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First Flight with Deminsys C interrogator

Technobis Fibre Technologies

1 INTRODUCTION

Technobis Fibre Technologies (TFT) is a company within the Technobis Group and is specialized in the development and supply of high speed / multi sensor fibre interrogator modules and sensors.

Technobis Fibre Technologies was founded in 2006 and focusing on the development of a high speed multi sensor / multi channel system for FBG interrogation to expand the use of FBG sensors up to the audible sound frequency range making it suitable for research on resonances and eigen frequency responses in high demanding environments.
The development resulted in the Deminsys 850nm, 19,3 kHz FBG interrogator system with max. 32 sensors.

" Deminsys is the fastest multi sensor / multi-channel FBG interrogator system in the market and that means it is very suitable for several fast, dynamic applications. "

By having multiple sensors per fibre you can create a very compact network of sensors. Due to its revolutionary (low weight, compact and solid state) design, Deminsys fit's perfectly into (research) programs for aerospace, medical & life science, industrial, maritime and crash test applications.

Technobis Fibre Technologies (TFT) and the Dutch National Aerospace Laboratory (NLR) made a first test flight with the Deminsys optical fibre measurement system using the NLR test aircraft PH-NLZ on October 24th 2008. The NLR's PH-NLZ test aircraft is a Fairchield Metro II, a twin turboprop aircraft with pressurised cabin. The PH-NLZ is equipped with independent electrical circuits and has special adaptations and accommodations for testing of measurement equipment and sensors.

2 OBJECTIVES

The aim of the flight test program is to demonstrate the initial feasibility, or Proof of Concept, of the FBG sensor technology and especially the Deminsys interrogator for use in an aircraft environment.
For this First Flight the Deminsys C 850nm 4-channel interrogator made by TFT is used.

Three parameters are selected to be recorded during several flight operations:

- Temperature, of the inner fuselage skin
- Strain, of the central wing connection beam
- Pressure, differential pressure between cabin and outside atmosphere

These parameters are measured using two optical fibres: one with 2 FBG's for strain and temperature reading, and one fibre with 1 FBG for the pressure transducer. For redundancy and backup reason there are 2 sets of fibres and sensors installed in the aircraft. A detailed description of the sensors and measurement parameters is given in chapter 3.

The PH-NLZ aircraft is equipped with a "conventional" data acquisition system, which enables a comparison with the system under evaluation. The chapter 'Flight Data Analysis' will go into detail on this comparison between readings of the optical FBG sensors and the conventional sensors of the aircraft.

3 FBG SENSORS & MEASUREMENT PARAMETERS

3.1 FBG sensors

A fiber Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation to the refractive index of the fiber core, which generates a wavelength specific dielectric mirror.

For redundancy and backup reasons there are 2 sets of fibres and sensors installed in the aircraft.

The FBG sensors have the following basic characteristics:
Fibre type: monomode type : SM750 & acrylate recoat
FBG length 10 mm
Center wavelength: between 830 and 865nm, actual values: 852.75 nm and 858.25 nm +/- 0.5 nm
Spacing between wavelength FBGs>=4.5nm
Reflectivity: >=90%
Spectral bandwith: <0.15nm @3dB

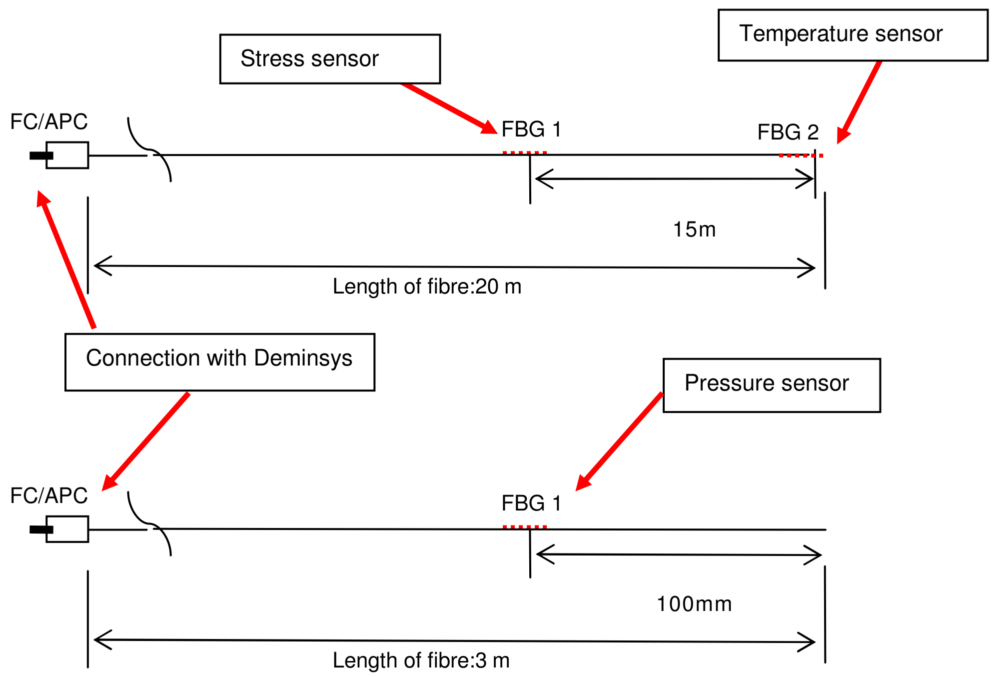

Figure 1: A sketch of the 2 fibres with FBG's

3.2 Measurement parameters

3.2.1 Fuselage inside skin temperature

The temperature of the fuselage inside skin is measured on a location in the rear side of the aircraft as no isolation material is mounted in this area.
The expected bandwidth of the temperature ranges is from -30ºC to 20ºC.

The temperature sensor exist off a FBG sensor attached to an aluminium carrier plate. This option of attachment of the FBG sensor to an aluminium carrier was chosen to increase the sensitivity and thereby enlarge the measurement resolution of the system.
To make the temperature sensor insensitive for mechanical pressures and deformations, the FBG with the aluminium carrier is placed in a aluminium case in which it can move freely. For proper thermal transfer the casing is partly filled with heat compound. The aluminium case has following outside dimensions: 30x20x2mm. The aluminium case is directly glued with X60 adhesive to the skin of the airplane. The reference temperature sensor is a PT 100 device which is attached by adhesive to the cover of the case.
See figure 2 for a photo of the temperature sensor.

Figure 2: temperature sensor with aluminium encasing

3.2.2 Wing beam strain measurement

The wing beam connects the left and right wing by a mechanical construction under the cabin floor. On this position the strain level was recorded. See the sketch in figure 3.

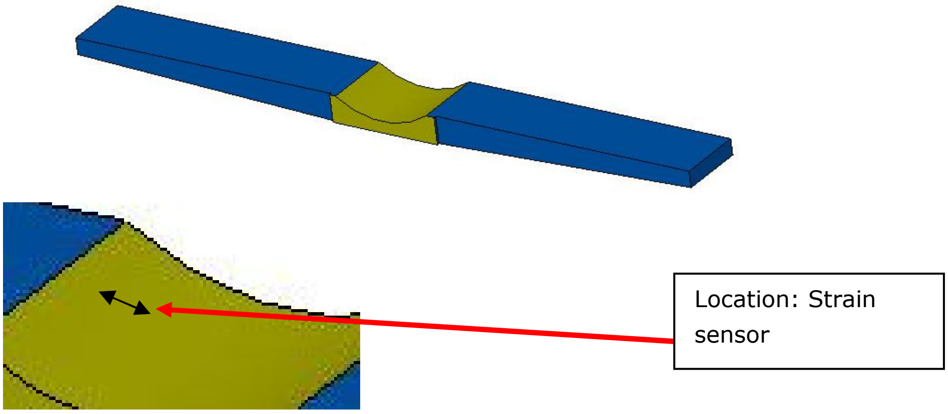

Figure 3: Sketch of the wing beam and strain sensor location

On this wing beam the strains are measured which are representative for the vertical loads on the aircraft wings. The FBG sensor was glued with X60 adhesive directly on the wing beam on a location next to an already present conventional resistive strain gauge. See figure 4.

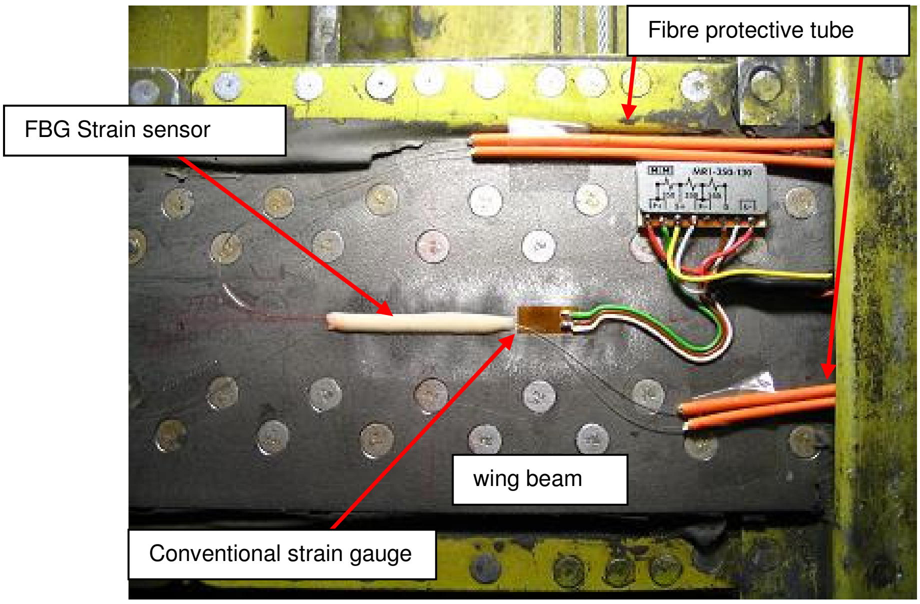

Figure 4: wing beam with FBG strain sensor and strain gauge

3.2.3 Atmospheric pressure measurement

The differential pressure between the cabin and atmospheric outside pressure was measured by means of a membrane type pressure transducer. The pressure range of interest ranges from 1050 to 500 mbar.
Figure 5 shows a sketch of the pressure transducer we designed for this application. A thin membrane plate of approximately 45mm diameter separates pressure chambers connected to cabin pressure on one side and outside atmospheric pressure on the other side. The resulting deformation of the membrane due to pressure differences in the two pressure chambers is measured by a FBG strain sensor which is glued in the extension of the membrane.

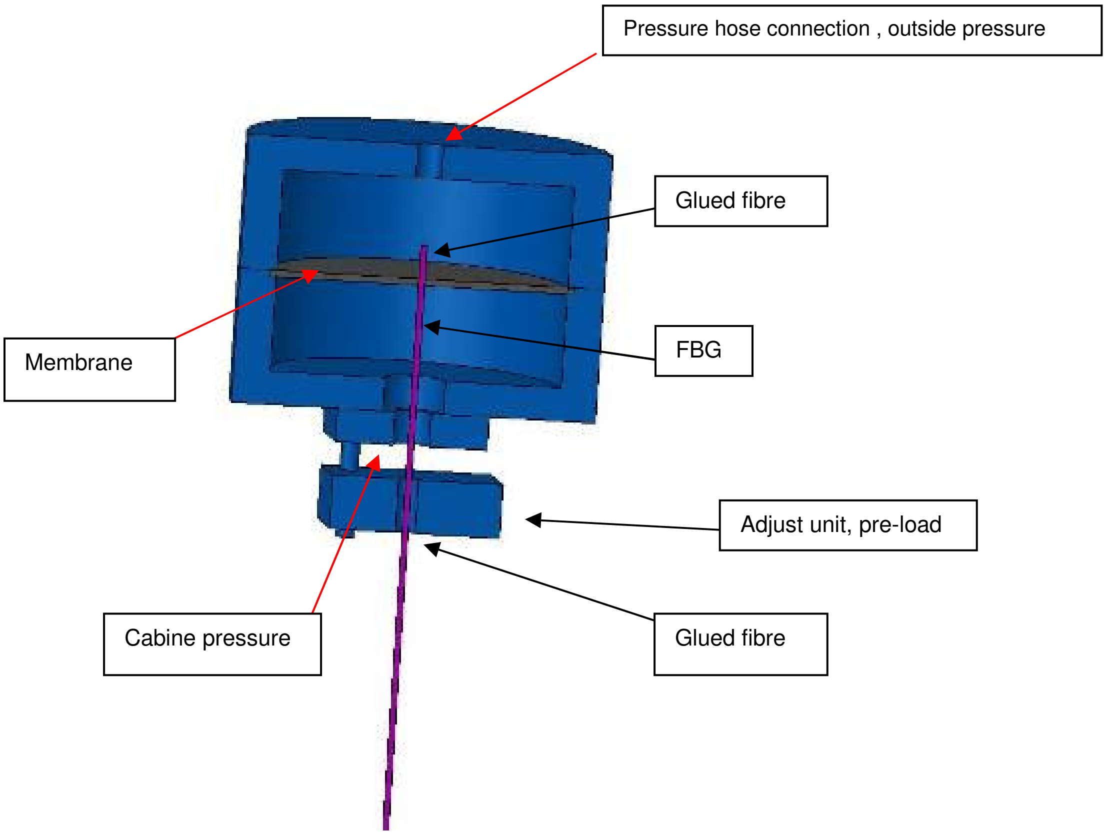

Figure 5: Pressure transducer

4 DEMINSYS C INTERROGATOR

The system that was used for the test flight was the Deminsys C 850nm 4-channel FBG interrogator system. Deminsys is a compact and highly robust interrogator for high speed dynamic measurements of FBG sensors. This WDM instrument enables high-resolution interrogation at multi-KHz frequencies.

4.1 Design specifications of the system

Specifications

Optical			
Bandwidth			35 nm
Centre Wavelength			835 – 870 nm
Number of optical channels		(1)	1, 2 or 4
Maximum number of sensors / Channel		(2)	8
Sampling frequency per sensor			19,3 KHz
Repeatability (3)	Wavelength	(4)	<= 2 pm
	Strain	(5)	<= 3 µstrain
Signal Noise			0.015 pm/√Hz
Dynamic Range (for 8 sensors per channel)			+/- 1000 µstrain /sensor
Optical Connector			E2000 or FP/APC

Mechanical	
Dimensions	80 x 80 x 240 mm
Weight	1.2 Kg

Environmental	
Operating Temperature	0 °C to + 40 °C
Storage Temperature	-20 °C to + 70 °C

Electrical	
Interface	Giga Ethernet
Input Voltage	+ 10 to + 24 VDC
AC/DC Converter	Included (100 – 240 VAC, 47 – 63 Hz)
Maximum Power Consumption	< 20W

1) Available in 1, 2 and 4 channel configuration
2) Subject to bandwidth restrictions
3) Per NIST Technical Note 1297, 1994 Edition, Section D.1.1.2
4) 1 σ value measured over 1 minute at max sampling frequency.
5) At 0,85 pm / µstrain

4.2 Aircraft installation

Deminsys C was installed during the flight in the cabin of the PH-NLZ test aircraft. The system was mounted on a mounting panel as depicted in figure 6 and 7.
An additional Deminsys C unit was placed as a backup unit.

All of the measurements have been conducted stand alone and all of the measurement files have been directly transmitted and recorded on the laptop on which the Deminsys C software was running. Due to the limited buffering and storage capabilities of the laptop, the test sessions consisted of several data sets. The data processing and compression has been conducted at a later stage.

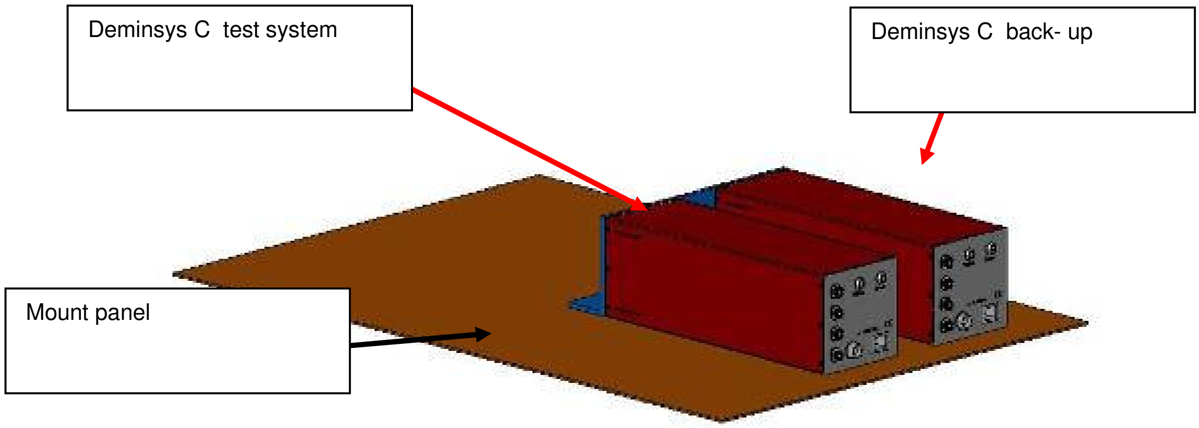

Figure 6: Deminsys mounting panel, sketch

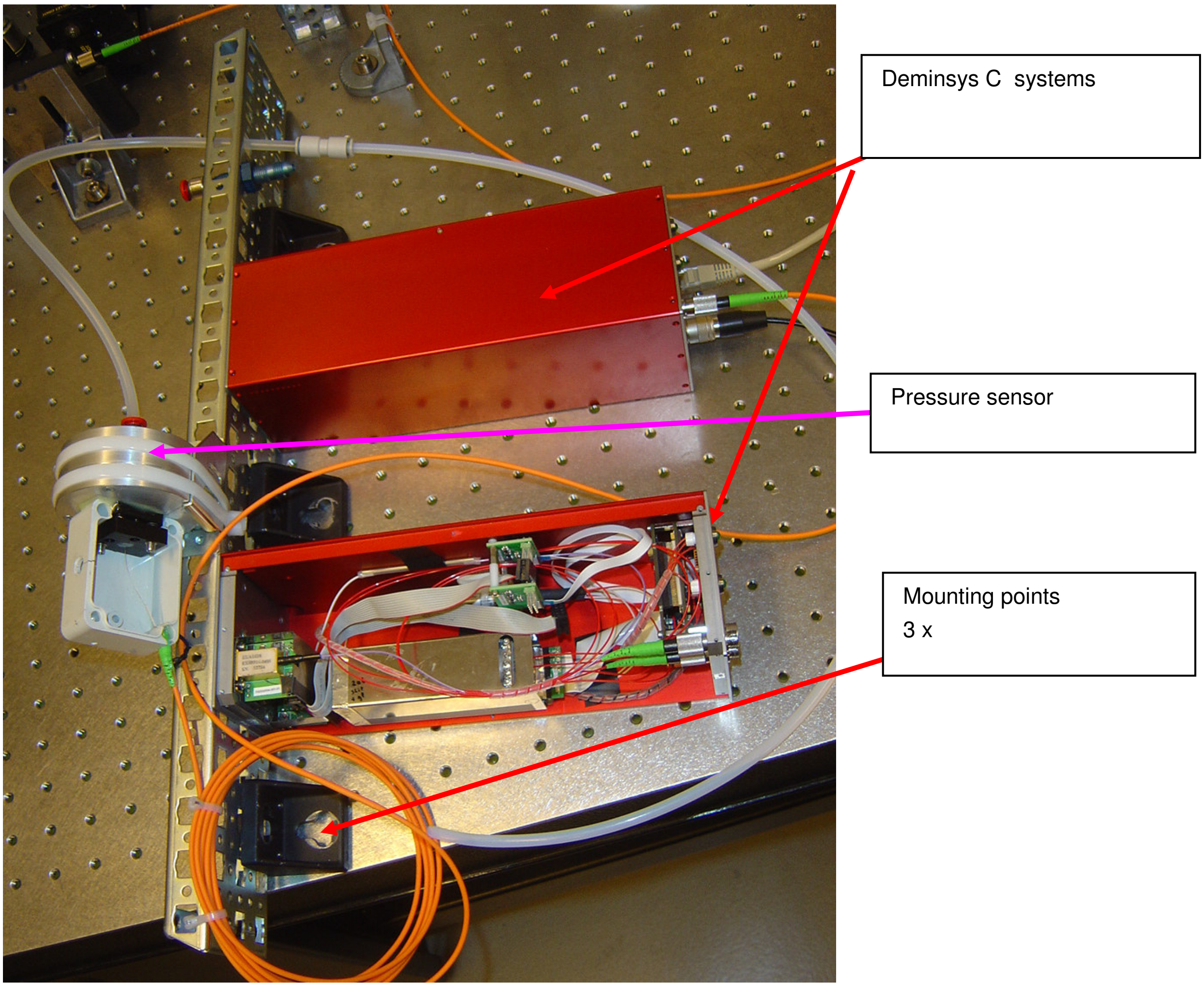

Figure 7: Deminys mounting panel, photo

5 FLIGHT TEST, DESCRIPTION AND MEASUREMENT DATA ANALYSIS

5.1 Flight test description

The tests have been conducted according to the flight plan CR ASFT-2008 version 1.0 created by the NLR.

The Citation Measurement System of the PH-NLZ aircraft is used to record and log the flight data of the standard systems and sensors. The data files logged by the Deminsys C software has no absolute time stamp that was synchronised to the airplane and its data recording, the synchronisation of the data sets is done during data processing in a later stage by matching specific events.

The flight crew consisted of: 2 pilots, an NLR Flight Test instrumentation engineer and 2 Deminsys FBG specialists.

The flight plan and data recordings consists off the following routines:

1. Measurement in the hangar:
    - Check of the sensors
    - Reference measurements
    - Fuelling process

2. In- flight measurements
    - Engine start
    - Taxi
    - Take off (Climb to FLl00—FLl5O)
    - Climb to an altitude where the OAT is more then 15 deg. Celsius lower than at ground level
    - Straight and level flight in relative smooth air
    - Straight and level flight in relative turbulent air
    - Turns with a max bank angle of 60 deg.
    - Descent Touch down

The test conducted in the hanger were to see if the system and the sensor were working properly. During the complete flight session the FBG sensors and FBG interrogator worked properly. The fuelling of the aircraft (adding mass to the wings) has no significant effect on the measurement. This is the case for Deminsys C as well as the conventional strain gauge.

The In-flight test has generated some interesting measurement results.
In next chapter of this report one can find an analysis of the measurement data during some flight routines and a comparison with the conventional sensor data.

5.2 Flight data analysis

The next section shows some of the data analysis and the interpretations.
The analysis has focused on the take off, turns section and touchdown routines, as these yield to the most interesting measurement data.

Some of the data analysis has been the work of Perot Systems, who used the software tools that have been developed for Lockheed Martin's JSF fighter.

5.2.1 Take off

In this section we will review the measurement data of the strain effect on the wing beam, the skin temperature and the air pressure. The take off routine was recorded during a time interval of 18 minutes during which the aircraft reached altitude of 15.000ft. The altitude versus time graph can be found in figure 8.
The take off point is clearly visible and occurs after 54 seconds after start of the data recording.

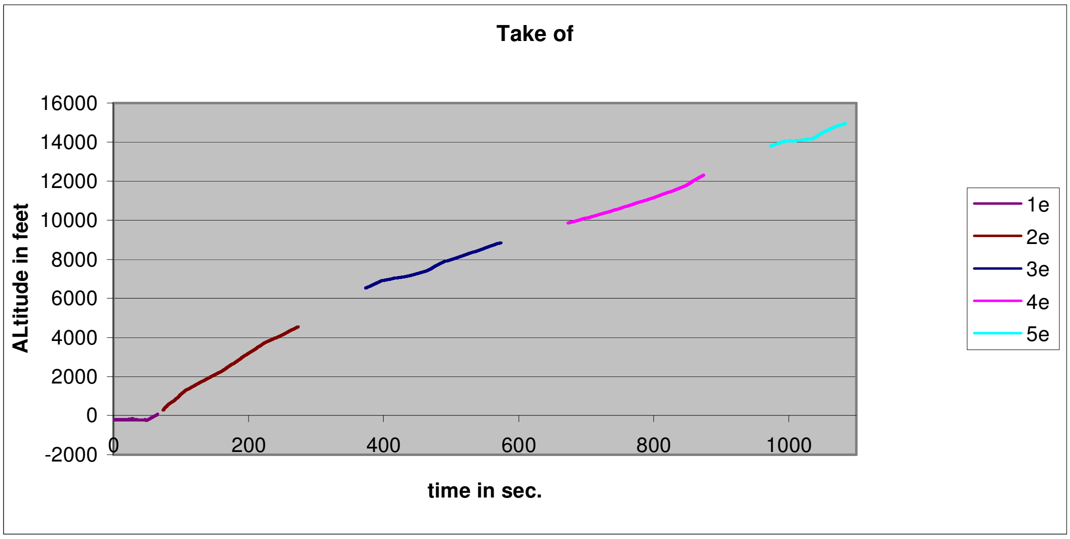

Figure 8: Take off, altitude versus time graph

Figure 9 and 10 show the fuselage skin temperature and air pressure data during the take off section. The yellow line represents the FBG sensor data. The 'Tskin' and 'Pcab' data lines are from the conventional PT100 temperature sensor and pressure transducer. The FBG sensor data is scaled with a constant magnification factor to match to the same amplitude of effect.

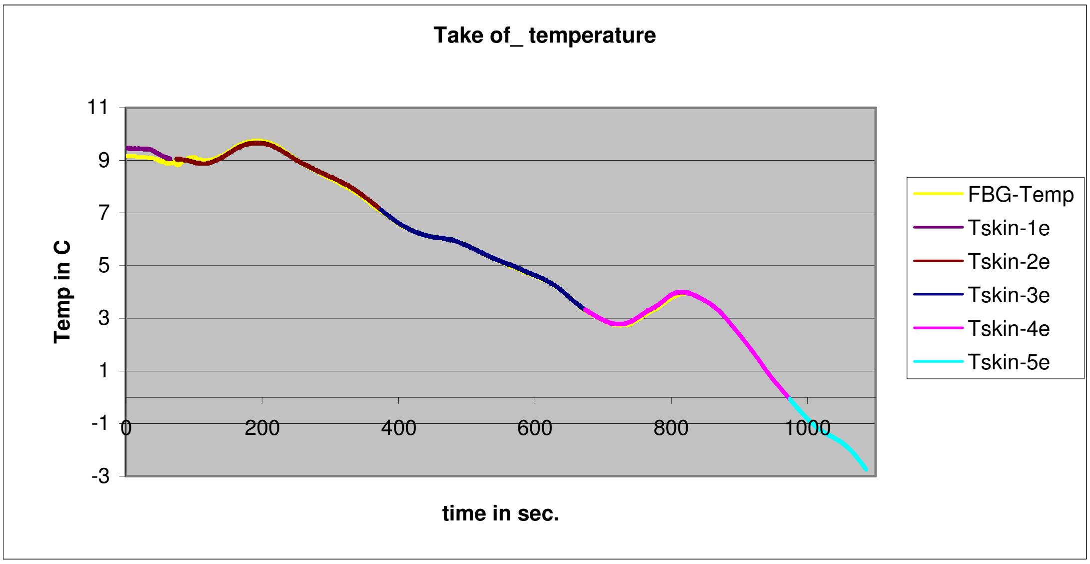

Figure 9: Take off, fuselage skin temperature

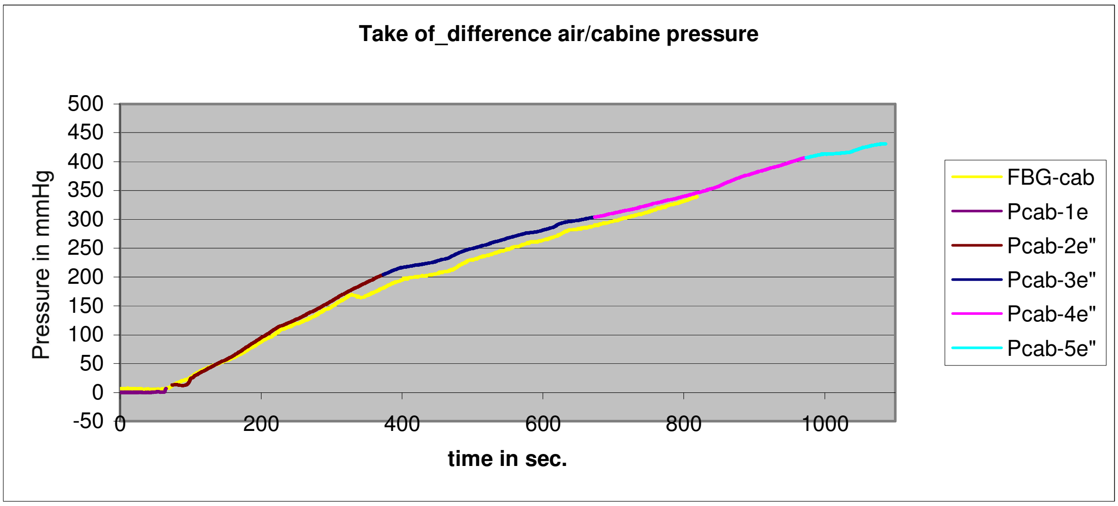

Figure 10: Take off: air pressure measurement

Figure 11 shows the strain measurement on the wing beam during take off. The time scale is zoomed in to the moment that the aircraft gets airborne at 54 sec's. There is a very clear correlation between the FBG sensor and the strain gauge data. The FBG sensor data is re-sampled to a data rate of 20Hz and scaled with a constant magnification factor.

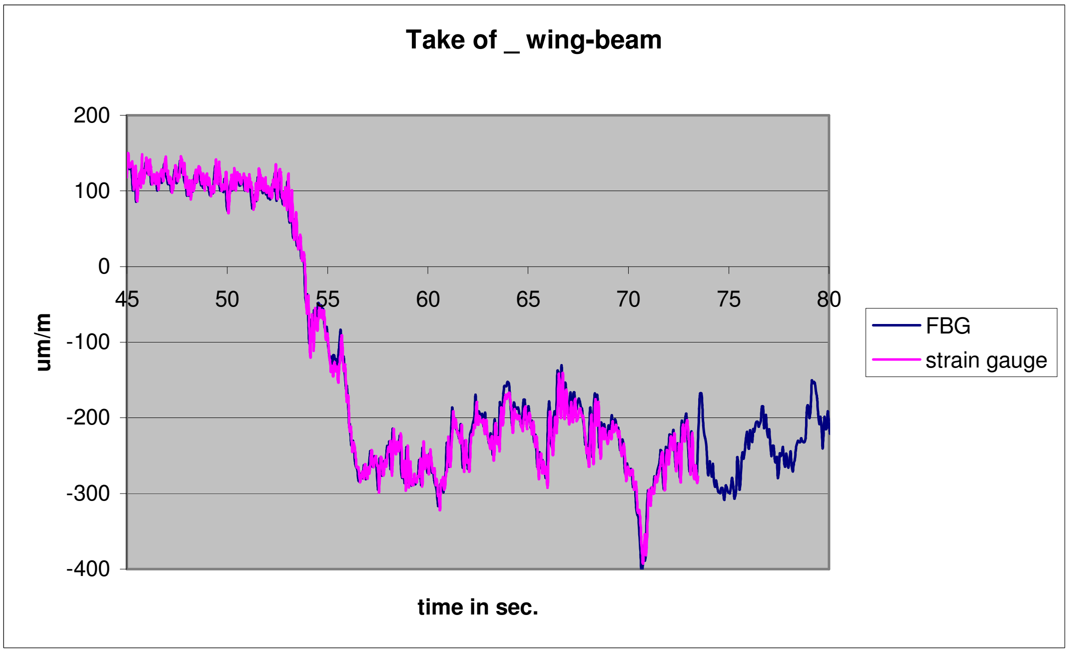

Figure 11: Take off: strain on wing beam

5.2.2 Turns section

The following 2 figures represent the strain measurements on the wing beam during the 'Turns' section.
Fig. 12 shows a strong resemblance between the data sets collected over a number of turns. The blue (middle), red (upper) and green (lower) line represent the angle of roll made by the airplane, data collected by the FBG sensor and the conventional strain gauge respectively. If the upper and bottom-line are put on top of one and other a near to perfect resemblance can be

seen. This strong correlation between FBG and strain gauge can also be seen in figure 13, in which the values of the FBG sensor are plotted versus strain gauge values.

The data analysis for the section has been the work of Perot Systems.

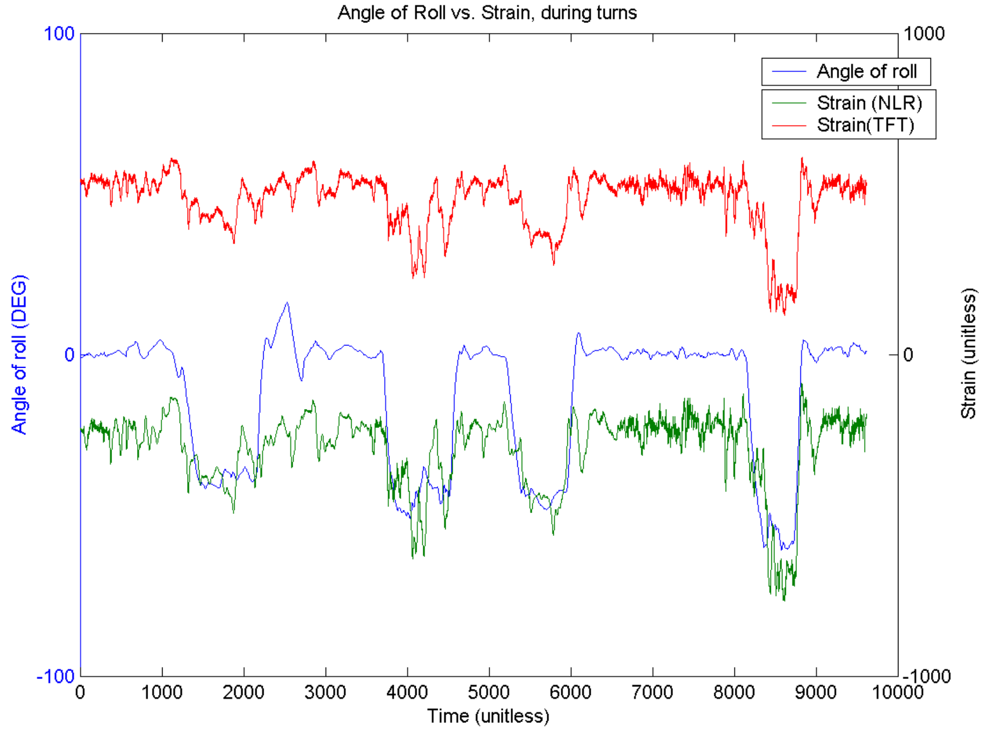

Figure. 12: Turns, strain of wing beam

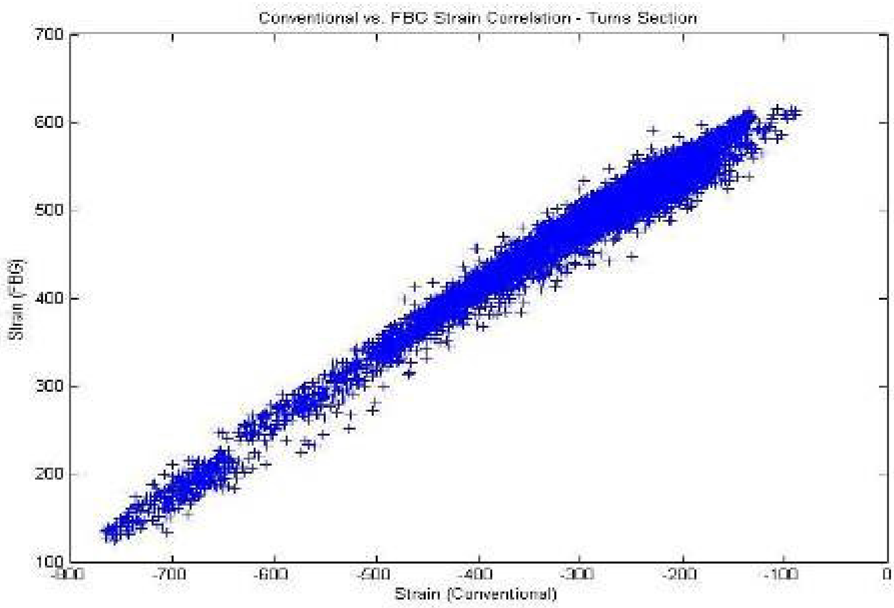

Figure 13: FBG versus stain gauge reading during turn section

5.2.3 Touch down

Figure 14 shows the strain measurement on the wing beam during the touch down. Again a very clear correlation visible between FBG and strain gauge sensor.

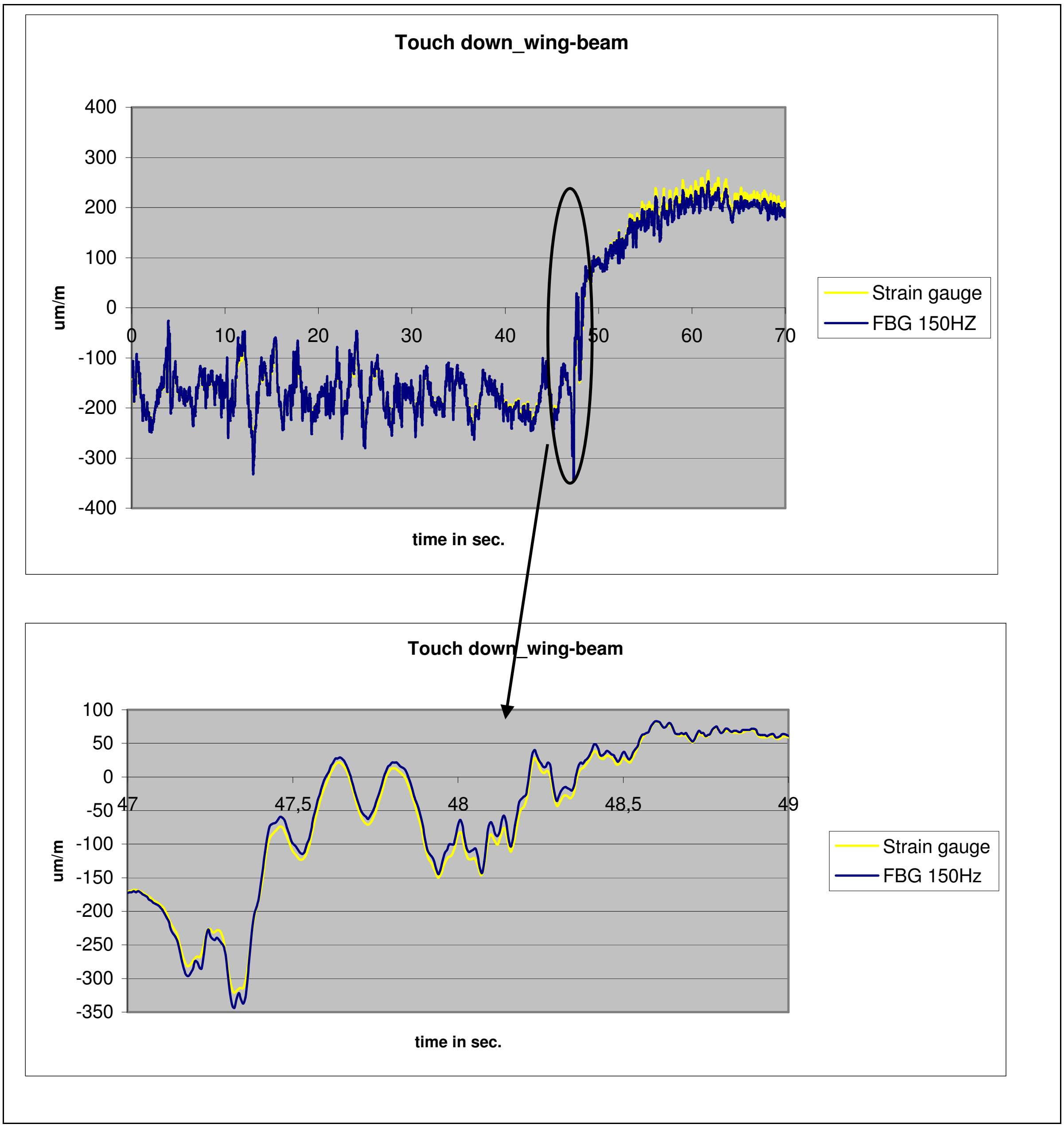

Fig. 14: Touch down, strain measurement on wing beam

5.2.4 Fuselage skin temperature versus altitude

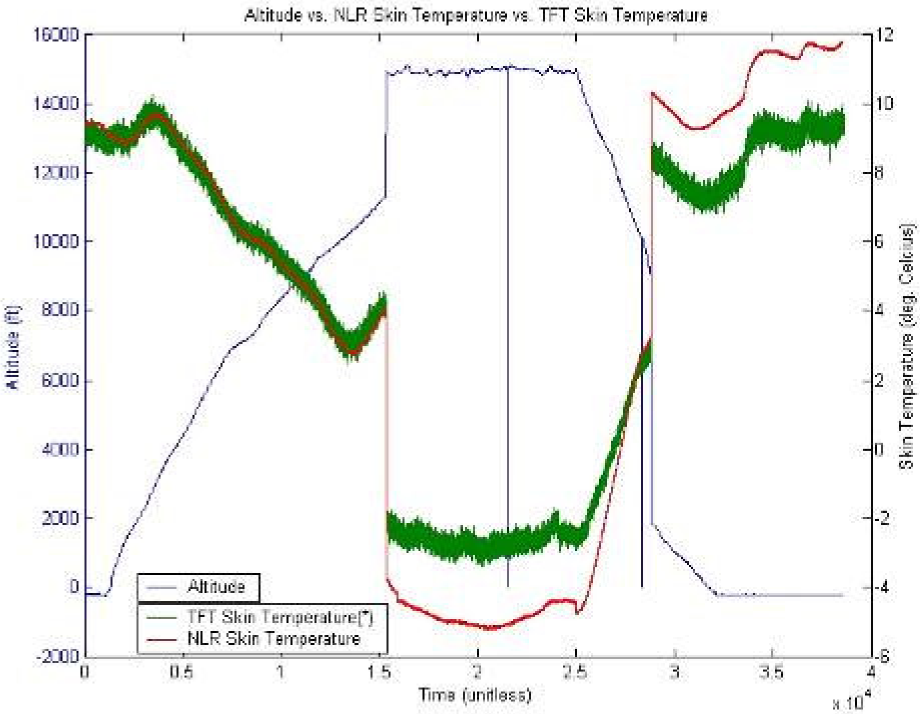

Figure 15: altitude and fuselage skin temperature versus flight time

Fig. 15 is a graphical display of the measured temperatures on different altitudes. The figure consists of the data of 3 datasets. The increase of altitude results in a decrease of temperature. In the first dataset one can clearly see a perfect alignment of the PT 100 data (thin red line) and the FBG data (thick green line). In data set 2 and 3 there is a temperature offset between FBG and PT100 data. The FBG data indicates a temperature 2 degrees Celsius lower PT100 data. After a recheck we found that the Deminsys software was starting a new dataset of at a new zero point thereby creating the offset in the signal.

In new Deminsys software versions this can be dealt with by choosing for absolute measurement mode.

6 CONCLUSION

The aim of the First Flight was to demonstrate the initial feasibility of Proof of Concept of the Deminsys interrogator unit for use in aircraft environment. This target was fully and successfully realised: the measurement system and sensors worked properly during the complete test program.
A number of datasets are recorded and analysed of the different flight routines. This data of the FBG sensor system shows a very strong correlation with the data of the convential measurement system. This is shown in the different graphs that are presented. The most important findings of the data analysis

- Strong correlation between conventional and FBG data
- Low noise level
- No bugs, peaks, missing data etc. in the data sets

The Deminsys software version that was used during this flight showed some limitations, like the missing time stamp and the changed reference ,zero, point after re/start of the data acquisition. New software upgrades are and will be launched with solutions for these indicated issues.

Technobis Fibre Technologies started the development and realization of a dedicated airworthy Deminsys version which will be fully qualified for aircraft operation.