

## TRL6 Testing of Hyperspectral Fourier Transform Spectrometer Instrument for CubeSat Applications

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### ABSTRACT

Hyperspectral infrared instruments have many potential applications in remote-sensing CubeSat constellations. This paper describes the design of a 6U-compatible infrared Fourier Transform spectrometer (FTS) instrument that is designed for meteorological and remote sensing applications, and describes the results of an environmental test campaign designed to increase the technology readiness level (TRL) of the instrument to TRL6. It includes a description of the major subsystems of the instrument, as well as performance test data before and after exposure. Potential applications for this instrument are discussed.

### THE HYPERCUBE MISSION AND OPERATIONAL CONCEPT

HyperCube™ is a constellation of 6U CubeSats equipped with mid-wave infrared (MWIR) hyperspectral instruments. The instruments measure three-dimensional (3-D) distributions of atmospheric water vapor, and by measuring the same region of the atmosphere at different times, they are able to infer wind velocities at multiple vertical locations in the atmosphere (i.e., 3-D wind measurements).

An operational CubeSat constellation would consist of 12 satellites, grouped into four “triplets” of satellites that have identical ground tracks but separated by about 15 minutes. The swath width allows for full global 3-D wind measurements every 6 hours. This allows frequent wind data ingestion into numerical weather forecast models.

The HyperCube satellite consists of two major sections; the instrument section and the spacecraft section. The instrument contains an FTS-based hyperspectral sounder, and its design utilizes heritage components from prior Harris hyperspectral instruments. The instrument includes an FTS interferometer, a cross-track step-stare scanner, a compact aft-optics telescope, a two-dimensional (2-D) infrared focal plane array (FPA), and an internal calibration target.

The step-stare scanner performs cross-track step-stares, each with a fixed stare time. Earth radiance passes through the scanner and feeds a corner-cube Michelson interferometer. The interferometer performs an optical path difference (OPD) sweep and creates a double-sided interferogram in each sweep. Simple focusing optics behind the interferometer place the optical beam

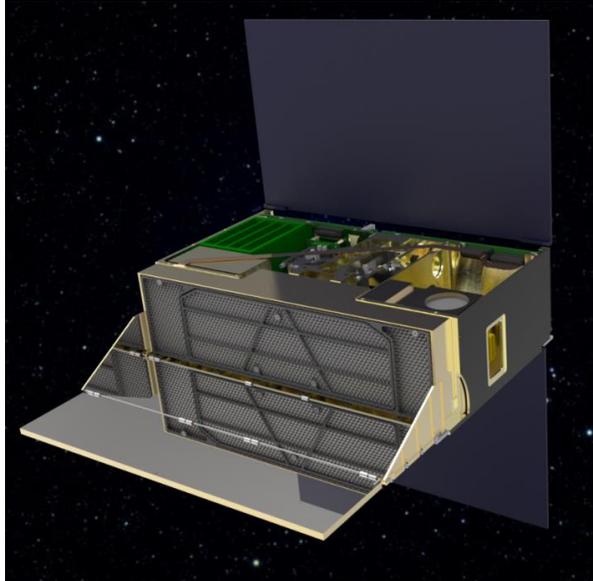
onto a 2-D FPA. The FPA is cooled to cryogenic temperatures using a two-stage passive cooler, similar to the cooler used by the Harris High-resolution Infrared Radiation Sounder (HIRS) instrument, with some new, innovative advancements to fit in the compact CubeSat geometry.

The mass of the full satellite is 12.2 kg, while the overall volume is 11.6 x 24 x 36.6 cm (6U). The instrument section requires 11 W of the total 21 W power distribution.

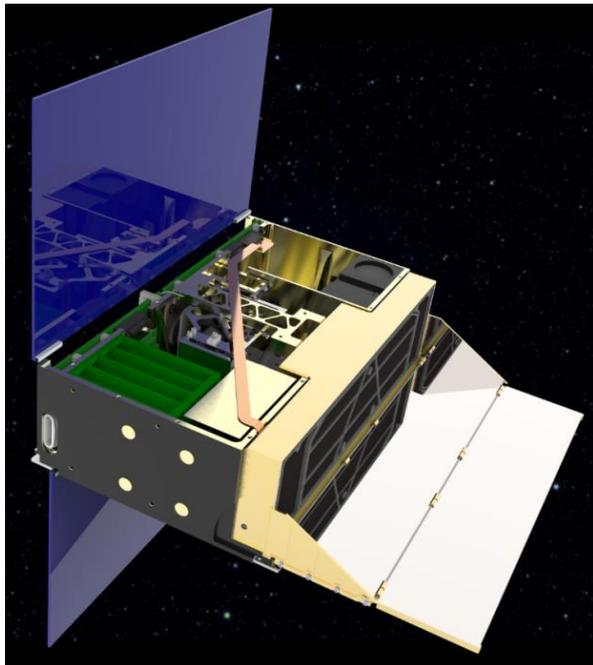
### HYPERCUBE FLIGHT DEMONSTRATION

Harris is developing a flight demonstration version of a HyperCube satellite that could be flown as early as 2019. During the flight demonstration, HyperCube will collect different types of data to demonstrate different types of missions. MWIR spectra, with high spatial and spectral resolution, will be collected providing moisture profiles at various altitudes in the atmosphere. Retrievals will be compared with those of CrIS, AIRS, and IASI. On subsequent passes of the CubeSat over the polar regions, polar winds are extracted from two 3-D moisture data cubes. Simultaneous Nadir Overpasses with CrIS and IASI are used to demonstrate calibration accuracy. An alternate collection method will allow trace atmospheric gases to be detected.

Figure 1 and Figure 2 show the overall design of the HyperCube Flight Demonstration satellite.



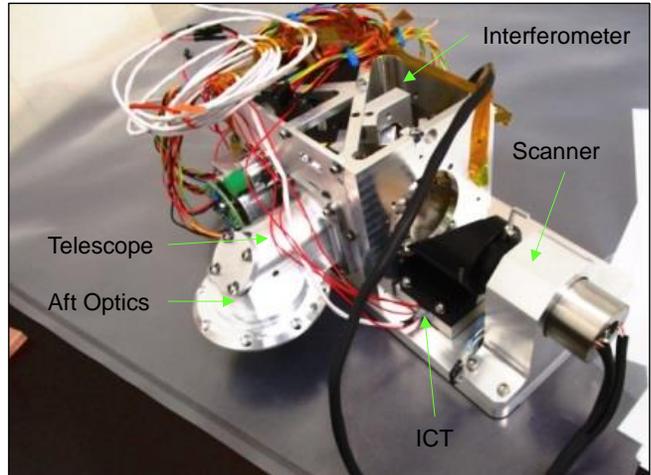
**Figure 1: HyperCube Flight Demonstration Satellite Design (Right View)**



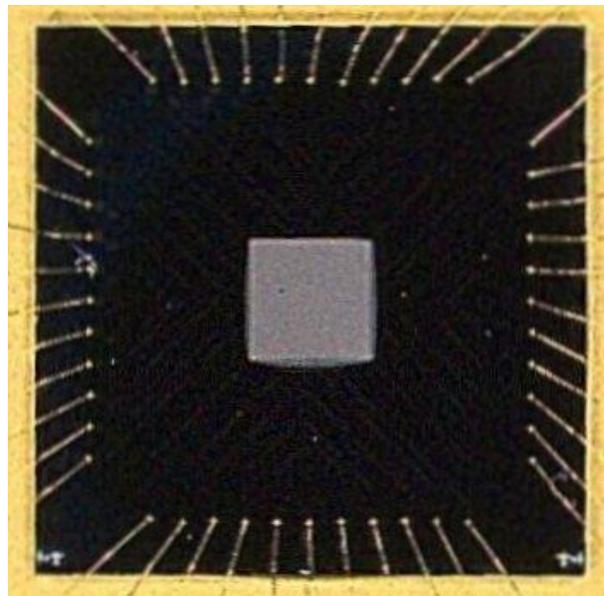
**Figure 2: HyperCube Flight Demonstration Satellite Design (Left View)**

## FLIGHT DEMONSTRATION INSTRUMENT DETAILS

Photographs of the key HyperCube instrument components are shown in figures 3 and 4. Figure 3 shows the main optomechanical portion of the instrument, which includes the cross-track step-stare scanner, internal calibration target, cornercube interferometer, and aft optics. Figure 4 shows the FPA used in the flight demonstration. It is a 6x6 MWIR FPA with a 9.5 micron cutoff.



**Figure 3: Main Opto-Mechanical Portion of the HyperCube Instrument**

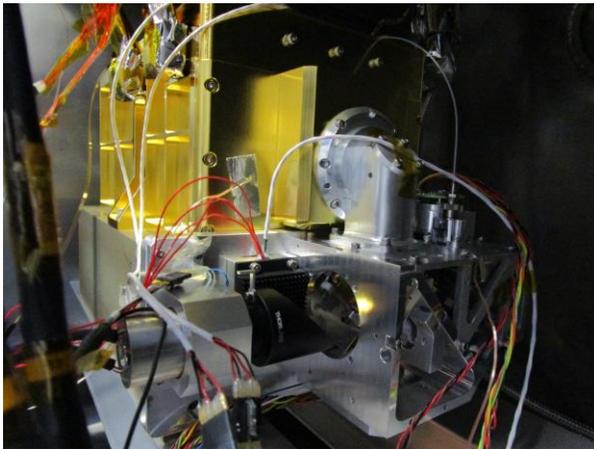


**Figure 4: FPA Used in the HyperCube Instrument**

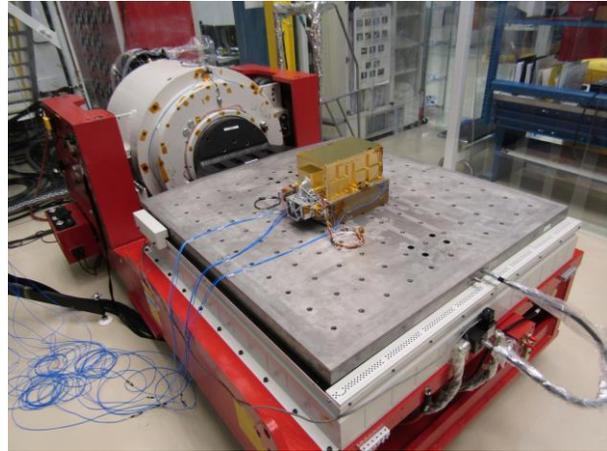
## INSTRUMENT ENVIRONMENTAL TEST PROGRAM

Near-term goals of the flight demonstration program were to demonstrate the maturity of the HyperCube instrument technology and confirm that it is ready for launch. These have now been achieved.

The HyperCube instrument has undergone a complete space environmental test program. This included an initial thermal-vacuum (TVAC) test to establish baseline instrument performance and show vacuum operation, a vibration test to prove that the instrument was capable of surviving typical launch conditions, and a post-vibe TVAC to verify that the instrument was functional after vibration and that its performance had not been degraded by the vibration exposure. Figure 5 shows the instrument in TVAC. The instrument is shown attached to a fixture that serves both as the cooler for the detectors and as the vibration test fixture. No significant issues observed during the vibration test. Figure 6 is a photograph of the instrument while in vibration test.



**Figure 5: HyperCube Instrument During TVAC Testing**



**Figure 6: HyperCube Instrument During Vibration Testing**

The noise equivalent spectral radiance (NEdN) performance of the HyperCube instrument was recorded in TVAC before and after vibration testing. Data collected during TVAC were consistent with NEdN simulations, and no changes were noted due to environmental exposure.

## CONCLUSIONS

Because the HyperCube instrument has now been successfully exposed to a relevant space environment, it is now considered to be at TRL6. Harris is currently in the process of completing the build of the remainder of the HyperCube satellite, with the goal of having it ready for launch in 2019.