Chapter 6 – RECENT EXAMPLES OF LARGE SCALE FOSS TESTING

6.1 NESC – COMPOSITE CREW MODULE STRUCTURAL TESTING

Dryden engineers successfully supported structural testing of the NASA Engineering Safety Center's (NESC's) full-scale Composite Crew Module (CCM) located at NASA Langley Research Center in 2009 – 2010. By deploying NASA-developed fiber optic sensors along the various windows, and docking port along the crew module; structural strains along these locations could be monitored in real time. Each optical fiber contained hundreds of strain sensors, where each sensor had a spatial resolution of 0.5 in and were sampled at least 20 times per second. The high spatial resolution of fiber optic sensors enabled strain mapping of geometrically complex regions throughout the CCM, where applying traditional strain gauges becomes difficult. These fiber optic strain sensors monitored repeatedly internal pressure loading test of the CCM in real time, with much faster strain-acquisition rate than commercially-available systems. Figure 6-1 shows the DFRC interrogation unit and regions (in red) where FBG sensors were located on the CCM test article. During structural testing, the crew module was subjected to internal pressure at up to 200% of design limit and under induced strain load to simulate conditions at space and re-entry via parachute deployment, respectively. Strain values observed from fiber optics sensors correlated well with finite-element predictions under different conditions, within 5% difference between predicted and measured values (Figure 6-2). The fiber sensors were also subjected to cyclic loads testing of the CCM and gave consistent readings, with no effect of material fatigue. At the end of the test program, the fiber optic sensors reliably measured strains during the ultimate CCM structure failure test, accurately recorded the time of failure, and observed the propagating shock wave as a result. Despite the high loads endured by the fiber sensors throughout testing, fiber optic sensing technology performed well and returned valuable data to assist in post-test data analysis.

Figure 6-1: Ground-Based Four-Fiber Interrogation System and NESC CCM Testing.

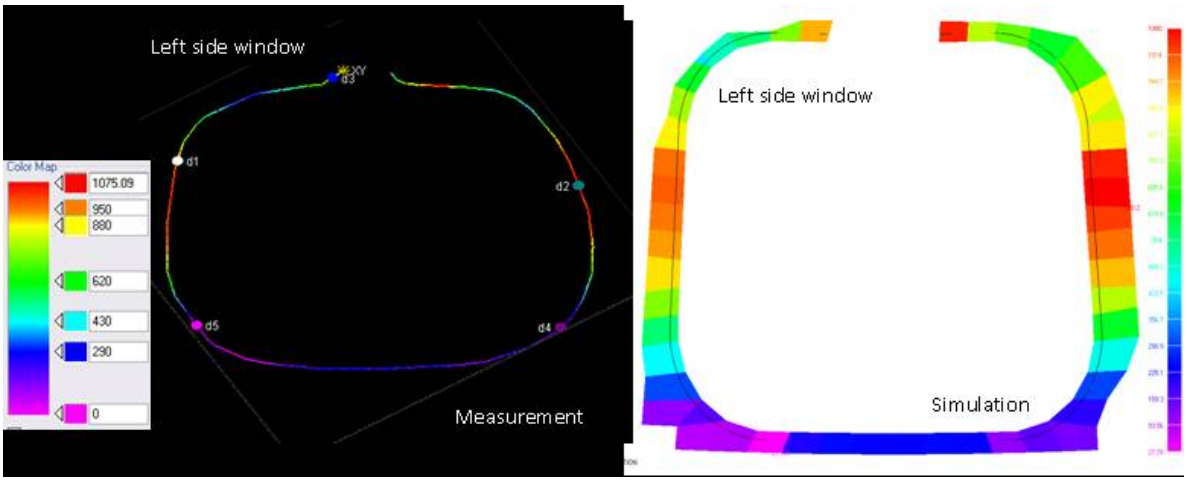


Figure 6-2: Sample Real-Time Measurement Data (Left) of the Fiber Sensor versus Simulation Result (Right) of the Left-Side Window of the CCM During Maximum Internal Pressure Load.

6.2 IKHANA

In June 2003, the Helios Prototype Unpiloted Aerial Vehicle (UAV) experienced significant pitch instability during low-altitude flight that lead to a catastrophic structural failure and in-flight break-up. One of the most significant lessons learned from the mishap investigation was the need to provide real-time measurement of wing dihedral to the test crew during flight (Thomas Noll, et al, "Investigation of the Helios Prototype Aircraft Mishap Volume 1 Mishap Report", NASA internal document, January 2004). A recent in-house study assessed the viability of using conventional strain gage instrumentation, and demonstrated that the wire weight alone represented a prohibitive weight penalty and was impractical to implement for many aerospace vehicles. Alternatively, lightweight and low profile fiber optic wing shape sensors in conjunction with computationally efficient transfer functions, were viewed as a promising approach to providing very accurate wing measurement calculations for eventual input to the flight control system for aero elastic motion control.

Flight validation testing was conducted at NASA Dryden in 2008 – 2009. Approximately 3000 FBGs were installed on the wings of NASA's Ikhana vehicle (Predator-B) shown in Figure 6-3. The FBGs were used to sense the shape and monitor the stress of the Ikhana wings in real time throughout each mission. Determining wing shape in real time serves as the first step toward achieving the important goal of controlling the shape of subsonic fixed wing aircraft. The resulting capability also provided a practical approach to accomplish structural health and loads monitoring during the experiment. Research tasks were performed in the areas of algorithm development, system development, environmental qualification testing, system/vehicle integration, sensor installation, ground test validation, and experiment integration.

NASA Photo ED07-0287-03

NASA Photo ED07-0038-045

Figure 6-3: Ikhana UAV Vehicle with Sensors Installed (Left); in Flight Prior to Experiment (Right).

Research was accomplished toward the development and experimental validation of analytical strain-to-displacement transfer functions. [6] These transfer functions were developed to obtain both in-plane strain mapping and out-of-plane displacement measurements simultaneously for complex flexible structures, such as the wings of the Ikhana and many other subsonic fixed wing aircraft.

The NASA Dryden designed FBG-OFDR system was developed, environmentally qualified, and integrated in the avionics bay of the Ikhana vehicle, as depicted in Figure 6-4. This figure also shows the layout of sensors installed for the flight experiment.

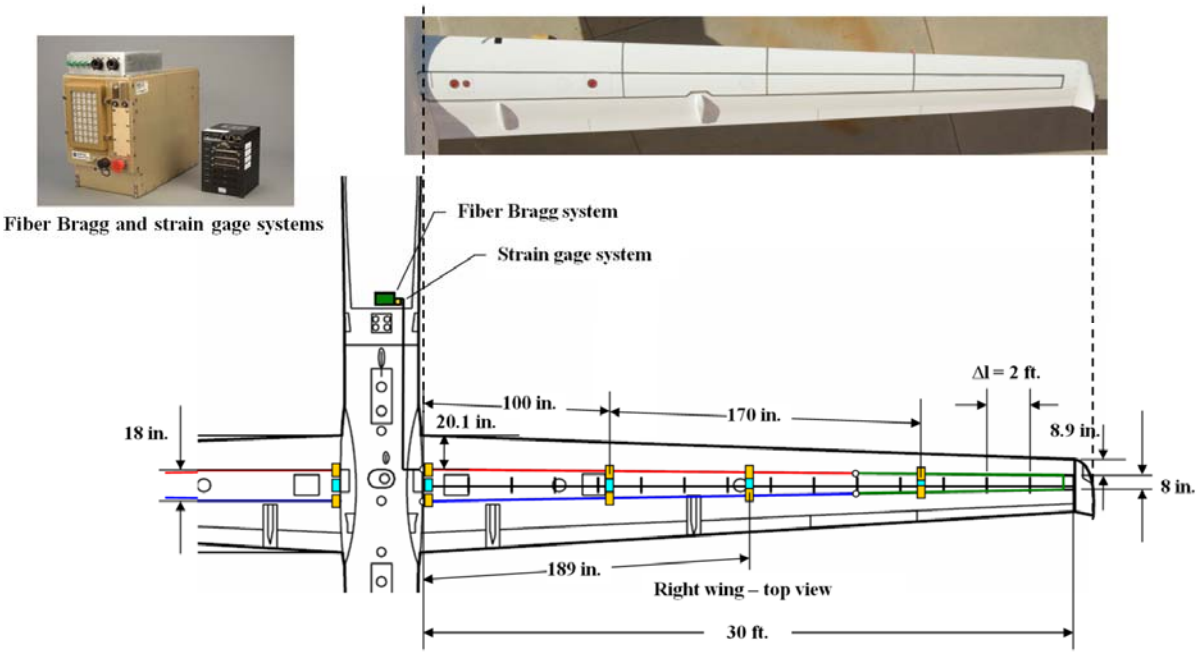


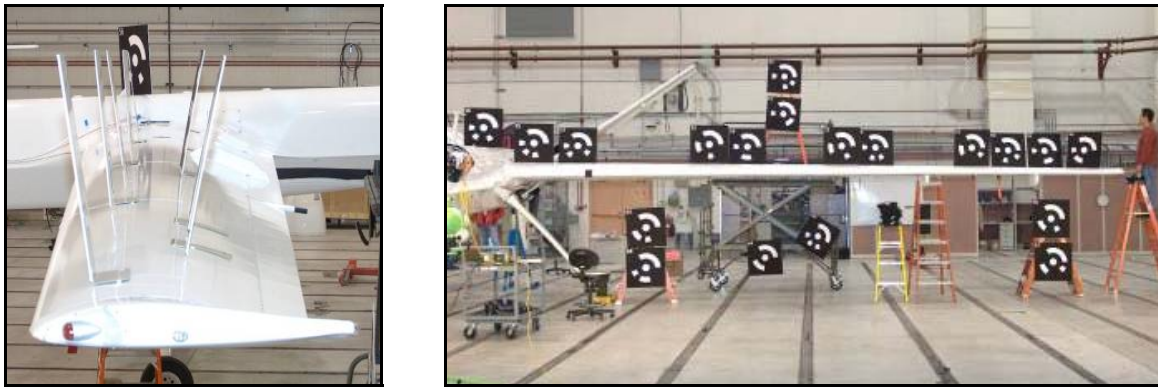
Figure 6-4: FBG Sensor Layout.

6.2.1 Sensor Attachment

In addition to approximately 3000 FBG strain sensors, 16 strain gages were used to validate FBG strain measurements. Eight conventional thermocouples were bonded to the upper wings of the vehicle and used primarily for strain sensor error correction as described in Chapter 4.

6.2.2 Ground Testing

Prior to flight testing, ground validation testing was conducted using Dryden's high resolution/high speed optical measurement system as the validation standard (Figure 6-5). The optical system utilized bar-coded targets placed on the left wing and center fuselage at 10 measurement locations. Five load cases were applied through the use of calibrated shot bags as shown in the figure. The maximum loads applied to the wings were limited to 200 lb, which produced displacements at the wing tips of only approximately 3 in. Despite these small displacements, agreement between FBG and optical systems at the wing tip was 2.8% and 4.8% for the two bending load cases.



NASA Photo ED08-0016-12

Figure 6-5: Ikhana Ground Testing.

From May until August 2008, 18 flight tests totaling 36 flight-hours were conducted on the Ikhana vehicle. To our knowledge, these flight tests represented the first flight validation test of FBG strain and wing shape sensing. Figure 6-6 shows a screen capture of a control room display showing the data telemetered from the aircraft in real time. The figure shows a photo of the Ikhana vehicle (a modified Predator-B) with superimposed flight data. The yellow data are the 2000 FBG strain measurements from wing tip to wing tip with FBG measurements located every 10 mm. The measurements are in micro strain with the axis on the right. The strain values corresponding to the center fuselage on the airplane are not real, but are FBG sensors on the optical fiber spooled in the fuselage on unsupported regions. The red data are wing displacement measurements from wing tip to wing tip (with units on the left). These data and the trace at the bottom of the figure were produced during a "pitch up pitch down" maneuver. The pilot pushed down on the stick quickly, then quickly pulls up for several cycles. The bottom trace shows the deflection of the wing tips during the maneuver. Overall, the FBG system performed well throughout entire flight without any issues.

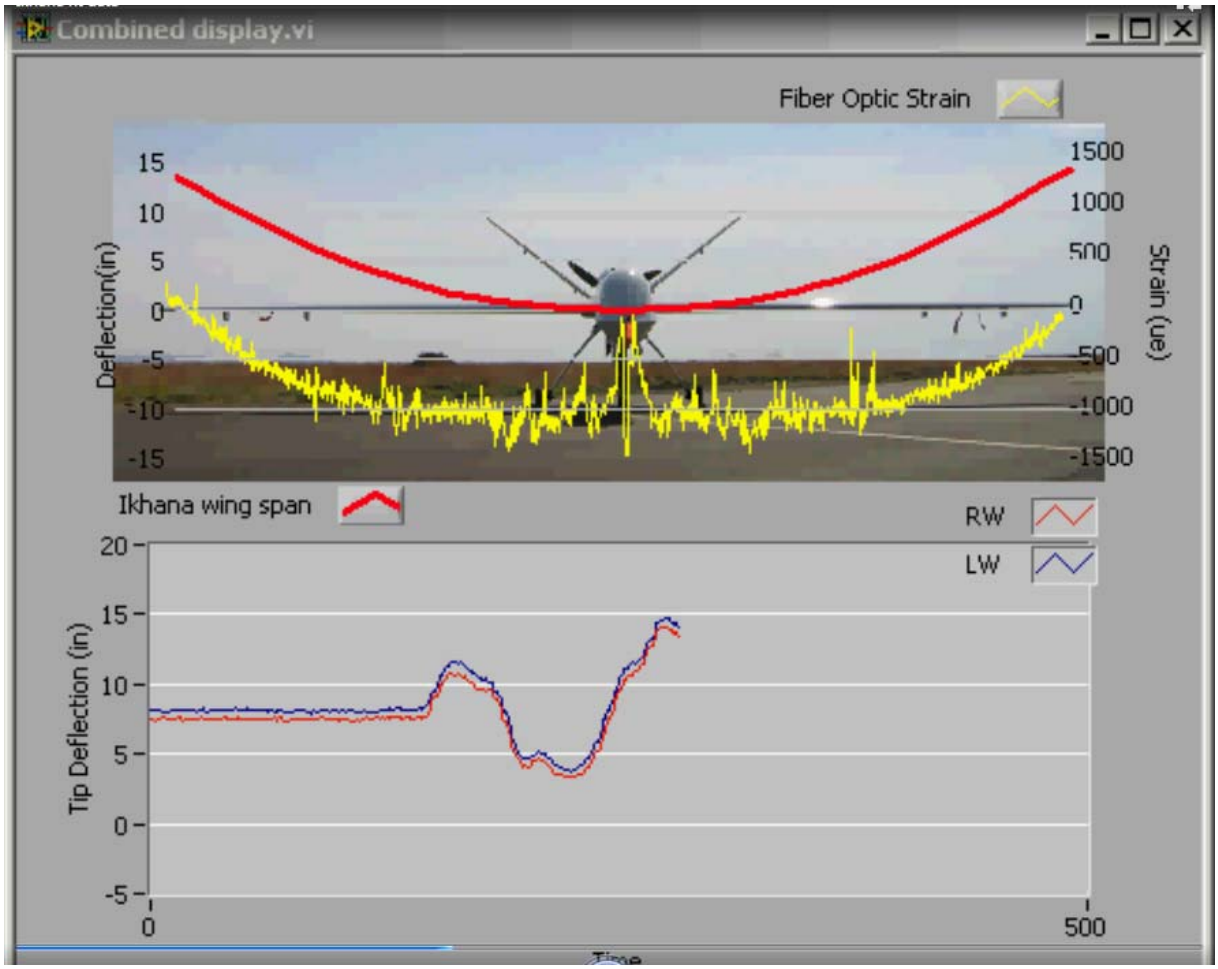


Figure 6-6: Ikhana Flight-Test Data.

6.3 GLOBAL OBSERVER

6.3.1 Flight Testing

Following the successful flight validation testing of FBG sensor technology on the Ikhana, NASA Dryden performed real-time strain sensing on AeroVironment's Global Observer aircraft, a full-composite Unmanned Aircraft Vehicle (UAV) capable of stratospheric flight (up to 65,000 ft) at long intervals (over 7 days) without landing or refuelling (Figure 6-7). Optical fibers with highly multiplexed FBG sensors were installed throughout the left wing of the Global Observer for strain monitoring. In total, eight 40-ft long fibers were installed along the front and aft wing portions of the left wing, as well as one fiber that was installed on the fuselage of the aircraft to measure torsion of the fuselage. These eight fibers were written with over 8,000 FBG sensors in total. Strain information was recorded in real time through in-flight data acquisition system at 20 samples per second per sensor. Global Observer completed its maiden-flight on August 5th, 2010 with the FOSS system onboard and archiving data. The FOSS system has performed well, monitoring the strain distribution along the leading and trailing edges of the upper and lower surfaces of the aircraft's left wing as well as on the aft fuselage, from take-off to mid-flight to landing. There were 5 subsequent test flights for the Global Observer, and the FOSS system successfully recorded the strain information for 4 of the 5 flights.

Figure 6-7: Flight Interrogation Unit and the Global Observer UAV.

6.3.2 Wing-Load Testing

In addition to real-time flight testing, AeroViroment has partnered with NASA Dryden for wing-load testing of both wings of a future Global Observer, to be built after the current flight-testing of GO-1. These load tests occurred in July 2010 at NASA Dryden's Flight Loads Laboratory. The purpose of the wing-load test was to monitor the strain of the wing panels under load and to monitor the wing shape of the panels using the NASA-patented wing shape algorithm. Eighteen fibers, each consisting of up-to 1000 FBG sensors, were bonded to the forward and aft portion of both wings as well as to the fuselage. The ground-based fiber optic strain-sensing acquisition system is composed of three rack-mount units, where each individual unit is capable of measuring 8 fiber channels simultaneously at 50 Hz per sensor per fiber. The data from each system was then broadcasted to a server where all the data were recorded and displayed in real time. If more than 24 channels were needed, acquisition units were easily added for more robust measurements. In summary, the wing-load test composed of subjecting each wing panel to 100% of design load in both positive load and negative load at various angles of attack. Structural response of the wings was successfully quantified in the FBG-OFDR, photogrammetry, and traditional strain-gauge systems at various locations. Post-data analysis verified that the FOSS measurement is in agreement with traditional strain gages. [24]