Appendix B

Introduction

To fulfill the requirements set forth in 47 CFR 5.63, the following appendix is submitted along with the application for an Experimental License. Each numbered paragraph responds to the corresponding paragraph in 47CFR5.63.

Paragraph-specific Responses

(a) Not applicable, as specified in paragraph (d) of this section.

(b) Not applicable.

(c) Not applicable.

(d1) The CAERUS mission from Space Engineering Research Center at the University of Southern California is a nanosatellite technology demonstration mission. The nanosatellite, commonly referred to as "Cubesat," is a 3U configured nanosatellite (10cm x 10cm x 30cm) with advanced power, micro-miniature propulsion, processing, attitude control and communications subsystems to be flown in low earth orbit for validation of the technology designs and applicability.

(d2) Communications facilities are necessary for operation of satellites in earth orbit. A conduit must exist to deliver commands to the spacecraft and receive telemetry and test results from it. Commands can include ephemeris or clock updates as well as specific tests to run or payload technologies to operate. Telemetry may include battery levels, temperatures, and other specific sensor values essential to maintain safe operation. All of this information is necessary for operation of a spacecraft. Radio frequency is the most mature and affordable method to achieve this communication.

(d3) Various methods exist for satellite communication. Some satellites utilize private, civil, or military relay satellites. As a non-profit research institution, these solutions are cost prohibitive for a student-based satellite. In addition, due to the miniaturized nature of the satellite bus, the electronic systems necessary for integration with relay satellites does not meet volumetric constraints. Some University teams have utilized amateur licenses to achieve communication. However, we have determined that this research project does not meet the requirements for amateur licensing (with the exception of the beacon). Therefore, we are applying for an experimental license. In addition, it is necessary that we be granted an experimental license in the amateur band (435-438Mhz) as this enables usage of extensive research done by University teams operating in the amateur band, as well as use equipment that is readily available in this frequency range that can meet the critical schedule constraints for this nanosatellite mission.

(e1a) There is no planned release of any type of debris during normal operations of the Caerus satellite. The satellite system does not use any type of pyrotechnic release mechanisms or any other debris generating devices.

(e1b) USC has performed initial collision assessment with small orbiting debris. The figure below (Figure 1) shows the assessment of small debris/meteoroid collisions using the NASA DAS program. Although the mission is only planned for 7 – 30 days, the analysis was run conservatively for half a year. (See chart at end of Appendix for area calculation.) The cross sectional area of the Caerus spacecraft is only 0.09m^2, worst case. The most likely flight condition of the satellite will reduce this area even further, thus mitigating its cross section area to potential collisions.

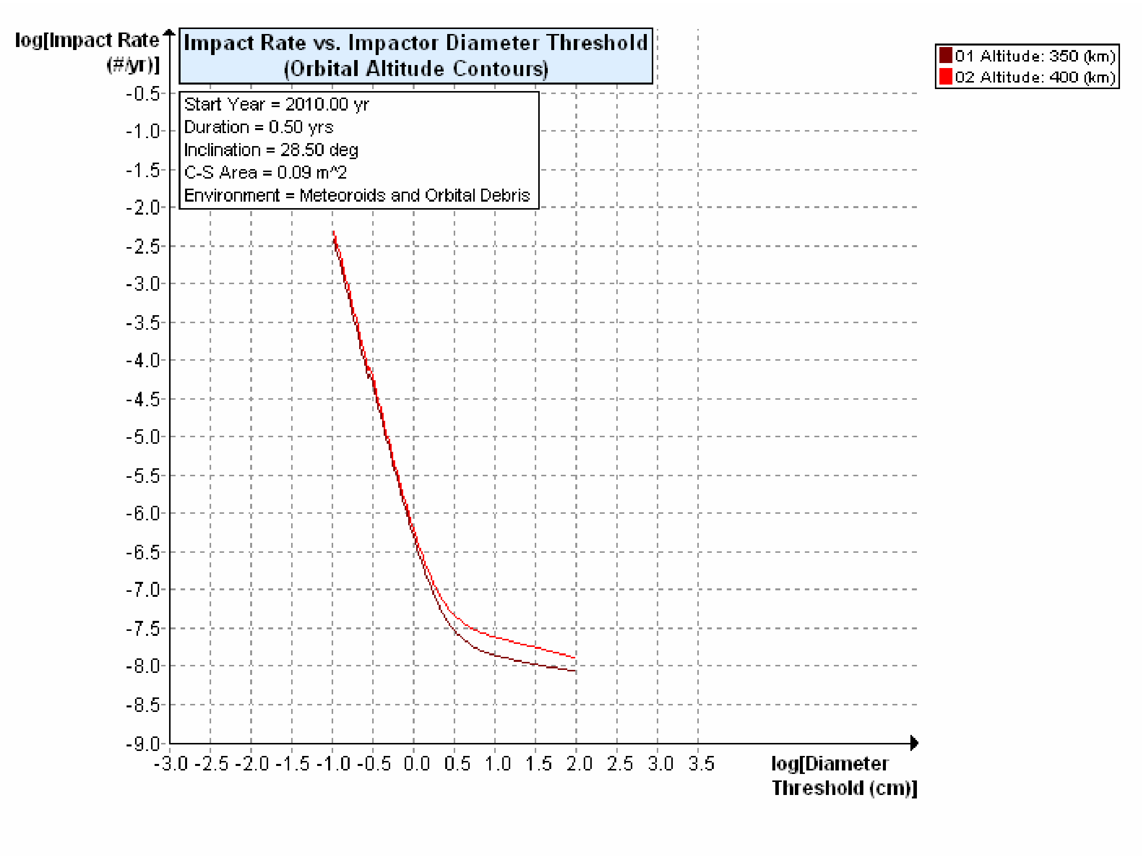

Figure 1

(e2) The USC Caerus team has assessed the probability of any accidental release of stored energy at less than 1% chance. The only source of potential explosion onboard is from a fully qualified propulsion tank, and analysis and testing has been done to develop a tank that conforms to the leak before burst standard. Additionally a burst discs is incorporated on the high pressure side of the tank interface. The burst disc is non-fragmenting, in that a small poppet valve will be released inside a captured container and release the pressure should it become necessary. The tank itself has been designed and tested to a "leak before burst" capacity, and no fragments at the leak pressure were generated in ground testing. The tank itself is internal to the structure of the nanosatellite, and is further shielded by body mounted copper plated body mounted circuit boards.

At the end of life, The Caerus team intends to deplete the fuel/pressure from the tank by instituting an orbit lowering burn, to put the spacecraft into a safe de-orbit transfer into the Earths atmosphere and to release the pressure inside the tank to zero.

(e3a) The USC Caerus team has access to the latest civilian TLE set of known orbiting objects through a licensed software system of Satellite ToolKit (STK) licensing by AGI. Through the Conjunctional Analysis module, the team is able to run analysis from the launch date plus 5 days in the future to assess potential conjunctions. These conjunctions are based on error ellipsoids from the latest TLE information on any particular object, and if it has maneuvered or changed its orbit since the last TLE update. The USC team has run a projected conjunction analysis for the proposed launch date with no conjunctions identified, however as part of the mission operations this analysis will be run daily for the Caerus satellite to assess possible collisions with other objects. Note, the expected conjunctions in the proposed orbit appear to be mostly the debris produced during the breakup of the Chinese anti-satellite weapons test. And example output of the STK module is shown in Figure 2.

```
Close Approach initial Satellite Database search undertaken-
14157 candidate satellites found in Satellite Database
14151 candidate satellites remain after date and propagation test
621 candidate satellites remain after apogee perigee filter
162 candidate satellites remain after path filter
89 candidate satellites remain after time filter
0 candidate satellites remain after range filter
No satellites found to have access
  within the specified constraints
Close Approach processing completed
```

Figure 2

In addition, the launch provider will provide conjunction analysis for the primary payload as well as mitigate interaction between the launch vehicle and any deployed payloads.

(e3b) The Caerus satellite has an active propulsion system on it equivalent to a few tens of meters of second of DeltaV. Through conjunction analysis (identified in e3a) the team will be able to assess probability of conjunction, and as required send a maneuver command to the satellite to provide a change in apogee/perigee or node crossing to mitigate any potential conjunction identified during its short duration on-orbit.

(e3c) The Caerus team ran an analysis of anticipated evolution over time (again from NASA DAS program) for expected lifetime, with no use of the onboard propulsion system. (Area-To-Mass ratio calculation is shown at the end of this Appendix for reference.) The satellite is expected to decay in no more than 90 days to a complete de-orbit and burnup in the Earths atmosphere (See Figure 3).

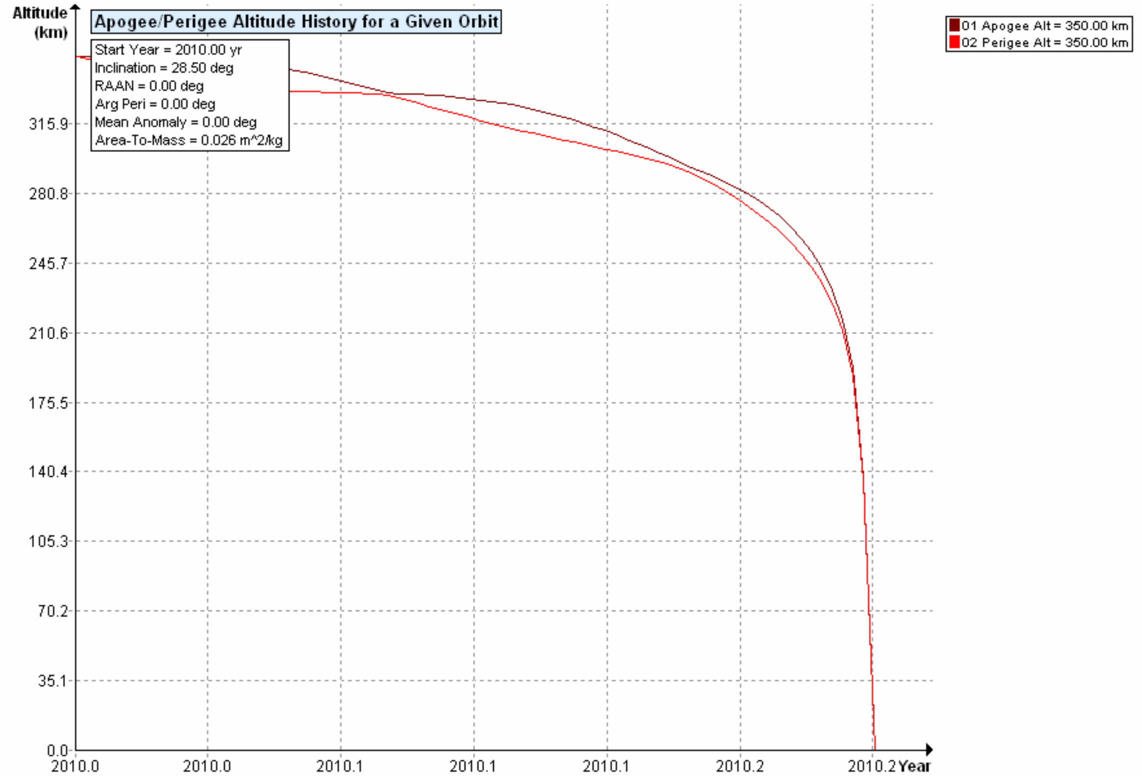

Figure 3

(e4a) At the end of the mission, the Caerus team intends to exercise the propulsion system to deplete the fuel/pressurant from the onboard tank by instituting an orbit lowering burn, to put the spacecraft into a safe de-orbit transfer into the Earths atmosphere. Approximately 10% of the fuel is required for de-orbit at the highest altitude envisioned during the mission, and through ground mission operations this will be assured available. If the propulsion system sees any type of "leak" that would deplete this, the mission team will institute a de-orbit burn before less than 10% is remaining to make sure we lower the apogee to lowest possible point. In the case of pressurant leak prior to a de-orbit burn or prior to the mission operations teams ability to command it to burn, the spacecraft will be placed in an attitude that maximizes its cross sectional area to the velocity vector, thereby maximizing drag and minimizing its time in orbit. (Refer to Figure 3 for expected lifetime without a de-orbit burn).

(e4b) The risk of casualty due to any part of the spacecraft reaching the ground is calculated at zero (see Figure 4). The spacecraft will not survive re-entry due to its very low mass and use of non-dense materials. An analysis with the NASA DAS software that shows its demise at an altitude of 63 km. The Cubesat was conservatively modeled as a solid block of aluminum to show worst case analysis.

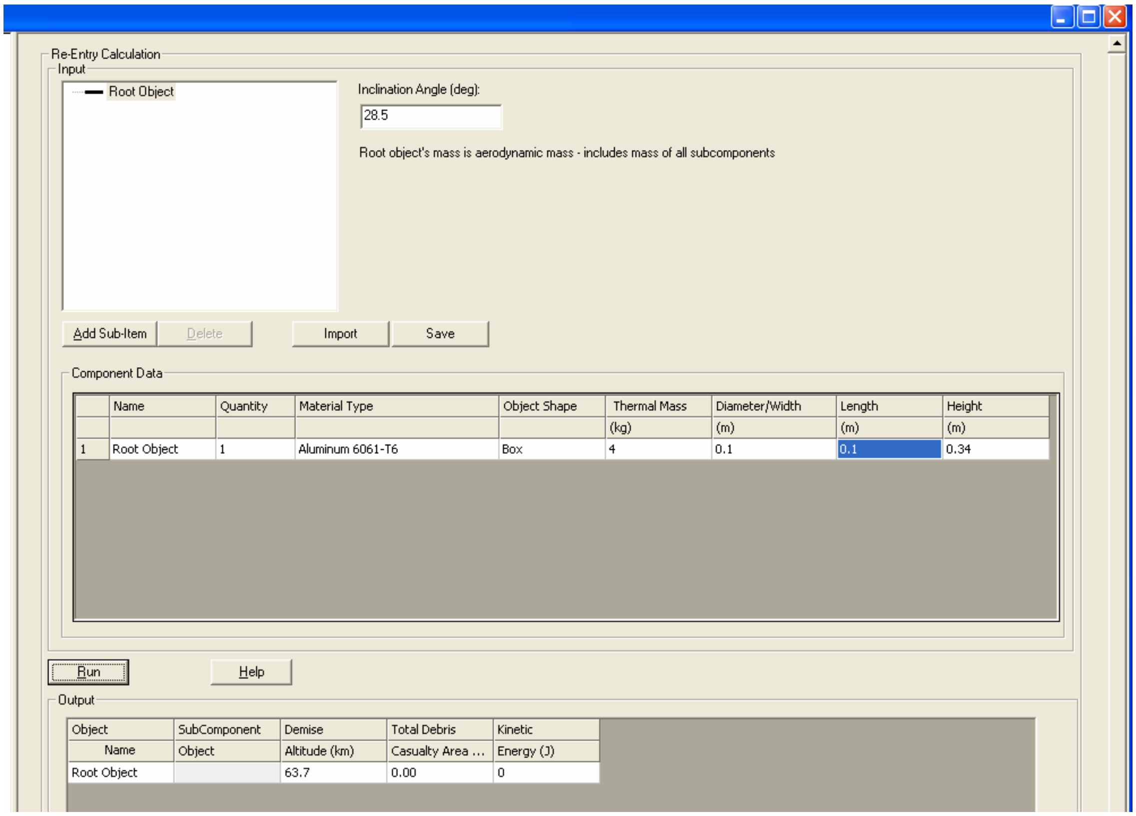

Figure 4

Area Calculations

Maximum

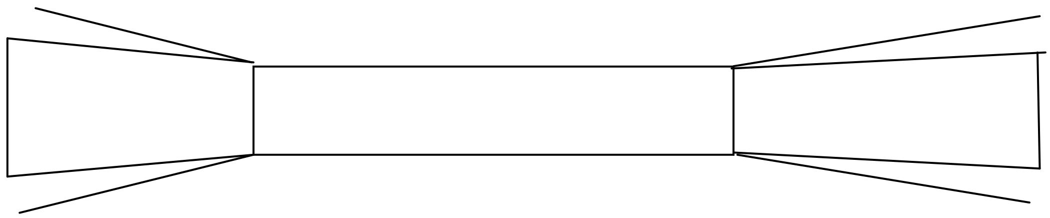

Figure 5

The maximum area configuration as viewed from the velocity vector is shown in Figure 5. Panels are fully deployed and spacecraft is flying side-on to the velocity vecotr. In this configuration, the area is established by 3 components – the center body and the solar panels on each end.

	Length (cm)	Height (cm)	Area (m^2)
Central Body	10	34	0.034
Left Solar Panel	10	30	0.0282*
Right Solar Panel	10	30	0.0282*
Total			**0.0904**

* Note that the area of the solar panels is reduced by their 20-degree declination **perpendicular to** the velocity vector. $A = l \cdot h \cdot \cos(\theta)$

Minimum

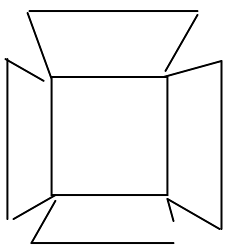

Figure 6

The minimum configuration as viewed from the velocity vector is shown in Figure 6. This configuration requires active attitude control to maintain a head-on orientation, which is not the intended attitude of the mission.

	Length (cm)	Height (cm)	Area (m^2)
Central Body	10	10	0.01
Left Solar Panel	10	30	0.0103*
Right Solar Panel	10	30	0.0103*
Top Solar Panel	10	30	0.0103*
Bottom Solar Panel	10	30	0.0103*
Total			**0.0510**

* Note that the area of the solar panels is reduced by their 20-degree declination **parallel to** the velocity vector. $A = l \cdot h \cdot \sin(\theta)$

Area to Mass Ratio's

	Area	Mass	Area-to-Mass
Lower Bound	Minimum [0.05m^2]	Maximum [4kg]	0.0128
Upper Bound	Maximum [0.09m^2]	Minimum [2kg]	0.0452
Mission Expectation	Average	Average	0.0236

Note: All calculations using these values are performed conservatively. Debris collision uses the largest area, and lifetime expectation uses the average ratio, under the assumption that active guidance fails (so we tumble and cannot use propulsion to de-orbit).