Thermal Vacuum and Control of Spacecraft VED's University of California, Irvine Midterm Presentation

Sponsors/Advisors: Dr. Khalid Rafique Dr. John LaRue





Introduction



Thermal Vacuum and Control of Spacecraft VED's



Background | Capstone Project

Background

 Spacecraft Thermal Management System (STMS) is senior design project tasked to design and assemble a variable emissivity device/surface (VED) as a prototype to design a thermal radiator for deep space mission i.e. no environmental thermal flux data is available. VED will self-regulate. It is an interdisciplinary project with students from MAE, Chem Engr and Mat Sci Depts., and Physical Sciences Dept.

Capstone Project - Objectives

- Focused on designing a thermal vacuum chamber to allow:
 - Thermal conduction and thermal radiation generation, detection, and testing capabilities within moderate to high-vacuum regime
- Design a thermal control system capable of:
 - Thermal flux detection and data extraction under both standard atmosphere and moderate to high-vacuum conditions
 - Will integrate thermal control system into the chamber to perform validation testing for:
 - Electrophoretic Display (EPD)
 - Smart Window Technology
 - NiO/WO_3 thin-films, connected via gel-electrolyte \rightarrow "electrochromic cell".

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Vacuum Chamber Design





Thermal Vacuum Chamber Design:

Objectives

Design and manufacture a thermal vacuum chamber that accurately simulates the thermal and flow physics of Low Earth Orbit (LEO), for the purpose of testing Variable Emissivity Devices (VEDs).

- Thermal Vacuum Chamber Requirements:
 - 1. Simulate the Solar radiation of LEO $(\sim 1366 \text{ W/m}^2)$.
 - 2. Reach and withstand high vacuum level $(10^{-3} 10^{-9} \text{ Torr}).$
 - 3. Enable thermal conductivity tests for VED's
- Chamber dimensions:

5.5"x7" & 0.25" wall thickness.



Fig. 1 Finalized CAD of the Thermal Vacuum System

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Thermal Vacuum Chamber Design:

Design Process

- Chamber material is 304 Stainless Steel, to minimize outgassing.
- Equipped with a NAVAC vacuum pump, rated at 12 CFM and reaches 5 microns.
- Consulted Pfeiffer Vacuum on the current design, and they provided design recommendations regarding overall system conductance.
- Chamber is fully manufactured and will be used for VED testing.



Fig. 2 Chamber Lid (pre-manufacturing) and Vacuum Fittings

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Fig. 3 NAVAC NP12DM



Fig. 4 Fully Assembled Thermal Vacuum Chamber



Thermal Vacuum "at home" Testing

□ Vacuum Chamber Performance Testing

- $\circ \quad \text{Pressure [hPa] in proportion to time [s] (Fig.5)}$
- Performed vacuum pump and full systems vacuum performance testing on the current design
- 0 Achieved 5 microns ultimate vacuum pump pressure
- Achieved 1.4 hPa pump pressure and 8 hPa chamber pressure (medium-vacuum regime)



Fig.5 Chamber Evacuation Trial, Captured on Arduino Pressure Transducer





Thermal Vacuum "at home" Testing

Vacuum System Leakage Testing (Pump-down Test)

- Pump-down test: due to outgassing, the chamber evacuation time should decrease after each trial if not leakages are present.
- Test results detected a leakage in the vacuum system, likely in the pressure transducer connection.
- The leakage test will be repeated once a vacuumcompatible gauge is obtained.







Solar Emittance Device (SED)







SolidWorks CAD model, v1







SolidWorks CAD model, v1



Fig. 7 Sample holder and bolts are made of 304 stainless steel to simulate the internal materials of the CubeSat

This is the first model that shows the SED on the right, viewport in the middle, and sample holder inside the chamber on the left



ANSYS Simulation

In this preliminary simulation, we see a radiation probe on the sample holder with a net negative radiation flux. This demonstrates that the light from the SED is getting into the chamber.



Fig. 8 SED Activation within the Vacuum Chamber Preliminary Design



Redesign of CAD

After collaborating with Lance from STMS (studying SEDs), I was recommended to enclose the SED in order to direct light into the viewport.









SolidWorks CAD model, v2



SED holder with enclosure





Electrophoretic Display (EPD) and Smart Window Technology





EPD Aesthetics: The Electrophoretic Display (EPD)

- Thermal Sensors will are to be placed on surface and back-side of module during thermal conductivity tests
 - Working Temperature (@ STP): 0° C 50° C
- EPD Dimensions:





Fig. 9 Electrophoretic Display (EPD), Panel Side



Fig. 10 Electrophoretic Display (EPD), Back Side





Smart Window Technology: Behavior



Fig. 11 Smart Window Technology (Opaque State-Off)



Fig. 12 Smart Window Technology (Transparent State-On)





Heat Transfer Analysis





EPD Thermal Conductivity Test: Conceptual Design

□ Diagram depicting preliminary EPD thermal conductivity test design set-up

HEATING PAD (65 Celsius)	
CONDUCTIVE SOLID (assume Copper)	
ELECTROPHORETIC DISPLAY (EPD - assume semi-conductive material)	
STANDARD AIR (ideal)	
CONDUCTIVE SOLID (assume Aluminum)	
THERMAL VACUUM CHAMBER BASEPLATE (304 Stainless Steel)	
DRY-ICE	

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Heat Transfer Model: EPD - Thermal Resistance Network

- $\hfill\square$ Model of EPD thermal conductivity test under vacuum
- Thermal Resistance Network of Model (*right*)
- Cu and Al conductivities depend on manufacturer
- Requires *heat flux sensors* (for q_1)
- Requires *K*-type thermocouples
- *Steady-state temperature* of baseplate must be achieved
- *Steady-state temperature* of heating pad is required
- Assuming all *areas*, *A*, and all *thicknesses L* are equal.

$$\boldsymbol{k_{EPD}} = \frac{q_1 L k_{Cu} k_{Al}}{A(T_1 - T_5) k_{Cu} k_{Al} - q_1 L (k_{Al} + k_{Cu})}$$



Fig. 13 EPD Thermal Conductivity Model (*left*); Thermal Resistance Network (*right*)





<u>Conceptual Design:</u> Thermal Conductivity Test

D Testing Visualization

- From bottom to top (Fig. 10)
 - Heat Exchanger (heat sink)
 - EPD placed on copper bolts
 - Aluminim plate
 - TC Control Lab (heat source, 65 °C)
 - MatLab/Simulink
 - Aerogel used as insluation
 - Will be purchased
 - Machine Al-plate and Cu-plate;
 - Purchase and machine with area [3.036 in²] equal to EPD



Fig. 14 TC Control Lab



Fig. 15 Conceptual Design – Thermal Conductivity Tests



TC-Control Lab: Demonstrating Temperature Control (MATLAB)









EPD - Reflectance and Transmissivity





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EPD Reflectivity Preparations

- **Arduino IDE**
 - EPD "Flash Point" Code (Figure)
 - Enables alternation between extreme black and extreme white states
- **Controls Panel**





Fig. 16 EPD Switching Between Extreme Black (left) and White States (right)



Fig. 17 ESP32 Development Board Dimensions

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Reflectance Testing

□ Mirror Reflectivity

- ~100% Reflectance
 - Nearly zero transmissivity
 - \circ 400 nm 750 nm wavelength

EPD Reflectivity

- Ranged between 11% 16%
 - \circ 16 % upper limit
 - Extreme white state: 16%
 - 0 11 % upper limit
 - Extreme black state: 11%





Fig. 18 Alina Testing Mirror Reflectivity



Fig. 19 Reflection [%] in Proportion to Wavelength [nm]



Capstone Project Timeline



Deadlines - Completed

• On track for each deadline

Gamma Future Deadlines

Authorization to ET-303 lab is needed

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Further Information/References

➢ Project Website ●



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