# Inspiring Students through an Attitude Determination and Control System

Caleb Gimpel & Kevin Burville

## Introduction to the team

Team SFU Satellite Design Team is a CubeSat design club based at Simon Fraser University. The team was established to pursue our interest and passion for space, while developing practical and applied experience.

The Attitude Determination and Control System sub-team is tasked with determining the position and orientation of the satellite, as well as actuating the satellite into position for various tasks, such as pointing the solar panels towards the sun, or the payload camera to a point on earth.

Although we are working towards a universal goal across the team, our sub-team tries to leverage our time to gain practical experience that can be applied to the Aerospace industry; wherever possible, we fabricate our components from scratch for full control over the design and to better understanding the dynamics of the system.

## "If you can teach it, you know it"

Building a satellite requires an extensive amount of research and resources; as students, those resources are further limited by a lack of applied experience. A considerable portion of time must be dedicated to researching how each component works and understanding the core concepts, and yet misinterpreting the research or making a mistake can lead to failure in the system and ultimately the mission. To ensure success, our team must cross reference all documents, all decisions made, as well as build upon the knowledge of each other and the resources available for free.

The most productive way for us to make progress is building off the work of previous and existing members on the team; the research component of the sub-system is only useful if the information is successfully relayed to its inheriting members. If a developer moves on from their position and somebody must take their place, reverse-engineering the work that has already been done is both a waste of time and prone to errors. Accordingly, we established an open-source team Wikipedia to collaborate and share our research with the intention of putting the research into our own words and adopting the mantra: "If you can teach it, you know it." The wiki is further used as a host to our reference documents, calculations and material selection, with the intention of being transparent in our decisions and open to criticism before finalizing the design.

After 4 months as a live website, our wiki has over 60 content pages, 1055 edits and 85 members; however, the site has been a target of spam bots, so the total member count is not an accurate reflection of the active users. The Wiki was a success within the ADCS team and of course it was expanded to the rest of the sub-teams. Our Wikipedia is located at: https://teamsfusat.wiki

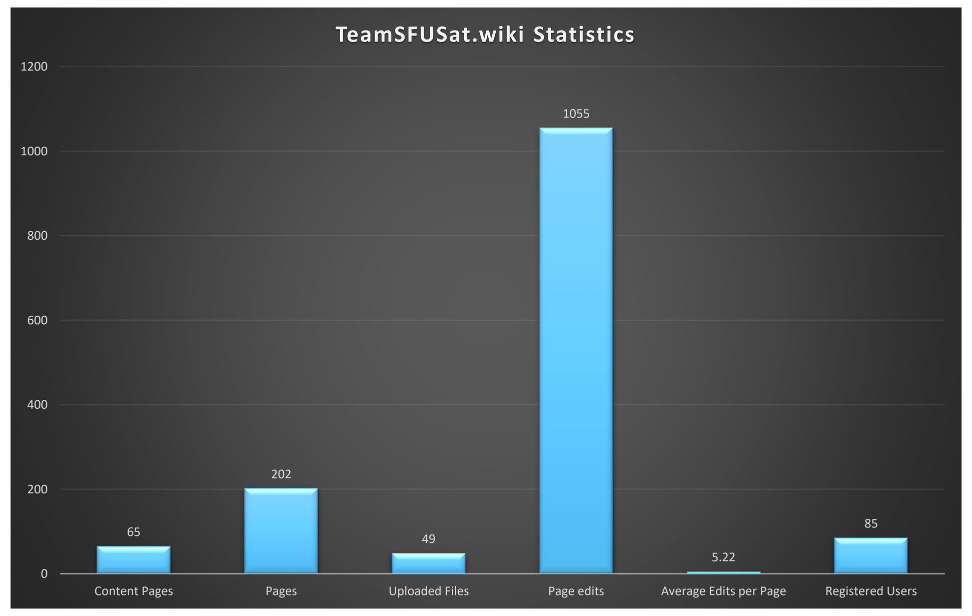


*Figure: TeamSFUSat.wiki statistics as of July 20th, 2019*

## What we do and how we do it

The current Canadian CubeSat Challenge (CSDC) determined the system payload to be a "Selfie Sat," where an amateur radio operator may communicate directly with the satellite and request in image of their coordinates. The satellite processes this request and actuates into position to snap the picture and downlinks it to the operator. An active control system is necessary for a system, with a fast response time and high accuracy. For the current CSDC, our team decided to develop a set of reaction wheels and magnetorquers in combination with multiple sensors to achieve this task.

To start, we defined the relevant known constraints on the system and started simple, such as the maximum acceptable time necessary to rotate the satellite 180º in a single axis. Using the constraints we calculated the minimum magnetic moment, which is a value that represents the strength of the magnetic field. From the magnetic moment, we can then design the magnetorquer based on the length and size of the core, along with the number of turns. Using an optimization algorithm in MATLAB, we determined the ideal values for the magnetorquer, which we then used as a target for fabrication. Although we do not have access to high-precision machinery such as a coil winding machine, we managed to wrap the wire as close to the ideal values as possible with the intention of accommodating for imperfections in the controller algorithm.

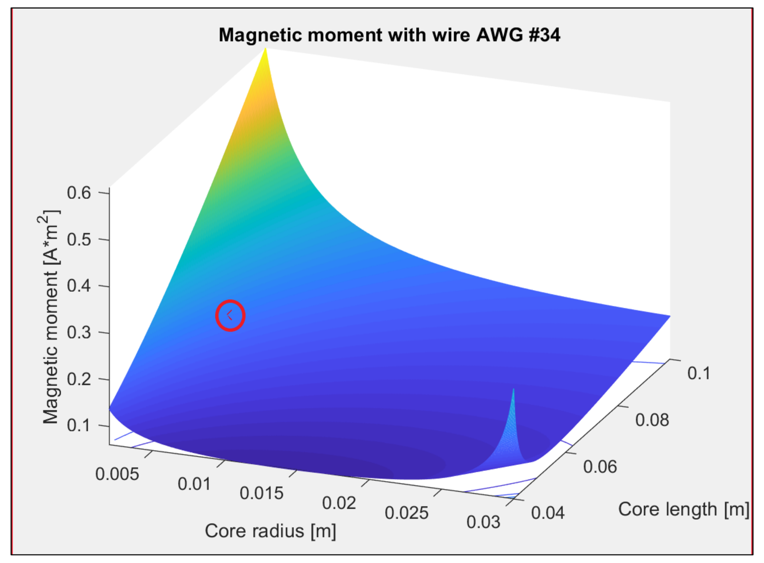


*Figure: Optimization of Core Length, Core Radius and Magnetic Moment*

Our approach to designing the reaction wheel was very similar to the magnetorquer: the constraints on the system are defined and the reaction wheel is designed within these limits. The most important constraint for the reaction wheel is the size of the flywheel mounted to the motor; provided the motor can generate enough torque on the flywheel, we can change the amount of momentum that will be applied on the satellite. For the fabrication of the reaction wheels, we are currently seeking access to a high precision CNC machine which will cut the flywheel to the tolerances necessary for mounting to the motor we selected.

*Figure: Magnetorquer Iteration One (Left) & Iteration Two (Right)*

Lastly, a series of sensors must be selected for determining valuable information about the CubeSat. Although we will not be fabricating the sensors from scratch, printed circuit boards (PCB's) must be custom designed and placed strategically throughout the CubeSat to receive input data and feed this into the controller.

## Conclusion

The purpose of the SFU Satellite Design Team is to inspire more students to seek a position in the space industry, while developing their technical experience. By working on projects that have a tangible result, it helps teach students the technical and practical experience that is necessary for success in the industry, such as design reviews and a design-test process with multiple iterations. The more students are involved in the process, the more they end up learning through their participation.

The entire design process is dependent on the research of its members and reliably communicating what is learned and how it applies to the project. The team Wikipedia is our reliable way to congregate information to a single, efficient location while remaining transparent in the work that we do. When new information is presented to the Wiki, members can always correct mistakes that are made, which keeps the work as accurate as possible. Most importantly, the Wiki is used as a place to show an understanding of the concepts by putting it into our own words, while also providing a familiar format for new team members that are overwhelmed with the amount of knowledge they must try to grasp as quick as possible.

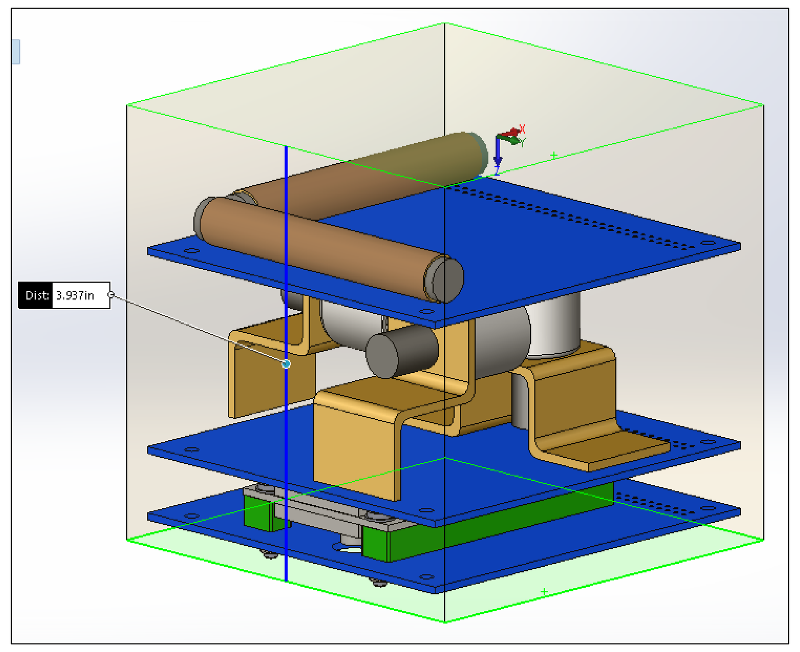

*Figure: First iteration of the actuator layout*

Lastly, no component in the design process goes unused: when an iteration is complete and proven obsolete, it has little use to the team as a practical component of the satellite. These components are excellent examples during outreach events, especially for younger children. When a kid listens to an explanation of a magnetic torque rod, it is boring to picture a homemade magnet – magnets are everywhere and unexciting. Yet, when a child listens to an explanation of a magnetic torque rod while they have something to touch and feel, it lights up their imagination when you tell them "this is going to space."

## Outreach

The SFU Satellite Design Team has considered educational outreach to be a key part of its purpose since its inception. Through our educational programs we have reached more than 10,000 kids. We attend events all over southern BC which focus on STEM education giving talks and presentations. Some of members designed an interactive GUI to interact with a 3D printed CubeSat and control its deployable solar panels.

To further expand our reach and impact we are working with our parent organization SFU Aerospace on the Decode workshop series. Decode is a 4-day robotics program for elementary school students; the program curriculum was built by students from design teams under SFU Aerospace which includes SFU Satellite Design Team, SFU Rocketry, SFU Astro Robotics, and Team Guardian (UAVs). The workshop is also taught by members of the design teams.

*Figure from left to right: Lukas, Jayden and Caleb at the Science Rendezvous SFU Satellite booth*

## Future work

There is still a considerable amount of further work to be done to complete our active control system. Our team is currently working on a full orbital and attitude simulation which we can feed into our control algorithm for initial tuning and mission planning. These simulations will allow us to budget our power usage and optimize our operation.

Additionally, we are developing a custom test rig to initially test our actuators in 1 degree of freedom and then with a full 3 degrees. Using custom designed PCBs and the control algorithm we will further tune our system and better parameterize our components. These more accurate parameters can then be fed back into our simulation to continually refine and improve.

Once testing begins, we will start our final flight PCB designs. Our final system will feature 3 custom PCBs as seen pictured in the conclusion. The ADCS MCU will collect data from sensors distributed around the satellite process that data in the control algorithm and output the control to our 3 magnetorquers and 3 reaction wheels. Meanwhile it will also be communicating with the GPS to update our position in orbit.

## Author Contact

**Simon Fraser University Satellite Design Team**
**Website:** www.sfusat.org
**Email:** sfusat@sfu.ca

**Caleb Gimpel:** Mechatronic Systems Engineering Student
**Email:** cgimpel@sfu.ca

**Kevin Burville:** Mechatronic Systems Engineering Student
**Website:** www.kevinburville.com
**Email:** kburvill@sfu.ca