DESIGNING THE PERSONAL TELESCOPE CUBE SATELLITE (PTC-SAT).

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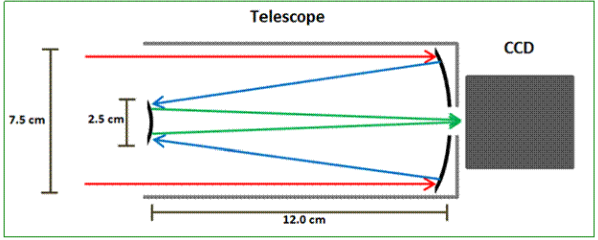
Introduction & Objective: CubeSats are an effort to create a cheaper and easier alternative to pre-existing space missions, which can become exhorbitantly expensive. A single CubeSat unit (1U) is a 10 cm cube, and is modular, stackable ontop one another, up to three units tall (3U). By imposing a lmit on size, cost also gets capped before growing out of hand, making CubeSat projects ideal for space programs to test new concepts cheaply, as well as open up the opportunity to devolp space missions in smaller organizations, such as programs in academia. The standardized size enables an easy way to launch the CubeSats as a secondary payload in pre-existing missions.

Our objective is to design our own CubeSat project while adhering to the guidelines set forth by NASA's Systems Engineering timeline, working as hard as possible to emulate the environment of a true space mission. The mission we choose to design, the Personal Telescope Cube Satellite, will be a 3U CubeSat that hopes to improve upon current CubeSat observational capabilites. To date, CubeSats emphasize observing the Earth down from above; we aim to observe upwards, developing a telescope powerful enough to take pictures of distant stars, and gather data on emitted light. This project is meant to span many years and REU groups. As this is the first year of the project, we are working on Pre-Phase A and Phase A designs, which entail determining the specifics of the telescope, modeling a hypothetical configuration of the CubeSat, and assessing feasibility and determining how to make sure our mission objective is obtainable.

Telescope: We chose to use a reflecting telescope, which uses a series of mirrors to collect light, rather than a refracting telescope, which uses a series of lenses. We decided that a reflecting telescope would be more beneficial because it would not suffer from chromatic abberrations, it would be cheaper, it would be lighter, and we could use a larger primary mirror than primary lens which means more light gathering power.

We chose to follow the reflecting Cassegrain design for our telescope. A Cassegrain telescope has a concave, parabolic or spherical primary mirror and a convex, parabolic or spherical secondary mirror. The light coming from a distant astronomical object enters the front of the telescope and strikes the primary mirror. The primary mirror directs the light to the secondary mirror, at which time the secondary mirror focuses the light through a small hole in the center of the primary. Once the light has passed through this hole, it can then be collected in an eyepiece, on a film slide, or on a CCD chip or other instrument.



For our telescope design, we chose a primary mirror with a 7.5 cm diameter and a 20.0 cm focal length. We chose a secondary mirror with a diameter of 2.5 cm and a -10.4 cm focal length. We chose these values for our primary and secondary mirrors because we feel they give us the most light collecting power we can have for the small amount of space we have to work with. We also chose to use a 3CCD camera so as to be able to gather scientific data with the telescope, as well as use it for astrophotography. A 3CCD camera is enternally equipped with a prism, which separates the incoming light into green, blue, and red, and three CCD chips, which each collect one of the three colors of light.

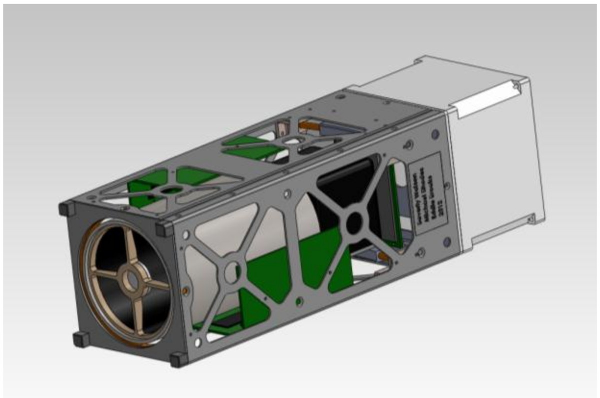
From the telescope specifications we have chosen, we will obtain the following results:

- Telescope effective focal length: 50.4 cm
- Telescope resolution: 1.93” (arcseconds)
- CCD Field of View: 0.73^{0} (H) x 0.55^{0} (V)
- Pixel Field of View: 1.9” (H) x 1.9” (V)

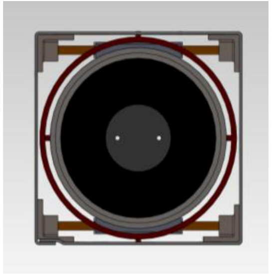
Modeling: Due to the uniqueness of our telescope payload, a custom built 3U structural frame was required to be designed. This structure must be large enough to accommodate for the housing and motion of the telescope and CCD camera enclosure, while leaving sufficient volume for the various electrical components required for a fully operating CubeSat. Factors limiting the structural size of the frame were the strict guidelines set for CubeSat dimensions and weight.

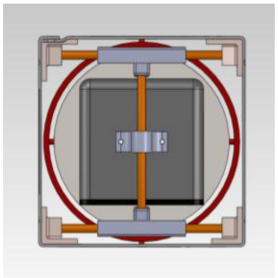
To meet these guidelines, the frame was designed following the parameters of the off the shelf skeletonized 3U CubeSat frame, with proper variations being made for our particular functions. The skeletonized model was selected to reduce the overall mass of the satellite. The frame was shortened to 2.5U to allow for the attachment of a 0.5U attitude control unit, thus remaining within the length limit for the entire satellite.

The design of the telescope assembly would require the most precision, as a minute deviation from the theoretical dimensions would result in failure. The telescope tube was designed to the size of the primary mirror, encompassing 1.5U of satellite length and leaving the corner volume for the insertion of custom electrical components. The second half of the telescope assembly consisted of an enclosure for the CCD camera. This was necessary to reduce undesired stray light disturbances from outside sources.



Mounting the telescope to the frame was an arduous task due to size limitations and the requirement for motion in two independent axes of rotation. Fine adjustments of the telescope within the frame were necessary to increase pointing accuracy. To achieve this, a system of rails and a pivotal ring were designed. The pivotal ring was positioned at the front of the telescope to create a pivot allowing motion of the telescope with respect to the frame. In the rear of the the telescope attached to the CCD camera enclosure is a radial rail system to provide guided rotational movement for the telescope assembly. Magnetic actuators attached to the telescope would provide the force for motion.





Attitude Control: In order to assess the feasibility of the observational goals of the PTC-Sat, the most important question was to see if there was an attitude control system powerful enough to keep the telescope steady enough to capture clean data. Initial research into CubeSat attitude control showed that for any observations not looking at the Earth, there was no control system powerful enough to stabalize the camera [1]. In order to achieve the mission, this called for the implementation of a two-tiered attitude control system, with coarse and fine adjustments working in tandem. For the coarse adjustments, a wide array of pre-existing parts and configurements are reasily available. A balance between price, avaialability, and size ultimately dictated we use the IMI-100, an attitude control system capable of pointing the entire bus with an accuracy within a single degree. This determination was based upon the resolution of the system's momentum wheels. The IMI-100 can impart a torque of up to ±0.635 mNm, increasing in increments of .005mNm. This corresponds to roughly a fraction of a degree in our telescope system.

Working on modeling the telescope in the bus in various ways, a pivoting model was developed, allowing internal motion independent of the position of the whole frame on a small scale. With this type of internal freedom, a system of magnetic actuators was deemed capable of controlling the position of the telescope, stabilizing it internally and making fine adjustments. Various sizes of actuators have been selected and ordered, ready for testing as the PTC-Sat begins to get assembled.

Conclusion & Future Work: This project was intended to last over the span of multiple REU projects. This was the first year of the PTC-Sat project, focusing our work into Pre-Phase A and Phase A planning and design. Following the structure of NASA's Systems Engineering timeline, we have laid the framework for the Personal Telescope Cube Satellite to be built. The mission of building a stellar observer inside a 3U CubeSat has been deemed feasible, and we have laid out the groundwork for assembly in the future. We designed a telescope, have planned how to keep it stable enough to observe distant stars, and have modeled the entire telescope to give guidance for construction.

Future work will involve testing and building. Following our designs, groups in future years will be able to test components for use, assemble the telescope, build the bus, and begin to write code to command the satellite once in orbit. Additionally, there is room for research in solar panel arrangement, figuring out how to ensure the telescope remains constantly powered and that all energy requirements are met.

References: [1] Christopher M. Pong et al., "Achieving high- precision pointing on ExoplanetSat: initial feasibility analysis", Proc. SPIE 7731, 77311V (2010); doi:10.1117/12.857992 © 2010