Foundational work on the GeoShade solar sail

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Project Objective 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.

Offset Carbon Emissions

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 turned to carbon offsets. Investments and fundings of various carbon offset projects will help reduce carbon footprints and build an environmentally friendly image. Geoshade is a privately funded offset project to reduce carbon emissions.

Key Customer Requirements

- Foundational work for the GeoShade project by exploring different configurations of the various subsystems.
- Tangible results for the sponsor to show off at fundraising events or elevator pitch.
- Proof of concept for the trajectory maneuver system using the sail panels.
- Translating the sponsor's ideas to CAD files or models for visual-aid purposes.
- Spearhead the potential problems that might be overlooked in the sponsor's original idea.

Subsystem 1: Mathematical model

The mathematical model in this project is an environment setup to analyze the sail's different dynamics components. We want to see how the sail would react if one of the panels or all the panels rotate at different velocity and acceleration. With the mathematical model, we can also derive a strategy to control the attitude of the vehicle.

The model focuses on controlling the pitch of the solar sail by manipulating the rotations of the three panels, which need to move in such a way to prevent the gyroscopic precession of the vehicle. The final equations that govern the dynamics of the sail are presented below and the corresponding variables are listed in table 1.

$$\vec{\tau}_b = \begin{bmatrix} -P_s A\cos(\theta_1)\cos(\phi_1) - P_s A\cos(\theta_2)\cos(\phi_2) - P_s A\cos(\theta_3)\cos(\phi_3) \\ P_s A\cos(\theta_1)\sin(\phi_1) + P_s A\cos(\theta_2)\sin(\phi_2) + P_s A\cos(\theta_3)\sin(\phi_3) \\ 0 \end{bmatrix}$$

$$\vec{\tau}_b = \vec{\gamma} \times I\vec{\Omega}$$

The input desired pitch of the vehicle is the variable $\vec{\gamma}$, which is used to determined a solution set $\{\theta_i, \phi_i\}$

Please check out our model 2 and 3 in the final report.

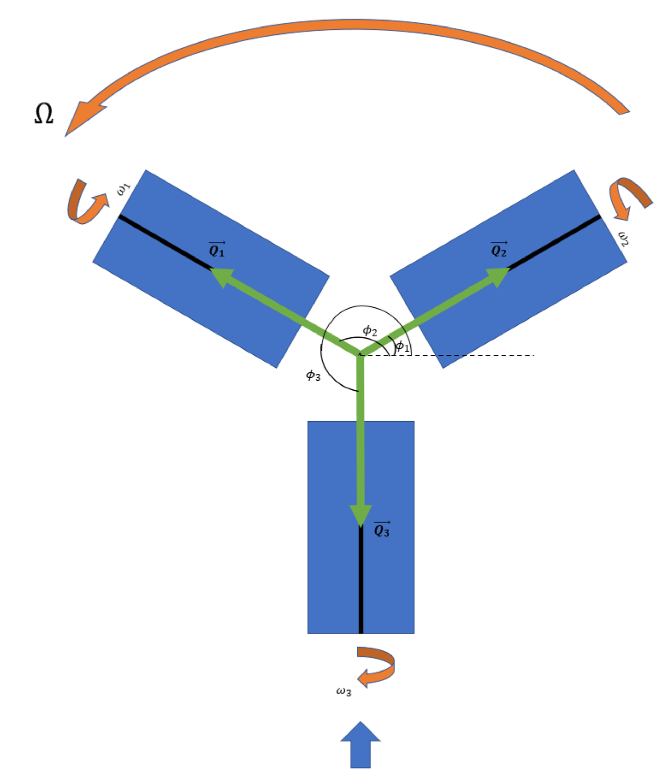
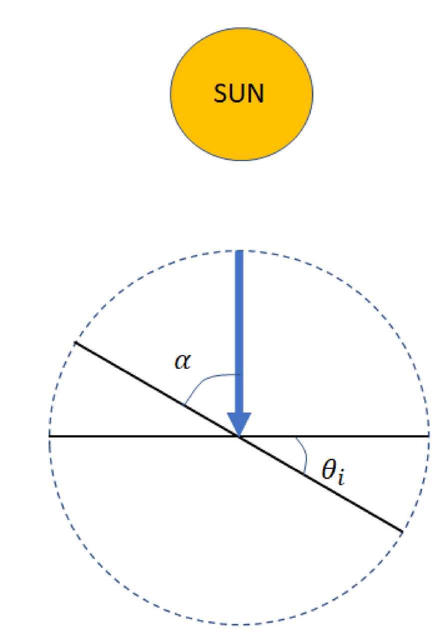


Figure 1: Free-body-diagram of the prototype sail panel.



$A_{eff} = A\cos(\theta_i)$

Figure 2: Side-view of the sun's radiation hitting the panel.

Subsystem 2: Folding design

For the unfolding mechanism, which is based on a concept provided by Tim Sippel, a structure that could be folded with the sail to minimize storage space was modeled. This foldable sail panel system design uses z shaped struts with mechanical latches to hold itself together while unfolding in space. In action, the outermost struts are not latched and can move freely about their hinge. The motor connected at the center strut is used to rotate the entire structure as the outermost struts move into place and unlock the next strut until the system is fully deployed.

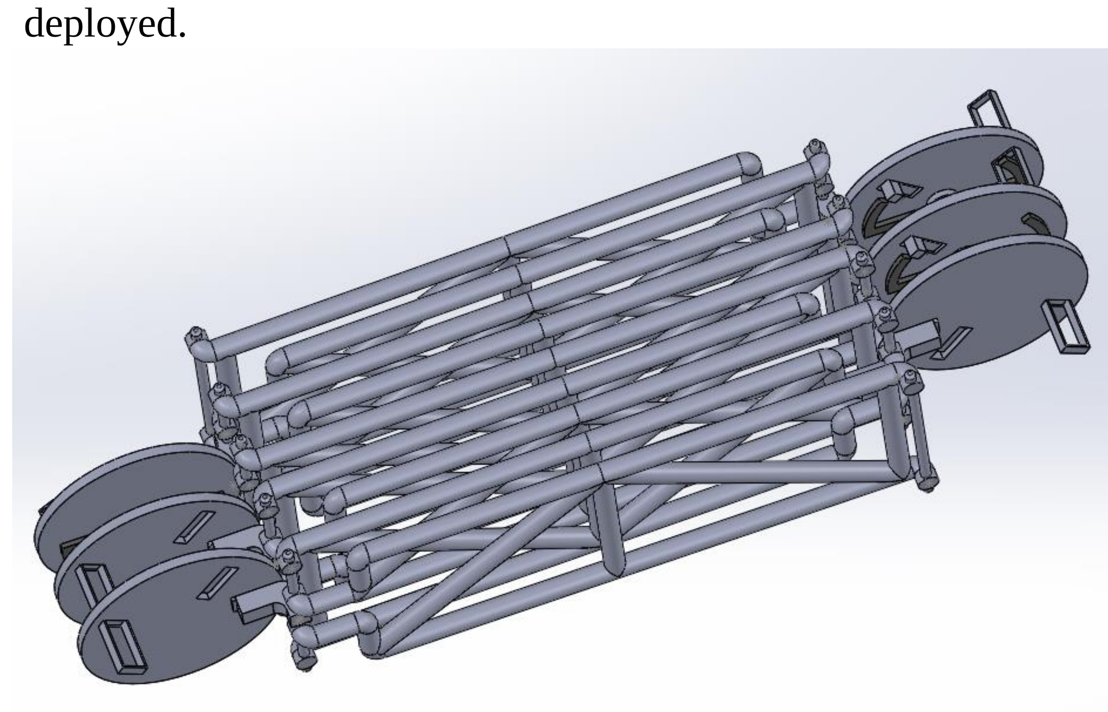


Figure 3: Foldable frame for sail deployment CAD design

Subsystem 3: Animation

The animation was created as requested by the sponsor to help with the visual aid in explaining the concept of using multiple sails to maneuver in space.

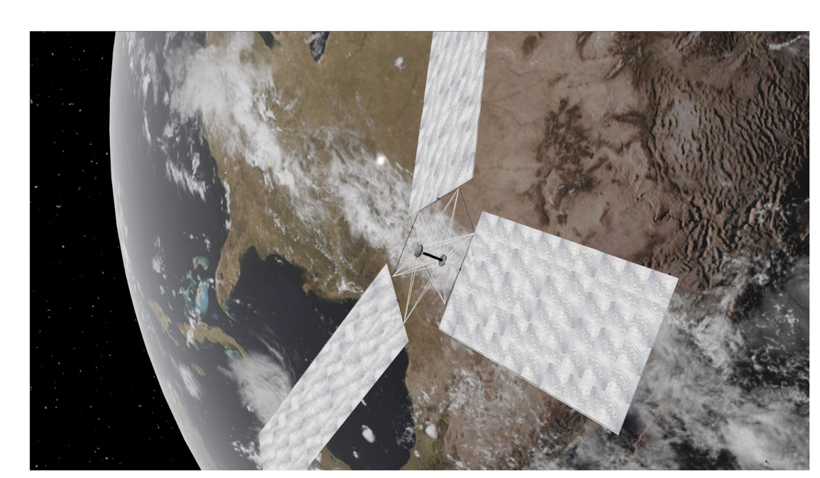


Figure 4: Animation created in Blender. Check out our QR code for the mp4 file.

P_s	Sun pressure $(9.12 * 10^{-6}\ Nm^{-2})^{(1)}$
A	Area of the sail panel (m^2)
θ_i	Angles relative to the vehicle's plane (Figure 1) (rad)
ϕ_i	Panel's angle relative to the positive x-axis (rad)
τ_b	Body torque of the vehicle (Nm)
I	Moment of inertia tensor of the vehicle
γ	Pitch velocity (rad/s)
Ω	Angular velocity vector of the stabilizing spin of the vehicle.

Table 1: List of variables

Measured Performance

The sponsor needs something to show-off the current progress of the project to gain the initial attraction and funding for the project. Due to the cost and knowledge constraint, we cannot validate our subsystems beyond simulation and visual inspection. However, we provided the foundational work and tangible results for the sponsor to use in future events.

For the mathematical model, we showed that the body torque vector can be controlled to prevent gyroscopic precession.

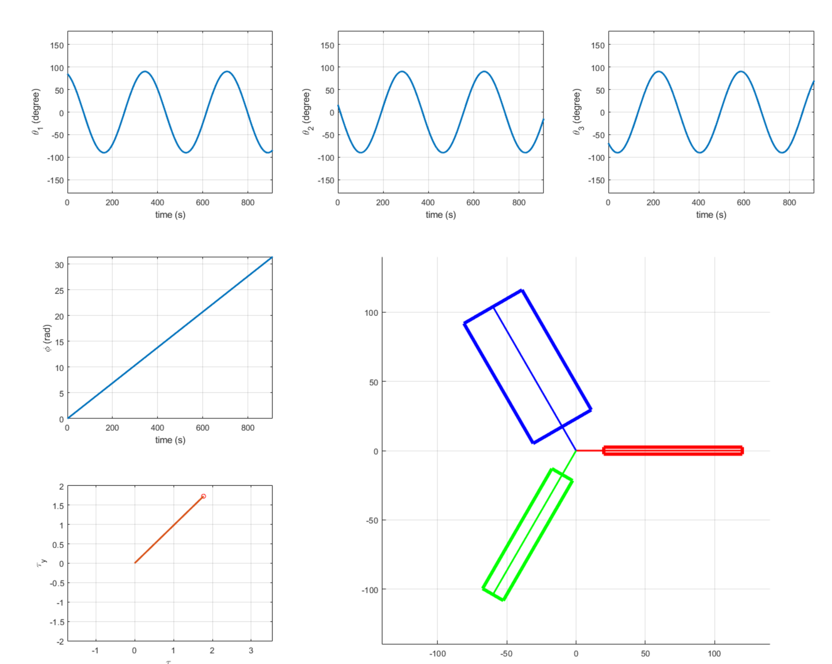


Figure 5: Manipulation of the individual panel can produce stable body torque for trajectory control.

Lessons Learned / Future Work

When it comes to modeling and design, start on basic prototypes right away. The faster you start, the faster you come across issues that need to be dealt with. Having an early model also helps as a show piece when you need feedback.

When it comes to a large project, the very first step should be to reduce it to multiple different smaller parts that interconnect. If the first step fails, the rest of the project will be significantly more challenging.

References

1. McInnes, C. R. (2005). *Solar Sailing: Technology, Dynamics and Mission Applications*. Berlin: Springer Bln.

Acknowledgments

We would like to thank Andrew Greenberg for the initial brainstorming and setting up the project. We would also like to acknowledge Dr. Sung Yi and Dr. Christopher Butenhoff for the suggestion of the wave propagation model.

Thank you to our sponsors

Thank you, Mr. Tim Sippel for the support of the project.

Further information

For inquiries, please email lchung@pdx.edu.

QR Code to the project animation and material.

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