Orbital Environment Simulator for Small Satellites

Daniel Erb
Space Systems Laboratory
University of Kentucky

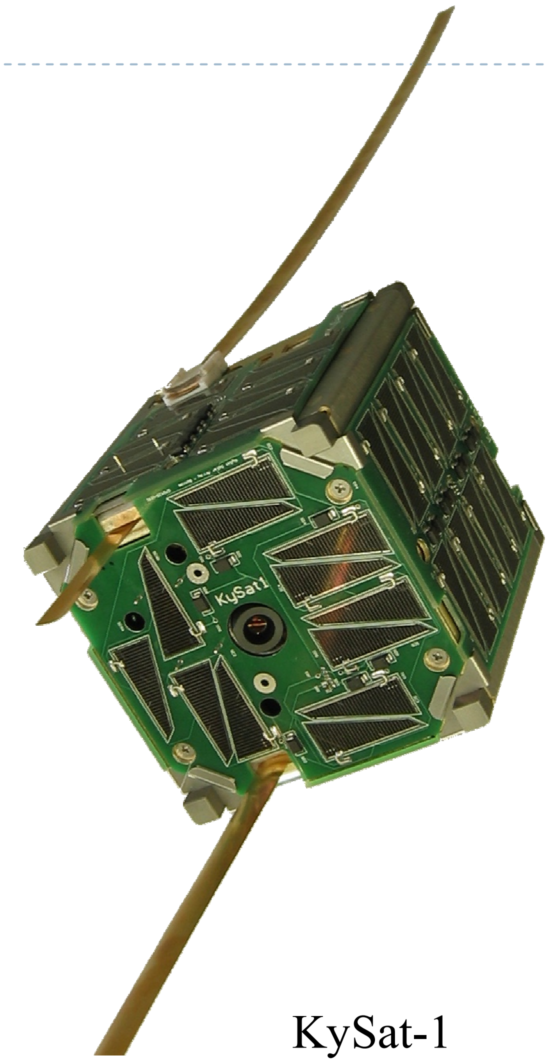
Overview

- Space Environment
- Orbital Environment Simulator
  - Attitude Propagator
  - Capabilities
- Attitude Stabilization Techniques
  - KySat-1: Passive Magnetic Stability
- Summary

Introduction

- CubeSat Standard
  - Standard launch mechanism:

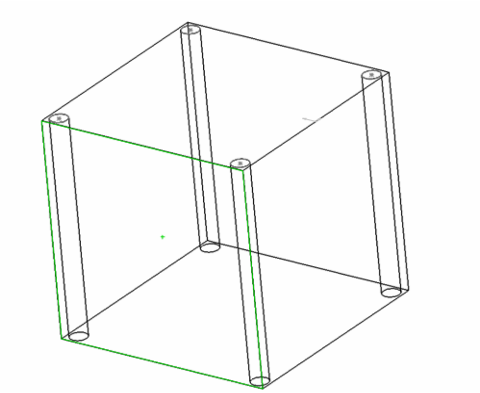
    P-POD
- Easy access to space
- Volume, Mass, and Power Constraints
- Passive Stability



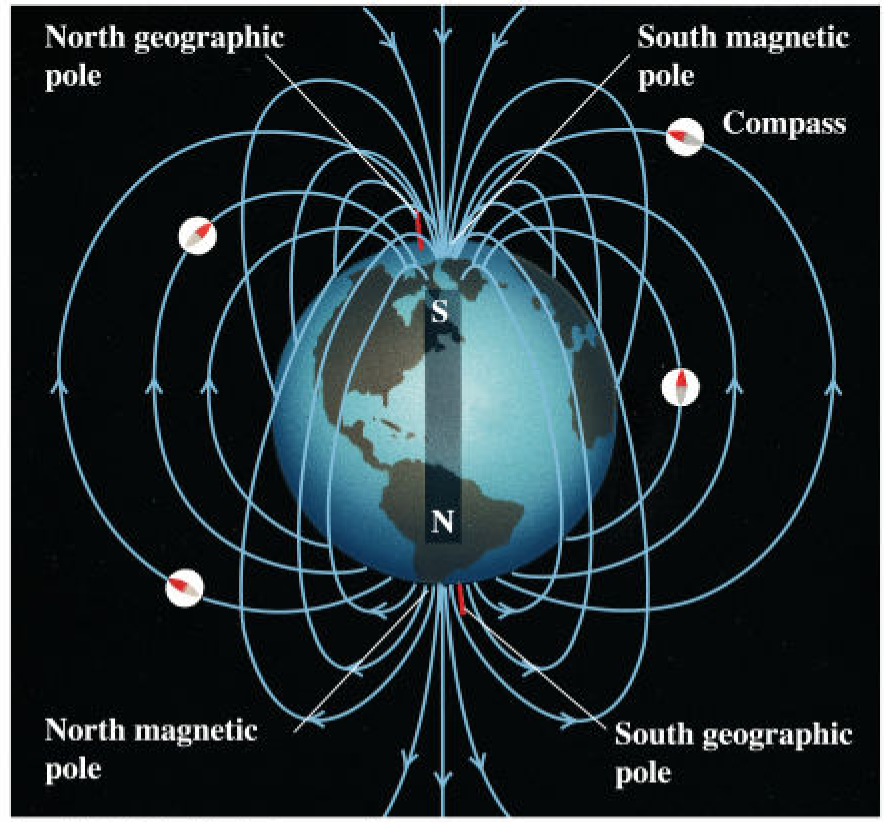
KySat-1

Magnetic Field

- Cause of disturbance torques
- Can be utilized for stabilization and angular rate damping



Magnet Placement in KySat-1



Gravity Gradient Torque

- Distributed mass experience different gravitational attraction across the body
- Axis of least inertia lines up with the gravity field lines
- Major Disturbance Torque for Asymmetric Satellites in LEO

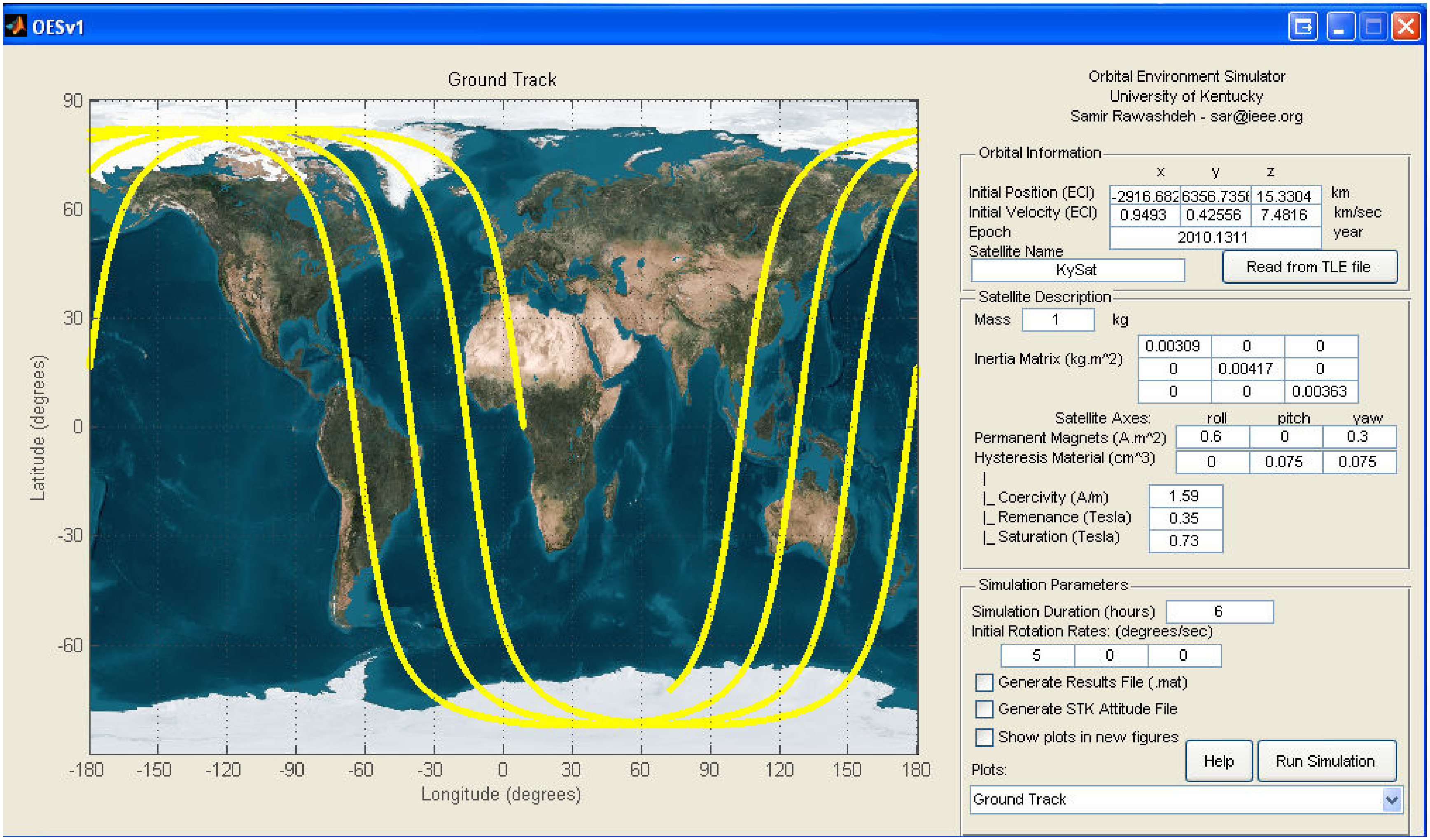
$$F = G\frac{m_{earth}\, m_{sat}}{r^2}$$

PuTEMP (concept) - Purdue

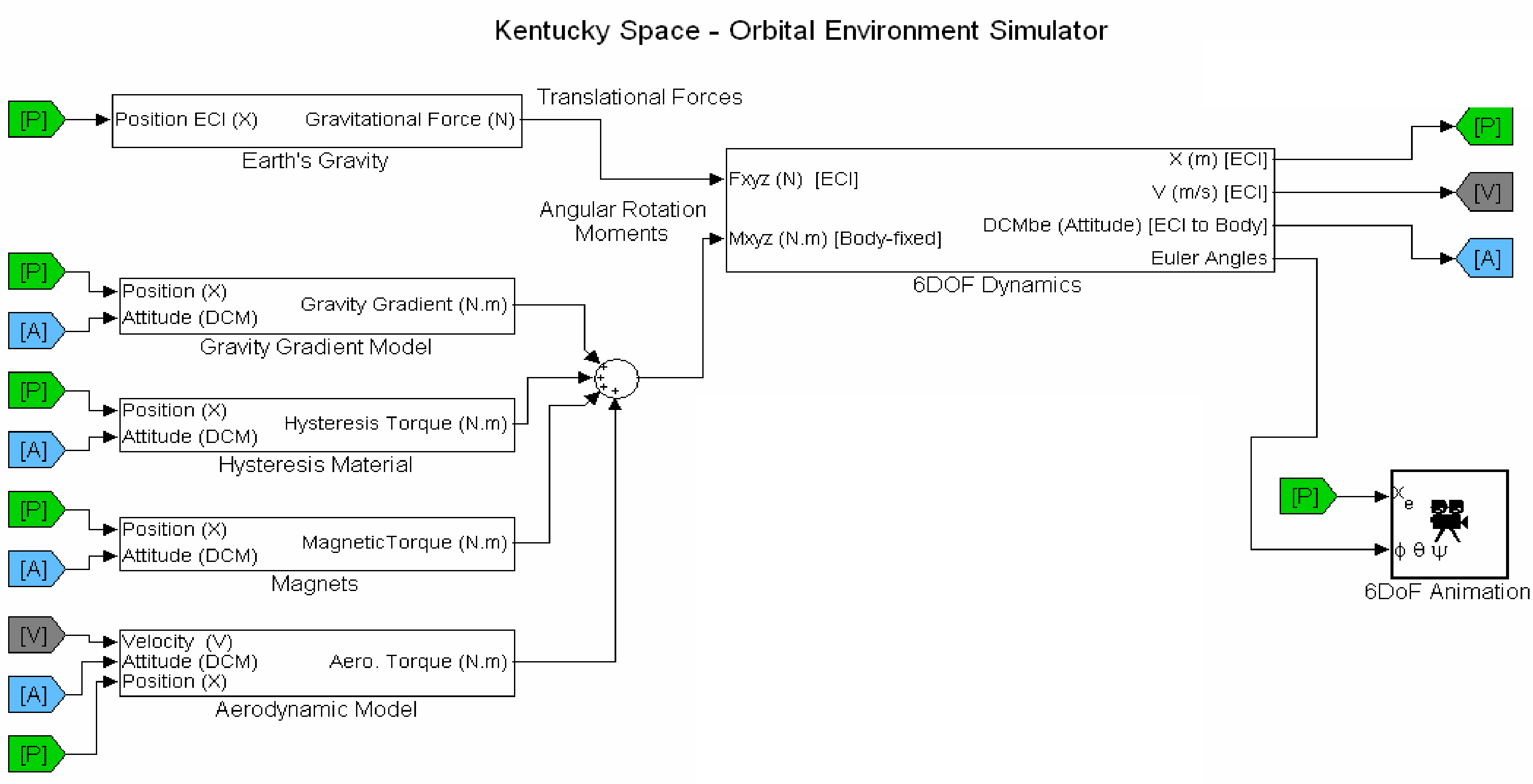
Orbital Environment Simulator

- Adjustable Spacecraft Description and Orbit
  - Mass and Inertia Matrix
  - Magnets and Hysteresis Material
  - Orbital Elements
- Simulate Effect of Orbital Environment on Satellite Attitude (in 6DOF):
  - Gravity Gradient
  - Magnetic Torques
  - Magnetic Hysteresis Material

Main Window


OESv1
Ground Track
90
60
30
0
-30
-60
Latitude (degrees)
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
Longitude (degrees)
Orbital Environment Simulator
University of Kentucky
Samir Rawashdeh - sar@ieee.org
Orbital Information
x y z
Initial Position (ECI) -2916.682 6356.735 15.3304 km
Initial Velocity (ECI) 0.9493 0.42556 7.4816 km/sec
Epoch 2010.1311 year
Satellite Name
KySat
Read from TLE file
Satellite Description
Mass 1 kg
Inertia Matrix (kg.m^2)
0.00309 0 0
0 0.00417 0
0 0 0.00363
Satellite Axes: roll pitch yaw
Permanent Magnets (A.m^2) 0.6 0 0.3
Hysteresis Material (cm^3) 0 0.075 0.075
|_ Coercivity (A/m) 1.59
|_ Remenance (Tesla) 0.35
|_ Saturation (Tesla) 0.73
Simulation Parameters
Simulation Duration (hours) 6
Initial Rotation Rates: (degrees/sec)
5 0 0
Generate Results File (.mat)
Generate STK Attitude File
Show plots in new figures
Help
Run Simulation
Plots:
Ground Track

Attitude Propagator

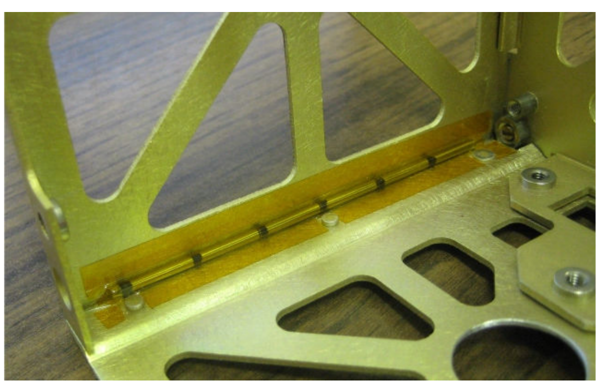


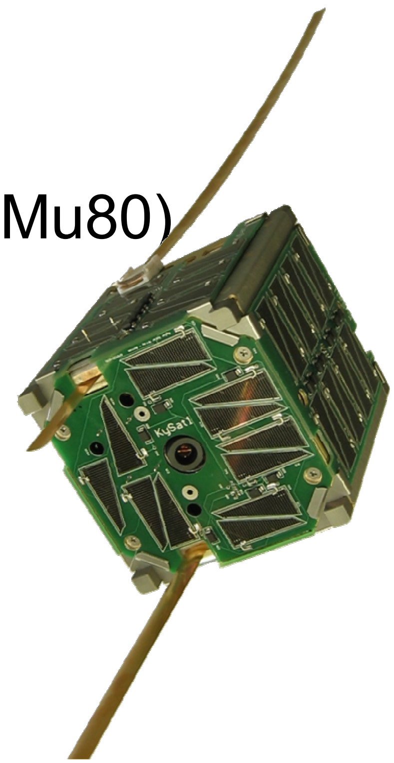
Capabilities

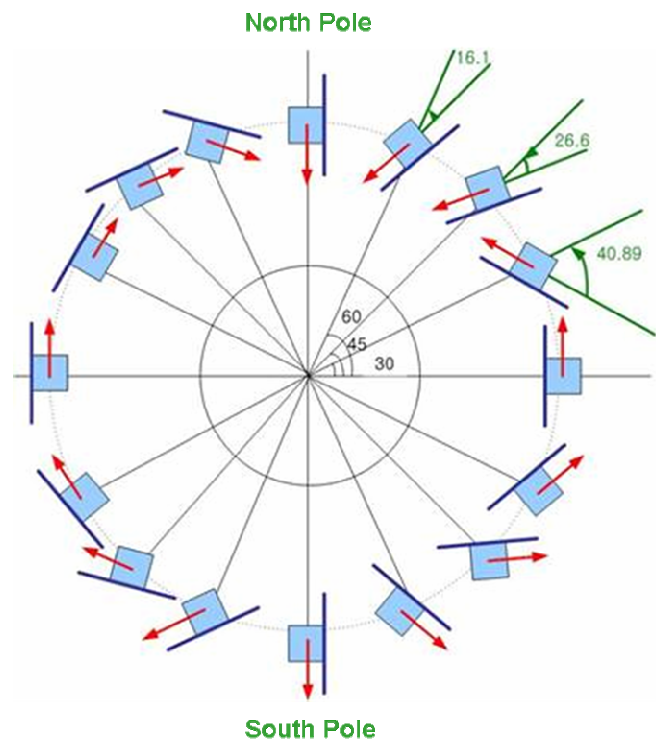
- Attitude Propagation (Gravity Gradient, Magnetic, and Hysteresis)
- Stability System Design Verification
- Plotting and Animation (STK)
- Extension to Active Attitude Control Systems
  - Reaction wheels
  - Magnetic torquers

Design Example

- Implemented on KySat-1
- Polar Orbit
- Align with Magnetic Field
  - Permanent Magnets
- Dampen Motion
  - Hysteresis Material (HyMu80)

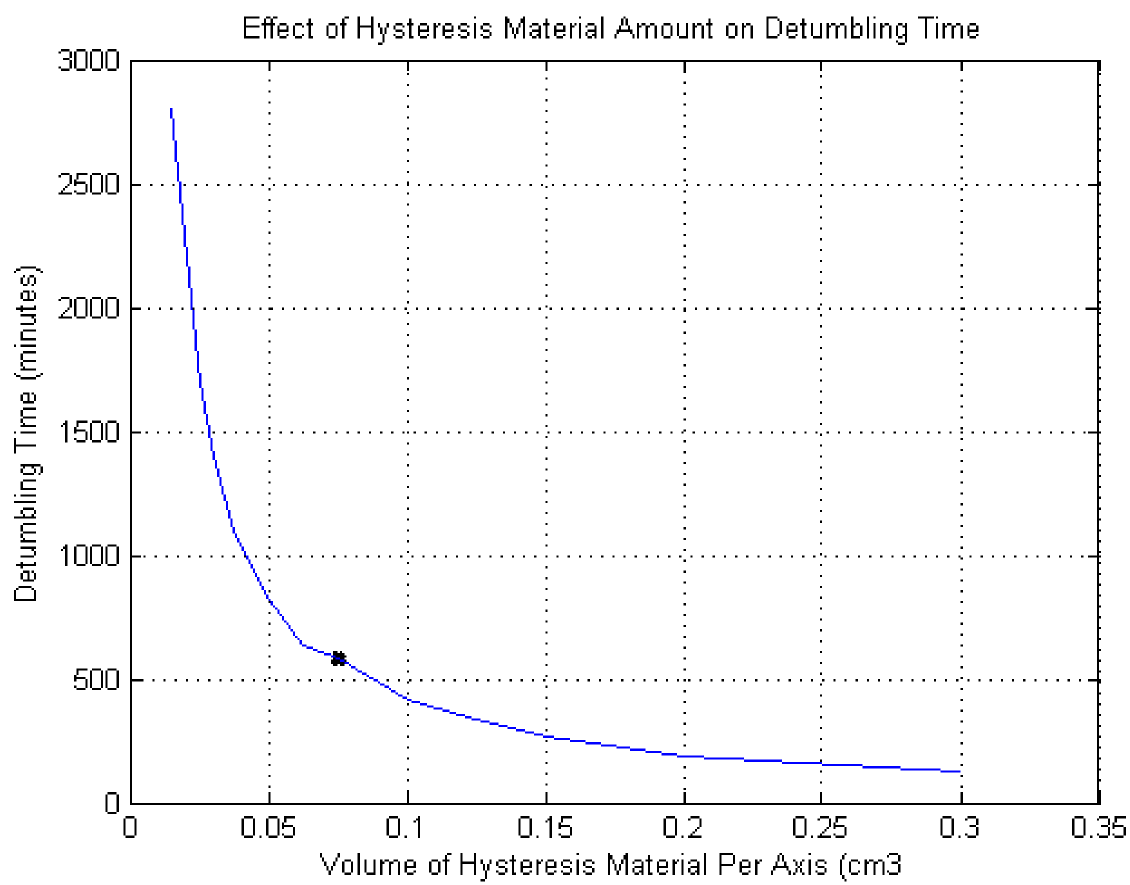




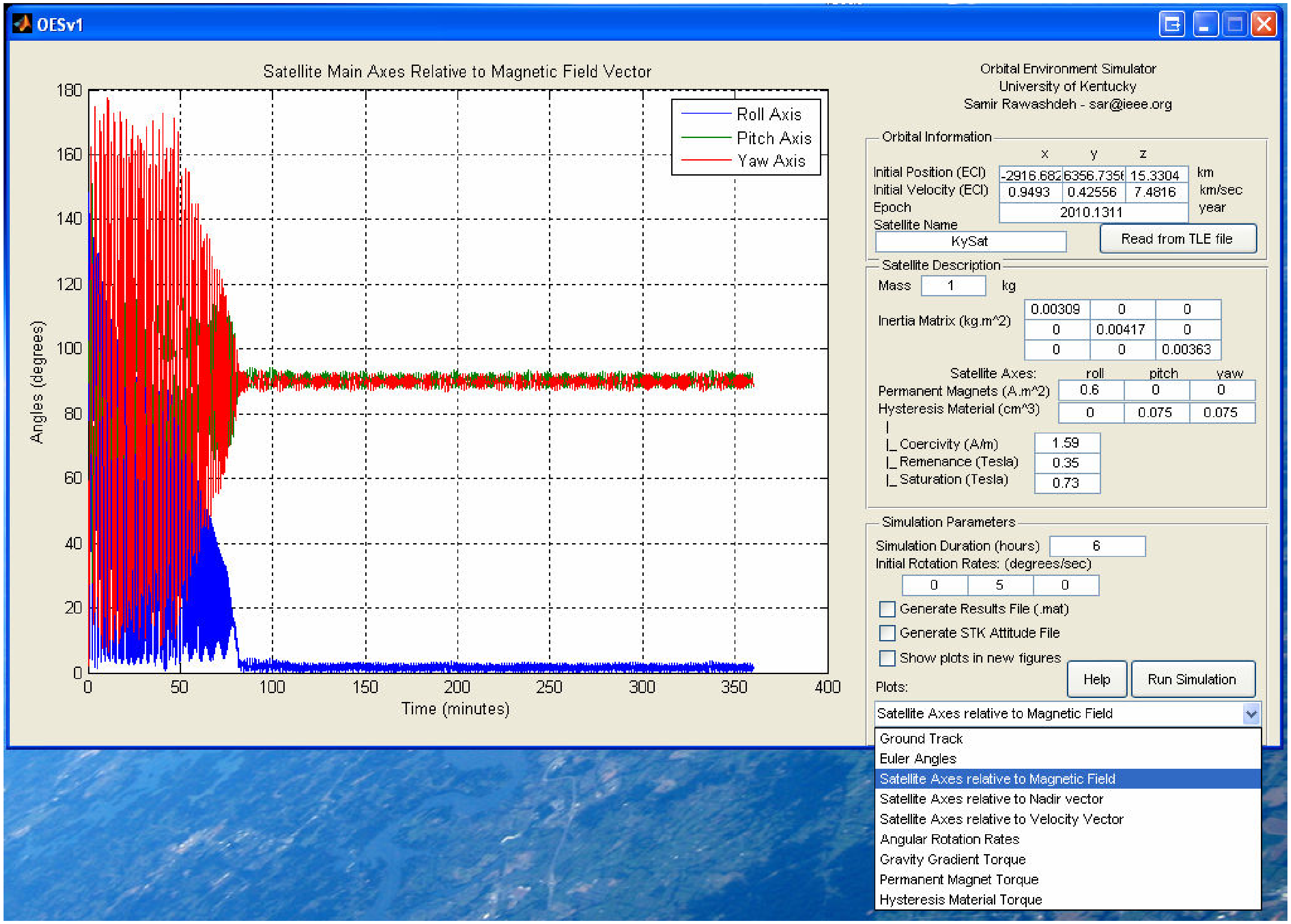


Design Space

- Magnet Strength proportional to worst-case disturbance torque
- Hysteresis material amount proportional to magnet strength



Simulator Results



KySat-1: Animation

Conclusion

- Orbital Environment Simulator
- Passive Stabilization
- Magnetic Hysteresis Damping
- Magnetic Stabilization
- Aerodynamic Stability in LEO

Thank You

Daniel Erb
Samir Rawashdeh

Space Systems Laboratory
Electrical & Computer Engineering
University of Kentucky

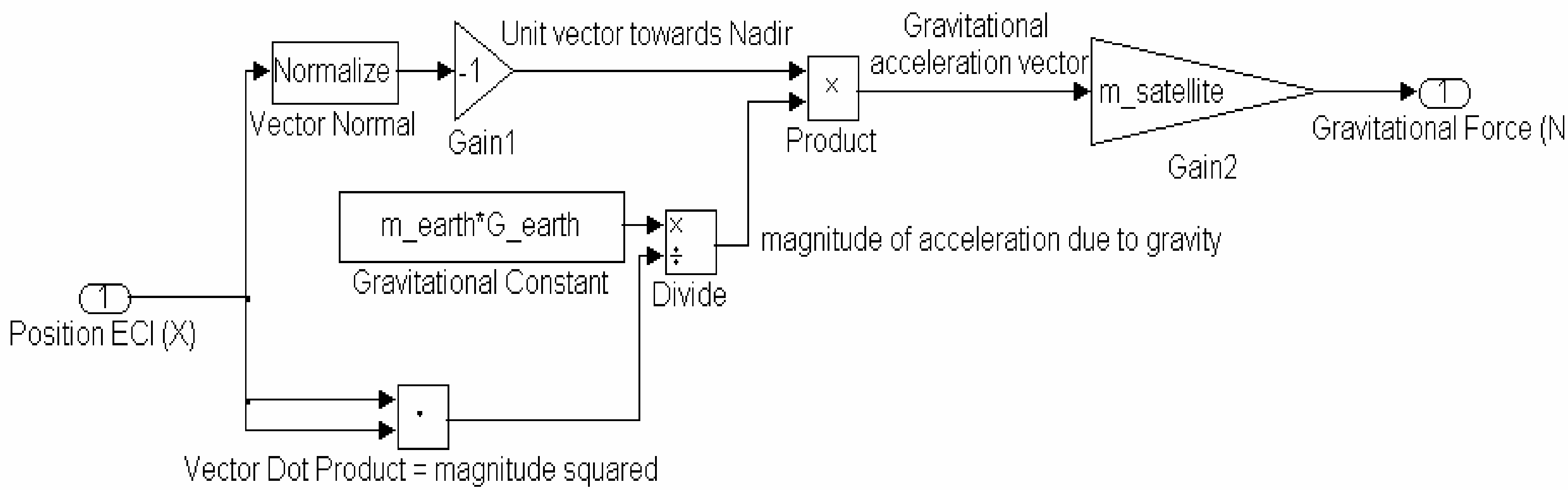
daniel.erb@uky.edu
sar@iee.org

www.kentuckyspace.com

Two-body Orbital Model

$$F = G\frac{m_{earth}\, m_{sat}}{r^2}$$

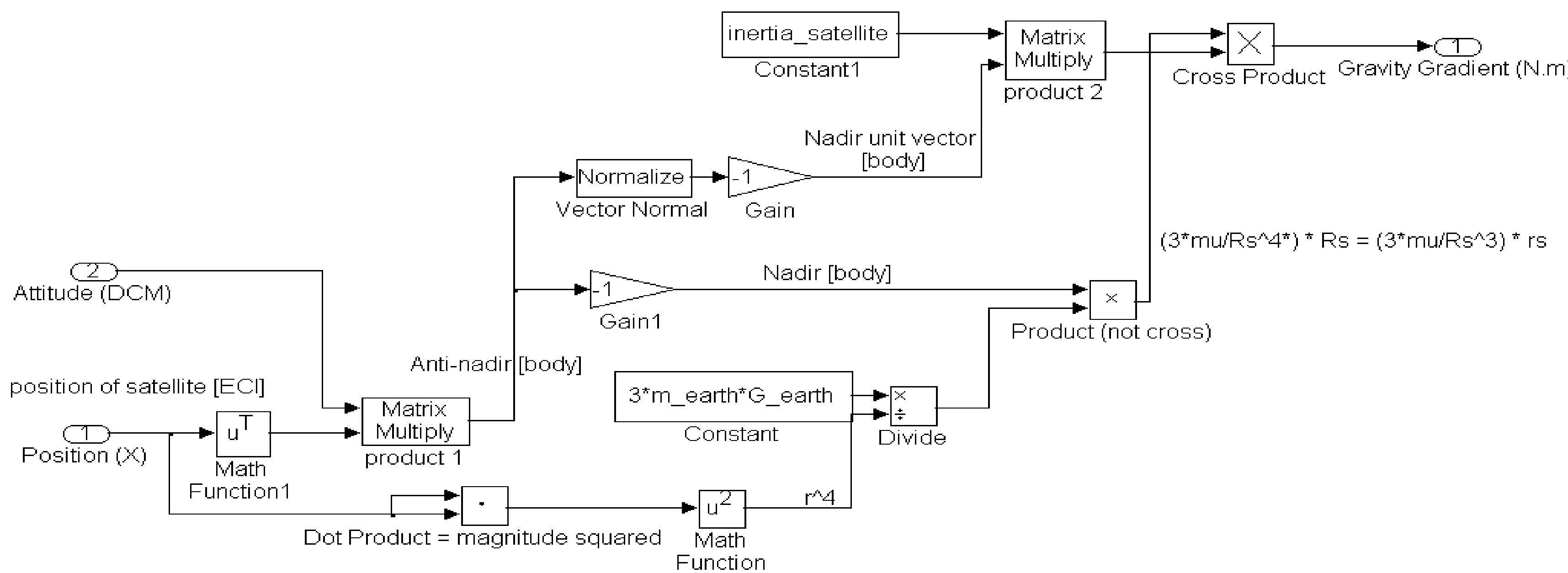
$$Acceleration = \frac{G * m_{earth}}{r^2} = \frac{G * m_{earth}}{\mathbf{X}_{ECI} \cdot \mathbf{X}_{ECI}}$$



Gravity Gradient Model

$$M_{gg} = \frac{3\mu}{R_0^{\ 3}} u_e \times J u_e$$

M_{gg}	gravity gradient torque
u_e	unit vector towards nadir
R_0	distance from the center of Earth to the satellite
J	inertia matrix
μ	geocentric gravitational constant

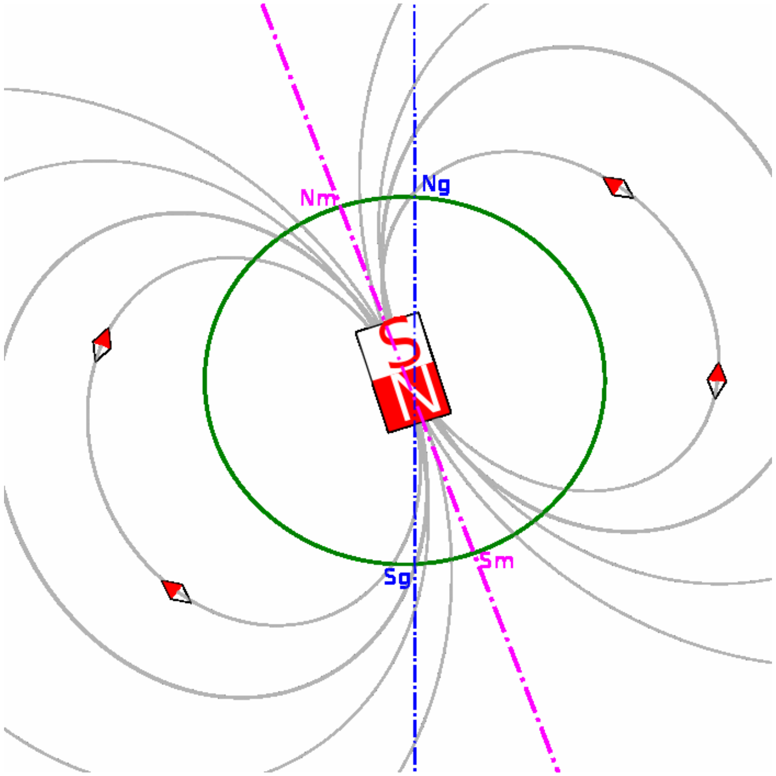


Magnetic Torque Modeling

- Magnetic Torque

$$\mathbf{M}_{\mathbf{magnetic}} = \mathbf{m} \times \mathbf{B}_{\mathbf{earth}}$$

- Earth Magnetic Model
  - Dipole Model
  - NOAA World Magnetic Model



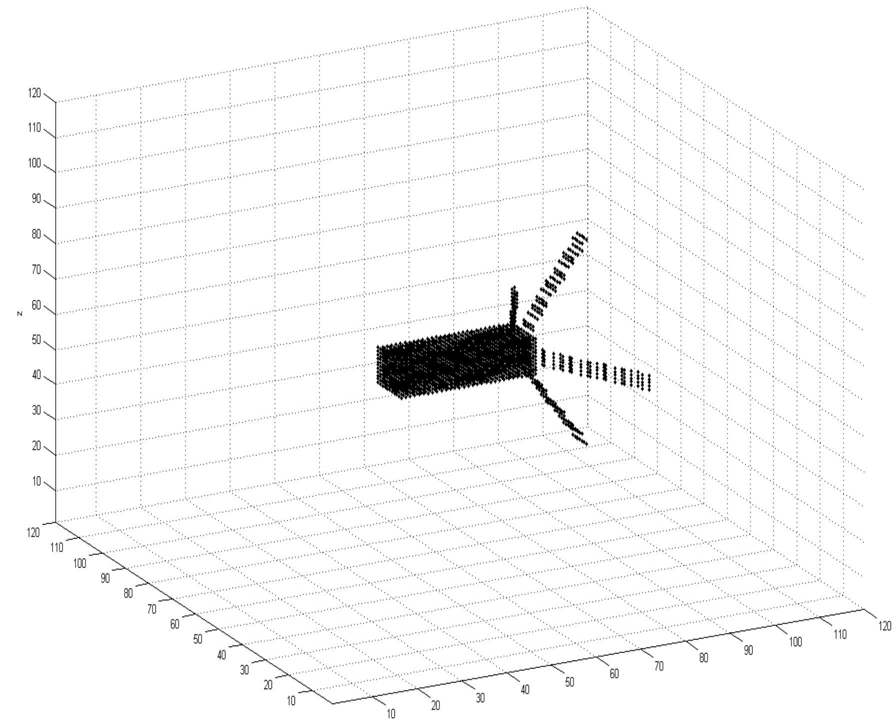
Simulink Model finds magnetic field at satellite position, then calculates the torque affecting the satellite dipole.

Aerodynamic Modeling

- Aerodynamic Torque

$$\mathbf{M}_{aero} = \frac{1}{2}\rho V^2 C_d A \left(\mathbf{u}_v \times \mathbf{s}_{cp}\right)$$

- Geometry Modeling
- Atmosphere modeling



Simulink Model uses a look up table generated in advance to describe a certain satellite to find the total aerodynamic torque affecting the satellite

Magnetic Hysteresis

- Magnetization curve
- Given Earth magnetic field, magnetic dipole of damping material is found
- Magnetic dipole of damping material interacts with the magnetic field and causes a torque