

# Non-Invasive Tension Measurement Devices for Parachute Cordage

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## I. Introduction

The need for lightweight and non-intrusive tension measurements has arisen alongside the development of high-fidelity computer models of textile and fluid dynamics. In order to validate these computer models, data must be gathered in the operational environment without altering the design, construction, or performance of the test article. Current measurement device designs rely on severing a cord and breaking the load path to introduce a load cell. These load cells are very reliable, but introduce an area of high stiffness in the load path, directly affecting the structural response, adding excessive weight, and possibly altering the dynamics of the parachute during a test. To capture the required data for analysis validation without affecting the response of the system, non-invasive measurement devices have been developed and tested by NASA. These tension measurement devices offer minimal impact to the mass, form, fit, and function of the test article, while providing reliable, axial tension measurements for parachute cordage.

## II. Measurement Needs and Requirements

Various tension measurements throughout a parachute are of interest to characterize the performance and capability of the system. Positive margins of safety are required throughout the structural members to ensure reliability, but this must be balanced with the desire to have a lightweight system. Improved knowledge of the stress fields throughout a parachute when using data acquired during development testing for higher confidence in the design. Additionally, with the capability to transmit data in real time to flight software on the payload, the data gathered by the gauges can be used to determine the best conditions for parachute deployment phases or actuate components (such as a reefing line cutter) during flight operation.

As with most data systems, size and weight should be minimized in order to reduce impacts to the system. This is particularly important with measurement devices of this type since a point mass could introduce dynamics or loads which are strictly a product of the presence of the measurement device itself. Additionally, the capability to add a measurement device without altering the state of the parachute components, both during instrumentation and after removal of the device, is important in demonstrating a given configuration. Finally, due to the harsh operational environments of a parachute (high packing pressures, large deployment forces, electromagnetic environment), the measurement device and any data acquisition hardware must be robust and reliable.

## III. Description of New Devices

NASA's need for a non-invasive load cell has lead to an industry and in-house collaborative development of multiple new devices, two of which are described below.

### A. Novatech Tension Gauge

The Novatech gauge was developed in collaboration with Novatech Measurements Limited and is based on their seat-belt tension load cell. The device is made of machined aluminum and can be installed over an existing cord without the need to dis-assemble or sever the structure. When tension is applied to the cord, the device acts as a three-point bending beam and elastically bends the main component of the device. This bending is captured by internal foil strain gauges that measure the surface strain of the beam. The strain gauges are configured in a full Wheatstone bridge circuit to provide accurate bending strain that is unaffected by temperature changes, wiring resistance, and torsion

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loads on the device. The device can be scaled to different sizes to measure tension in textile reefing lines, suspension lines, and even riser lines of a parachute.

### **B. JSC C-Gauge**

The C-Gauge was designed in-house by JSC engineers to provide a low-cost and custom solution for measuring tension in parachute structures. The C-Gauge has a small metallic body with two small legs that attach to the cord, connected by a larger beam that spans the space between the legs, forming a shape similar to the letter C. Foil strain gauges are attached to the inner and outer surfaces of the connecting beam. When the cord is stretched, the tension in the cord goes through the legs and into the beam, causing it to bend. This bending creates a tension and compression stress in the bottom and top surface of the beam, respectively. The strain gauges capture the tension and compression strains, which can be later be correlated to the tension in the cord. The use of multiple strain gauges create a half Wheatstone bridge that mitigates any torsion loading of the gauge and provides a direct measurement of the axial tension load of the cord. The C-Gauge can be scaled to multiple sizes to meet the expected tension of the cord of interest.

## **IV. Test Program**

Accurate tension measurements in a dynamic parachute environment requires extensive testing both on the ground and in flight. Ground testing in a controlled lab environment can produce static loading on parachute components and offer excellent and repeatable conditions for evaluating tension measurement systems. Static testing was used to calibrate both devices against a pre-claibrated load cell. Tensile, cyclic, and sustained loading tests were completed using an electromechanical load frame to tension a Kevlar cord and measure the tension using both the Novatech gauge and C-gauge devices.

Flight testing was also completed on the Novatech design. Unlike ground testing, flight testing can evaluate the devices through a dynamic loading regime and impart accelerations and g-forces on the device that are similar to what it will see in its expected lifetime. The Novatech gauge was used on a NASA full-scale drop test to measure the tension in a textile riser line for a 116-ft ring-sail parachute. A smaller version of the device was also used to measure reefing line tension on an Airborne Space Systems drop test using a 40-ft ring-sail parachute. Further flight testing of the C-gauge device is expected to be completed in 2017.

## **V. Preliminary Results**

Both devices performed well in ground testing and a successful calibration was completed for each device prior to dynamic testing. The Novatech device used on the parachute riser line produced clear data, but a consistent calibration was not able to be achieved due to the construction of the test article. The Novatech device used on the reefing line of the smaller parachute canopy produced clear data, and a reliable calibration curve was generated. The sub-scale reefing line tension data will be used to refine the analytical models and designs for future parachutes.

Additional flight testing is scheduled to be completed with further development of both devices. The results of all tests will be offered as a comparison between devices and as supporting validation on the design of these novel, non-invasive tension measuring devices.

## **VI. Conclusion**

Both the Novatech and C-gauge devices offer a solution to a much needed, non-invasive measurement system. The implementation of these devices reduces the impact to the test article configuration by allowing structural members to remain in a state representative of the intended design while gathering the required tension data. The design, analysis, and testing completed so far on both devices shows favorable results and additional testing is scheduled to fully characterize the performance of each system. With the completion of additional tests and improved development and design, a unique measurement device will be offered as a method to validate complex analytical models by capturing real-world test data in parachute systems.