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LIDAR AND LASER TECHNOLOGY FOR NASA'S CLOUD-AEROSOL TRANSPORT SYSTEM (CATS) PAYLOAD ON THE INTERNATIONAL SPACE STATION (JEM-EF)

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ABSTRACT

This paper describes the ISS lidar technology provided by Fibertek, Inc. in support of the NASA GSFC CATS mission and provides an assessment of the in-flight systems performance and lessons learned. During February the systems successfully operated in space for more than 300 hours using 25 W average power lasers and photon counting of aerosol atmospheric returns.

1. INTRODUCTION

Fibertek is supporting NASA's new Cloud-Aerosol Transport System (CATS) lidar for the International Space Station (ISS). CATS ISS is a Japanese Experimental Module – Exposed Facility (JEM-EF) payload launched in January 2015. The lidar has successfully completed more than 300 hours of operation during its February commissioning period. This program shows that it is possible to develop a rapid (24-month), low-cost ($14M [ref 1]) lidar instrument and successfully deploy it on ISS. The 300 hours of operation already exceeds the annual operational time for a typical aircraft remote sensing NASA lidar. This program establishes a technology heritage that lowers the risk and raises the Technology Readiness Level (TRL) for future science and technology validation remote sensing lidars.

2. METHODOLOGY

NASA's ISS CATS lidar is very unlike other space lidars costing hundreds of millions of dollars. The ISS CATS mission was really developed by a small team in a manner like a UAV mission to the space station. Goddard Space Flight Center (GSFC) and Fibertek leveraged mature heritage designs and spaceflight processes where affordable. The lasers were built to Fibertek's aircraft and flight optical standards while the lidar system and laser electronics were built using known radiation-tolerant parts at an affordable cost. Much of the systems electronics functionality was driven into high-performance Actel field programmable gate arrays (FPGAs) to minimize EEE parts count. Many EEE parts were uncertified flight parts or aerospace quality parts made from the same die as space parts. We estimate that more than 95% of the EEE parts have space-qualified plug-compatible equivalents and can be upgraded from Class D to Class C/B.

3. RESULTS

This program demonstrates that the ISS can enable a new generation of space lidars important for weather and global change research including for aerosols, methane, carbon dioxide, water vapor, ozone, and wind lidars that are currently under development (**Figure 1**).

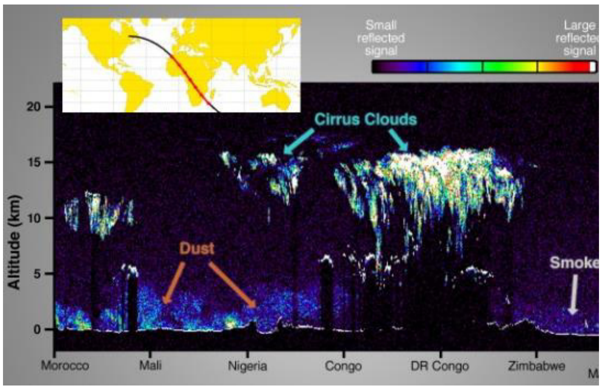

Figure 1: CATS Lidar In-Flight Aerosol Data Showing Aerosols, Saharan Dust, Clouds, and Smoke from Fires Across Africa [2]

This paper describes the ISS lidar technology provided by Fibertek in support of the CATS mission and provides an assessment of the in-flight systems performance and lessons learned. A description of the instrument's major subsystems and photos of the systems during test and completed is shown in **Figure 2**.

CATS is a NASA GSFC lidar design that consists of the telescope, receiver optics, fiber-coupled detectors, telescope cover, boresight prisms, cover actuators, high-spectral-resolution lidar receiver, lidar controller, and lasers.

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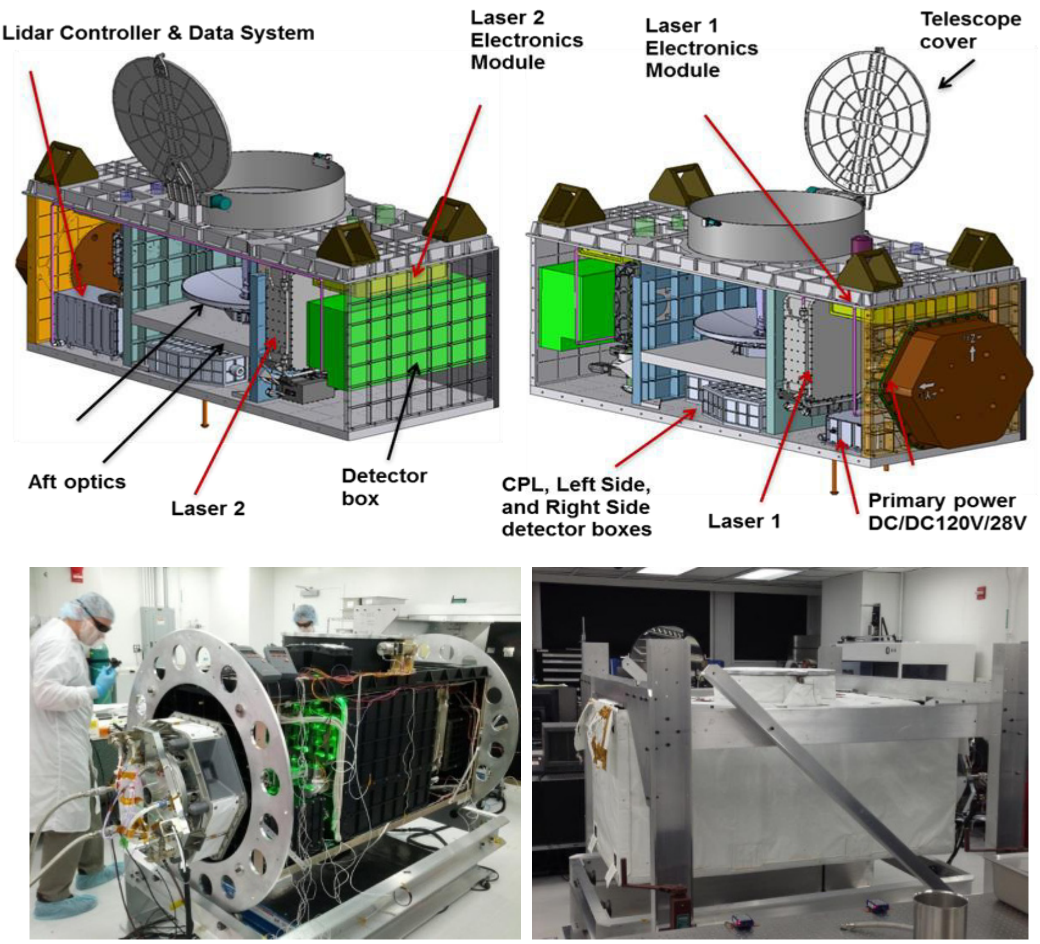

Figure 2: CATS During Integration (left) and Complete with Thermal Blankets (right)

JEM-EF payload is shown in **Figure 2** during integration at NASA GSFC. References 2-5 provide greater detail of the NASA CATS-ISS program objectives and goals, instrument design, and a more detailed description of the CATS lidar and Fibertek-provided lidar electronics and laser. CATS is a high-performance photon-counting lidar that provides aerosol lidar science data and validates new lidar technology.

Fibertek provided CATS subsystems including the lidar flight controller; two state-of-the-art 25 W average power flight lasers with operation at 1064, 532, and 355 nm; a high-power DC/DC converter (from 120V to 28V); two fault-tolerant safety interlocks; and an ISS simulator (**Figure 3**). Fibertek also developed and/or tested the ISS communications to Mil-Std-1553, Ethernet, fiber distributed data interfaces (FDDI), desktop lidar instrument controller interface, and command and control and science data communications link to the GSFC instrument Principal Investigator (PI) through the Marshall Space Flight Center (MSFC) Telescience Resource Kit (TReK) system. NASA GSFC designed, built, and integrated the overall completed JEM payload and provided the items in white: telescope, boresight prisms and cover actuators, and receiver optics and detectors.

Control Board: Lidar instrument control is provided to the CATS instrument operator through an Internet connection and the ISS downlink. Command and control functions for the instrument are implemented from a ground-based control station. The control board commands and activates up to 10 lidar operational scenarios. It provides a control interface for the two lasers, monitors and reports laser operations status and laser energies at all wavelengths, receives laser fire pulse timing information from the lasers, and triggers the receiver data collection operations. Instrument health and safety, activation of the boresighting mechanisms and the telescope cover, digital control of the secondary power supply, and receiver etalon tuning are also functions of the control board.

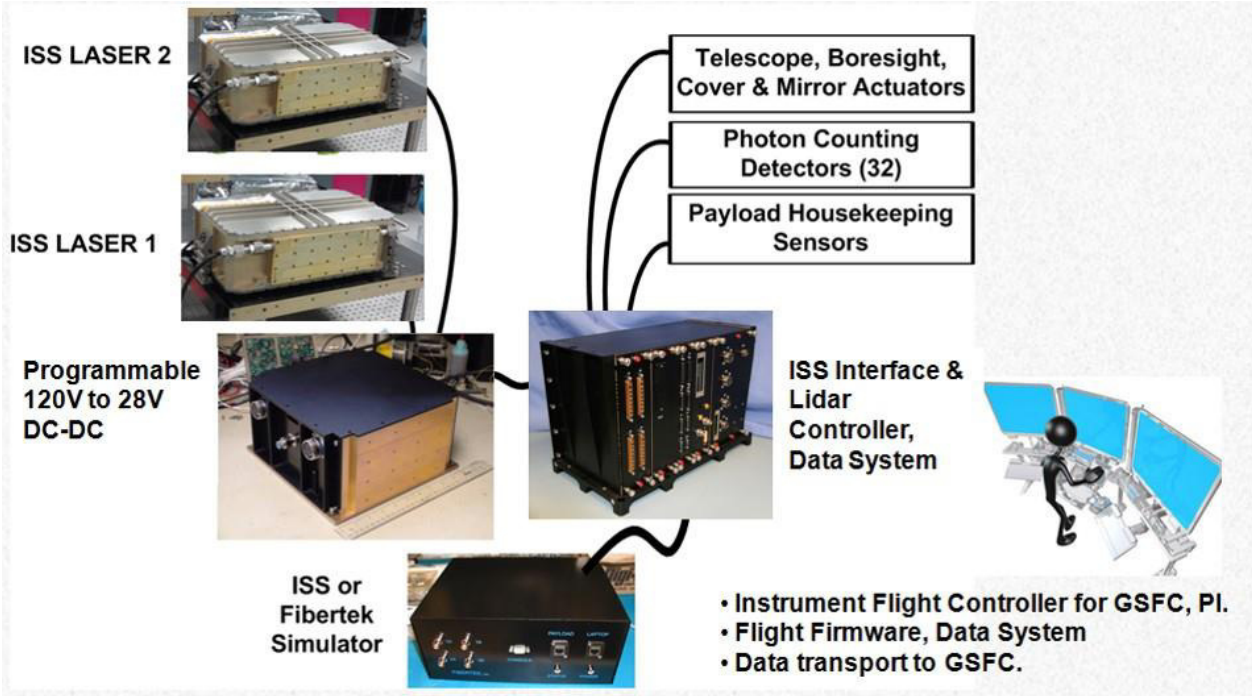

Figure 3: Description of the Fibertek-Provided Items to the ISS CATS Lidar

Data Capture Board: The data capture board supports 24 Avalanche photodetector (APD) photon-counting detector channels. The captured signals are time tagged and sent to the communications card for buffering, packetizing, and transmission to the ISS for downlink. Analysis of the data is not performed onboard the CATS instrument.

Safety: GSFC and Fibertek worked with Johnson Space Center (JSC) and MSFC to ensure all command and control functions required for instrument operation and safety. The systems can be turned off by the instrument manually or by automatic interlocks. The laser and systems can also be powered off without instrument assistance through a two-fault relay. All instrument health status, laser status, and safety functions are monitored by the control board.

ISS CATS Lasers: The CATS 25 W lasers exceed the performance of the CALISPO, ICESat-1, and upcoming ICESat-2 lasers in terms of laser power, beam quality, and spectral linewidth. Laser 1 produces 5 mJ/pulse total pulse energy with half at 1064 nm and 532 nm. Laser 2, shown in **Figure 4**, is a single-frequency transform-limited system that provides 6 mJ total energy at 1064, 532, and 355 nm.

The third harmonic generator is located outside the main laser and can be bypassed if ultraviolet (UV) lifetime issues occur. Laser 2 is not single frequency and operates at 1064 nm and 532 nm. Both lasers provide a high beam quality of <1.5 M2 at all wavelengths.

4. CONCLUSIONS

NASA's ISS CATS program has successfully demonstrated that a small team can rapidly and cost-effectively design, build, test, and deploy a space lidar capable of hundreds and thousands of hours of operation. Lidars can be developed to study focused earth science questions and to develop and validate technology for observatory class 3- to 5-year missions.

ACKNOWLEDGMENT

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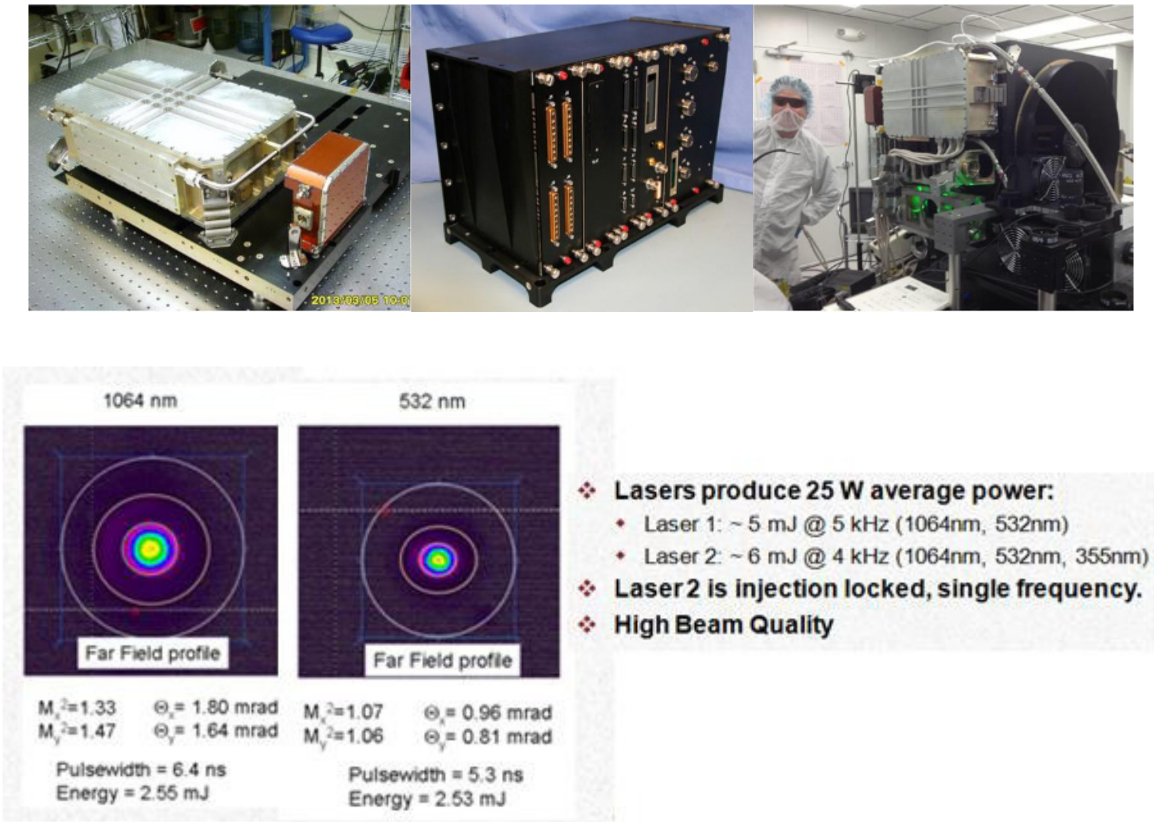

Figure 4: CATS Laser 2, Lidar Controller, and During Laser Integration (left to right)

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[5] Ti Chuang, et al., "Space-Based, Multi-Wavelength Solid-State Lasers for NASA's Cloud Aerosol Transport System for the International Space Station (CATS-ISS)," Proc. SPIE 8599, Solid State Lasers XXII: Technology and Devices, 85990N (March 6, 2013); DOI: 10.1117/12.2005545.