Development of an Open-Source Satellite Design Toolkit

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Objective

To develop an open source toolkit that will optimize the design and performance of small satellites. For the VISORS project, specifically, the toolkit will help design CubeSats that will monitor coronal heating.

Introduction

While the Sun's temperature appears to increase near the core, recent observations find that there is a sharp increase in temperature at the corona, the outermost part of the Sun [1].

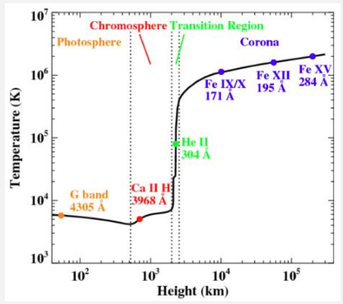


Figure 1. Temperature relative to distance from surface of sun

Scientists have yet to fully comprehend this phenomena, especially due to the technological limitations preventing them from accurately modeling the corona's environment.

Figure 2. SolarALMA(top) Project, CoMP(bottom)

Methodology

OMTools

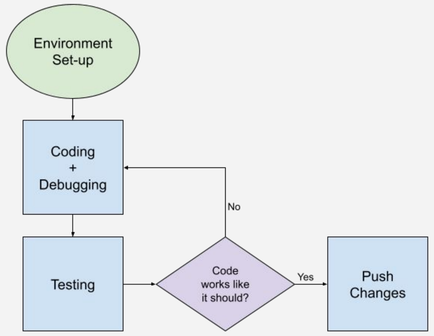


Figure 3. A flow chart of the steps for modeling each discipline

1. Obtain necessary operating systems, tools, and packages
2. Create Python scripts within Visual Studio Code
3. Use OMTools to declare components and model equations
4. Produce an N2 diagram to visually check the relationships established and use to debug
5. Push to remote repository on Github

Surrogate Modeling Toolbox

Battery

- Battery models will be made to represent the behavior of the battery cells as a function of state of charge (SOC) and temperature.

Figure 4. 3.7V, 2600mAh, Battery – Samsung

Thermal

- Surrogate modeling toolbox will be utilized to generate equations from physical data
- Existing thermal equations will be implemented into an open source python package to generate thermal models to represent physical limitations in spacecraft

Results

Attitude

- A model that could compute the external torques due to reaction wheels and thruster misalignment was successfully built
- The model correctly calculated external torques and integrated aspects of a satellite's attitude dynamics
- The model produced the correct values for its partial derivatives given power

```
class RWSpeedRK4(RK4Comp):
    def initialize(self):
        self.options.declare('num_times', types=int)
        self.options.declare('step_size', types=float)
        # moment of inertia for BCT RWP015 reaction wheel
        self.options.declare('mmoi', types=float, default=3e-5)
        self.options['external_vars'] = [
            'external_torques_x',
            'external_torques_y',
            'external_torques_z',
```

Figure 5. A sample of the code worked on for the reaction wheels.

Battery

- An equivalent circuit model for the battery cell in use was created in order to approximate the transient effects and behavior of the battery cell as a circuit.
- Surrogate models for the predicted behavior of internal resistance and open-circuit voltage vs. state of charge were also modeled using the Surrogate modeling toolbox

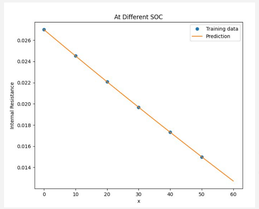


Figure 6. Internal Resistance at different SOC

Thermal

- A thermal model for the heat conduction for the solar panels is created from existing thermal equations as well as surrogate models
- In addition, the model contains additional information on the effect of temperature on solar panel efficiency and constraints to enforce safe temperature ranges

Discussion

Attitude

- OMTools was used to create a model that correctly computed external torques in the x, y, and z-direction given a function of angular velocity and power
- By using this model, researchers may determine the satellite's attitude, or orientation, in space
  - Ex) Orienting and maneuvering the two Cubesats between its charging phase and its observation phase while in orbit

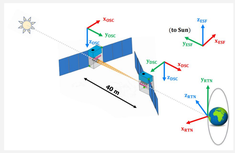
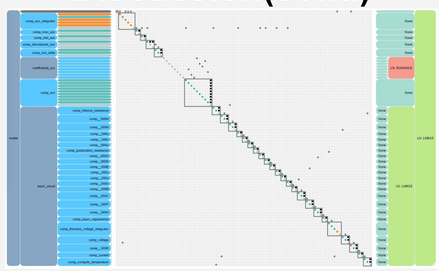


Figure 7. An diagram of the CubeSats in their Observation mode.

Discussion(cont.)



Battery

- The simplest equivalent circuit is an RC circuit and since the battery cell is not an RC circuit, surrogate models were used to model the outcome of interest experimentally which would otherwise be very difficult to measure directly
- The battery models will help the VISORS team determine efficient power and current draw for the different hardware components on board the Cubesat such as the communication system, actuators, and valves

Thermal

- Using surrogate models and existing heat transfer equations, we created a thermal model for the cubesats in the VISOR project
- The model allows us to determine heat distribution throughout the entire cubesat and therefore, determine limiting temperatures
  - Implements several important subsystems in the project
  - Thermal interactions between subsystems like batteries and solar panels dictate the crucial component of the missions that could result in failures if otherwise not properly modeled

Conclusion/Future Work

- The open-source toolbox will set precedence for the design and optimization of future small satellites
- Coded models for satellite attitude, battery, and thermal disciplines in Python using existing OpenMDAO framework and incorporating it into a new framework called OMTools
- Models for the attitude, battery, and thermal(?) disciplines were successfully created and tested
- Next step in the research are to expand the toolkit to include models for other satellite disciplines (e.g. propulsion, orbital mechanics, communication, etc.)

References

[1] Choi, Charles Q. "Earth's Sun: Facts About the Sun's Age, Size and History." Space.com, Future US, Inc, 14 Nov. 2017
[2] Morton, R. J., Tomczyk, S., and Pinto, R. F., "A Global View of Velocity Fluctuations in the Corona below 1.3 R☉ with CoMP", The Astrophysical Journal, vol. 828, no. 2, 2016. doi:10.3847/0004-637X/828/2/89.
[3] Jafarzadeh, Shahin & Wedemeyer, Sven & Fleck, Bernhard & Stangalini, Marco & Jess, David & Morton, Richard & Szydlarski, Mikolaj & Henriques, V. & Zhu, Xiaoshuai & Wiegelmann, Thomas & Guevara G., Juan & Grant, Samuel & Chen, Bin & Reardon, Kevin & White, Stephen. (2020). An overall view of temperature oscillations in the solar chromosphere with ALMA, www.researchgate.net/publication/344485695_An_overall_view_of_temperature_oscillations_in_the_solar_chromosphere_with_ALMA

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