TEAM ALPHA CUBESAT

GROUND TOURNAMENT 2 PRELIMINARY DESIGN REVIEW REPORT

MCDP

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

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

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INTRODUCTION

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

MISSION STATEMENT

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

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

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

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

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

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

TEAM ROSTER - MEMBERS, ADVISORS & INTERNATIONAL LIAISONS

ALPHA CUBE SAT TEAM MEMBERS:

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

ALPHA CUBESAT TEAM ADVISORS:

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

ALPHA CUBESAT TEAM INTERNATIONAL LIAISONS:

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

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

Definitions:

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

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

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

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

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

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

TEAMMATES & SPONSORS

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

CONCEPT OF OPERATIONS

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

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

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

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

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

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

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

CONCEPT OF OPERATIONS NARRATIVE

The concept of operations is premised on the

- Conceptual Design (Prototype)

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

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

CONCEPT OF OPERATIONS DIAGRAM

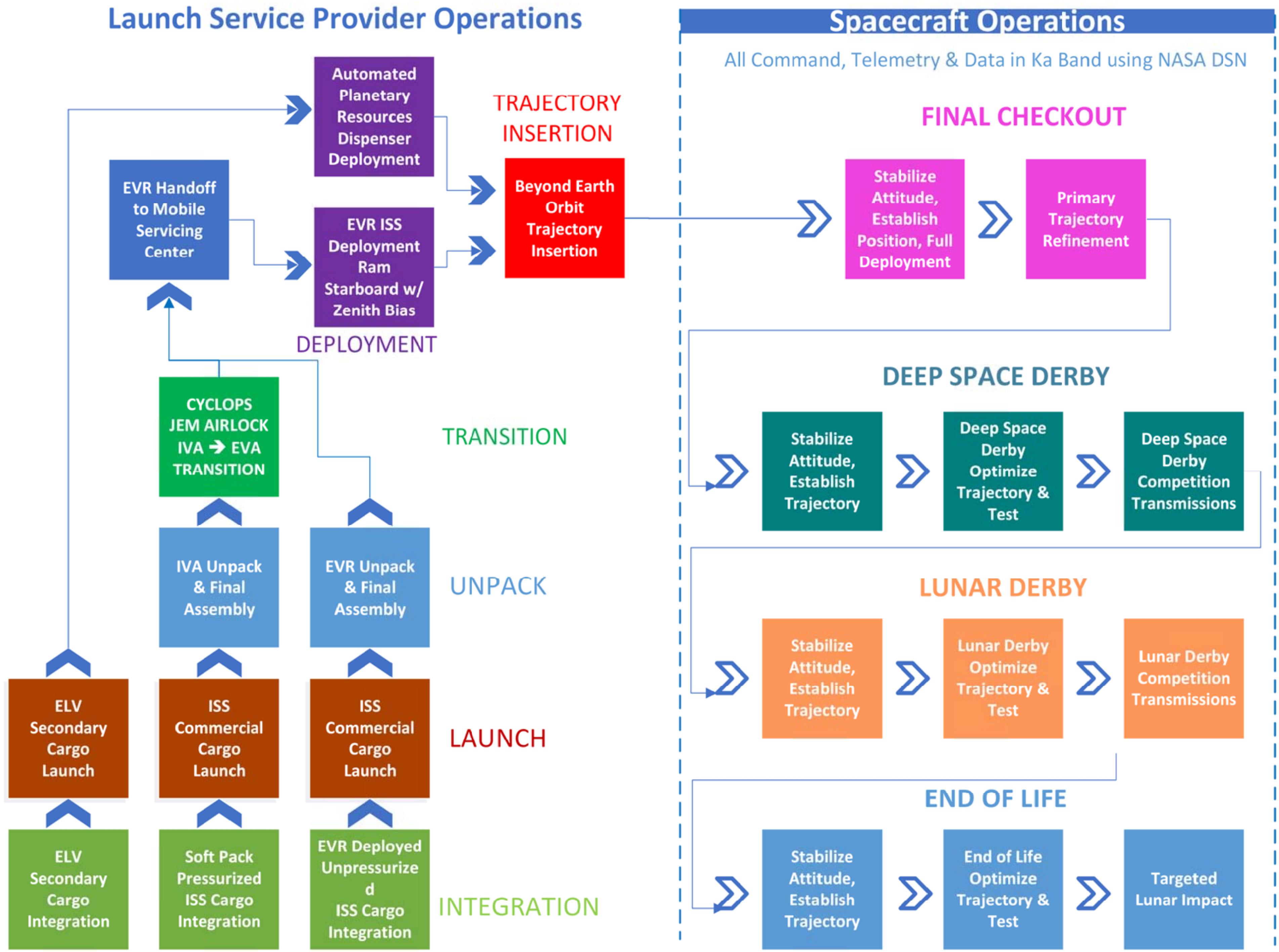
The concept of operations is shown in Diagram 1-1 Alpha CubeSat Concept of Operations. The information is currently shown in a block diagram format and will be updated with pictorial elements for the GT-1 data package. The defined mission phases with anticipated image annotations include:

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

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

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

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


Launch Service Provider Operations
Spacecraft Operations
All Command, Telemetry & Data in Ka Band using NASA DSN
Automated Planetary Resources Dispenser Deployment
EVR Handoff to Mobile Servicing Center
EVR ISS Deployment Ram Starboard w/ Zenith Bias
DEPLOYMENT
TRAJECTORY INSERTION
Beyond Earth Orbit Trajectory Insertion
FINAL CHECKOUT
Stabilize Attitude, Establish Position, Full Deployment
Primary Trajectory Refinement
CYCLOPS JEM AIRLOCK IVA → EVA TRANSITION
TRANSITION
IVA Unpack & Final Assembly
EVR Unpack & Final Assembly
UNPACK
ELV Secondary Cargo Launch
ISS Commercial Cargo Launch
ISS Commercial Cargo Launch
LAUNCH
ELV Secondary Cargo Integration
Soft Pack Pressurized ISS Cargo Integration
EVR Deployed Unpressurize d ISS Cargo Integration
INTEGRATION
DEEP SPACE DERBY
Stabilize Attitude, Establish Trajectory
Deep Space Derby Optimize Trajectory & Test
Deep Space Derby Competition Transmissions
LUNAR DERBY
Stabilize Attitude, Establish Trajectory
Lunar Derby Optimize Trajectory & Test
Lunar Derby Competition Transmissions
END OF LIFE
Stabilize Attitude, Establish Trajectory
End of Life Optimize Trajectory & Test
Targeted Lunar Impact

MISSION CONSIDERATIONS

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

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

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

Conceptual Design (Prototype)

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

DEVELOPMENT CONSIDERATIONS

Integration & Launch Trade

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

Deployment Trade

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

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

GROUND SEGMENT CONSIDERATIONS

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

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

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

STRUCTURAL CONSIDERATIONS

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

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

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

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

LAUNCH CONSIDERATIONS

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

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

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

DEPLOYMENT CONSIDERATIONS

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

Deployment (assuming integration as IVA pressurized commercial cargo)

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

Deployment (assuming integration as EVR unpressurized commercial cargo)

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

- Recharge batteries

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

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

- Apply preload (if applicable) to deployment spring

- Release on confirmation of ready to launch

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

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

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

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

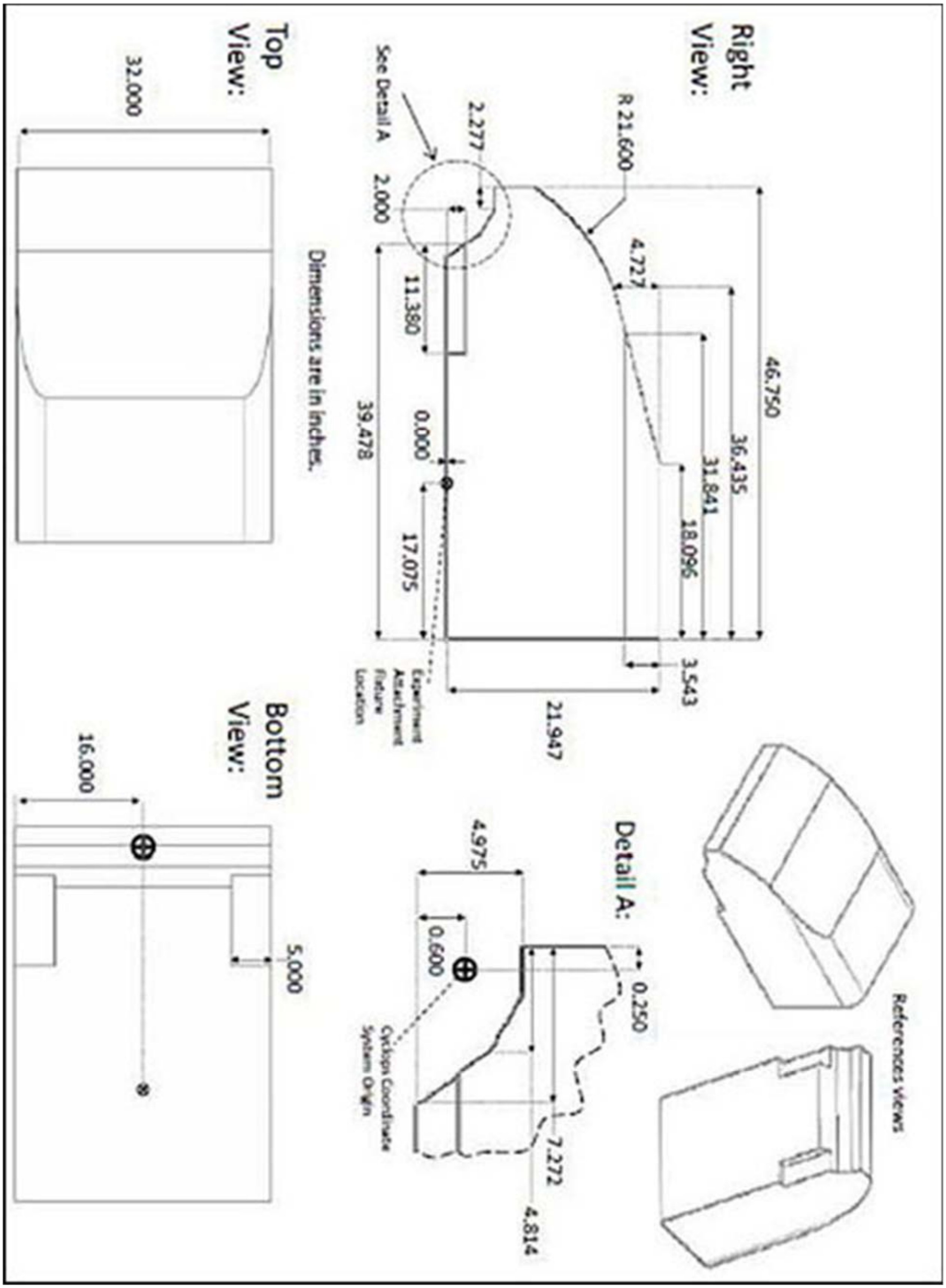


Diagram 1-2 CYCLOPS Deployment Volume

TRAJECTORY CONSIDERATIONS

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

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

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

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

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

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

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

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

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

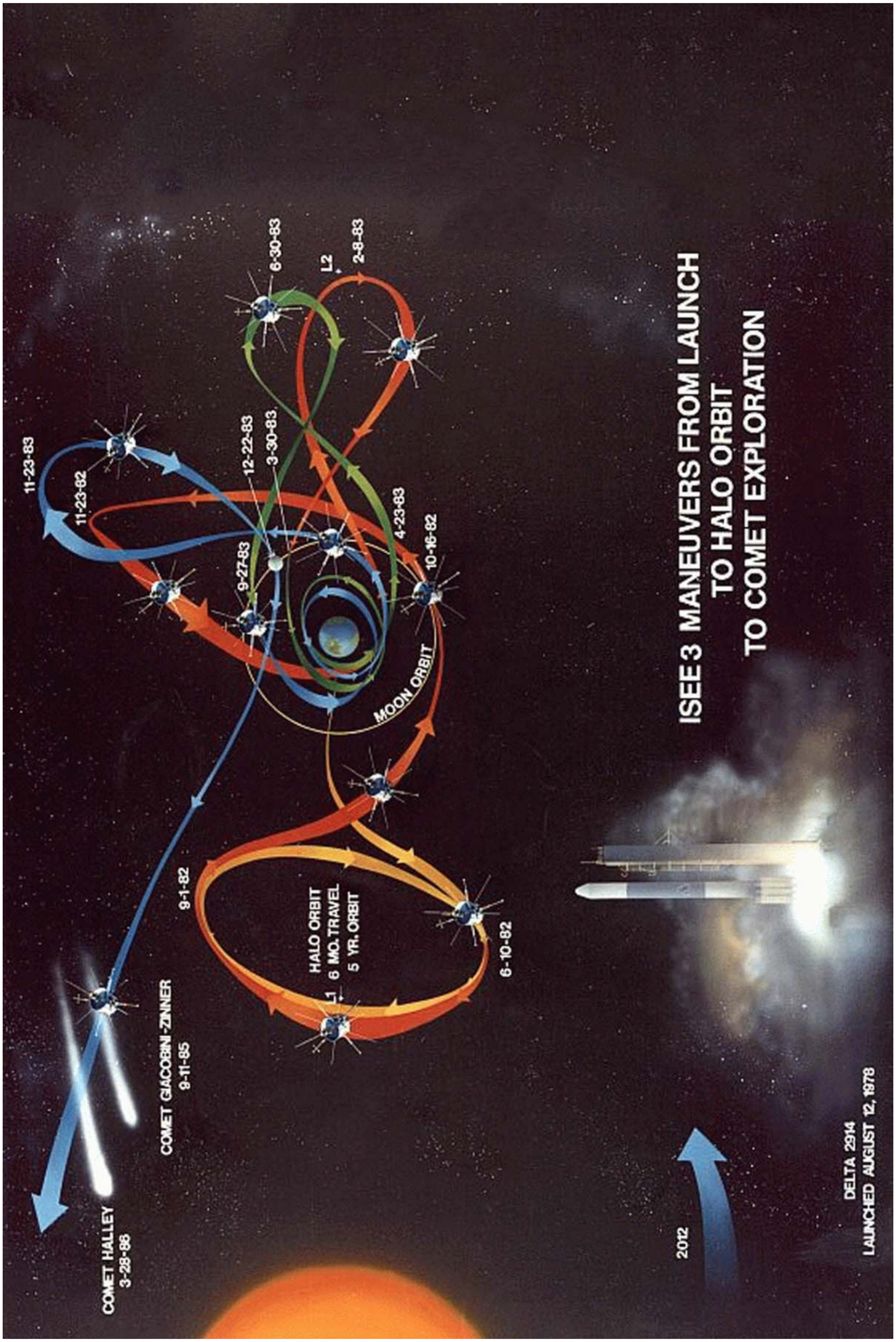
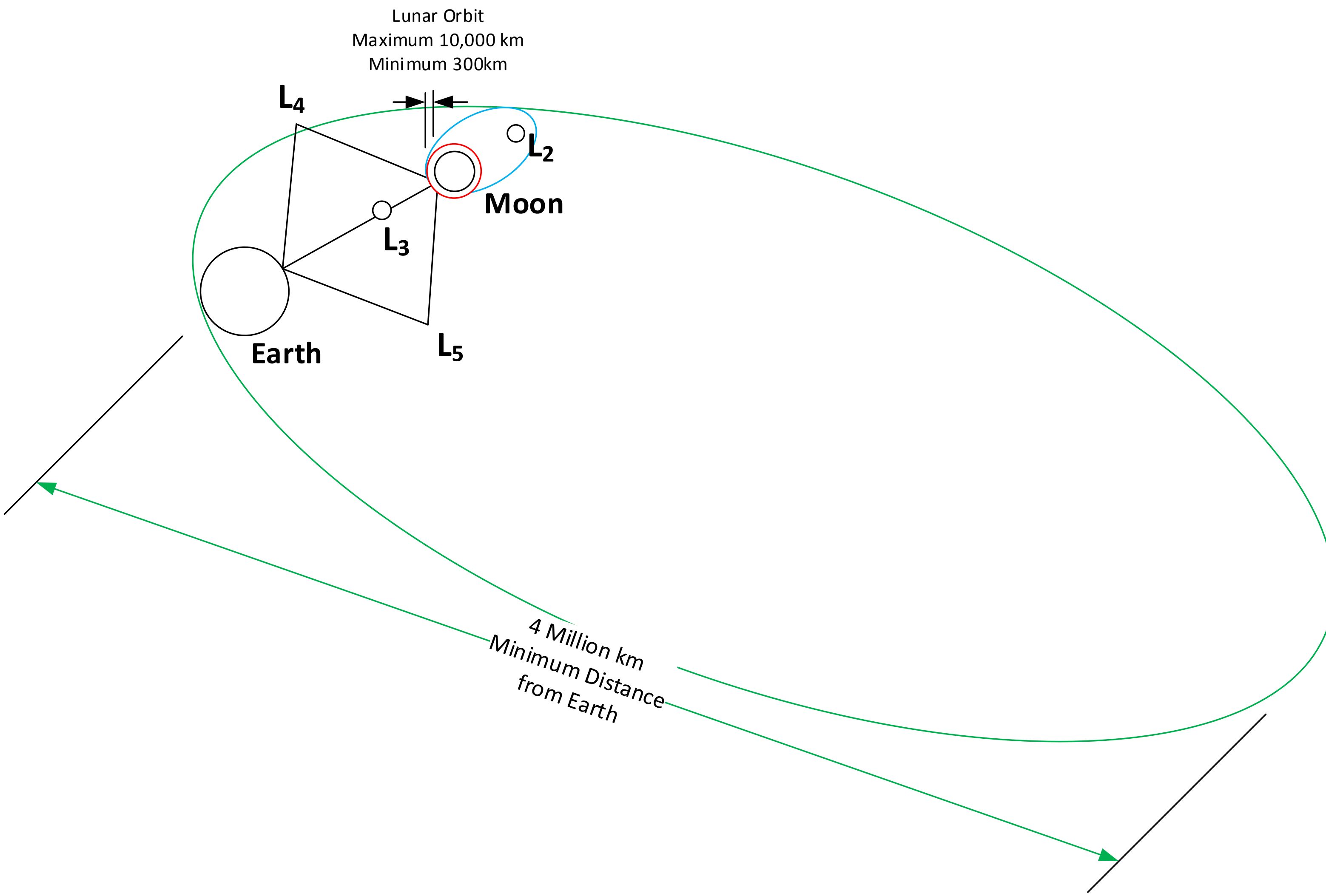


Diagram 1-3 ISEE 3 Orbital Trajectory

Diagram 1-4 Alpha CubeSat Notional Orbital Trajectory



Not To Scale

Gary barnhard - More info re trajectories

From: Eric Dahlstrom <Eric.Dahlstrom@InternationalSpace.com>
To: Gary Barnhard <Barnhard@barnhard.com>
Date: 2/5/2016 10:14 PM
Subject: More info re trajectories
Cc: Ethan Shinen Chew <spacefelix@gmail.com>

Gary,
Here is a bit of text that can be used related to the trajectories.

I started looking for diagrams that showed similar trajectories, and I discovered these other references by teams that are designing the NASA funded lunarcube missions. I have attached a screenshot of one of their figures. The difference for ACS is that we go out to 4M km first.

- Eric

The Alpha Cubesat mission intends to first achieve the 4 million km Deep Space Derby objective, and then return to the Moon to enter lunar orbit and achieve the second objective. Alpha Cubesat seeks to demonstrate the flexibility of maneuvers within cis-lunar space using a cubesat form factor and the associated reduced cost. We anticipate this capability will be useful for many future missions of small spacecraft.

The plan to travel to 4M km and then return to the Moon means our mission is perfectly suited to use the exterior transfer Weak Stability Boundary class of trajectories identified by Dr. Edward Belbruno. This class of trajectories reduces the energy (and delta-velocity) needed to maneuver in the Earth-Moon system, and to enter into ballistic capture into a high elliptical lunar orbit. From that initial elliptical lunar orbit, ACS would reduce the aposelene to achieve the target elliptical lunar orbit. The use of the Weak Stability Boundary ballistic capture, along with maneuvers between constant energy stable and unstable manifolds within the Earth-Moon-Sun system, enable extensive maneuvers and orbit changes with very low delta-v. Several missions have already demonstrated the success of this approach, including Hiten, SMART-1, Grail, and others. Alpha Cubesat seeks to demonstrate the use of these techniques with low cost cubesat systems.

Similar low delta-v trajectories (making use of Weak Stability Boundary ballistic capture and stable and unstable manifolds) have been identified in other studies, including those supporting NASA sponsored lunar cubesat missions [Ref 1,2,3]. A variety of independent trajectory analysis tools are available that can be used to find these optimal solutions.

[1] Folta, David, Donald Dichmann, Pamela Clark, Amanda Haapala, Kathleen Howell, “Lunar Cube Transfer Trajectory Options”, AAS/AIAA Space Flight Mechanics Meeting; 25th, 20150001351, GSFC-E-DAA-TN19549, Jan 11, 2015.
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150001351.pdf

[2] Folta, David, Donald Dichmann, Pamela Clark, Amanda Haapala, Kathleen Howell, “LunarCube Transfer Trajectory Options”, 4th International Workshop on LunarCubes, Oct 2014.
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150001297.pdf

[3] Folta, David C., Natasha Bosanac, Davide Guzzetti, and Kathleen C. Howell, “An Earth-Moon System Trajectory Design Reference Catalog”, IAA-AAS-DyCoSS2-03-02, 2014.
https://engineering.purdue.edu/people/kathleen.howell.1/Publications/Conferences/2014_IAA_FolBosGuzHow.pdf

Also, a couple of Ed Belbruno’s references have links.

Belbruno, E.; Gidea, M.; Topputo, F., Weak Stability Boundary and Manifolds, SIAM J. Appl. Dyn. Sys., Vol. 9, No. 2, pp 1061-1089, 2010.
http://edbelbruno.com/wp-content/uploads/2016/01/Belbruno-WSB2010-1.pdf

Post, K.; Belbruno, E.; Topputo, F., Efficient Cis-Lunar Trajectories, in Proceedings: GLEX- 2012.02.3.6x12248, Washington, D.C., May 22-24, 2012.
http://edbelbruno.com/wp-content/uploads/2016/01/Belbruno-Efficient-Cis-Lunar-Trajectories2012-1.pdf

(The figure below is figure 19 on page 14 of Folta reference 1)

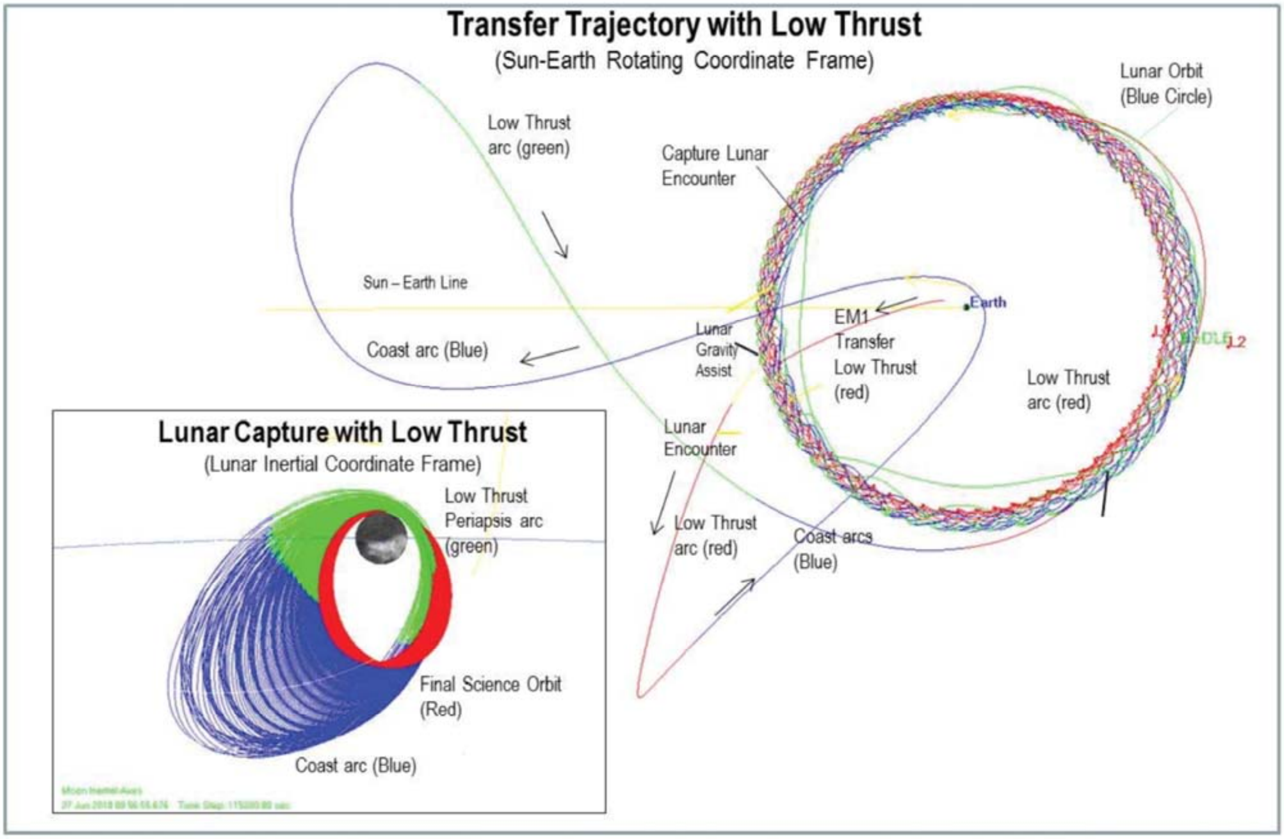


Figure 19. ARTEMIS-Like Transfer Design with Decreased EM-1 Velocity

ATTITUDE CONTROL SYSTEM CONSIDERATIONS

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

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

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

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

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

COMMUNICATION CONSIDERATIONS

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

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

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

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

ARTICULATED SUBSYSTEM CONSIDERATIONS

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

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

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

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

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

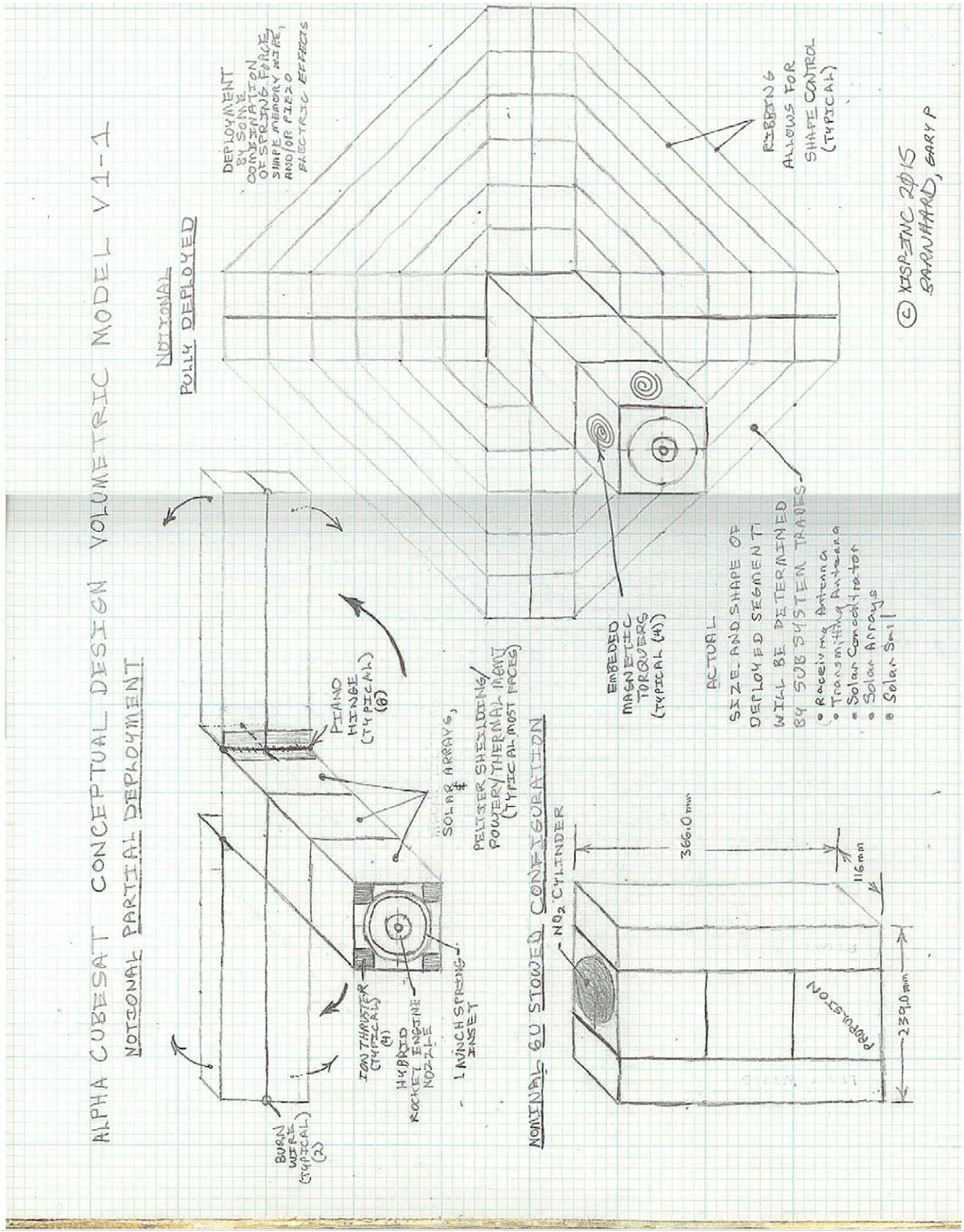


Diagram 1-5 Alpha CubeSat Conceptual Design Volumetric Model V1-1

ELECTRICAL CONSIDERATIONS

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

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

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

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

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

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

NAVIGATION CONCEPTS

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

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

PROPULSION CONSIDERATIONS

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

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

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

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

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

COMMAND & CONTROL CONCEPTS

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

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

THERMAL CONSIDERATIONS

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

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

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

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

SAFETY & QUALITY ASSURANCE CONSIDERATIONS

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

Representative known risks include:

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

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

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

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

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

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

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

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

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

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

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

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

CONCEPTUAL CONSIDERATIONS

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

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

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

CONCEPTUAL METHOD OF DISPOSAL

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

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

PRELIMINARY FREQUENCY ALLOCATION DATA PACKAGE

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

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

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

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

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

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

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

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

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

All contest compliant transmissions will be through the NASA DSN.

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

NASA Deep Space Network (Primary)

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

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

Not known at this time.

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

Not known at this time.

EL-CID STATUS

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

We have identified the following potential interacting nodes:

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

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