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Executive Summary

The Lower Ionosphere Satellite (LionSat) orbit and attitude team was given vague specifications for its subsystem. The orbit is required to be in the ionosphere while making scientific readings in the ram and wake of the spacecraft. The available power, lifetime of the satellite, and frequency of passing over the Arecibo ground station will affect orbit selection. This pass over Arecibo is desirable in order to correlate probe measurements with ground station measurements. The guidance, navigation, and control (GNC) team has determined through a trade study that an oblate spinner would be the optimal configuration for the spacecraft. Cold gas thrusters or magnetic torquers would most likely control the attitude of the oblate spinner. The GNC subsystem will have an impact on other subsystems so extensive communication with other teams is ongoing to select the optimal system. A flow down chart was made to determine as well as visualize the impact the other subsystems on the GNC subsystem as well as the GNC subsystem on other subsystems. Another trade study is underway to choose an option involving multiple thrusters and multiple nozzle orientations for attitude control. A Global Positioning System (GPS) system will be placed on LionSat for orbit determination and a magnetometer is being considered for additional scientific as well as navigational ability. Preliminary disturbance torques have been characterized for the orbit, but information such as antenna pointing accuracy and tolerance in probe measurements are needed to further refine these estimates. The estimated propellant mass for the LionSat mission is around 0.6kg for a 6-month mission using cold gas thrusters, as well as the ion engines. An STK simulation has been created to visualize and determine the attitude of the satellite. This simulation did not account for gravity
gradient effects therefore correspondence with an STK associate resulted in simulation files that consider gravity gradient effects. These files can be modified for the needs of LionSat.
**System Requirements**

To properly design the GNC subsystem, a list of requirements had to be made based on what is known by the LionSat teams. If LionSat is launched on the Space Shuttle, then the inclination of its orbit will be approximately 51.7 degrees because the International Space Station (ISS) resides in an orbit with this inclination. For a Minotaur launch the inclination will depend on the contents of the primary payload. The basic configuration for the spacecraft has been decided to be an either oblate or a prolate spinner, which is spun up by the ion thruster. From the standpoint of stability an oblate configuration would be more desirable. Two methods are under consideration, namely cold gas thrusters and magnetic torquers are discussed later. Ion thrusters for attitude control are not discussed due to excessive power restrictions and precession of the ascending node. To determine LionSat’s position a GPS receiver will be onboard. The required pointing accuracy will be between 5 and 10 degrees, and mission altitude will be between 300 and 400 km.

**Attitude Method Trade Study**

One of several trade studies the team is undertaking is to determine the method to control LionSat’s attitude. Methods under investigation include prolate spinner, oblate spinner, gravity-gradient, prolate spin combined with gravity-gradient, and dual spin. Each method was broken into important categories and then weighted for those that have the most impact of the design. The categories with weight are: simplicity (2), weight (3), power (3), stability (2), lifetime (1), science (4), and cost (4). Based on the trade study the GNC team recommends using an oblate spinner, however a prolate spinner has not been ruled out. To achieve an oblate spinner, the GNC team will be working closely with
the structures team, rendering the proper inertia matrix. Modifications to the inertia matrix will be done through the arrangement of internal components, the possible implementation of booms, and fuel distribution for the thrusters. The total trade study is shown in Appendix A.

Magnetic Torquers

This section presents a preliminary investigation of magnetic torquers for attitude control. Possible advantages of magnetic control over other technologies are that this method requires no fuel for operation, the magnitude of the torque is controllable, and it does not require any attitude determination system. Since magnetic torquers require no fuel for operation this cuts down on the mass of the system and the structural complications that come with designing a fuel tank. The control software can manage the magnitude of the thrust by varying the current through the torquer. Varying the current is free of losses in efficiency (Isp) that can come with electric and cold gas thrusters. Another benefit of precisely controlling the torque is that the system does not tend to overcorrect. As a result, damping systems that usually accompany gravity gradient and momentum wheel control may not be needed.

Disadvantages and difficulties of magnetic control include interference with scientific instruments and command and data handling (C&DH) hardware, and increased power consumption. Concerns regarding interference caused by the magnetic field have been discussed and continued discussions should occur. Stanford’s nano-satellite, Emerald, uses a magnetic control system with the total attitude dynamics control system using 0.23 W-hr per orbit\(^1\). Since Emerald has a comparable mass and altitude to that of
LionSat, it is expected that a magnetic torquer would not take up a sizeable portion of the power budget.

**Cold Gas**

One other possibility for the thrusters is to use the ion thrusters for spin-up, and using cold gas thrusters for attitude control and maintenance. Cold gas thrusters have a much lower specific impulse than the ion engines do, however the thrust provided by a cold gas thruster is much higher than in the ion engines. Since the cold gas thrusters can use Xenon as a propellant, the propellant for the ion engines and the cold gas thrusters can come from the same fuel tank. Using only one fuel tank cuts down on complexity, weight, and cost of the mission.

Cold gas thrusters can also provide variable amounts of thrust, depending on what they will be used for. Since LionSat will be spinning at a very low spin rate, around two revolutions per minute, the cold gas thrusters will need to provide a very low thrust to reorient the angular momentum vector to the desired position. If a cold gas system is chosen for LionSat the engineers must be careful to choose a system that can provide the needed thrust. Using cold gas thrusters on LionSat will require about 0.51 kg of propellant. **Appendix H** shows calculations for fuel consumption.

**Disturbance Torques**

A pointing accuracy of 5 to 10 degrees is required by certain scientific instruments and to maintain communications. In order to estimate the amount of attitude control required, the strength of the disturbance torques have been calculated. These torques, along with the pointing accuracy and amount of attitude corrections, will also be...
used to determine the amount of propellant and power the attitude control system will require. Using the equations located in Appendix E from “Space Mission Analysis and Design”, approximations of the gravity gradient, magnetic field, solar radiation, and aerodynamic drag torques were obtained. These torques can be found in Table 1, shown on the following page. The entire disturbance torque calculations can be seen in Appendix F.

Table 1: Estimated Disturbance Torques Encountered by LionSat

<table>
<thead>
<tr>
<th>Disturbance Torques (µN-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Gradient</td>
</tr>
<tr>
<td>Magnetic Field</td>
</tr>
<tr>
<td>Solar Radiation</td>
</tr>
<tr>
<td>Aerodynamic Drag</td>
</tr>
</tbody>
</table>

From the estimated values in Table 1, the strongest disturbance torque is about 53 µN-m, a result of the Earth’s magnetic field. The other disturbance torques are much smaller with respect to the magnetic field torque. These values are likely to change as the spacecraft and mission parameters are progressively refined.

Using the chart in Appendix C, estimates of orbit lifetimes based on aerodynamic drag were calculated. An initial estimate of the coefficient of drag of 2 was used. The cross sectional area was calculated from the dimensions of a rectangle .45 m by .49 m. A mass of 20 kg, the projected mass of the spacecraft, was used. Using these values, circular orbits with altitudes of 300 km and 450 km would stay in orbit approximately 25 and 275 days, respectively. Obviously altitude, which is still unknown, plays a critical role in the lifetime of the mission.

Another mission requirement is a flyover of the Aricebo ground station to take additional ionosphere measurements. The flyover is a possibility if the satellite is put
into a correct orbit. Figures of how different orbital elements affect the ground track were obtained from *Fundamentals of Astrodynamics and Applications*³ to show that this is a possibility.

**Sensors**

Several options of attitude determination have been considered and a preliminary set up has been determined. A GPS team has been examining the operation of a GPS unit for orbit determination. A sun sensor and a horizon sensor will be used for attitude determination on the light and dark sides of the Earth, respectively. A magnetometer will be used for attitude determination and for science. Estimated specifications for the sensors in Appendix J were obtained from both Dr. Croskey and Reference 4.

**RF Ion Thrusters**

The thrusters to be used on LionSat are miniature radio frequency (RF) ion thrusters. These thrusters use radio signals at specified frequencies to ionize and accelerate Xenon atoms to produce thrust. The use of RF ionization removes the need for magnetic confinement of ionizing electrons because of high frequency electric field reversals. This technology also eliminates the need for electron-emitting cathodes and an anode in the ionization chamber². By removing the cathode and anode the ion thruster will have restart capability and will not need to be used continuously. A specific impulse on the order of 3000 sec is attainable by the engine and thrust levels are on the order of 600 \( \mu N \).

The amount of Xenon propellant that will be required for the mission is around 0.6 kg. The calculations used in determining the fuel requirements are in Appendices G\&I. In place of using the engines for attitude control, cold gas thrusters have been
investigated, however, for achieving and maintaining the spin rate the ion thrusters can be used.

**Thruster Configuration Trade Study**

This preliminary trade study concerns the configuration of the ion thrusters for use on the nano-satellite. Each parameter is weighted according to the number in parenthesis. The different configurations are then ranked in that parameter between one and five. A value of five is most desirable and a value of one is the least desirable.

The four-fixed configuration corresponds to four thrusters, two on the sides for spin-up and one on the top and bottom for attitude maintenance. The two gimbaled configuration has the thrusters only on the sides but can be pointed for either spin-up or attitude correction. The two four-way fixed thrusters are again on the sides, but each have a nozzle pointed in one of the four principal directions, controlled by nozzle cut-off valves. This may be reduced to only a spin-up thruster direction and an attitude thruster direction.

According to this study, the recommended thruster configuration is the 4 fixed. This trade study will be pursued more in depth now that the orbit type has been determined. The total trade study is shown in Appendix B.

**Satellite Tool Kit**

A preliminary orbit and attitude analysis has been started using STK software package. This file contains the LionSat satellite, State College and Arecibo locations and is in a 56 degree inclination and 300 km altitude. The other orbital elements have not been determined, as of now the orbit is assumed to be circular. The scenario file can be
found at \textit{L:\401 LionSat GNC\STK simulation}. This file does not take into consideration gravity gradient effects on the attitude of the satellite. There has been email correspondence with an STK associate named Sergei Tanygin and the email received from him is in \textbf{Appendix L}. He sent two files that take into account gravity gradient effects for attitude and can be modified for LionSat. These files are in two folders named datadisplaystyles and ggtest located in the aforementioned location.

\textbf{Future Work}

The following is where the next GNC team should pick up our work and focus their attention. An action item list is in \textbf{Appendix K} to assist the next team in understanding where we left off and what we decided. A trade study on the method of attitude acquisition has to be conducted between cold gas and magnetic torquers. A timeline has to be constructed including how long it will take to acquire the attitude, when disturbance corrections need to be made, length of time for probe measurements, and end of mission lifetime. The power, mass, volume, and data rates of sensors to be used in our subsystem need to be refined. The system flow down of requirements has to be refined; disturbance torques, inertia matrix, and STK simulation need to be updated.
References


## Trade Study of Attitude Control Method

<table>
<thead>
<tr>
<th>method</th>
<th>Sci Instru</th>
<th>Power</th>
<th>Structure/Thermal</th>
<th>Propulsion</th>
<th>Communications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spin-prolate</strong></td>
<td>Spin rate is too fast for sample rate</td>
<td>cover entire craft in solar arrays, high power to maintain att</td>
<td>same as proposal</td>
<td>spin up and attitude control</td>
<td>requires torid radiation shape</td>
</tr>
<tr>
<td><strong>Spin-oblate</strong></td>
<td>probes farther away from body of spacecraft</td>
<td>cover entire craft in solar arrays, low power to maintain att</td>
<td>longer probe booms, thrusters on booms? With probe?</td>
<td>just enough to spin up</td>
<td>requires torid radiation shape</td>
</tr>
<tr>
<td><strong>Gravity Gradient</strong></td>
<td>no spinning</td>
<td>lowest power</td>
<td>boom for mass distribution</td>
<td>very little, thrusters?</td>
<td>can use focused helical</td>
</tr>
<tr>
<td><strong>Spin+GG</strong></td>
<td>ideal for probes</td>
<td>high power, due to momentum wheels or thrusters</td>
<td>similar to GG, need mass boom also</td>
<td>spin up (less than pure spinners)</td>
<td>can use focused helical</td>
</tr>
<tr>
<td><strong>Dual Spin</strong></td>
<td>ideal for probes</td>
<td>high power, due to momentum wheels and motor</td>
<td>very complex, rotating interfaces and platforms</td>
<td>attitude control</td>
<td>requires torid radiation shape</td>
</tr>
</tbody>
</table>
Trade Study of Attitude Control Method

<table>
<thead>
<tr>
<th>method</th>
<th>simplicity(2)</th>
<th>weight(3)</th>
<th>power(3)</th>
<th>stability(2)</th>
<th>lifetime(1)</th>
<th>science(4)</th>
<th>cost(4)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spin-prolate</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>66</td>
</tr>
<tr>
<td>Spin-oblate</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>41</td>
</tr>
<tr>
<td>Gravity Gradient</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>Spin+GG</td>
<td>6.5</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>6</td>
<td>85</td>
</tr>
<tr>
<td>Dual Spin</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>127</td>
</tr>
</tbody>
</table>
Appendix B

Trade study concerning thrusters on LionSat

<table>
<thead>
<tr>
<th>Thruster type</th>
<th>4 fixed</th>
<th>2 gimbaled</th>
<th>2 4-way fixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>simplicity of design (4)</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>thruster efficiency (3)</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>attitude controllability (3)</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>implementation cost (4)</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>life expectation (2)</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>power efficiency (4)</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Area occupied (3)</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Weight (3)</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>total</td>
<td>95</td>
<td>67</td>
<td>74</td>
</tr>
</tbody>
</table>
Appendix C

Earth orbit lifetimes: circular orbits.
Appendix D

Surface Area and Inertia Calculations

2/11/03

Initial estimate

Chris Scott

(45°)

(67.5°)

(22.5°)

24.5°

18.5°

\[
\text{Area of octagon} = 2 \sqrt{2} \left( \frac{24.5}{2} \right)^2 = 1.67756 \text{ m}^2
\]

\[
\text{Area of plate} = \left( 0.45 \right) \left( 0.17639 \right) = 0.0838755 \text{ m}^2
\]

\[
S, \text{ Area of } \frac{5}{6} = 8 \left( 0.0838755 \text{ m}^2 \right) + 2 \left( 1.67756 \text{ m}^2 \right) = 1.10065 \text{ m}^2
\]
Modeling Inertia based on cylinder of radius \(2.4354\,\text{m}\) and height of \(0.45\,\text{m}\). Uniformly distributed mass of \(20\,\text{kg}\),

\[
\begin{align*}
I_x &= I_y = \frac{1}{12} m (3R^2 + h^2) \\
&= \pi (20\,\text{kg}) (3(0.24354\,\text{m})^2 + (0.45\,\text{m})^2) \\
&= 63403.8658\,\text{kg}\cdot\text{m}^2
\end{align*}
\]

\[
I_z = \frac{1}{2} m R^2 \\
= \frac{1}{2} (20\,\text{kg}) (0.24354\,\text{m})^2 \\
= 59311.7376\,\text{kg}\cdot\text{m}^2
\]
Appendix E

Equations to Determine Approximate Disturbance Torques

Gravity Gradient Torque
\[ T_g = \frac{3\mu}{2R^3} |I_z - I_y| \sin(2\theta) \]

Magnetic Field Torque
\[ T_m = D \cdot B \]

Solar Radiation Torque
\[ T_{sp} = F(c_{ps} - c_g) \]
Where \( F = \left( \frac{F}{c} \right) A_s (1 + q) \cos(i) \)

Aerodynamic Drag
\[ T_a = F(c_{pa} - c_g) = F \cdot L \]
Where \( F = \frac{1}{2} \rho \cdot C_d \cdot A \cdot V^2 \)
# Appendix F

## Physical Constants

<table>
<thead>
<tr>
<th>Solar Constant-$F_s$ (W/m$^2$)</th>
<th>Spd. of Light-$c$ (m/s)</th>
<th>Grav. Parameter-$u$ (km$^3$/sec$^2$)</th>
<th>Magnetic Moment of Earth $M$ (tesla$\cdot$m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1367</td>
<td>3.00E+08</td>
<td>398600</td>
<td>7.96E+15</td>
</tr>
</tbody>
</table>

## Spacecraft Physical Parameters

<table>
<thead>
<tr>
<th>$r$ (m)</th>
<th>$h$ (m)</th>
<th>$I_x$ (Kg m$^2$)</th>
<th>$I_y$ (Kg m$^2$)</th>
<th>$I_z$ (Kg m$^2$)</th>
<th>$A_s$ (m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.634058658</td>
<td>0.634058658</td>
<td>0.593117316</td>
<td>1.006516</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Variables

<table>
<thead>
<tr>
<th>Alt orbit (km)</th>
<th>$R$ orbit (km)</th>
<th>theta (deg)</th>
<th>reflectance factor-$q$</th>
<th>Ang. of Incidence-$i$ (deg)</th>
<th>(Cp-cg) (m)</th>
<th>Residual Dipole-D (A$\cdot$m$^2$)</th>
<th>Earths Magnetic Field-B (tesla$\cdot$m$^3$)</th>
<th>rho (kg/m$^3$)</th>
<th>Cd</th>
<th>V (m/s)</th>
<th>$L = (Cpa-cg)$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>6678</td>
<td>5</td>
<td>0.6</td>
<td>0</td>
<td>0.24354</td>
<td>1</td>
<td>5.34569E-05</td>
<td>1.00E+11</td>
<td>2</td>
<td>7725.835</td>
<td>0.2</td>
</tr>
</tbody>
</table>

### Gravity Gradient Torque

\[ T_g = \frac{(3u/2R^3)}{|I_z - I_y|} \sin(2\theta) \]

\[ T_g (N\cdot m) = 7.16386E-09 \]

### Magnetic Field Torque

\[ T_m = D\cdot B \]

\[ T_m (N\cdot m) = 5.346E-05 \]

### Solar Radiation Torque

\[ T_{sp} = F(Cp-cg) \]

\[ F = \frac{(Fs/c)\cdot As(1+q)\cdot \cos(i)}{7.33817E-06} \]

\[ T_{sp} (N\cdot m) = 1.78714E-06 \]

### Aerodynamic Drag Torque

\[ T_a = F^*(Cpa-cg) = F^*L \]

\[ F = 5.\rho \cdot C_d \cdot A \cdot V^2 \]

\[ F = 7.776E+14 \]

\[ T_a = 1.555E+14 \]
<table>
<thead>
<tr>
<th>Color Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Calculations by Chris Scott</td>
</tr>
<tr>
<td>Variable (Currently Approx.)</td>
</tr>
<tr>
<td>Based on Radius</td>
</tr>
</tbody>
</table>
Appendix G

Calculation for correcting the h vector due to the precession of the ascending node with the Ion thruster

\[
h = Iw
\]

\[
\begin{bmatrix}
0 & 0.634058658 & 0 & 0 & 0 \\
0 & 0 & 0.634059 & 0 & 0 \\
0.1242222 & 0 & 0 & 0.593117 & 0.20944
\end{bmatrix}
\]

3-axis is spin axis

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spin Rate(#/min)</td>
<td>2</td>
</tr>
<tr>
<td>Spin Rate(rad/s)</td>
<td>0.20944</td>
</tr>
<tr>
<td>Thruster Force(N)</td>
<td>0.0006</td>
</tr>
<tr>
<td>Thruster Time (s)</td>
<td>5</td>
</tr>
<tr>
<td>Satellite Radius (m)</td>
<td>0.24354</td>
</tr>
<tr>
<td>Change In Angle (deg)</td>
<td>5</td>
</tr>
<tr>
<td>Angular Momentum(Ns)</td>
<td>0.372667</td>
</tr>
<tr>
<td>Isp (s)</td>
<td>3500</td>
</tr>
<tr>
<td>( \delta \phi )</td>
<td>1.047</td>
</tr>
<tr>
<td>Torque Impulse</td>
<td>0.001</td>
</tr>
<tr>
<td>Thrust Impulse</td>
<td>0.006</td>
</tr>
<tr>
<td>Torque Efficiency</td>
<td>0.233</td>
</tr>
<tr>
<td>delta Theta</td>
<td>0.004</td>
</tr>
<tr>
<td>delta Theta (real)</td>
<td>0.001</td>
</tr>
<tr>
<td>Number Pulses</td>
<td>96.000</td>
</tr>
<tr>
<td>Time(s)</td>
<td>2879.999</td>
</tr>
<tr>
<td>Time(hours)</td>
<td>48.000</td>
</tr>
<tr>
<td>Time(days)</td>
<td>2.000</td>
</tr>
<tr>
<td>mdot(kg/s)</td>
<td>1.749E-06</td>
</tr>
<tr>
<td>Fuel Used(kg)</td>
<td>8.395E-06</td>
</tr>
<tr>
<td>Fuel for 6mo(kg)</td>
<td>0.0015114</td>
</tr>
</tbody>
</table>

18
Appendix H

Calculation for correcting the h vector due to the precession of the ascending node with the cold gas thrusters

\[
\begin{bmatrix}
I & 0 & 0 \\
0 & I & 0 \\
0 & 0 & I
\end{bmatrix}
\]

Spin Rate(#/min) 2
Spin Rate(rad/s) 0.20944
Thruster Force(N) 0.5
Truster Time (s) 0.3
Satellite Radius (m) 0.24354
Change In Angle (deg) 5
Angular Momentum(Ns) 0.372667
Isp (s) 300

\[
\begin{align*}
\text{deltaPhi} &= 0.063 \\
\text{Torque Impulse} &= 0.073 \\
\text{Thrust Impulse} &= 0.300 \\
\text{Torque Efficiency} &= 0.243 \\
\text{delta Theta} &= 0.196 \\
\text{delta Theta (real)} &= 0.048 \\
\text{Number Pulses} &= 1.834 \\
\text{Time(s)} &= 55.013 \\
\text{Time(hours)} &= 0.015 \\
\text{Time(days)} &= 0.001 \\
\text{mdot(kg/s)} &= 0.000170068 \\
\text{Fuel Used (kg)} &= 0.002806784 \\
\text{for 6mo(kg)} &= 0.505221171
\end{align*}
\]
Appendix I

Spin up calculations using Ion thrusters

<table>
<thead>
<tr>
<th></th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Radius (m)</td>
<td>0.24354</td>
</tr>
<tr>
<td>Thruster Force(N)</td>
<td>0.634059</td>
</tr>
<tr>
<td>Number of Thrusters</td>
<td>0</td>
</tr>
<tr>
<td>Spin Rate (revs/min)</td>
<td>0.593117</td>
</tr>
<tr>
<td>Spin Rate (rad/sec)</td>
<td>0.20943951</td>
</tr>
<tr>
<td>Isp (s)</td>
<td>3500</td>
</tr>
<tr>
<td>g</td>
<td>9.8</td>
</tr>
<tr>
<td>Moment</td>
<td>0.000292248 Nm</td>
</tr>
<tr>
<td>AngAccel</td>
<td>0.000460916 Rad/sec2 Oblate</td>
</tr>
<tr>
<td>Starting from rest</td>
<td>Time (sec) 454.3980961</td>
</tr>
<tr>
<td></td>
<td>Time (min) 7.573301602</td>
</tr>
<tr>
<td></td>
<td>Time (hr) 0.126221693</td>
</tr>
<tr>
<td></td>
<td>Fuel Used 7.94865E-06</td>
</tr>
</tbody>
</table>
Appendix J

**All values are approximate**

Orbit Inputs
- Probe Team
- Communications Team
- Power Team

Orbit Requirements
- LEO
- Orbit Decay

Requirements Flow Down Diagram

GNC

Orbit

Control

Control Sensors
- No Active Control
- Natural Orbit Decay

GPS
Acc – Very
P – 12 W
W – 4 Kg
f – TBD
DR – TBD

Sun Sensors
Acc – 1 Deg
P – .1 W
W – .1 Kg
f – 1 Hz
DR – TBD

Earth Horizon Sensors
Acc – .5 Deg
P – 1 W
W – .5 Kg
f – 1 Hz
DR – TBD

Magnetometer
Acc – 5 Deg (Att)
P – 5 V @ 20 mA
W – Light (Dr. C)
DR – TBD

Sensor Information Cross Checked for Suitability With
- Power Team
- Structures Team
- CD&H Team

Attitude

Attitude Inputs
- Probe Team
- Communications Team
- Power Team
- Thermal Team
- Structures

Attitude Requirements
- Attitude Knowledge ~ 5 Deg
- Pointing Accuracy ~ 10 Deg
- Spin Rate ~ 2 RPM

Other Possible Attitude Control Methods
- Magnetic Torquer
- EMI interference??
- Cold Gas
- Flow interactions??

Sensors

RF Ion Thruster
P – 11.8 W
W – 1 Kg

Control & Spin-up

Control Information Cross Checked for Suitability With
- Power Team
- Structures Team
- CD&H Team
- Probe Team
## Appendix K

### LionSat Orbit and Attitude Open Action Item List

<table>
<thead>
<tr>
<th>Item #</th>
<th>Action</th>
<th>Assigned to</th>
<th>Assigned on</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preliminary inertial elements Ix, Iy, Iz surface area</td>
<td>Chris Scott</td>
<td>4-Feb</td>
<td>Number assumed a 20 kg spacecraft with even distributed mass</td>
</tr>
<tr>
<td>2</td>
<td>Determine how many attitude sensors and type</td>
<td>Chris Scott/Tom Jakub</td>
<td></td>
<td>IR, Magnetometer, GPS?</td>
</tr>
<tr>
<td>3</td>
<td>Determine the altitude of the spacecraft, at deployment and measurements</td>
<td>Team</td>
<td>300-450 km?</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Obtain a description of the canister deployment; spin rate</td>
<td>Mike/Josh-Tim Structures</td>
<td></td>
<td>E-mail conversation with Sven-reference to the nanosat webpage</td>
</tr>
<tr>
<td>5</td>
<td>Determine the maximum spin rate of the spacecraft</td>
<td>Tom Jakub</td>
<td>4-Feb</td>
<td>Measurement from the probe, sampling rate-EE team between 6 and 10 rpm</td>
</tr>
<tr>
<td>6</td>
<td>Have a helical antenna conversation with systems integration and Sven/EE team (changed to rigid monopole/underevaluation?)</td>
<td>Tom Jakub</td>
<td>4-Feb</td>
<td>Position on sat., beamwidth, e-mail presponse from Sven need further contact</td>
</tr>
<tr>
<td>7</td>
<td>Characterize the ion thrusters to be used. RF Xenon Ion Thrusters</td>
<td>Tim Meisenhelder</td>
<td>4-Feb</td>
<td>Frank conducted a conversation with Dr. Micci, reference textbooks for more info. T= 618 microN, Isp = 3831, P = 11.8 W- Possible use of cold gas for attitude control</td>
</tr>
<tr>
<td>8</td>
<td>Determine environment encounter for the spacecraft. Disturbance torques, magnetic fields</td>
<td>William Chadwick</td>
<td>6-Feb</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>What are the limits on the natural frequencies? Different components, subsystems</td>
<td>Josh/Structures</td>
<td>4-Feb</td>
<td>Josh responded that the spacecraft needed to be above 100 Hz</td>
</tr>
<tr>
<td></td>
<td>Task</td>
<td>Responsible</td>
<td>Due Date</td>
<td>Notes</td>
</tr>
<tr>
<td>---</td>
<td>----------------------------------------------------------------------</td>
<td>---------------</td>
<td>----------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>10</td>
<td>Conduct a conversation with Sven to obtain a better understanding for the need to fly over Arecibo.</td>
<td>Tom Jakub</td>
<td>6-Feb</td>
<td>E-mail conversation with Sven, distributed to team</td>
</tr>
<tr>
<td>11</td>
<td>Conduct a trade study for gimbaled thrusters vs. multiple fixed thrusters</td>
<td>Michael Haddad/Frank Walter</td>
<td>4-Feb</td>
<td>Now need to refine</td>
</tr>
<tr>
<td>12</td>
<td>Observe if STK has information pertaining to the Minotaur.</td>
<td>William Chadwick</td>
<td>4-Feb</td>
<td>None</td>
</tr>
<tr>
<td>13</td>
<td>Investigate the difference that altitude and inclination have on a groundtrack</td>
<td>William Chadwick</td>
<td>4-Feb</td>
<td>Provided charts, images out of Vallado describing the effect</td>
</tr>
<tr>
<td>14</td>
<td>Start a requirement flowdown to determine the type or orbit and the amount of attitude accuracy required</td>
<td>Michael Haddad/Frank Walter</td>
<td>12-Feb</td>
<td>Depends on the conversation with other groups, antenna, probe, etc.…Need to refine further</td>
</tr>
<tr>
<td>15</td>
<td>Trade study investigating the possible use of a gravity gradient boom. Expanded to all types of attitude control</td>
<td>Frank Walter</td>
<td>18-Feb</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Investigate Passive Magnetic attitude control</td>
<td>Chris Scott</td>
<td>18-Feb</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Determine the amount of time in the sun for the power team based upon orbit characteristics</td>
<td>William Chadwick</td>
<td>25-Feb</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Determine how long to spin up to 2 rpm (oblate)</td>
<td>Tim Meisenhelder</td>
<td>18-Mar</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Select second attitude sensor see item #2</td>
<td>Chris Scott/Tom Jakub</td>
<td></td>
<td>IR (earth sensor)?</td>
</tr>
<tr>
<td>25</td>
<td>Conduct a conversation to confirm GPS and its attitude determination ability</td>
<td>Team</td>
<td></td>
<td>Cannot be used</td>
</tr>
</tbody>
</table>
### Appendix L

#### LionSat Orbit and Attitude Open Action Item List

<table>
<thead>
<tr>
<th>Item #</th>
<th>Action</th>
<th>Assigned to</th>
<th>Assigned on</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Confirm the 10 RPM limit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Create a box diagram of electrical circuit</td>
<td></td>
<td></td>
<td>sensors, actuators, GPS, magnometer, ion thruster</td>
</tr>
<tr>
<td>22</td>
<td>Select an attitude control mechanism, (when ion thrusters are not allowed)</td>
<td></td>
<td></td>
<td>momentum wheel, thrusters, cold gas</td>
</tr>
<tr>
<td>23</td>
<td>Determine power requirements of subsystem components</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Determine mass of the system</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix M

Here’s the (edited) response from Sergei Tanygin at AGI regarding Grav. Grad. simulation.

++++++++++++++++++++++++++++++++++++++++++

Robert G. Melton
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(814) 865-7092 (fax)
rgmelton@psu.edu

-----Original Message-----
From: Tanygin, Sergei [mailto:stanygin@stk.com]
Sent: Friday, April 11, 2003 11:12 AM
To: Robert G. Melton
Subject: RE: gravity-gradient effects in STK

A couple of things are going on with gravity gradient:

1) Existing “feature” of simulator’s architecture prevents user from correctly using GrvGrdTorque vector from Vector Tool as input to the simulator
   a. Position vector needed for GrvGrdTorque computation is mapped not to the propagated attitude, but to the attitude which was defined on Satellite’s attitude tab before propagation. Note that user can still request components of this vector to be supplied relative to the propagated attitude, but, of course, it is too late as the vector itself was computed incorrectly
   b. Work-around: user can request both inertia matrix and position vector relative to the propagated attitude (since this vector computation does not depend on attitude, only its components that need to be reported do, the vector will be computed and mapped correctly to the propagated attitude). The script than performs 3 line-of-code computation of GG torque using supplied inertia and position vector

2) Once propagated, newly created attitude data file can be assigned to become attitude definition for the satellite. After that, GrvGrdTorque vector in Vector Tool can be used to report GG torque experienced along the propagated trajectory

I’m sending example scenario created in STK 4.3. It has 2 identical axisymmetric satellites starting from the same initial conditions. The only difference is that one of them is torque free, whereas the other is subjected to GG torque from MATLAB plug-in script designed according to 1b. There are three Attitude View windows – one for torque free satellite and two for different views of GG subjected satellite. The GG subjected satellite displays its body axes and traces z-body direction in two frames simultaneously: one relative to VNC frame (which is also the frame of the Attitude Sphere, where you can also see horizon line), the other z-body trace is relative to the torque free satellite – i.e. error. I’m also sending another zip file that contains styles needed to Data Displays set up to show GG torque and attitude errors induced. You need to place unzipped style files under you configuration area: <some path, usually C:\stk\Conf\styles\Satellite. In this scenario, I already propagated both satellites for 1 hr, so you can just load it and animate to see the effect. This should get your students started as they can modify inertia, orbit and attitude to their specs.

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