

## App Overview

The software tool described in this report is intended to be used to compare CubeSat passive attitude stabilization schemes, size passive components, and assess the expected performance of passive systems. To use the software tool, the user must have purchased and configured the Princeton Satellite Systems CubeSat Toolbox. Then, the following alterations and additions must be made, using MATLAB scripts which will be available to download from the Princeton NanoSat Lab website:

1. The following files must be accessible to MATLAB, either in a directory added to the path or in the working directory:
  - `CubeSatADSSDesign.m`
  - `CubeSatSimulation.m` (Appendix A.1)
  - `NorthDeviation.m` (Appendix A.2)
  - `AttitudeCheck.m` (Appendix A.3)
  - `IntegrateIMU.m` (Appendix A.4)
  - `PlotApp.m` (Appendix A.5)

These are entirely new scripts written for the software tool.

2. The following files in the CubeSat Toolbox, in the directory CubeSat Toolbox → CubeSat → Simulation, must be replaced with new versions:

- `CubeSatEnvironment.m`
- `CubeSatRadiationPressure.m`

These are files included in the CubeSat Toolbox that have minor alterations.

3. The file `RHSCubeSatHysteresis.m` must be added to the same directory (CubeSat Toolbox → CubeSat → Simulation). This is another script written for the software tool. (See Appendix A.6.)

To run the CubeSat ADSS Design and Simulation app, either run the script `CubeSatADSSDesign.m` or launch `CubeSatADSSDesign.mlapp` in MATLAB App Designer and click “Run”.

The software tool allows the user to configure a CubeSat of any size between 1U and 3U, define its mass and center of mass location, give it passive magnetic control components (torque rod, hysteresis rods, permanent magnet), and validate its compliance with CDS Rev. 14, as well as defining its orbit (either by selecting a default or by defining the orbital elements), tipoff rates, and attitude determination sensors. In addition, the timing and fidelity of the simulation can be tuned.

The software tool provides multiple visualizations of the CubeSat’s orbit, computes disturbance torques, and allows the user to assess the passive system they configured by looking at Euler angles, pointing data, and the outputs of the attitude determination subsystem.

The requirements for the software tool were originally enumerated in a specification document that laid out the following overall goals:

1. Allow user configuration of inputs, and output of relevant data.
2. Plot as many outputs graphically as possible.
3. Make the whole software tool as intuitive and straightforward as possible.
4. Comment code comprehensively, make any necessary usage manual, as well as any necessary manual for future students to change/add functionality to the tool.

As the project evolved, based on improving understandings of passive stabilization schemes and the capabilities of MATLAB App Designer, the specifications changed

accordingly, resulting in the software tool described in this report. This chapter serves as both a usage manual and a guide to change or add functionality to the software tool.

## 3.2 Inputs

The inputs which the user can alter and customize in `CubeSatADSSDesign.m` fall into three main categories: the satellite itself (section 3.2.1), the satellite's orbit and attitude (section 3.2.2), and the parameters of the simulation (section 3.2.3).

### 3.2.1 Components and Configurations

When the user runs the CubeSat ADSS Design and Simulation app, they are sent to the CubeSat Inputs tab, shown in Figure 3.1.

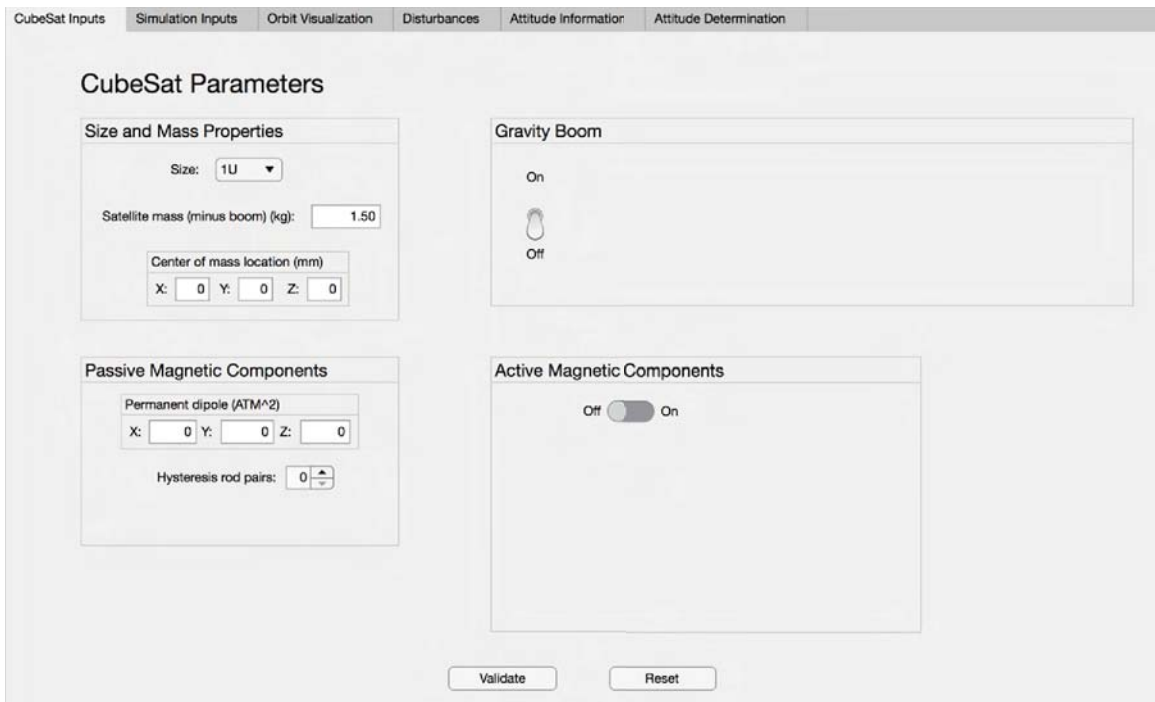


Figure 3.1: CubeSat Inputs tab upon app startup.

#### Size and Mass Properties

Within the Size and Mass Properties panel (Figure 3.2), the user can define the CubeSat size as 1U, 1.5U, 2U, or 3U; enter the mass of the satellite, not including

the boom end mass, in kilograms; and enter the location of the center of mass of the satellite in the CubeSat coordinate system (see section 2.1) in millimeters.

Figure 3.2: Size and Mass Properties panel.

The default mass is three quarters of the maximum CubeSat mass according to CDS Rev. 14, which is 2 kg per CubeSat unit (e.g., a default value of 3 kg for a 2U CubeSat, based on a maximum mass of 4 kg) [44]. If the user enters a mass that is beyond the CDS limit, a warning message will display, but the user may continue (for example, if the user wishes to use the software tool to simulate a non-CubeSat small satellite).

### Gravity Boom

The gravity boom is one of the optional components; when the switch is flipped to ‘On,’ the rest of the panel displays, as shown in Figure 3.3.

Figure 3.3: Gravity boom definition panel.

First, the user defines the boom end mass in kilograms and the boom length in centimeters (measured from the geometric center of the satellite). As mentioned above, the end mass is independent from the satellite mass defined in the Size and

Mass Properties panel. If the entered boom end mass plus the previously entered satellite mass add up to a mass beyond the CDS limit, a warning message will display, but the user may choose to continue.

Then, the user may choose two, one, or no boom deployment triggers; these determine what conditions, after the CubeSat is considered ‘detumbled’ (see section 3.2.2), must be met for the gravity boom to deploy. As each box is checked, its associated numerical entry field becomes visible. The latitude trigger defines the latitude above which (or below which, for a negative latitude) the CubeSat will deploy. The attitude determination trigger defines how long, in minutes, the attitude determination sensors must all have the Earth in their boresights before the gravity boom deploys. These triggers are intended for use with the classic semi-passive scheme, which takes advantage of geomagnetic field lines recombining near the poles to deploy the gravity boom when the CubeSat dipole (due to a magnetic torque rod) is properly aligned with the local vertical (see section 1.2.3). If neither box is checked, the gravity boom deploys at the very beginning of the simulation.

Finally, the user can define whether the boom deploys in the nadir (+Z CubeSat axis) or zenith (−Z CubeSat axis) direction.

### Passive Magnetic Components

In the Passive Magnetic Components panel, shown in Figure 3.4, the user can define the satellite’s permanent dipole (in the CubeSat coordinate system), in units of Amp-turns-meters squared, as well as the number of pairs of magnetic hysteresis rods and the CubeSat axes along which the rods will point.

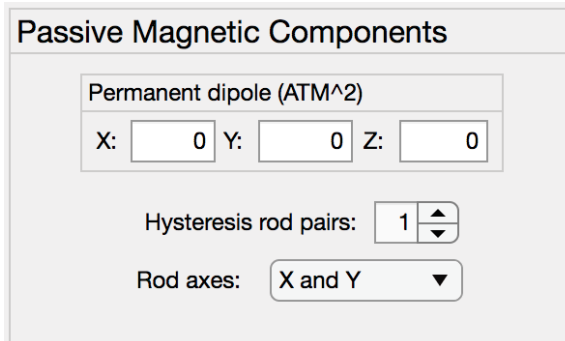


Figure 3.4: Passive Magnetic Components panel.

## Active Magnetic Components

The active magnetic component, a torque rod, is the other optional component. When the slider is ‘On,’ the rest of the panel displays (see Figure 3.5).

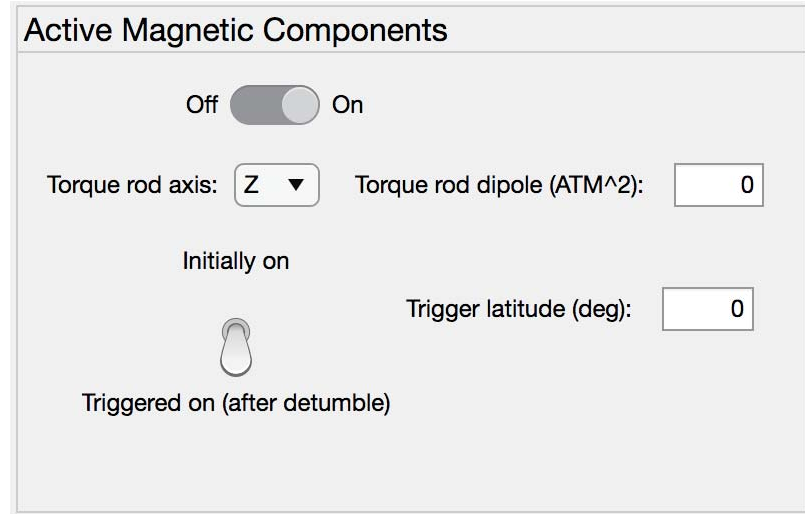


Figure 3.5: Active Magnetic Components panel.

Within the panel, the user can determine the axis of the torque rod and its dipole in units of Amp-turns-meters squared. In addition, the user can flip the switch to select whether the torque rod is initially on (active from the beginning of the simulation) or triggered on at some latitude once the satellite is detumbled. In either case, the torque rod turns off when the gravity boom is deployed.

### ‘Validate’ and ‘Reset’

Once the CubeSat and its passive stabilization system have been identified, the user can select the ‘Validate’ button to assess their configuration’s compliance with CDS Rev. 14. In addition to the mass limits mentioned above, the following constraints on the center of mass position are also checked:

| Size | X/Y Axis Limits | Z Axis Limits |
|------|-----------------|---------------|
| 1U   | ±2 cm           | ±2 cm         |
| 1.5U | ±2 cm           | ±3 cm         |
| 2U   | ±2 cm           | ±4.5 cm       |
| 3U   | ±2 cm           | ±7 cm         |

Table 3.1: CDS Rev. 14 center of mass limits [44].

Selecting ‘Validate’ will display a window with information about the configured CubeSat, as well as a flag of whether or not the satellite is CDS compliant. Even if the CubeSat is noncompliant, the user can choose to proceed.

Selecting ‘Reset’ will restore all default values in the CubeSat Inputs tab, including turning off the gravity boom and torque rod.

### 3.2.2 Orbit and Attitude

The user will then move to the Simulation Inputs tab, shown in Figure 3.6, before running the simulation.

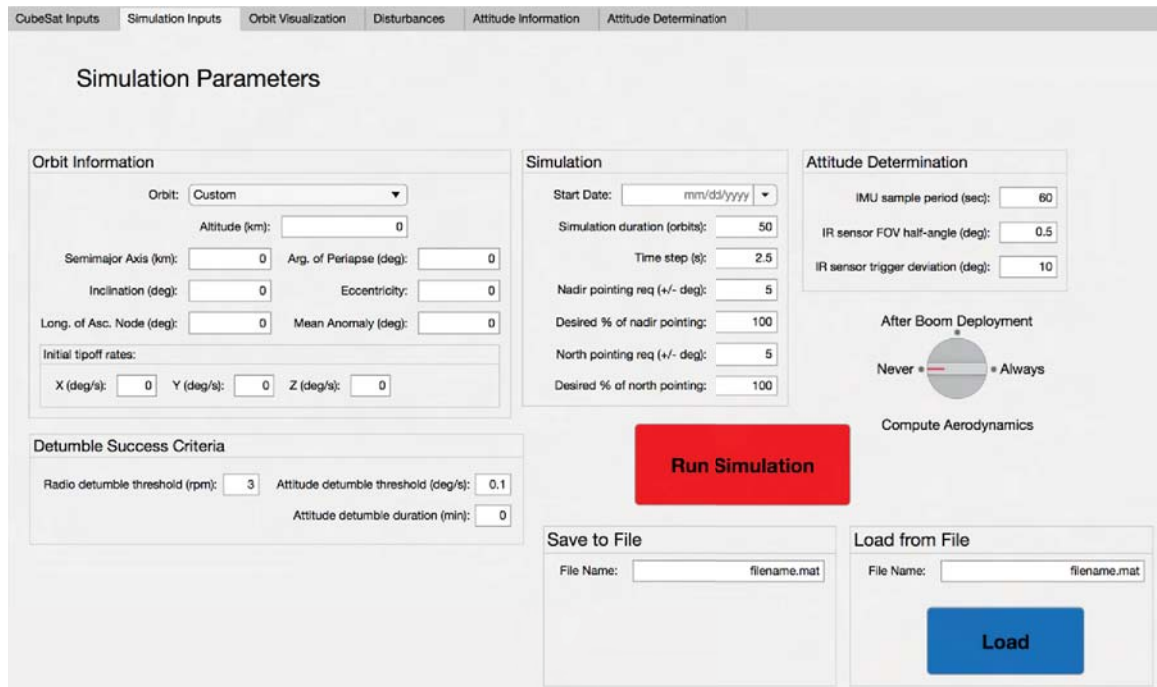


Figure 3.6: Simulation Inputs tab.

#### Orbit Information

In the Orbit Information panel (Figure 3.7), the user can define the orbital elements and the initial tipoff rates in the spacecraft body frame. Three custom orbit presets are available: a sun-synchronous polar orbit at an altitude of 500 km, the ISS orbit, and an equatorial orbit. The orbital elements of the presets are given in Table 3.2.

The user can choose a preset, or define a custom orbit. Additionally, when the user changes the altitude, the semimajor axis of the orbit updates, and vice versa.

Figure 3.7: Orbit Information panel.

| Element                                  | Sun-Synch Polar | ISS           | Equatorial |
|--|-----------------|---------------|------------|
| Semimajor Axis ( $a$ )                   | 6878 km         | 6798 km       | 6878 km    |
| Inclination ( $i$ )                      | $97^\circ$      | $51.64^\circ$ | $0^\circ$  |
| Longitude of Ascending Node ( $\Omega$ ) | $0^\circ$       | $215.8^\circ$ | $0^\circ$  |
| Argument of Periapse ( $\omega$ )        | $0^\circ$       | $70.44^\circ$ | $0^\circ$  |
| Eccentricity ( $e$ )                     | 0               | $5.65e-5$     | 0          |
| Mean Anomaly ( $M$ )                     | $0^\circ$       | $0^\circ$     | $0^\circ$  |

Table 3.2: Orbital elements of preset orbits.

### Detumble Success Criteria

In the Detumble Success Criteria panel, the user defines the conditions that must be met for the CubeSat to be considered ‘detumbled.’ There are actually two different detumble thresholds: the first, the radio detumble threshold, determines when the CubeSat’s radio can establish a link (the default value is 3rpm); the second is the attitude detumble threshold, which is the condition which must be met before any of the triggers governing gravity boom deployment can be considered. The attitude detumble threshold considers only rotation about roll and pitch, because gravity gradient stabilization does not affect yaw (see section 1.2.1). In addition to the threshold in terms of angular rate, the user can define a duration, in minutes, for which all of the attitude determination sensors must be detecting the Earth in order for the CubeSat to be considered detumbled. This adds flexibility to the configured CubeSat, which can either use an accurate IMU to verify reaching a detumbled state, or rely on its attitude determination subsystem to define a ceiling on the angular rate.



| Detumble Success Criteria       |                                |                                      |                                  |
|---------------------------------|--------------------------------|--------------------------------------|----------------------------------|
| Radio detumble threshold (rpm): | <input type="text" value="3"/> | Attitude detumble threshold (deg/s): | <input type="text" value="0.1"/> |
|                                 |                                | Attitude detumble duration (min):    | <input type="text" value="0"/>   |

Figure 3.8: Detumble Success Criteria panel.

### Attitude Determination

In the Attitude Determination panel, the user can define the sample period of the IMU (used in the simulated reconstruction of attitude based on IMU data, section 3.3.3), the FOV half-angle of the attitude determination IR sensors ( $\varrho_{1/2}$  in section 2.5.3), and the maximum allowed nadir deviation for the IR sensors to trigger ( $\delta$  in section 2.5.3).

| Attitude Determination             |                                  |
|------------------------------------|----------------------------------|
| IMU sample period (sec):           | <input type="text" value="60"/>  |
| IR sensor FOV half-angle (deg):    | <input type="text" value="0.5"/> |
| IR sensor trigger deviation (deg): | <input type="text" value="10"/>  |

Figure 3.9: Attitude Determination panel.

### 3.2.3 Simulation Options

The last inputs defined by the user before running the simulation parametrize the simulation itself.

#### Simulation Parameters

The Simulation panel, shown in Figure 3.10, allows the user to select the start date of the simulation, the simulation (in units of orbits), and the time step of the simulation.

In addition, the user can define the nadir and north pointing requirements, as well as the desired percentage of the time, post-detumble, that the satellite meets those

**Simulation**

Start Date:  ▾

Simulation duration (orbits):

Time step (s):

Nadir pointing req (+/- deg):

Desired % of nadir pointing:

North pointing req (+/- deg):

Desired % of north pointing:

Figure 3.10: Simulation parameter definition panel.

requirements. These parameters are relevant only to the post-processing and display of the simulation information.

**Aerodynamic and Optical Calculations**

Also in the Simulation Inputs tab, the user can select whether aerodynamic and optical forces and torques should be computed for the entire simulation, only after the gravity boom is deployed, or not at all. This option is included because these computations, particularly when small time steps are used, significantly increase the runtime of the simulation, and the aerodynamic and optical torques are often of smaller orders of magnitude than the gravity gradient and magnetic torques.

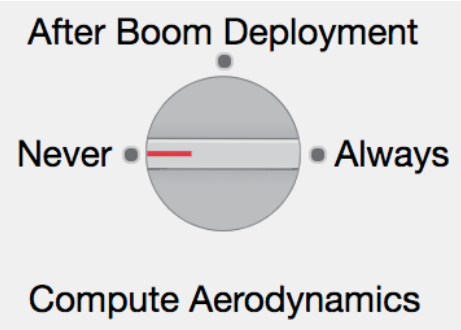


Figure 3.11: Aerodynamic and optical calculation dial.

## Save to/Load from File

After the simulation is complete, the user can save all of the information related to the run to a `.mat` file with the name of their choosing using the ‘Save to File’ button. The file will be saved in the current MATLAB working directory.

Alternatively, instead of re-running a simulation of an already-simulated passive stabilization scheme, the user can forego defining any of the parameters in the CubeSat Inputs and Simulation Inputs tabs and load a previously saved `.mat` file using the ‘Load from File’ button. All of the simulation outputs will be displayed in the other tabs, but without the time it would take to run the simulation.

## 3.3 Simulation

Once the user has configured their passive attitude stabilization system and given the parameters of the simulation, they will select ‘Run Simulation’; at this point, the MATLAB app `CubeSatADSSDesign.m` packages the user inputs and passes them to the master simulation file, `CubeSatSimulation.m`. When the simulation is complete, the data is processed and displayed within the app.