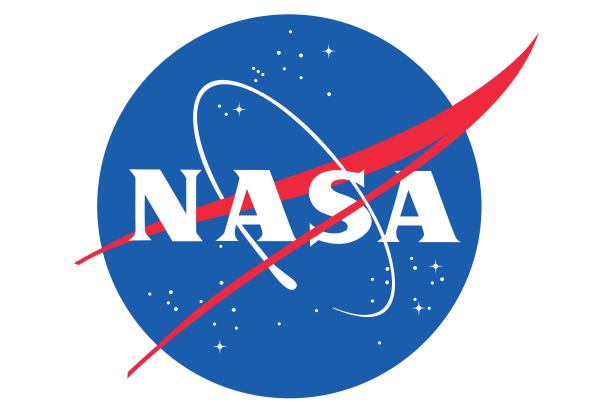


Cryogenic Thermal Management for CryoCube-1

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Abstract

Thermal management techniques were developed that allow an experiment carried by the CryoCube-1 cubesat to reach cryogenic temperatures in low Earth orbit. CryoCube-1 will collect data on cryogenic fluid phenomena in microgravity, supporting the design of in-space propellant depots or long-duration cryogenic propulsion stages. The same passive thermal management methods are applicable to uses such as infrared imaging or cooling superconductors. CryoCube-1 is predicted to achieve a temperature of approximately 100 K in its experiment tank, which will condense oxygen initially stored as a compressed gas. The experiment is instrumented with a video camera that views the interior of the tank via an optical fiber bundle, a pressure sensor, and two Reduced-Gravity Cryo-Trackers® for temperature and wet/dry status. CryoCube-1 will be ready for launch in 2016. Development of the spacecraft is a cooperative effort between Sierra Lobo, Inc., and NASA KSC under a Space Act Agreement. Follow-on missions are planned that will deliver data on stratification and slosh of cryogens and achieve lower temperatures through the addition of active cooling.

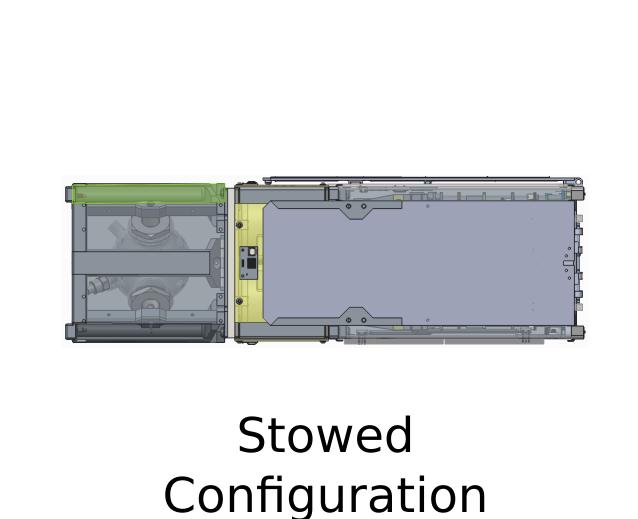
Radiation

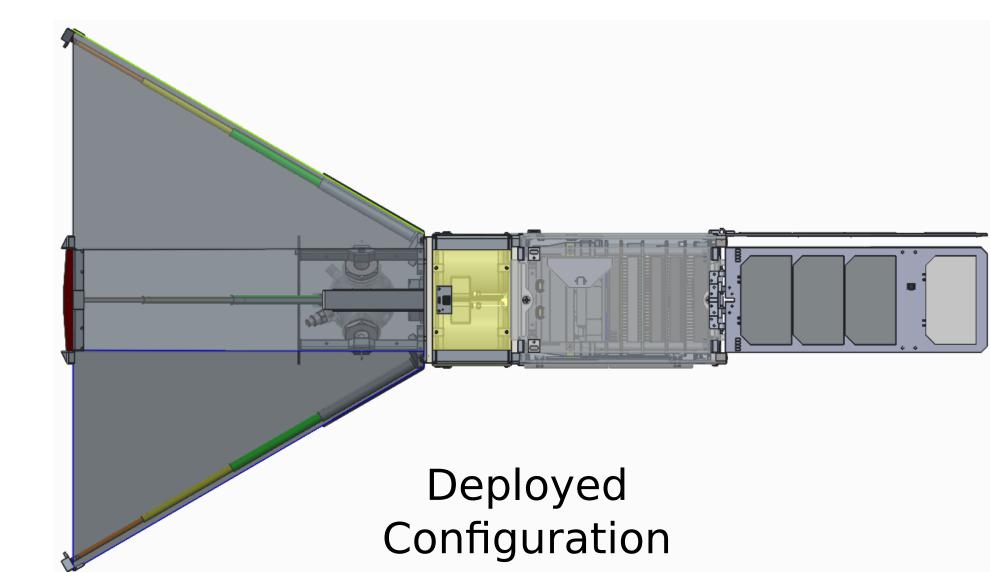
The dominant feature of CryoCube's thermal design is a shield that prevents sunlight, Earth IR, and albedo from illuminating the experiment. The open end of the shield allows the experiment tank to radiate to space. At 100 K, the power radiated by the tank to space is approximately 30 mW. In the desired attitude, the x axis is forty degrees from nadir-pointing, and the positive z axis, which points from the center of the spacecraft through the experiment, points at least fifty degrees away from the sun at all times.



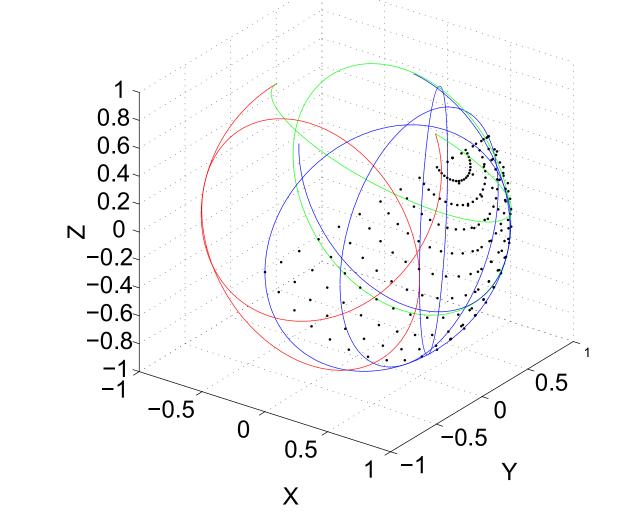
Sunshield Prototype

The shield stows in the 6.5 mm-high volume between the rails of the P-POD. Telescoping struts extend the shield.



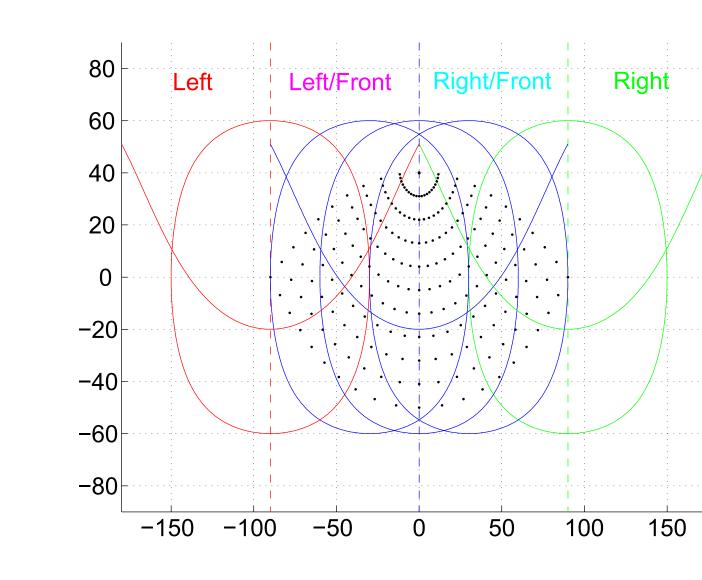


CryoCube uses information from an array of one-dimensional sun sensors (planar photodiodes), a magnetometer, and a MEMS gyroscope to determine its attitude and angular velocity. The sun sensor configuration, using photodiodes with half-angles of sixty degrees, avoids reflections from the spacecraft body and compensates for the effect of Earth albedo.

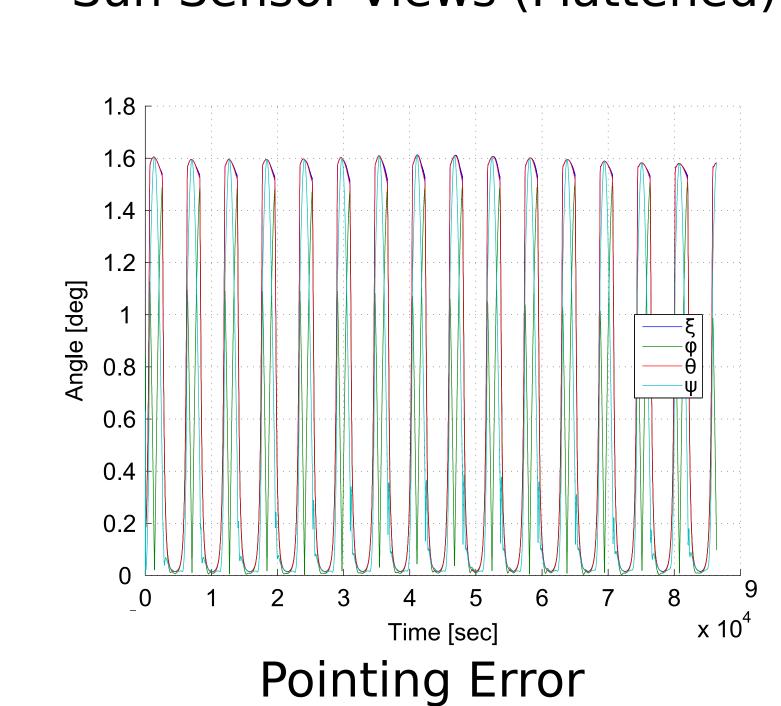


Sun Sensor Views

A genetic-fuzzy controller was developed to control attitude. Taking into account uncertainty in attitude determination and all disturbance torques, the maximum pointing error in a 500 km orbit is predicted to be less than 5 degrees.

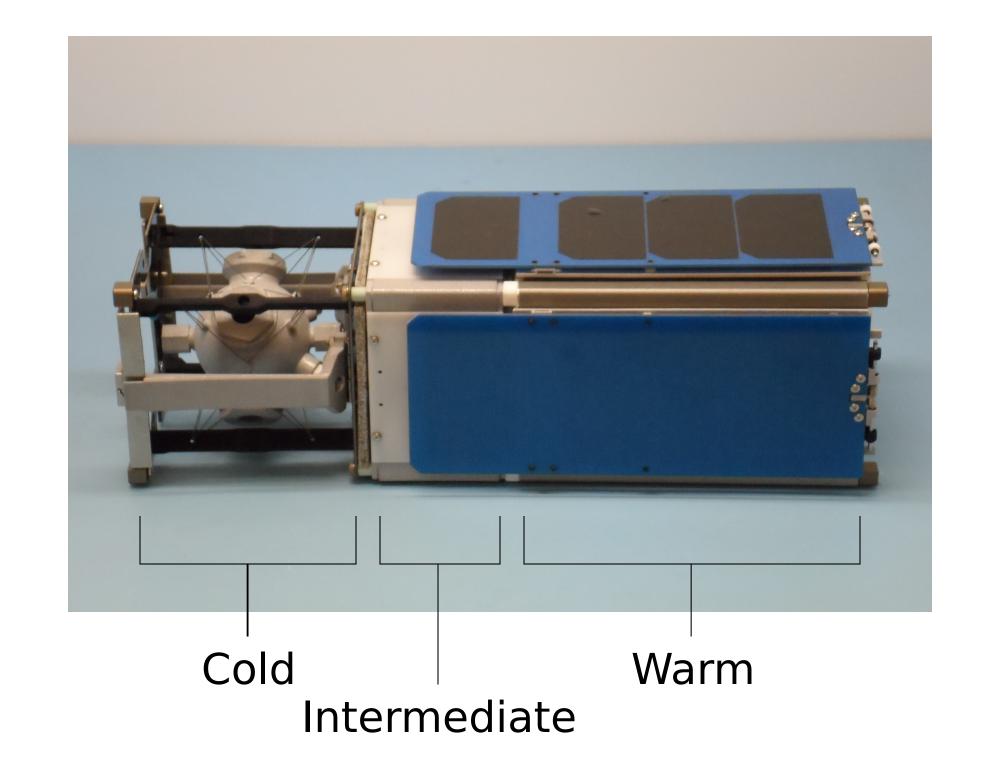


Sun Sensor Views (Flattened)

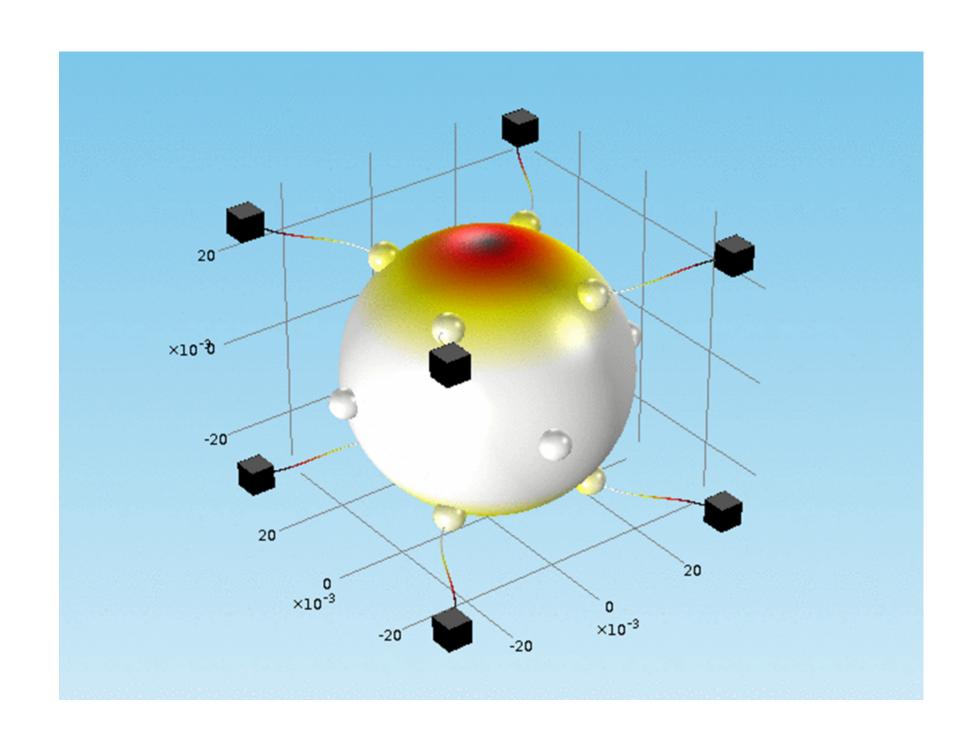


Conduction

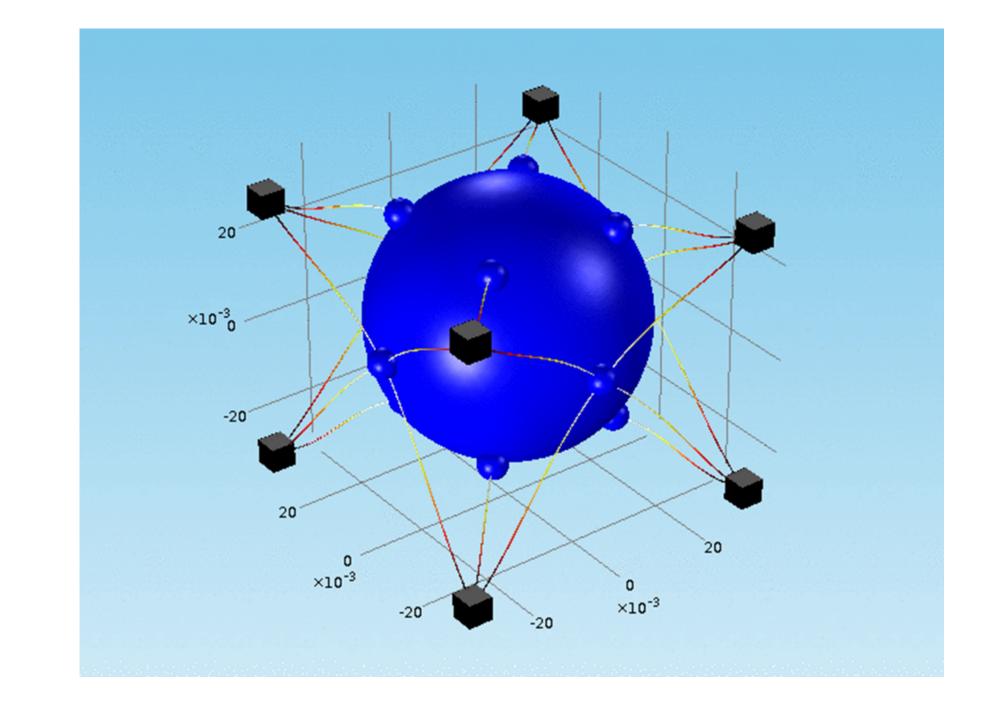
The spacecraft is separated into three sections by low-conductivity standoffs and multi-layer insulation. The bus section is cold-biased with heaters used to keep it in the operating range of the electronics. The experiment section reaches a temperature near 100 K. The oxygen storage section reaches an intermediate temperature.



Conduction to the experiment tank is minimized by suspending it using Spectra lines. For a boundary temperature of 300 K, the heat leak through the lines is 4 mW. The lines are sized for vibration during launch of 30 g rms. Suspending the tank by eight lines was found to have a resonance at an unacceptably low frequency. Splitting each of the lines into three smaller-diameter lines increased the lowest mode to 520 Hz.



Lowest resonance = 166 Hz (Twisting)



Lowest resonance = 520 Hz

Other heat leaks include the fill line, which contributes a heat leak of 3 mW, and the electrical connections for the Reduced-Gravity Cryo-Trackers® and pressure sensor, which contribute a total heat leak of 20 mW. Still and video monitoring of the tank's contents take place through viewports with no contact with the tank. The video camera is located in the warm section of the spacecraft, with a fiber bundle guiding light from the tank to the camera. Illumination is provided by LEDs outside the tank that have been tested for operation at cryogenic temperatures. The duty cycle of the LEDs is low to minimize heat input.

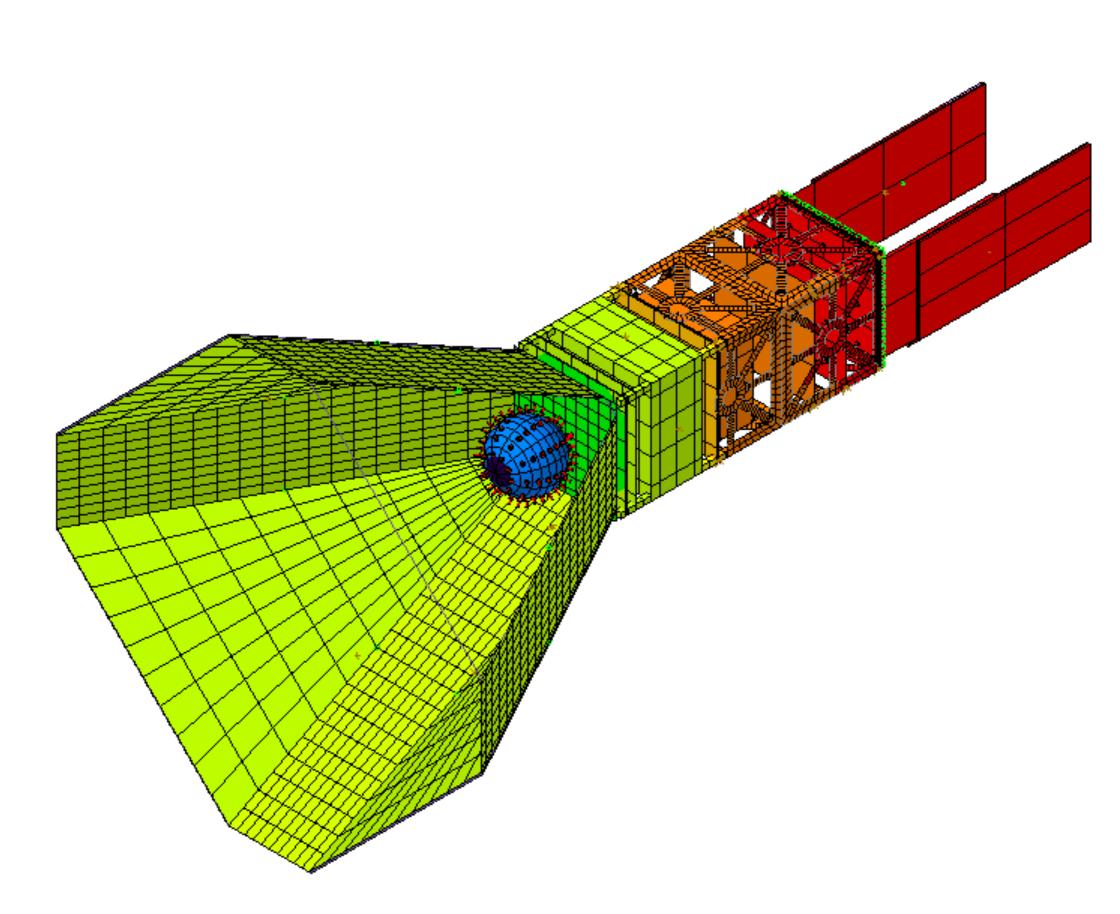
Performance Prediction

Thermal Desktop and Comsol Multiphysics were used to predict the thermal performance. At the worst-case angle between the solar vector and orbit plane, the tank reaches a steady-state temperature of less than 120 K, which is adequate for condensing oxygen (at a pressure of 1 MPa). The tank cooling time is approximately 3.5 days.

Calculated Experiment Tank Temperature

Config.	Description	Thumbnail	Steady State Tank Temperature
1	Sun-pointing, nadir during eclipse		108 K (after 10 days)
2	z axis to orbit plane tilt of 60°, β = 60°		80 K (after 3.5 days)
	z axis to orbit plane tilt of 40°, β = 0° (worst case)		104 K (after 3.5 days)

Thermal analysis was repeated for degraded optical properties. It was found that significant reductions in performance of the shield and MLI(50% change in emissivity) led to an increase in temperature of less than 2 K. However, a 50% change in the optical properties of the tank coating led to an increase of 7 K. Due to the low temperatures and limited surface area of the tank, it would be expected that this area would be most sensitive to changes. Therefore, special attention must be paid to the application and protection of this coating before the spacecraft launch. Based on this analysis, the thermal perfomance of CryoCube is sufficient to support mission objectives.



Temperature Distribution

For More Information

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