strain amplitude level. The 20kHz sampling speed makes it possible to evaluate the sensor signals with a time resolution of 51µs. We were able to determine the location of impact with an accuracy of ~5cm.

For the next phase we selected a complete composite wingcontrol surface for the setup with the aim of identifying the influencing parameters of the elastic wave propagation and sensor detection through experimental analysis. We attached four FBG sensors to the wing-control surface, which had outer dimensions of 1200x500mm.

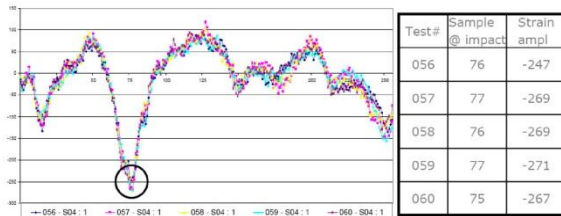


SHAPE SENSING USING OPTICAL FIBRE SENSORS

The graph below shows the measurement signals, representing the mechanical strain versus time, following a simulated impact. The difference between the arrival time of the impact waves at the different sensors provides a measure of the impact location. The sum of the weighted strain amplitude levels of the sensors calculates the impact energy.



We demonstrated the repeatability and accuracy of the method by comparing the measurement signals for five tests of one FBG sensor. For the timing accuracy we found ± 1 measurement sample deviation across the five consecutive tests, which equals a measurement accuracy of $< 51.8\mu s$. For the strain amplitude measurement, the deviation is less than 10% as shown in the image below.



3 RESULTS

Development activities are in progress, and initial results confirm the expected good potential of the method for SHM. In addition to these initial results, we found that impacts below 1.0 Joule can be detected across the wing section (see Figure 5), a layout with four sensors shows promising results, and the ribs and spars in the structure have a significant influence on the behavior of the elastic impact waves.

The location of an impact on a surface can in principle be determined with a minimum of three FBG sensors. We use four because the redundant sensor helps to validate the impact location provided by the other three sensors and to more precisely calculate it. Finally, the prediction of the impact location shows good correspondence with the actual point of impact.

Our investigations are currently focusing on different parameters related to elastic wave-propagation characteristics such as propagation speed and deflection amplitudes. These parameters include the mechanical properties of the structural material (i.e., stiffness at the impact and sensor locations and internal components of the structure's configuration, such as spars and stiffeners), the energy of the impact, the velocity of the object on impact, and the hardness of the object. A better understanding of the effect of these parameters on elastic wave propagation will help to improve our impact analysis algorithms and methods.