HASP Student Payload Application for 2014

Payload Title: Thermal Energy Control and Particle Air Filter System (TECPAFS)			
Payload Class: (check one) ☑ Small ☐ Large	Institution: Inter-American University of Puerto Rico		Submit Date: 20/12/2013

Project Abstract:

Thermal Energy Control and Particle Air Filter System (TECPAFS) will focus on air particle collection of the aerosol mass and size distribution over different altitudes of the HASP flight. Quantifying organic concentrations of persistent organic compounds in the troposphere and lower stratosphere. This way determining the influence of meteorological parameters, such as wind speed, temperature and relative humidity, on the variations of aerosol shape and size distributions and persistent organic pollutants (POP levels).

Thermal Phase Change Material Composites will integrate in the payload as another experiment for thermal radiation control, taking advantage of HASP high altitud, low density and low temperature conditions. The results of the thermal data collection and storage should determine the viability of the thermal phase change material and also validate this system for a future CubeSat launch integration. This proyect is supported by the IAUPR, NASA Puerto Rico Space Grant and the government of Puerto Rico(PRIDCO) to train aerospace workforce for the island.

Team Name: Aerospace Engineering and Satellite Internship (AESI)		Team or Project Website: www.iaergpr.com
Student Team Leader Contact Information:		Faculty Advisor Contact Information:
Name:	Emmanuel M. Torres Oquendo	Prof. Amilcar Rincón Charris
Department:	Mechanical Engineering	Mechanical Engineering
Mailing Address:	RR12 Box 9901	500 Dr. John Will Harris
City, State, Zip code:	Bayamón, Puerto Rico 00956	Bayamón, Puerto Rico 00957
e-mail:	etorresoquendo@gmail.com	arincon@bayamon.inter.edu
Office telephone:		787-279-1912 ext. 2249
Cell:	787-941-9395	
FAX:		

Table of Contents

I. Abstract

Thermal Energy Control and Particle Air Filter System (TECPAFS) will focus on air particle collection of the aerosol mass and size distribution over different altitudes of the HASP flight. Quantifying organic concentrations of persistent organic compounds in the troposphere and lower stratosphere. This way determining the influence of meteorological parameters, such as wind speed, temperature and relative humidity, on the variations of aerosol shape and size distributions and persistent organic pollutants (POP levels).

Thermal Phase Change Material Composites will integrate in the payload as another experiment for thermal radiation control, taking advantage of HASP high altitud, low density and low temperature conditions. The results of the thermal data collection and storage should determine the viability of the thermal phase change material and also validate this system for a future CubeSat launch integration. The space engineering program at IAUPR - AESI is supported by the IAUPR, NASA Puerto Rico Space Grant and the government of Puerto Rico(PRIDCO) to train aerospace workforce for the island.

II. Mission Overview

A. Mission Objectives

- To accurately obtain aerosol mass and size distribution at different altitudes,
- To quantify atmospheric concentrations of persistent organic compounds in the troposphere and lower stratosphere,
- To determine the influence of meteorological parameters, such as wind speed, temperature and relative humidity, on the variations of aerosol shape and size distributions, and POP levels,
- To characterize the thermal properties of a phase change material for optimum space thermal control,
- Develop and manufacture a structure for adequate phase change material incorporation and
- Test and analyze the different behavior of the phase change material at drastic temperature changes.

B. Theory and Background

1. Persistent Organic Pollutants (POPs)

Atmospheric particles have the potential to significantly affect the entire planet through their role in heterogeneous chemistry in the troposphere and stratosphere, as well as their effect on the global climate. The physical and optical properties of atmospheric particles in the troposphere are highly diverse, due to different sources and meteorological processes. Their occurrence, residence times, physical and chemical properties, such as size distributions and chemical composition, all vary greatly of many orders of magnitude. Therefore, the vertically resolved measurement of physical properties of particles is of great interest. Such measurements are crucial in advancing our understanding of aerosol fate and transport.

Environmental fate and transport of persistent organic pollutants (POPs) can be characterized by the physical properties of atmospheric particles. POPs are routinely emitted into the atmosphere either naturally or by human activities such as industrial sources and motor vehicles. They are characterized as semi-volatile since they can exist both in gas phase or get attached to an air-borne particle. These compounds include organochlorine pesticides (OCP), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and poly brominated organic compounds.

2. Phase Change Materials (PMCs)

The sun is the source nearly of all energy in the world. We use solar energy in two basic forms. One form is an electrical energy (after PV cell conversion) and the second form is heat energy. The sunshine fluctuates during a cycle of day-night, summer-winter etc. The fundamental claim on solar energy efficiency is necessity of energy storage in electrical and heat accumulators.

Phase Change Materials (PCMs) are ideal products for thermal management solutions. This is because they store and release thermal energy during the process of melting & freezing (changing from one phase to another). When such a material freezes, it releases large amounts of energy in the form of latent heat of fusion, or energy of crystallization. Conversely, when the material is melted, an equal amount of energy is absorbed from the immediate environment as it changes from solid to liquid.

This property of PCMs can be used in a number of ways, such as thermal energy storage whereby heat or coolness can be stored from one process or period in time, and used at a later date or different location. PCMs are also very useful in providing thermal barriers or insulation, for example in temperature controlled transport.

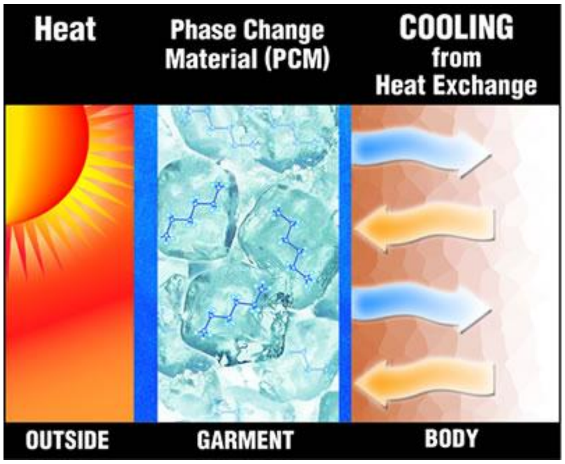


Figure 1 – PCM's working diagram

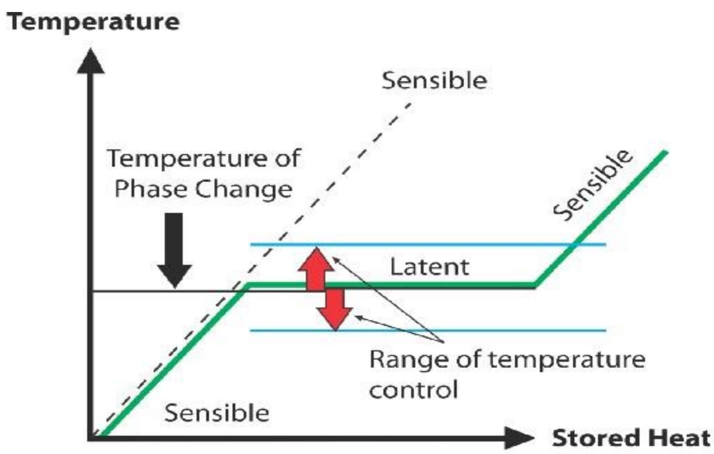


Figure 2 – Behavior of the PCM's storing energy

Latent heat is the energy released or absorbed by a body or a thermodynamic system during a constant-temperature process. A typical example is a change of state of matter, meaning a phase transition such as the melting of ice or the boiling of water.

PCMs latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change. However, the only phase change used for PCMs is the solid–liquid change. Liquid-gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid–gas transitions do have a higher heat of transformation than solid–liquid transitions. Solid–solid phase changes are typically very slow and have a rather low heat of transformation.

Initially, the solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat.

Figure 3 – Reaction of the PCM's absorbing, storing and releasing energy

Types of PCMs

Organic PCMs

Paraffin (C_nH_{2n+2}) and fatty acids ($CH_3(CH_2)_{2n}COOH$)

- Advantages
    1. Freeze without much supercooling
    2. Ability to melt congruently
    3. Self-nucleating properties
    4. Compatibility with conventional material of construction
    5. No segregation
    6. Chemically stable
    7. High heat of fusion
    8. Safe and non-reactive
    9. Recyclable
- Disadvantages
    1. Low thermal conductivity in their solid state. High heat transfer rates are required during the freezing cycle
    2. Volumetric latent heat storage capacity is low
    3. Flammable. This can be easily alleviated by a proper container
    4. To obtain reliable phase change points, most manufacturers use technical grade paraffins which are essentially paraffin mixture(s) and are completely refined of oil, resulting in high costs

Inorganic

Salt hydrates (M_nH_2O)

- Advantages
    1. High volumetric latent heat storage capacity
    2. Availability and low cost
    3. Sharp melting point
    4. High thermal conductivity
    5. High heat of fusion

6. Non-flammable

- Disadvantages
    1. Change of volume is very high
    2. Super cooling is major problem in solid–liquid transition
    3. Nucleating agents are needed and they often become inoperative after repeated cycling

Eutectics

Organic-organic, organic-inorganic, inorganic-inorganic compounds

- Advantages
    1. Eutectics have sharp melting point similar to pure substance
    2. Volumetric storage density is slightly above organic compounds
- Disadvantages
    1. Only limited data is available on thermo-physical properties as the use of these materials are very new to thermal storage application

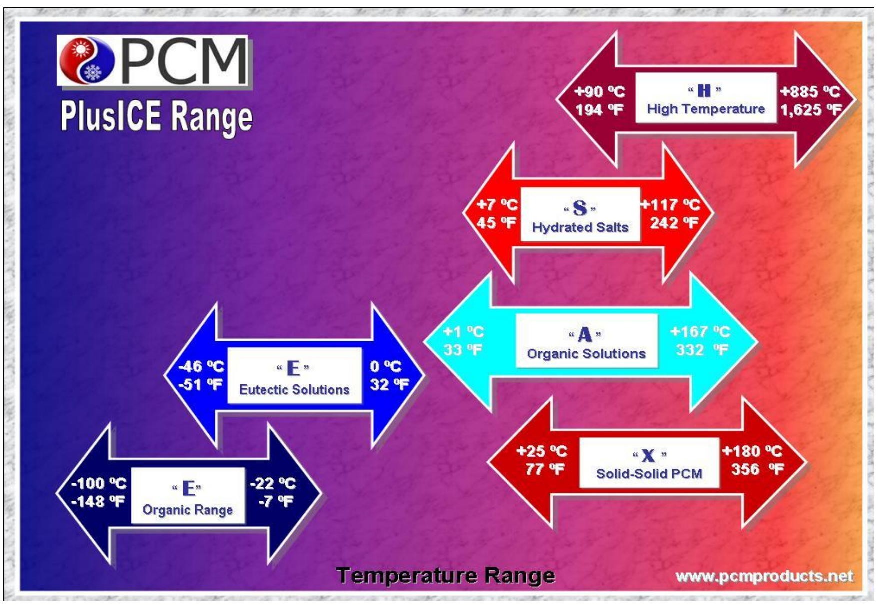


Figure 4 – Temperature range of work from the PCMs

Thermodynamic properties

The phase change material should possess:

- Melting temperature in the desired operating temperature range
- High latent heat of fusion per unit volume
- High specific heat, high density and high thermal conductivity
- Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem
- Congruent melting

Kinetic properties

- High nucleation rate to avoid supercooling of the liquid phase
- High rate of crystal growth, so that the system can meet demands of heat recovery from the storage system

Chemical properties

- Chemical stability
- Complete reversible freeze/melt cycle
- No degradation after a large number of freeze/melt cycle
- Non-corrosiveness, non-toxic, non-flammable and non-explosive materials

Economic properties

- Low cost
- Availability

Encapsulation of PCMs

- Macro-encapsulation: Early development of macro-encapsulation with large volume containment failed due to the poor thermal conductivity of most PCMs. PCMs tend to solidify at the edges of the containers preventing effective heat transfer.
- Micro-encapsulation: Micro-encapsulation on the other hand showed no such problem. It allows the PCMs to be incorporated into construction materials, such as concrete, easily and economically. Micro-encapsulated PCMs also provide a portable

heat storage system. By coating a microscopic sized PCM with a protective coating, the particles can be suspended within a continuous phase such as water.

- Molecular-encapsulation is another technology, developed by DuPont de Nemours that allows a very high concentration of PCM within a polymer compound. It allows storage capacity up to 515 kJ/m^2 for a 5 mm board (103 MJ/m^3). Molecular-encapsulation allows drilling and cutting through the material without any PCM leakage.

C. Concept of operations (Con-Ops)

The first scientific payload will be running once the launch begins. The first payload will depend in the altitude of the satellite. Form point 0 to 1 the first filter assembly will allow the flow of air to obtain the samples. From point 1 to 2 the first assembly closes and the second filtering assembly will allow the flow of air. From point 2 to 3 the second assembly will close and the third assembly opens. Once the payload reaches the maximum altitude the scientific mission of the first payload and the mission for the second payload starts. The experiment of the second payload will run from point 3 to 4. From point 4 to 5 the system will shut down at the descent.

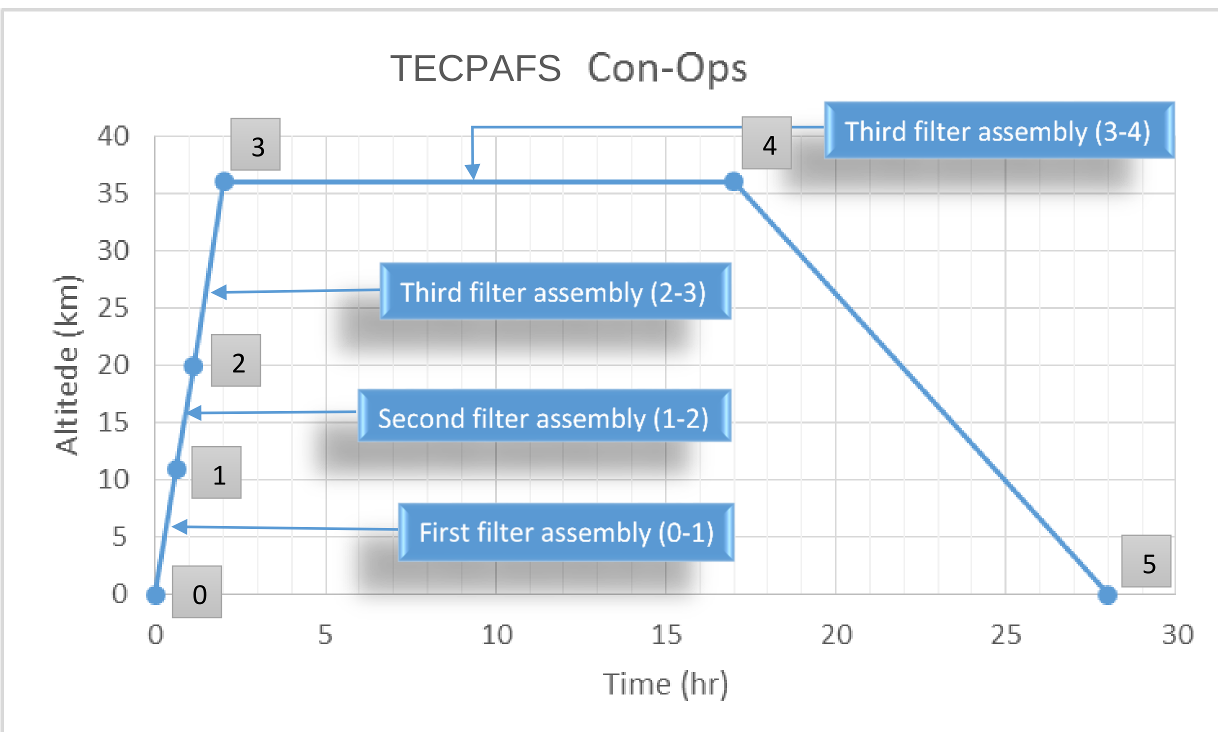


Figure 5 - Con-Ops for TECPAFS

III. Payload Design Details

A. Filter Assembly Specifications

In this study, Acrodisc® PTFE membrane filters, diameter of 25 mm, will be used to collect atmospheric particles. Particles will be trapped as they passes through the filter assembly consist of three PTFE filters of pore size, 1.0, 0.45 and 0.2 μm, respectively. The filter system will be activated at different times and altitudes during the fight. The first two filter assemblies will have only PTFE filters whereas the third one will have a 0.2 μm PTFE filter and polyurethane foam (PUF) for the purpose of collecting the gas phase of the POPs. This first filter assembly will be opened from near ground until the tropopause (approximately10km) where temperature decreases with altitude. The second filter assembly will stay open between tropopause and the stratosphere where there is no significant temperature change (approximately 10-20km). Finally, the third filter and PUF assembly will stay open at 35km and collects the particles as well as gas phase of the POPs.

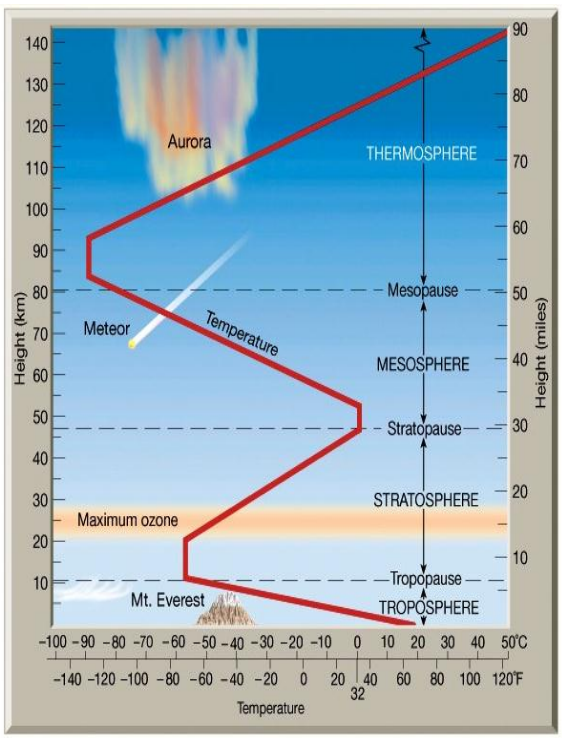


Figure 6 – Atmosphere temperature gradient

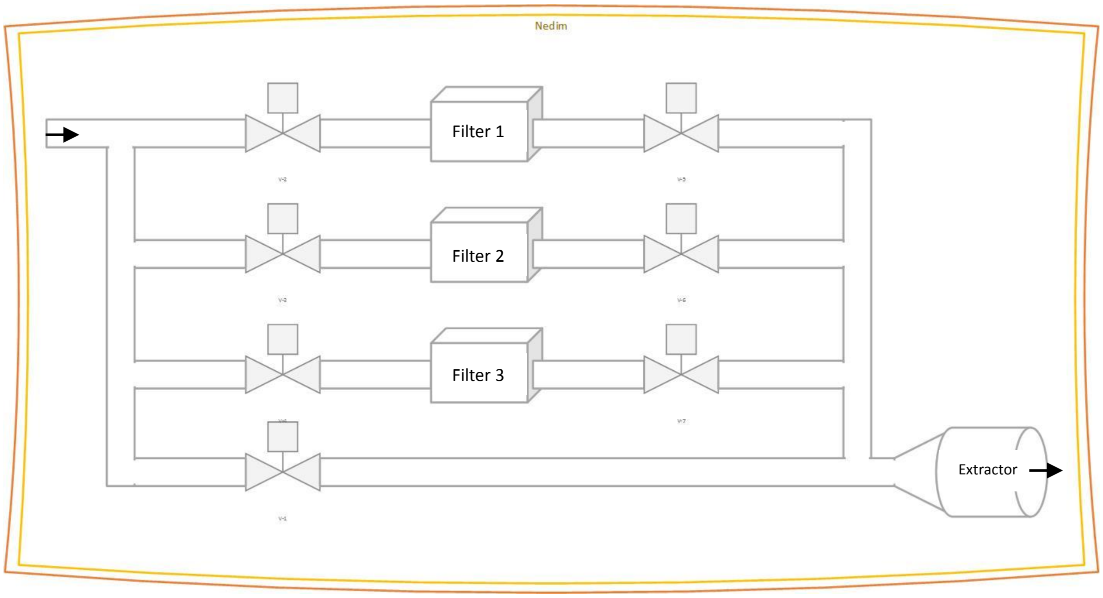


Figure 7 - Valve Assembly

The shape and elemental composition of the particles collected at three different altitudes will be analyzed using a TESCAN scanning electron microscope (SEM) Model VEGA 3 XMU. This instrument is available at the Bayamon campus of Inter American University. The PUF sample will be Soxhlet extracted with a 20:80 dichloromethane (DCM): petroleum ether (PE) solution for 24 h. The sample will be spiked with POPs surrogate standards prior to extraction. The analysis of the samples will be performed using a Varian 450-GC coupled to an ion trap mass spectrometer Varian 240 MS.

In this study, we would like to determine and interpret the changes in the size and shape of the atmospheric particles and concentrations of persistent organic compounds along three altitudinal gradients. We hope to gain experience and insight into the atmospheric contamination with POPs and use this experience for a near future study to be conducted in the tropical atmosphere of PR.

B. PCM Specifications

The specific payload test is on phase change material, as paraffin. The paraffin is also known as alkane, as it is an organic compound ($C_{n}H_{2n+2}$). Also, as an organic phase change material, is one of the most used and cheapest. For the TECPAFS payload, the paraffin is the material to be used as it's manufactured openly (RubiTherm RT) and another granulated encapsulated (RubiTherm GR), at a certain range in temperature to be compared one with the other, for the current analysis and information gathered, the temperature range to be work is from 40°C to 70°C. An example of the PCM to be used:

Figure 8 – Paraffin RubiTherm RT at 52°C

Figure 9 – Encapsulate RubiTherm GR at 42°C

The most important data:	Typical Values	
Melting area	49-53 main peak: 52	[°C]
Congealing area	52-48 main peak: 52	[°C]
Heat storage capacity ± 7,5%	173	[kJ/kg]*
Combination of latent and sensible heat in a temperatur range of 44°C to 59°C.	48	[Wh/kg]*
Specific heat capacity	2	[kJ/kg·K]
Density solid at 15 °C	0,88	[kg/l]
Density liquid at 80 °C	0,76	[kg/l]
Heat conductivity (both phases)	0,2	[W/(m·K)]
Volume expansion	12,5	[%]
Flash point (PCM)	>200	[°C]
Max. operation temperature	85	[°C]

Figure 10 – RubiTherm RT52

The most important data:	Typical Values:	
Melting area	38-43 Maximum: 41	[°C]
Congealing area	43-37 Maximum: 42	[°C]
Heat storage capacity ± 7,5%	57	[kJ/kg]*
Combination of latent and sensible heat in a temperatur range of 35°C to 50°C.	16	[Wh/kg]*
Specific heat capacity	1,5	[kJ/kg·K]
Bulk density	0,8	[g/cm³]
Heat conductivity	0,2	[W/(m·K)]
PCM content	30	[%]
Flash point	190	[°C]
max. operation temperature	70	[°C]

Figure 11 – RubiTherm GR42

The paraffin, as other phase change materials, can store sensible and latent heat which can be used to control the temperature on a given structure by storing or releasing thermal energy.

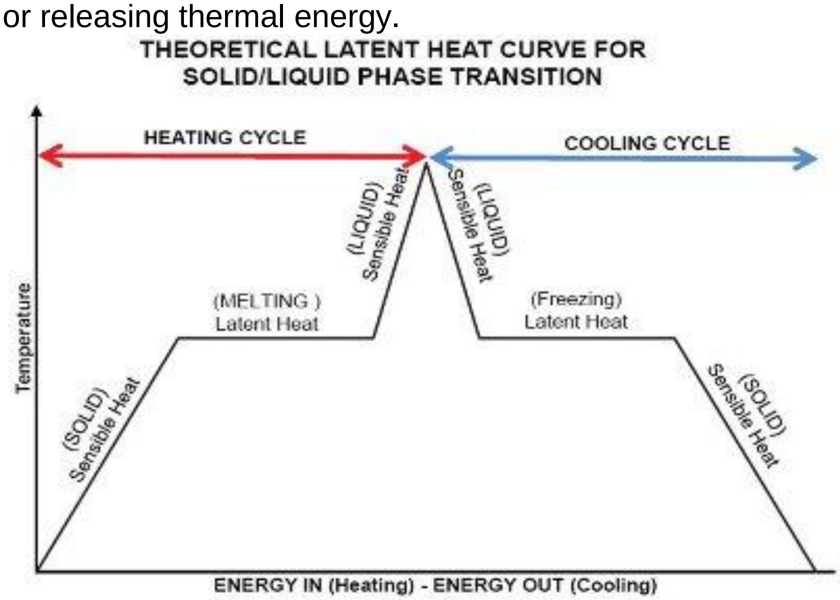


Figure 12 - Behavior of the PCM's heating and cooling cycles

Given the properties of the PCM's it is shown in that the thermal conductivity of the materials is low, this makes the material exhibit itself as an insulation material. The method of testing the PCM and, at the same time, the purpose of this proposal is for the material to be artificially exposed to high temperatures, produced by heat films placed on the structure, and low temperatures which are the natural conditions of the atmosphere at the altitude that the HASP is put on. The thermal sensors that are put on the structure that contain the PCM is acquiring the different temperature readings and making data packages, to determine the charge and discharge of thermal energy for each PCM. Given the HASP altitude of flotation (~36km) the temperature information found, demonstrated that the low temperature conditions to test the PCM's, which are on a range of -30 to -20°C. (Figure 6 – Atmosphere temperature gradient)

The main goal for the PCM working conditions and temperature range, as well as, the importance of it being an insulator material and properties under below 0°C temperatures, is because it is to be implicated on a CubeSat satellite project. The CubeSat will be in space conditions and under a range of temperatures from -70 to 130°C and the need of PCMs and other thermal control mechanisms are needed for an optimum performance of the CubeSat components. Simulations and other thermal analysis will be done for the satellite project and for the PCM, to compare with the data sheets, real time tests are needed to determine their properties.

C. *Electrical Power Sub-System*

The electrical power subsystem shall regulate the incoming (30V/0.5A) coming from the HASP platform. This sub-system will consist of a single printed circuit board (PCB) that will collect, regulate and distribute the power necessary for all of TECPAFS payload active components. Power from HASP will be regulated by a series of different buck DC-DC converters that will regulate all needed outputs. In general a 5V and a 3.3V standard buck DC-DC converter will be required and other voltages will be added to design as requested by other sub-system requirements. Input Power from HASP will be in parallel to all output buck converters. If necessary current limiters will control current peaks in order to asses power consumption standardization.

Power regulated will be passed down to all components of the TECPAFS payload and all grounds will be returned to the power distribution and control board (PDCB). The PDCB will pass grounds through a series of transistor switches that will control all component grounds. The microcontroller will automatically turn on and off electrical components depending on functionality procedures dictated by the software algorithms inside the microcontroller.

D. Data Handling and Command Sub-System

The DHCS will consist of a PCB containing a microcontroller and power distribution transistors switches (PDCB). This subsystem will control the switching power of all components and will acquire data from all sensors. This data will be process and parsed toward a storage component in the meantime an sd card. The temperature array analog data will be processed and parsed by the microcontroller through the ADC ports of the microcontroller. All temperature parsed data will be stored on a SD card for post flight data collection.

The barometer data will determine altitude of HASP on order to digitally activate filter valves. The first filter will activate from ground as TECPAFS system activates opening valves front and back from Filter 1 in order to collect aerosol particles until HASP reaches the tropopause at 10km of altitude. Barometer lecture of 10km of altitude will make microcontroller close valves for filter 1 valves and open valves for filter 2 that will collect aerosol particles from the tropopause until stratosphere. Reaching the stratosphere will activate the valves from filter 2 close and open filter 3 valves until reaching the 35km.

Any other command or data collection should be added as requested or determine by other sub-systems.

Block Diagram

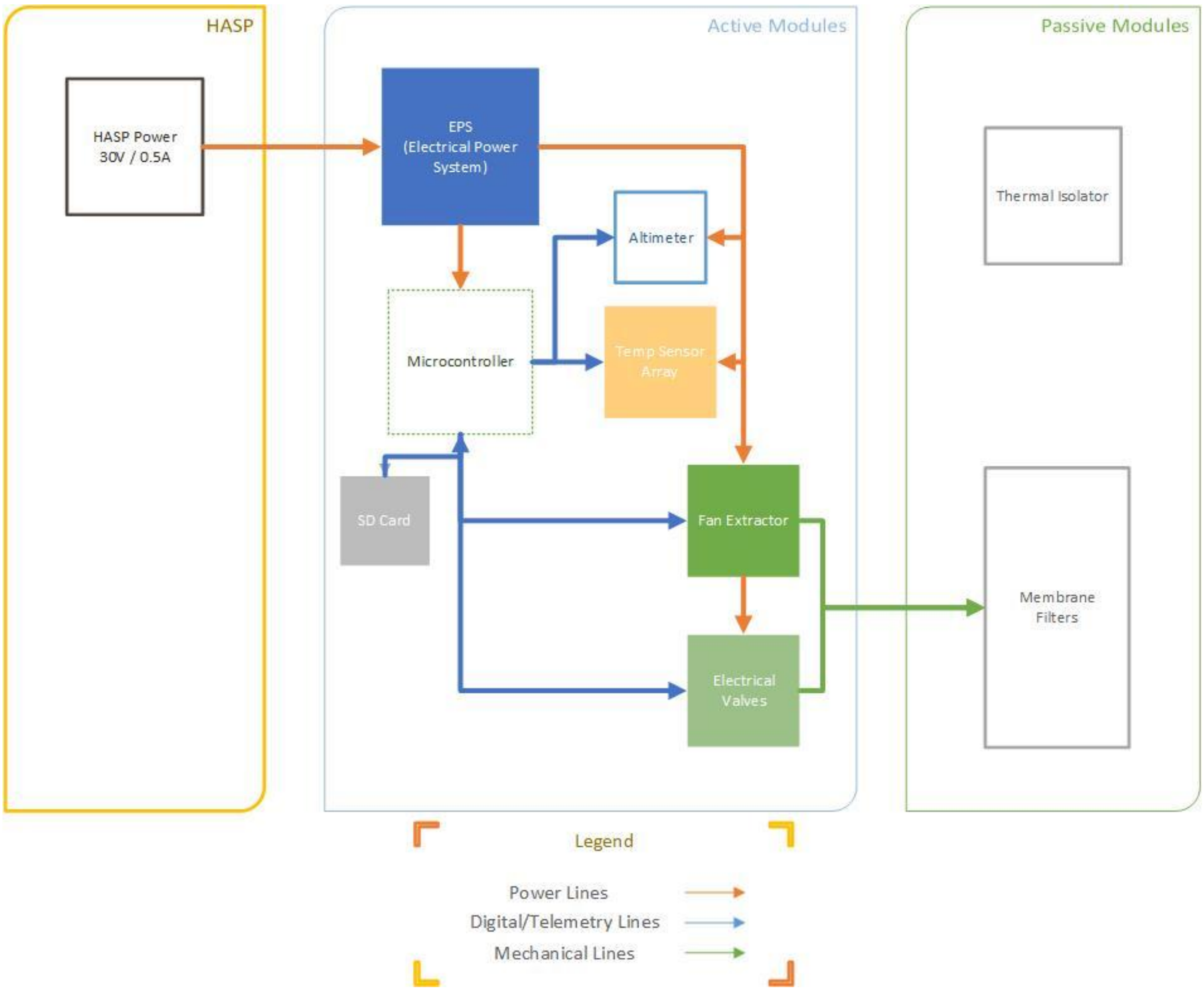


Figure 13 - Block Diagram

E. Structure

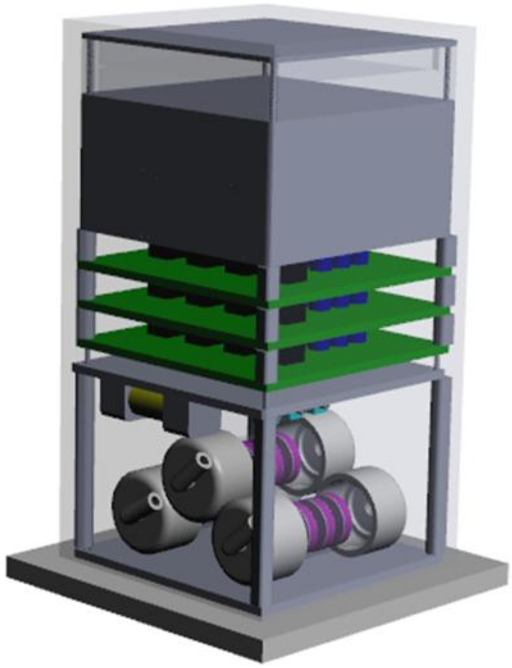


Figure 14 - 3D Structure

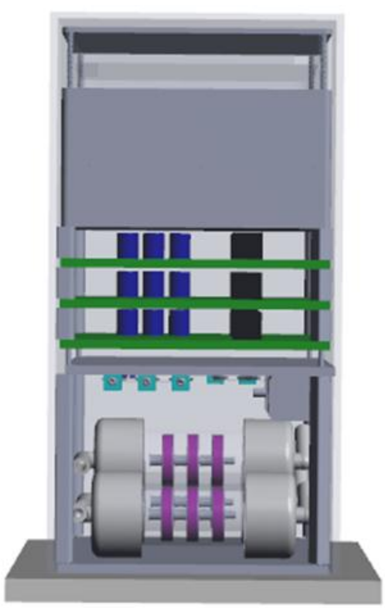


Figure 15 - Front View

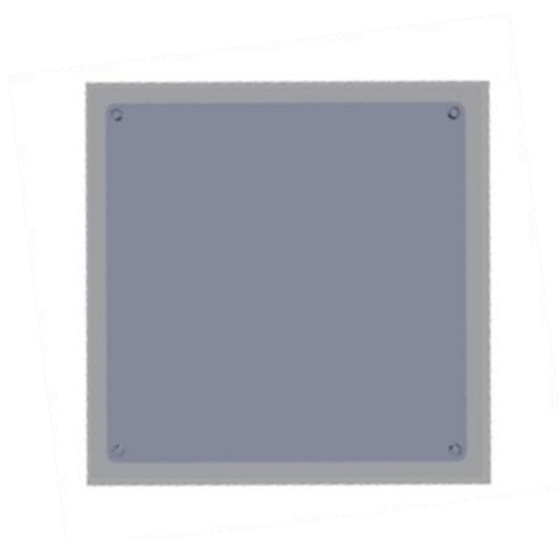


Figure 16 - Front View

The base of the structure has dimensions of 15cm x 15cm, the total height of this prototype is approximately 30cm. This is a preliminary structure; further studies are being done to optimize and change the structure if needed. The body has dimensions of around 12cm x12cm. The structure is made of aluminum 6160, for CubeSat applications, the same material is used.

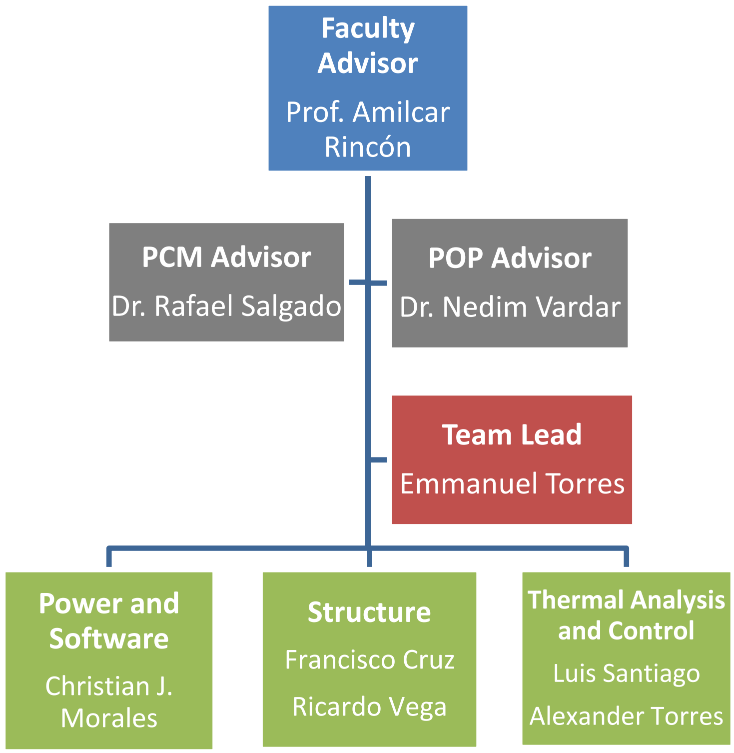
F. *Mass and Power Budget*

Mass and Power Budget			
Components	Mass (kg)	Voltage (V)	Power (W)
Solenoid Valve	0.250	12	6
Boards & micro	0.035	5	0.2
Extractor Fan	0.010	5	2
Filter Assembly	0.150	0	0
Tubing	0.010	0	0
Structure	0.011	0	0
	Total		Max Power
	2.266		14.2

The maximum power was calculated considering that there will be at most 2 solenoid valves at a single time as well as the extractor fan and the circuitry. Since when this componens are in use they will consume the most power, they where taken into consideration for the maximum power. The total mass is calculated considering that the system will contain 7 solenoid valves, the circuitry, the extraction fan, the three filter assemblys, tubing and connections and the structure, fasteners and test plates. All the mass measured is periminary since the components may chand in order to improve the design.

IV. Project Management Plan

The TECPAFS payload has the need of incorporating the structure and thermal analysis team together, as well as, the power team. As such, the organization of the team is as shown:



Subsystems

The TECPAFS payload consists of 3 critical subsystems. Each subsystem will be tasked to a group member who will report directly to the team lead of the project.

- Thermal Analysis and Control – phase change material design, temperature control, and weather condition change.
- Power – voltage regulation, wiring, circuit components, and the electrical integration and coordination of all sensors and controllers.
- Structure – case design, structure material, and structure incorporation.

There will be a total of 7-8 students working on the TECPAFS project.

V. Waiver Request

In order to aquier the samples of the atmosferic particle at hight altitudes, a payload on the HASP gondola is needed. This is necessary to accurately obtain aerosol mass and size distribution at different altitudes and to quantify atmospheric concentrations of persistent organic compounds in the troposphere and lower stratosphere. As for the thermal payload the space will be neded to characterize the thermal properties of a phase change material for optimum space thermal control and to test and analyze the different behavior of the phase change material at drastic temperature changes. Since the equipment required to simulate the conditions at high altitudes is available at the university at the time, we plan to use this oportunity as a stepingstone to aquire external fund in the future.

VI. References

[1] Company, P. C. (2013). *Phase Change Material*. Retrieved from Phase Change Energy Solution : http://www.phasechange.com/index.php/en/

[2] Company, P. P. (2009). *PCM Thermal Energy Storage*. Retrieved from Phase Change Material: http://www.pcmproducts.net/

[3] Dr. Simone Raoux, P. M. (2006). Material Science: Theory and Experiment. In *Phase Change Material Science and Applications* (pp. 125-143).

[4] School of Energy & Environmental Studies, *Thermal Energy Storage Laboratory*, Khandwa Road Campus, Devi Ahilya University, Indore 452017, India