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Experimental analysis of jet engine air channel impact resistance by means of strain gauges and FBG sensors

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Abstract. New generation of the jet trainer is being developed based on the aerodynamic concept of the original L-39s, but contemporary technology and equipment are utilized. The composite air channel is one of the important parts, which are newly designed. One of the requirements for the air channel is a birds and hail strike resistance. Numerical simulation of impact loading must be compared with experimental results and this article focuses on the description of data acquisition from the impact experiment using a strain gauge and a Fiber Bragg Grating (FBG) optical sensors and comparison of experimental data with numerical solution.

Introduction

The jet trainer L-39 Albatros is legendary aircraft and almost three thousand manufactured planes are still operated by many air forces around the world. The new generation of jet trainer represents deep modernization of the L-39 combining latest engine and aircraft systems technology with traditional advantages of legacy L-39s such as excellent handling qualities, easy maintenance, robust design and low operational costs. One important element of the structure is the air channel. The new air channel design is based on a composite material, with a view to increasing life and using a new jet engine. One of the requirements for aviation structure is resistance to bird and hail impact [2, 3]. The Czech Aerospace Research Centre (VZLÚ) has the equipment and a lot of experience with this type of tests. The prototype of the air channel was attached to the test stand, and tests were carried out in the VZLÚ. The results obtained using a strain gauge and FBG sensors during tests are described in this paper.

Composite Air Channel

A complete air channel (see Fig. 1) is composed of three main components parts. The main material used for the air channel is pre-impregnated carbon fibre reinforced plastic (CFRP), A193-PW Hexply fibre with 8552 epoxy matrix. This particular combination is used due to previous experience of Aero Vodochody Aerospace (AVA) with the material. Carbon fibre is used for its high strength to weight ratio. Woven fabric is desirable for its higher impact resistance and due to the complexity of the part shape. The minimum used number of CFRP layers is 12, while the maximum no. of layers is 24 at the main reinforcement.

Left and right parts of air channel are connected by means the air channel brace, and the brace is fitted to the fuselage by using four rods, which are main load connections between the fuselage and the air channel. Air channel extension was not included in experiment setup.

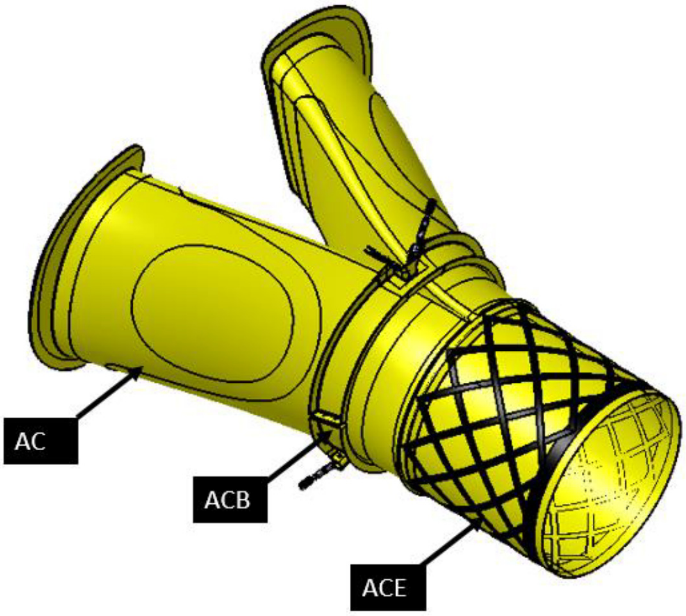

Fig. 1: A figure example (no punctuation here) Composite air channel (AC – Air Cannel, ACB – Air Cannel Brace, ACE – Air Channel Extension) [4]

Impact Experiments

The impact experiments were made at the VZLÚ according airworthiness requirements [1]. The composite air channel without extension (see Fig 2 left) was installed to the test bed simulating real stiffness of fuselage and it was impacted by bird and hails fired by an air gun (see Fig. 2 right).

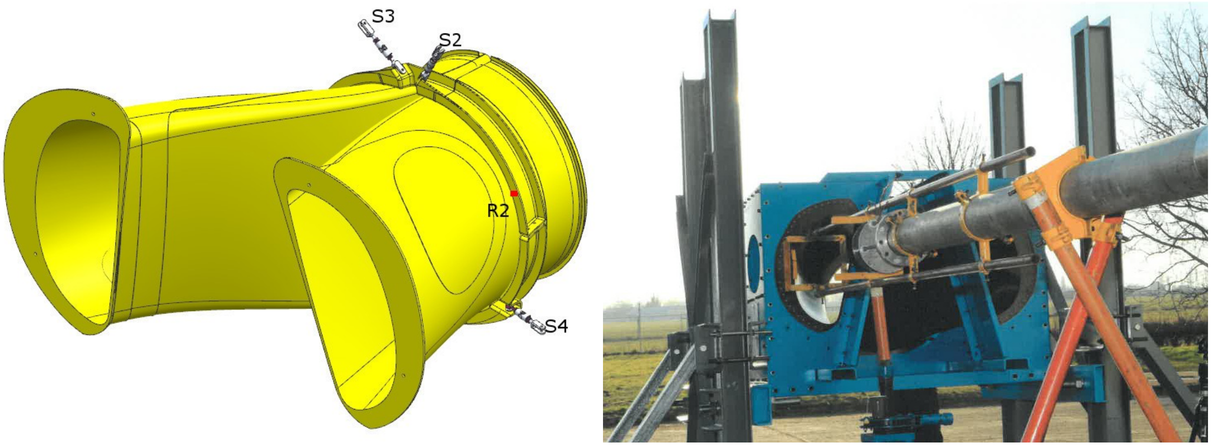

Fig. 2: Location of instrumented rods (left) and installed air channel in test bed (right)

Left inlet was impacted by 1 kg bird (Bird Strike) and right inlet was impacted by series of 50 mm (Hail Strike 1, 2) and 25 mm hails (Hail Strike 3 – 5). Loading of rods and air channel parts was monitored by sensors and displacement was filmed using the high speed cameras.

Strain Gauge Instrumentation

The air channel was connected with the test bed by means of the four instrumented rods. Two strain gauges T rosette HBM XY11-3/350 were installed on each rod and the full bridge connection was used to determine the axial load transmitted by the rod and to eliminate temperature affecting the measured strain, see Fig. 3 left. Calibration of the instrumented rods was done on the material load machine before and after impact tests (see Fig. 3 right) to obtain relationship between measured strain and loaded force.

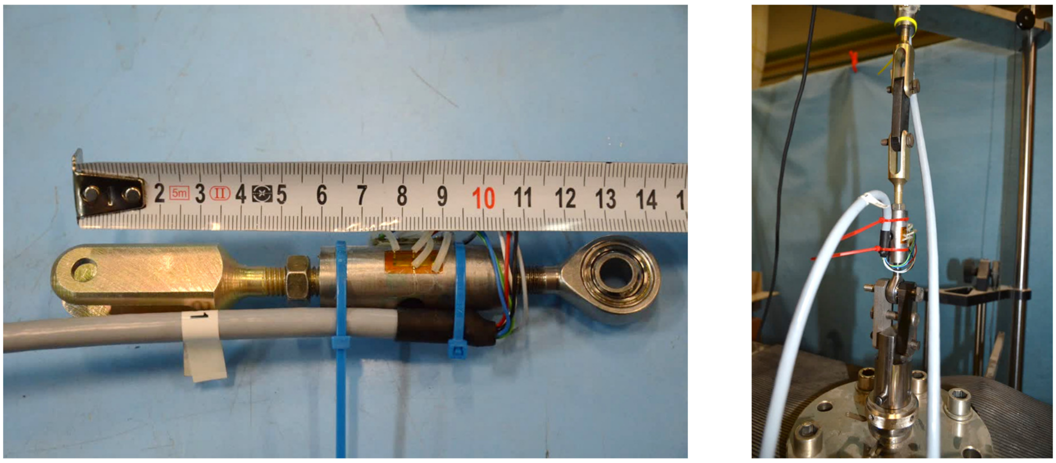

Fig. 3: Instrumented rod (left) and calibration by load machine (right)

Signals from strain gauges were measured by HBM Quantum measurement unit with 19.2 kHz sample frequency, see Fig. 4 where measured data for bird strike experiment are plotted. Reaction forces were computed from signals multiply by obtained calibration constants [5].

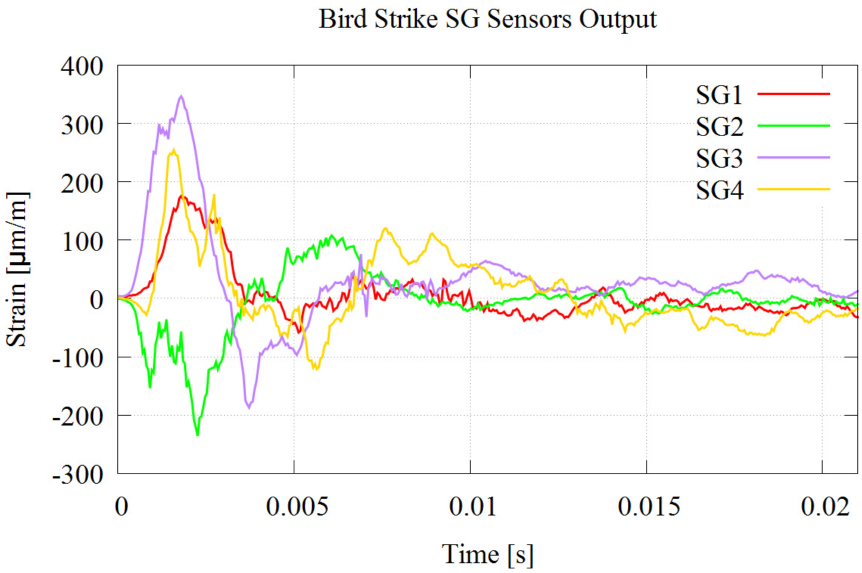

Fig. 4: Measured signal of loaded rod during bird strike

FBG sensors

Two optical fibres with total of nine FBG sensors were installed on the outer surface of air channel. Sensor position on the left part of air channel can be seen in Fig. 5. So-called draw-tower ORMOCER® coated optical fibres were used to ensure reliability during the impact, with the following configuration:

1. Left air channel part: 5 pcs of FBG sensor, outer diameter of optical fibre 0.195 mm, grating length 8 mm, central wavelength: 1505 nm (FBG1), 1510 nm, 1515 nm, 1520 nm, 1525 nm (FBG5), routing of optical fibre and locations of single FBG sensors are pictured in the left part of Fig. 5.
2. Right air channel part: 4 pcs of FBG sensor, outer diameter of optical fibre 0.195 mm, grating length 8 mm, central wavelength 1529 nm (FBG1), 1533.5 nm, 1538 nm, 1542.5 nm (FBG4), routing of optical fibre and locations of single FBG sensors are pictured in the right part of Fig. 5.

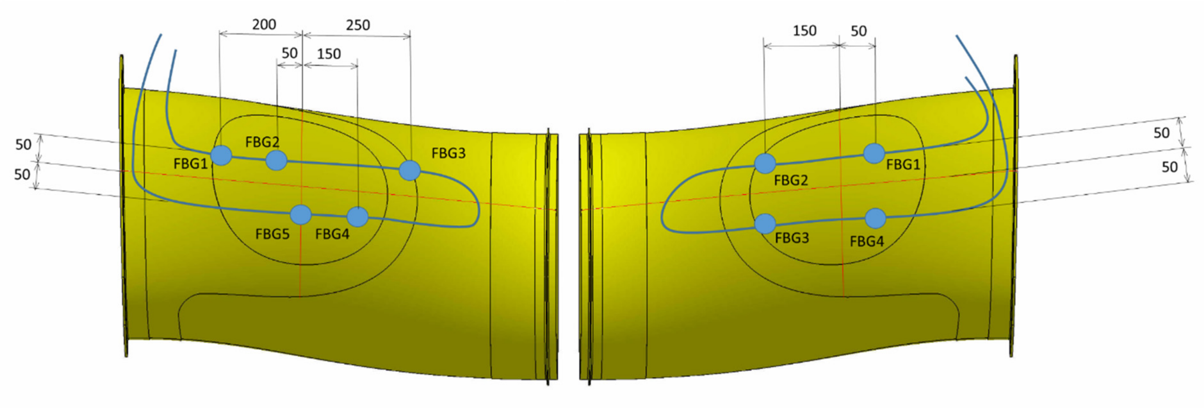

Fig. 5: FBG sensors configuration on the left (left) and right air channel part (right)

Fibre optic sensors were installed onto the cured air channel surface (see Fig. 6), because due to the complicated air channel prepreg composite lay-up process it wasn't possible to embed any sensors inside the structure. In the first step, optical fibres were fixed on the cleaned and degreased surface using the cyanoacrylate adhesive. In the next step, FBG sensors were completely covered using the hand lay-up composite process (combination of thin Glass fabric and L285 epoxy resin system). The remaining parts of optical fibres were protected using the thick layer of epoxy resin with glass micro-balloons. Both ends of the optical fibre were fusion spliced to the protective cables with FC/APC connectors. These splices were also covered and protected by the glass fabric. Careful protection of FBG sensors and optical fibre routing was important because of harsh conditions during the final assembly of the air channel and its preparation for impact test (placing inside the test-bed, other measurement methods instrumentation etc.).

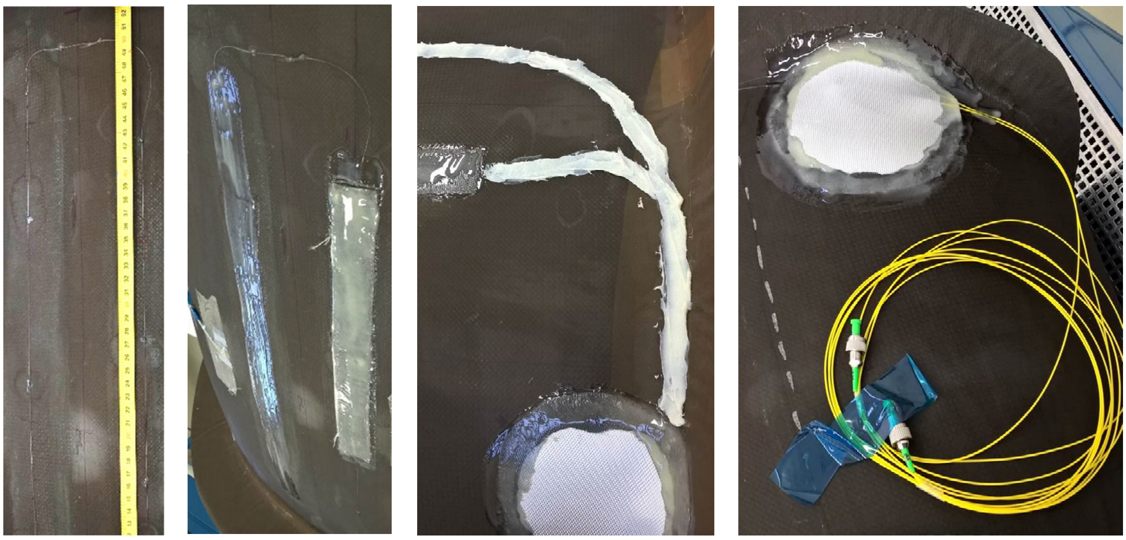

Fig. 6: FBG sensor installation procedure (from left to right): 1. Optical fibre fixed on the air intake surface; 2. Covering layer applied over the FBG sensors area (thin Glass fabric / Epoxy resin); 3. Covering layer to protect optical fibre routing (mixture of epoxy resin and micro-balloons); 4. Glass fabric protection of fusion splices and optical pigtails with FC/APC connectors

Safibra FBGuard 1550 FAST DAQ device was used to capture signal from the FBG sensors. Mechanical strain from FBG sensors versus time was measured with maximum frequency of 11.6 kHz, which is enough to cover impact load itself plus air channel twisting and bending after impact. All FBG sensors were able to measure during the whole test campaign. Signal measured by FBG sensors during bird strike test can be seen in Fig. 7, data from hail strike tests are shown in Fig. 8 and 9.

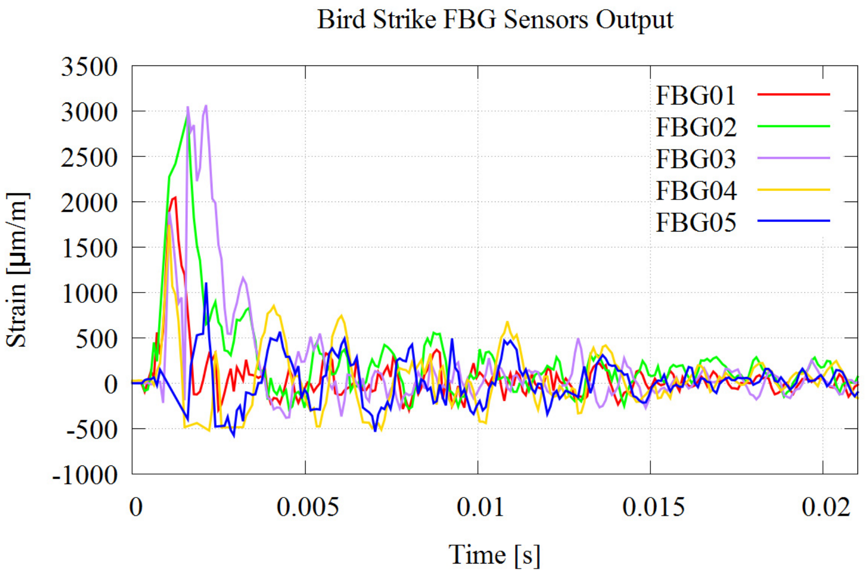

Fig. 7: Strain measured by FBG sensors on left inlet during bird strike

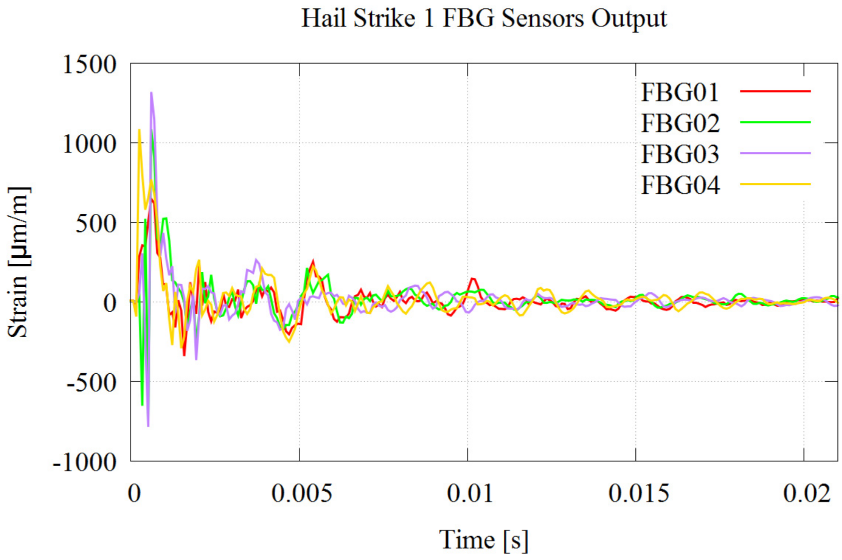

Fig. 8: Strain measured by FBG sensors on right inlet during hail strike 1

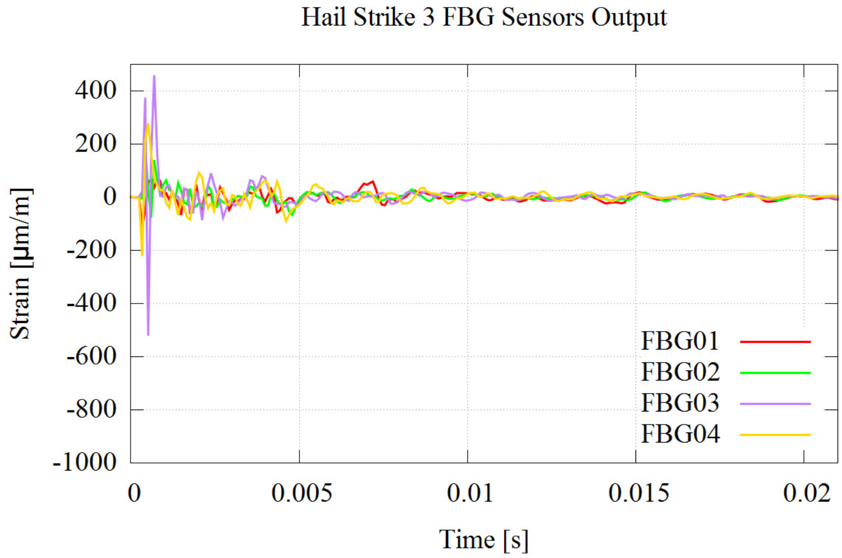

Fig. 9: Strain measured by FBG sensors on right inlet during hail strike 3

Numerical Simulation

Numerical simulation bird strike was made by VZLÚ. A bird strike is a high-velocity impact in which materials with a huge difference in properties come into contact with each other, resulting in nonlinear material behaviour, high strain rates, and extremely large deformations. Nonlinear finite element software has the capability to predict the loads and deformations of both the bird projectile and the complex aircraft component being impacted within acceptable levels of accuracy. In high-velocity impacts, the pressure on the bird tissues severely exceeds their limits, causing the bird material to behave like a fluid. An explicit solver of the ABAQUS FE software was used for numerical simulation, when geometry of bird projectile was simplified and elastic-plastic material model was used [6, 7]. The Smoothed Particle Hydrodynamics technique was used for projectile model damage propagation [8, 9]. Data from numerical simulation of bird strike was compared with experimental data with good agreement, see Fig. 10 where are plotted reaction force measured by means instrumented rods versus computed reactions.

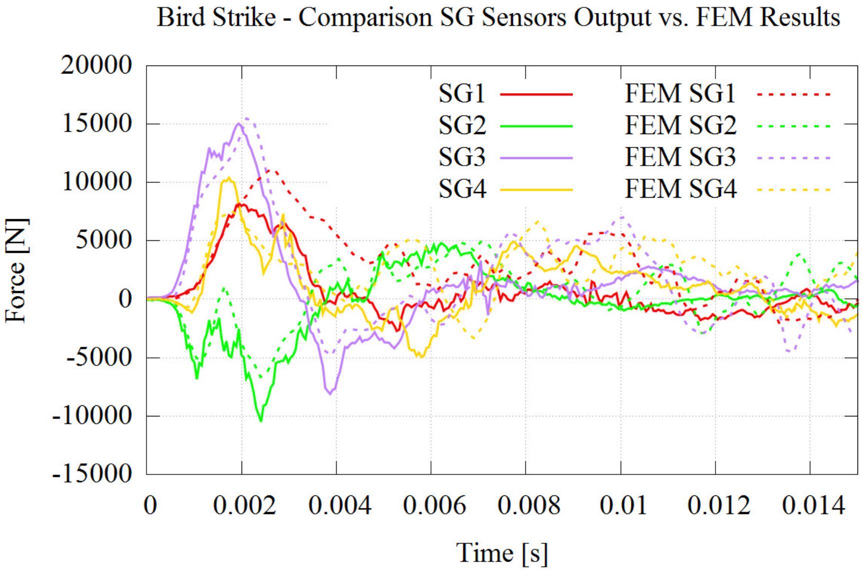

Fig. 10: Comparison measured and computed signal of loaded rod during bird strike

Comparison of strains measured by FBG sensors and computed results is plotted in Fig. 11.

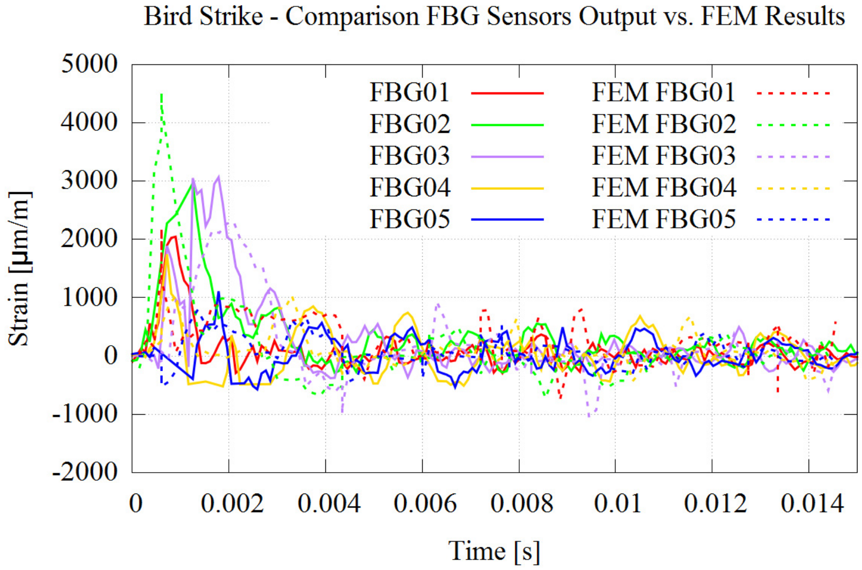

Fig. 11: Comparison measured and computed signals on left inlet during bird strike

Conclusions

Impact resistance of the composite air channel was confirmed. Strain Gauges were used for measurements reaction force during impact tests. Numerical simulation of bird strike was made and obtained experimental data and numerical simulation are in good agreement. It was proven that it is possible to make durable connection between the cured Carbon/Epoxy composite and optical fibre/ FBG sensor using the hand layup manufacturing method. All optical fibres and FBG sensors were functional during the complete impact load test. No sensors were detached from the composite surface. FBG sensors provided good data source for numerical analysis of the structure.

Acknowledgement

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