



TEAM ALPHA CUBESAT

CONCEPTUAL DESIGN REVIEW REPORT

Version 5
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INTRODUCTION

This document is intended to satisfy the NASA Cube Quest Challenge Conceptual Design Review (Ground Tournament – 1) data submission requirements in combination with the Safety Review Presentation, and Secondary Payload Users Guide (SPUG) Questionnaire. The format of this document follows the Concept Registration Data Package by Team Alpha CubeSat dated April 30, 2015, augmented based on guidance provided in the Ground Tournament Workbook.

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.

A series of four Ground Tournaments (GTs) will be conducted prior to both the Deep Space Derby and Lunar Derby. Any registered Competitor Teams – regardless of whether they intend to compete for launch on EM-1 or obtain their own launch – may

participate in any or all of the GTs. Competitor Teams that successfully compete in at least GT4, and declare their intention to launch on EM-1, are eligible for selection to integrate, launch, and be deployed from EM-1 for in-space Challenges purposes.

TEAM ROSTER - MEMBERS, ADVISORS & INTERNATIONAL LIAISONS

ALPHA CUBE SAT TEAM MEMBERS:

- Gary Barnhard – Team Leader, CEO/Systems Engineering Lead
- Matteo K. Borri – Attitude Control System Lead
- Ethan Shinen Chew – Propulsion System Lead, Systems Engineering Whip
- Mike Doty – CAD/Systems Integration Lead
- Anastasia Ford – Systems Engineering Intern
- Adam Glickman – Safety & Quality Assurance Lead
- Eric Gustafson – Thermal System Lead
- Aaron Harper – Communications System Lead, Propulsion & Power
- Brian Martin – Guidance, Navigation & Control Lead
- TJ McKinney – Radiation & Shielding
- Joseph Rauscher – Contract Specialist/Documentation
- Jephrey Rodriguez – CAD/CAE/Testing
- John Tascione – Structures & Mechanisms

ALPHA CUBESAT TEAM ADVISORS:

- Pat Barthelow – Communications systems
- Chris Cassell – STK & Orbital Dynamics
- Eric Dahlstrom – Astrophysics
- James DiCorcia – Mechanical systems
- Craig Foulds – Systems engineering
- Jerry Isdale – Software architecture

ALPHA CUBESAT TEAM INTERNATIONAL LIAISONS:

- Issac DeSouza – Electrical engineering
- Daniel Faber – Systems engineering
- Joe Hatoum – Commercial collaboration

TEAMMATES & SPONSORS

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

- 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)

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)

3. Deployment Kinetic Energy Transfer Trade

- SLS Secondary Payload Planetary Systems release mechanism based on the maximum allowable payload mass for a 6U deployer, an ejection rate of 4.6 ± 0.2 feet/sec (1.4 ± 0.06 m/sec) is anticipated for the Alpha CubeSat spacecraft. (baseline)
- ISS deployment using Special Purpose Dexterous Manipulator (SPDM) adapted (i.e., EVR interface added) Planetary Systems release mechanism (or equivalent) based on the maximum allowable payload mass for a 6U deployer, an ejection rate of 4.6 ± 0.2 feet/sec (1.4 ± 0.06 m/sec) is anticipated for the Alpha CubeSat spacecraft.
- Enhanced mechanical spring assisted deployment, with zero preload until launch is one possible augment for ISS based deployment if it is determined to be compliant with the rules.
- Potential augments will be investigated to level playing field by accounting for energy imparted by the launch vehicle. Any use of such

augmentations is subject to a favorable ruling by the Cube Quest Challenge Administration

- 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, solar sail, and cold gas thrusters 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 Band Links
 - Establish attitude and position control (magnetic torquers)
 - 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 – SLS or 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

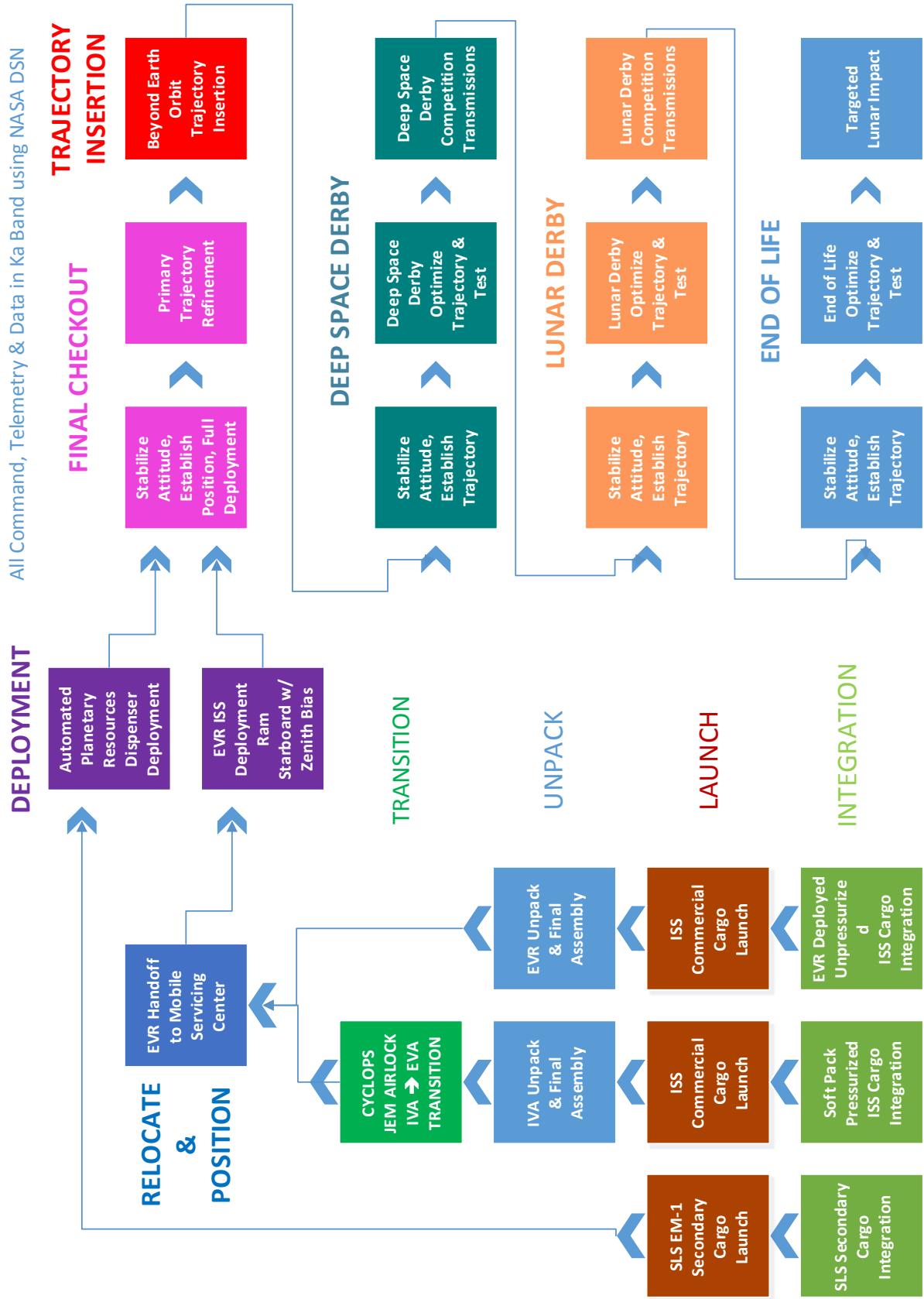
The use of the NASA Deep Space Network is the baselined ground station(s).

All command, telemetry, and data transmissions are baselined to be in Ka band (nominally 26.5 GHz – 40 GHz). data flow including anticipated frequencies, and the Cubesat.

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.

Diagram 1-1 Alpha CubeSat Concept of Operations

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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)

Deployment Kinetic Energy Transfer Trade

- SLS Secondary Payload Planetary Systems release mechanism based on the maximum allowable payload mass for a 6U deployer, an ejection rate of 4.6 ± 0.2 feet/sec (1.4 ± 0.06 m/sec) is anticipated for the Alpha CubeSat spacecraft. (baseline)
- ISS deployment using Special Purpose Dexterous Manipulator (SPDM) adapted (i.e., EVR interface added) Planetary Systems release mechanism (or equivalent) based on the maximum allowable payload

mass for a 6U deployer, an ejection rate of 4.6 ± 0.2 feet/sec (1.4 ± 0.06 m/sec) is anticipated for the Alpha CubeSat spacecraft.

- Enhanced mechanical spring assisted deployment, with zero preload until launch is one possible augment for ISS based deployment if it is determined to be compliant with the rules.
- Potential augments will be investigated to level playing field by accounting for energy imparted by the launch vehicle. Any use of such augments is subject to a favorable ruling by the Cube Quest Challenge Administration

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 70 m Goldstone dish was determined to not be required for the Deep Space Derby or the Lunar Derby so the baseline is standard DSN services based on the use of DSS-25 (and like ground station dishes). All communications to and from Alpha CubeSat will be in Ka band.

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 a secondary payload launch opportunity on the Space Launch System EM-1 is an attractive opportunity given that the drop off point is along a Cis-Lunar Injection Trajectory. However, the net energy advantage of the higher orbit may be overtaken by the energy requirements for a subsequent transition to a suitable Deep Space Derby trajectory after addressing the Lunar Derby Challenge.

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.

Q2: What sort of satellite sleep mode or off mode during launch? When are we allowed to turn it on?

A2: According to the Space Launch System Secondary Payload User's Guide (SPUG) SPUG paragraph 5.1.4, Electromagnetic Interference:

"The secondary payloads are passive during integration with the SLS vehicle and during launch and ascent. The secondary payload will delay any signal transmission for 15 seconds after deployment. Therefore, no radiated RF emissions by the integrated secondary payload / deployer unit on the vehicle are expected."

SPUG paragraph 6.6, Radiated Emissions:

“Electronic emissions from secondary payloads are controlled by requiring the secondary payload to remain powered off until deployment. The secondary payload can transmit a signal no earlier than 15 seconds after deploying. The secondary payload must also demonstrate that the payload is not susceptible to the electronic emission environment and will not result in inadvertent operation of payload functions. To prevent radiated RF emissions on the vehicle, the secondary payload must have one RF inhibit for power output that is less than 1.5W and two RF inhibits for power output equal to or greater than 1.5W.”

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.

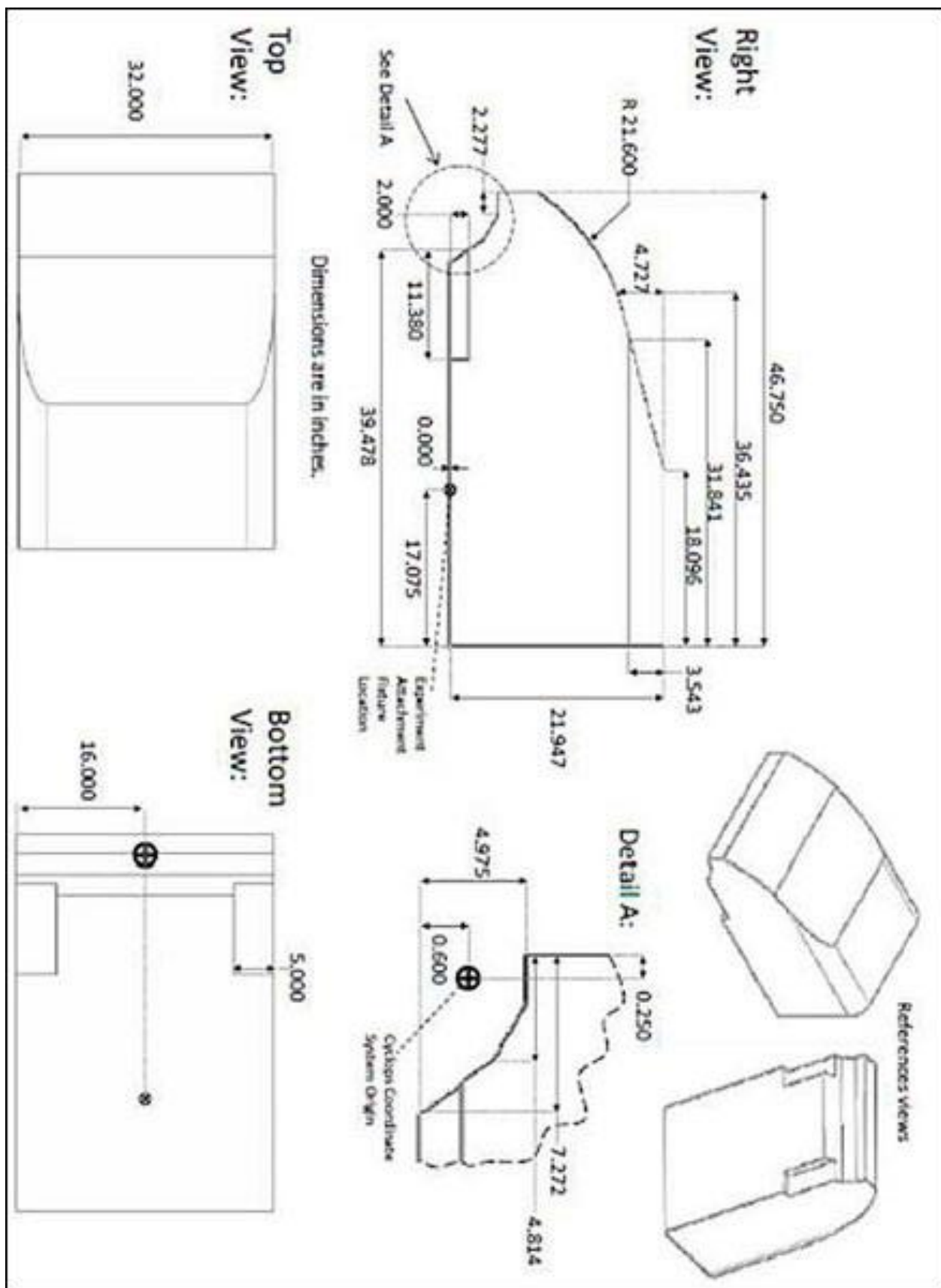


Diagram 1-2 CYCLOPS Deployment Volume

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.

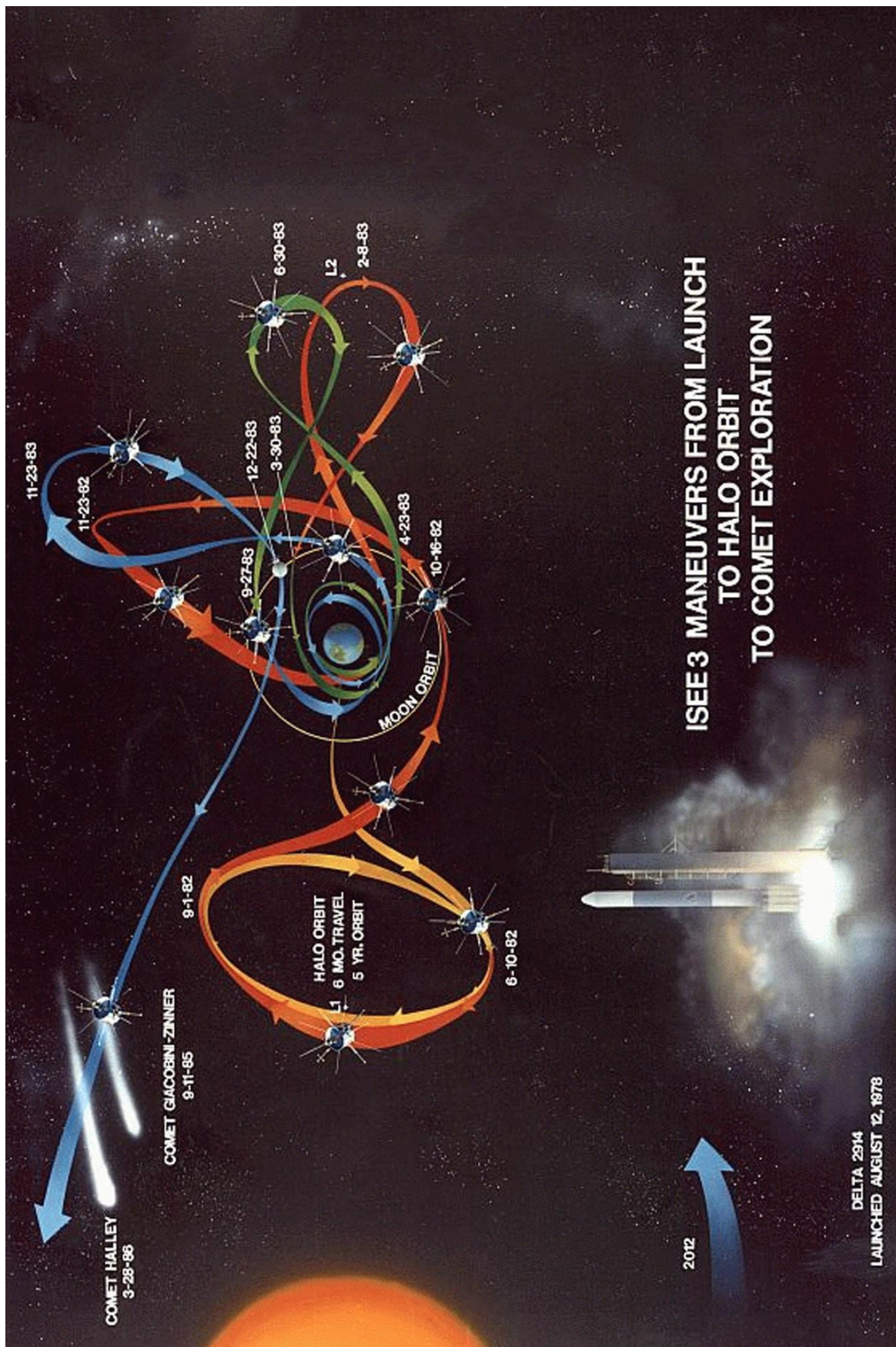
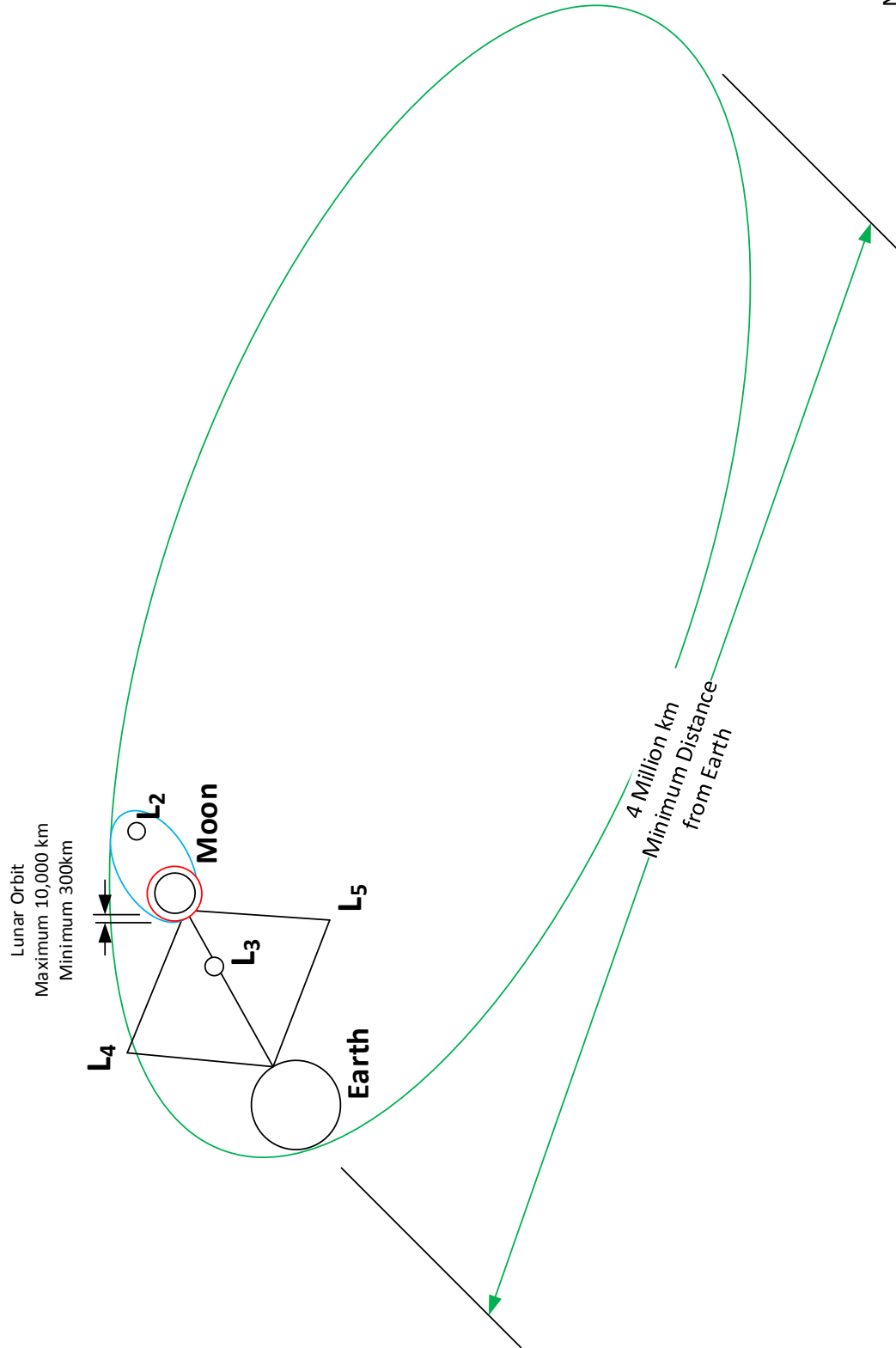


Diagram 1-3 ISEE 3 Orbital Trajectory

Diagram 1-4 Alpha CubeSat Notional Orbital Trajectory



Not To Scale
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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 (CO₂) 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.

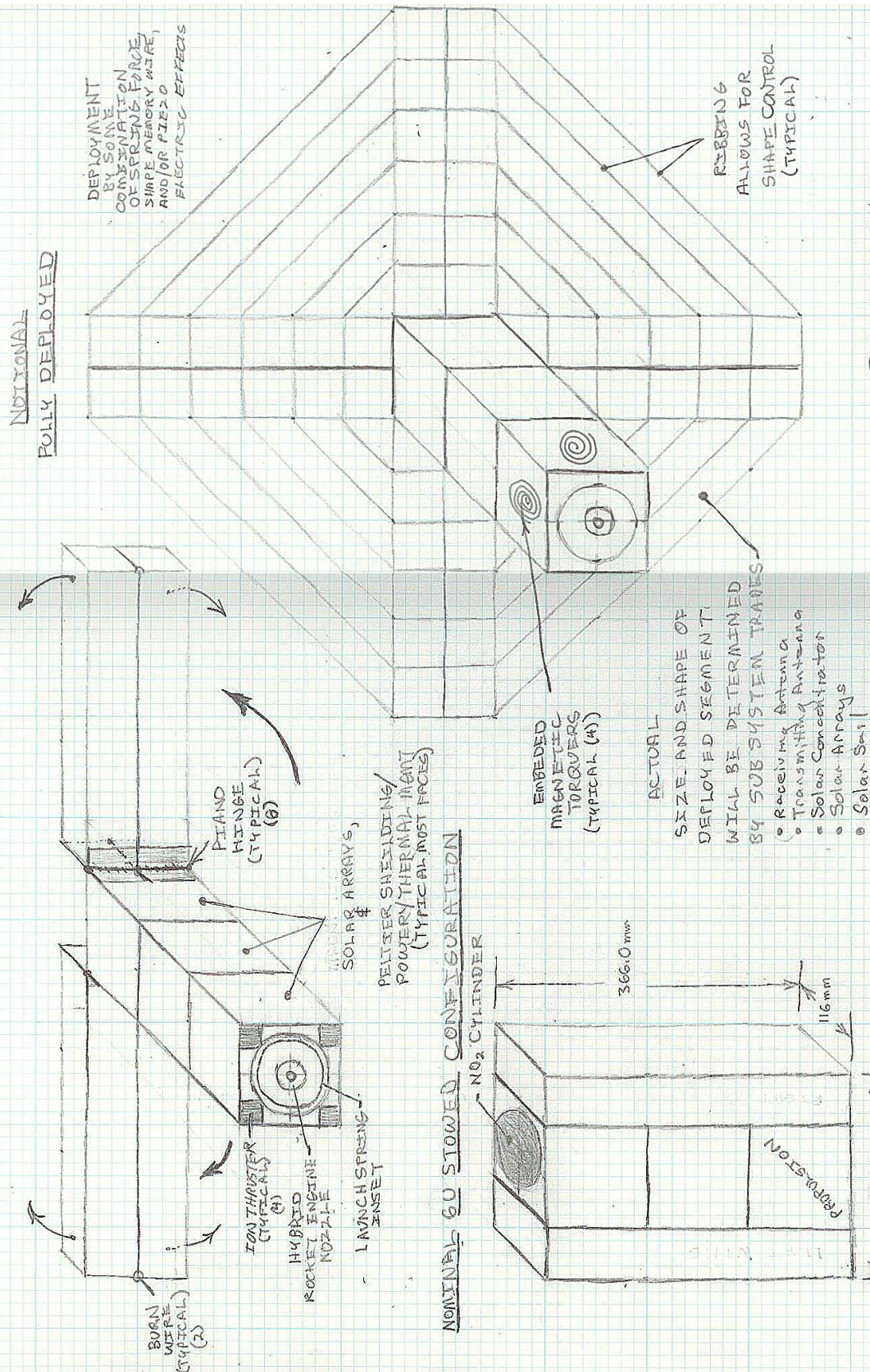
The release will be by commanded burn wire or equivalent, freeing the bottom portion of the two tandem 1.5U x 3U sections with the hinge point being opposite edges of the top of the Alpha CubeSat. The solar arrays/reflector/rectenna will then unfurl based on release of captive spring tensioners.

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.

ALPHA CUBESAT CONCEPTUAL DESIGN VOLUMETRIC MODEL V1-1 NOMINAL PARTIAL DEPLOYMENT



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BARNHARD, GARY P

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, Cold Gas Thrusters, and a solar sail/rudder 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.

Q13: What is the review/waiver process that will be required for propellant or blow-down tanks that meet the criteria of being pressure vessels (either through pressure, internal energy, or pressure + hazardous materials)?

A13: Depending on the criteria that caused the item to be deemed pressure vessel (energy storage/pressure level/content toxicity) you will need to provide structural analysis and finally pressure testing data on the vessel. If the vessel is a Commercial-Off-The-Shelf (COTS) item the vendor certification data will probably be sufficient as long as you stay within the products design parameters. If the vessel is of a new design you'll need to have several with some being tested to destruction through yield and burst tests. You also have to show a vessel leaks before rupture (doesn't become a bomb). And you may have to add safety features into a pressure system (relief valves, burst discs, active monitoring, etc.) which is all dependent on what your system is and how you have it designed. You will have to present your plans to the PSRP for how you're going to qualify a pressure vessel at Phase II. At Phase III you will have to present your data showing test conditions and results. Don't forget, in many cases the "pressure" issue doesn't stop w/the vessel but also continues to other components which must meet similar requirements.

The drive to use alternate minimum energy trajectories stems from the need to have a reasonably small propellant mass fraction onboard the satellite. Conventional trajectory solutions have been found to yield untractable solutions. Accordingly, there is need to further improve the mass fraction by choosing propulsion systems appropriate for low-energy trajectories and propellants that grant improved specific impulse, and reduced propellant volume. Furthermore, with the long-endurance mission profile, we need to select propulsion systems and propellants that are long-term storable and maintain high reliability over an extended lifetime.

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 satellite debolt and extracts from SLS

Test - Movement Test and cycled at hot and cold temperatures

Risk - Hang up while exiting the SLS

Prevention - Satellite 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) Planned frequency band(s) for satellite command and control, navigation, and high-speed telemetry

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

2) Planned date(s) for filing for FCC ELA or STA license(s) (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) Planned number and location(s) of ground/space stations

- 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) Name of owner/operator of planned ground station(s)

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.

CONCEPTUAL DESIGN ELEMENTS

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

- 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

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 Astrogator 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			
Milestone	Date	Date End (if applicable)	Status
Cube Quest Challenge Team Registration Opens	November 24, 2014	December 31, 2018	Challenge Announced
In-Space Competition; non-EM-1 launches	November 24, 2014	EM-1 Launch + 365 days	Competition Begins
Summit	January 7, 2015		Attended
Notice of Intent to Form Team Alpha CubeSat	January 1, 2015		Submitted & Confirmed
Formal Registration Acceptance	March 2, 2015		Confirmed
Notice of Intent of Team Alpha Cubesat to Compete	March 2, 2015		Submitted & Confirmed
Mission Concept Registration Data Package	April 30, 2015		Submitted
Monthly Report Team Inception through March 2015	April 30, 2015		Submitted
Monthly Report - April 2015	May 7, 2015		Submitted
Monthly Report - May 2015	June 7, 2015		Submitted
Cube Quest Challenge Townhall	June 11, 2015		Attended
Monthly Report - June 2015	July 7, 2015		Submitted
Alpha CubeSat Conceptual Design Review			
GT1 Data Submission	July 3, 2015		Submitted
GT1 Tournament	August 3, 2015		
Monthly Report - July 2015	August 7, 2015		
Phase 0 Safety Review	TBD		
Monthly Report - August 2015	September 7, 2015		
Monthly Report - September 2015	October 7, 2015		
Monthly Report - October 2015	November 7, 2015		
Monthly Report - November 2015	December 7, 2015		
Monthly Report - December 2015			
Alpha CubeSat Preliminary Design Review			
GT2 Data Submission	January 3, 2016		
GT2 Tournament	February 3, 2016		
Alpha CubeSat Critical Design Review			
GT3 Data Submission	July 3, 2016		
GT3 Tournament	August 3, 2016		
Alpha CubeSat Flight Readiness Review			
GT4 Data Submission	January 6, 2017		
GT4 Tournament	February 6, 2017		
Winning CubeSats Delivered for SLS Integration	March 1, 2017		
In-Space Competition; EM-1 launches	EM-1 Launch (early 2018)	EM-1 Launch + 365 days	

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)

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).

Analysis

Ka-band is preferred due to the extreme bandwidth possible despite issues with supply of components (compared to UHF) as well as trouble with weather occlusion. Unfortunately, relatively few amateur radio operators have the equipment which matches our needs in terms of frequency and power on Ka-band.

UHF is the second choice due to the inexpensive and ubiquitous availability of components and forgiving mechanical tolerances. The range of UHF signals as well as their ability to penetrate weather allow such a link to be quite reliable. The relatively modest requirements of a UHF link would mean that an innumerable number of amateur

radio operators would be available to provide ground station services. The downside is that there is a hard limit on how much data may be put on the bandwidth of a UHF signal, which would impact the number of packets the vehicle would be able to transmit within the contest period.

Other bands are more difficult in terms of procuring cubesat compatible components or have interference issues with terrestrial services. The tradeoffs made between UHF and Ka-band often occur with these intermediate frequencies, but in general require a compromise which is unworkable on more than one side, eg. a C-band transceiver would require fairly large components which are not as commonly available, and would suffer some weather attenuation anyway.

Given a choice between Ka-band and UHF for downlink, the choice is quite clearly Ka-band due to the bandwidth capabilities and smaller components, particularly the antenna assembly. For uplink, UHF is a clear winner in the reliability and that it is relatively impervious to weather related issues. Space is at a premium, so it may be necessary to limit ourselves to one band when it comes to the antenna and transceiver. This is where Ka-band equipment shines.

Baseline

For the above reasons a Ka-band downlink is considered baseline. The uplink / Command and Control link may either use Ka-band or UHF due to a rather low bandwidth requirement. A selection has not been made at this time.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Alternatives under consideration

- Ka-band (32GHz)
- UHF (460MHz)
- L-band (915MHz)
- C-band (5.7GHz)
- X-band (10GHz)
- Ku-band (12-18GHz)
- Laser or other photon-based communication methods

Identified cost, schedule, and technical risks

Solution and cost TBA. A partner organization is independently developing a Ka-band transceiver, and would be willing to license a solution specific to the requirements. It is unclear if their development schedule will occur in time for use in the competition. In the event that they cannot meet this schedule, off the shelf components are available for both the transceiver and antenna.

The required power and gain characteristics have been modeled in a strawman link budget which is attached in the Section VIII. ENGINEERING WORKBOOKS, VENDOR

DATA & OTHER REFERENCES Should it be necessary to test other bands, this task is now a half-second process using this tool.

Other related tournament questions not already addressed

None at this time (TBA)

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:

Performance: 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, calculate 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.

Availability: 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 be 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)

Purpose/Responsibility

The purpose of the structures and mechanisms subsystem is to:

- Rigidly mount all spacecraft components
- Contain all components within required form factor
- Provide mechanical acoustic, vibration and thermal resilience of the complete system, particularly during launch and space operations
- Maintain CG during flight ops
- Provide mount points for articulation of solar panel deployment

The responsibility of this system is to rigidly mount all components and retain them within the physical package constraints as defined by the contest and volumetric limits of the payload carrier as defined by the SLS secondary payload users guide.

Driving requirements

In order to rigidly mount all spacecraft components and contain all components within required form factor, it must provide mechanical acoustic, vibration and thermal resilience of the complete system, particularly during launch and space operations. The structure must provide mount points for articulation of solar panel deployment as well as other deployable structures as required.

Trade space

Tradespace was governed by three factors

1. Aligning the propulsion thrust vector with the body centerline
2. Ensuring maintenance of center of gravity by aligning all components symmetrically around body centerline
3. The packing and deployment of solar panels was balanced between max area and compliance with the SLS carrier

Analysis

The analysis in physical modeling indicated optimum design as stated above with tri-fold solar panels as defined within the power section.

Baseline

A centerline 3U structure containing the main propulsion unit with symmetrical 1/2 U thick 3U high wings and tri fold spring loaded solar panels is considered baseline.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

None at this time (TBA)

Identified cost, schedule, and technical risks

Risks deployment issues of both the spring loaded solar panels and deployment.

Other related tournament questions

None at this time (TBA)

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 be 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)

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:

Precision: 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.

Speed: 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.

Parsimonious use of resources both consumable and renewable: 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 be 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)

Purpose/Responsibility

Provide propulsion (delta-V) in order to reach the locations specified in both the Deep Space and Lunar Derbies. This system pertains to any methods of propulsion used to move in space. It includes all tanks, propellant lines, engines, oxidizers, fuel grain, valves and sensors for the main kick motor as well as all subsystems necessary for operation of the ion thrusters. It is the responsibility of this system to remain within mass and volume limits as specified within the structural design and competition rules, selecting each of these engine types and their associated chemistries based upon the needs defined.

Driving requirements

Propellant selection must take handling toxicity, reactivity, total required volume, and mass limitations into account. Propulsion chemistry deemed unsafe or unsuitable in these areas will be deselected.

Preliminary calculations of both ISS and SLS release (whichever is higher) place the total delta-V required at 8401.37 m/S in combination of chemical and ion propulsion. Upgrading this 18% for margin yields a total system delta-V required at 9913.62 m/S.

The Ion thrust system was best used within mission segments requiring more than 1000m/S since this is best left to the long burn characteristics of the ion thruster provide a reaction mass of sufficient density could be procured.

Trade space

The main motivation of the trade space study was to find high ISP propellants and chemistries which meet safety considerations of the SLS and ISS environments and provide sufficient delta-V within the volumetric constraints of the vehicle as defined within the competition rules.

Several propellants were evaluated ranging from compressed gas and monopropellants to highly energetic hypergolic combinations such as hydrazine and nitrogen tetroxide. the most obvious health and safety risk combinations were eliminated as well as low ISP options. The lower limit was set at 200 Sec based upon a first order hohmann trajectory from LEO to the four million km point defined in the deep space derby competition, to LLO. 200 Sec was the lower limit where a positive mass fraction of propellant and spacecraft structure.

That said all monopropellants and high energy hypergolics were eliminated by both safety criteria and minimum ISP requirements. Among the bipropellants available, hybrids were favored due to their ease of handling and safety. Of the three selected hybrids all three meet these requirements:

- N2O/Paraffin
- N2O/Asphalt

- Lithium Aluminum Hydride-Hydrogen Peroxide Hybrid

Further consideration was made for the volumetric limits of the design due to the low density of the propellants. Using purely chemical solutions required propellant volumes which exceeded the physical size of the craft. For this reason, the trajectory was modified to permit the use of Ion thruster which was fitted to provide the required delta-V where this was a possibility. Further an assessment on trajectory and propulsion systems using both the hybrid and ion systems showed promise in meeting all competition requirements.

Analysis

While the nitrous oxide / paraffin system was attractive in its relative safety, the low volume of the fuel core created no solution where the fuel core could remain within the 3U length constraint. Nitrous oxide / asphalt systems faced similar constraints. The issue stems from the low density of the fuel core yielding a larger volume for the required Isp.

One attractive alternative is a Lithium Aluminum Hydride-Hydrogen Peroxide Hybrid. This would yield the required delta-V with materials which are relatively safe and inert. It has the added benefit of being hypergolic, requiring only the H₂O₂ flow to initiate the burn. This allows a hybrid rocket motor of this design to be restartable if not directly throttleable.

The Ion thruster system allows the use of several reaction propellants. Using Xenon as a dense gas, the relatively low density compared to solids limits the total delta-V this system can provide. Using iodine allows the use of a high density solid, which in turn reduces the total volume required to complete this mission to something that can fit within the craft's available volume

Baseline

While the volume constraints of the N₂O/Paraffin or N₂O/Asphalt severely limit the available delta-V, using the ion thrusters for the majority of the maneuvers reduces the requirements to the point where the volume required is permissible. Depending on thermal characteristics, the N₂O/Paraffin or Asphalt formulation is baselined, though some effort will be put into evaluating a Lithium Aluminum Hydride-Hydrogen Peroxide Hybrid.

The Ion thruster under consideration is a set of four Busek Bit-1 thrusters arranged on the same axis as the chemical rocket motor. These may be considered baseline.

Block diagram

See Unified Systems Block Diagrams v5.pdf in appendix.

Design Alternatives under consideration

Some effort will be put into evaluating a Lithium Aluminum Hydride-Hydrogen Peroxide Hybrid for the main rocket motor, and partner solution may be available for a higher performance ion engine.

Identified cost, schedule, and technical risks

Solution and cost TBA. A partner organization is independently developing an Ion thruster, and would be willing to license a solution specific to the requirements. It is unclear if their development schedule will occur in time for use in the competition. In the event that they cannot meet this schedule, Busek Bit-1 Thrusters are available for use.

Safety risks include the chemistries of the propellants and oxidizers as well as their safe handling, pressurization of the gas/liquids as well as their storage in a vacuum with the thermal cycles typical of a space environment.

Technical risks involve the ignition and reignition of the motor. Many of the calculations should be reviewed to reassess assumptions and verify the formulae and variables.

Electrical propulsion physics and trajectories should be reviewed to ensure accuracy and viability.

Other related tournament questions

None at this time (TBA)

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. Spatial 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 be 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.

SYSTEM BUDGETS

Volume Budget

SPACECRAFT SYSTEMS	Volume without Contingency (U)	Contingency		Volume with Contingency (U)
		%	(U)	
Electrical Power System (EPS)				
<i>Power Management and Distribution</i>	0.250			0.250
<i>Solar Arrays (conformal exterior)</i>				0.000
<i>Batteries (conformal propulsion tank corners)</i>				0.000
Communications System (COMM)				
<i>Ka Band Radio</i>	0.500			0.500
<i>Antenna (TX+RX integrated w/solar arrays)</i>				0.000
Data Management System (DMS)				
<i>On Board Computer</i>	0.250			0.250
Structures & Mechanisms				
<i>Integrated with each system</i>	0.000			0.000
Attitude Determination & Control System (ADCS)				
<i>Subsystems</i>	0.250			0.250
Guidance, Navigation & Control System (GN&C)				
<i>Subsystems</i>	0.250			0.250
Propulsion System				
<i>Hybrid Trajectory Injection Motor Core</i>	2.000			2.000
<i>Hybrid Trajectory Injection Motor Fuel Tank</i>	1.000			1.000
<i>Ion Thrusters (Four Total)</i>	0.500			0.500
<i>Ion Propellant Tanks (Two Total)</i>	1.000			1.000
Thermal System				
<i>Integrated with each system</i>	0.000			0.000
Primary Payload Encoded Bit Stream				
<i>Allocated to Data System</i>	0.000			0.000
Scar for Secondary Payload (future)	0.000			0.000
<i>Estimated Spacecraft Total Volume</i>	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
<i>Power Management and Distribution</i>	0.000			0.000
<i>Solar Arrays (conformal exterior)</i>	0.000			0.000
<i>Batteries (conformal propulsion tank corners)</i>	0.000			0.000
Communications System (COMM)	0.000			
<i>Ka Band Radio</i>	0.225			0.225
<i>Antenna (TX+RX integrated w/solar arrays)</i>	0.000			0.000
Data Management System (DMS)	0.000			
<i>On Board Computer</i>	0.094			0.094
Structures & Mechanisms	0.000			
<i>Integrated with each system</i>	0.000			0.000
Attitude Determination & Control System (ADCS)	0.000			
<i>Subsystems</i>	0.000			0.000
Guidance, Navigation & Control System (GN&C)	0.000			
<i>Subsystems</i>	0.000			0.000
Propulsion System	0.000			
<i>Hybrid Trajectory Injection Motor Core</i>	3.000			3.000
<i>Hybrid Trajectory Injection Motor Fuel Tank</i>	6.000			6.000
<i>Ion Thrusters (Four Total)</i>	1.000			1.000
Thermal System	0.000			
<i>Integrated with each system</i>	0.000			0.000
Primary Payload Encoded Bit Stream	0.000			
<i>Allocated to Data System</i>	0.000			0.000
Scar for Secondary Payload (future)	0.000			0.000
<i>Estimated Spacecraft Total Mass</i>	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		Power with Contingency (w)
		%	(w)	
Electrical Power System (EPS)	90.000			90.000
<i>Power Management and Distribution</i>	0.000			0.000
<i>Solar Arrays (conformal exterior)</i>	0.000			0.000
<i>Batteries (conformal propulsion tank corners)</i>	0.000			0.000
Communications System (COMM)	0.000			
<i>Ka Band Radio</i>	0.000			0.000
<i>Antenna (TX+RX integrated w/solar arrays)</i>	0.000			0.000
Data Management System (DMS)	0.000			
<i>On Board Computer</i>	0.000			0.000
Structures & Mechanisms	0.000			
<i>Integrated with each system</i>	0.000			0.000
Attitude Determination & Control System (ADCS)	0.000			
<i>Subsystems</i>	0.000			0.000
Guidance, Navigation & Control System (GN&C)	0.000			
<i>Subsystems</i>	0.000			0.000
Propulsion System	0.000			
<i>Hybrid Trajectory Injection Motor Core</i>	0.000			0.000
<i>Hybrid Trajectory Injection Motor Fuel Tank</i>	0.000			0.000
<i>Ion Thrusters (Four Total)</i>	0.000			0.000
Thermal System	0.000			
<i>Integrated with each system</i>	0.000			0.000
Primary Payload Encoded Bit Stream	0.000			
<i>Allocated to Data System</i>	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 Transceiver	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										
Total Volume Budget										5.82
Estimated Spacecraft Level Volume Margin (U)										6
Estimated Spacecraft Level Volume Margin (%)										0.18
										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
<u>Spacecraft Programmatic</u>		
§ 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
<u>Flight System Overview</u>		
§ CAD Model	Section V - Spacecraft Architecture	Provided
§ Spacecraft Block Diagram	Section V - Spacecraft Architecture	Provided
§ Interfaces	Section V - Spacecraft Architecture	Provided
<u>System Designs</u>		
<u>Electrical Power System (EPS)</u>	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
<u>Communications System (COMM)</u>	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
<u>Data Management System (DMS)</u>	Section V - Systems Overview DMS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
§ On Board Computer	Section V - Systems Overview DMS	Provided
<u>Structures & Mechanisms (S&M)</u>	Section V - Systems Overview S&M	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
<u>Attitude Determination & Control System (ADCS)</u>	Section V - Systems Overview ADCS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
<u>Guidance, Navigation & Control System (GN&C)</u>	Section V - Systems Overview GN&C	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
<u>Propulsion System (PROP)</u>	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
<u>Thermal System (TCS)</u>	Section V - Systems Overview TCS	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
<u>Primary Payload - Encoded Bit Stream</u>	Section V - Primary Payload	Provided
§ System Block Diagram	Section VIII - Engineering Workbook	Provided
<u>Scar for Secondary Payload (future)</u>	Section V - Secondary Payload	Future
§ System Block Diagram	Section VIII - Engineering Workbook	Future
<u>Preliminary Safety Assessment</u>	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)

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