Real-time Stress Concentration Monitoring of Aircraft Structure during Flights using Optical Fiber Distributed Sensor with High Spatial Resolution

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For efficient and reliable design and operation of aircraft, monitoring of deformation and strain during flights is beneficial. Optical fiber sensors are highly applicable for this purpose. They are light-weighted and flexible, which allows less invasive installation to aircraft structures. In addition, they are capable of distributed monitoring, which enables efficient measurements by collecting strain distributions along a single fiber. By using optical fiber distributed sensors with a high spatial resolution such as mm order, it is even possible to monitor local strain distribution profiles at stress concentration areas. The stress concentration is critical for structural integrity, whereas difficult phenomenon to predict and accurately observe without such a distributed sensing technique.

We have developed an optical fiber distributed sensing technique using long-length fiber Bragg gratings (FBGs) and optical frequency domain reflectometry (OFDR). The OFDR-FBG technique allows us to monitor real-time strain distributions during flights along the FBGs with a 1.6 mm spatial resolution and a 151 Hz sampling rate [1, 2]. We applied this monitoring technique to a middle-sized business jet (Cessna Citation Soverign), and conducted flight tests. In this study, we report time histories of strain distribution profiles during various maneuvers especially focusing on stress concentration areas.

Figure 1 shows the sensing configuration for the flight tests. We conducted two campaigns of the flight tests. For the first campaign (in 2016), we monitored a stringer of the fuselage and the aft-bulkhead. We bonded a 5 m-long FBG along the stringer and a 50 cm-long FBG to the surface of the aft-bulkhead diametrically. For the second campaign (in 2017), we monitored a main wing. We bonded a 10 m-long FBG to the bottom surface of the wing along the spar.

Figure 2-4 show examples of monitoring results. Strain values are the variations from the state at which the aircraft was on the ground. Figure 2 shows a strain distribution along the main wing when the aircraft banked-turned. The position indicated the location from the wing root (= 0 m) to the wing tip (= 8 m). The deflection of the wing with the upward wing tip induced a tensile strain distribution on the bottom side, having larger amplitudes at the root. We added the rib locations with dotted lines in the graph. As clearly seen especially at the wing root, the abrupt strain distribution variations due to the stress concentration existed at the rib locations. Some of them showed larger values, which illustrated the importance of the actual data monitoring. Figure 3 shows a strain distribution along the fuselage stringer when the aircraft banked-turned. The position indicated the location from close to the main wing (= 0 m) and in the traveling direction. We observed tensile strains having larger values for locations closer to the main wing. At the banked-turn, the fuselage was under bending load, and deflected downwards at the aircraft nose. Therefore, the tensile strains were induced on the top side of the fuselage. We added the locations of the fuselage frames with dotted lines. We saw the agreement between the locations of the frames and the stress concentrations with lower strain amplitudes. This was considered to reflect the stiffening effect. Figure 4 shows a strain distribution of the aft-bulkhead after takeoff. We saw tensile strains, which represented that the bulkhead “inflated” due the lower air pressure outside of the fuselage. On the back side of the aft-bulkhead, there were stiffeners. Among the monitoring area, a part of the stiffener was located at 200 mm. We saw larger tensile strains at the stiffened area. We surmised that the overall deformation of the fuselage due to the air pressure and temperature variations induced bending to the aft-bulkhead, which caused tensile strains at the thicker area with the stiffener.

We could successfully observe overall strain distributions and local stress concentrations, which were insightful. Some of them were the data that was difficult to predict purely by theoretical analysis. This highlighted the importance and the effectiveness of the sensing technique with the high spatial resolution. We will further examine the monitoring data through comparison with structural analysis of the aircraft.

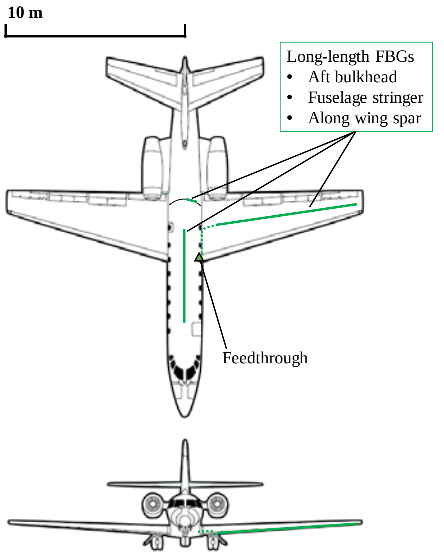

Figure 1. Sensing configurations for flight tests..

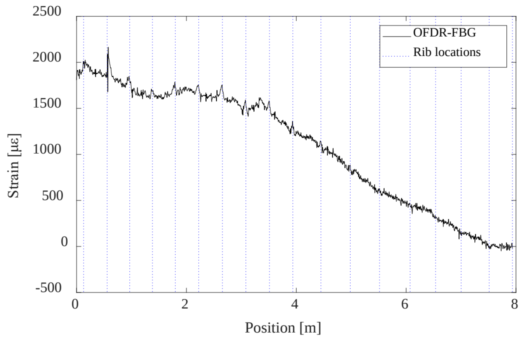

Figure 2. Strain distribution of main wing during banked turn..

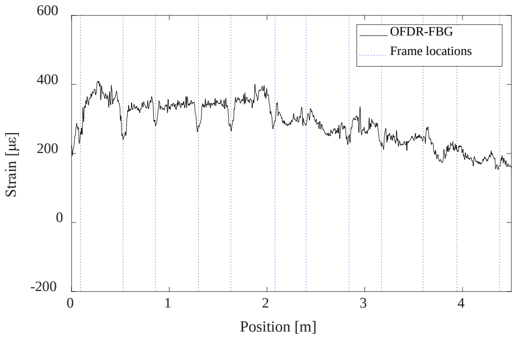

Figure 3. Strain distribution of fuselage stringer during banked turn..

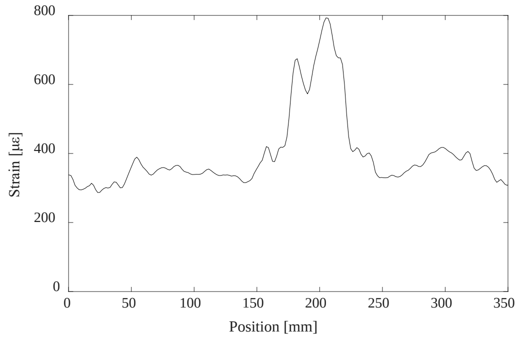

Figure 4. Strain distribution of aft-bulkhead after takeoff.

References
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[2] D. Wada, H. Igawa, M. Tamayama, T. Kasai, H. Arizono, and H. Murayama, "Flight demonstration of aircraft wing monitoring using optical fiber distributed sensing system," Smart Materials and Structures (2018) (accepted).

Keywords: Fiber Bragg grating (FBG), Optical fiber distributed sensors, Strain distribution, Stress concentration, Structural health and usage monitoring