Structural Analysis of Balsa Wood Airframes

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Objectives of Test

- Acquire and stress test Atmospheric Senior Design team’s balsa wood surrogate wing.
- Configure Piezo-accelerometers to work with our DAQ system to record data.
  - Secure piezo accelerometer to surrogate wing, and perform impulse tests to better understand the Power Spectrum against frequency response.
- Construct a Wheatstone bridge and attach it to the surrogate wing.
  - Load the surrogate wing with 1 lb sandbags, measure the deflection, and create a better understanding of the material properties of balsa wood wings for future design classes.

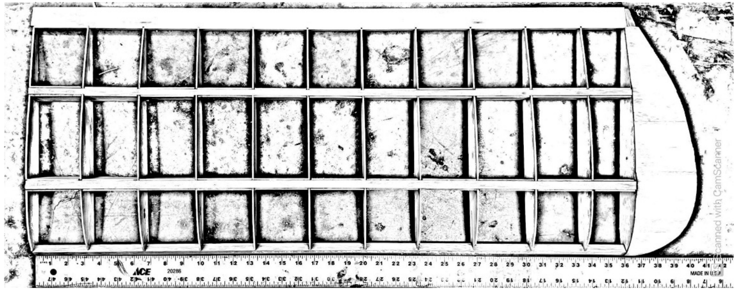

Figure 1a: Planform view of Surrogate Wing with Scale

Figure 1b: Sandbag Loading on wingtip

Apparatus

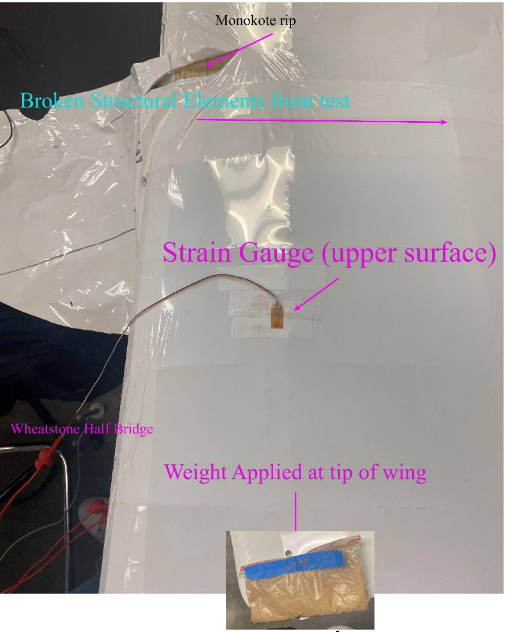

Figure 1a: Part 2 Lab setup

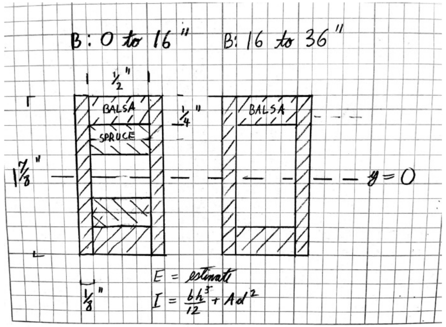

Figure 1b: Inner Geometry of wing

Figure 1c: Fully Dimensioned Wing

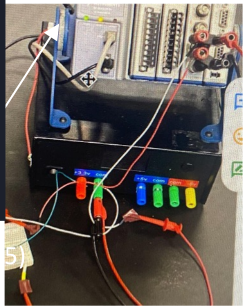

Figure 2: NI DAQ for Parts 1 and 2

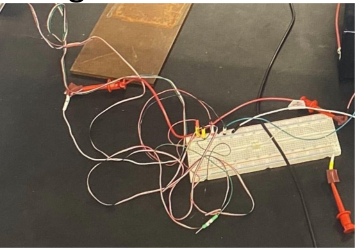

Figure 3: Breadboard for Parts 1 and 2

Figure 4: Wheatstone Half-Bridge

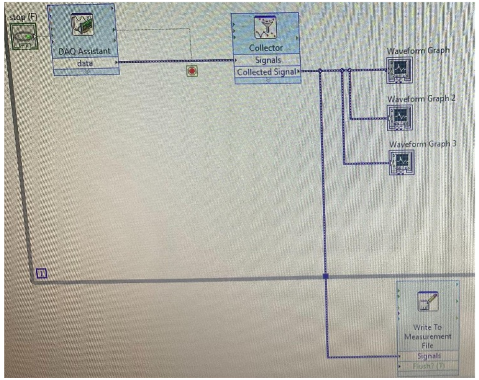

Figure 5: VI for Part 1

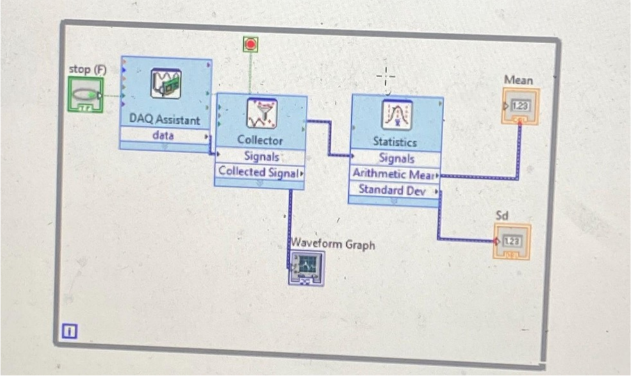

Figure 6: VI for Part 2

Method for Tests Part 1 and 2

- **Part 1:** DAQ was powered on and configured. A piezoelectric sensor was attached to upper surface of wing at quarter-chord using magnetic putty. Experiment was initiated and the wing was struck near the edge by a mallet. This experimental setup is shown in the video here. Experiment was repeated three times.

- **Part 2:** Piezoelectric sensor was removed. A load cell was mounted to bottom and top surfaces of the wing. Load cell was attached to a half-bridge Wheatstone configuration. Measurement of unloaded wing was first taken for calibration. A 1 lb sandbag was placed at edge of wing. Load cell data was collected. The number of sandbags was incremented one by one until 5 lbs were placed on the wing’s edge. The experiment was repeated can be seen here.

Part 1 Results

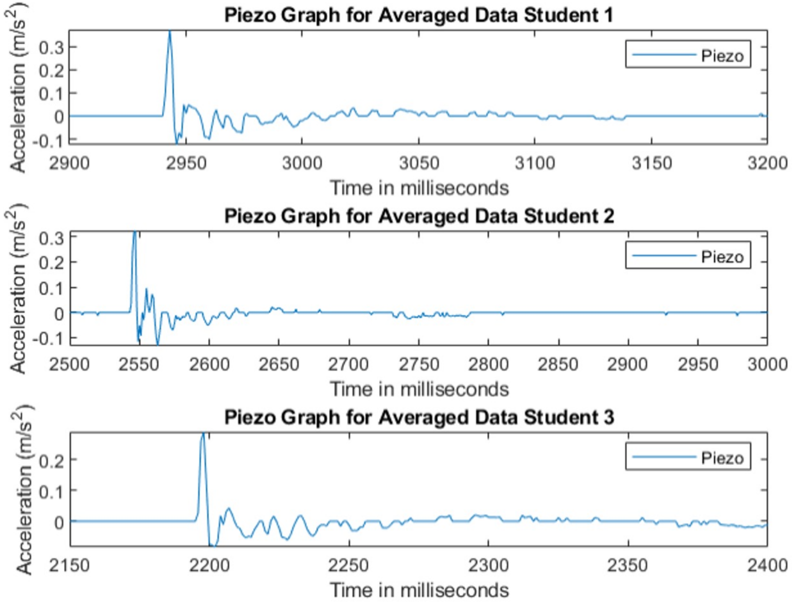

Figure 6: Raw Data from all 3 Impulse Tests

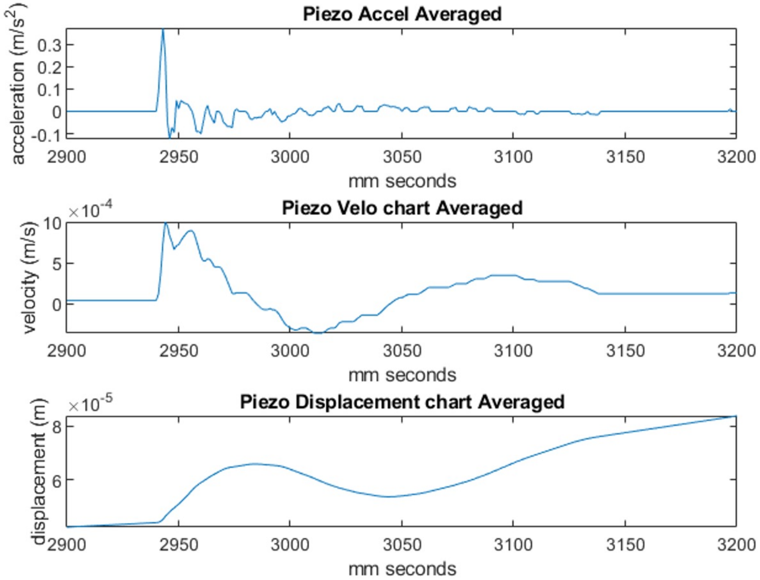

Figure 7: Run 1 Acceleration, Velocity, and Displacement

- Figure 6 displays the results for all three impulse tests we performed on our surrogate wing. All results remained nominal and matched expectations due to the increased rigidity of our balsa wood wing.
- In Figure 7 we solve for the velocity and displacement by taking the cumulative sum (or integrated) over the acceleration twice in order to better understand the impulse test responses for the first hit. The results again were as predicted. The wing did not deflect much because of the relatively small impact of the hammer imparted impulse, and the amount of inertia the wing had considering it was over 6 feet long.

Part 1 Results

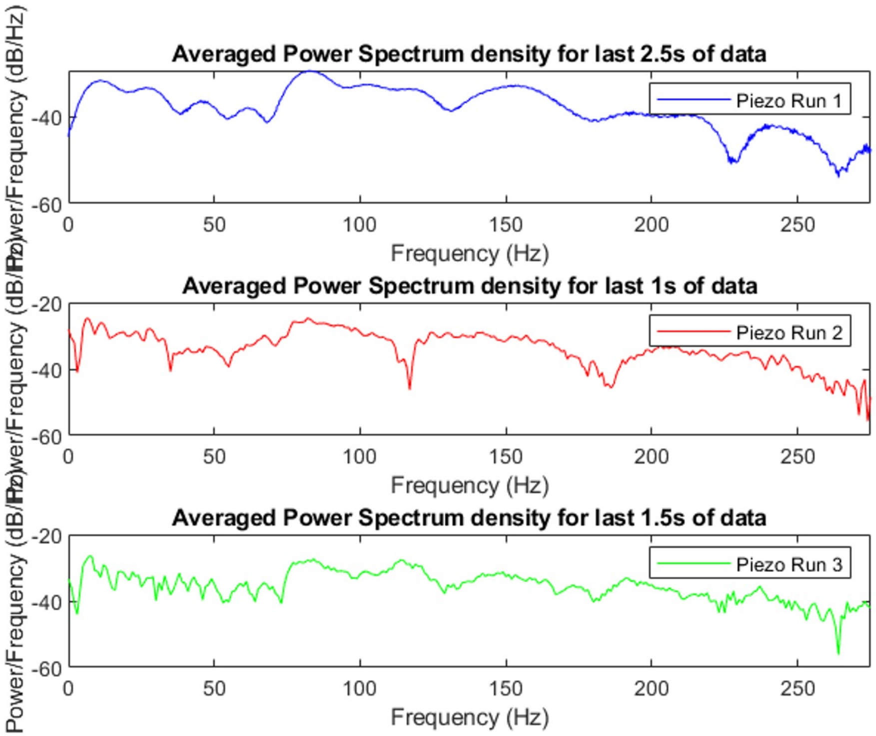

Figure 8: Power/Frequency vs Frequency Response graphs

- We utilized a Fourier transform in order to plot out the frequency response of the impulses. As well as the Power/Frequency domain with the equation **psd = 10*log(abs(freq_domain))** in order to gain a better understanding of the response of the wing.
- Ideally we would have seen one peak that had a higher amplitude than other in the resonance series, but we did not quite receive that result. Instead we had nearly identical amplitude peaks that appeared at the 8 Hz frequency and near the 75 Hz frequency.
- Our theory for why this occurs is due to the intricate nature of a fully built wing. In class we studied the frequency response of a wing with on solid aluminum ¼ chord spar. For our wing we had a multispecies and geometrically varying wing that would induce different frequencies at different lengths of the wing.
- We believe that the differing resonance frequencies correspond to the two main materials that make up this wing, Balsa and a Spruce doubler on the top and bottom spars of each wing.

Part 2 Results

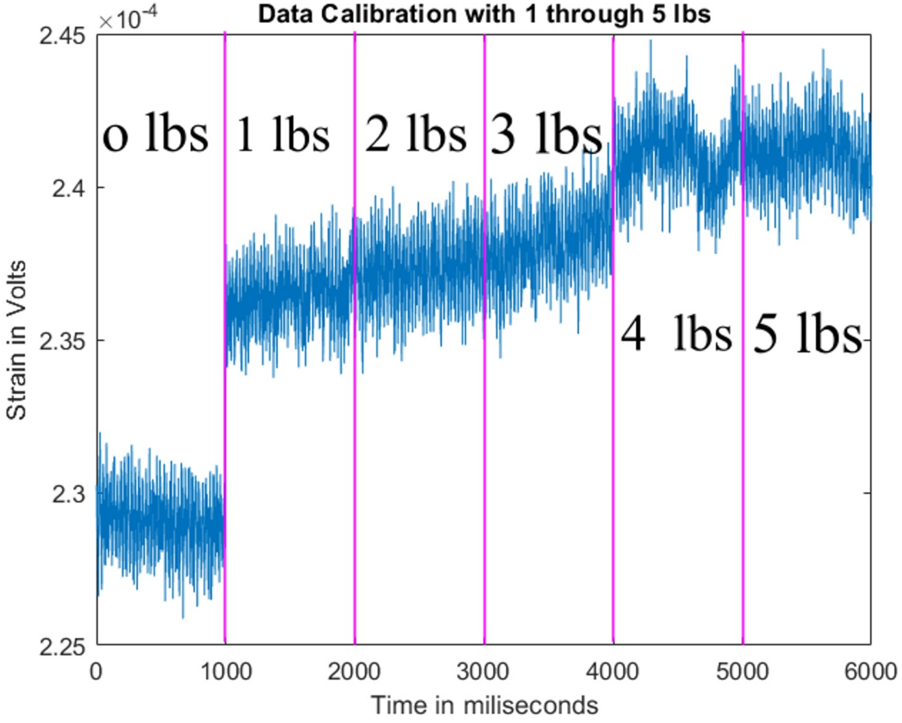

Figure 9: Load Calibration Plots

- We calibrated the experiment with 1 lb increments from 0 to 5 lbs in stand bags. We originally intend to go up to 10 lbs, but at 4 lbs the main wing spar ribbing that held the upper and lower ¼ chord together sheared in half. Thus we had to stop at 5. The increase in shaking can be see around the 4 lbs and 5 mark when the fracture occurred.

- After the voltage was zeroed out with the averaged unloaded voltage the equation disp = 1.579*V_out + .308 was used to calculate the actual displacement that the wing experienced.

- The interesting finding from this section was that when the strain gauges were applied to the monokote (thin plastic foil over internal structure) it highly skewed out results. As will be seen in the final results section for Part 2.

Part 2 Results

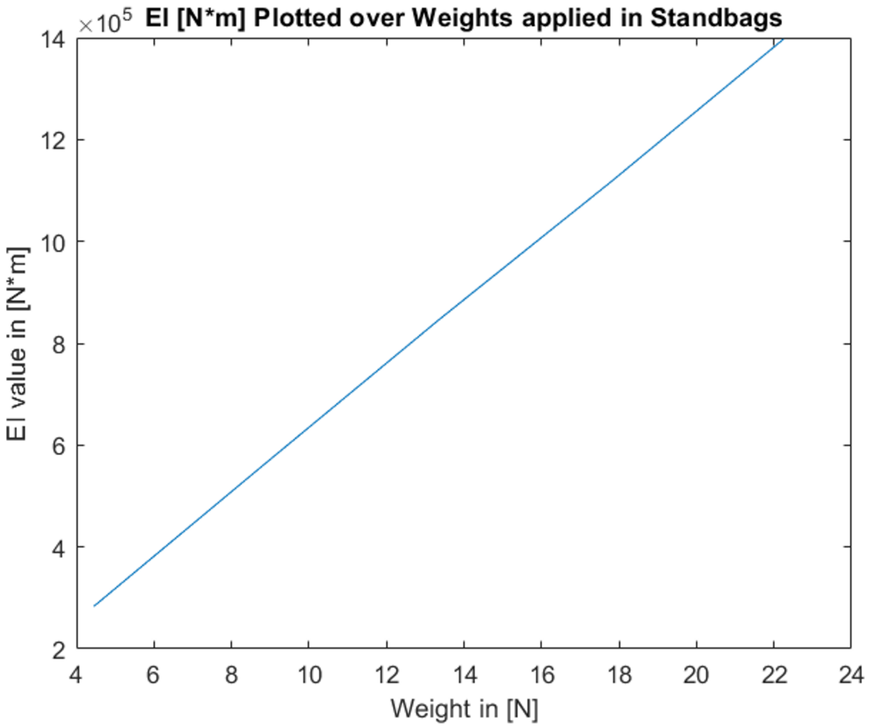

Figure 10: Plot of EI vs applied weight in Newtons

- The Results for obtaining our EI value for this experiment were conducted by applying the calibrated displacement we acquired in the previous slide to the equation
- **EI = W/(disp)*(y + x/2^2 + x/6^3)^-1**
- In order to solve for the EI of the wing. Again, the geometry and materials of the wing make it difficult, and the assumption that all weight was barred by the ¼ spar is applied in these calculations and plots.
- We adhered the strain gauge to the monokote rather than apply it directly to the balsa wood ¼ spar. Our argument for doing so was it is part of the wings structure so it should be included. The problem with this is that the monokote stretched at a far greater rate when the load was applied than the wood will bend in the internal structure.
- This resulted in a linear "runway" EI evaluation in our plot. The plot should have been much more flat, and if we could redo the experiment we would probably have cut out the monokote and applied our strain gauges directly to the wing rather than the monokote surroundings.
- We predicted the EI values to 13194e+05 lbf-in^2, and our results are within that range, but obviously the monokote's high elasticity really hampered the results we wanted to find in this part of the experiment.

Conclusions

- Impulse and static load tests were performed to study the frequency response-power spectrum relationship and material properties of the wing respectively
- Acceleration measurements from Piezo accelerometer in Impulse Test matched expectations with nominal values under increasing wing rigidity
- Wing deflections from impulse test remained minimal as expected given small impulse excitation force and large inertia of wing
- Resonant frequency was observed at two locations instead of an expected single occurrence likely due to inhomogeneous material properties of wing (i.e. Balsa and Spruce materials)
- Flexural rigidity plot as function of applied dead load in second part of experiment exhibited linear relationship and thus differed from theoretical behavior of a flat curve
- Sources of Error:
  - 1) Power Spectrum Density Plot: Inhomogeneity of material properties making up the wing structure
  - 2) Flexural Rigidity Plot: Application of Strain Gauge to Monokote rather than Balsa Wood

Future Work and Ideas

- Through this experiment the Deadstick Engineering Team will be able to enter Senior Design II with a better understanding of the frequency response of balsa wood aerofoils.
- The research done here will be critical when designing and evaluating the structural deficiencies of our Test Demonstrator Vehicle (TDV) during the flyoff portion of our design class.
- In the past seniors design teams have had to deal with extensive flutter issues, especially with the aircraft we will be utilizing. Consequently, the understanding gained here will guide us on what frequency domains will lead to excessive flutter in our TDV.
- Going into our Preliminary and Critical Design reviews the Deadstick Engineering team will know to pay close attention to vibrations occurring at the 7-10 Hz and 70-75 Hz regions in order to reduce the risk of aerodynamics flutter and resonance within our structure.