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LUNAR ICECUBE: DEVELOPMENT OF THERMAL MANAGEMENT SYSTEM

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ABSTRACT

Design of a thermal control system for Lunar IceCube faced several challenges. Firstly, components have vastly different requirements for operational temperature range and heat dissipation. Secondly, the spacecraft does not have enough external surface to reject waste heat by traditionally designed thermal control system. Thirdly, integration of components into a single thermal control system represents a challenge due to several factors: namely, thermal interference between components due to high packing density; incompatibility of some components which are made by different vendors.

The paper discusses a successful solution of the mentioned above problems. It shows that customization of thermal control systems for each group of components with similar thermal requirements enables successful resolution of thermal challenges.

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1. INTRODUCTION

1.1. Mission description

NASA has selected a 6U cubesat mission to search for water ice and other resources from above the surface of the moon.

Called Lunar IceCube, NASA Broad Agency Announcement for the development of advanced exploration systems. Among the first small satellites to explore deep space, Lunar IceCube will help lay a foundation for future small-scale planetary missions. In addition to providing useful scientific data, Lunar IceCube will help inform NASA's strategy for sending humans farther into the solar system. Lunar IceCube, in short, could ultimately help scientists understand the role of external sources, internal sources, and micrometeorite bombardment in the formation, trapping, and release of water on the moon.

Under the university-led partnership, Morehead State's Space Science Center has built the 6-U satellite and provides communications and tracking support via its 21-meter ground station antenna. Busek provides the state-of-the-art electric propulsion system and Goddard will construct IceCube's only miniaturized instrument, the Broadband InfraRed Compact High Resolution Explorer Spectrometer (BIRCHES). The instrument will prospect for water in ice, liquid, and vapor forms from a highly inclined elliptical lunar orbit. Goddard also will model a low-thrust trajectory taking the pint-size satellite to lunar orbit with very little propellant. The Lunar IceCube design is shown in Fig.1.

IceCube will prospect for lunar volatiles and water during its six months in lunar orbit. IceCube's BIRCHES will investigate the distribution of water and other volatiles as a function of time of day, latitude, and regolith age and composition. Its study is not confined to the shadowed areas in contrast to the NASA Jet Propulsion Laboratory's Lunar Flashlight which will locate ice deposits in the moon's permanently shadowed craters.

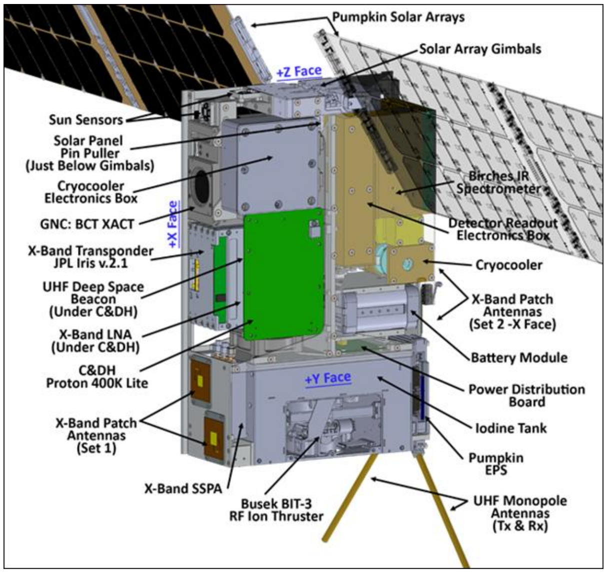

Figure 1 IceCube Design

BIRCHES carries a 1,000,000-pixel detector that will sense infrared signals emanating from the lunar surface. To record those signals, instrument developers have designed a read-out channel linking each pixel to an amplifier that then bolsters the signal.

1.2. Thermal management

1.2.1. ***Challenges of thermal management***.

Heat rejection in space can occur only via radiation. Leaving aside a possibility of using deployable radiators cubesats have limited surface ability for heat rejection. Out of several variables (knobs) which can be used to control heat rejection- the most obvious are radiator size and temperature. Other parameters, like IR emissivity, are assumed optimized. However, radiator temperature increase leads inadvertently to rise of the electronics which could be undesirable. We optimize combination of these two radiator parameters, namely, size and temperature, to increase waste heat rejection.

1.2.2. Difference between large comsat and cubesat regarding thermal management

There is a significant difference in internal architecture of nanosats and comsats which affects heat transfer efficiency inside of the s/c and rejection of waste heat from s/c to space. In nanosats, almost all components are mounted on" shelfs" which are connected to chassis. While for traditional comsats, heat producing elements are mounted directly to radiators eliminating thermal resistance of shelfs, brackets, etc. which could significantly increase temperature difference between electronics and radiator surface.

For heat flows of small density, such resistances are negligibly small. However, this resistance could lead to temperature difference of 20C and greater if waste heat of electronics exceeds 20-30 watts.

Radiators on G.E.O. satellites are always mounted on the north and south sides of the satellites while cubesats radiators can be mounted on any side depending on spacecraft orientation.

1.2.3. Cubesats thermal management

One of the most likely problem for cubesats is that body mounted radiator does not have enough surface to reject waste heat at reasonable temperature. If several components with different temperature ranges are connected to the same radiator, the radiator size and operating temperature are defined by the component with lowest upper limit of the operating temperature. As an example, let's consider a case when two components, say, battery and amplifier, are connected to the same radiator. The upper temperature limits for battery and amplifier are 35 C and 70 C correspondingly. Then, the radiator should be designed to reject a combined waste heat from both components at the lowest upper limit temperature, that is, 35C.

This approach leads to large radiator size. However, if the radiator would be split into several separate radiators with tailored temperature for each component, total surface of all radiators will be significantly smaller. So, it would be advantageous to use the same radiator for a group of components with similar temperature ranges.

1.3. Mission LifeTime

Lunar IceCube mission lifetime is shown in Fig. 2. It consists of several phases depicted in Fig.2. and has several operational modes shown in Table 1. Each mode has different thermal environments. Lunar IceCube thermal management system must accommodate all environments and keep instrument temperatures within required temperature ranges.

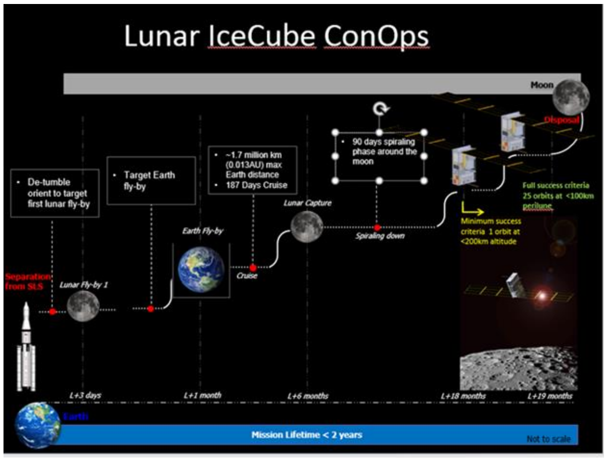

Figure 2 Lunar IceCube Mission life

Table 1. Operation Modes

Deployment and Early Ops (10 days)	Deployment, Detumbling & Orientation
	Recovery
	Ranging & System Checkout
	Heating propellant
	Calibrating ACS
	Thrust Vector Orientation
Cruise (73.5 days)	Thrusting
	Comm and Navigation
	Standby
Capture & Transition (293 days)	Periapsis lowering
	Nav and Tracking
	BIRCHES Calibration
Science Orbit - 7 hrs (single)	BIRCHES Calibration & Data collection
	Nav and Tracking
	Communication
	Standby

1.4. Modes

After the launch, once the rocket reaches a certain position on its way to the moon, the spacecraft is released and will follow its trajectory to the final destinations in and around the moon.

A propulsion system, Busek's RF Ion BIT-3 thruster, will get IceCube to its destination in about three months.

Busek's miniaturized electric thrusters, to author knowledge, the world's only propulsion system powered with an iodine propellant, will drive the spacecraft along a path using gravity wells of the sun, Earth and moon, looping around Earth a couple times and then to its destination. Because the thrusters have a small impulse, an orbital path takes advantage of gravitational acceleration from the Earth and moon.

While low-thrust systems minimize fuel, they can't accommodate a rapid change in the orbit's velocity. IceCube propulsion system allows to naturally capture a lunar orbit.

1.4.1. Science Orbit

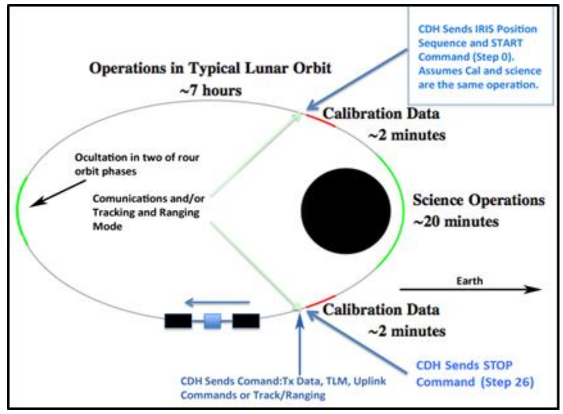

Figure 3 Science Orbit

2. DEVELOPMENT OF THERMAL MANAGEMENT OF LUNAR ICECUBE

Thermal requirements for Lunar IceCube are shown in Table 2 and 3.

Table 2 Temperature Requirements

LUNAR ICE CUBE SUBSYSTEMS THERMAL RANGES			
Subsystem		In Space Temp Survival (°C)	In Space Temp Operations (°C)
C&DH	Proton 400K	-40 to +85 °C	-24 to +61 °C
Electrical Power	Articulated Solar Array (Solar panels, gimbals & drive articulators)		-30 to +70 °C
	EPS		-40 to +85 °C
	Batteries	-20 to +40 °C	Charge: 0 to +45°C Discharge: -20 to +60°C
AD&ACS	BCT XACT (Star Tracker, Reaction Wheels, Sun Sensor)	-30 to +70 °C	-30 to +35 °C Star Tracker degrades from +35°C to +65°C
Communications	JPL Iris, SSPA, LNA	-20 to +50 °C	-20 to +50 °C Change rate 2°C/min max
	X-Band Patch Antennas (LGAs)	-50 to +125 °C	-50 to +125 °C
	UHF Beacon	-20 to +70 °C	-20 to +50 °C
Propulsion	Propulsion Subsystem	-30 to +80 °C	-35 to +75 °C
Payload	BIRCHES Spectrometer Optical BOX	-45 to +85 °C	-10 to +40°C
	BIRCHES DRE (Detector Readout Electronics)	-20 to +70 °C	110K-115K
	Compact Cryocooler	-20 to +70 °C	-10 to +40°C

The power requirements fluctuate with time as Fig. 4 and depends on the flight mode.

Table 3 Averaged Power requirements

EPS	2.2
C&DH	13.3
UHF Beacon	21.4
BIT-3 Propulsion	35.0
ADS	2.8
ACS - Reaction Wheel	20.0
Solar Panel Gimbal	5.6
BIRCHES Payload	25.0
Xband -LNA	1.0
IRIS SSPA	27.0
IRIS	12.4

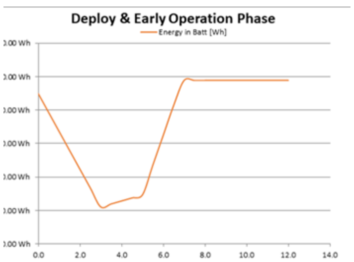

Figure 5 Example of Power Requirement

2.1. IceCube Thermal Challenges

Problem: Total heat dissipation of Lunar IceCube should be about 100 Watts including 25% margin. “Back envelop” calculations indicated that a total radiator area of 0.3 m^2 is needed to reject waste heat at reasonable temperature. However, only 0.24 m^2 of Total surface area is available (optimistically speaking). It means that not enough radiator area to dump all wasted heat at reasonable temperature.

Solution:

- Split radiator area to several sections
- Connect components with similar operating temperature and temperature range to the same radiator
- Raise radiator temperature to maximally allowable level

Complexity: heat generation by components changes as mission progressed. Therefore, heat generation in total for the same group can change that will lead to change of the radiator temperature.

2.2. Use of Thermal Model

- Determine if component temperatures meet temperature requirements for all possible orbits and conditions
- Optimize radiator configuration.
- Determine boundary conditions for components at the interface with chassis.

The Lunar IceCube thermal model is shown in Fig. 5 and Fig. 6.

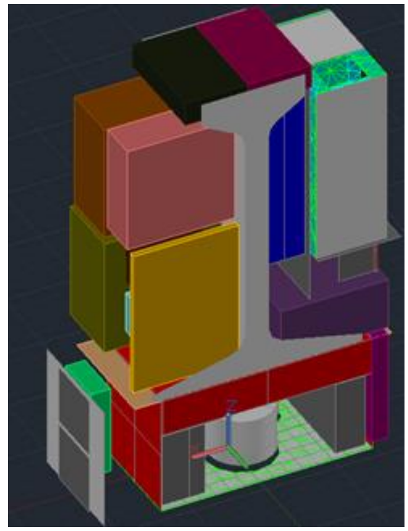

Figure 4 Lunar IceCube Thermal Model

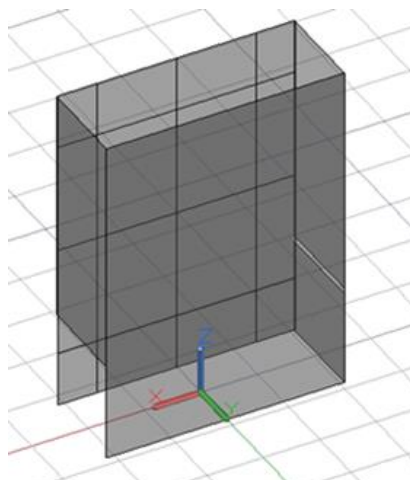

Figure 6 Radiator system for Lunar IceCube

2.3. Radiators

Radiators are mounted on 5 sides of the s/c. + Z side cannot be used as radiator. – Z side radiator is part of BIT3 assembly and not accessible to Lunar IceCube Thermal control system.

Table 4 Radiator Assignments

radiator	component	radiator	component
-X	Optical Box	-Z	BIT3
	ADS_ACS		C&DH PR_N 400K
+X	reaction wheel		BIT3 Chassis
	Sol Array Gimbals		reaction wheel
	reaction wheel		IRIS SSPA
-Y	IRIS	+Y	BAT_PAK
	IRIS SSPA		EPS
	BIT3 Chassis		Detector Electronics
			CryoCooler & cold finger
			Mounting

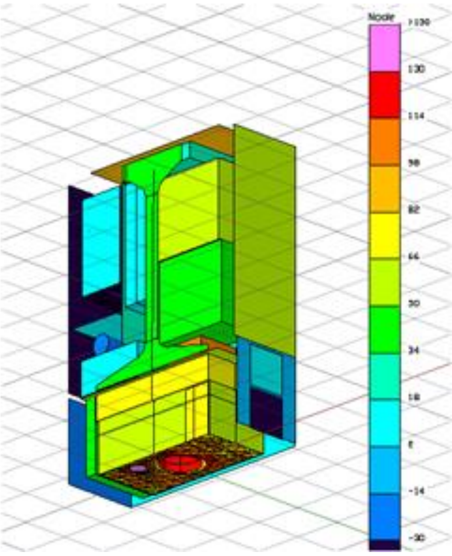

Figure 7. Temperature Distribution

3. SIMULATION RESULTS

As Fig 7 shows, the Lunar IceCube has significant temperature difference across the spacecraft, f. ex, in the worst-case temperature varies from -160C (BIRCHES) up to +130 C (BIT3). Significant temperature gradients lead to heat flow between components which should be taken into consideration.

4. CONCLUSION

- It is not easy to design a temperature control system for a s/c where it is not enough area of external surface to reject waste heat into space at normal temperature.
- Need to satisfy different requirements on different phases of mission timeline makes design of the temperature control system even more complicated.
- Splitting components in groups attached to different radiators allows to meet temperature requirements for majority of components through entire mission timeline and increase radiator temperature. It leads to more efficient radiator performance and reduction of radiator size.
- It is shown that per current design radiators will dissipate heat during mission phases to keep the subsystems within operating temperatures
- Further improvement of thermal management can be done using innovative approaches like Phase Change Material (PCM) to control component temperature.
- When s/c includes components from different vendors, thermal model should be developed and used simultaneously with mechanical design. It allows optimization of component location and sharing the same radiator by different components
- Spacecraft thermal model determines boundary conditions at the interface between a component and the spacecraft. A thermal model developer does not need to know temperature behavior inside of components