In-Flight Strain Measurement for Composite Airframe Load Characterization

Team 206 Project Technical Presentation to the 2026 IREC

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INTRODUCTION

Custom composite materials provide benefits to the Case Rocket Team for their low weight, high strength, and customization. It is, however, difficult to simulate its response to the forces of flight. Thus, implementing meaningful design requirements becomes challenging. To better understand the stresses that these composite materials face during rocket flight, a one-of-a-kind strain measurement system was implemented for the IREC competition rocket. This system utilizes 14 precision strain gauges coordinated by a high-speed microcontroller to create a clear picture of the strain on key areas of the rocket during all phases of the rocket's flight. These data, paired with external lab testing to determine the stress-strain relationship of our composite parts, can be used to determine the forces on the rocket during flight. This information will save manufacturing time, cost, and engineering complexity by creating quantifiable standards and streamlined procedures for the composites production process.

INITIAL TESTING AND THEORY

The theory behind strain gauges is simple. The gauges themselves are precise electrical resistors, whose resistance changes linearly with strain[1]. To get a useful measurement from this process, the change in resistance must be converted to a change in voltage. Additionally, the signal must be amplified significantly to illuminate small changes in strain. A COTS board known as a strain gauge module was used for both of these tasks. The modules used a Wheatstone bridge circuit to convert from a change in resistance to a change in voltage, with operational amplifiers to shift and amplify the signal.

The largest challenge in designing the initial system was determining a means to quickly and precisely store these voltages. Initial strain measurement tests utilized a LabJack T7 data acquisition (DAQ) device. The LabJack was a powerful device in its own right, but its autonomous operation abilities were insufficient, so it was determined that a custom DAQ system was required.

DESIGNING ELECTRONICS

To store and interpret the analog signals produced by our strain gauges, they must first be converted to digital signals. Reading and serializing voltages requires an analog-to-digital converter (ADC) and some form of storage device. For the first part of this system, Texas Instruments' ADS1256 analog-to-digital converter was chosen because it supports 8 channels with 24 bits of precision and a maximum sampling rate of 4,374 Hz when cycling channels[2]. Because there are more than 8 strain gauges on the rocket, two ADCs were used.

MicroSD cards were chosen because of their relatively low cost, high write speeds, and compatibility with computers. Unfortunately, the high-vibration environment of high-powered rocket flight renders the electrical contacts of microSD cards unreliable. After some research, a circuit board with a microSD card soldered to the board was discovered, which remained reliable under high vibrations.

The Arduino Nano RP2040 was selected as the microcontroller for its price, speed, and dual-core nature. Using a microcontroller with dual-core capabilities was especially important as it allowed for simultaneous data acquisition and storage. The Arduino handled communication with both ADCs, the microSD card, and an onboard accelerometer, which was used to detect flight. The whole system was programmed in C++, with interfaces for the ADCs and accelerometer written from scratch.

INTEGRATION OF STRAIN GAUGES

Strain data were collected in the nose cone, coupler, body tube, boattail, and fins. A pair of perpendicular gauges was applied in each of these five areas along the same radial axis in order to more easily interpret and model data post-flight. An additional pair of gauges was applied 180° and 90° from this radial axis in the coupler and on the fins, respectively. Strain measurement on perpendicular fins allows for a more detailed view of phenomena such as fin flutter. In addition, an antipodal set of measurements allows a better interpretation of the material deformation.

While strain gauges are widely used in aerospace industries for testing and structural analysis, the application of strain gauges for these specific circumstances was an immense challenge that required an extensive application process to be developed. Strain gauge best practices were taken from MicroMeasurement's Instruction Bulletin B-127[3] , and the first gauges were applied to flat carbon fiber sheets. These sheets were used to tune the application process in an environment less challenging than the actual contours of the rocket. On these test sheets, the most effective surface preparation techniques, adhesive amounts, and an apparatus that would allow for two gauges to be applied simultaneously were all determined. This apparatus was assembled by sterilizing an acrylic plate and taping gauges perpendicularly on the top. Wires were then managed to avoid unnecessary forces on the gauges during the application process. This tape-gauge apparatus was then removed from the sterilized acrylic and onto an application area that was sanded with isopropyl alcohol and scrubbed with M-Prep Neutralizer 5A in accordance with Instruction Bulletin B-129-8[4]. Here, an activating agent and M-Bond 200 were used in precise quantities to create an even film of adhesive between the gauge and application surface. It was found that 0.05mL - 0.03mL of M-Bond 200 and an amount of activating agent that could be held by surface tension ($\approx$ 0.01mL) on the gauge provided the best results. Once sufficient testing on these carbon fiber panels was complete, we moved to cylindrical test tubes and tuned the application process further. After consistently getting appropriate results from test pieces, we moved to applying gauges to the rocket.

Unlike the uniform test coupons current procedures were designed for, the application procedure had to allow for hard-to-reach curved surfaces and include protection from heat generated by the motor, the ejection charges, and the physical separation of the nose cone.

In order to protect from heat, critical wiring was insulated, gauges were layered with epoxy, and gauge modules were placed into PETG enclosures. Reinforced enclosures were used to prevent the fragmentation of any components damaging the recovery process. Special attention was required for the gauges in the nosecone because they exist above the separation point of the rocket. A sealed VGA cable interface was put in the recovery bulkhead, allowing for the pressure of separation to disconnect the nosecone electronics. Similar separation systems were used with DB-25 cables throughout the rocket in order to ease the integration process.

In order to address the aerodynamic concerns of attaching gauges on external fin faces, gauges were applied in between layers of carbon fiber, yielding smooth external surfaces. This required testing to ensure the gauges would survive the carbon fiber layup process, which included elevated temperatures and the pressures of a vacuum. A thin layer of epoxy was applied to protect the gauges before performing the layup.

CHARACTERIZATION OF COMPOSITE MATERIALS

Strain alone is not enough information to determine the forces and displacement of the materials in the rocket during flight. When undergoing elastic deformation, Young's modulus characterizes the linear relationship between stress and strain. Because the Case Rocket Team manufactures composites in-house, the Young's modulus of each part needs to be determined experimentally. To that end, the manufacturing team created extra of each part with a strain gauge for this purpose.

The Case Rocket Team works with a lab at Case Western Reserve University to test the modules. Using the Instron machine in the lab, precise forces and displacements can be applied to the test materials. With strain gauges on those test pieces, the Young's modulus can be calculated.

RESULTS, CONCLUSIONS, AND FUTURE WORK

On the ground, the system successfully read from 14 strain gauges simultaneously at over 500 Hz, with a precision of 0.015 microstrain. This, paired with successful lab experimentation, will provide crucial information to be used in next year's composite manufacturing process. This will provide the team with quantifiable needs for composite tubes. Although the system was a successful first iteration, there are plans to improve future implementations of the measurement systems with custom PCBs. Custom boards will allow for higher precision and sampling rates, and a less intrusive system, as each location will be its own independent system. This removes the need for complex wiring throughout the entire rocket.

REFERENCES

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