TEAM ALPHA CUBESAT

GROUND TOURNAMENT 2 PRELIMINARY DESIGN REVIEW REPORT

Version 1

Team Alpha CubeSat
c/o XISP-Inc
8012 MacArthur Boulevard
Cabin John, MD 20818-1608

gary.barnhard@alphacubesat.com
+1 301 229 8012
http://www.alphacubesat.com

TABLE OF CONTENTS

INTRODUCTION

This document is intended to satisfy the NASA Cube Quest Challenge Preliminary Design Review (Ground Tournament – 2) data submission requirements. Since Alpha CubeSat is now planning on using an alternate Launch Services Provider the SLS Safety Review materials, and Secondary Payload Users Guide (SPUG) Questionnaire are no longer directly applicable. The format of this document follows the Concept Registration Data Package by Team Alpha CubeSat dated April 30, 2015, as augmented based on guidance provided in the Ground Tournament -2 Workbook version 3.

MISSION STATEMENT

The Alpha CubeSat Team is out to win the NASA Cube Quest Challenge. The Cube Quest Challenge, sponsored by NASA's Space Technology Mission Directorate Centennial Challenge Program, offers a total of $5 million to teams that meet the challenge objectives of designing, building and delivering flight-qualified, small satellites capable of advanced operations near and beyond the moon.

Our teams founding sponsor is Xtraordinary Innovative Space Partnerships, Inc. (XISP-Inc) http://www.xisp-inc.com

Our strategy is to succeed through a combination of competition and cooperation. We intend to leverage all available assets implementing the project as part of multiple profit driven technology development efforts underway by our teammates and sponsors. The balance of the Alpha CubeSat spacecraft will be predominately made up of Commercial Off The Shelf (COTS) purchases (with some repackaging), as well as a limited amount of semi-custom development work.

Our strength will be our ability to define, engineer, orchestrate, implement, and integrate an engineered solution for the challenge that incorporates design elements which have sufficient enduring value to make the engineering and resource commitment necessary to actualize them worthwhile for the Team Alpha CubeSat participants.

It is the intention of Team Alpha CubeSat to compete in both the Deep Space and Lunar Derby missions for all prizes offered.

The Cube Quest Challenge is designed to foster innovations in small spacecraft propulsion and communications techniques. Cash prizes will be awarded to and shared between registered Competitor Teams that meet or exceed technical objectives for communication from at least 4,000,000 kilometers from Earth during the Deep Space Derby. Cash prizes will be awarded to and shared between registered Competitor Teams that are able to meet or exceed technical objectives for propulsion and communication from lunar orbit during the Lunar Derby.

TEAM ROSTER - MEMBERS, ADVISORS & INTERNATIONAL LIAISONS

ALPHA CUBE SAT TEAM MEMBERS:

- Gary Barnhard – Team Leader, CEO/Systems Engineering
- Ethan Shinen Chew – Propulsion systems
- Mike Doty – CAD/Systems Integration
- Anastasia Ford – Systems Engineering Intern, Structures
- Eric Gustafson – Thermal Systems
- Brian Martin – Guidance, Navigation & Control
- TJ McKinney – Radiation & Shielding
- Jamie Pulliam – Multimedia Production
- Joseph Rauscher – Contract Specialist/Documentation
- Eric Shear – Propulsion systems
- John Tascione – Structures & Mechanisms

ALPHA CUBESAT TEAM ADVISORS:

- Pat Barthelow – Communications systems
- Chris Cassell – STK & Orbital Dynamics
- Eric Dahlstrom – Astrophysics
- James DiCorcia – Mechanical systems
- David Dunloip – Lunar Science Liaison
- Craig Foulds – Propulsion systems
- Aaron Harper – Communication systems

ALPHA CUBESAT TEAM INTERNATIONAL LIAISONS:

- Matteo K. Borri – Attitude Control Systems
- Issac DeSouza – Electrical engineering
- Daniel Faber – Systems engineering
- Joe Hatoum – Commercial collaboration

A Team participant (Member, Advisor, or International Liaison) may be listed as “Inactive” if they have not participated in at least one Team coordination meeting and/or team related activity in the last reporting period (i.e., they have no activity to report). Current Team Alpha CubeSat policy is that participants that have contributed to the Team in some meaningful way will be maintained on the list even if listed as inactive unless they specifically request to be removed. Team participants can be dropped at any time by their request. New Team participants can be added by acclamation after attending one or more Team meetings and a suitable role defined. New Team participants must meet the requirements as specified in the definitions below.

Definitions:

Team Alpha CubeSat has defined and agreed to definitions for the following roles: Team Member, Team Advisor, and International Liaison. These definitions have been deemed consistent with the Cube Quest Challenge Rules and have been adopted as specific requirements for Team Alpha CubeSat.

Registered Team Members are asserting that they are willing to help Team Alpha CubeSat, agree to fill out the required paperwork, play by the Cube Quest Challenge and Team Alpha CubeSat rules, and be available for such Team assignments/work product commitments as their respective schedules permit.

Team Advisors are asserting that they are willing to help Team Alpha CubeSat, play by the Cube Quest Challenge and Team Alpha CubeSat rules, but cannot necessarily make specific time and/or work product commitments.

International Liaisons are asserting that they are willing to help Team Alpha CubeSat, play by the Cube Quest Challenge and Team Alpha CubeSat rules, but necessarily cannot make work product commitments.

These definitions are subject to revision by Team Alpha CubeSat or if directed by the Cube Quest Challenge Administration.

Candidates to be a Registered Team Member must provide the signed registration form and a copy of their photo ID. If you do not provide the Form and a copy of your ID you will participation will be reclassified.

TEAMMATES & SPONSORS

- Xtraordinary Innovative Space Partnerships, Inc. (Commercial)
- Barnhard Associates, LLC (Commercial)
- Deep Space Industries, LLC (Commercial)
- Space Development Foundation (Non-profit)
- National Space Society (Non-profit)

CONCEPT OF OPERATIONS

The Alpha CubeSat Concept of Operations is outlined below and shown in Diagram 1-1 Alpha CubeSat Concept of Operations. The driving factors have been a series of trades and opportunities resulting from innovative partnerships the team has been able to develop. Each of these are addressed in more detail in the Conceptual Mission Design section. The driving factors identified to date include:

1. Integration & Launch Trade
    - The largest number of launch opportunities for CubeSats would be afforded bybeing manifested as ISS commercial cargo.
    - Baseline: Soft Pack Pressurized International Space Station (ISS) Cargo & ISS IntraVehicular Activity (IVA) Japanese Experiments Module (JEM) airlock transition to ExtraVehicular Robotic (EVR) Low Earth Orbit to Deep Space and CIs-Lunar Trajectory Insertion.
    - Alternate 1: EVR Deployed Unpressurized ISS Cargo & ISS logistics storage (JEM back porch) to EVR Low Earth Orbit to Deep Space and Cis-Lunar Trajectory Insertion.
    - Alternate 2: Leverage the expanding fleet of expendable launch vehicles such as secondary payload on SpaceX's Falcon 9, OrbitalATK's Antares, ULA's Atlas/Delta/Vulcan, or NASA's SLS Secondary Cargo & the Payload Planetary Services Systems release mechanism.

2. Deployment Trade
    - ISS IntraVehicular Activity (IVA) Japanese Experiments Module (JEM) airlock transition to EVR Low Earth Orbit to Deep Space and Cis-Lunar Trajectory Insertion (Baseline)
    - ISS logistics storage (JEM back porch) to EVR Low Earth Orbit to Deep Space and Cis-Lunar Trajectory Insertion (Alternate 1)
    - SLS Secondary Payload Planetary Systems release mechanism – NASA modified or equivalent (Alternative 2)

3. Deployment Kinetic Energy Transfer Trade
    - ISS deployment integrated with a Launch Service Provider's Trajectory Insertion Bus using Special Purpose Dexterous Manipulator (SPDM) adapted (i.e., EVR interface added) release mechanism (or equivalent). (Baseline)

    - The use of an alternative Launch Service Provider offering deliver to a beyond Earth Orbit Trajectory Insertion Point is deemed by Team Alpha CubeSat to be consistent with both the letter and the spirt of the prevailing CubeQuest Challenge rule set. Team Alpha CubeSat requests confirmation that the proposed Launch Services Provider RFP and Letter of Intent are deemed compliance by the Cube Quest Challenge Administrator.

- Any constraints on the allowable space for deployment infrastructure that is beyond the nominal 6U envelope need to be defined.

4. Leverage DSI/XISP-Inc Colab, Hardware and Software technical collaboration opportunities.
5. Make use of alternate minimum energy trajectories (e.g., ISEE3 example, bi-elliptic, weak stability boundary, libration point, etc.)
6. Mission Concept will be based on combined Deep Space and Lunar Derby missions
7. The spacecraft will be a development testbed to gain operational experience/data points to raise technology readiness levels of various subsystem design elements.
8. An ultra-lightweight 3-D printable primary structure using one or more of the allowable aluminum alloys is baselined, but alternatives will be considered.
9. The use of unified bus backplane(s) is baselined.
10. The use of integrated receiving antenna (rectenna) and solar arrays is baselined.
11. The use of hybrid band gapped solar cells/solar concentrators is baselined.
12. The use of a short duration high thrust propulsion system is baselined. An in-line hybrid Nitrous Oxide and Acrylic/Paraffin propulsion system is the leading alternative at this time.
13. The use of a long duration and/or repetitive use low thrust propulsion system is baselined. Some combination of ion thrusters, and other low thrust alternatives will be incorporated into the Alpha CubeSat design and will be scaled to meet the mission requirements. The current baseline is four (4) ion thrusters.
14. The structural layout is assumed to be a 3U center stack with tandem .5Ux3U volumes on either side.

CONCEPT OF OPERATIONS NARRATIVE

The concept of operations is premised on the

- Conceptual Design (Prototype)

    - Nominal Volume 6U (1Ux2Ux3U) CubeSat, constrained by SLS secondary payload requirements
    - Nominal Mass 14.0 Kg, constrained by SLS requirements
    - No operational fractionation, other than launch and orbital injection staging.
    - All qualifying transmissions must be from flight test article to Earth, without relay
    - Satisfying all other Cube Quest Challenge rules
- Preliminary Design (ProtoTest)
- Detailed Design/Construction (ProtoFlight)
- Flight Readiness / Flight Safety Review
- Integration for Soft Pack Launch
- Commercial Cargo Launch Soft Pack Pressurized Cargo to the International Space Station
- Deployment
    - IVA unpack and assemble baselined, EVR unpack and assemble alternate
    - Recharge batteries
    - Insert sealed compressed gas cylinder(s) as applicable (Nitrous Oxide and Carbon Dioxide)
    - IVA to EVA transition via Japanese Experiments Module (JEM) Air Lock Slide Table & CYCLOPS
    - Transfer to the Mobile Servicing Center (MSC) - Special Purpose Dexterous Manipulator (SPDM) attached to the Space Station Remote Manipulator System (SSRMS) attached to the Mobile Base System.
    - Transition the MSC to a suitable location for a RAM (forward) – Starboard (right side truss) – Zenith bias (away from Earth) release of the flight article
    - Apply preload (if applicable) to deployment spring
    - Release on confirmation of ready to launch
- Stabilization & Checkout
    - Establish Command & Telemetry Communication Links via available Ka and X Band Links
    - Establish attitude and position control
    - Obtain navigation fix using best available tools (e.g., geospatial positioning constellations, etc.)
    - Activate synchronization to near real time state model & verify state of system
    - Calculate timing for orbital injection burn
- Trajectory Insertion
    - Align for orbital injection burn
    - Engage short duration high thrust propulsion system

    - Ignition on confirmation of ready to launch
- Stabilization & Configuration for Qualifying Transmissions
    - Re-establish Command & Telemetry Communication Links
    - Establish attitude and position control
    - Obtain navigation fix
    - Complete deployment of solar arrays & antenna
    - Establish ability to engage and test primary data link
    - Engage long duration low thrust propulsion system
- Deep Space Derby Qualification Transmission
    - Qualification Transmission Dry Run Iteration
    - Configure for Qualification Transmission with Deep Space Network (DSN)
    - Execute Qualification Transmission with DSN
- Lunar Orbit Qualification Transmission
    - Lunar Orbit Insertion
    - Configure for Qualification Transmission with DSN
    - Execute Qualification Transmission with DSN
- Lunar Orbit Extended Configuration Testing
- Lunar Orbit Decay to Termination

CONCEPT OF OPERATIONS DIAGRAM

The concept of operations is shown in Diagram 1-1 Alpha CubeSat Concept of Operations. The information is currently shown in a block diagram format and will be updated with pictorial elements for the GT-1 data package. The defined mission phases with anticipated image annotations include:

- Integration – Stowed Alpha CubeSat as Secondary Payload, pressurized IVA softpack cargo, or unpressurized EVR cargo.
- Launch –Commercial Cargo (e.g., Falcon 9, Antares/Atlas)
- Unpack – IVA Astronaut or EVR SPDM/JEM Fine Arm
- Transition – CYCLOPS JEM Airlock IVA➔EVA transition mechanism
- Relocate & Position – JEM RMS & Mobile Servicing Centre (MSC)
- Deployment – Ram Starboard with Zenith bias release from SPDM operating as part of the MSC.
- Final Checkout – Deployed Alpha CubeSat
- Trajectory Insertion – Primary orbital injection motor burn,
- Deep Space Derby – Trajectory image with key events
- Lunar Derby – Trajectory image with key events
- End of Life – Trajectory image with key events

The use of the NASA Deep Space Network is the baselined ground station(s).

All downlink data will be Ka Band at 32 GHz. All Uplink data will be in X band at 7,145 MHz.

An annotated rendered graphic is in preparation but was not available in time for this package submission. The completed graphic shall be on a single page no smaller than 8.5 x 11 inches and no larger than 11 x 17 inches with type face no smaller than 10 point.

SEE REVISED CONOPS DIAGRAM IN APPENDIX

MISSION CONSIDERATIONS

Leverage DSI/XISP-Inc Colab, Hardware and Software technical collaboration

Mission Concept will be based on combined Deep Space and Lunar Derby missions

The spacecraft will be a development testbed to gain operational experience/data points to raise technology readiness levels of various subsystem design elements.

Conceptual Design (Prototype)

- Nominal Volume 6U (1Ux2Ux3U) CubeSat, constrained by SLS requirements
- Nominal Mass 14.0 Kg, constrained by SLS requirements
- No operational fractionation, other than launch and orbital injection staging.
- All qualifying transmissions must be from flight test article to Earth, without relay
- Satisfying all other Cube Quest Challenge rules

DEVELOPMENT CONSIDERATIONS

Integration & Launch Trade

- Space Launch System (SLS) Secondary Cargo EM-1 (Baseline)
- Soft Pack Pressurized International Space Station (ISS) Cargo (Alternate 1)
- ExtraVehicular Robotic (EVR) Deployed Unpressurized ISS Cargo (Alternate 2)

Deployment Trade

- SLS Secondary Payload Planetary Systems release mechanism – NASA modified (Baseline)
- ISS IntraVehicular Activity (IVA) Japanese Experiments Module (JEM) airlock transition to EVR Low Earth Orbit to Deep Space and Cis-Lunar Trajectory Insertion (Alternate 1)
- ISS logistics storage (JEM back porch) to EVR Low Earth Orbit to Deep Space and Cis-Lunar Trajectory Insertion (Alternate 2)

The allowable space for deployable infrastructure that is beyond the nominal 6U envelope is defined in the Planetary Services Deployer Users Guide. Of particular note to Alpha CubeSat is the solar array/antennas can be accommodated folded to body of the spacecraft.

GROUND SEGMENT CONSIDERATIONS

Use of the NASA Deep Space Network (DSN) is baselined for receiving/calculating contest defined Navigation Elements. Command, Telemetry, and qualifying data transmissions are anticipated to use the DSN as the primary communication link provider. The DSN supports Ka Band transmission and reception and has the largest number of readily characterized and available ground stations. For the purposes of link budget calculations the DSN 34m BWG Ka Band at 32 GHzdownlink standard service is sufficient. All uplink communications from the DSN to Alpha CubeSat will be in X band at 7.145 MHz.

The use of the National Science Foundation Arecibo Observatory has been identified as a limited window backup facility in the event of an emergency condition which warrants its use.

Based on calculated link margins the ability to allow for communication links via the NASA Near Earth Network (NEN), other alternate ground stations, as well as amateur radio facilities will be defined where possible to allow for greatest possible coverage at minimum cost as well as provide for additional opportunities for engagement during certain phases of the mission.

STRUCTURAL CONSIDERATIONS

The structural layout is assumed to be a 1Ux1Ux3U center stack with tandem .5Ux1Ux3U volumes on either side.

An ultra-lightweight 3-D printable primary structure using one or more of the allowable aluminum alloys is baselined. Structural elements may be printed, cast, and/or machined depending on the prototype, prototest, and or protoflight considerations applicable.

Q10: Is there an error in the NASA SPUG specified 6U CubeSat dimensions of 239.0 x 366.0 x 113.0 mm? The SPUG provides a link to the Planetary Systems Launcher as the dispenser for the competition. The Planetary Systems Launcher document states that it supports a payload size of 239.0 x 366.0 x 116.0 mm. Is there an error?

A10: The maximum internal dimensions should be 239 X 366 X 116 mm. It was a typo in the SPUG document, and will be corrected.

LAUNCH CONSIDERATIONS

The Launch Trade space is first between launch from sea level to LEO, MEO, GEO, or Cis-Lunar Injection trajectory.

It is anticipated that the largest number of launch opportunities would be afforded by being manifested as either pressurized International Space Station (ISS) softpack commercial cargo or unpressurized ExtraVehicular Robotics (EVR) commercial cargo. However, this necessitates the use of alternate minimum energy trajectory solutions in order to allow for suitable non-propellant mass fractions.

The use of an alternate secondary payload launch opportunity based on the integration challenges of non-standard Cubesat specifications, incorporation of novel technologies, and potential cost is not anticipated to be a viable option.

DEPLOYMENT CONSIDERATIONS

The deployment volume of the mechanism used for IVA to EVA transition via the Japanese Experiment Module (JEM) Airlock is shown in Diagram 1-2 CYCLOPS Deployment Volume.

Deployment (assuming integration as IVA pressurized commercial cargo)

- IVA unpack and assemble
- Recharge batteries
- Insert sealed compressed gas cylinders (Nitrous Oxide and Carbon Dioxide)
- IVA to EVA transition via Japanese Experiments Module (JEM) Air Lock Slide Table & CYCLOPS
- Transfer to the Mobile Servicing Center (MSC) - Special Purpose Dexterous Manipulator (SPDM) attached to the Space Station Remote Manipulator System (SSRMS) attached to the Mobile Base System.
- Transition the MSC to a suitable location for a RAM (forward) – Starboard (right side truss) – Zenith bias (away from Earth) release of the flight article
- Apply preload (if applicable) to deployment spring
- Release on confirmation of ready to launch
- Supplemental deployment spring could be sized to nominal propulsion module nozzle cavity

Deployment (assuming integration as EVR unpressurized commercial cargo)

- EVR unpack and assemble via the Mobile Servicing Center (MSC) - Special Purpose Dexterous Manipulator (SPDM) attached to the Space Station Remote Manipulator System (SSRMS) attached to the Mobile Base System.

- Recharge batteries

- Insert sealed compressed gas cylinder(s) with Robotic Systems Integration Standards (RSIS) compliant interfaces (Nitrous Oxide and Carbon Dioxide)

- Transition the MSC to a suitable location for a RAM (forward) – Starboard (right side truss) – Zenith bias (away from Earth) release of the flight article

- Apply preload (if applicable) to deployment spring

- Release on confirmation of ready to launch

- The inclusion of additional deployment spring force provisions facilitated by ISS Robotic Systems (Special Purpose Dexterous Manipulator (SPDM) Orbital Replaceable Unit (ORU) Tool Changeout Mechanism (OTCM) center line nut driver will be examined.

The use of an alternate Launch Services Provider is now baselined. The RFP and the Letter of Intent we have received to date follow:

(1) Launch Services Provider RFP is attached as Appendix.

(2) Launch Services Provider Letter of Intent is attached as Appendix.

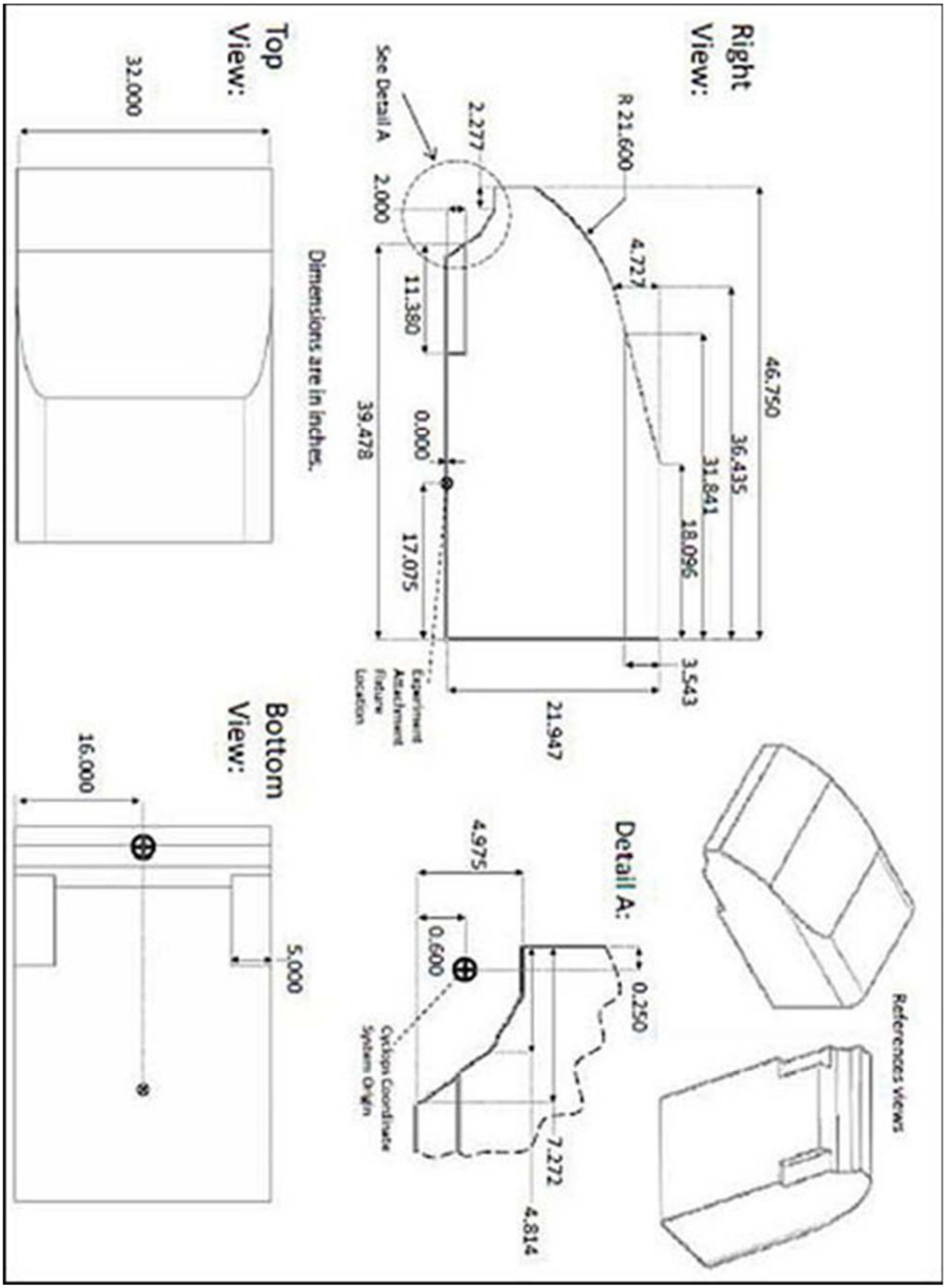


Diagram 1-2 CYCLOPS Deployment Volume

TRAJECTORY CONSIDERATIONS

The competition baseline assumption utilizes launch on SLS EM-1 which transfers Alpha CubeSat into a region well beyond lunar distance. Here Sun-Earth-Moon gravitational perturbations can be used to good effect to meet the competition requirements with modest propulsion expenditure.

The nominal EM-1 separation state (ICPS Disposal State) results in a fairly close trailing-edge lunar swingby with lunar periapse altitude of about 1375 km, and yields escape into heliocentric space if no adjustments to the trajectory are made by the spacecraft. Because of the sensitivity of the lunar swingby dynamics, a relatively small maneuver applied prior to the swingby can be leveraged into a much larger trajectory change post-swingby. Considerable control of the post-swingby trajectory can be exerted with a maneuver of no more than 50 m/s applied during the 4-day timeframe between the ICPS Disposal and the lunar swingby. Because of the sensitivity of the swingby, it is important to get a good orbit determination (OD) of the spacecraft state. The first day, approximately, after ICPS Disposal should be used for OD prior to committing to a swingby-adjust maneuver.

Because of the relatively short timeframe, this maneuver may most effectively be executed by the chemical propulsion system, if that system has a restart capability. The ion propulsion system, as currently configured, may be able to effect only about a 7 m/s velocity change during the pre-swingby period due to the low thrust level. That thrust level is likely adequate during the mission phases further from Earth, where velocities are lower.

Thus a pre-swingby maneuver would be used to increase the periapse altitude of the lunar swingby (so less energy is gained from it), or a gradual post-swingby braking maneuver is applied by the ion system, or a combination of both. The intent is that Alpha CubeSat does not greatly exceed the 4 million km distance from Earth needed to meet the Deep Space Derby portion of the competition requirements.

After the Deep Space Derby requirements are met we transition to the Lunar Derby portion of the competition. The vantage point of 4 million km is nearly 3 times the distance of the Earth-Sun L1 or L2 regions, so a number of low-energy/multi-body trajectory strategies may be brought to bear in order to bring Alpha CubeSat to the desired lunar orbit. The classic example to what length the use of alternate minimum energy trajectories can be taken is shown in Diagram 1-3 ISEE 3 Orbital Trajectory. Such dynamics also take considerable time, so the competition requirement for 1 year endurance of flight operations will likely be met in the process.

Such a low-energy trajectory may serve to transition Alpha CubeSat from the 4 million km distance to setting up a “Weak Stability Boundary” (WSB) entry into lunar orbit. Such dynamics were used by Edward Belbruno and James Miller to facilitate, in 1991, capture of the Japanese spacecraft Hiten into lunar orbit “ballistically” (i.e., no propulsion needed). Such a capture is only weakly bound to the Moon, and further use of the chemical and/or ion propulsion systems will be needed to bring Alpha CubeSat to within the 300 to 10,000 km lunar orbit requirement of the competition.

Such WSB lunar orbit capture, as executed by Hiten, was dependent on solar perturbation, while the spacecraft was several lunar distances from Earth, to accelerate and thus raise the perigee of the orbit to lunar distance. The solar perturbation effect, whether it accelerates (as desired) or decelerates, depends on the Sun-Earth-spacecraft angle when the solar perturbation is strongest (i.e., the spacecraft at apogee of the loop leading to lunar capture). Geometrically this effect, whether accelerating or decelerating, falls into quadrants when expressed in a Sun-Earth rotating frame of reference. Alpha CubeSat has no control over which of these quadrants it will be launched into by EM-1. That will be determined by the time that the launch occurs. However, since it performs the Deep Space Derby portion of the competition first, it is expected that there will be the ability, via low-energy trajectory design, to control setup of the needed entry geometry for WSB capture into lunar orbit.

We are currently calculating alternate minimum energy trajectories that would allow for a deep space orbital injection from an ISS deployment that would result in a return trajectory that would achieve lunar orbit within a permissible and tractable time frame for the Alpha CubeSat mission. A notional representation of such a trajectory is shown in Diagram 1-4 Alpha CubeSat Notional Orbital Trajectory. The Alpha CubeSat propulsion system will need to make up the additional delta-V capability required in order to transfer from ISS to lunar distance or beyond. This must be accomplished through some combination of propulsion system optimization (e.g., high thrust short duration subsystems “hybrid injection motor”, and low thrust long duration subsystems “ion thrusters”), and alternate minimum energy trajectory optimization. The magnitude of this challenge will be established by ongoing iterations of the propulsion calculations and the trajectory analysis. For the purposes of the competition it is assumed that volume and mass remain constrained by the SLS/EM-1 deployment envelope even with ISS deployment.

Furthermore, since the small size and mass of the satellite by competition requirements limits the available mass and volume for all systems including the propulsion system and propellants additional trajectory optimization will likely be necessary even once analysis shows closure of propulsion requirements with positive margins. One of the design trades is using alternate minimum energy trajectories to reduce the propellant volume requirement and allow reallocation of space and mass to on-board hardware. First-order calculations of required propellant mass fractions for conventional Hohmann and bi-elliptic trajectories required propellant mass fractions on the order of ~80-90% for a short duration high thrust propulsion system.

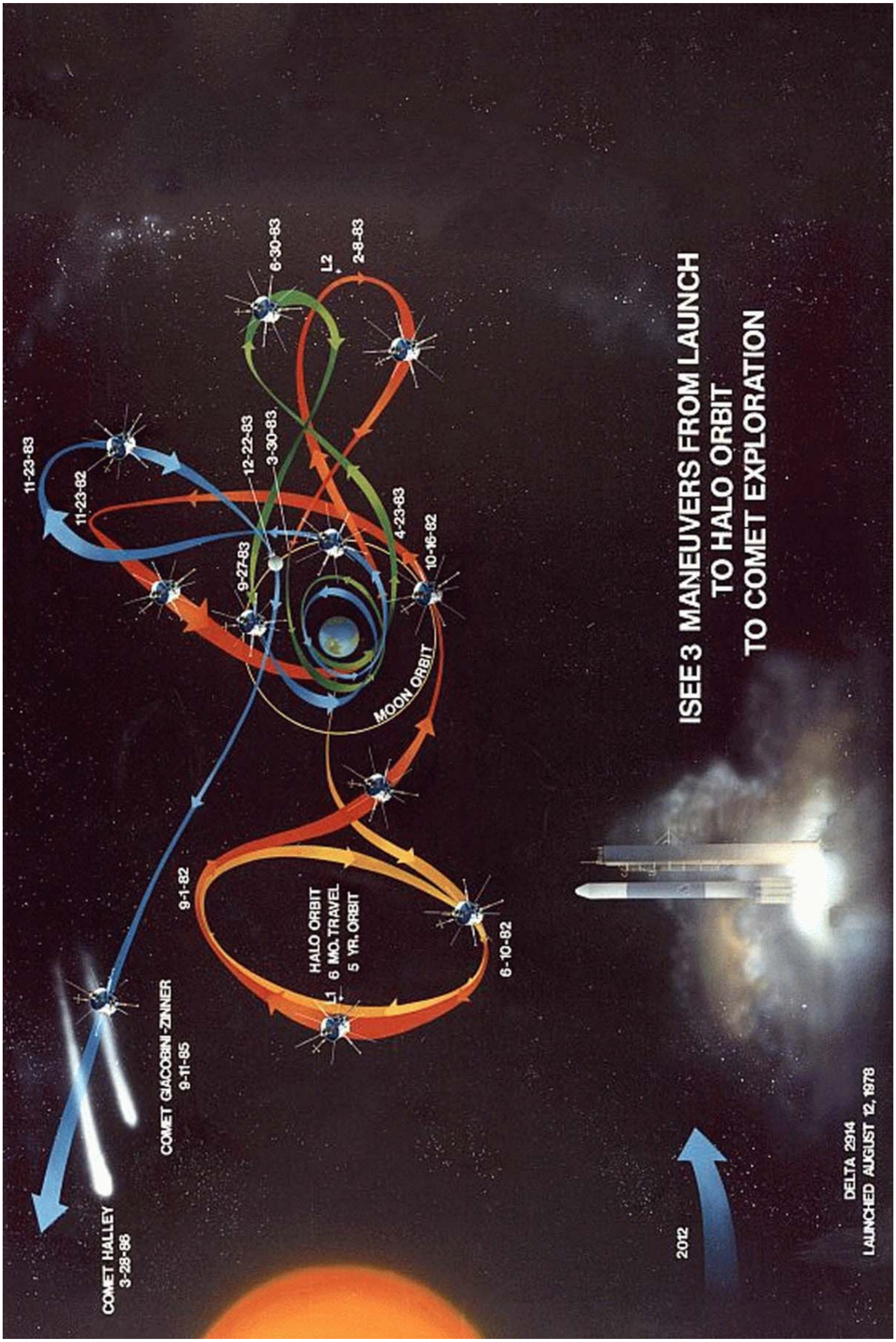
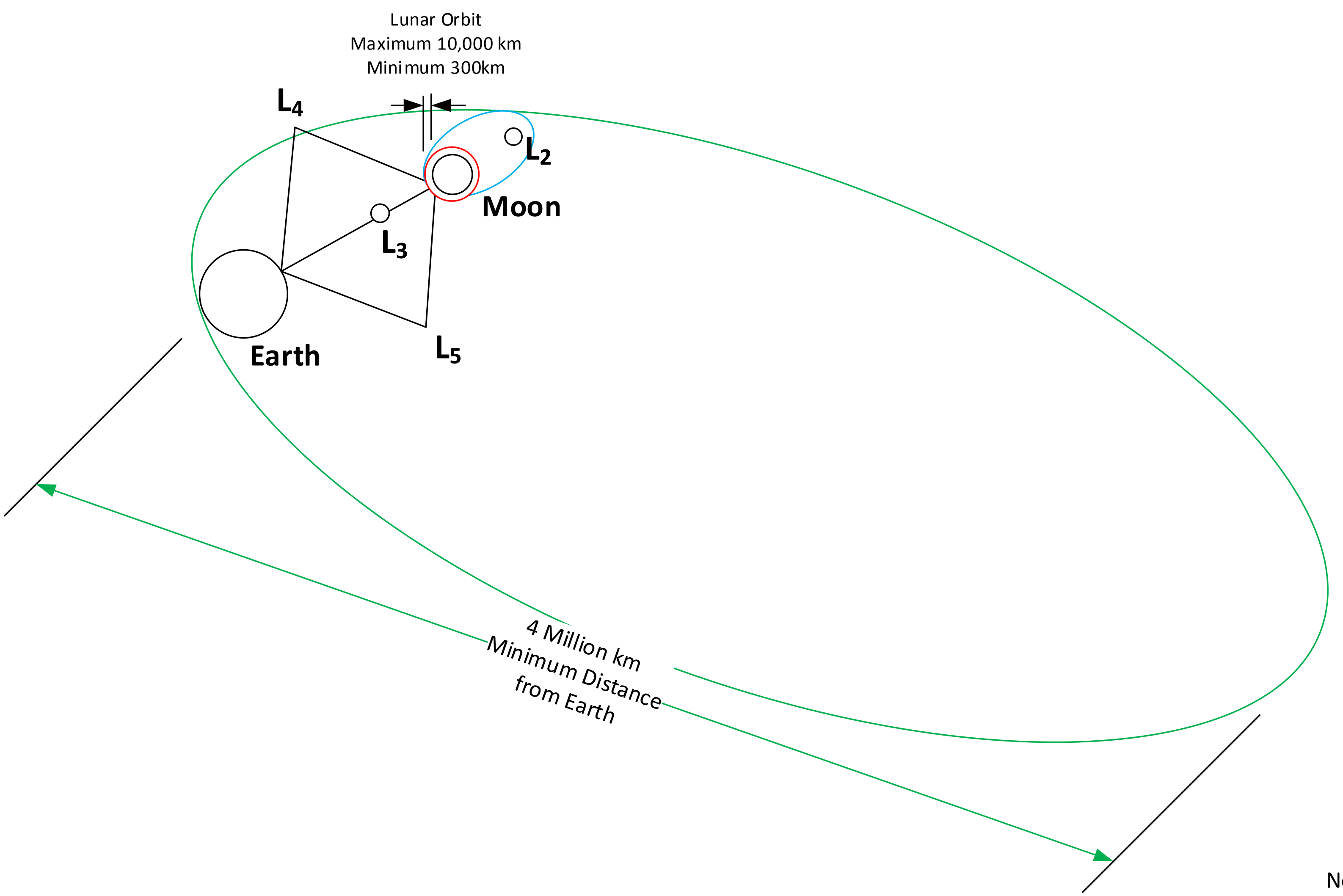


Diagram 1-3 ISEE 3 Orbital Trajectory

Diagram 1-4 Alpha CubeSat Notional Orbital Trajectory



Not To Scale

SEE TRAJECTORY UPDATE IN APPENDIX

ATTITUDE CONTROL SYSTEM CONSIDERATIONS

The Alpha CubeSat Attitude Control System is likely to consist of four main components.

- Magnetic Torquers to facilitate alignment after deployment in Low Earth Orbit before the trajectory insertion burn. Magnetic Torquers may also be of some use in Lunar Orbit and/or to assist in some configuration issues.
- Ion Thrusters to provide a low thrust long duration propulsion option.
- Cold Gas (CO_2) Thrusters will be incorporated if the mass budget permits.
- 3 axis Reaction Wheels will be defined as an option for incorporation if the mass budget permits.
- Sun sensors will be incorporated as explicit elements and/or as calculable derived data from other subsystems.

The notional placement of these subsystem components is shown in Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V 1-1.

The inclusion, number and placement of the Magnetic Torquers will depend on their mass and their calculated utility during each phase of the mission.

The possibility exists that alternate fuels when combined with a sufficient amount of power could improve performance if not obviate the need for one or more of the Attitude Control System elements.

COMMUNICATION CONSIDERATIONS

Ka Band is the frequency baseline for communications. The notional available layout real estate for transmitting and receiving antenna elements is shown in Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V 1-1.

Resources permitting, or if mission requirements dictate, a non-standard frequency allocation request and/or experimental license request will be filed to allow use of a higher regulated or unregulated frequency band.

The Alpha CubeSat link budget is still under development. However, based on the combination of baselined frequency choice, the baselined use of the DSN, and the assumption that the electrical power system can through a combination of solar cells and batteries provide sufficient power to drive the transmitter through a well pointed antenna, the ability to receive some amount of data is a virtual certainty. As to how often data transmission can be done, what the achievable throughput will be, and the longevity of the system – these and all the other Cube Quest Challenge metrics be addressed as part of the Alpha CubeSat design iteration and recursion.

Communications system broadcast power and pattern and radio hardware and antenna systems must be designed and/or selected to sufficiently meet the Cube Quest challenge requirement to communicate over a distance of 4 million km from Earth. It must also enable a sufficient burst data and net data transmission rate and volume to meet competition requirements.

ARTICULATED SUBSYSTEM CONSIDERATIONS

The combined folded solar arrays/reflector, receiving/transmitting antenna, and potential solar sail/rudder will be released after the successful completion of the Deep Space/Cis-Lunar orbital injection burn. The notional deployment volumes are shown in Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V 1-1.

The release will be by commanded burn wire or equivalent, freeing the bottom portion of the two tandem 1.5U x 3U sections with the hinge point being opposite edges of the top of the Alpha CubeSat. The solar arrays/reflector/rectenna with then unfurl based on release of captive spring tensioners.

Completely unfurled the Solar Arrays/Rectenna will lock into place allowing the deployed canopy to be optimized for use in some combination of ways. It is anticipated that the size and shape of the canopy can and will be optimized to concentrate sunlight on to solar cells, serve as a transmitting antenna, serve as a receiving antenna, act as a solar sail with some modest but measurable efficacy, as well as acting as a Ka/W band rectenna for pre or post non-contest related tests.

For improved reliability of these systems, the design will be biased to towards mechanical simplicity and the reduction and/or elimination of moving parts to reduce system wear and increase reliability. Such will be done by the use of spring-force deployment systems released by being cut free by burn or muscle wire.

At this time, we do not anticipate the use of complex electromechanical systems such as servos.

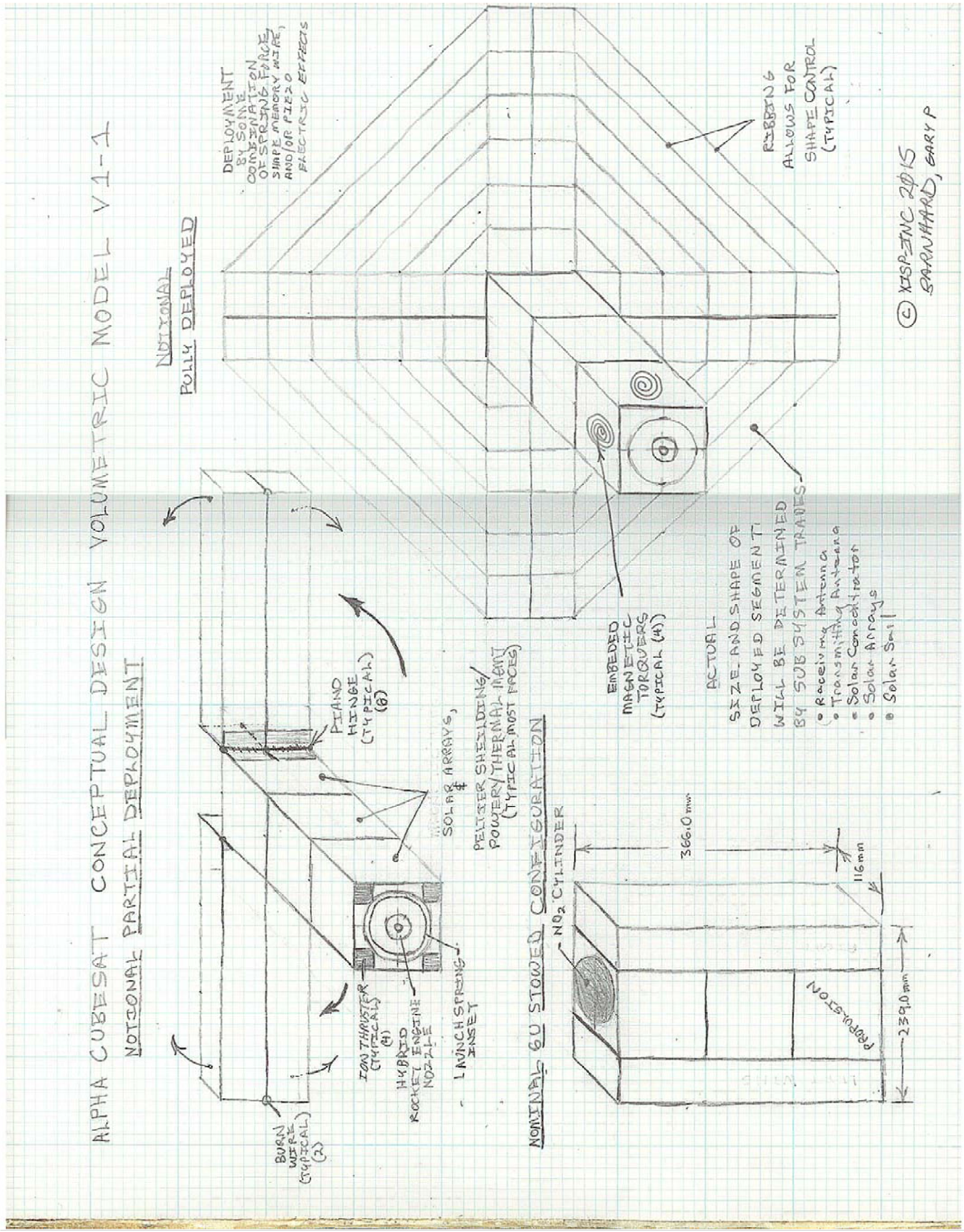


Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V1-1

ELECTRICAL CONSIDERATIONS

The notional layout real estate for Solar Cells and Peltier surfaces are shown in Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V 1-1.

The use of hybrid band gapped solar cells with solar concentrators is baselined.

The use of unified bus backplane(s) is baselined.

The use of integrated receiving antenna (rectenna) technology with direct or indirect solar array functionality is baselined.

Power requirements and use scheduling of all electrical systems for communications, guidance, navigation and control, propulsion and sensors will drive the sizing and type designation of the solar power system as well as power storage.

Power management will need to be planned and controlled on the vehicle to optimize the power system for operations and size and mass on the limited available size and mass of the Alpha CubeSat system.

NAVIGATION CONCEPTS

It is anticipated that Alpha CubeSat will obtain a navigation fix using best the available tools (e.g., geospatial positioning constellations, etc.) while in LEO, and by the DSN while on the competition trajectory for the Deep Space Derby and the Lunar Derby.

The provision of geospatial positioning constellation access will be negotiated services with the respective constellation managers in coordination with NASA, our teammates, and sponsors.

PROPULSION CONSIDERATIONS

The notional placement of the propulsion system components is shown in Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V 1-1.

Alpha CubeSat intends to use some combination of Ion Thrusters (baseline), and other alternative systems to provide Low Thrust Long Duration Propulsion capabilities.

The use of a long duration and/or repetitive use low thrust propulsion system is baselined. Some combination of ion thrusters, solar sail, and cold gas thrusters will be incorporated into the Alpha CubeSat design scaled to meet the mission requirements.

In addition, the use of a short duration high thrust propulsion system is baselined for the initial orbital injection maneuver. An in-line hybrid Nitrous Oxide and Acrylic/Paraffin propulsion system is the leading alternative at this time.

The possibility exists that alternate fuels when combined with a sufficient amount of power could improve performance of one or more of the selected propulsion components.

COMMAND & CONTROL CONCEPTS

The Alpha CubeSat will make use of an augmented set of the NASA ARC Mission Control technologies suite that will enable a near realtime state model of the system to be used to manage all command, telemetry, and data streams.

Resources from robotics control law and open-source Guidance, Navigation and Control (GNC) methods will be employed to develop GNC systems, hardware for a flight computer and control software, for Alpha CubeSat.

THERMAL CONSIDERATIONS

The Alpha CubeSat will spend most of its life after leaving LEO in full sun. However, given the distances involved and the limited amount of on-board power consumed during most operational states (though not all) measures must be provided to both generate and dissipate heat.

Likely scenarios include the need to turn the transmitter on often enough to help keep the satellite warm and to turn it off/throttle it when it is in danger of overheating.

Passive systems such as shading, coloring and active deployment of shades and louvers are also likely systems needed. Where the passive systems do not suffice, active thermoelectric systems will be deployed for mechanical simplicity.

It is anticipated that the management of thermal cycling may prove to be a defining factor in the longevity of the system.

SAFETY & QUALITY ASSURANCE CONSIDERATIONS

An integral part of the Ground Tournament GT1 objectives is the maturation of the spacecraft design to a level suitable for a Phase 0 safety review. This section identifies known areas of safety and quality assurance risks which must be addressed because they are likely to be of particular concern (i.e., the tall poles in tent). This list of hazards is not intended to be all inclusive or complete at this time. It is intended as starting point to define and draw out the material required for the Phase 0 Safety Review Presentation.

Representative known risks include:

Risk - Loose parts in SLS cause damage to other cubesats
Prevention -
Product overall integrity - Shake test to 10 G intended
Model Harmonics -
Fasten with secure fittings
Test - Shaker Test

Risk - Electrical safety
Prevention - Switch activates after clearing launch tube / and or after unfasten sequence from mount
Test - Model and mechanical test movements

Risk - Compressed Gas escape
Prevention - Pressure test tanks
Use known tanks from a standard parts supplier
Test - Pressure test

Risk - Failure to un-mount from SLS
Prevention - Mechanical and x systems to ensure satelite debolt and extracts from SLS
Test - Movement Test and cycled at hot and cold temperatures

Risk - Hang up while exiting the SLS
Prevention - Satelite is smooth in initial configuration of storage and extraction/ejection
Smooth surfaces
Test - Snag test with a net or other edge or other surfaces most likely to drag on

Risk - Unable to track cubesat at initial ejection
Prevention-
Test - Model RF, pointing, power, and comm sequences during deployment from SLS
Test - Long Range RF test for profile

Risk - Battery Charge depletions from initial shipping of cubesat to launch.
Prevention - Health test, final charging, solar panel quick charge after mechanical panel deploy
Test - All systems

Risk - Panel Deploy
Prevention - Simple mechanical system of burn wire with springs and latches
Test - Mechanical Hot / Cold / Vacuum test of panels
Each panel has a mechanical process to force open stuck openings - Spiraling / spinning craft

Section VII provides a Safety Phase 0 Presentation Content Matrix which provides pointers to the applicable content within this report.

Know hazard areas that will require a payload unique safety brief include:

- Grounding/Bonding
- Separation Switches
- Battery Concepts
- Battery System Diagram
- Compliance with Proposed Battery Charging Requirements
- Propellant Safety

Team Alpha CubeSat is approaching Safety compliance by developing compliance tables which first identify the possible hazards (i.e., Standard and Unique), the approach to assessing the safety risk associated with each (i.e. approach to meeting IDRD Safety Requirements), the Anticipated Hazards, the Design Options to be Assessed (alternative designs to mitigate identified hazards), as well as the special concerns associated with Payload and SPDS Battery Charging Requirements.

CONCEPTUAL CONSIDERATIONS

The Alpha CubeSat design will implement a combination of selective Peltier shielding/power generation/thermal management tiles, a protected core operating system kernel, Error Correcting Code (ECC) memory, a self-throttling thermally managed multi-core processor, and a heartbeat reboot/recovery timer.

It is anticipated that the combination of the above measures should materially mitigate the impact of the anticipated radiation exposure allowing a higher performance processor to be flown, potentially a state-of-the-art multi-core mobile processor.

The Alpha CubeSat design will consider a full range of processor/single board computing options ranging from available RAD hardened units to the Intel Next Unit of Computing (NUC) Core i5 systems.

CONCEPTUAL METHOD OF DISPOSAL

The Alpha CubeSat Team understands and acknowledges the NASA Cube Quest Challenge Requirements that every possible effort needs to be made to prevent disturbance of lunar legacy sites and/or contamination of the Mars biosphere by either a malfunctioning or an end-of-life Cube Quest Challenge related flight article.

Depending on the available resources Alpha CubeSat will either be commanded to a lunar impact or if more appropriate a Deep Space non-returning trajectory.

PRELIMINARY FREQUENCY ALLOCATION DATA PACKAGE

The NASA Cube Quest Challenge Mission Concept Registration Data Package is required to address the preliminary frequency allocation data package. This is pursuant to Cube Quest Challenge Rule 5 and subsequent Rules which require development and submission of a Radio Frequency Authorization to assist with the licensing process. This requires the download and installation of the EL-CID software, and the use thereof to create a compliant license filing application.

Q8: What is a "Preliminary Frequency Allocation Package", as referred to in Rule 3?

A8: The “Preliminary Frequency Allocation Package” should include, as a minimum, the following information:

1) <u>Planned frequency band(s) for satellite command and control, navigation, and high-speed telemetry</u>

Ka Band, specific frequency selection will be driven by the available transmitters, receivers, and frequency contention considerations if any.

2) <u>Planned date(s) for filing for FCC ELA or STA license(s)</u> (needed before transmitter operations)

As soon as an acceptable transmitter package can be found and a satisfactory and sufficient answer to any frequency contention considerations.is arrived at, the filing will be made. FCC licensed radio operators are on staff as engineers and advisors.

3) <u>Planned number and location(s) of ground/space stations</u>

- DSN Earth Station Goldstone (DSN-25 Primary during Deep Space Derby)
- DSN Earth Station Madrid (Primary, similar asset and requirement to above)
- DSN Earth Station Canberra (Primary, similar asset and requirement to above)
- -
- NEN Earth Station Whitesands
- Satellite International Space Station (for alternate ISS launch if selected)
- Satellite TDRSS Constellation
- Satellite Alpha CubeSat
- -
- Alternate Earth Stations (TBD)
- Amateur Radio Earth Stations (TBD)

All contest compliant transmissions will be through the NASA DSN.

4) <u>Name of owner/operator of planned ground station(s)</u>

NASA Deep Space Network (Primary)

Alternate Ground/Space Stations will be considered based on a case by case basis.

5) Planned transmitter power, modulation method, and coding (if known at this time)

Not known at this time.

6) Planned operational scenarios (overview and summary of command and control concepts, number of transmissions per day/week, etc.)

Not known at this time.

EL-CID STATUS

Team Alpha CubeSat has downloaded and installed the EL-CID software and initiated the development of a preliminary Frequency Allocation Data Package.

We have identified the following potential interacting nodes:

- DSN Earth Station Goldstone
- DSN Earth Station Madrid
- DSN Earth Station Canberra
- NEN Earth Station Whitesands
- Satellite International Space Station
- Satellite TDRSS Constellation
- Satellite Alpha CubeSat
- Alternate Earth Stations (TBD)
- Amateur Radio Earth Stations (TBD)

Further development of a compliant license filing application within EL-CID will occur once frequencies and power levels have been firmed up in terms of regulatory compliance and link budget.

ACS PRELIMINARY CUBE QUEST DESIGN REVIEW PACKAGE

The material presented here is the preliminary design elements as they are currently defined for Alpha CubeSat. The material is organized in the following fashion:

A. OVERALL SYSTEM DESIGN

MISSION GOALS

Team ACS intends to complete in both the Cube Quest Challenge Deep Space Derby and the Lunar Derby for all prizes.

For the Deep Space Derby ACS the Judges must verify that ACS has reached the minimum required distance from Earth (4,000,000 kilometers, as defined in the Rules). While maintaining at least this distance for prize eligibility, ACS will then seek to accomplish the communications and longevity achievements.

Judges score will score the Competitor Team performances and NASA will award the following Deep Space Derby Prizes (details and constraints are given in the Rules):

1. BEST BURST DATA RATE: $225,000 will be awarded to the Competitor Team that receives the largest, and $25,000 will be awarded to the Competitor Team that receives the second largest volume of error-free data from their CubeSat over a 30-minute period.

2. LARGEST AGGREGATE DATA VOLUME SUSTAINED OVER TIME: $675,000 will be awarded to the Competitor Team that receives the largest, and $75,000 will be awarded to the Competitor Team that receives the second largest, cumulative volume of error free data from their CubeSat over a continuous 28-day (calendar days) period.

3. SPACECRAFT LONGEVITY: $225,000 will be awarded to the Competitor Team with the longest elapsed number of calendar days, and $25,000 will be awarded to the Competitor Team with the second longest elapsed number of calendar days between the first and the last confirmed reception of data from their CubeSat.

4. FARTHEST COMMUNICATION DISTANCE FROM EARTH: $225,000 will be awarded to the Competitor Team that receives at least one, error-free, CubeSat generated data block from the greatest distance and $25,000 will be awarded to the Competitor Team with the second greatest distance.

Distance must also meet minimum Challenge requirement.

For the Lunar Derby Prizes, the Judges must verify that ACS has achieved a verifiable lunar orbit (as defined in the Rules) to win an equal share of the Lunar Derby Prize. While maintaining a verifiable lunar orbit, ACS will acquire as much error-free data within single continuous 30-minute periods, and as much error-free data within any 28-day (calendar day) period.

Judges will score ACS performances according to the Rules. NASA will award the following Lunar Derby Prizes (refer to the Rules for details and constraints):

1. LUNAR PROPULSION: $1,500,000 will be divided equally between all Competitor Teams that achieve at least one verifiable lunar orbit, with a maximum of $1,000,000 to any one Competitor Team.

2. BEST BURST DATA RATE: $225,000 will be awarded to the Competitor Team that receives the largest, and $25,000 will be awarded to the Competitor Team that receives the second largest, cumulative volume of error-free data from their CubeSat over a 30-minute period.

3. LARGEST AGGREGATE DATA VOLUME SUSTAINED OVER TIME: $675,000 will be awarded to the Competitor Team that receives the largest, and $75,000 will be awarded to the Competitor Team that receives the second largest, cumulative volume of error free data from their CubeSat over a contiguous 28-day (calendar) period.

4. SPACECRAFT LONGEVITY: $450,000 will be awarded to the Competitor Team that achieves the longest elapsed number of calendar days, and $50,000 will be awarded to the Competitor Team that achieves the second longest elapsed number of calendar days, between the first and last confirmed reception of data from their CubeSat.

The ACS winning tactics/capabilities for each derby and corresponding prize challenge are as follows:

Deep Space Derby - alternate launch options, propulsion options, ballistic escape and capture minimum energy trajectories

- **Burst Rate:** Ka Band, Available Power & CPU Cycles, NASA DSN
- **Aggregate Data Volume:** Ka Band, Available Power & CPU Cycles, NASA DSN
- **Spacecraft Longevity:** Simplicity of design elements, redundancy, fault tolerance
- **Farthest Comm Distance:** Driven by return trajectory requirements therefore TBD

Lunar Derby - alternate launch options, propulsion options, ballistic escape and capture minimum energy trajectories

- **Lunar Orbit:** minimum energy resonance orbits
- **Burst Rate:** Ka Band, Available Power & CPU Cycles, NASA DSN
- **Aggregate Data Volume:** Ka Band, Available Power & CPU Cycles, NASA DSN
- **Spacecraft Longevity:** Simplicity of design elements, redundancy, fault tolerance

SYSTEM-LEVEL REQUIREMENTS

Team ACS and the ACS Spacecraft must meet the following spacecraft and/or system-level requirements:

1. Abide by the prevailing Cube Quest Challenge rules as defined in Document No.: CCP-CQ-OPSRUL-001 Cube Quest Challenge Ground Tournaments, Deep Space Derby, and Lunar Derby Operations and Rules December 4, 2014 Revision C, December 30, 2015 and subsequent revisions as made applicable.
2. ACS Spacecraft Requirements Matrix has been abstracted from Document No.: CCP-CQ-OPSRUL-001, and have been flowed into Table X.X.
3. All abstracted rules are classified as either administrative or technical requirements.
4. All technical requirements are further classified as either spacecraft and/or system level requirements applicable to one or more systems/subsystems.
5. All technical requirements have been flowed into the spacecraft system/subsystem design development and analysis process.

SYSTEM-LEVEL BLOCK DIAGRAMS/DESIGN DESCRIPTION

System-level block diagrams (e.g., CubeSat, ground systems including ground stations, mission operations center, data center, communications networks, ground operators, etc.) have been prepared for all defined ACS Systems. The diagrams provided are as follows:

- Alpha CubeSat Spacecraft
- Communications System (COMM)
- Electrical Power System (EPS)
- Data Management System (DMS)
- Guidance, Navigation & Control (GN&C)
- Structures & Mechanisms System (S&Mech)
- Propulsion System (PROP)
- Thermal Control System (TCS)
- Payload Systems (PS)
- Ground Systems
- Launch Service Provider (LSP) Systems

IDENTIFICATION OF ALL REQUIRED ENVIRONMENTS FOR ACS

The ACS spacecraft is anticipated to be transported by motor vehicle in a shock mounted case until it is delivered to the Launch Service Provider integration facility.

The ACS Launch Service Provider will be keep ACS in a thermally stable clean room/storage environment until integrated for launch.

The ACS spacecraft may be shipped to the International Space Station (ISS) as pressurized or unpressurized cargo in consultation with the Launch Service Provider based on flight space availability and NASA flight safety guidance.

The ACS spacecraft in-space operating environments are still being characterized. Initial analysis suggests that a combination of sunpointing and occasional use of the Ka transceiver should help prevent inordinately low temperatures. High periods of use of the Ka transceiver likely will require thoughtful planning to mitigate the potential for thermal throttling.

REQUIREMENTS ANALYSIS

The ACS requirements analysis to date has started with the following design considerations outlined in the introductory sections. Additional details can be found the system/subsystem write-ups which follow.:

TECHNOLOGY READINESS LEVEL

The estimated Technology Readiness Level (TRL) for each ACS System/Subsystem has been flowed into Table X.X ACS Technology Readiness Level.

TRL definitions used are as defined in NASA/SP-2007-6105 Rev 1 pg 296.

A rational for each stated TRL is provided.

The logical construct used is that Commercial Off The Shelf (COTS) services/components available from multiple vendors are by definition TRL 9. Services/components flying on the ACS spacecraft as technology development missions are by definition no higher than TRL 7.

SUMMARY OF SYSTEM LEVEL MARGINS

ACS has established the following system level margins to be tracked and refined as we proceed with mission development.

- ACS Spacecraft Volume Budget
    - The ACS spacecraft volume budget allocated to the system/subsystem level closes with a positive margin of XX%.
    - It is anticipated that further optimization of the ACS spacecraft volument budget can be accomplished by repacking COTS systems/subsystems if necessary.
    - The ACS spacecraft volume budget is presented in Appendix Table XX ACS Spacecraft Volume Budget.
- ACS Spacecraft Mass Budget
    - The ACS spacecraft mass budget allocated to the system/subsystem level closes with a positive margin of XX%.

  - It is anticipated that further optimization of the ACS spacecraft mass budget can be accomplished by repacking COTS systems/subsystems if necessary.
  - The ACS spacecraft mass budget is presented in Appendix Table XX ACS Spacecraft Mass Budget.
- ACS Spacecraft Power Budget
  - The ACS spacecraft power budget allocated to the system/subsystem level closes with a positive margin.
  - It is anticipated that further optimization of the ACS spacecraft power budget can be accomplished by a combination of load management rules if necessary.
  - The ACS spacecraft power budget is presented in Table Appendix XX ACS Spacecraft Power Budget.
- ACS Spacecraft Trajectory Delta-V budget.
  - The ACS spacecraft trajectory Delta-V budget allocated to the system/subsystem level closes with a positive margin.
  - It is anticipated that further optimization of the ACS spacecraft trajectory Delta-V budget can be accomplished by a combination of optimization of the High Thrust Short Duration (HTSD), Low Thrust Long Duration (LTLD) propulsion capabilities as well as the ballistic escape and capture trajectories to be used.
  - The ACS spacecraft trajectory Delta-V budget is presented in Appendix Table XX ACS spacecraft trajectory Delta-V budget.
- ACS Spacecraft Communications Link Budget
  - The ACS Spacecraft Communications Link budget allocated to the system/subsystem level closes with a positive margin.
  - It is anticipated that further optimization of the ACS Spacecraft Communications Link budget can be accomplished by a combination of optimization of the High Thrust Short Duration (HTSD), Low Thrust Long Duration (LTLD) propulsion capabilities as well as the ballistic escape and capture trajectories to be used.
  - The ACS Spacecraft Communications Link budget is presented in Appendix Table XX ACS Spacecraft Communications Link budget.

SUMMARY OF KEY MISSION RISKS AND MITIGATION STRATEGIES

- Be sure to include trajectories, ranges, velocities, orbital mechanics and propulsive maneuvers analysis that support communications range and directional elements (antennas, solar arrays, pointing requirements, etc).

B. Implementation Plan

C. Ground Systems and Mission Operations Designs

D. Systems/Subsystems Design

- Spacecraft Architecture
    - CAD Model
    - Systems Block Diagram
    - Interfaces
    - Schedule
- Systems Overview
- System Designs
    - Electrical Power System (EPS)
        - Power Management and Distribution
        - Solar Arrays (conformal exterior)
        - Batteries (conformal propulsion tank corners)
    - Communications System (COMM)
        - Ka Band Radio
        - Antenna (TX+RX integrated w/solar arrays)
    - Data Management System (DMS)
        - On Board Computer
    - Structures & Mechanisms
    - Attitude Determination & Control System (ADCS)
    - Guidance, Navigation & Control System (GN&C)
    - Propulsion System (PROP)
        - Hybrid Trajectory Injection Motor Core
        - Hybrid Trajectory Injection Motor Fuel Tank
        - Ion Thrusters
        - Ion Propellant Tanks
    - Thermal System
    - Primary Payload - Encoded Bit Stream
    - Scar for Secondary Payload (future)
- System Budgets
    - Volume Budget
    - Mass Budget
    - Power Budget

SPACECRAFT ARCHITECTURE

The Alpha CubeSat spacecraft design is driven by the preceding considerations and is reflected in the Computer Aided Design (CAD) models, the overall systems block diagram, individual Systems block diagrams, individual System/Discipline Consideration Models (e.g., spreadsheet calculations to the STK software suite) and the interface models to be developed based on the outlined flow taxonomy which follows. Due to file size considerations these materials have not been interleaved into this report.

Systems Integration

- **CAD Model (*.pdf)**
  - Alpha CubeSat Spacecraft Cover
  - Alpha CubeSat Exploded View
  - Alpha CubeSat Exploded View w/ Annotations
  - Alpha CubeSat Stowed View
  - Alpha CubeSat Deployed View from Aft
  - Alpha CubeSat Deployed View from Forward
- **Systems Block Diagrams**
  - Unified Systems Block Diagrams v5.pdf
- **Spacecraft Mass, Power, and Volume Budgets & Misc. Tables**
  - Baseline Budget Cross Check.xlsx
  - Conceptual Engineering Review Workbook v5.xlsx/.pdf
    - Team Alpha CubeSat Roster
    - Mode – State Transitions
    - Milestone Schedule (embedded)
    - Dimensions
    - Table of Contents (embedded)
    - Spacecraft Configuration Summary Table
    - Systems Active in Modes-States
    - Mass and Volume Budgets
    - Power Budget
    - Phase 0 Safety Review Readiness
  - Team Alpha CubeSat Roster
    - Team Alpha CubeSat Organization-V5.pdf

System/Discipline Consideration Models

- Models unless noted are located in the Team Alpha CubeSat Conceptual Engineering Review Workbook Set which is supplied as a formatted appendix to this report.
  - Communications System (COMM)

        - Link Budget Worksheet.xlsx
    - Guidance, Navigation & Control System (GN&C) / Trajectories
        - AlphaCubesat_ThrustCalc01_CRC.xlsx
        - WSB_lunar-capture.pdf
        - Dahlstrom – ISDC Halfway.pdf
        - STK Astrogater Model under development
    - Propulsion System (PROP)
        - ACS Delta-V Propulsion Calculations.xlsx
    - Thermal System
        - Solar Panel Heat Rejection.xlsx
        - Energy balance –CubeSat.xlsx

Interfaces

- Flow Taxonomy
    - Mass
        - Solid
        - Liquid
        - Gas
    - Information
        - Commands
        - Data
        - Telemetry
    - Energy
        - Kinetic
        - Magnetic
        - Electrical
        - Thermal
        - Light
        - Radiation

Team Alpha CubeSat Schedule

The architectural and engineering development of the Alpha CubeSat spacecraft is tracking to the following external Cube Quest Challenge schedule show below.

A detailed internal engineering development and program schedule is being assembled but has not been completed because the architecture of the system, is being driven by the COTS first strategy adopted. Accordingly, is likely to remain fluid until the make versus buy decisions are firmed up in the Preliminary Design Phase.

Team Alpha CubeSat Schedule as of February 5, 2016			
Milestone	**Date**	**Applicability**	**Status**
Cube Quest Challenge Team Registration Opens	November 24, 2014	Yes	Challenge Announced
In-Space Competition; non-EM-1 launches	November 24, 2014	Yes	Competition Begins
Cube Quest Summit	January 7, 2015	Yes	Attended
Notice of Intent to Form Team Alpha CubeSat	January 1, 2015	Yes	Submitted & Confirmed
Formal Registration Acceptence	March 2, 2015	Yes	Confirmed
Notice of Intent of Team Alpha Cubesat to Compete	March 2, 2015	Yes	Submitted & Confirmed
Mission Concept Registration Data Package	April 30, 2015	Yes	Submitted
Monthly Report Team Inception through March 2015	April 30, 2015	Yes	Submitted
Monthly Report - April 2015	May 7, 2015	Yes	Submitted
Monthly Report - May 2015	June 7, 2015	Yes	Submitted
Cube Quest Challenge Townhall	June 11, 2015	Yes	Attended
Monthly Report - June 2015	July 7, 2015	Yes	Submitted
Alpha CubeSat Conceptual Design Review Process			
GT1 Data Submission	July 3, 2015	Yes	Submitted
GT1 Tournament	August 3, 2015	Yes	Submitted
Monthly Report - July 2015	August 7, 2015	Yes	Submitted
ACS Conceptual Design Review	August - October	Yes	Team agreed press to PDR
Cube Quest Summit II	October 21, 2015	Yes	Attended
Cumulative Monthly Report - January 2015 - January 2016	February 2, 2016	Yes	Submitted
Alpha CubeSat Preliminary Design Review Process			
GT2 Data Submission	February 5, 2016	Yes	Pending
GT2 Tournament	March 1, 2016	Yes	Pending
ACS Preliminary Design Review (PDR)	March - April	Yes	Team Vote
Alpha CubeSat Critical Design Review Process			
GT3 Data Submission	August 5, 2016	Yes	Future Event
GT3 Tournament	September 7, 2016	Yes	Future Event
ACS Critical Design Review (CDR)	September - October	Yes	Team+LSP+NASA Vote
Alpha CubeSat Flight Readiness Review Process			
GT4 Data Submission	February 3, 2017	Yes	Future Event
GT4 Tournament	March 1, 2017	Yes	Future Event
ACS Flight Readiness Review (FRR)	March - December	Yes	Team+LSP+NASA Vote
ACS Delivery to Launch Service Provider (LSP)	FRR Complete + 1 month	Yes	Future Event
ACS Delivery to Deep Space Trajectory Insertion Point	FRR Complete + 3/6 months	Yes	Future Event
In-Space Competition; EM-1 scheduled launch date	EM-1 Launch (early 2018)	Reference	Sliped to Late 2018
End of Competition	EM-1 Launch + 365 days	Yes	Future Event

SYSTEMS OVERVIEW

Team Alpha CubeSat has organized the narrative material for each defined System in the following manner:

- **Purpose/Responsibility** – The purpose of each System and its assigned responsibilities are defined.
- **Driving requirements** - The requirements which a given System must meet that are most constraining and/or the most difficult to accommodate (e.g., the tall poles in the tent).
- **Trade space** - The set of potentially viable design solutions for each System is bounded by some combination of first principles physics, driving requirements, as well as cost (i.e., commercial off the shelf ➔ new product), schedule (i.e., availability of product, orchestration of component builds/testing/mandatory design and flight safety reviews/final assembly/integration/launch), and technical (i.e., Technology Readiness Level (TRL), flight heritage, performance/redundancy/availability/margin adequacy) risk.
- **Analysis** - The qualitative and quantitative processes used to evaluate the trade space to draw out the design solutions that are both satisfactory and sufficient.
- **Baseline** – Each System has a baseline architecture which defines the set of subsystems/components which are considered part the System in question for the purposes of the mission.
- **Block diagram** - Each system has a block diagram which shows the delineated subsystems/components, the physical interfaces, augmentations under consideration, and special considerations of note.
- **Design Alternatives under consideration** – These design alternatives come into play where there is either a known System deficiency requiring an augmentation, an area of risk which could require a major design change, and/or an opportunity to enhance System performance that is sufficiently compelling to warrant consideration
- **Identified cost, schedule, and technical risks** – The baseline design choices selected for each System have some identified cost, schedule, and technical risk which the flight project is buying off on mitigating prior to launch..
- **Other related tournament questions** - The tournament workbook, and other Cube Quest Challenge technical documentation raises some number of specific questions which for convenience should explicitly reference where elsewhere in the design document they are or will be addressed, or alternatively addressed in this section.

ELECTRICAL POWER SYSTEM (EPS)

Purpose / Responsibility

The purposes of the Electrical Power System, in order of priority, is to:

1. Accept current from solar panels to operate loads and charge batteries
2. Power loads using stored electrical power when power from solar panels is insufficient or unavailable
3. Measure and report battery condition as well as temperatures to environmental control subsystem
4. Measure and report current draw from discrete subsystems and busses
5. Provide some level of solar output data to GNC which will be used to sanity check sun sensor position data
6. Provide power to secondary payloads as appropriate

It is the responsibility of the power system to maintain the batteries within their nominal envelope in terms of charge / discharge currents, state of charge, and temperature while providing power to all subsystems.

Driving Requirements

All system requirements are driven by the most severe test of the system. Physically, this is the high vibration environment of launch. Thermally, this is deep space solar exposure under high load or fast charge. Maintaining the electrical storage, generation, and load management will be critical in all phases of the mission. Full on load numbers are calculated at 66.5 Watts. The battery system must be able to provide power to necessary systems during the lunar derby while passing through the moon's shadow without suffering damage from an excessively deep discharge or forcing a shutdown of critical systems.

Trade Space

Total load is calculated to be 66.5 Watts, so with the six 3u solar assemblies providing an estimated 96 Watts, there is a sizable margin for both charging concurrent with operation as well as non-optimal off-axis charging which may be necessary to maintain a communication link or stabilize the internal temperatures of the craft. It should not be necessary to expand the panels, but it may become necessary to articulate the panels on one axis should later mission analysis reveal this as a requirement.

Internal battery storage is specified as a 12VDC Li-Ion 7.8 Ah unit if volume and mass budget permit. This should require little in the way of charging on the pad with the craft in a powered down configuration and would provide power during portions of the mission where pointing the communications equipment precludes directing the panels directly sunward or while in lunar orbit in the moon's shadow. Battery-only run time from fully charged is estimated to be 2 hours and 49 minutes at 50% load.

Analysis

While the solar panels in full sun provide plenty of power, there are mission parameters which preclude directing the craft so that the panels are perpendicular to the sun. To keep things simple and reliable the goal was to avoid unnecessary articulation, but depending upon other mission parameters it may become impossible to maintain the battery charge while accomplishing other mission objectives. This may make it necessary to articulate the panels on one axis (180 degrees on pitch axis).

Battery storage is almost excessive for the deep space leg of the mission, but in lunar orbit, up to half of the orbital path will be in lunar shadow. Depending on mission parameters unknown at this time, the battery capacity will need to be reassessed. Should additional capacity be required in the same or less space, other battery configurations or chemistries may be necessary.

The power system will need to be able to remove power from a malfunctioning subsystem temporarily to prevent damage and potentially bring this system back online (hard reset), as well as drop power from less critical systems to conserve power, bringing them back online once current flow is back under control. This is relatively simple to accomplish with hall effect current sensing.

Baseline

The use of commonly available cubesat solar panels in a fixed dual 2x3u stowed, 6x3u deployed configuration providing 96 Watts of power in full sun is baselined.

The use of a 12VDC Li-Ion 7.8 Ah battery is baselined and will be reevaluated once the lunar orbit period is known.

Current control will either be a thermal circuit breaker for loads or hall effect current sensors with solid state relays (SSRs) to interrupt current when necessary. The system using sensors and SSRs is baselined due to the flexibility of this approach.

Some communication between GNC and EPS to verify sensor data (sun position sensor) is baselined.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Alternatives under consideration

- No other power generation methods besides solar panels are being considered
- Other power storage methods and battery chemistries are being considered to include LiFe and supercapacitors.
- Some subsystem power control channels may be grouped to simplify the circuit and reduce the size of the power control subsystem.

Identified cost, schedule, and technical risks

Specific off the shelf solution and cost TBA. A partner organization is independently developing a EPS system for a variety of applications including cube- and nanosats.

They have indicated that the product is open source hardware and would be able to adapt the design to our specific requirements. It is unclear if their development schedule will occur in time for use this product in the competition. In the event that they cannot meet this schedule, off the shelf components are available for all major components.

There is a chance that some of the subsystem power estimates are off. In this event, we do have an adequate margin to allow for it without having to rework the system.

Some battery formulations, most notably Lithium Polymer (LiPo), become unstable in the event of physical damage, excessive temperature or charge / discharge rates. These formulations of not being considered.

Other related tournament questions not already addressed

None at this time (TBA)

COMMUNICATIONS SYSTEM (COMM)

Purpose / Responsibility

The purposes of the Communications System, in order of priority, is to:

1. Receive and validate commands (CMD)
2. Relay commands to the appropriate subsystem or bus
3. Transmit telemetry including vehicle and subsystem status information (TLM)
4. Transmit the required data for competition packets
5. Transmit and receive data as required for secondary payloads

It is the responsibility of the Communications System to perform the above tasks while staying within legal limits in terms of frequency allocation and power. To this end, licensed radio operators are on staff, both as engineers and advisors.

Driving Requirements

The requirements are driven by the most severe test of the system. Physically, this is the high vibration environment of launch. Thermally, this is deep space solar exposure. Legally Alpha Cubesat's communication system must stay within regulatory bounds in terms of frequency allocation and output power levels. After these requirements have been satisfied, the functional requirement is to provide high speed communications over the 4,000,000 km distance required by the Deep Space Derby portion of the competition.

The maximum distance of the Lunar Derby is under 10% of the distance required by the deep space derby, so a communication system designed to operate in the latter environment will exceed the requirements of the former.

Trade Space

Two frequency bands are currently under consideration, though the team remains open to the use of others. Ka-band (32GHz) is highest on the list followed by UHF (460MHz). Other bands under consideration are L-band (915MHz), C-band (5.7GHz), X-band (10GHz), and Ku-band (12-18GHz).

System Requirements

List all subsystem requirements, duplicating the requirements in the System Design Chapter that are relevant to the communications subsystem. Show how they are derived from, and their relationships to, the system-level requirements that are listed in the System Design Chapter.

Power requirement 35W, actual calculated is 33.3.

Thermal dissipation 30W, actual calculated is 28.3

System Design

Describe and illustrate the subsystem design of the communications subsystem. Show how the subsystem design, once fully implemented, will satisfy all subsystem requirements. Include Interfaces to other subsystems, relevant COTS parts cut sheets or specifications and any other documentation necessary to fully describe the communications subsystem.

In particular, the communications subsystem design description should include:

Alpha will use a Tethers Unlimited SWIFT-KTX programmable SDR transceiver with both a KA band transmitter and an X band receiver on board. The solar panels on the craft double as the antenna arrays thanks to integrated reflectarray antennas similar to that used on ISARA. These arrays have a pencil beam pattern for Ka band, and will also include a region of small antennas for X band reception.

• Complete descriptions of the ground station(s) including locations, transmitters, receivers and antenna patterns

The use of NASA DSN resources is baselined for uplink and downlink, primarily DSN-25 (Goldstone), DSN-34 (Canberra), and DSN-54 (Madrid). The capabilities of these stations are well documented in NASA records, available here: http://deepspace.jpl.nasa.gov/dsndocs/810-005/104/104H.pdf Other ground stations may be used in a backup or contest role including the equipment of HAM radio operators.

• Planned RF frequency bands, or, for optical communications, wavelengths

Uplink (command and control) activity will occur on X band at or around 7.145 GHz. The high speed downlink for telemetry, contest data packets, and payload will occur on Ka band at or around 32 GHz

• Planned transmission powers, modulation methods and coding approaches

The uplink (command and control) activity will use standard QPSK modulation at 30-50W to the dish feed, yielding a link margin of at least 19dB. Higher power transmissions are not a problem. Command and control data security will follow standard practice.

The Ka band high speed downlink will use 16QAM modulation with Reed Solomon forward Error Correction (FEC) at 5W or less. Other power settings, modulation, and FEC methods may be tried should the link fail, as these may be implemented via software commands.

- Include supporting analysis. Analysis should include environmental conditions, margins, uncertainties, assumptions, and operating states, modes and phases.

The supporting analysis is available in the included link budget. The links close, but there may be insufficient margin to achieve a reliable link in the event the receiving station(s) are occluded with heavy cloud cover. Should such conditions occur, it may still be possible to participate in the contest by increasing the transmitter power to a full 5W (intermittently and subject to thermal management) and/or slow the data rate. All of these changes may be triggered by commands on the X band system, which has a substantial margin and is largely unaffected by weather.

System Analysis

Please refer to the included link budget. The analysis tool used is mature and well documented within the spreadsheet. TRL data is available in the included Alpha Cubesat Technology Readiness Level (TRL) document.

DATA MANAGEMENT SYSTEM (DMS)

Purpose/Responsibility

The purposes of the Data Management System, in order of priority, is to:

1. Provide reliable data paths between all spacecraft Systems, subsystems, and/or buses.
2. Provide satisfactory and sufficient computational capacity to process all received command scripts as needed.
3. Provide satisfactory and sufficient computational capacity to process all telemetry including vehicle and subsystem status information (TLM) as needed for transmission.
4. Provide satisfactory and sufficient computational capacity to process and execute all required mode/state transitions.
5. Provide satisfactory and sufficient computational capacity to generate the required encoded bit stream for competition packets.
6. Provide satisfactory and sufficient computational capacity to support secondary payload requirements

It is the responsibility of the Data Management System to perform the above tasks meeting all defined quality of service requirements (i.e., performance, availability, and security) without exceeding the prevailing power and thermal limits for any given operational mode/state as well as not endangering its own ability to function

Driving requirements

The requirements are driven by the most severe test of the system which is anticipated to be the vibration environment at launch and maintaining operational stability in a long duration enhanced radiation environment subject to significant thermal cycling.

The quality of service requirements:

<u>Performance</u>: The DMS must have sufficient computational capacity (Central Processing Unit cycles, cache memory, main memory, and bulk addressable data storage space) to maintain all required code accessible, perform required housekeeping, calculated the encoded bit stream, and ensure that transmit buffer is kept filled to capacity when required to do so. The DMS must throttle its functions as necessary to not exceed the prevailing power and thermal limits for any given operational mode/state as well as not endangering its own ability to function due to high or low temperature conditions.

<u>Availability</u>: The DMS must routinely deal with multiple single event memory upsets without reboot or restart, recover from known cascading multiple event/unanticipated processing conflicts without restart, as well as recover from unknown cascading faults by restart. While the time to recover to a normal operational state is not a quantified requirement at this time, it is anticipated that it will be bounded by a watchdog timer to maximize the probability of recovery in the event of an uncharacterized failure.

Security: The DMS must be able to authenticate the source and validate the integrity of any command scripts received. The DMS must only allow the execution of authenticated and validated command scripts.

It is not anticipated the computational requirements to generate the required encoded bit stream for competition packets will stress the available capacity.

There are no secondary payload computational requirements defined at this time.

Trade space

The set of potentially viable design solutions for the Data Management System is bounded by some combination of first principles physics, driving requirements, as well as cost (i.e., Commercial-Off-The-Shelf (COTS) ➔ new product), schedule (i.e., availability of product, orchestration of component builds/testing/mandatory design and flight safety reviews/final assembly/integration/launch), and technical (i.e., Technology Readiness Level (TRL), flight heritage, performance/redundancy/availability/margin adequacy) risk.

There exist multiple space qualified and potentially space qualifyable Data Management System components and integrated Systems which are available on a COTS basis that could meet or exceed the Alpha CubeSat Data Management System requirements.

Analysis

Current analysis level is qualitative assessment of vendor specification sheets, ongoing technical discussions with other cubesat System developers as well as cubesat users concerning their selections/available products.

In the event that mass, volume, power, and/or other requirements end up driving the Alpha CubeSat to an alternate COTS or semi-custom Data Management System it is anticipated that all elements of defined risk are manageable if not mitigateable.

A near realtime state model of the system is planned to be built using the open source Mission Control Technology suite (a.k.a. WARP) as it is being augmented by the Team Alpha CubeSat founding sponsor (XISP-Inc). This will provide a simulation/operations support environment for interface verification and validation as well as ongoing assessment of system performance, availability, and security. This augmented tool kit is anticipated to be used throughout the development, testing, integration, and operations of the flight system.

Baseline

For the purposes of establishing a conceptual engineering baseline for the Data Management System, and allied systems we have chosen Blue Canyon Technologies XB1 complete CubeSat bus solution as a COTS solution readily adaptable to our design (it is designed to be split into two .5U packages) that meets or exceeds our defined requirements.

The XB1 is a highly integrated, precision spacecraft platform including:

- Ultra high-performance pointing accuracy,
- robust power system,
- command and data handling,
- RF communications,
- propulsion interfaces, and
- multiple flexible payload interfaces.
- Precision stellar-based attitude determination & control provided by dual star trackers.
- Supports precision orbit propagation of multiple target objects with flexible pointing commands to enable a wide range of missions.
- The XB1 Flight Software and simulation environment supports user-developed flight applications.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

There are no currently known design System deficiencies with the baseline Data Management System solution.

A simulation and operations support environment is being developed to test the efficacy of the system on both a qualitative and quantitative basis.

In the event a System deficiency requiring an augmentation surfaces, an area of risk which requires a major design change is identified, and/or an opportunity to enhance System performance that is sufficiently compelling to warrant consideration emerges it is anticipated that the design to interfaces will defined as to allow plug-in/plug-out replacement.

Identified cost, schedule, and technical risks

There are no currently identified cost, schedule, and/or technical risks associated with the Data Management System baseline design choice that have been flagged as an issue.

However, since the baseline Data Management System is a highly integrated solution if a significant deintegration/repackaging of subsystem components emerges as a requirement the baseline choice will most likely need to change.

Other related tournament questions not already addressed

None at this time (TBA)

Alpha CubeSat Structures Chapter

Dimensions and Mass Properties of ACS Structure

The structural layout is defined to be a 1Ux1Ux3U center stack with tandem 0.5Ux1Ux3U volumes on either side. This configuration is to position the main propulsive system thrust through the center of gravity of the spacecraft. Deployable trifold solar panels will be attached to the 2Ux3U sides of the spacecraft. Our size is constrained by the SLS Payload User's Guide (SLS-SPIE-HDBK-005) as defined in table 5-1 on page 22, our maximum stowed dimensions cannot exceed:
Width: 239.00mm
Length: 366.00mm
Depth: 113.00mm
Mass: 14 kg.
The outer chassis will bear a significant portion of the design loads and will be modeled in a finite element analysis to prove structural integrity.
The Alpha CubeSat chassis outer mold line dimensions and mass follow the SLS Payload constraints.

<u>Alpha CubeSat chassis outer dimensions and mass properties:</u>
Width: 239.00mm
Length: 366.00mm
Depth: 98.00mm
Maximum Mass: 1 kg
Internal Volume: 6,302 cubic centimeters

The internal volume was calculated assuming similar chassis thickness (approximately 17 mm) as Pumpkin CubeSat products. For example, the Pumpkin 6U CubeSat (SUPERNOVA-Rev00_20140925.doc) states outer length of their spacecraft as 365 mm and inner dimension as 329.2 mm bringing the internal volume to 7000 cc. ACS internal volume is 9.2% smaller due to less depth as a result of folded solar panels.

<u>ACS Inner dimensions:</u>
Width: 206 mm
Length: 329 mm
Depth: 93 mm

These body outer and inner mold line dimensions do not include deployables in their stowed configuration such as the solar panels (each panel is 2.5mm thick per ClydeSpace information) and antenna. The plan is to use three 6U sized panels from ClydeSpace per solar panel array totaling six panels total. With trifold panels, the solar panels in their stowed configuration are expected to be 7.5mm thick in a triple stack and will be faced against the two 2Ux3U faces of the 6U body.

The Alpha CubeSat outer stowed dimensions including all deployables vary from the chassis outer dimensions by 15 mm (symbolizing the 7.5mm thick folded solar panels on either side of the spacecraft) in the depth dimension bringing the Depth to 113.00 mm total. The solar panel mass will not exceed 2.346 kg taking into account a 15% structural mass reserve.

The center of mass envelope is defined in the table below from the CubeQuest Challenge requirements:

Parameters	Units	6U	
		Min.	**Max.**
Center of Mass, X	in. (mm)	-1.57 (-40)	+1.57 (+40)
Center of Mass Y	in. (mm)	+0.39 (+10)	+2.76 (+70)
Center of Mass Z	in. (mm)	+5.24 (+133)	+9.17 (+233)

Construction

Two options exist for the construction of the outer chassis of the ACS. It is most economical to obtain materials as off-the-shelf, space ready cubesat pieces from Pumpkin and custom machine the pieces to fit our configuration. The materials used for the chassis will be primarily AL7071 and Al6065.

It is also possible we will find a vendor motivated by demonstrating their machining technology that will 3-D print our primary structure using identical aluminum alloys as are commonly used in cubesat construction.

The chassis of the ACS spacecraft will undergo optimization iterations to acquire the lowest mass possible. For the structural analysis, the factors of safety planned to be used are 1.1 for Yield Strength and 1.5 for Ultimate strength as taken from NASA Payload Flight Equipment Requirements and Guidelines for Safety–Critical Structures (SSP 52005 Rev D) Table 5.1.2-1 Minimum Safety Factors For Payload Flight Structures Mounted to Primary and Secondary Structure.

The critical deployable mechanisms on ACS are the two solar panel arrays. Attachment points for the solar panels are constructed as follows. Each wing panel of the trifold are attached to the central panel by leaf-springs from tape measure strips to provide attachment and a mechanism to spring them open. The central panel is attached to the forward face (opposite of the engine exhaust) by a wire coil spring that allows the folded trifold 90 degrees of articulation to fold the stowed panel against the cubesat's 6U body faces. It also provides a mechanism to spring the arrays into their fully-deployed position and a mast attachment point from the array to the satellite body that can be articulated by rotation around the mast's axis to point the array towards the sun

The following section describes the design loads applicable to structure design.

DESIGN LOADS

Launch Loads
The maximum structural loads on the ACS spacecraft will occur during launch.
Launch vibrations have been summarized as x, y, z directional loads in g's as seen in the table below. A finite element analysis is planned for the chassis design and the launch loads will be applied as forces on the satellite located at the contact points of the deployment mechanism and moments around the center of gravity.

ACS will be designed to structural standards as defined in the DESIGN LOADS section of the NASA SECONDARY PAYLOAD INTERFACE DEFINITION AND REQUIREMENTS DOCUMENT (SLS-SPIE-RQMT-018).
Table 3-7 Secondary Payload Component Loads Due to Random Vibration from the Secondary Payload IDRD states:

Configuration 1a – 41lb Payload		
Axial	**Lateral**	**Radial**
±28.2g	±15.6g	±18.0g
Configuration 1b – 60lb Payload		
Axial	**Lateral**	**Radial**
±18.0	±14.3	±18.0
Configuration 2 – Sequencer		
Axial	**Lateral**	**Radial**
±28.2g	±15.6g	±18.0g

The above loads are the maximum load case scenario to be experienced by ACS and correspond to attaining the SLS EM-1 launch.
These loads will be applied to a finite element model of the ACS chassis to prove the design will have sufficient structural integrity.

Temperature Loads
It is also stated in the Secondary Payload IDRD (SLS-SPIE-RQMT-018) that the thermal environment range for spacecrafts is -143 degrees F to +200 degrees F. A finite element model of the ACS structure will undergo a transient thermal analysis to simulate rapid temperature change characteristic of the extreme space environment.

Propulsion Loads
The propulsion loads are planned to not exceed an acceleration higher than 1g. This will be accomplished by designing the HTSD propulsion system to have the appropriate limited thrust. At current, at the fully-loaded mass of 14kg, the thrust maximum can be 137.2N. This

maximum thrust will have to be reduced as the vehicle expends mass in propellants and deployed payloads over the mission.
At this time, COTS solutions for cubesat propulsion have demonstrated thrust that is below this maximum. The exception is the N_2O-40% Aluminized Paraffin Hybrid Motor that will exert 10.204gs at 14kg.

However, it is expected that with a proper redesign of the propulsion system to have a throttle, an adjusted chamber pressure, throat area and engine bell expansion ratio, the thrust maximum limit can be achieved.

For more details on propellant amounts, including the total mass of propellant for the GT-2 baselined combination HTSD & LTLD propulsion system that respectively uses a N_2O-40% Aluminized Paraffin Hybrid Motor and 4 Busek BIT-1 electric ion thrusters fueled by Iodine, see the Propulsion Chapter of this document. The propellant masses were developed using the original DeltaVs of the GT-1-level trajectory and propulsion system analysis that were required to complete the ACS mission and meet the vehicle mass and volume requirements.

The maximum loads produced by propulsion on the ACS will be applied to the flight configuration (with solar panels deployed) to assure structural integrity of the solar panel deployment mechanism. A finite element model will be created of the ACS and deployed solar panels to test the attachment points specifically and prove they will withstand propulsion loads.

ATTITUDE DETERMINATION & CONTROL SYSTEM (ADCS)

Purpose/Responsibility

The purposes of the Attitude Determination & Control System (ACDS), in order of priority, is to:

1. Provide the necessary, satisfactory, and sufficient sensors to support attitude determination.
2. Provide the necessary, satisfactory, and sufficient actuators to support attitude control.
3. Provide the executable control law logic to read the sensor data and command the actuators to achieve any commanded attitude within a reasonable time frame.

It is the responsibility of the Attitude Determination & Control System to perform the above tasks meeting all defined quality of service requirements (i.e., precision, speed, and parsimonious use of resources both consumable and renewable) without exceeding the prevailing power and thermal limits for any given operational mode/state as well as not endangering its own ability to function

Driving requirements

The requirements are driven by the most severe test of the system which is anticipated to be the vibration environment at launch and maintaining operational stability in a long duration enhanced radiation environment subject to significant thermal cycling and wear due to use.

The quality of service requirements:

Precision: ACDS must meet the attitude determination precision necessary to live within the error bounds of the initial Guidance, Navigation & Control (GN&C) orbital trajectory insertion requirements and any subsequent maneuver requirements. In addition, the ACDS control authority must be satisfactory and sufficient both in total and in usable increments to maintain sun pointing and/or Earth pointing attitudes as needed.

Speed: ACDS must be able to control attitude to a defined point within a reasonable time frame as defined by the mission operations timeline and the available resources.

Parsimonious use of resources both consumable and renewable: ACDS must provide optimized solutions for any control actions to insure the parsimonious use of all resources (e.g., consumable and renewable).

There are no secondary payload ACDS requirements defined at this time.

Trade space

The set of potentially viable design solutions for the Attitude Determination & Control System is bounded by some combination of first principles physics, driving requirements, as well as cost (i.e., Commercial-Off-The-Shelf (COTS) ➔ new product), schedule (i.e., availability of product, orchestration of component builds/testing/mandatory design and flight safety reviews/final assembly/integration/launch), and technical (i.e., Technology Readiness Level (TRL), flight heritage, performance/redundancy/availability/margin adequacy) risk.

There exist multiple space qualified and potentially space qualifyable Attitude Determination & Control System components and integrated Systems which are available on a COTS basis that could meet or exceed the Alpha CubeSat Attitude Determination & Control System requirements.

Analysis

Current analysis level is qualitative assessment of vendor specification sheets, ongoing technical discussions with other cubesat System developers as well as cubesat users concerning their selections/available products.

In the event that mass, volume, power, and/or other requirements end up driving the Alpha CubeSat to an alternate COTS or semi-custom Attitude Determination & Control System it is anticipated that all elements of defined risk are manageable if not mitigateable.

A near realtime state model of the system is planned to be built using the open source Mission Control Technology suite (a.k.a. WARP) as it is being augmented by the Team Alpha CubeSat founding sponsor (XISP-Inc). This will provide a simulation/operations support environment for interface verification and validation as well as ongoing assessment of system performance, availability, and security. This augmented tool kit is anticipated to be used throughout the development, testing, integration, and operations of the flight system.

Baseline

For the purposes of establishing a conceptual engineering baseline for the Data Management System, and allied systems we have chosen Blue Canyon Technologies XB1 complete CubeSat bus solution as a COTS solution readily adaptable to our design (it is designed to be split into two .5U packages) that meets or exceeds our defined requirements.

The XB1 is a highly integrated, precision spacecraft platform including:

- Ultra high-performance pointing accuracy,
- robust power system,
- command and data handling,
- RF communications,
- propulsion interfaces, and
- multiple flexible payload interfaces.

- Precision stellar-based attitude determination & control provided by dual star trackers.
- Supports precision orbit propagation of multiple target objects with flexible pointing commands to enable a wide range of missions.
- The XB1 Flight Software and simulation environment supports user-developed flight applications.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

There are no currently known design System deficiencies with the baseline Attitude Determination & Control System solution.

A simulation and operations support environment is being developed to test the efficacy of the system on both a qualitative and quantitative basis.

In the event a System deficiency requiring an augmentation surfaces, an area of risk which requires a major design change is identified, and/or an opportunity to enhance System performance that is sufficiently compelling to warrant consideration emerges it is anticipated that the design to interfaces will defined as to allow plug-in/plug-out replacement.

Identified cost, schedule, and technical risks

There are no currently identified cost, schedule, and/or technical risks associated with the Attitude Determination & Control System baseline design choice that have been flagged as an issue.

However, since the baseline Attitude Determination & Control System is a highly integrated solution if a significant deintegration/repackaging of subsystem components emerges as a requirement the baseline choice will most likely need to change.

Other related tournament questions not already addressed

None at this time (TBA)

GUIDANCE, NAVIGATION & CONTROL SYSTEM (GN&C)

Purpose/Responsibility

The purposes of the Guidance, Navigation & Control System (GN&C), in order of priority, is to:

1. Provide the necessary, satisfactory, and sufficient sensors *i.e., Sun Sensor, Star Trackers) to support guidance and navigation (i.e., position and trajectory determination).
2. Provide the executable control law logic to read the sun sensor data and make it available to support Attitude Determination and Control System Sun and Earth pointing solutions as needed..
3. Provide the executable control law logic to read the Star Tracker data and calculate delta trajectory solutions from uploaded baseline.

It is the responsibility of the Guidance, Navigation & Control System to perform the above tasks meeting all defined quality of service requirements (i.e., precision, speed, and parsimonious use of resources both consumable and renewable) without exceeding the prevailing power and thermal limits for any given operational mode/state as well as not endangering its own ability to function

Driving requirements

The requirements are driven by the most severe test of the system which is anticipated to be the vibration environment at launch and maintaining operational stability in a long duration enhanced radiation environment subject to significant thermal cycling and degradation of optical surfaces.

The quality of service requirements:

<u>Precision</u>: GN&C must meet the position and trajectory determination precision necessary to live within the error bounds of the uploaded baseline trajectory at each phase of the mission. In addition, the GN&C must be able to provide position and trajectory determination to enable the ACDS to maintain sun pointing and/or Earth pointing attitudes as needed.

<u>Speed</u>: GN&C must be able to calculate the spacecraft position and make trajectory determination (based on deltas from uploaded baseline trajectory solutions) within a reasonable time frame as defined by the mission operations timeline and the available resources.

<u>Parsimonious use of resources both consumable and renewable</u>: GN&C must provide position and trajectory determination capabilities sufficient to allow uploaded navigation solutions to be optimized to insure the parsimonious use of all resources (e.g., consumable and renewable).

There are no secondary payload GN&C requirements defined at this time.

Trade space

The set of potentially viable design solutions for the Guidance, Navigation & Control System is bounded by some combination of first principles physics, driving requirements, as well as cost (i.e., Commercial-Off-The-Shelf (COTS) ➔ new product), schedule (i.e., availability of product, orchestration of component builds/testing/mandatory design and flight safety reviews/final assembly/integration/launch), and technical (i.e., Technology Readiness Level (TRL), flight heritage, performance/redundancy/availability/margin adequacy) risk.

There exist multiple space qualified and potentially space qualifyable Guidance, Navigation & Control System components and integrated Systems which are available on a COTS basis that could meet or exceed the Alpha CubeSat Attitude Determination & Control System requirements.

Analysis

Current analysis level is qualitative assessment of vendor specification sheets, ongoing technical discussions with other cubesat System developers as well as cubesat users concerning their selections/available products.

In the event that mass, volume, power, and/or other requirements end up driving the Alpha CubeSat to an alternate COTS or semi-custom Attitude Determination & Control System it is anticipated that all elements of defined risk are manageable if not mitigateable.

A near realtime state model of the system is planned to be built using the open source Mission Control Technology suite (a.k.a. WARP) as it is being augmented by the Team Alpha CubeSat founding sponsor (XISP-Inc). This will provide a simulation/operations support environment for interface verification and validation as well as ongoing assessment of system performance, availability, and security. This augmented tool kit is anticipated to be used throughout the development, testing, integration, and operations of the flight system.

Baseline

For the purposes of establishing a conceptual engineering baseline for the Data Management System, and allied systems we have chosen Blue Canyon Technologies XB1 complete CubeSat bus solution as a COTS solution readily adaptable to our design (it is designed to be split into two .5U packages) that meets or exceeds our defined requirements.

The XB1 is a highly integrated, precision spacecraft platform including:

- Ultra high-performance pointing accuracy,
- robust power system,
- command and data handling,

- RF communications,
- propulsion interfaces, and
- multiple flexible payload interfaces.
- Precision stellar-based attitude determination & control provided by dual star trackers.
- Supports precision orbit propagation of multiple target objects with flexible pointing commands to enable a wide range of missions.
- The XB1 Flight Software and simulation environment supports user-developed flight applications.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

There are no currently known design System deficiencies with the baseline Guidance, Navigation & Control System solution.

A simulation and operations support environment is being developed to test the efficacy of the system on both a qualitative and quantitative basis.

In the event a System deficiency requiring an augmentation surfaces, an area of risk which requires a major design change is identified, and/or an opportunity to enhance System performance that is sufficiently compelling to warrant consideration emerges it is anticipated that the design to interfaces will defined as to allow plug-in/plug-out replacement.

Identified cost, schedule, and technical risks

There are no currently identified cost, schedule, and/or technical risks associated with the Guidance, Navigation & Control System baseline design choice that have been flagged as an issue.

However, since the baseline Guidance, Navigation & Control System is a highly integrated solution if a significant deintegration/repackaging of subsystem components emerges as a requirement the baseline choice will most likely need to change.

Other related tournament questions not already addressed

None at this time (TBA)

PROPULSION SYSTEM (PROP)

DEVELOPMENT SUMMARY:

The GT-2-level propulsion system development has evaluated several candidate COTS options and determined a few that can deliver on the DeltaV requirements of the ACS mission trajectory. As of GT-2, we have updated our trajectory analysis to take advantage of low-energy and Weak Stability Boundary characteristics of the EM system, we have greatly reduced our DeltaV requirement from the GT-1 total of ~1.3km/s to 180m/s (CITATION: Trajectory Report for GT-2 and Belbruno Trajectory).

The main benefit of this reduced DeltaV requirement is that we can now consider several COTS propulsion systems and propellants for evaluation. We first determined those who had, by the manufacturer's specifications, were able to provide a DeltaV for a 6U cubesat that exceeded our required DeltaV in stock configuration. We estimated by scaling the DeltaVs of these systems to a 6U vehicle. The propulsion system candidates, their scaled DeltaVs and TRLs are as follows (compared to our GT-1 Baseline configuration):

System	Propellant(s)	Scaled DeltaV for 6U (m/s)	TRL
Phase 4 CAT (P4-50) Ambipolar Thruster	Iodine	989.5 (1,979 for 3U)	6
	Water	744 (1,499 for 3U)	6
Tethers Unlimited HYDROS	Water	150 (Scalable to >2km/s)	6
BASELINE: Busek BIT-1	Iodine	1,333.6 (GT-1 Calculation)	5
BASELINE: Hybrid Motor	N2O-40% Aluminized Paraffin	228.0 (GT-1 Calculation)	5

CITATION: Manufacturer's Specifications on propulsion systems.

From here, the candidates will be evaluated by their following qualities:

Quality	Purpose
Propellant Safety	Compatibility to NASA Cabin Standards to allow vehicle operations in the ISS <INSERT CITATION TO NASA STANDARD>.
System Mass & Volume	Determination of fit of propulsion system into 6U mass and form factor.
Total Runtime Required	As several of the candidate systems have a total thrust of 1N or less, it is expected runtimes will need to be extended to impart the required total impulse for a given DeltaV for a specific trajectory maneuver.
Maximum Thrust Does Not Exceed 1g Acceleration	Due to ACS's deployables having a structural limit of 1g (9.8 m/s^2 of acceleration for in-space maneuvers.

These qualities can be quantified as so:

- Propellant Safety – Per the NASA Cabin Safety Standards <INSERT CITATION TO NASA STANDARD>, we are not permitted to use propellants that are inherently reactive, unstable or toxic to life. Propellants and individual components must be inert on their own when unprovoked by any external energetic force and in safed configuration.
- System Mass & Volume – Prior GT-1 propulsion development work had placed a goal limit of less than 3,000 cm^3 volume and 10 kg mass for the propulsion system and propellants to allow reservation for other systems. The propulsion system must meet or exceed the same requirements.

- Total Runtime Required – In orbital mechanical analysis, maneuvers are approximated as instantaneous accelerations given that the propulsion system burn time is sufficiently short compared to the trajectory's transit time. Also, propulsion systems have an upper limit on the operation time. Hence, to allow accuracy to the trajectory analysis, the runtime should not exceed more than 1% of a given flight leg. Also the runtime should not exceed the manufacturer's lifetime limit. To enable this, the propulsion system needs to have sufficient thrust and runtime to impart sufficient impulse for a given DeltaV maneuver.
- Maximum Thrust Does Not Exceed 1g Acceleration – Propulsion system, for the 6U mass of 14kg, must not have a thrust that exceeds 137.2N so that acceleration on the vehicle does not exceed 1g (9.8 m/s^2). This is due to the defined structural limit of deployable systems in the Structures & Mechanisms section of the ACS GT-2 report (CITATION).

ANALYSIS:

The candidate propulsion systems were analyzed using classical propulsion theory and information on the DeltaV of the specified GT-2-level trajectory. Manufacturer's specifications on the propulsion systems' I_{sp}, Thrust, Propellants were used to develop quantifications of the propulsion system's mass and volume and total runtime required within, if applicable, the above maximum thrust limit.

The following information was gathered. More can be seen in the attached Propulsion Analysis Workbook (ATTACH).

System	Propellant(s)	Propellant Mass (kg)	Propellant Volume (cm^3,U)	Total Runtime (days, % of Total)
Phase 4 CAT (P4-50) Ambipolar Thruster	Iodine	0.51	102.85, 0.10	10.71 (3.40%)
	Water	0.16	158.36, 0.16	66.26 (21.03%)
Tethers Unlimited HYDROS	Water	0.85	854.85, 0.85	0.04 (0.01%)
BASELINE: Busek BIT-1	Iodine	0.21	43.41, 0.04	72.87 (23.13%)
BASELINE: Hybrid Motor	N2O-40% Aluminized Paraffin	1.28	1042.05, 1.04	0.0002 (0.00%)

CONCLUSIONS:

The reduced DeltaV of the Belbruno trajectory allows us to eliminate the combination HTSD-LTLD propulsion system. All propulsion systems meet the mass and volume limitations established.

The only two propulsion systems that have been elimiated are the Phase 4 CAT (P4-50) Ambipolar Thruster using Water and Busek BIT-1 using Iodine have overly long propulsion runtimes required to impart the required impulse for the required DeltaV.

The remaining candidates that meet requirements are the N2O-40% Aluminized Paraffin HTSD motor, HYDROS and Phase 4 CAT (P4-50) Ambipolar Thruster using Iodine.

FUTURE DESIGN METHODOLOGY:

At this time, the most important determinant to select a propulsion system for HTSD system that meets mission requirements is I_{sp} as it determines the DeltaV capable. The baselined propulsion system using N2O-40% Aluminized Paraffin for HTSD have an expected and demonstrated I_{sp} of 200s. With these values, the propulsion system has sufficient DeltaV to meet the predicted DeltaV required by the GT-2-level trajectory analysis. For this reason, any other propulsion system candidate needs to meet or exceed this I_{sp} minimum.

Also, from the structural requirements, the propulsion system design is required to not have the vehicle at any time and at any loaded mass under HTSD propulsion experience an acceleration higher than 1g. This is the structural limit of deployable systems. It is intended that this will be accomplished by designing the system to have limited thrust by an appropriate sizing of the elements and operating conditions of the rocket nozzle and combustion chamber.

For this reason, there is a strong need to understand the math and physics-based relationship between Thrust and I_{sp} for HTSD propulsion. For HTSD propulsion, the Thrust and I_{sp} are related to the design of the propulsion system's combustion chamber dimensions, chamber pressure, throat area and nozzle expansion ratio. For this reason, a unique combustion chamber and nozzle will be sized and baselined that fits into the 6U form factor and produces the appropriate thrust at or higher than the required I_{sp}. From this, a variety of propulsion systems and propellant configurations can be evaluated.

THERMAL CONTROL SYSTEM (TCS)

Purpose/Responsibility

The purpose of the Thermal Control System is to dissipate System heat loads:

1. Electrical Power System Passive Thermal Dissipation
   - Solar Array Subsystem Passive Dissipation
   - Power Management and Distribution Subsystem Passive Dissipation
   - Battery Subsystem Passive Thermal dissipation
2. Data Management System Passive Thermal Dissipation
3. Propulsion System Passive Thermal Dissipation
4. Communications System Passive Thermal Dissipation
5. Guidance Navigation and Control System Passive Thermal Dissipation
6. Attitude Determination and Control System Passive Thermal Dissipation
7. Structures & Mechanisms Passive Thermal Dissipation

It is the responsibility of the Thermal Control System to assure that the spacecraft neither becomes too hot and sustains damage or becomes too cold and sustains damage.

Driving requirements

The Thermal Control System must maintain the heat balance in at least three challenging modes.

1. During the use of the hybrid propulsion system
2. During extended flight with either the ion thrusters on or off
3. During competition communications tests

Trade space

The set of potentially viable design solutions for the Thermal Control System is bounded by some combination of first principles physics, driving requirements, as well as cost (i.e., commercial off the shelf □ new product), schedule (i.e., availability of product, orchestration of component builds/testing/mandatory design and flight safety reviews/final assembly/integration/launch), and technical (i.e., Technology Readiness Level (TRL), flight heritage, performance/redundancy/availability/margin adequacy) risk.

The Thermal System uses some combination of tools to move heat:

1. Heat Pipes (baseline)
2. Peltier Effect Tiles (potential augment 1)
3. Phase Change Materials (Single) (potential augment 2)
4. Phase Change Materials (Dual) (potential augment 2)

The Thermal System uses some combination of tools to mitigate and/or reject heat to the environment:

1. Attitude Precision (Sun Pointing)
2. Radiator (Passive)
3. Temperature Sensors
4. Thermal Management Controllers
5. Spacial Adjacency of Equipment
6. Distribution of Equipment in Spacecraft
7. Power Cycling of Equipment

It is anticipated that all identified tools and strategies will be used with the exception of the three identified augments. The augments will be used if the passive tools to move heat are deemed insufficient.

Analysis

The qualitative and quantitative processes used to evaluate the trade space to draw out the design solutions that are both satisfactory and sufficient.

We have completed a thermal dissipation calculation for a solar panel.

We have created a spreadsheet based heat balance model

We need to verify the accuracy of the Emissivity values for all radiating surfaces or surfaces with solar load (earth load or moon load).

We are maintaining calculation workbook book with scanned notes and sketches.

The cognizant thermal engineer has outlined 5 different internal load cases:

I1 through I5.

1. All systems off
2. Full Power, Everything turned on, absolute worst case
3. Standby Mode
4. Transmit only
5. Normal Operation

And 5 different positional based external load cases

1. Ex1) LEO Day
2. Ex2) LEO Night
3. Ex3) Moon Orbit Day
4. Ex4) Moon Orbit, Dark Side
5. Ex5) Deep Space (i.e. far enough away from large objects there is only a solar load)

This makes for 25 load cases.

We are starting the analysis with I5-EX5. Deep space-normal operation and will then continue to develop I5-EX1 LEO Day, normal operation. Once the template is setup, the other 23 cases will be generated as time permits.

Energy Balance Assumptions.

- Also assumed no power scenario in LEO.
- Exented surfaces used were minimal. Approximately .1 meters squared of surface area for rejected heat to space.
- Standard concept of conducting the system waste heat to the back side of the satellite, located away from the solar load,

The Energy Balance spreadsheet assumes the Ion thruster would have 50% of its surface area exposed and radiating to space. This helped reduce the size of additional heat rejecting surfaces we have to consider as part of the design. We may be able to get away without such features (exposed heat pipe surfaces), but it will mean less radiative power to emit unwanted energy, and higher operating temperatures for the onboard systems. Looks like in LEO we will be on the order of 330 K (57 C) external surface temperatures when running at full power and Ion Thrusters turned on.

Baseline

The heat loads, tools, and strategies for dissipation, movement, and overall management have been identified on a qualitative basis and the quantitative analysis has begun.

Based on the available mass, volume, and power only passive systems are baselined.

If subsequent analysis determines active systems are required several options have been identified and will be actively tracked as resources that can be added to the design if required.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

There are no currently known design System deficiencies with the baseline Thermal Control System solution.

A simulation and operations support environment is being developed to test the efficacy of the system on both a qualitative and quantitative basis.

In the event a System deficiency requiring an augmentation surfaces, an area of risk which requires a major design change is identified, and/or an opportunity to enhance System performance that is sufficiently compelling to warrant consideration emerges it is anticipated that the design to interfaces will defined as to allow plug-in/plug-out replacement.

Identified cost, schedule, and technical risks

There are no currently identified cost, schedule, and/or technical risks associated with the Thermal Control System baseline design choice that have been flagged as an issue.

Other related tournament questions

None at this time (TBA)

PRIMARY PAYLOAD

Purpose/Responsibility

The primary payload for Alpha CubeSat is the Cube Quest Challenge encoded bit stream generator.

Driving requirements

Deep Space Derby Prizes:

• **Best Burst Data Rate:** $225,000 will be awarded to the competitor team (as defined in challenge rules) that receives the largest volume of error-free data from their CubeSat over a 30-minute period from greater than 4 million kilometers; $25,000 will be awarded to the competitor team that receives the second largest volume of error-free data.

• **Largest Aggregate Data Volume Sustained Over Time:** $675,000 will be awarded to the competitor team that receives the largest cumulative volume of error-free data from their CubeSat over a continuous 28-day period from greater than 4 million kilometers; $75,000 will be awarded to the Competitor team that receives the second largest volume of error-free data.

• **Spacecraft Longevity:** $225,000 will be awarded to the competitor team with the longest elapsed number of days between the first and the last confirmed reception of error-free data from their CubeSat from greater than 4 million kilometers; $25,000 will be awarded to the competitor team with the second longest elapsed number of days between the first and the last confirmed reception of error-free data.

• **Farthest Communication Distance from Earth:** $225,000 will be awarded to the competitor team that receives at least one, error-free, CubeSat-generated data block from the greatest distance beyond a minimum of 4 million kilometers; $25,000 will be awarded to the competitor team with the second greatest distance.

NASA will award the following Lunar Derby Prizes:

• **Lunar Propulsion:** $1,500,000 will be divided equally between all competitor teams that achieve at least one verifiable lunar orbit, with a maximum of $1,000,000 to any one competitor team.

• **Best Burst Data Rate:** $225,000 will be awarded to the competitor team that receives the largest cumulative volume of error-free data from their CubeSat over a 30-minute period while in lunar orbit; $25,000 will be awarded to the competitor team that receives the second largest volume of error-free data.

• **Largest Aggregate Data Volume Sustained Over Time:** $675,000 will be awarded to the Competitor team that receives the largest cumulative volume of error-free data from their CubeSat over a continuous 28-day period while in lunar orbit; $75,000 will be awarded to the competitor team that receives the second largest volume of error-free data.

• **Spacecraft Longevity:** $450,000 will be awarded to the competitor team that achieves the longest elapsed number of days between the first and last confirmed reception of error-free data from their CubeSat while in lunar orbit; $50,000 will be awarded to the competitor team that achieves the second longest elapsed number of days between the first and last confirmed reception of error-free data.

Trade space

The only trade space with respect to the primary payload is determining which competitions your team will compete in. In the case of Team Alpha CubeSat we have chosen to compete in both the Deep Space Derby and the Lunar Derby, and will attempt to design to win all challenges.

Analysis

We will develop both qualitative and quantitative models to evaluate the efficacy of the Team Alpha CubeSat design.

The current level of analysis shows that the:

- communication link budget closes with positive margin for both the Deep Space Derby and the Lunar Derby.
- The first order trajectory calculation based on SLS launch closes for the combined mission. The ISS trajectory calculation requires further work.
- The first order propulsion calculations based on SLS launch closes for the combined mission. The ISS trajectory calculation requires further work.
- The first order volume, mass, and power budgets based on SLS launch closes for the combined mission. The ISS trajectory calculation requires further work

Baseline

This report defines a baseline architecture for each System that appears tractable for SLS launch baseline. The ISS alternative requires further work.

Block diagram

Each system has a block diagram which shows the delineated subsystems/components, the physical interfaces, augmentations under consideration, and special considerations of note.

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

There are no primary payload design alternatives that have been defined or are anticipated.

Identified cost, schedule, and technical risks

The choice to baseline participation in both the Deep Space Derby and the Lunar Derby as well as all competitions has some elements of increased risk. However, the baseline design choices selected for each System appear to have resulted in a more robust spacecraft design which likely may prove more capable of meeting the competition performance objectives. Team Alpha CubeSat will rely on both qualitative and quantitative analysis to determine if the aggregated cost, schedule, and technical risk which the flight project is buying off can be practically mitigated prior to launch.

Other related tournament questions

SCAR FOR SECONDARY PAYLOAD

Not applicable at the present state of the design. Multiple commercial opportunities have been identified and will be defined to a level that would allow them to be accommodated if the design margin is determined to be available.

OPERATIONAL MODES AND TRANSITIONS

A block diagram showing the anticipated Alpha CubeSat Mode/State Transitions is attached in the System Block Diagram Package. This diagram was extrapolated from an existing 3U communication spacecraft design (BitSat, by Deep Space Industries, Inc) with unique extensions to accommodate additional modes and allow for a more deterministic transition flow.

Based on our qualitative assessment it is anticipated that a simplified control logic flow is possible for Alpha CubeSat focused on three primary flight regimes:

1. Prepare for operations
2. Achieve a Navigation Milestone
3. Achieve a Communication Milestone

A conventional Alpha CubeSat Mode/Transitions table is also attached System Block Diagram Package.

Volume Budget

SPACECRAFT SYSTEMS	Volume without Contingency (U)	Contingency %	Contingency (U)	Volume with Contingency (U)
Electrical Power System (EPS)				
Power Management and Distribution	0.250			0.250
Solar Arrays (conformal exterior)				0.000
Batteries (conformal propulsion tank corners)				0.000
Communications System (COMM)				
Ka Band Radio	0.500			0.500
Antenna (TX+RX integrated w/solar arrays)				0.000
Data Management System (DMS)				
On Board Computer	0.250			0.250
Structures & Mechanisms				
Integrated with each system	0.000			0.000
Attitude Determination & Control System (ADCS)				
Subsystems	0.250			0.250
Guidance, Navigation & Control System (GN&C)				
Subsystems	0.250			0.250
Propulsion System				
Hybrid Trajectory Injection Motor Core	2.000			2.000
Hybrid Trajectory Injection Motor Fuel Tank	1.000			1.000
Ion Thrusters (Four Total)	0.500			0.500
Ion Propellant Tanks (Two Total)	1.000			1.000
Thermal System				
Integrated with each system	0.000			0.000
Primary Payload Encoded Bit Stream				
Allocated to Data System	0.000			0.000
Scar for Secondary Payload (future)	0.000			0.000

Estimated Spacecraft Total Volume	6.000	0.00%	0.000	6.000

Total Allowable Spacecraft Volume (U)	6.000			6.000

Mass Budget

SPACECRAFT SYSTEMS	MASS without Contingency (kg)	Contingency		MASS with Contingency (kg)
		%	(kg)	
Electrical Power System (EPS)	2.913			3.000
Power Management and Distribution	0.000			0.000
Solar Arrays (conformal exterior)	0.000			0.000
Batteries (conformal propulsion tank corners)	0.000			0.000
Communications System (COMM)	0.000			
Ka Band Radio	0.225			0.225
Antenna (TX+RX integrated w/solar arrays)	0.000			0.000
Data Management System (DMS)	0.000			
On Board Computer	0.094			0.094
Structures & Mechanisms	0.000			
Integrated with each system	0.000			0.000
Attitude Determination & Control System (ADCS)	0.000			
Subsystems	0.000			0.000
Guidance, Navigation & Control System (GN&C)	0.000			
Subsystems	0.000			0.000
Propulsion System	0.000			
Hybrid Trajectory Injection Motor Core	3.000			3.000
Hybrid Trajectory Injection Motor Fuel Tank	6.000			6.000
Ion Thrusters (Four Total)	1.000			1.000
Thermal System	0.000			
Integrated with each system	0.000			0.000
Primary Payload Encoded Bit Stream	0.000			
Allocated to Data System	0.000			0.000
Scar for Secondary Payload (future)	0.000			0.000
Estimated Spacecraft Total Mass	13.232	5.80%	0.768	13.319
Total Allowable Spacecraft Mass (kg)	14.000			14.000

Power Budget

SPACECRAFT SYSTEMS	Power without Contingency (w)	Contingency %	Contingency (w)	Power with Contingency (w)
Electrical Power System (EPS)	90.000			90.000
Power Management and Distribution	0.000			0.000
Solar Arrays (conformal exterior)	0.000			0.000
Batteries (conformal propulsion tank corners)	0.000			0.000
Communications System (COMM)	0.000			
Ka Band Radio	0.000			0.000
Antenna (TX+RX integrated w/solar arrays)	0.000			0.000
Data Management System (DMS)	0.000			
On Board Computer	0.000			0.000
Structures & Mechanisms	0.000			
Integrated with each system	0.000			0.000
Attitude Determination & Control System (ADCS)	0.000			
Subsystems	0.000			0.000
Guidance, Navigation & Control System (GN&C)	0.000			
Subsystems	0.000			0.000
Propulsion System	0.000			
Hybrid Trajectory Injection Motor Core	0.000			0.000
Hybrid Trajectory Injection Motor Fuel Tank	0.000			0.000
Ion Thrusters (Four Total)	0.000			0.000
Thermal System	0.000			
Integrated with each system	0.000			0.000
Primary Payload Encoded Bit Stream	0.000			
Allocated to Data System	0.000			0.000
Scar for Secondary Payload (future)	0.000			0.000
Estimated Spacecraft Total Power	66.460			0.000
Total Spacecraft Power Margin* (w)	23.540			0.000

*Assumes solar array as source, battery can supplement and/or make up for non-optimal pointing.

Baseline Design Correlation/Cross Check

Alpha CubeSat Mass Budget Correlation							
System	**Subsystem**	**Part Name**	**Description**	**Vendor**	**Quantity**	**Mass**	**Total Mass**
						gram	**gram**
Power	Solar Array	3U CubeSat Solar Panel	Solar Reflectenna Array	Pumpkin	12	170	2040
Electronics	Bus	XB1 Cubesat Bus	AGPS, C&DH, EPS and Battery Pack	GomSpace	1	1150	1150
	Ka Transceiver	SWIFT-KTX	Ka Band Transciever	Tethers Unlimited	1	500	500
Propulsion	Ion Thrusters	BIT-1	Ion Thruster	Busek	4	53	212
	Ion Tank		Ion Iodine Propellant and Tank		2	3129.09	6258.188
	Ion Feed Valve		Ion Feed Valve	Busek	4	35	140
	Chemical	Chemical Propulsion	Aerojet unit with propellant as reference	Aerojet	1	3200	3200
Total				**Maximum Consumption**			**13500.188**
Estimated Baseline Mass Consumption							13500.19
Total Mass Budget							14000
Estimated Spacecraft Level Mass Margin (kg)							499.81
Estimated Spacecraft Level Mass Margin (%)							3.57%

Alpha CubeSat Power Budget Correlation							
System	**Subsystem**	**Part Name**	**Description**	**Vendor**	**Quantity**	**Power**	**Total Power**
						watts	**watts**
Power	Solar Array	3U CubeSat Solar Panel	Solar Reflectenna Array	Pumpkin	12	8.00	96.00
Total				**Maximum Production**			**96.00**
Electronics	Bus	XB1 Cubesat Bus	AGPS, C&DH, EPS and Battery Pack	GomSpace	1	6.30	6.30
	Ka Transceiver	SWIFT-KTX	Ka Band Transciever	Tethers Unlimited	1	16.00	16.00
Propulsion	Ion Thrusters	BIT-1	Ion Thruster	Busek	4	10.00	40.00
	Ion Tank		Ion Iodine Propellant and Tank		2	0.00	0.00
	Ion Feed Valve		Ion Feed Valve	Busek	4	0.04	0.16
	Chemical	Chemical Propulsion	Aerojet unit with propellant as reference	Aerojet	1	4.00	4.00
Total				**Maximum Consumption**			**66.46**
Estimated Baseline Power Consumption							66.46
Total Power Budget (watts)							96.00
Estimated Spacecraft Level Power Margin (watts)							29.54
Estimated Spacecraft Level Power Margin (%)							30.77%

Alpha CubeSat Volume Budget Correlation

System	Subsystem	Part Name	Description	Vendor	Quantity	Length	Width	Height	Volume	Total Volume
						mm	mm	mm	U	U
Power	Solar Array	3U CubeSat Solar Panel	Solar Reflectenna Array	Pumpkin	12	100.00	100.00	2.00	0.02	0.24
Electronics	Bus	XB1 Cubesat Bus	AGPS, C&DH, EPS and Battery Pack	GomSpace	1	200.00	100.00	50.00	1.00	1.00
	Ka Transceiver	SWIFT-KTX	Ka Band Transciever	Tethers Unlimited	1	86.00	86.00	45.00	0.33	0.33
Propulsion	Ion Thrusters	BIT-1	Ion Thruster	Busek	4	34.60	dia.	28.80	0.11	0.43
	Ion Tank		Ion Iodine Propellant and Tank		2	150.00	100.00	50.00	0.75	1.50
	Ion Feed Valve		Ion Feed Valve	Busek	4	20.00	20.00	25.00	0.01	0.04
	Chemical	Chemical Propulsion	Aerojet unit with propellant as reference	Aerojet	1	227.00	100.00	100.00	2.27	2.27
Total						**Maximum Consumption**				**5.82**

Estimated Baseline Volume Consumption	5.82
Total Volume Budget	6
Estimated Spacecraft Level Volume Margin (U)	0.18
Estimated Spacecraft Level Volume Margin (%)	3.07%

Based on the available mass, power and volume budgets as well as the current baseline component assessments there are positive spacecraft margins for mass, power and volume.

Based on the calculated values some reoptimization of the System level design may be warranted to allow for System and subsystem margin allocation as part of the preliminary design process.

SLS SECONDARY PAYLOAD USERS GUIDE QUESTIONNAIRE – GT1

The SLS Secondary Payload Users Guide Questionnaire Alpha CubeSat GT1 response is attached as a separate appendix.

SAFETY PHASE 0 PRESENTATION

The Alpha CubeSat Safety Phase 0 Presentation development status is outlined on the following table Phase 0 Safety Review Readiness Assessment.

Phase 0 Safety Review Readiness Assessment		
Descriptive Element Name	**Location of Content in Document**	**Status**
Phase 0 Cover Page	Boiler plate	Available
Agenda	This outline	Available
Spacecraft Programmatics		
§ Payload Objectives	Section I - Mission Statement	Provided
§ Payload Team Roster	Section I - Team Roster	Provided
§ Payload Concept of Operations	Section II - Concept of Operations	Provided
§ Space Operational Sequences	Section II - Concept of Operations	Provided
§ Launch Related Activities	Section II - Concept of Operations	Provided
§ Schedule	Section V - Team Alpha CubeSat Schedule	Provided
Flight System Overview		
§ CAD Model	Section V - Spacecraft Architecture	Provided
§ Spacecraft Block Diagram	Section V - Spacecraft Architecture	Provided
§ Interfaces	Section V - Spacecraft Architecture	Provided
System Designs		
Electrical Power System (EPS)	Section V - Systems Overview EPS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
§ Power Management and Distribution	Section V - Systems Overview EPS	Provided
Grounding/Bonding		Under Development
Separation Switches		Under Development
§ Solar Arrays (conformal exterior)	Section V - Systems Overview EPS	Provided
§ Batteries (conformal propulsion tank corners)	Section V - Systems Overview EPS	Provided
Battery Concepts		Under Development
Battery System Diagram		Under Development
Compliance with Proposed Battery Charging Requirements		Under Development
Communications System (COMM)	Section V - Systems Overview COMM	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
§ Ka Band Radio	Section V - Systems Overview COMM	Provided
§ Antenna (TX+RX integrated w/solar arrays)	Section V - Systems Overview COMM	Provided
Data Management System (DMS)	Section V - Systems Overview DMS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
§ On Board Computer	Section V - Systems Overview DMS	Provided
Structures & Mechanisms (S&M)	Section V - Systems Overview S&M	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
Attitude Determination & Control System (ADCS)	Section V - Systems Overview ADCS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
Guidance, Navigation & Control System (GN&C)	Section V - Systems Overview GN&C	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
Propulsion System (PROP)	Section V - Systems Overview PROP	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
§ Hybrid Trajectory Injection Motor Core	Section V - Systems Overview PROP	Provided
§ Hybrid Trajectory Injection Motor Fuel Tank	Section V - Systems Overview PROP	Provided
§ Ion Thrusters	Section V - Systems Overview PROP	Provided
§ Ion Propellant Tanks	Section V - Systems Overview PROP	Provided
Propellant Safety		Under Development
Thermal System (TCS)	Section V - Systems Overview TCS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
Primary Payload - Encoded Bit Stream	Section V - Primary Payload	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
Scar for Secondary Payload (future)	Section V - Secondary Payload	Future
§ System Block Diagram	Section VIII - Engineering Workbook	Future
Preliminary Safety Assessment	Section III - Safety & Quality Assurance	Provided
§ Standard Hazards	Section III - Safety & Quality Assurance	Provided (Introduction)
§ Unique Hazards	Section III - Safety & Quality Assurance	Provided (Introduction)
§ Approach to Meeting IDRD Safety Requirements	Section III - Safety & Quality Assurance	Provided (Introduction)
§ Anticipated Hazards	Section III - Safety & Quality Assurance	Provided (Introduction)
§ Design Options to Be Assessed	Section III - Safety & Quality Assurance	Provided (Introduction)
§ Payload and SPDS Battery Charging Requirements	Section III - Safety & Quality Assurance	Provided (Introduction)

ENGINEERING WORKBOOKS, VENDOR DATA & OTHER REFERENCES

All specification sheets and referenced papers is available as compendium of source documents.

Trajectory Workbook
Launch Services Provider Workbook

Communications System (COMM)
- COMM Engineering Workbook
- COMM Vendor Data
- COMM Other References

Electrical Power System (EPS)
- EPS Engineering Workbook
- EPS Vendor Data
- EPS Other References

Data Management System (DMS)
- DMS Engineering Workbook
- DMS Vendor Data
- DMS Other References

Guidance, Navigation & Control (GN&C)
- GN&C Engineering Workbook
- GN&C Vendor Data
- GN&C Other References

Structures & Mechanisms System (S&Mech)
- S&Mech Engineering Workbook
- S&Mech Vendor Data
- S&Mech Other References

Propulsion System (PROP)
- PROP Engineering Workbook
- PROP Vendor Data
- PROP Other References

Thermal Control System (TCS)
- TCS Engineering Workbook
- TCS Vendor Data
- TCS Other References

Payload System (PPS)
- TCS Engineering Workbook
- TCS Vendor Data
- TCS Other References

Ground Systems
- GRDS Engineering Workbook
- GRDS Vendor Data
- GRDS Other References