Deployment System for Three Axis CubeSat Electric Field Instrument

Dana Turse*, Larry Adams* and Chris Esser*

Abstract

To address Heliophysics scientific objectives, CTD is currently developing the deployment system for the CubeSat Electric Field Instrument (CEFI), a 3D vector electric field instrument that can be accommodated on a CubeSat. CEFI is enabled by CTD's deployable composite boom technology that provides lightweight, stiff, straight, thermally stable booms capable of being stowed within a CubeSat form factor. The boom technology will also provide the CubeSat community with the capability to include one or more deployable booms with lengths greater than 5 meters for future CubeSat missions. CTD recently demonstrated this technology through the fabrication and testing of prototypes.

Introduction

Our present understanding of magnetosphere-ionosphere coupling is limited, partly due to the lack of broad statistical observations of the 3-dimensional (3D) electric field in the altitude region between 300 and 1000 km. This understanding is of national importance not only because of its intrinsic scientific worth, but also because it is a necessary step toward developing the ability to measure and forecast the "space weather" that affects modern technology. Observations from different altitudes and from different magnetospheric activity levels are required to differentiate between spatial and temporal variability. Therefore, the availability of multi-point 3D electric field measurements in this region would greatly improve our understanding of how energy flows and dissipates in the ionosphere.

The high cost of space access and short satellite lifetimes at low altitudes make traditional satellites uneconomical for performing these measurements. Therefore, it is desirable to develop smaller and lower-cost sensor/satellite systems, such as CubeSats, so that the largest possible number of distributed measurements can be economically made in this region. These science objectives can be met using multiple CubeSats in Low Earth Orbit if they each include 3-axis electric field instruments. Therefore, CTD is developing the CubeSat Electric Field Instrument (CEFI), a 3D vector electric field instrument that can be accommodated in less than half of a 6U (10x20x30 cm) CubeSat. This instrument is enabled by CTD's game changing deployable composite boom technology that provides lightweight, stiff, straight, thermally stable booms capable of being stowed within a CubeSat form factor. This technology will also provide the CubeSat community with the capability to include one or more deployable booms with lengths greater than 5 meters for future CubeSat missions.

CEFI Overview

CEFI will be a 3-axis electric field instrument with six rigid booms packaged into half the volume of a 6U CubeSat. The rigidity of the booms is a key characteristic that enables the instrument to be integrated on a 3-axis stabilized CubeSat platform. A notional 6U spacecraft is shown in Figure 1 with the instrument in both the stowed and deployed configurations. The instrument consists of the internal electronics and six spherical sensors mounted on long rigid graphite composite booms. The opposing sensors can be used to form three orthogonal dipoles or be measured individually depending on the instrument measurement mode. The booms are baselined at 2.5-m long, forming a dipole length of 5 m.

* Composite Technology Development, Inc., Lafayette, CO

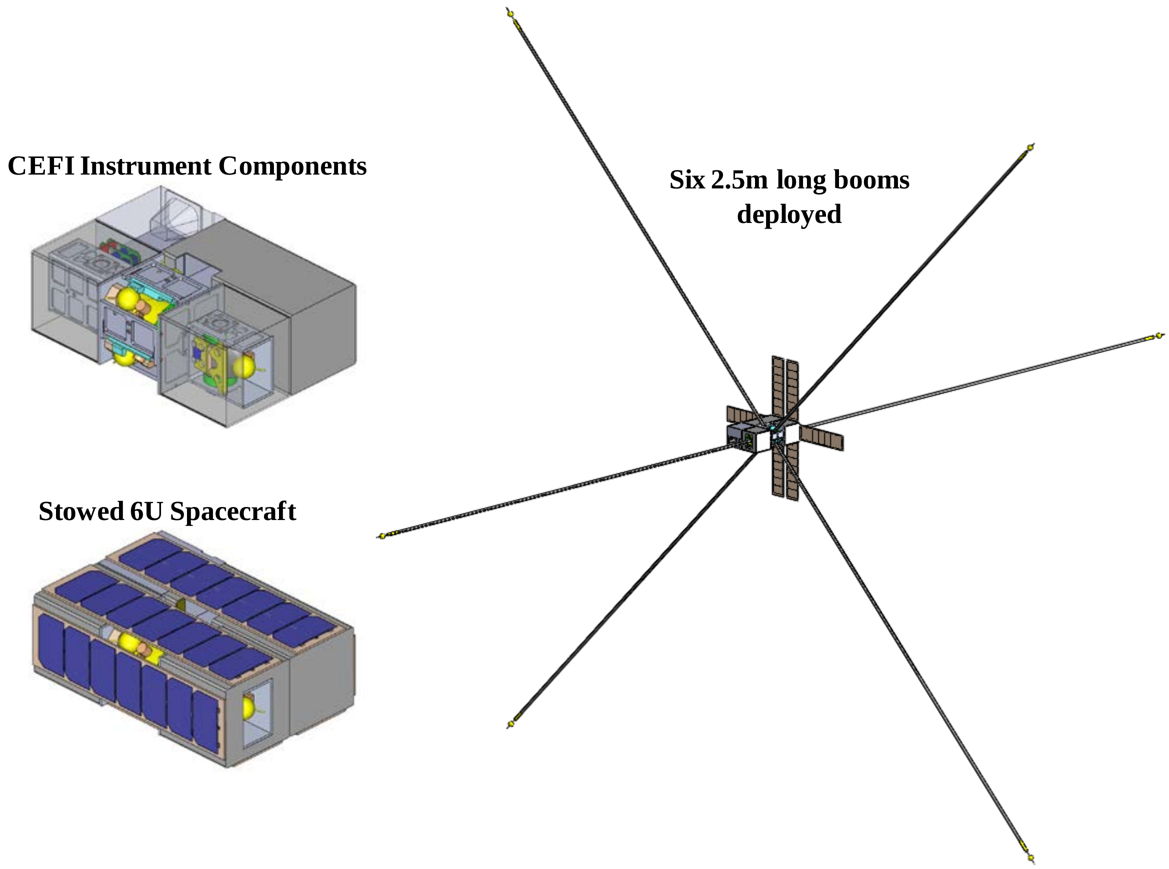


Figure 1. Notional Spacecraft Incorporating CEFI in Stowed and Deployed Configurations

This innovative boom system will use three separate mechanisms. The central mechanism will have four booms and sensors wrapped around a single hub (see Figure 2). These four booms deploy 45° to the sides of the spacecraft in a single plane. The remaining two booms deploy from individual mechanisms on each end of the 3U volume. The central four-boom mechanism and the single-boom mechanisms are shown in Figure 2. All six graphite composite booms and their tip sensors will be identical.

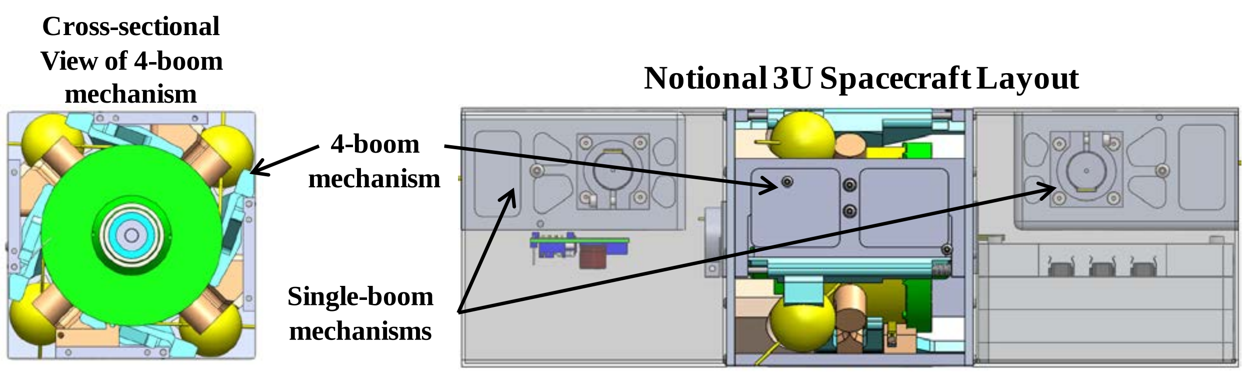


Figure 2. Notional 3U Instrument Layout

<u>Carbon Fiber Reinforced Composite Booms</u>

The baseline booms are 2.5-m long with a diameter of 1.27 cm (0.5”). Manufactured from graphite composite, these booms are extremely lightweight, stiff and thermally stable. Instrument pointing stability is a key requirement. It is estimated that stability needs to be within 0.1° between orthogonal pairs. The boom stiffness and thermal stability will enable this requirement to be met. In particular, the booms must have significantly more deployed stiffness than typical CubeSat appendages, such as carpenter's tape springs or conventional slit-tube beams.

One of the main reasons that CTD is capable of providing such a stable sensor platform is the patented Slit-Lock™ technology. Traditional slit-tube booms have low torsional stiffness, as well as reduced bending stiffness and stability due to shear compliance at the seam. To address these issues, CTD has developed Slit-Lock™ technology (US Patent #8863369), which involves the locking of edge features, such as those pictured in Figure 3, as the boom deploys. By locking the edges, the slit-tube attains near closed-section properties, drastically improving stability in both bending and torsion.

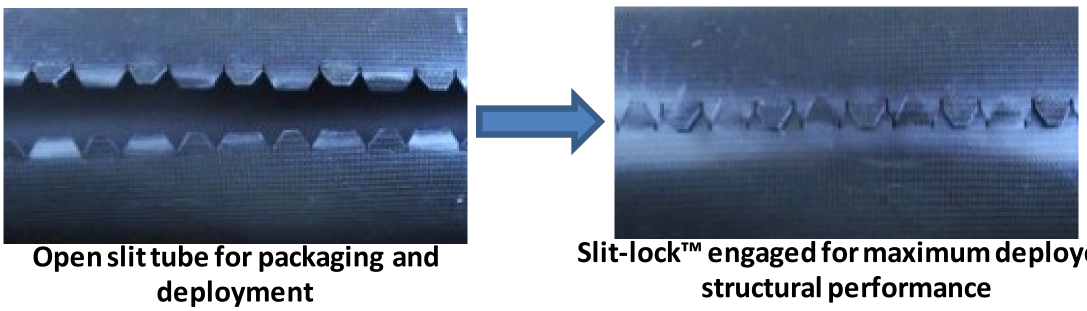


Figure 3. Slit-Lock™ Technology Used to Improve Boom Structural Performance

Furthermore, Slit-Lock™ edge features are aligned when the boom is stowed, allowing them to be engaged to keys on the end caps of the spool (see Figure 4). The slot and key engagement guarantees that the boom will spool and unspool at precisely the same rate every time. The engagement also allows much higher forces to be driven from the spool into the boom as it deploys, which increases margin of safety on deployment torque.

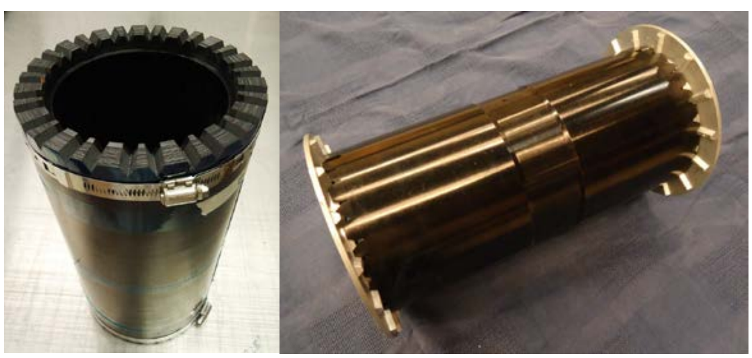


Figure 4. Aligned Slit-Lock™ Edge Features and Matching Keys on End Caps of Stowage Spool

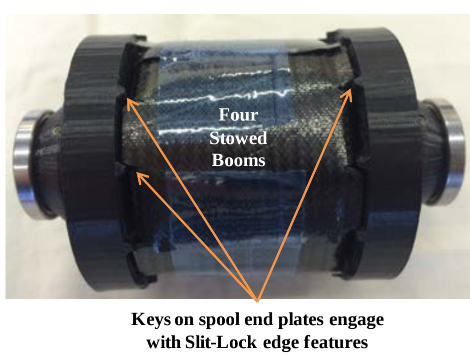


Figure 5. Keyed Slit-Lock™ Edge Features

The boom's thermal stability also has a significant effect on the instrument's performance. Solar flux along the boom can result in a temperature gradient across the cross-section of the boom. This is typically problematic for deployable spacecraft appendages, since this gradient can result in significant "thermal bending". Fortunately, graphite composite booms can be designed so that the laminate has a near-zero CTE, which enables pointing accuracy to be maintained despite potentially large on-orbit thermal gradients. The baseline booms developed for CEFI are estimated to experience less than a 0.1° pointing shift as a result of thermal bending.

Root-Lock™

CTD's CubeSat boom technology further enhances stability by enabling the boom to regain its full cross-section at the end of deployment, as illustrated in Figure 6. This is referred to as "Root-Lock" (patent pending). This root closure provides for high root stiffness and strength, which is particularly important for maintaining the pointing accuracy of a very long and narrow boom. Typical slit-tube booms have a "transition zone" where the boom transitions from flat (on the spool) to curved, and the cross-section is never able to fully recover, leaving the boom with reduced properties at the root. Spacecraft maneuvers can therefore result in significant bending at the root. In CTD's baseline design, the beam is able to transition off of the spool and clamp down around a root plug, providing the maximum amount of root stiffness to the structure (see Figure 6).

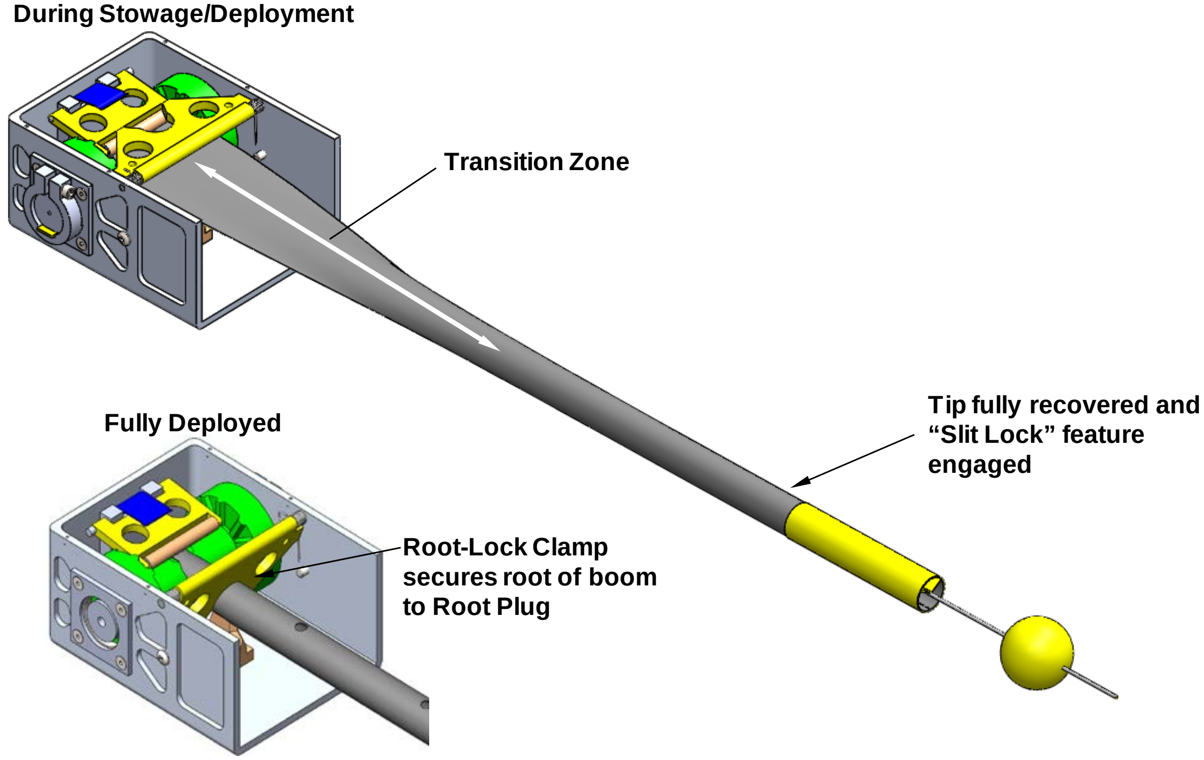


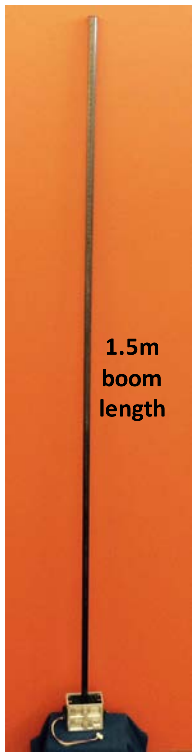
Figure 6. Root-Lock™ enables boom to regain cross-section at end of deployment, drastically improving root strength and stiffness.

Actuation, Positional Feedback, and Deployment Verification

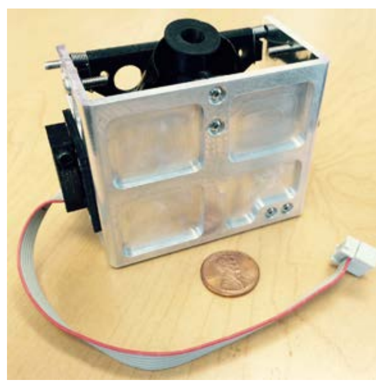
The baseline design involves driving out the booms with a small motor that is efficiently integrated within the stowage spool of each unit. CTD has demonstrated the use of both stepper and DC motors (brushed and brushless), depending on application requirements. For this application, we have selected a brushed DC motor with a 141:1 gear head and attached encoder. This motor consumes less than 5 W while running at 12 V. Deployment time is expected to be less than 5 minutes, but can be tailored to be faster or slower depending on the application requirements. The motor measures 16 mm in diameter, 45 mm in length and weighs less than 45 g total (motor, gear head and encoder combined). The attached encoder provides precise positional feedback and deployment verification.

Fabrication and Demonstration of Prototypes

Under NASA funding, CTD recently manufactured and demonstrated prototypes of both the single-boom and quad-boom mechanisms, shown in Figure 7 and Figure 8, respectively. These booms are 1.5-m long and 12.7-mm (0.5-in) diameter. Both mechanisms incorporate Slit-Lock™ and Root-Lock™. These mechanisms have been stowed and deployed several times without failure or anomalous behavior.



Deployed

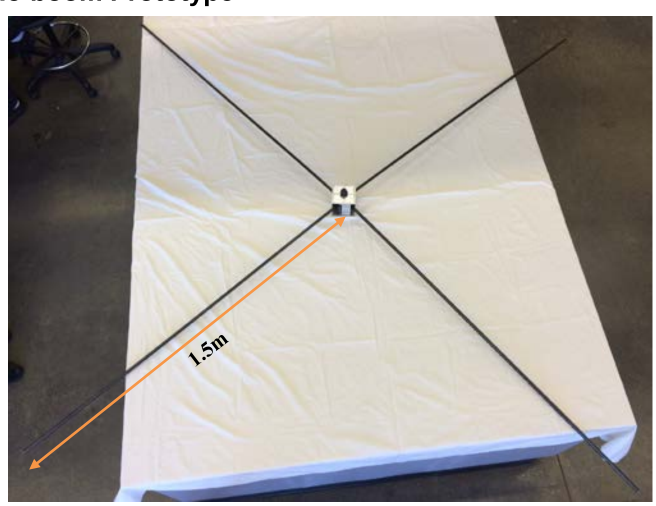


Stowed

Figure 7. Single-boom Prototype

Fully Stowed

Partially Deployed



Fully Deployed

Figure 8. Quad-boom Prototype

Both meet the form factor requirement for the CubeSat instrument. Stowed dimensions for each unit are presented in Figure 9 and Figure 10.

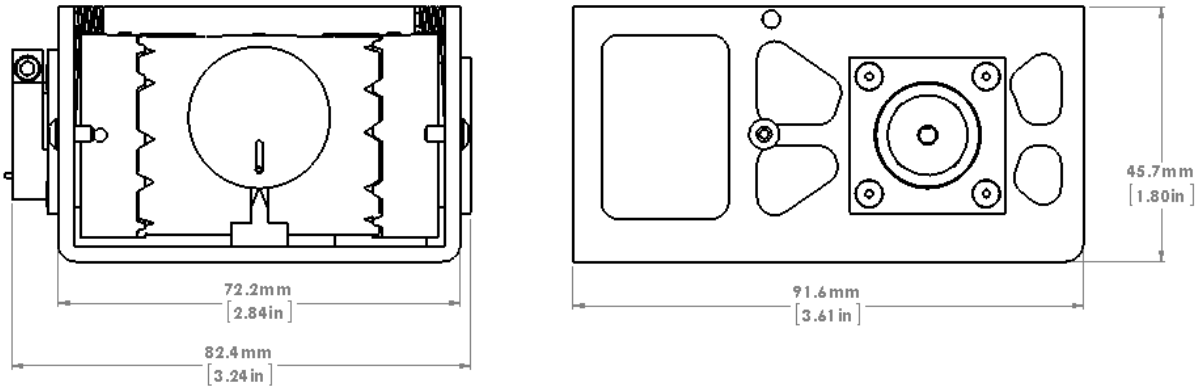


Figure 9. Single-boom Unit Stowed Dimensions

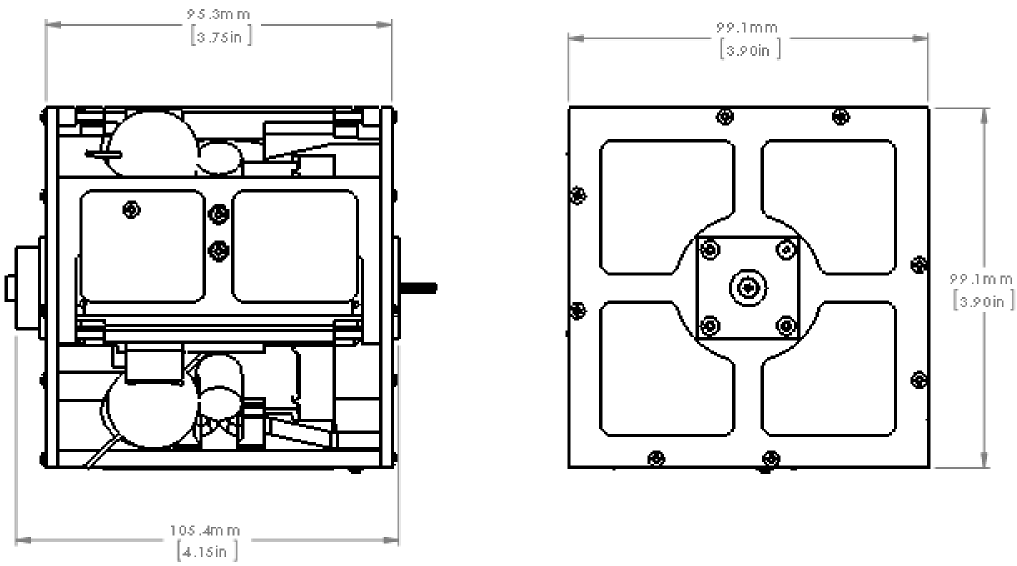


Figure 10. Quad-boom Unit Stowed Dimensions

CTD is now working on integrating the tip-mounted sensors into these units. This will involve the installation of an embedded, multi-conductor wire harness along the length of each boom that can be rolled up with the structure. Furthermore, a slip ring will be implemented within the stowage spool of each unit such that sensor signals and power can be transferred across the rotating interface. CTD is also currently developing miniaturized control electronics that can be incorporated into the 3U volume.

Conclusions

Accurate measurements of vector electric fields in the ionosphere are vital to making progress towards our understanding of the physics of the heliosphere. Housing a vector e-field instrument on a CubeSat enables multi-point 3D electric field measurements to be economically made in this region. CTD is therefore developing the deployment system for the CubeSat Electric Field Instrument, which is enabled by CTD's deployable boom technology. Under NASA funding, CTD recently designed, manufactured and successfully demonstrated this deployment system. Next steps for the technology include the implementation of tip-mounted sensors, wiring harness, slip ring and miniaturized drive electronics. This technology has wide applicability to many CubeSat applications, and could also be used as an antenna, instrument boom (magnetometer, Langmuir probe, etc.), gravity gradient boom, or as the deployable structure for a solar array, drag sail, solar sail, etc.