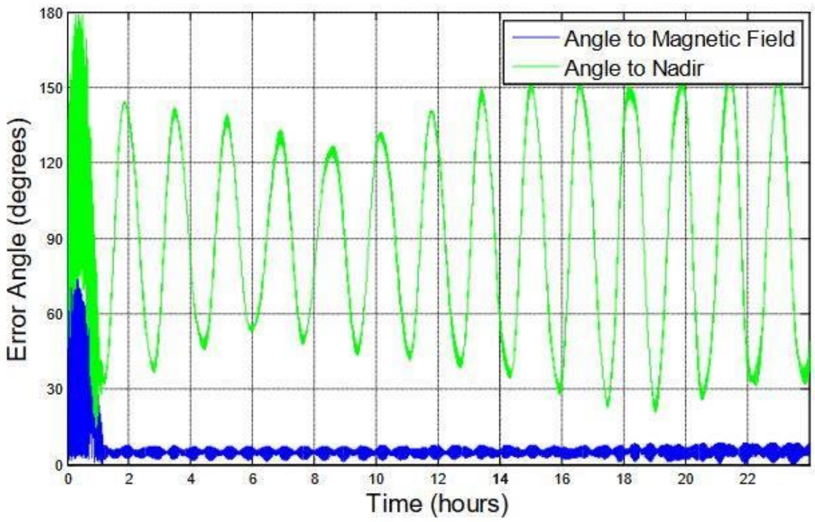
ADCS Actuator sizing

There is different way to stabilize a satellite. Some of them use Thruster to do it. For us it is prohibited (it is the rule for CubeSat's). Reaction wheels are also an option but it is too big for our kind of satellite.

There Is two main way to correct the attitude using the magnetic field: Passive or active attitude correction.

- The passive implementation use permanent magnet to "fix" the orientation on the earth magnetic field. It is an interesting method as it need no power to be used. The following figure show how the orientation is impacted using permanent magnet:



  As we can see, although this method is effective, it cannot be implemented on our satellite as our mission is to test the tether which needs to be correctly aligned with earth. Indeed, those curves show that due to the shape of the magnetic field, the tether cannot perfectly point toward earth during the full rotation

- The active implementation use magnetorquers (which are coils) to actively move the satellite. Even if it consumes power, it is the most interesting way to create a satellite rotation.

So, the choice of actuator seems obvious we will use active actuator: Magnetorquers.

a) Low level feasibility studies

Temperature range: The component should work between -40 and 80°C

Mass: We should limit the mass of those components even if they will be one of our heaviest components

Dimensions: It should fit in the CubeSat so it must be less than 10cm in each direction (at least)

Electrical consumption: It should be the lowest possible since the capacity of energy production of EPS is limited.

b) Sizing:

Two principal technologies are used:

- Coils with or without an iron heart which have to be implemented on board
- Coils around solar panels (so with no hearth to boost the resulted magnetic moment

Seller	Name	Properties				Performance		Observation
		Mass (grams)	Temperature range (°C)	Dimensions (mm)	Supply Voltage (V)	Power Consumption (W)	Magnetic Moment (Am²)	
NewSpace Sytem	CubeSat Magnetorquer Rod	<30	-35 to +75	70 x 9 x 9	5	0.200	>0.2	Solenoid
Stras Space	Nanosatellite Magnetic Torque Rods	60	-30 to +100	70 x 14 x 14		0.180	0.4	Small homemade magnetorquer Solenoid
Nano Avionics	Magnetorquers SatBus MTQ	140		95.9 x 90.2 x 28	5	0.210	0.07	3 magnetorquers on the ADCS board
GOMspace	P110 Series				3.3	until 3.3	0.038	Installed on Solar pannel

The most convenient type of magnetorquers seems to be the one located on solar panel (as it requires no space inside), but as we can see they generate a less important magnetic moment (around 10 times less). Nonetheless, many new student CubeSat have homemade magnetorquers on the back of 3 solar panels. This technique seems efficient and will be hardly considered as a potential option.

ADCS Sensor sizing – Magnetometer

To determine our attitude, we need at least one vector to be able to process our orientation (actually we need two of them and we will use relative sensors when we can only use one). Using the data of sensors such as magnetometer can let us determine the earth vector.

a) Low level feasibility studies

Temperature range: The component should work between -40 and 80°C

Mass: We should limit the mass of this component

Dimensions: It should fit in the CubeSat so it must be less than 10cm in each direction (at least)

Electrical consumption: It should be the lowest possible since the capacity of energy production of EPS is limited.

Precision: It should be able to measure the earth magnetic field (which is around 30µT at this altitude)

b) Sizing:

Seller	Name	Interface	Properties				Performance		
			Mass (grams)	Temperature range (°C)	Dimensions (mm)	Supply Voltage (V)	Power Consumption (mA)	Measurement Range	Resolution
NewSpace Systems	Magnetometer	RS485	85	-25 to +70	96 x 43 x 17	5	145	-60 000 nT to +60 000 nT	7.324 nT
HoneyWell	HMC2003_3-axis magnetic sensor hybrid	RS 232	*40-100*	-40 to +85	20 x 12 x 27	6 to 15	20	-200 to +200 µT	4 nT
HoneyWell	HMR2300R_3-axis strapdown magnetometer	RS 422 / RS 485	40 (board only)	-40 to +85		6.5 to 15	45-55	-200 to +200 µT	6.7 nT
HoneyWell	HMR2300_smart digital magnetometer	RS-232 / RS-485	98	-40 to +85		6.5 to 15	27-35	-200 to +200 µT	6.7 nT
Surrey (SSTL)	Magnetometer	D-type DC	190	-20 to +50	36 x 90 x 130	12	25	-60 to +60 µT	
SpaceQuest, Ltd	MAG-3 Satellite Magnetometer	9 Pin Male "D" Type	100	-55 to +85	35.1 x 32.3 x 82.6	15 to 34 VDC or 5V regulated	30		

- We can either choose 3 one axis magnetometer or 1 three axis magnetometer. As most of the cubesat use them, HonewWell magnetometer seem a reliable solution

ADCS Sensor sizing – Sun sensor

To determine our attitude, we need at least one vector to be able to process our orientation (actually we need two of them and we will use relative sensors when we can only use one). Using the data of sensors such as sun sensor can let us determine the sun vector.

a) Low level feasibility studies

Temperature range: The component should work between -40 and 80°C

Mass: We should limit the mass of those components

Electrical consumption: It should be the lowest possible

b) Sizing

First, we look at sun sensors sold by space constructors:

Seller	Name	Price	Interface	Properties				Performance		
				Mass (grams)	Temperature range (°C)	Dimensions (mm)	Supply Voltage (V)	Power Consumption (mA)	Accuracy (°)	Field of View (°)
SolarMEMS	nanoSSOC -A60	2 200 €	Analog	4	-30 to +85	27.4 x 14 x 5.9	3.3 / 5	< 2	< 0.5	60
SolarMEMS	nanoSSOC -D60	3 600 €	Digital	6.5	-30 to +85	43 x 14 x 5.9	3.3 / 5	< 23	< 0.5	60
NewSpace Systems	Fine Sun Sensor	12 000 $	Digital	35	-25 to +75	34 x 32 x 20	28	7.5 average / 26 peak	< 0.1	140
NewSpace Systems	CubeSat Sun Sensor	3 300 $	Analog	<5	-25 to +50	33 x 11 x 6	5	< 10	< 0.5	114
Crystal Space	Crystalspace S1U Sun sensor			<5	-25 to +85	26 x 26 x 6		< 20mW active mode		45

As we can see solar sensors by themselves are **too expensive** to be bought that way. That's why we are studying the opportunity to **sun sensors integrated on solar panel. For example, the sun sensors on the PC110UC-SUN solar panel have those characterizes:**

Parameter	Condition	Min	Typ	Max	Unit
Course Sun Sensor Current Cosine error	Short current at 1367 W/m^2		930 1.85	 3.5	µA °
Temperature Sensor • Range • Resolution • Vcc • Current • Temperature coefficient		-55 1.5 0.21	 3.3 260 0.233	+150 3.5 490 0.25	°C °C V µA %/°C

Simulations

We need to run simulations to validate our choice of components. The software will need:

- To simulate the concerned part in the space environment (force models, vacuum, radiation, temperature…).
- To take parameters (such as elevation, weight …) modifiable.

a) Visualization software

We first studied **STK** which provided useful features such as:

As we can see this software is pretty complete and allows to run tests such as defining the trajectory of the satellite projected on earth, see the evolution of our satellite in space and model sensors.

Accurate Earth representation	WGS84, MSL and Earth motion (pole wander, nutation, sidereal time)
Dynamic vehicle position	Great arc, ballistic, two-body, J2, J4 SGP4, SPICE and STKExternal (data file)
Dynamic vehicle orientation	Coordinated turn, nadir and velocity oriented, pre-computed (data file)
Sensor field of view (FOV) and pointing	Simple conic and rectangular FOV, fixed and external pointing (data file)
Pre-defined vector geometry	Points, vectors, angles, axes and coordinate systems
Standard object database	Thousands of satellites, facilities, aircraft and sensors
Import, analyze and export GIS data	Import and export KML and shapefiles

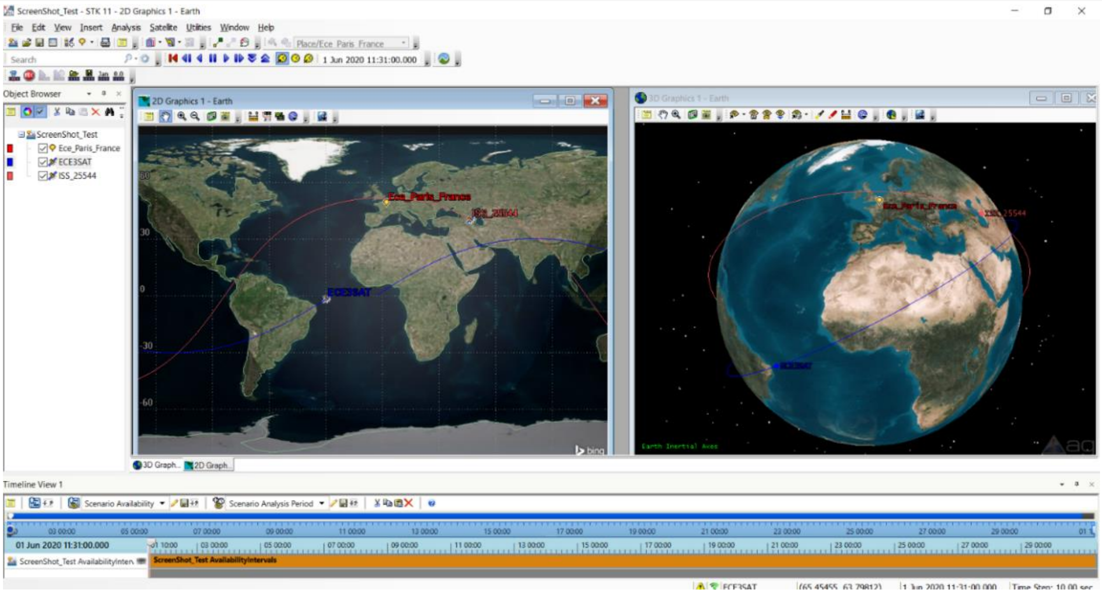


Figure 1 : view in STK software

In definitive this software is interesting but the module STK Solis (for attitude calculation) is not available.

The **VTS** software provided by the CNES also has potential: using position and attitude measurements (in the form of quaternions or Euler angles…) it can show us the movements of the satellite.

It is an interesting and powerful alternative to STK.

b) Computation of the attitude

Our software needs to be able to determine the CubeSat's attitude through, possibly hardware preprocessed, sensor data. To do so we will need to simulate the action of the actuators (probably Magnetorquers) with software tools such as Matlab/Scilab.

Those software will be useful to draw block diagrams, leading to exploitable data. Some even give interesting modules such as:

- The Control Toolbox for CubeSat mission:

Spacecraft Control Toolbox Product Comparison

Topic	Feature	CubeSat	SCT Academic	SCTPro
License		University team	Students, Classroom	Single User or Site License
Attitude Dynamics and Control	*Rigid body, gyrostat*	✔	✔	✔
	Multibody, flex, wire		✔	✔
	Control	PID 3 axis	+ loop shaping, discrete time, state space, LQ, eigenstructure assignment	
	Pointing budgets		✔	✔
	Sun nadir, bias momentum, spinner with wheels			✔
	Landing and ascent GN&C			✔
Actuator/Sensor Models	*Reaction wheel, blowdown propulsion*		✔	✔
	Gyros, sun sensor, horizon sensor, magnetometer		✔	✔
	Star camera model, high fidelity RWA, GPS models			✔

However, this module is expensive, so we cannot use it.

- The **MARMOTTES** C++ library, developed by the CNES, was also an option but it **cannot be installed** in his current form (which is not likely to change in the future). That's why he is now deprecated (2006)
- The **CelestLab** module gives useful features too, such as modeling of the **geomagnetic field depending on the location**. Nonetheless, it **does not provide all the features we need for the simulation of the attitude**.
- The studies of all those modules (including Propat in Matlab) gave us one conclusion: complete simulation for the attitude cannot be found in one software. Moreover, most of the libraries we tried where for the best not friendly and for the worst not working at all. As we wanted a complete simulation tool that we could understand and complexity through time, our **choice** was then to **develop our own simulation in java**.

Later, we think it would be useful to create a simulation in order to validate actuators' specifications and reaction time. The aim would be to choose the best actuators for the ECE3SAT.

- Actuators sizing thanks to the simulation:

  We would be able to choose some parameters:

  - CubeSat's information (altitude, mass, center of mass)
  - Magnetorquers' information (number of coils, number of layers, power supply, coil's surface)

  The software needs to simulate the conditions:

  - Earth's magnetic field
  - CubeSat's rotation velocity
  - CubeSat's orientation state
  - Coils activation patterns