**Capstone # 007**

Progress Report

Winter 2020

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**Industry Advisor:**

Andrew Greenberg

**Company:**

GeoShade

**Date:**

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**Executive Summary:**

Prior to the beginning of the term, our team got together and discussed how we would complete this project. We asked our sponsor about the scope of the project and his expectations. Professor Andrew Greenberg, a faculty advisor for the Portland State Aerospace Society, took part in our discussions with Tim in order to narrow the scope of the project and recommended some research ideas. Several meetings were held succeeding the discussion with Tim and Professor Greenberg. These meetings consisted of members sharing their preliminary research about solar sailing and deployment mechanisms. After three weeks of research, we divided ourselves into three groups that would focus on different topics.

We had several ideas concerning how the requirements and needs of the sponsor would be met. Our first idea was to build a robotic assembly located at the central hub. The robot would be used to assemble parts in space after the sail was deployed. Thereafter, we narrowed the scope of the project to system modelling, deployment procedures, and actuators; one group was assigned to each of these categories.

Three teams developed a plan to learn as much as possible about their respective topic. The research consisted of looking at successful and unsuccessful solar sails, academic literature, heat transfer texts, and physics texts. Every two weeks, the capstone team would assemble to speak with the academic advisor and the sponsor. These meetings were an opportunity to get feedback, share progress, share concerns, and share results. Over the course of the term, we had issues like being unable to conduct experiments due to lack of resources. However, we were able to perform relevant experiments for topics such as wave propagation and the analysis of a carbon tube’s natural frequency; the sponsor intends to use this carbon tube for deployment purposes. For the upcoming term, the group will use the data collected from the experiments to perform further analysis.

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**Introduction:**

Tim Sippel is the current owner of Geoshade, a company whose goal is to use a solar sail, named the Geoshade, to combat climate change. Tim intends to have the Geoshade funded as a carbon offset product that emphasizes cost-effectiveness. The Geoshade is currently in a concept phase and gradually moving towards the design phase. For our capstone, we are tasked to help Tim transition into this phase by conducting research and developing designs for Geoshade. Currently, our team is focusing on three tasks, which include developing a mathematical model for the controls, finding a folding method for the sail, and determining a cost-effective actuation method for sail deployment and attitude control.

To better understand the Geoshade, we started by learning how a regular solar sail functions. Solar sails are spacecraft that use highly reflective sails to harness the momentum from photons as a means to push themselves through space. A key factor to note here is that solar sails do no primarily use fuel for propulsion; this, it weighs substantially less than the standard rocket. The low weight and lack of rocket fuel make solar sails a viable vehicle to travel long distances.

Geoshade’s physical structure sets itself apart from its solar sailing counterparts. Most solar sails are composed of one sail that unfolds outwards from the central hub. However, the Geoshade intends to use centrifugal force to keep a web patterned frame stretched out as the sails deploy from the sides, not the center of the hub. Additionally, the Geoshade comprises over five hundred sails. Each sail measures roughly fifty by one hundred meters. The Geoshade uses many large sails in order to maximize reflection.

A large reflective surface is required if the solar sail is to reflect a sufficient amount of solar radiation. As a carbon offset, a solar sail becomes more profitable as it reduces emissions more effectively than the carbon offsets products that are used on Earth.

**Mission statement:**

By June 2020, provide ground-work research on system modeling, deployment procedures, and actuators to cost-effectively offset carbon emissions through the implementation of solar sail technology.

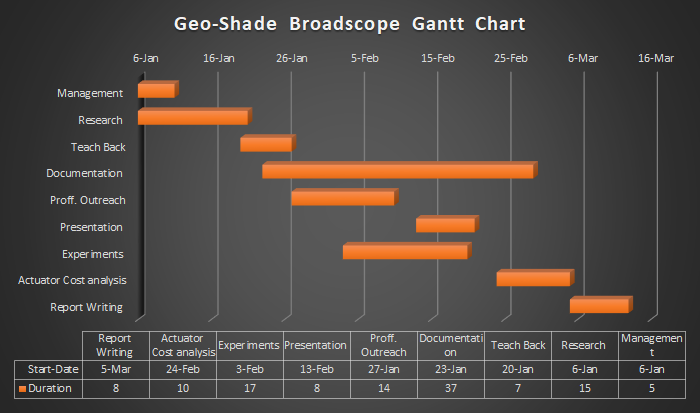
Carbon neutrality is the first step towards reducing the effects of greenhouse gases. To progress past the comfortable threshold of renewable energy and reduction of waste, we have turned to carbon offsets. Investments and fundings of various carbon offset projects will help reduce carbon footprints and build an environmentally friendly image. Geo-Shade is a privately funded offset project to reduce carbon emissions.

The purpose of the Capstone group 007 is to determine Geoshade’s design requirements so that it may be used as a means of reducing solar radiation. The Geoshade sail material is comprised of CP1 polyimide to harness the momentum of the sun for propulsion. Deployment of the sail entails commonly available servo motors to help pull the necessary rods and sails from their initial positions. In addition to deployment, the motors orientate five hundred and twelve individual panels in and away from solar rays to create enough thrust to send the solar shade into orbit at Lagrange 1.

One of the goals in this project is to keep Geo-Shade’s environmental impact at $10 per ton of carbon dioxide while keeping the weight of it at 10 g/m². A lighter load would help achieve the goal of keeping Geo-Shade in orbit for 20 years.

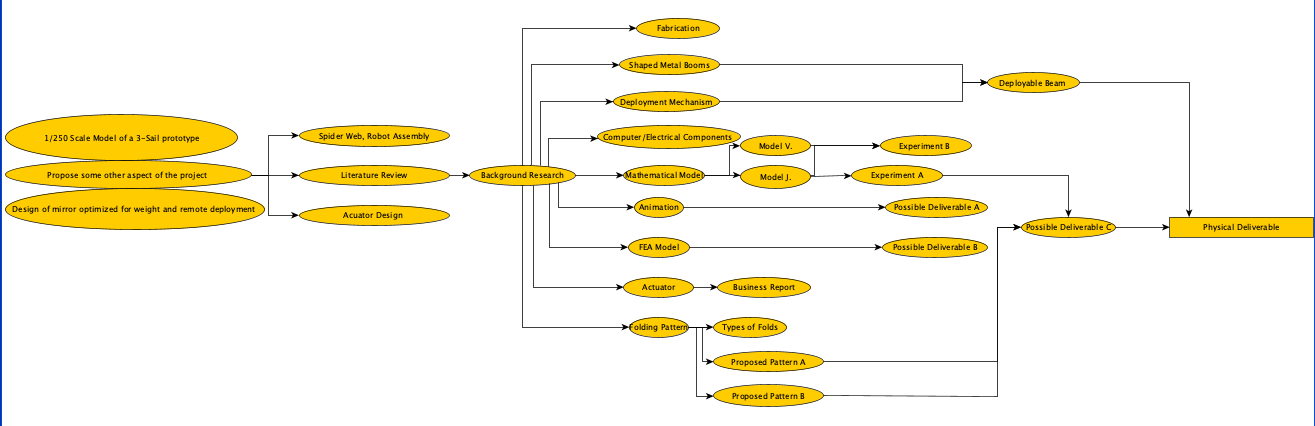
**Top-level Gantt Chart:**

Our team has rigorously worked on the Geoshade capstone for the last three months and is still in progress of laying out the foundation for the completion of the project. In the beginning, the team focused on conducting preliminary research while narrowing down the scope of the project. With time, the workload was divided among groups that performed experiments, academic research, and management. The figure below describes project progress, the duration of each task and other tasks that supported our research.



**Design Concept Chart and Process**

The GeoShade design concept has developed overtime throughout our discussions in meetings. The flowchart below describes our overall progress:

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As stated in the concept design development process, the team discussed the selected topics that must be implemented for GeoShade. Initially, we considered designing a 1/250th scale prototype for the actual design; however, due to the sheer size of the solar sail, the main components of the project were scaled down to three categories. Andrew Greenberg, a member of the Portland State Aerospace Society, suggested that we work on a scaled-down version of the Geoshade. The three categories that we agreed to work on were developing a mathematical model for the solar sail dynamics, the deployment mechanism, and the design of an actuator mechanism.

As we progressed in formulating the needs of the customer, we realized the optics values provided by the suppliers were not accurate; thus, we conducted a brief experiment to get the value of a parameter needed in a mathematical model. With the help of the model, we would be able to determine what actuator properties are needed for design requirements.

An experiment was conducted on a 2.5 micron CP1 material to verify if one of our models accurately estimated torque propagation rates. The results of the experiment will determine what path the mathematical modeling team will take. If the model accurately estimates torque propagation rates, the model can be used to determine what dimensions can or can't be used for the sail; it can also assist in the analysis of attitude controller design. If the model were inaccurate, the modeling team would need to determine a better model.

Discussions were held with the client to inform him of the importance of conducting multiple experiments. The deployment team discussed deliverables and the possibility of using a deployable mechanism as a means of launching the sail. Possible deliverables consist of comparing folding patterns to see which one corresponds to the fastest unfolding rate and creating an animation of the solar sail as it unfolds in space.

**Detailed Design Progress:**

The overarching purpose of a mathematical model is to describe Geoshade’s dynamic motions. To begin the mathematical analysis, several factors were neglected and assumed to be contributing minimally to the overall dynamics. Some of those factors are the billowing of the sail, bending, and the deflection of the general frame. From initial research, it was determined that the physical structure of GeoShade is unique; thus, no dynamic model is present for this structure.

Geoshade dynamics are difficult to model due to missing information such as a reflectivity estimation model, an orbital mechanics model, and a wave propagation model; all these models are intended to be incorporated into the final mathematical model. The supplementary models are complex in nature and require a strong mathematical background in order to apply them.

To select a model for the sail reflectivity estimation, the model must be easily understood for it to be applied to the 2.5 micron CP1 material. Many reflectivity models are present in academic literature. Some of them were used in our analysis of solar sail forces due to the optical properties of the CP1 material. Many orbital mechanics models are available; however, they require an extensive knowledge in orbital mechanics. Due to the lack of expertise and time, we disregarded the orbital considerations of GeoShade. Wave propagation models are readily available from any physics textbook. We employed a one-dimensional wave propagation model to calculate the transverse speed of the CP1 material. The wave propagation model was experimentally validated in one of our experiments.

Deployment system was developed in a similar manner where we researched the current available folding methods in literature that can be applied to the GeoShade configuration. However, all available folding methods apply only to small rectangular solar sails that unfold away from a central hub. The GeoShade has five hundred and twelve rectangular panels that fold from one edge to another. The sponsor has a novel folding method that can be applied to GeoShade; however, due to the lack of computational modeling knowledge, we cannot rigorously test the proposed folding method. We intend to bring the folding concept to the physical setting by building a mock-up of the folding and packaging pattern.

Deflection of the GeoShade frame was a consideration in our design. Complex dynamical interaction between different components can cause resonance, which can compromise the structural integrity of the frame. The final frame design uses carbon fiber rods to support folding and packaging. We conducted Finite-Element-Analysis on the carbon fiber rod with varying lengths to estimate the natural frequency of the rod. The natural frequency is also determined experimentally by analyzing data corresponding to the impulse response of the rod in order to validate our FEA method.

There are a variety of actuators that can be used for a range of applications. Since, we are a capstone group without significant financial backing, our credibility is diminished as we attempt to obtain technical details and cost estimates for our actuator selection. We rely primarily on actuator designs in academic literature, which is a problem because they lack cost estimates and support. Another option that was considered was to use a standard, high quality, and low-cost actuator for the GeoShade design.

Space environment is highly hostile to electronics due to the sun’s intensive gamma radiation output. To implement off-the-shell motor, the motor would need to be radiation hardened in order to shield the electronics from harm. This, however, is a problem because the cost estimate for radiation hardened electronics goes beyond two hundred thousand dollars.

**Conclusion:**

Each member of the modelling group was tasked to research how solar forces and torque can be modelled for 1 by 1.5 m sail panel in space. Two incomplete models were created. One resolved the forces acting on each panel based on optical properties. The other described how the torque of each sail panel affected the orientation of the central hub.

The models that were created were incomplete due to unknown variables. For example, the solar force model required constants for front and back emissivities; we do not have these constants. A general solar force model was found in one of the sources provided by the sponsor. However, the model requires knowledge of tensor calculus, math that no member of the group is familiar with. We are considering having a member study tensor calculus while other viable options are searched for. For the remainder of the capstone, the modeling team will either determine front and back emissivities for the CP-1, study tensor calculus, or perfect the wave propagation model.

The deployment team began their research by looking at the failures of older solar sail models. Specifically, they identified the design flaws of each sail so that the Geoshade would contain none of them. The deployment group is currently working on determining how folding patterns affect unfolding rates. The two folding patterns that are being analyzed are the accordian fold and a folding pattern suggested by the client. For the next term, the deployment team intends to use simulations to analyze sail deployment. As a deliverable, the deployment group is considering working on a deployment animation or a mock up. An experiment was conducted to determine the optical properties of CP1. The deployment group will compare the experimental results to the manufacturer specifications to identify any discrepancies.

The actuator team began their research by determining what kind of actuators Geoshade would need. Specifically, they looked at rotational, linear, and magnetic actuators that are used in space. After the actuators were classified, they were organized into subgroups based on weight, radiation hardening properties, and geometry. The cost, advantages, and disadvantages of each actuator are being organized into a report for the sponsor.

One of the biggest concerns about actuators is the costly radiation hardening process. Fortunately, the actuator group discovered a few sources who claim that rust may be used to reduce radiation hardening effects and actuator weight.

The actuator team is currently finalizing their report for the sponsor. Once it is complete, they will work with the deployment team for the sake of productivity. An actuator can’t be selected or designed until a mathematical model for the Geoshade is complete; thus, while the mathematical model is being worked on, the actuator team will assist the deployment team.

Geoshade is far from being complete. From the beginning, the capstone group was aware that this project would be primarily research based. Our hope by the end of next term is to provide our sponsor the foundation to build Geoshade.