FACHHOCHSCHULE
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Austrian Network for Higher Education

University of Applied Sciences

Orbital assessment

CLIMB

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List of Abbreviations

STK	*Systems Tool Kit*
MATLAB	*Matrix Laboratory*
FHWN	*Fachhochschule Wiener Neustadt*
CAD	*Computer Aided Design*
ADCS	*Attitude Determination and Control System*
HPOP	*High-Precision Orbit Propagator*
FEEP	*Field Emission Electrical Propulsion*

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1. Introduction

This junior team project ties into the overarching development of the CLIMB CubeSat. Its goal is to gain knowledge about the different parameters that affect the satellite's performance, especially generated solar power and required torque. The aim of this project is also to create an automated program using STK (Systems Tool Kit) and MATLAB (Matrix Laboratory) to allow a prediction of CLIMB's behavior during its time in orbit.

CLIMB will be launched into a high inclination sun-synchronous orbit, raising its apogee over time until a target altitude of 1000 km is reached. Since the exact orbit is currently unknown an orbit analysis must be performed. Moreover, the effect of the satellite's attitude has to be evaluated, both for the power budget and for the torque budget.

Combining these two budgets would be a crucial step for the future, to capture the entire energy generated by the solar cells, the system losses and the energy used for alignment and orbit raising.

2. CAD model

The shape of the model used for this project resembles the newest working CAD model, excluding all internal subsystems. It consists of the simple outer geometry of the satellite with deployed solar panels and the solar panels themselves [Figure 1]. The rear side does not feature solar panels, since the number and placement of those is not known at the time of this project.

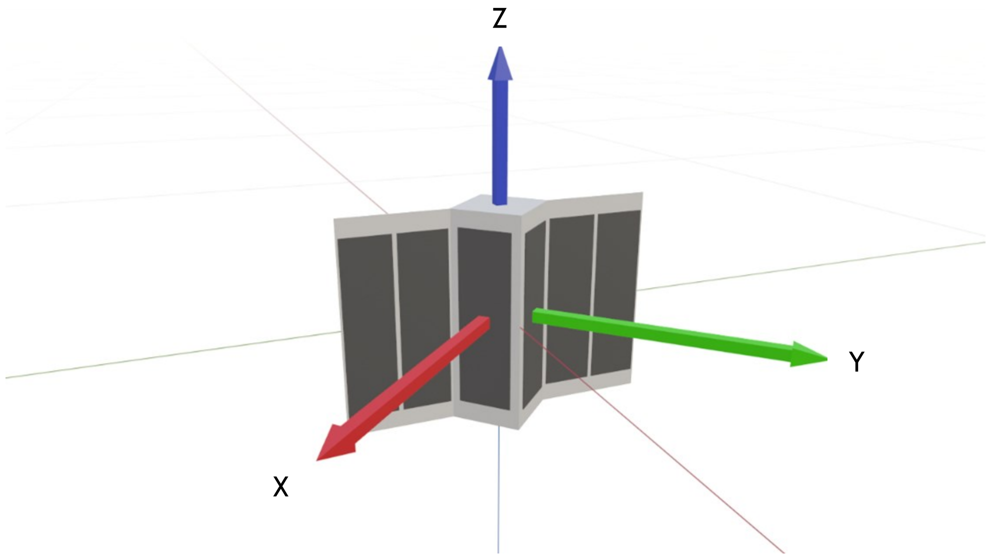


Figure 1: CLIMB model and axis system used throughout the project

The axis system was chosen as depicted above in Figure 1. Additionally, for analysis the following vectors and an angle play important role: Sun-vector, for solar energy generation. Nadir, to navigate during communication time. Lastly, velocity and angle between velocity vector and Z axis for thrust mode constraint. [Figure 2]

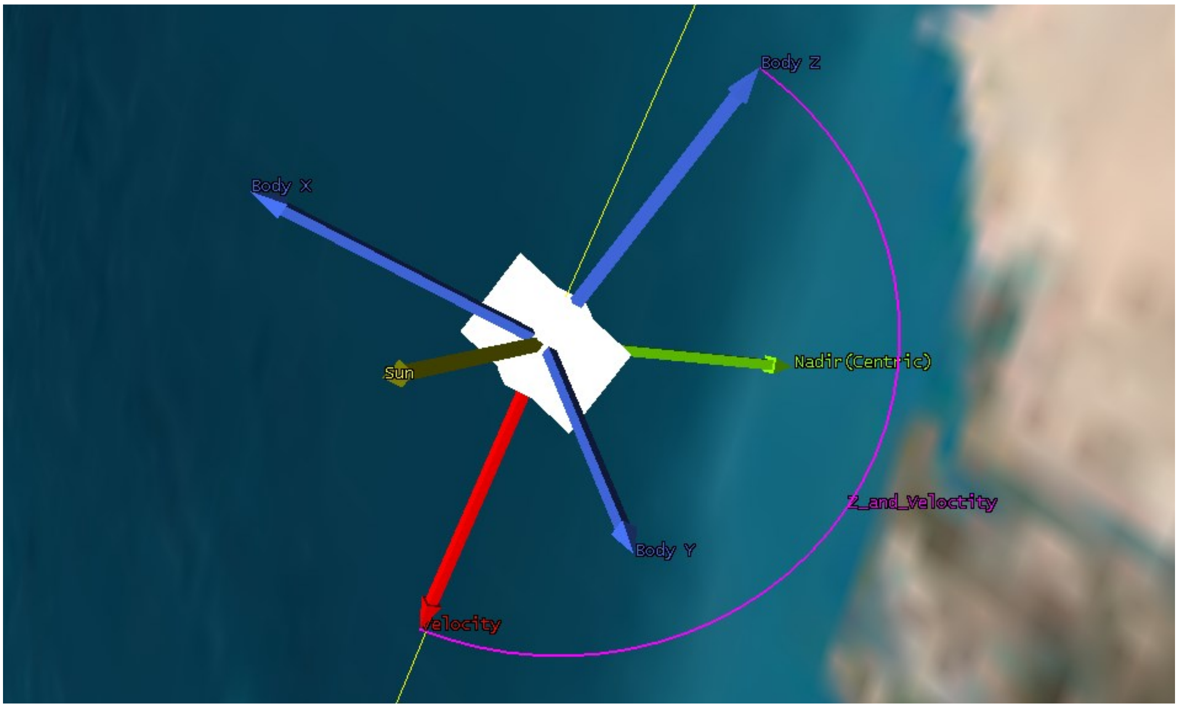


Figure 2: Important vectors: Body axes (blue), Sun (yellow), Nadir (green), Velocity (red)

Furthermore, mass and Moment of inertia of CLIMB were used in modelling of the satellite in STK calculations as shown in Table 1:

Table 1. Physical properties of CLIMB

Mass, m, kg	4.22
Moment of inertia about X axis, I_{xx}, kg·m^2	$5.04 \cdot 10^4$
Moment of inertia about Y axis, I_{yy}, kg·m^2	$5.33 \cdot 10^4$
Moment of inertia about Z axis, I_{zz}, kg·m^2	$2.28 \cdot 10^4$

3. Power Budget

The power budget of the satellite needs to be monitored and predicted in order to ensure that the CLIMB can use its different subsystems to compute, turn and thrust, to be able to process its internal data, communicate with the ground station and raise its orbit. This analysis takes into account the power generated by the solar panels on the satellite. Apart from the solar panel efficiency itself, no additional efficiencies or losses to and from the EPS and other subsystems is included. The analysis is split into two categories: The effect of the satellite's orbit on the solar power, and the effect of its orientation relative to the Sun.

3.1 Impact of CLIMB's orbit on lighting times

The Orbit of the Satellite around Earth changes the amount of time in which CLIMB is in direct sunlight, potentially receiving power, and the time period where it is in the Earth's shadow. Other planetary bodies do not have a significant effect on the lighting, especially when averaged over the Satellite's lifetime.

CLIMB's orbit is Sun-synchronous, which means, that its orientation relative to the Sun does not change. This is achieved by taking advantage of Earth's uneven magnetic field. This irregular field causes all orbits to rotate around Earth as time progresses. By choosing the correct relation between inclination and altitude, the speed of this rotation can be set to the negative of Earth's angular velocity around the Sun. This allows these two angular velocities to cancel out and the orbit to be stationary in the rotating reference system within the Sun.

The orbit of CLIMB is also near-circular. Therefore, the only remaining variable that is left to define the orbit (aside from inclination and attitude) is the LAN (Longitude of Ascending Node). This value refers to the angle between the reference direction and the point where a spacecraft on that orbit crosses the reference plane while ascending [Figure 3].

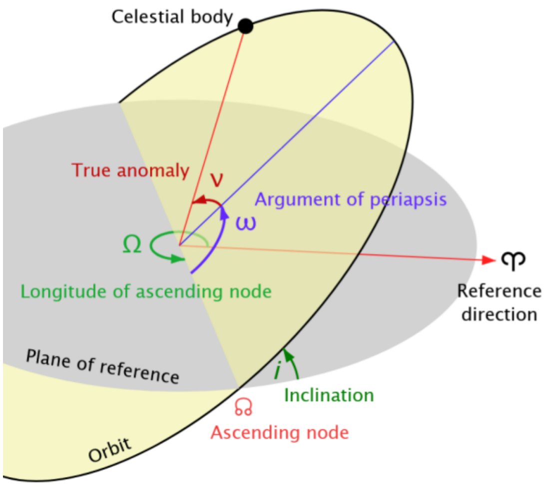


Figure 3: Kepler Elements used to define the position of a spacecraft

The combination of these three variables was analyzed using STK Analyzer to determine their effects on the Lighting times of the Satellite. The communication times are also examined, they are discussed in the "Link Budget" section.

The J2Perturbation Model was used to simulate the Sun-Synchronous Orbits. The satellite Model has the rough shape of the CLIMB Satellite and was estimated at 4kg. The series of simulations runs for one day from the 17th of April 2023 onward. The simulation time was reduced to one day in order to minimize computing time. Because the Orbits are sun synchronous, the lighting times (which are the main focus) should not be affected and the communication times would only change slightly.

3.1.1 Lighting time simulation

Inputs:

- LAN (Longitude of Ascending Node) [deg]
- Altitude [km]
- Inclination is tied to the Altitude for Sun-Synchronous Orbits (The linear relation: $Inc = 0.004 \cdot Alt + 95.5°$ was used) [deg]

Outputs:

- Total Sunlight Time [s]

Scenarios:

The Analysis was done over 432 Scenarios, combining Altitudes from 400 km up to 1500 km in steps of 100 km with LANs from 0° to 350° in steps of 10°.

3.1.2 Lighting time results

It was found that the higher the altitude, the more time the satellite spends in Sunlight. This happens, due to the fact that the higher the altitude of a circular orbit, the smaller the percentage of the circle that is in shadow. When the LAN happens to be at or near the terminator (for this analysis at approximately 30° and 210°), the differences in altitude do not matter anymore, because the Satellite is in constant sunlight. [Figure 4]

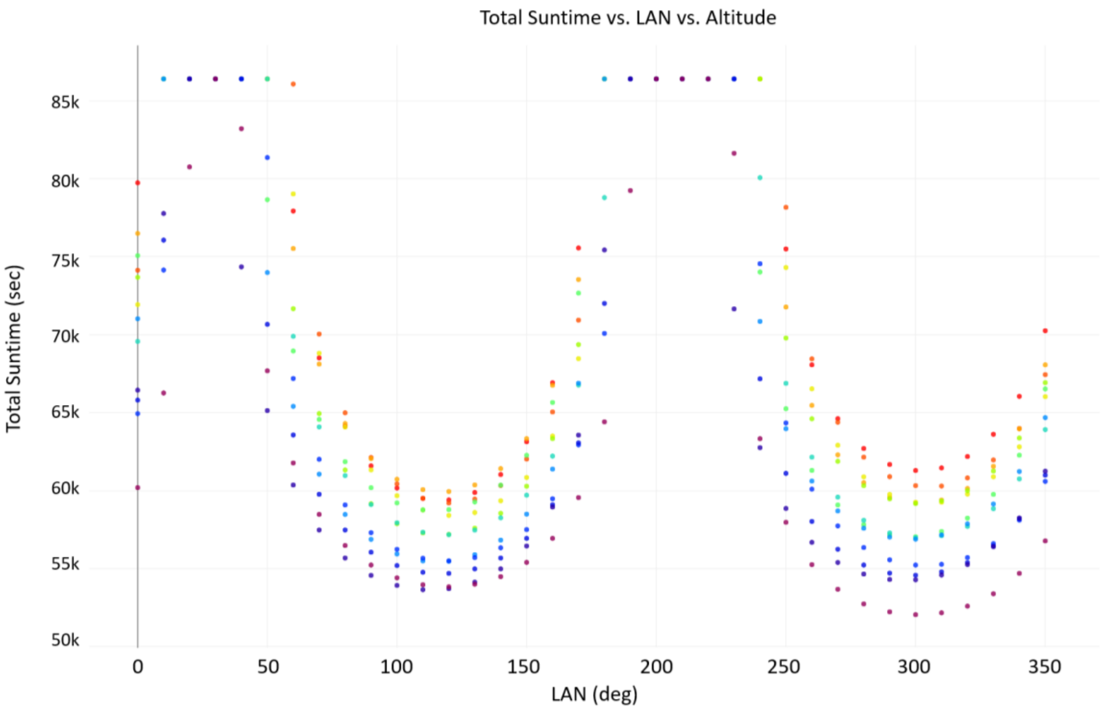


Figure 4: Total Sunlight (y-axis) vs LAN (x-axis) vs Altitude (color: purple (low) to red (high))

This indicates that LAN's at or near the terminator provide the highest possible lighting times. [Figure 5] also shows that for this region around the terminator is less sensitive to deviations from this possible optimum.

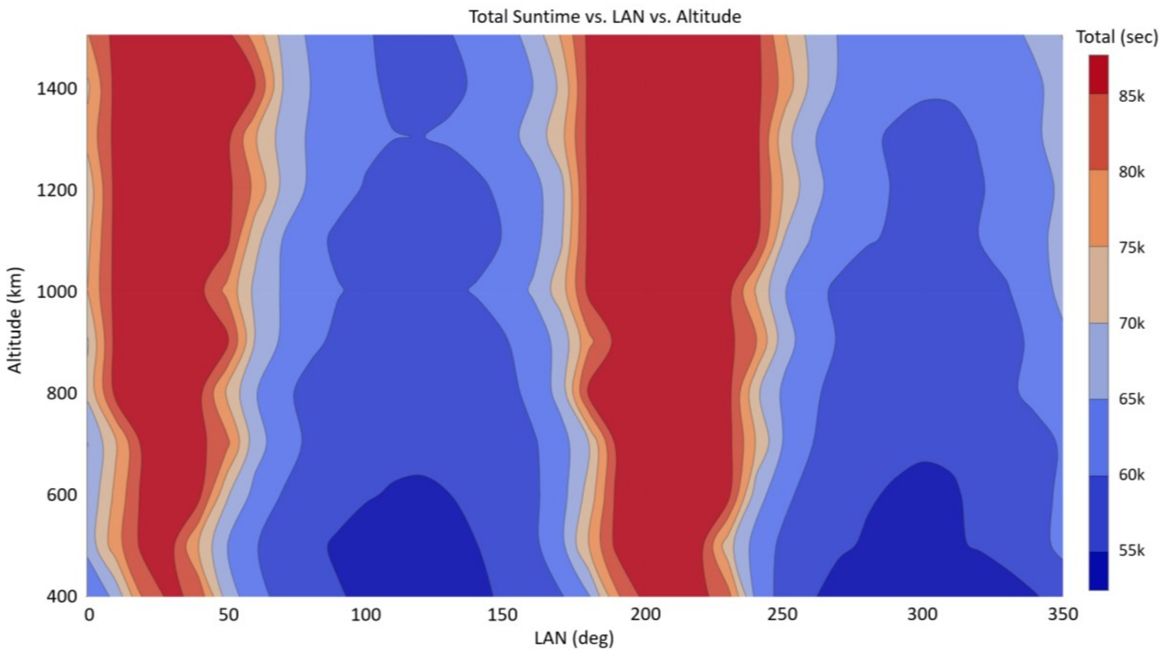


Figure 5: Total Sunlight (color) vs LAN (x) vs Altitude (y)

3.2 Impact of CLIMB’s orientation on its solar power generation

The goal of this sensitivity study is to get an idea about the behavior of the CLIMB satellite for different orientations relative to the sun and to find out the optimal orientation for maximum power generation by the solar panels.
This analysis was achieved using MATLAB and provides relative values for the power which are useful for comparison of power generation and loss, however the actual power generated by the satellite is calculated by STK’s solar panel tool. Also, the values given by the MATLAB program are a slight underestimation due to the geometrical assumptions used for the calculations.

3.2.1 Methodology

The axis system used for the MATLAB simulation differs from the main coordinate system as shown in Figure 6:

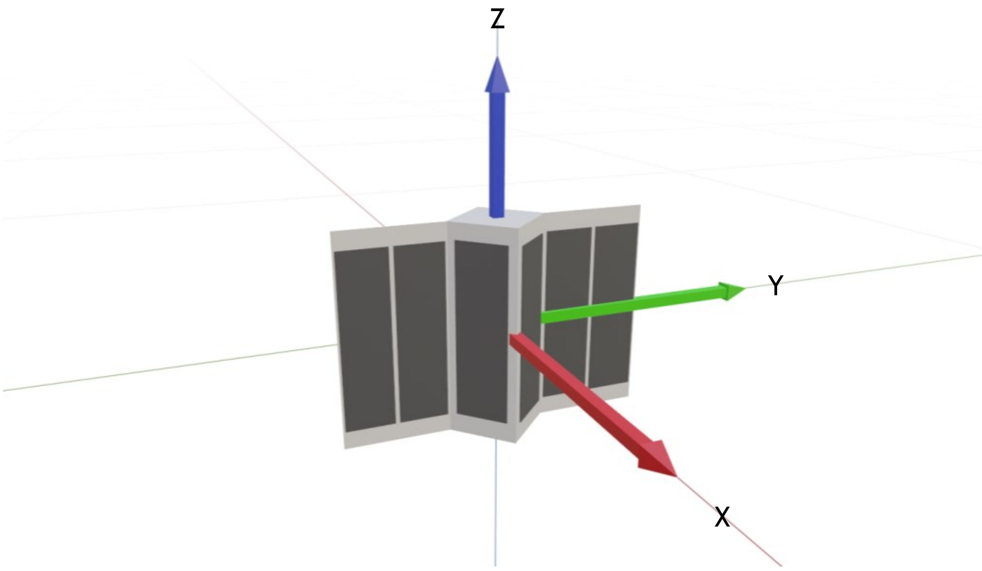


Figure 6: Axis system used for MATLAB analysis.

The coordinate system is a fixed reference system, meaning it is not attached to the satellite and does not rotate with it. The sun is “fixed” along the positive X-Axis, therefore the incoming light rays are parallel to this axis. This allows us to neglect rotations around the X-Axis, since any rotation around this axis has no effect on the angle between the light rays and the surface of the panels (which determines the received power). The only rotations we have to take into account are around the Y- and Z-Axis.
A rotation around the Y-Axis can be easily modelled since there is no change in geometry along the Z-Axis. This results in a simple sinus-curve that represents the power generation. [Figure 7]

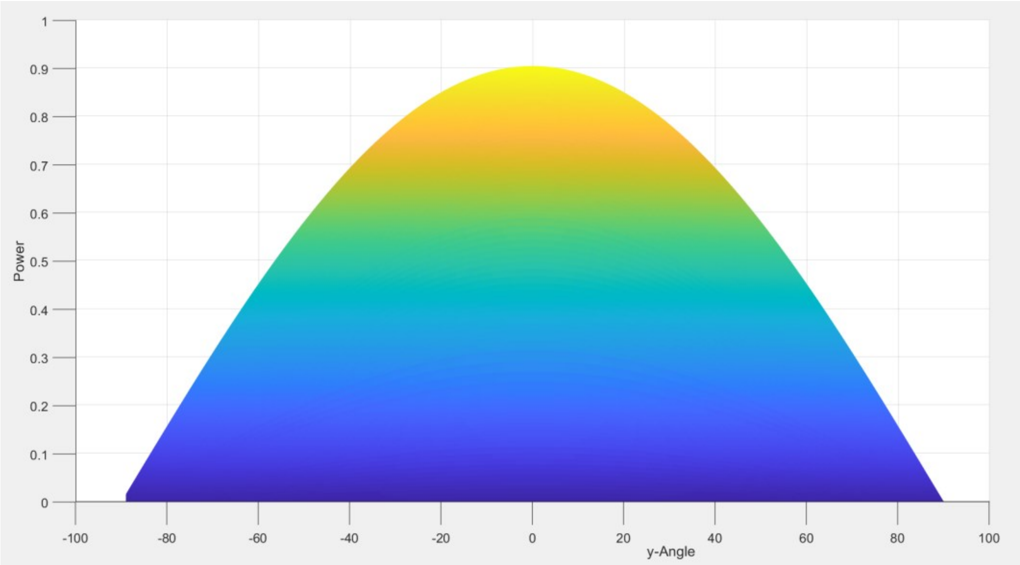


Figure 7: Power generation variation over Y-Angle

Notice, that the maximum power is at 90%. This value is in reference to the power attainable by all panels on the satellite pointing directly at the sun. Since the CLIMB satellite has cells mounted on two sides that are at a 45° angle to the other panels, they can never achieve the 100% mark.

A rotation around the Z-Axis however proves to be more complex. The geometry of the satellite and the layout of the solar cells causes some of them to occlude the others and receive different angles of light-rays. To model this behavior, the complete rotation around the Z-Axis was split into smaller sections, where the power for each cells acts according to a simpler function. (It may be easier to see the satellite as stationary with the sun rotation around it.)

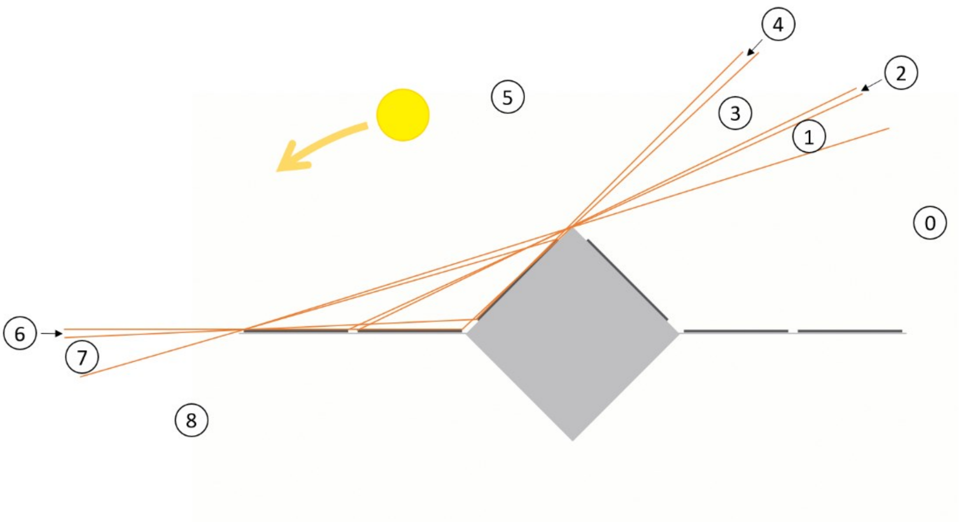


Figure 8: Sections that make up a full rotation around the Z-Axis.

The sections shown in Figure 8 only model the three panels on the left, for the remaining three panels, the behaviour was mirrored. The power function for each panel was layer atop each other to create the resulting graph shown in Figure 9:

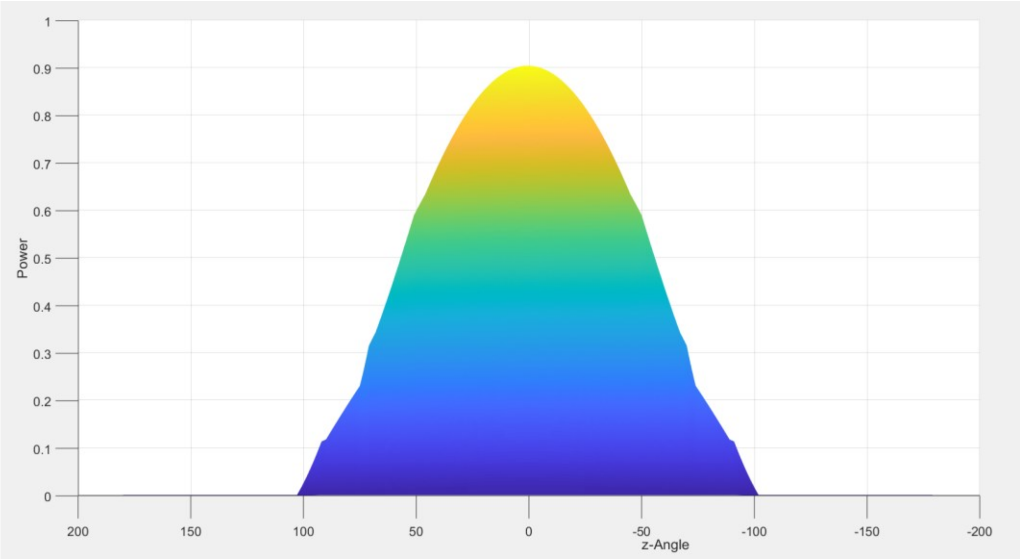


Figure 9: Power generation variation over Z-Angle

3.2.2 Results

Combining these two rotations, all possible attitudes can be modelled in one plot [Figure 10]. Using this plot, we can find the optimal orientation. This turns out to be Y-Angle = 0° and Z-Angle = 0°, aligning the deployed panels to directly face the sun, and the two middle panels at a ±45° angle. The maximum power is 90% of the power achieved by all panels directly facing the sun, which is of course impossible.

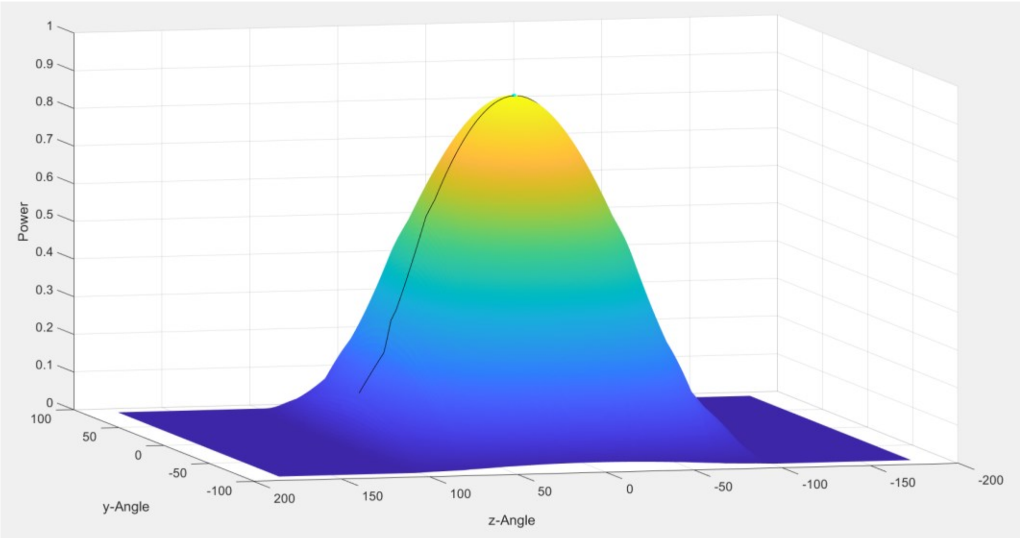


Figure 10: Power vs rotation around the Y-Axis and Z-Axis

We can also deduce, that even for a larger pointing error of ±10° the power is only reduced by 1%. Furthermore, this plot allows us to assess the power of a satellite rotating around an arbitrary fixed axis. The example below outlines the power generated by CLIMB rotating around (1,-0.5,2) and an angle of 30° between this axis and the sun, along the black line. The cyan dot marks the orientation that provides the most power with the given constraints. Here it amounts to 59%. [Figure 11]

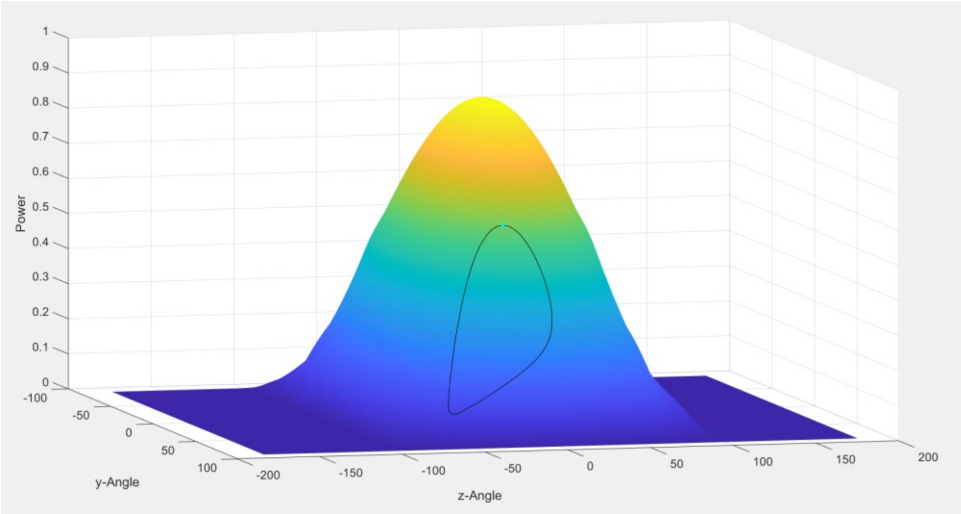


Figure 11: Example of the power generated by a rotating satellite

3.2.3 Power generation and losses due to communication alignment

The power generation of the CLIMB satellite was analyzed for different orbits of 700 km. The RAAN (Right Ascension of Ascending Node) was varied to achieve different times in sunlight and different attitudes for the sun pointing and communication mode. Apart from the total power generated, an important metric is the losses that occur per communication window as a result of an imperfect alignment at the sun. The analysis was performed over 5 days, including an average of 27 communication windows, evaluating the mean power output over the entire duration.

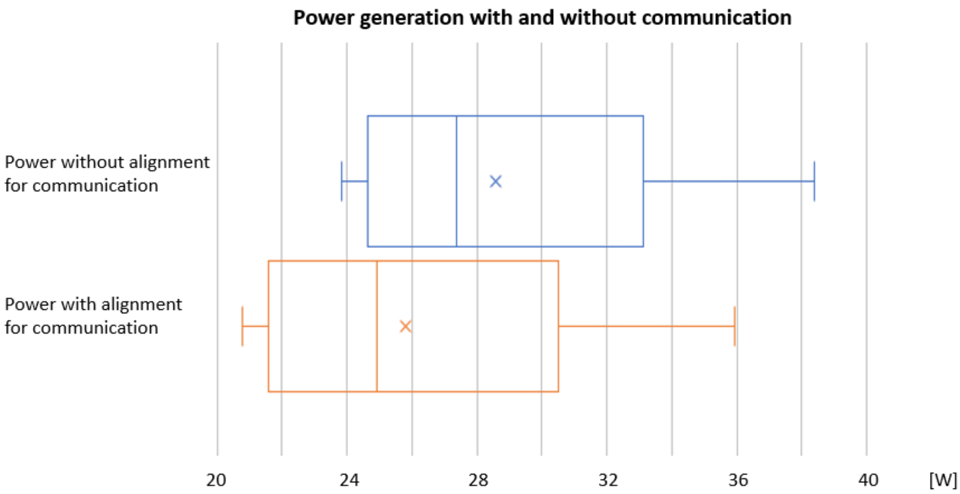


Figure 12: Power generation with and without communication

The power generation shows large variations, as can be seen in Figure 12. This is due to the different lighting times of the analyzed orbits. We can however see, that with alignment for communication, the generated power is reduced consistently. Each targeted communication window brings about a loss in power of 102 mW on average. However, we cannot forget, that the turning itself consumes power, which may add a significant loss on top of the solar power loss.

4. Link Budget

The simulation, which was performed for the Lighting times also investigated the possible communication times between the satellite and ground station for each of the scenarios. The examined link budget only considers whether there is a direct line of sight between these two objects. Losses due to large distances or low elevation angles are not taken into account.

4.1.1 Link budget results

The analysis shows that LAN has no significant effect on the Communication time. It only increases with increased Altitude. This is presumably because the ground track moves over the ground station a roughly equal number of times, no matter the "starting point". [Figure 13, Figure 14]

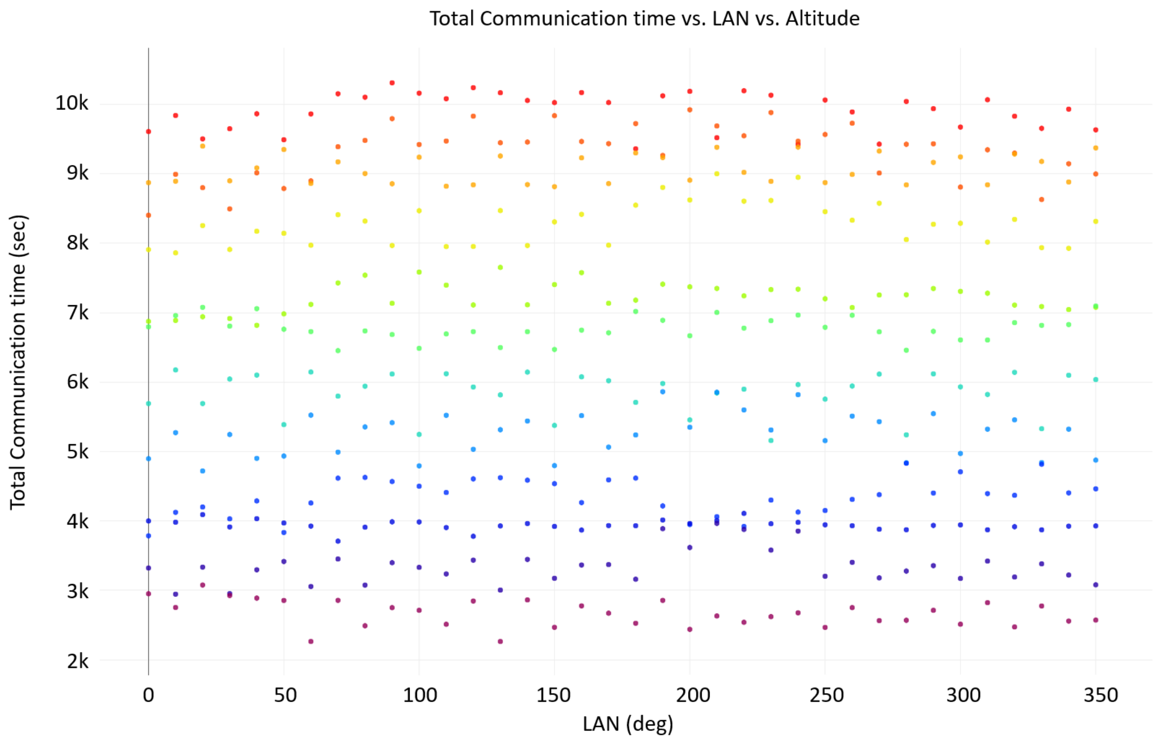


Figure 13: Total Communication Time (y) vs LAN (x) vs Altitude (color: purple (low) to red (high))

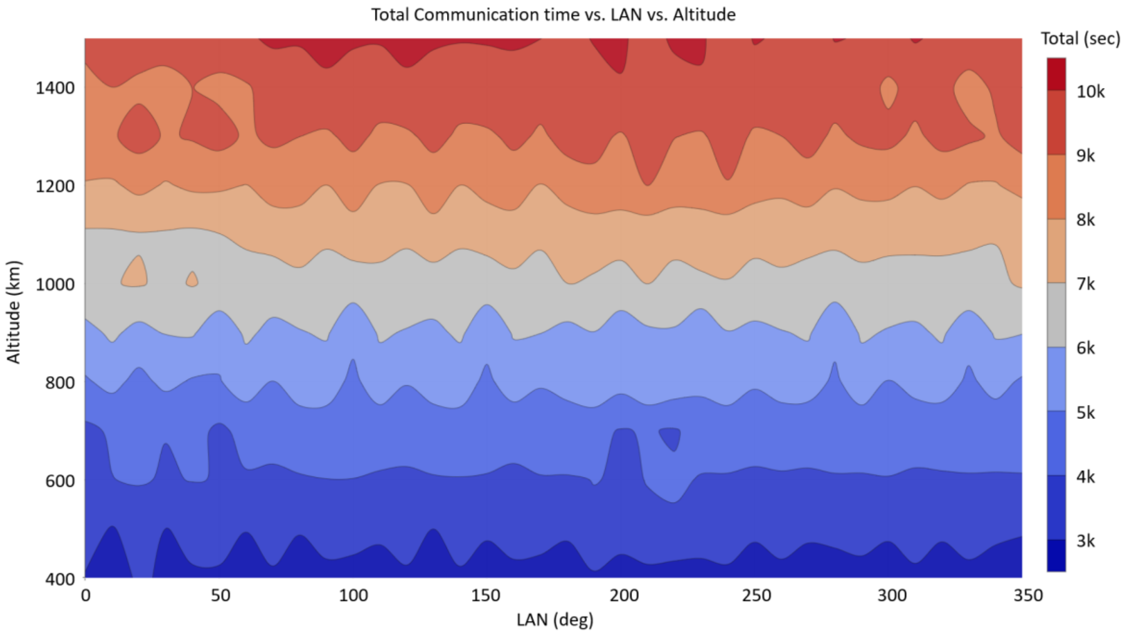


Figure 14: Total Communication Time (color) vs LAN (x) vs Altitude (y)

5. Torque Budget

Attitude determination and control subsystem (ADCS) is utilized to determine the orientation, to position and to maintain the attitude of the spacecraft during its operation.
There are two main types of torques required to be controlled by ADCS: external and internal. Internal type of torque occurs by ejecting particles whose momenta have momentum around a point of reference, such as firing rockets when their thrust vector is not aligned with the center of mass [1]. External torques are created by a force that has a momentum around a reference point such as Aerodynamic Drag, Gravity, or Solar Pressure. External types of torques build up angular momentum and can be solved only by having external torquers, such as Magnetic torquers [1].
In CLIMB there are mainly external types of torque sources, namely: Aerodynamic drag, Magnetic, Gravity gradient, Solar radiation, and Thrust misalignment. The common torquer used for CubeSats to counteract these sources of disturbances is a Magnetic Torquer (rod). It works by engagement of the spacecraft's magnetic field with the Earth's nearby field, resulting in an external force being applied to the vehicle. The advantage of Magnetic Torquers is that they can be controlled by electricity and do not require any fuel, however a big disadvantage is that it is unable to generate a rotational force along the direction of the local field. When a satellite orbits an equatorial plane, it cannot counteract disturbance torque components in south-north orientation. Hence, choosing magnetic torquer imposes restriction on orbit choice [1].
Some ADCS units for CubeSats, in combination with external torquers also include momentum storage torquers such as Momentum and Reaction wheels. As the name suggest they are high precision rotational wheels, usually three, sometimes four as a redundancy in case of failure. These wheels rotate around fixed axes and actuated by means of motors. The difference is that Reaction wheels have nominally zero speed to have fine pointing capability, but may have a nonlinear response due to friction, while momentum wheel operates at high average speed at thousands of rpm to provide momentum bias, meaning making the bias direction insensitive to disturbance torques [1].
To outsource the ADCS, expected required torque and momentum must be assessed. In this chapter rough estimations will be done on approximate calculations.

5.1 Torque due to disturbances

As mentioned above, environmental drag and perturbations also need to be considered in long time missions. However, Figure 15 shows how Atmospheric Drag at altitudes higher than 500 km is negligible compared to Earth's gravity and J2 perturbation. J2 perturbation describes the perturbation caused by the oblateness of Earth gravity. In STK, two body models such as J2 and J4 do not include atmospheric drag, solar radiation pressure or a third body gravity. J4 includes a few more terms compared to J2 in full gravity field model and hence J2 is used for an analysis up to weeks while for an analysis lasting more than a month J4 is favoured. "The J2 and J4 terms cause only periodic oscillations to semi-major axis, eccentricity and inclination, while producing drift in argument of perigee, right ascension and mean anomaly"[2]. High-Precision Orbit Propagator (HPOP) can be used to get the most accurate perturbation model; however, it shall give more accurate results only when more parameters of the orbit are known such as drag coefficients at chosen altitude, Geomagnetic Index, etc.

For Torque analysis J2 and J4 perturbations were used. Additionally, Torque that can arise from FEEP Thrust malfunction by an angled offset was calculated.

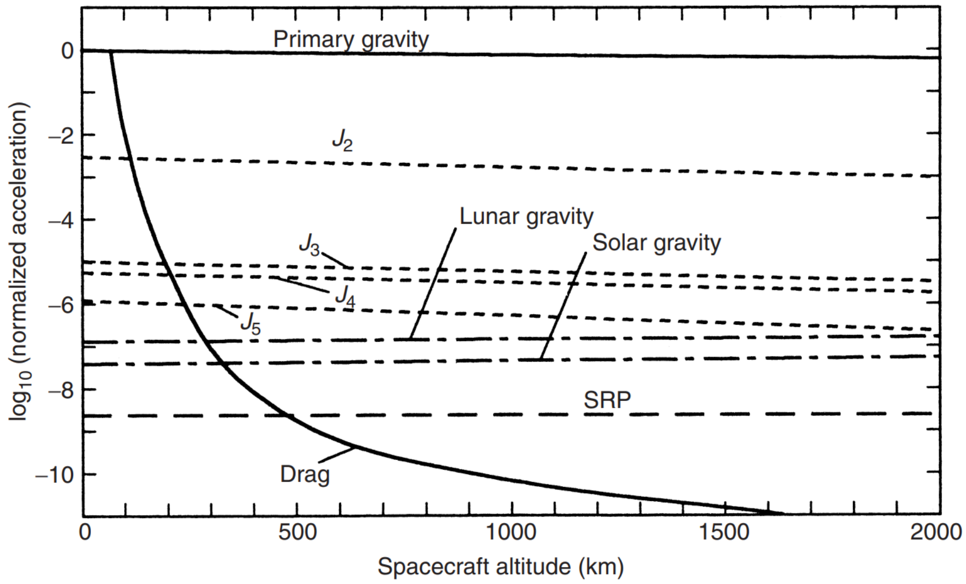


Figure 15: Relative importance of orbit perturbation [1].

If F is 350 micronewton, the thruster is located at distance of L=130 mm from the Center of Gravity and it would create a vector that is shift by α, 5 degrees as shown in Figure 16. The moment arm, r would be calculated as in Equation 1

$$r = sin\alpha \cdot L = 11.3\ mm \tag{1}$$

Torque generated by thrust and this moment arm is calculated as follows.

$$T = F \cdot r = 4\ \mu Nm \tag{2}$$

As a result of Thrust fired for 10 mins, ADCS would have to store Angular momentum of 2.4mNms calculated in Equation 3

$$\Delta L = T * \Delta t = 2.4\ mNms \tag{3}$$

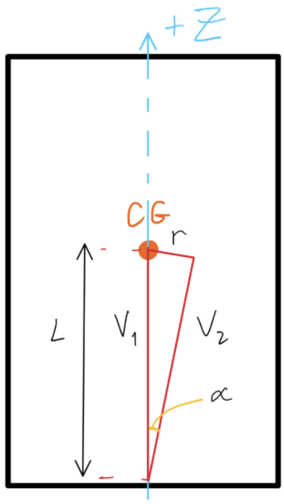


Figure 16: Thrust vector misalignment.

5.2 Torque due to alignment

CLIMB will utilize an ADCS to align itself in space for different purposes. In this section torque and angular momentum required for these transitions are evaluated.

5.2.1 Pointing modes

During its operation CLIMB will have different attitude positions or modes. These modes are summarized in Table 2 and mentioned vectors are visualized in Figure 2.

Name	Description	Alignment method
Thrust Mode	Thrust vector is aligned with velocity vector to have optimum change of velocity, dV.	-Z vector is aligned to Velocity Vector. X and Y axis constrained to have 45 degrees with Sun Vector.
Sun Pointing mode	Maximum Power is generated by positioning solar panels normal to sun vector.	X and Y axis aligned to have 45 degrees with Sun Vector. -Z vector is constrained to Velocity Vector.
Communication mode	Align S-band antenna with the Ground Station.	-Y axis is aligned with line of sight to Ground Station. -Z vector is constrained to Velocity Vector.

Table 2. Pointing Modes of Climb

CLIMB will try to maximize its time in so-called sun-pointing mode. As it was analysed before, the best power generation is possible by facing solar panels normal to the sun. The constraint between -Z and Velocity vector are introduced to comply with FEEP thruster requirement, so that the angle between thrust vector and velocity vector should not exceed 75 degrees at all times. Angle constraints cannot set to be ‘no more than’ a certain value, so the constraint option was chosen. In STK a constraint between vector means the minimisation of angle between two vectors.

At certain time CLIMB needs to align its S-band antenna, which is on the -Y side of the satellite, with the Ground station located at FHWN to send data. The Z axis was constrained for the same reason mentioned above in Sun pointing mode.

Moreover, every time the satellite passes its perigee, it shall align itself for a certain time such that the thruster provides optimum dv performance. As only a single axis is aligned, other two axes could be constrained to set the solar panels normal to the Sun vector. This constraint is not required, however it can be chosen optionally to optimise solar generation.

The satellite in Sun Synchronous orbit will have different pointing modes, however in all cases the angle between Z and Velocity vector must be more than 105 degrees. Because this constraint cannot be set as input in the attitude control of the satellite, the angle was checked to comply with restrictions after setting each pointing mode.

5.2.2 Methodology and Exemplary Results

To evaluate Torque and Momentum the following steps were conducted.

1. Set up attitude position sequence.
2. Set maximum slew rate for transitions.
3. Extract data with 60 seconds frequency:
    a. Time
    b. Yaw, Pitch, Roll in degrees (rotation around Z, Y and X axes of the satellite, respectively)
    c. Yaw, Pitch, Roll rate in deg/sec
4. The following data were calculated using extracted data:
    a. Yaw, Pitch, Roll angular acceleration.
    b. Torque in X, Y, Z axes.
    c. Total Torque
    d. Cumulative Torque
    e. Change in Angular momentum in X, Y, Z in axes.
    f. Total Change in Angular momentum
    g. Cumulative Change in Angular momentum

In this section, the mentioned steps are explained in detail by setting exemplary STK scenario:

The simulation lasts for 24 hours, as we are interested in daily number of communication and how we can predict how much Torque it might require. To demonstrate, an Example Scenario is calculated from the 1st of May, 10:00:00 am until the 2nd of May, 10:00:00 am in 2023.

The Ground Station is located at FHWN via latitude and longitude of 47.8 deg and 16.2 deg respectively. A half cone angle of a 85 degree sensor was attached to the Ground Station to simulate elevational obstacles that might reduce connection time. Reducing the half cone angle just by 5 degrees usually resulted in the number of access window decreasing to half.

The satellite was modeled using CAD model shown in Figure 1 and properties mentioned in Table 1 In the J2 perturbation propagator type of orbit.

Most important step is setting the Target pointing options, including slew rate and these steps are mentioned in Appendix 1in detail. Slew rate is the rate at which a satellite rotates in angle change between two modes.

A maximum Slew rate of 1 deg/sec and maximum slew time of 10 mins is chosen. Typical maximum slew rates for CubeSat ADCS vary between 1.5 and 2 deg/sec per axis, hence the maximum Slew rate of 1 deg/sec should be good value, as the lower the slew rate change, the lower is torque.

As it can be noticed from Figure 17, the slewing happens before and after each 4 communication windows and last 10 mins. Each slew ends before the start of communication mode and starts after it ends, meaning slewing does not decrease communication time.

And lastly, the Thrust Mode is modeled as mentioned in Table 2 and is added as a first segment before Sun pointing mode. Thrust Mode lasts 20 minutes, including 10 minutes of thrust and the same amount of time for adjustment.

Name	Source	Number	Start Time	Stop Time
AlignConstrain	Basic	1	1 May 2023 10:00:00.00	1 May 2023 10:20:00.00
AlignConstrain1	Basic	2	1 May 2023 10:20:00.00	1 May 2023 14:54:43.34
Slew	Targeted	1	1 May 2023 14:54:43.34	1 May 2023 15:04:43.34
FHWN	Targeted	1	1 May 2023 15:04:43.34	1 May 2023 15:17:30.08
Slew	Targeted	1	1 May 2023 15:17:30.08	1 May 2023 15:27:30.08
AlignConstrain1	Basic	2	1 May 2023 15:27:30.08	1 May 2023 16:31:39.58
Slew	Targeted	2	1 May 2023 16:31:39.58	1 May 2023 16:41:39.58
FHWN	Targeted	2	1 May 2023 16:41:39.58	1 May 2023 16:55:33.35
Slew	Targeted	2	1 May 2023 16:55:33.35	1 May 2023 17:05:33.35
AlignConstrain1	Basic	2	1 May 2023 17:05:33.35	2 May 2023 04:27:33.35
Slew	Targeted	3	2 May 2023 04:27:33.35	2 May 2023 04:37:33.35
FHWN	Targeted	3	2 May 2023 04:37:33.35	2 May 2023 04:51:06.54
Slew	Targeted	3	2 May 2023 04:51:06.54	2 May 2023 05:01:06.54
AlignConstrain1	Basic	2	2 May 2023 05:01:06.54	2 May 2023 06:05:23.92
Slew	Targeted	4	2 May 2023 06:05:23.92	2 May 2023 06:15:23.92
FHWN	Targeted	4	2 May 2023 06:15:23.92	2 May 2023 06:28:43.58
Slew	Targeted	4	2 May 2023 06:28:43.58	2 May 2023 06:38:43.58
AlignConstrain1	Basic	2	2 May 2023 06:38:43.58	2 May 2023 10:00:00.00

Figure 17:Alignments and schedule for CLIMB on exemplary date.

Before proceeding with output and calculations, the constraint from the FEEP thruster for the thrust vector should be checked for fulfillment, as the angle between -Z axis and Velocity vector is minimized but is not provided with a maximum limit. Hence, the angle between +Z axis and Velocity vector displayed in Figure 2 is calculated to be always above 117 degrees as shown in Figure 18.

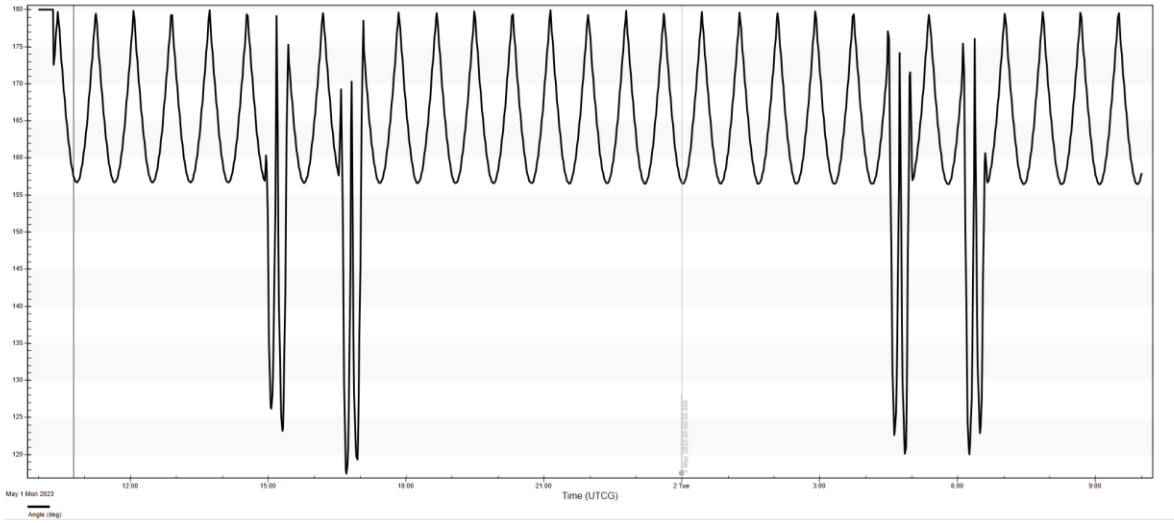


Figure 18: Change in Angle between +Z and Velocity axis.

The next step is to generate an output report in Excel of the angular velocities with a time step of 60 seconds, visualized in Figure 19, and to calculate the angular acceleration, α from Equation 4.

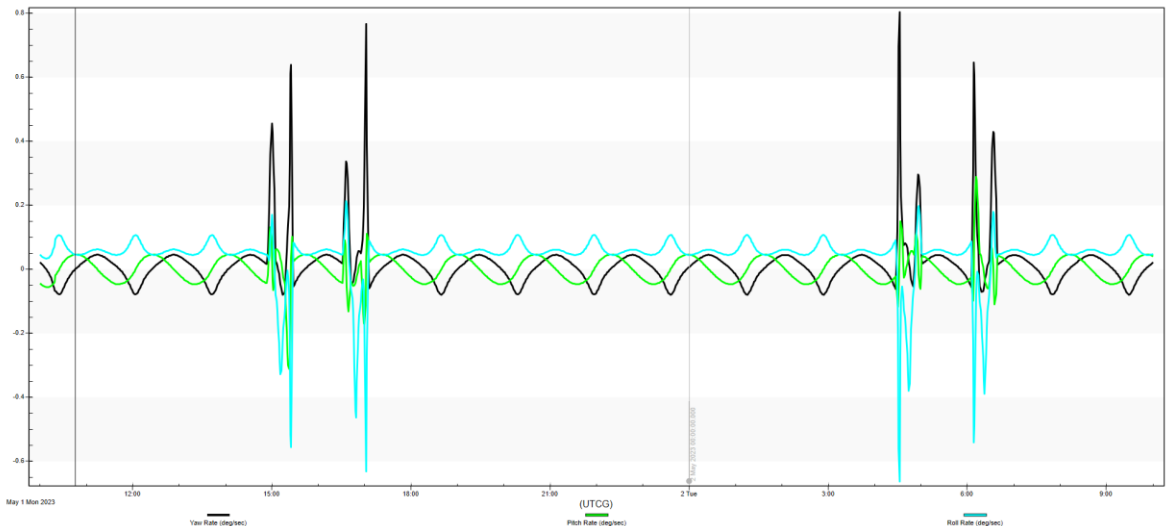


Figure 19 : Angular velocity from exemplary date.

$$\alpha = \frac{d\vartheta}{dt} \tag{4}$$

It should be noted that Yaw, Pitch and Roll relate to rotation around Z, Y and X axis of the satellite, respectively. Angular acceleration because of slew is shown in Figure 20.

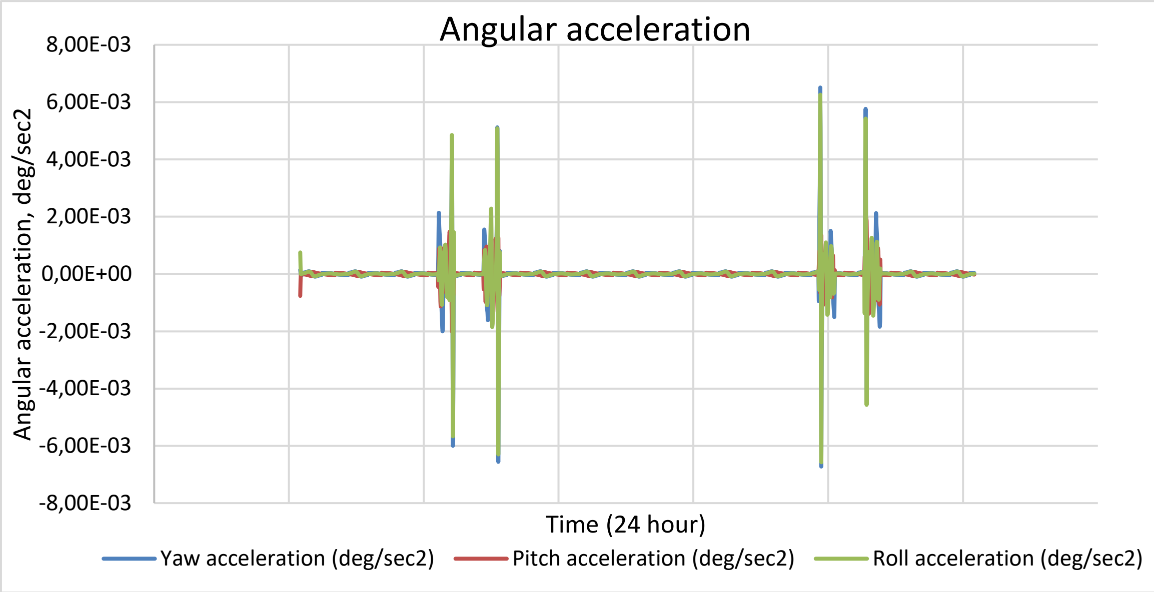


Figure 20: Angular acceleration from exemplary date.

With the calculated angular acceleration, α and known moment of Inertia in X, Y and Z axes from Table 1, Torque,T in three axes required for changes can be calculated according to Equation 5.

$$T = I \times \alpha \tag{5}$$

Torque at time instances and Cumulative Torque are shown in Figure 21and Figure 22 respectively.

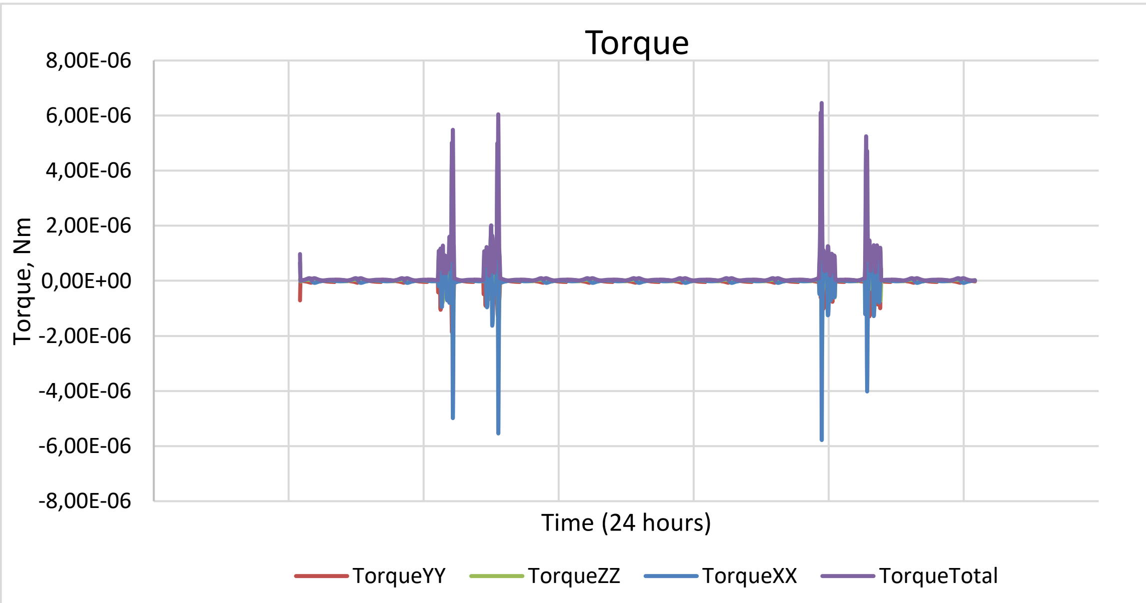


Figure 21: Torque at time instance

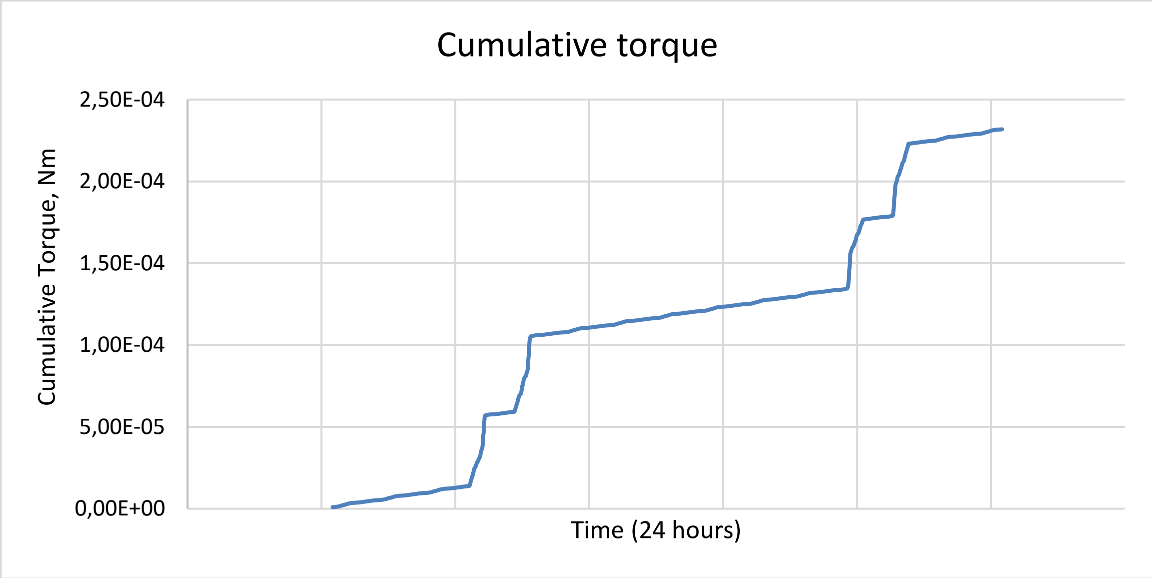


Figure 22: Cumulative Torque

Apart from maximum Torque limit, angular momentum storage is also an important parameter. Change in Angular Momentum, dL can be calculated as

$$\mathrm{d}L = T \cdot dt \tag{6}$$

Angular Momentum change and Cumulative Torque are shown in Figure 23 and Figure 24.

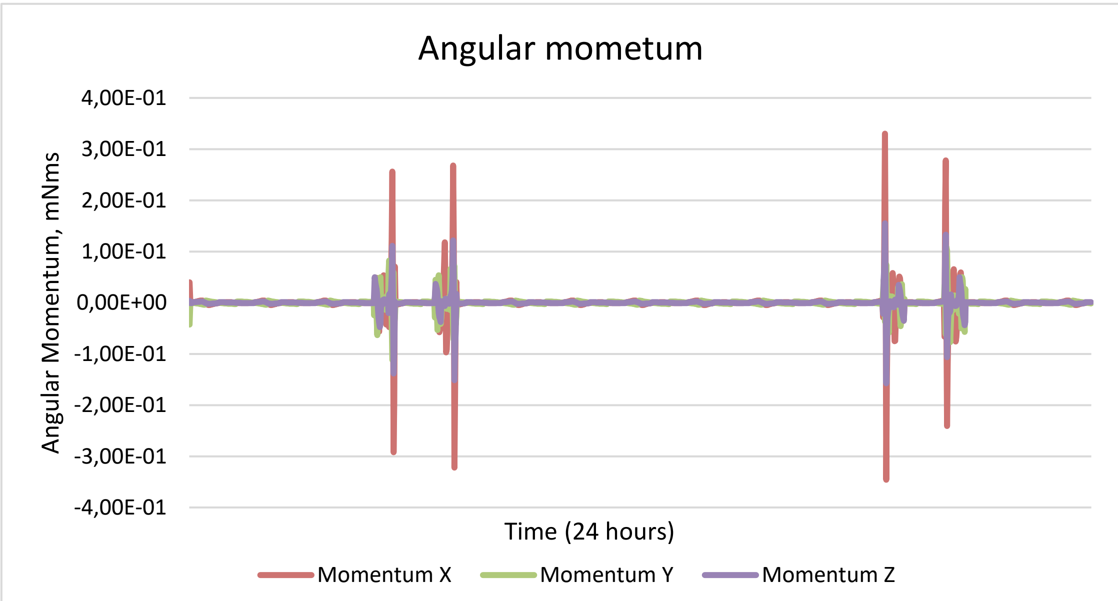


Figure 23: Angular momentum

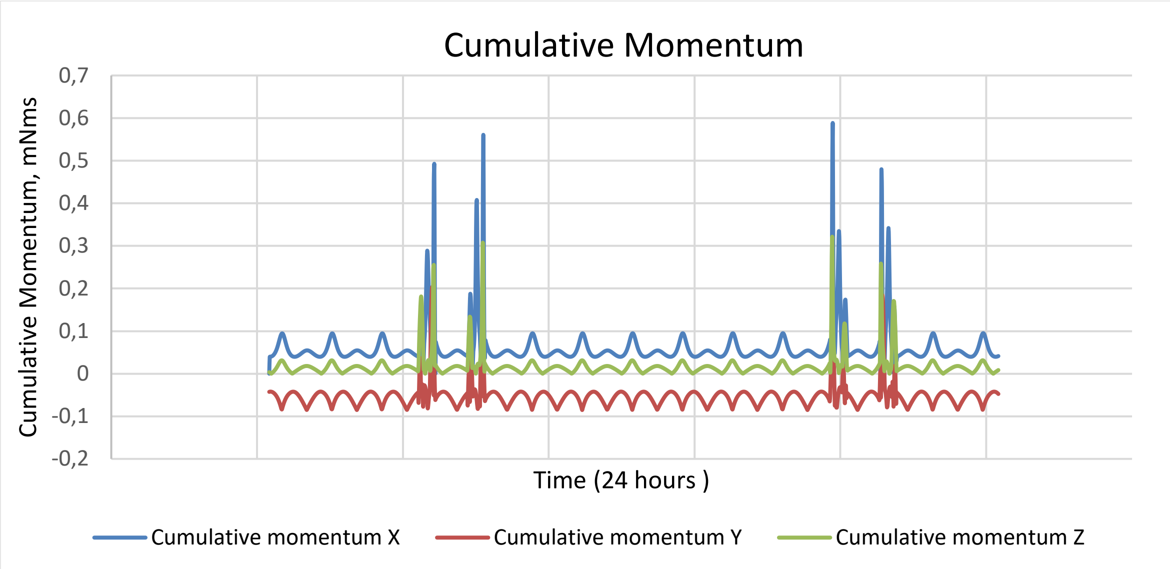


Figure 24: Cumulative Angular Momentum

5.3 Summary

From Figure 18 to Figure 24 different peaks that arise during 24-hour period are depicted.

The switch from Thrust mode to Sun pointing mode after 20 minutes did not change drastically, as their alignment options are very similar. The Z axis changed from being “aligned” in Thrust mode to “constrained” in Sun Pointing Mode. Hence, the angle of rotation required for transition was very low.

There are 4 major peaks arising due to changes from Sun Pointing Mode to Communication mode and back from Communication mode to Sun Pointing Mode. These transitions result in 0.006 mNm which is far below the usual 0.1 mNms limit met in selected ADCS’ for CubeSats. Furthermore, to perform a transition to communication mode the satellite needs to store up to 0.6 mNms angular momentum, until it rotates back to Sun Pointing mode. The resultant angular momentum change is also below regular ADCS value, because ADCS angular storage depending in the size usually can store up to 6 mNms. CLIMB will need at least 3 mNms angular momentum storage, including Thruster misalignment, 2.4 mNms and transition due to mode change, 0.6 mNms. These also do not include environmental perturbation, that accumulate over long period of time.

It should be noted that there were also minor picks equal to the number of periods of the satellite during 24-hour scenario. It might be due to environmental perturbation, as they also occur periodically. These picks result in maximum of 0.1 mNms angular change in two axes per rotation.

In conclusion, by having 1 deg/sec slew rate for CLIMB mode changes and applying the alignments suggested above, it was possible to predict some of the required Torque and Angular Momentum Storage in a rough estimation, that are below existing commercial ADCS limits.

6. Summary

In our Junior Team Project we were able to create tools to calculate:

- Effect of different orbits on CLIMB power and link budget
- Solar power at different altitudes and attitudes
- Torque Budget

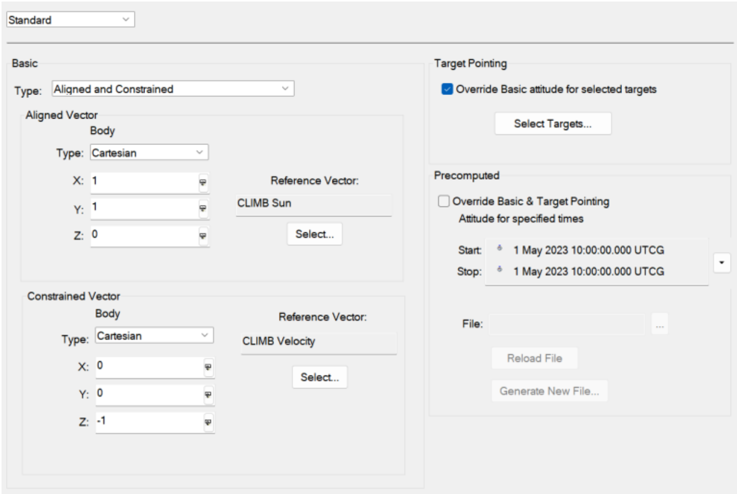
Torque budget calculation could be improved by adding detailed environmental perturbation accumulative effects during CLIMB's lifetime, calculated analytically over a range of altitudes in addition to the already calculated Torque budget. These calculations would lead to determining the saturation time and together with a desaturation mode that is to be determined, we can plan and automize the ADCS control over complete mission time. Combining this model with the incoming solar power would provide the team with more complete knowledge about the satellite's energy budget.

7. References

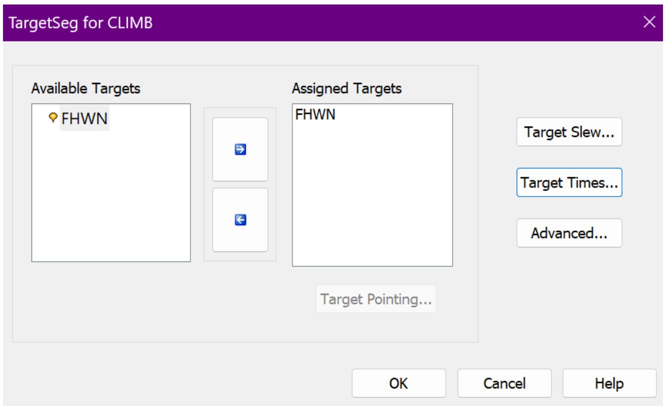
[1] P. Fortescue, G. Swinerd, and J. Stark, *Spacecraft Systems Engineering Fortescue/Spacecraft Systems Engineering*. Chichester, Uk John Wiley & Sons, Ltd, 2011.
[2] “STK Help,” *STK Help*, Jun. 23, 2023. https://help.agi.com/stk/ (accessed Jun. 29, 2023).

Appendix 1. Pointing Mode steps

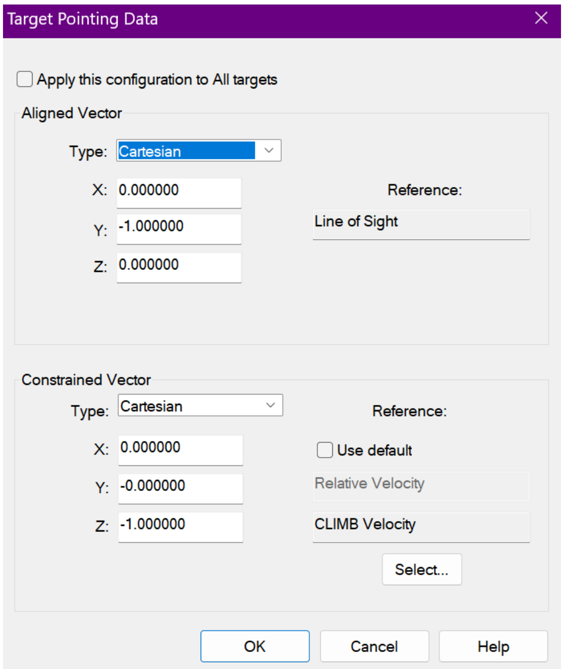
1. Setting Sun Pointing Mode as standard altitude. And Overwriting with Target Pointing/ Communication Mode.



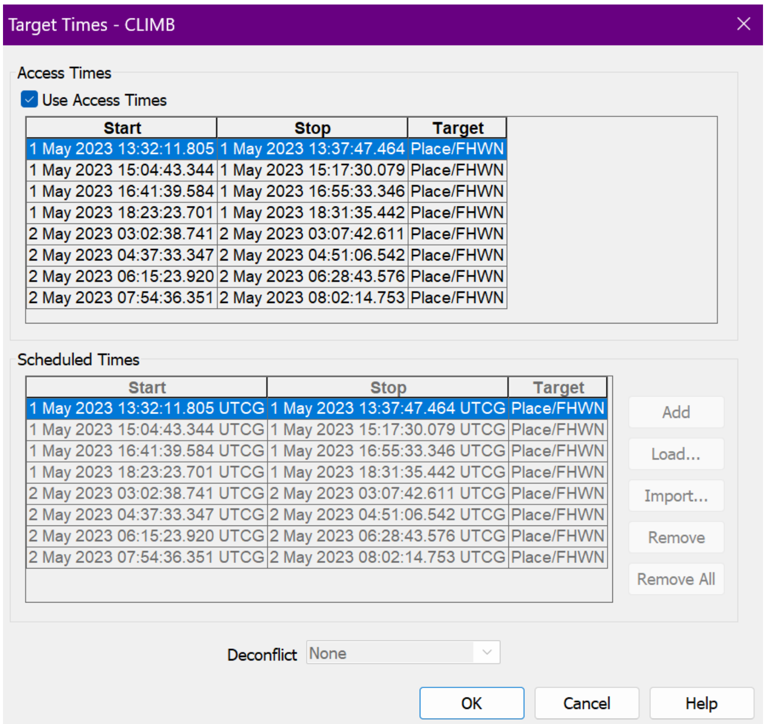
2. Selecting FHWN as assigned target and click Target Pointing



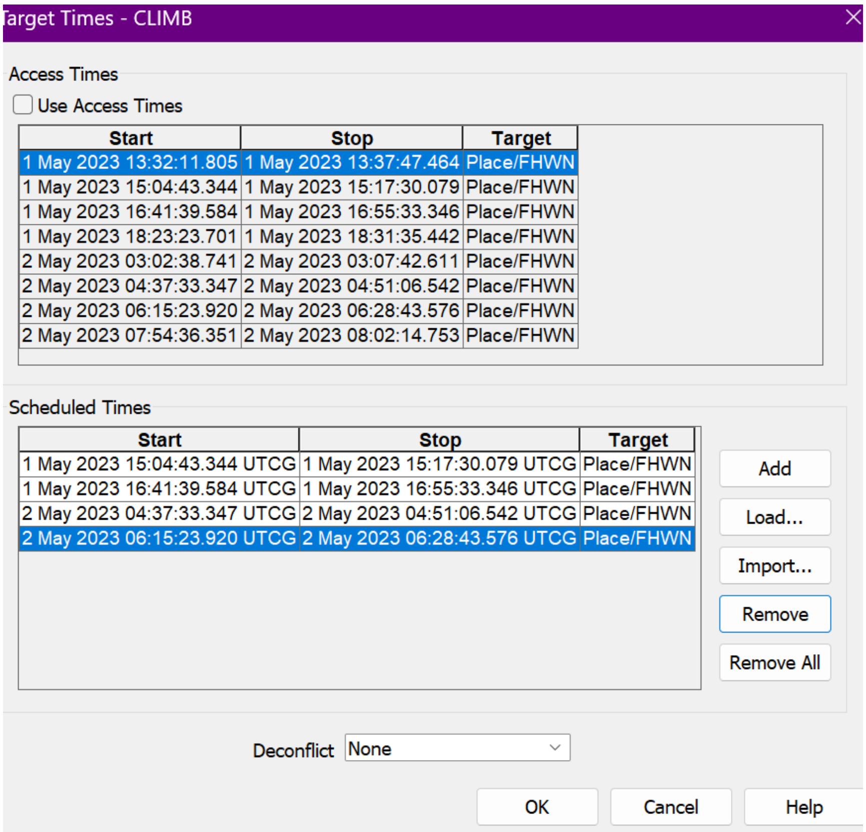
3. Applying Communication Mode alignment according to Table 1



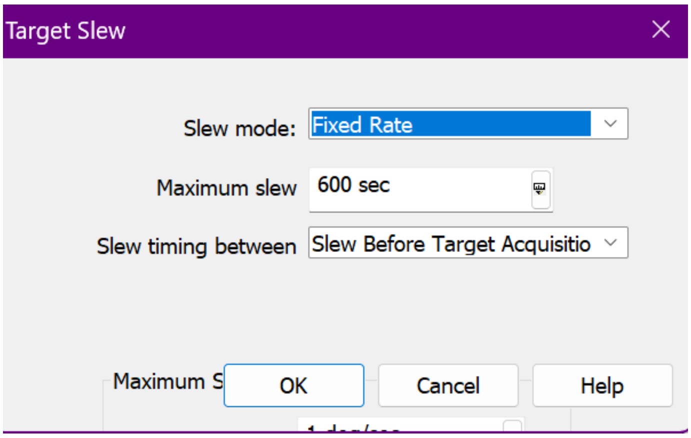
4. In Step 2 window select Target Times. And in a new window Click Use Access Times. This will bring all 8 access times with FHWN, as it does not find sensor with 85 degrees cone as a Target.



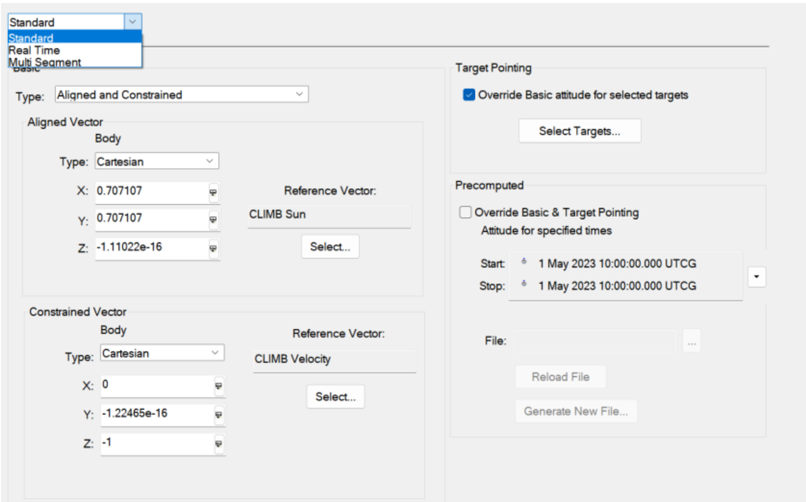
5. Unclick Use Access Time. Now all previous access time are copied to “Scheduled Times”. After comparing how many are there actual access times from Link access report between Satellite and Sensor in FHWN, unnecessary windows are manually deleted.



6. In Step 2 window Select target slew. Choose Fixed rate mode with maximum slew rate and maximum slew time. Slew timing must be Before Acquisition.



7. All steps and times can be reached by changing attitude from “Standard” to “Multi Segment” attitude type.



Name	Source	Number	Start Time	Stop Time
AlignConstrain	Basic	1	1 May 2023 10:00:00.00	1 May 2023 14:54:43.34
Slew	Targeted	1	1 May 2023 14:54:43.34	1 May 2023 15:04:43.34
FHWN	Targeted	1	1 May 2023 15:04:43.34	1 May 2023 15:17:30.08
Slew	Targeted	1	1 May 2023 15:17:30.08	1 May 2023 15:27:30.08
AlignConstrain	Basic	1	1 May 2023 15:27:30.08	1 May 2023 16:31:39.58
Slew	Targeted	2	1 May 2023 16:31:39.58	1 May 2023 16:41:39.58
FHWN	Targeted	2	1 May 2023 16:41:39.58	1 May 2023 16:55:33.35
Slew	Targeted	2	1 May 2023 16:55:33.35	1 May 2023 17:05:33.35
AlignConstrain	Basic	1	1 May 2023 17:05:33.35	2 May 2023 04:27:33.35
Slew	Targeted	3	2 May 2023 04:27:33.35	2 May 2023 04:37:33.35
FHWN	Targeted	3	2 May 2023 04:37:33.35	2 May 2023 04:51:06.54
Slew	Targeted	3	2 May 2023 04:51:06.54	2 May 2023 05:01:06.54