Optimal Design of Composite Wing Spar Subjected to Fatigue Loadings

CAL POLY SAN LUIS OBISPO

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Students at the Cal Poly Department of Mechanical and Aerospace Engineering were tasked with the challenge of ensuring that a wing structure is within design limits. To accomplish this task, a Finite Element Analysis (FEA) of the wing and loading conditions was created and a structural test performed. The FEA model was then validated using Micro-Measurements System 8000 data system and strain gages.

Company/Institute: Department of Aerospace Engineering*, and Mechanical Engineering**, California Polytechnic – San Luis Obispo

Industry/Application Area: Aerospace Industry - FEA Model Validation

Products Used:

- System 8000 Data Acquisition
- Uniaxial Strain Gages
- Rosette Strain Gages
- M-Bond 200 Adhesive
- M-Coat A Protective Coating

The Challenge

Composite materials are used increasingly in the aerospace industry because of their high strength to weight ratio. Structures are currently over-designed to ensure that they are safe for fatigue loads. An example of these fatigue loads is the wing of an aircraft displacing up and down during steady flight. Even though the repeated displacements do not cause stresses above the material's ultimate stress, the wing could ultimately fail after many cycles.

The main objective of this research is to compare the experimental and finite element analysis (FEA) model results. The System 8000 Data Acquisition with uniaxial and rosette strain gages will be used in this investigation. Manufacturing multiple wing designs to study fatigue loads is costly, therefore it is advantageous to use an FEA model. Such a model can be used to apply loads and constraints onto a geometry built in computer aided design (CAD) software. It is important to ensure that the simulation model accurately represents the loads and boundary conditions of the experimental test.

The Solution

Composite wing models which consisted of two span-wise spars, end ribs, and a wing skin were manufactured. Each wing had 16 strain gages bonded onto the skin so that strain values at each location could be compared to the FEA model. In order to ensure that data was consistent and accurate, American-made strain gages from Micro-Measurements® were used. For data collection, a System 8000 data acquisition (DAQ) instrument made by the same manufacturer as the strain gages was utilized. The wing was put in a rigid fixture as shown in Fig.1, so that static and fatigue bending loads could be applied. The experimental test setup used in the study is shown in Fig. 2.

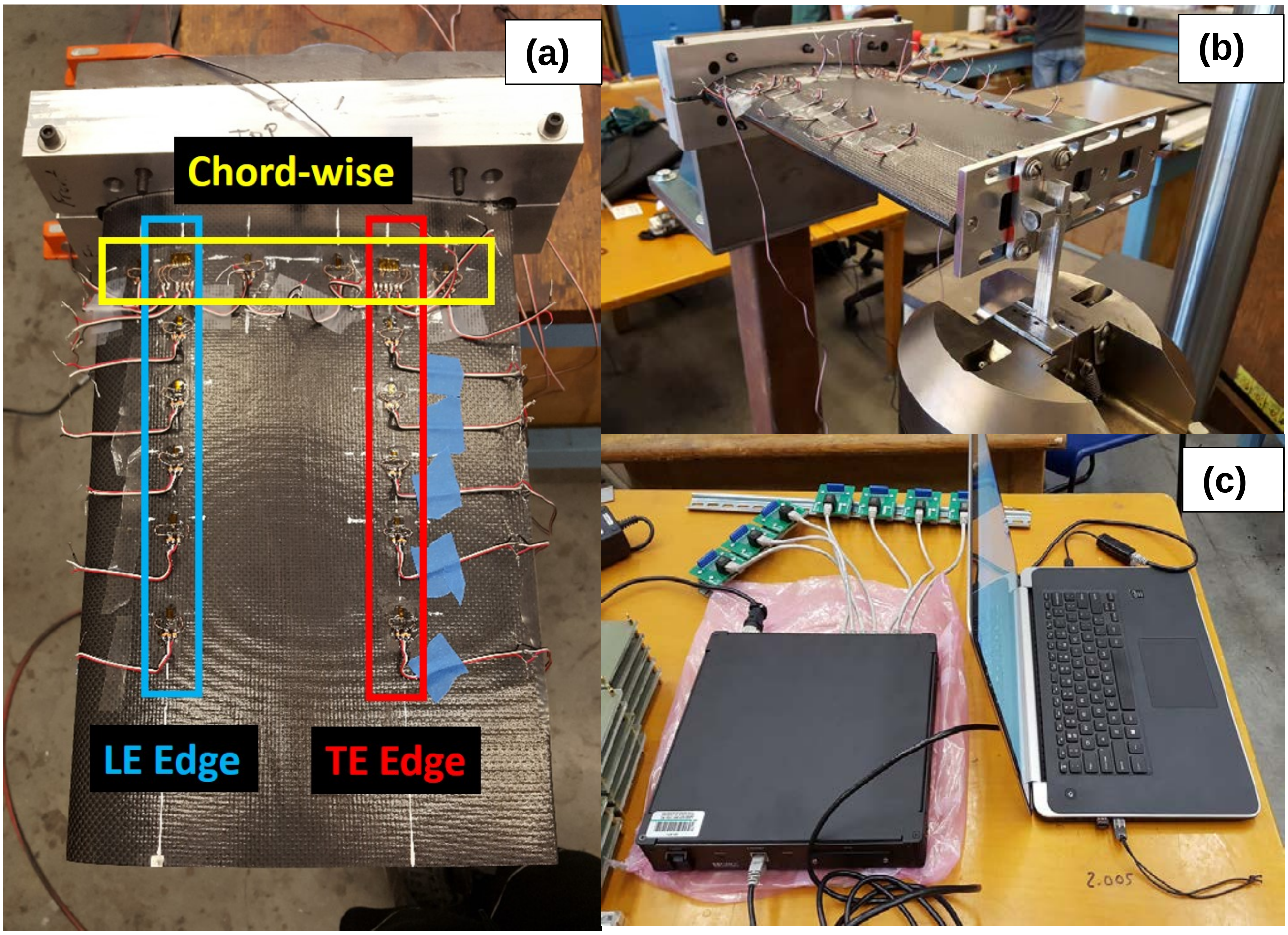

Figure 1: (a) Composite wing model with strain gages applied to the top skin surface. (b) Composite wing with strain gages mounted in the rigid fixture and Instron machine before fatigue testing. (c) System 8000 DAQ connected to a laptop for data collection from strain gages during testing.

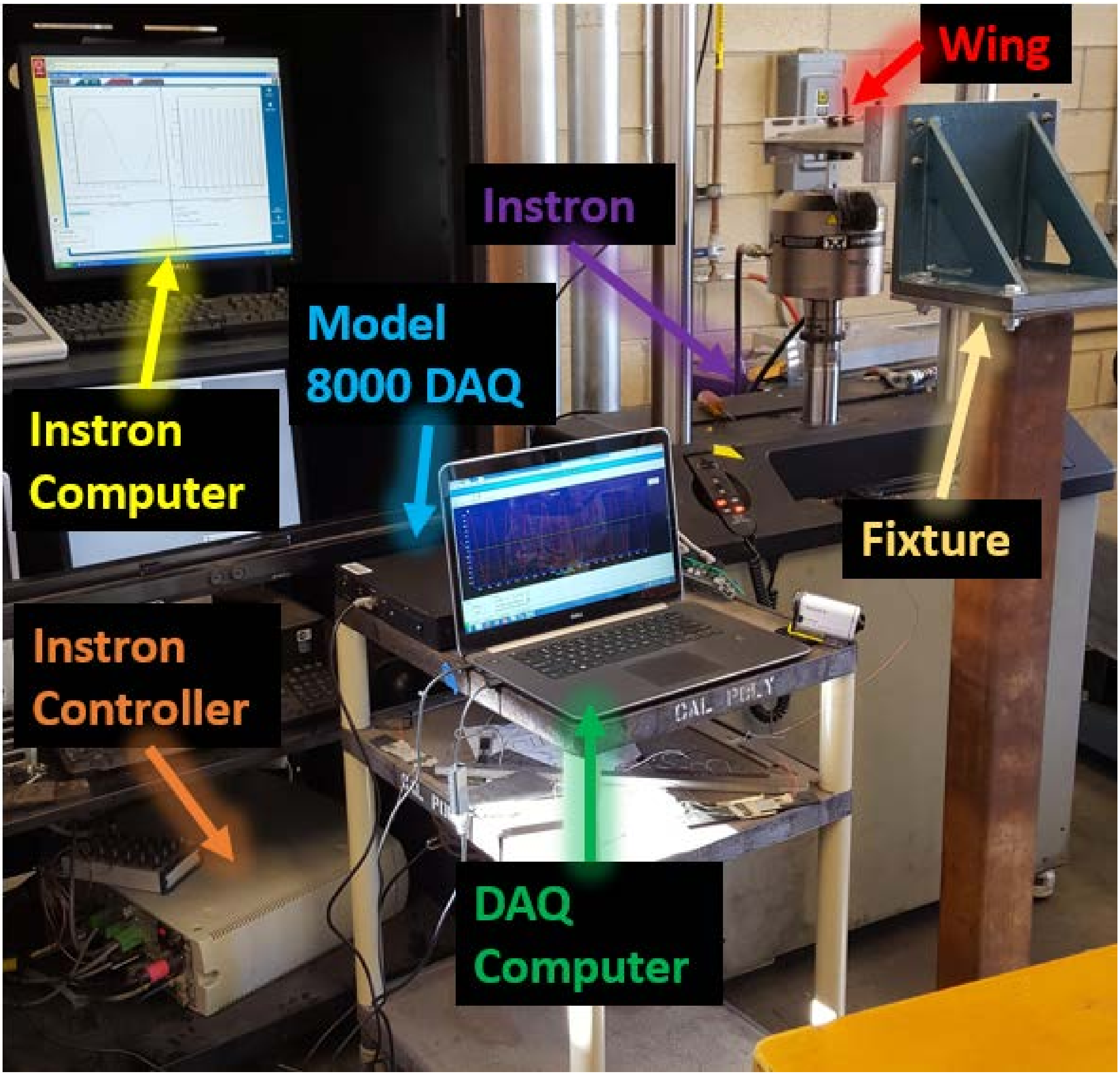

Figure 2: Experimental test setup

While the wing is under load, strain data from the gages is collected and compared to the simulation. The wing was displaced by 0.03 inches fully reversed, at a frequency of 10 Hz, until 100,000 cycles or failure. Once the model was validated, it could then be used to study the effects of the internal structure of the wing on static and fatigue load resistance. Strain data was also periodically collected during the fatigue test to ensure that the driving displacement and frequency were consistent. Strain data collected from the leading and trailing edge during the fatigue test using the System 8000 DAQ is shown in Fig. 3 below.

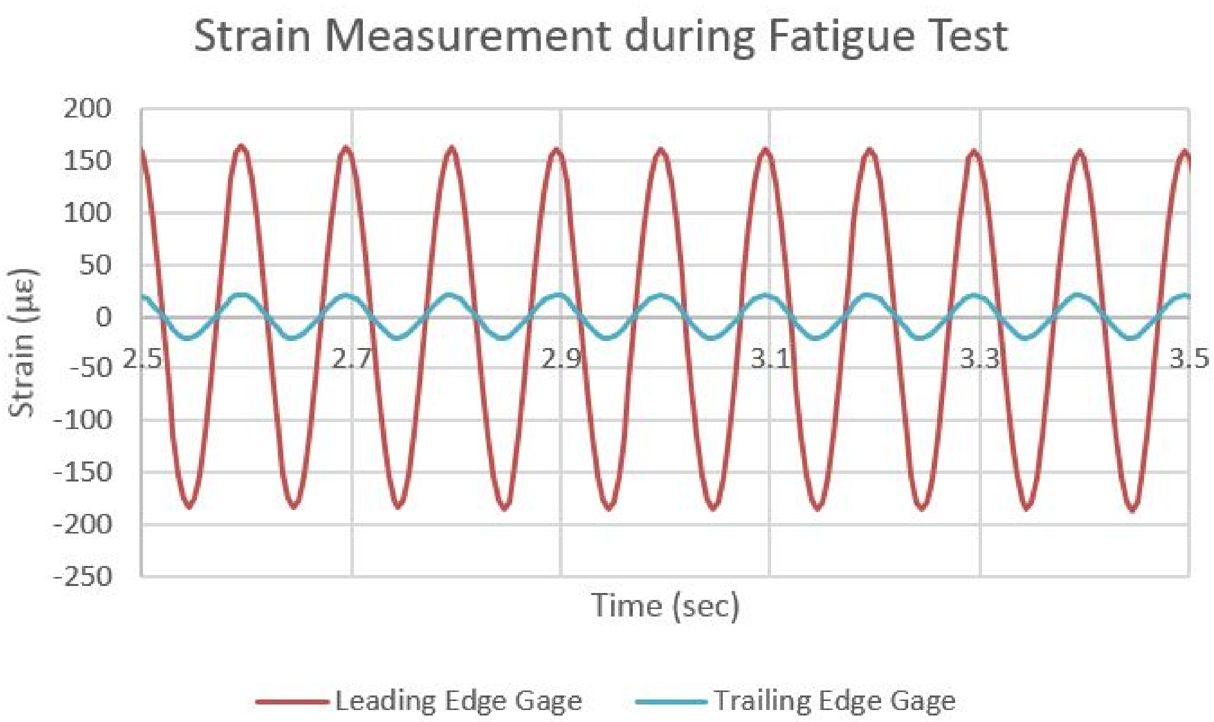

Figure 3: Strain data at leading and trailing edge during fatigue test.

The User Explains

Aircraft wings undergo numerous wing deflections during their service life that can lead to cracks in parts or joints. In order to mitigate this risk, engineers use very conservative factors of safety, which leads to heavier structures. The consequence is lower fuel economy leading to increased operation cost. To address this problem, I aimed to create a model validated with experimental test results. The model can be used for design trade studies. With Micro-Measurements® strain gages I was able to conclude that my FEA model simulated the strains along the leading edge of the wing. With the analysis model validated, additional spar designs can be analyzed. By comparing the strains between different spar designs, I was able to determine the optimal design for static and fatigue bending loads. The strains along the leading edge from the simulation model and experimental test are plotted in the Fig. 4 below. The Micro-Measurements® DAQ, along with their strain gages, ensured ease of setup and accurate data collection.

Results from the trailing edge and along the chord did not match as closely as the leading edge group. This can be explained by either the boundary conditions of the experimental test or inconsistent bond lines along the trailing edge. I believe that by addressing manufacturing and assembly issues, the errors at those two locations could be diminished. In order to investigate this area, experimental testing with strain gages is recommended.

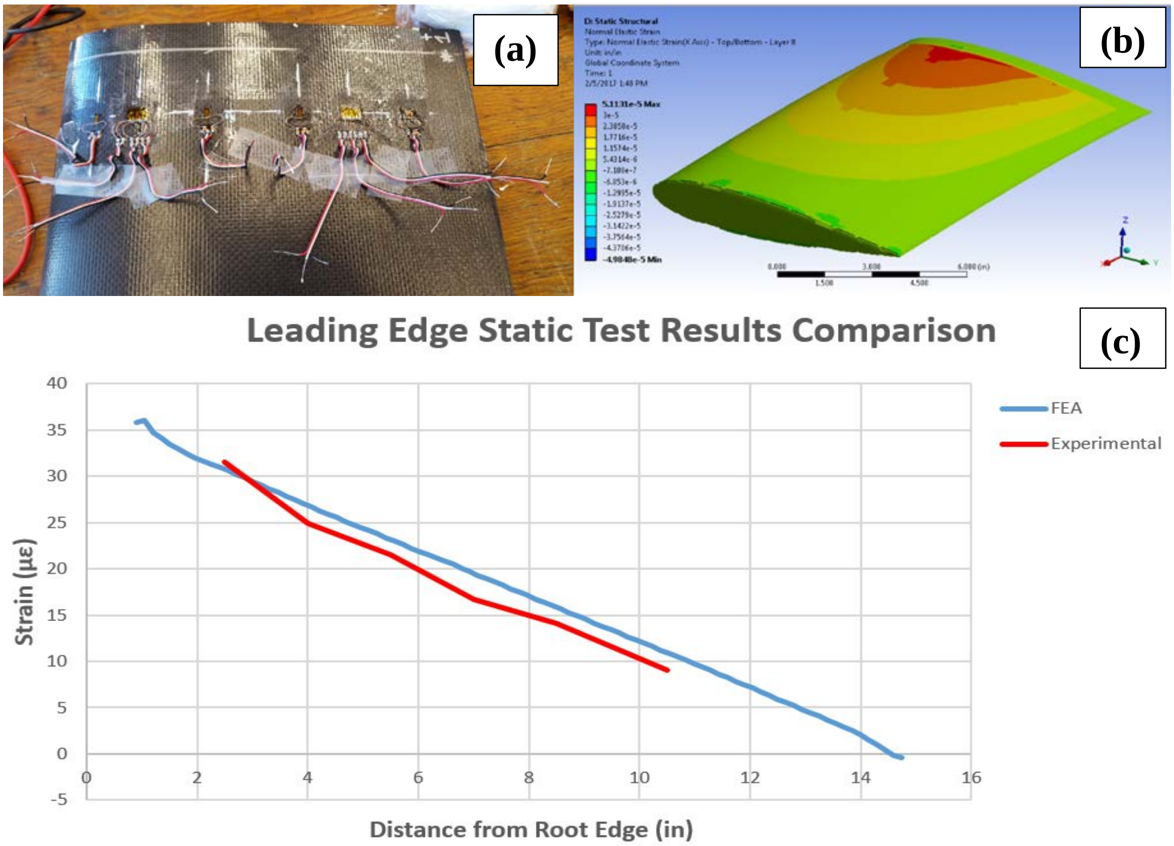

Figure 4: (a) Strain gages along the chord wise direction. (b) Strain contour plot from the FEA software. (c) Experimental and FEA strain results along the leading edge spar.

"With Micro-Measurements® strain gages, I was able to conclude that my FEA model simulated the strains along the leading edge of the wing."

Acknowledgement:

By taking into account the successes and mishaps of this project, I hope that other students will be able to yield even better strain correlations. I hope that my project will serve as a pathway for others that want to study fatigue or composite structures. Cal Poly SLO's motto "learn by doing" is important by showing that analytical methods actually represent experimental test conducted with structures. It is important for engineering students to have access to resources necessary for laboratory experiments to enhance their learning. Micro-Measurements® strain gages and its System 8000 data acquisition instrument were essential to this project because they allowed us to compare the results between the experiment and the simulation model.

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