Halfway to Anywhere - Cislunar and Deep Space Cubesats Missions From ISS

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Science fiction author Robert Heinlein once said, "Once you're in low Earth orbit you're halfway to anywhere." This statement while playing a bit fast and loose with a strict accounting of kinetic energy requirements, is far from hyperbole. This paper examines both how to leverage the advantages and mitigate the disadvantages of using the International Space Station (ISS) as a beyond Earth orbit transportation node for multiple applications.

Nomenclature

Δv	=	change in velocity, delta-V, km/s
R_a	=	radius at apoapsis, for an orbit around the Earth apogee, km
R_p	=	radius at periapsis, for an orbit around the Earth perigee, km
L_2	=	Sun-Earth Lagrange or Libration Point 2
I_{sp}	=	Specific impulse, s

I. Introduction

The concept of using a space station in low Earth orbit (LEO) as a transportation node, and a departure point for spacecraft going to other destinations, has existed since the dawn of the space age. "Earth orbit rendezvous" was considered during the early Apollo program, before "Lunar orbit rendezvous" was selected as the architecture. The Space Transportation System was proposed to be composed of three elements - the Space Shuttle, the Space Station, and a space-based Orbital Transfer Vehicle. The use of a space station as a transportation node for lunar and Mars vehicles was studied extensively during the Space Station Freedom program.

Besides breaking up the kinetic energy requirements into more manageable increments other advantages include the design of space-based vehicles intended only to operate in LEO and beyond, avoiding launch loads on the completed vehicle, allowing on-orbit testing and checkout, and the potential to assemble large light-weight structures including aerobrakes.

During the International Space Station (ISS) development a combination of the descoping of requirements, the change in orbital inclination, and the delay of deep space missions, removed the transportation node mission as an ISS design driver. However, in recent years, the increasing capabilities of cubesats, and the development of innovative deployment systems have allowed nanosatellites destined for LEO to be deployed from the ISS. Use of simplified delivery to ISS as soft pack cargo from Earth, the Japanese Kibo laboratory airlock to transition flight systems to the EVA environment, careful orbital design, and simplified deployment mechanisms for orbital trajectory insertion have served as a useful first step toward demonstrating ISS as a transportation node. Soon there will be the next generation of logistics carriers and a larger commercial airlock which will offer enhanced opportunities. With increasing interest in developing cubesats to operate in Cislunar or interplanetary space, the question arises - is there a way to effectively deploy Cislunar and deep space bound cubesats from ISS?

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II. Mission Definition

Historically, most space missions have focused on single-use Earth-to-destination transportation. To develop a fully space-faring civilization, we need to evolve toward reusable, refueled, space vehicles that can provide transportation between multiple destinations - a different kind of space transportation architecture. This kind of transportation architecture is important for space development, space resource use, and space exploration. Elements of these kind of space architectures have been proposed or used in the past (Lunar orbit rendezvous and the LEM, 'Earth orbit rendezvous', Space Transportation System – Space Shuttle + Space Station + Orbital Transfer Vehicle (OTV), etc.). Previously, the assembly and deployment of lunar and deep space vehicles was a major mission of the space station - but these missions were deferred as ISS was assembled. The servicing and transportation operations were a dominant part of the Space Station Phase B Dual Keel design as shown in Figure 1 Space Station Phase B Dual Keel Configuration Service Facility

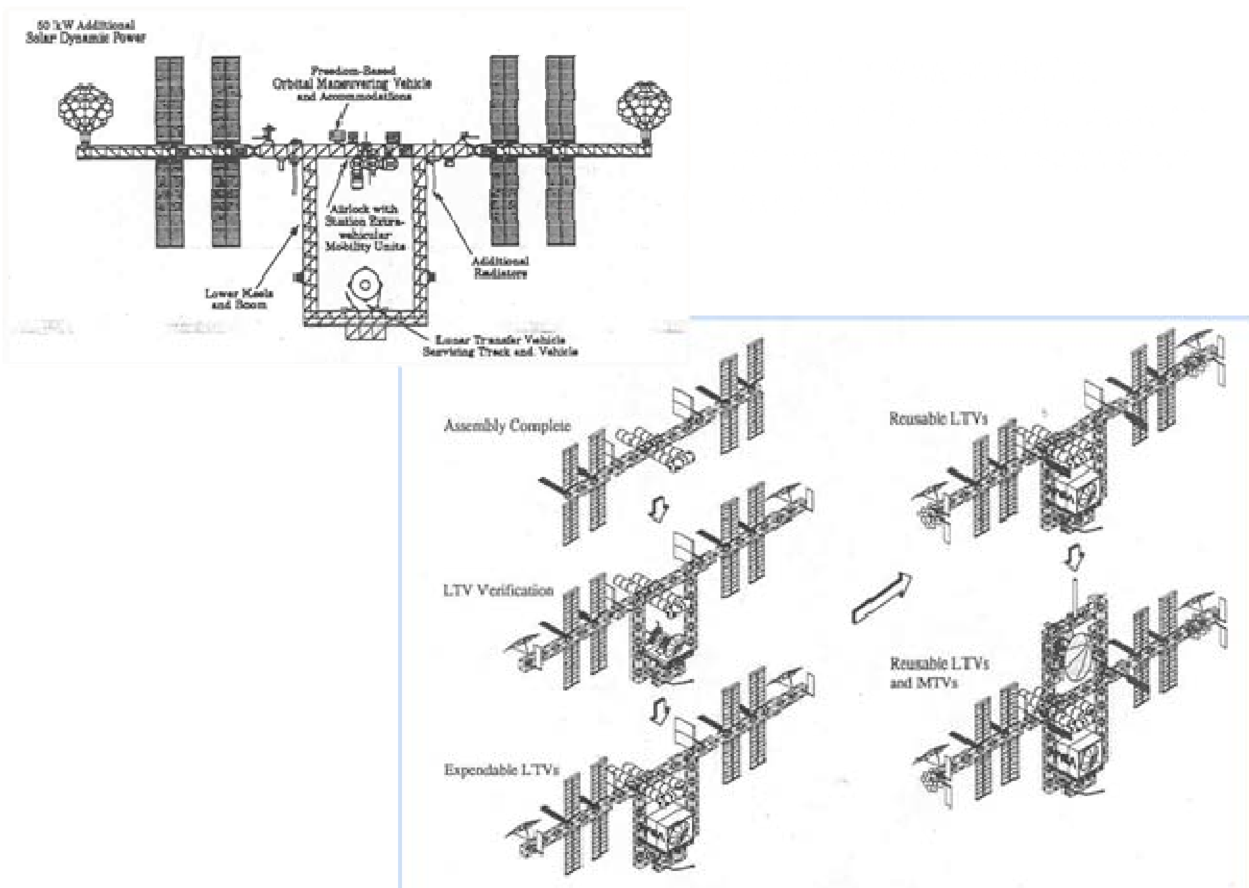

Figure 1. Space Station Phase B Dual Keel Configuration Service Facility

New opportunities with cubesats (including deployment from ISS) allow elements of these transportation architectures to be demonstrated (e.g. propellant option demos), and isolated from developing infrastructure for test.

The challenges include accomplishing the remaining change in velocity needed to achieve injection into the orbit of interest, mitigating the impact of exposure to the Van Allen Radiation Belts, as well as meeting the enhanced durability requirements due to allowing time-to-destination to be a variable in order to take advantage of alternate minimum energy transfer trajectories. Achieving optimal transfer trajectories will require some combination of low thrust long duration propulsion and high thrust short duration propulsion, as well as the ability to readily calculate minimum energy transfer opportunity launch windows (e.g., ballistic escape and capture trajectories, weak stability boundaries, libration point orbits, etc.) as needed. The pioneer for these types of trajectory calculations was Robert W. Farquhar who set the bar for the intersection between orbital dynamics and art with the ISEE-3/ICE missions and paved the way for subsequent missions.[1] In more recent years, multiple other researchers have continued the work including Dr. Edward Belbruno who has significantly extended the solution space of alternate minimum energy trajectories.[2,3,4]

For vehicles using low thrust (such as ion drive or solar sail), starting from LEO will mean a slow climb through the Earth's radiation belts. Like other users of the ISS, you will require either external payload compatibility using robotic arm deployment, or deliver the spacecraft internally and fit within airlock size restrictions to be taken outside ISS. There will be ISS safety restrictions on materials, propellant, and the need to conform to crew scheduling, and other limited ISS resources, such as airlock or robotic arm use. The advantages of deploying a deep space cubesat from ISS include serving as a pathfinder for future vehicles, and include a range of advantages discussed below. The cubesat components will experience reduced launch loads when packaged on the ISS logistics vehicles. There is a potential to design for on-orbit assembly, mechanism deployment, or other reconfiguration into flight configuration. A cubesat deployed from the ISS could be designed with large, low mass structures that would be difficult to deploy autonomously. This can include human or robotic assembly, and human tended deployment. There is potential control over deployment timing for optimal orbit or sunlight parameters. Finally there will be visibility of the spacecraft deployment, and the potential for initial operation and check out of the vehicle while it is close to ISS. The reduced barriers to the use of ISS for cubesat deployments open up the opportunity to demonstrate the use of ISS as a transportation node. This initial step can serve to test designs and operations which can be used in the future for a complete space transportation architecture.

A. What missions will pave the way?

The NASA CubeQuest Challenge Team Alpha CubeSat (ACS) proposal to use a launch through ISS option for participation in both the Deep Space Derby and the Lunar Derby in 2018 is likely the first test case. ACS will set an operational precedent for using ISS as a launch platform for deep space missions. ACS is a technology development and demonstration mission including novel launch and deployment methods, use of alternate minimum energy trajectories, use of Ka Band software defined radio, and use of lunar resonance orbits. 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. The ACS Team is out to win the NASA Cube Quest Challenge competing for all offered prizes. ACS will demonstrate innovative satellite instrumentation while following progressive, low-energy trajectories to reach a deep space altitude of 4 million km (about 10x farther than the moon!) before returning to the moon and establishing a strategic resonance orbit. Design freedom and launch options afford an intrepidity lacking in new satellite missions: the courage to prove never flown before instruments, demonstrate efficient experimental orbits, and develop new launch opportunities for future cubesats. Innovative trajectories and orbits will also provide high definition access of the moon's surface as well as backup communication provisions for independent space missions.

The intention of the ACS mission is not just to win contest prizes, it is to help mitigate the cost, schedule, and technical risk associated with the short, mid, and long term applications of using the ISS as a beyond Earth orbit transportation node. This mission will provide both a testbed environment for the required technologies and a clear pathfinder demonstration mission.

This work can be mission enhancing if not mission enabling for a range of Earth facing, space operations/development, and space exploration missions. This effort forges a bridge between technology development, technology demonstration, and technology deployment. Furthermore, if this work can be successfully infused into infrastructure, the ISS and the systems that evolve from it will foster the commercial development of beyond Earth orbit transportation services. Accordingly, this work serves to reinforce the United States relevancy in the global high-tech marketplace as well as providing extraordinary opportunities for international cooperation and collaboration.

B. Advantages & Disadvantages

The use of the ISS as a transportation node allows for a number of innovations in spacecraft design that can be taken advantage of:

1) Assemble IVA or EVR in LEO
2) Avoid aerodynamic loads
3) Avoid launch loads
4) Potential for large structures
5) Potential for space manufacturing
6) Design for vacuum
7) Pure ‘space’ spacecraft

The key point is that there is a different level of design optimization – optimize for in-space use; that can become dominant.

Furthermore, it is not just a question of what is done but how it is done. Having the ISS serve as a Propulsion Test Bed provides a streamlined technology development, demonstration, and deployment path for many options including but not limited to:

1) bi-propellants (non-toxic, non-hazardous)
2) solar electric/ion thrusters
3) power beaming[6]
4) resistojets (e.g., scavenged water, methane, etc.)
5) mono-propellants (non-toxic, non-hazardous)
6) solar sails

An on-orbit Propulsion Test Bed would foster the development of a wide range of low and high thrust options that could be mixed and matched to best meet the delta-V requirements for a range of beyond Earth orbit missions (See Figure 2. Approximate Δv in Cislunar Space).

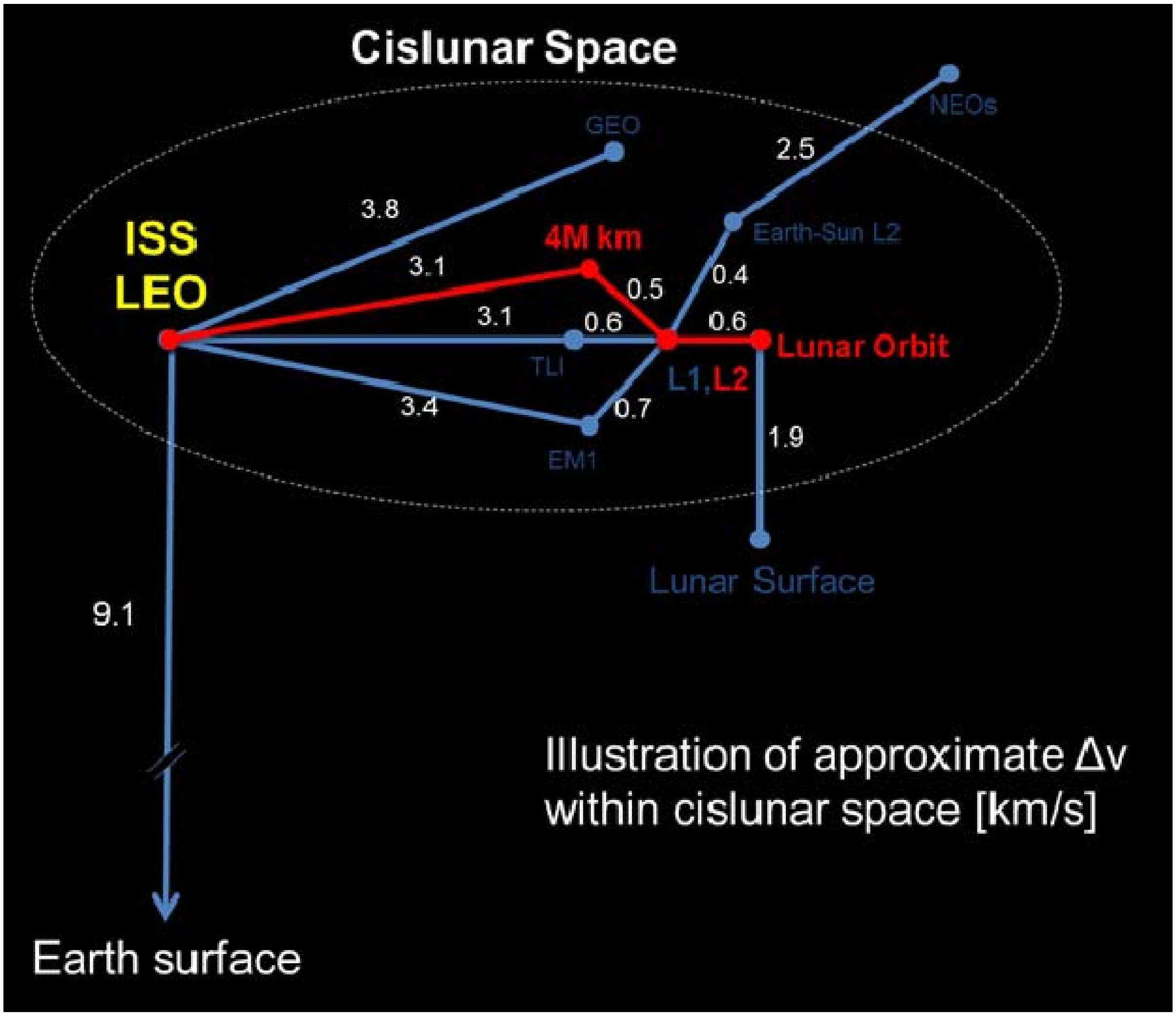

Figure 2. Approximate Δv in Cislunar Space

There are significant trajectory and delta-v implications of starting from LEO :

1) Classic "minimum" energy trajectories are not optimal
2) Alternate minimum energy trajectories become tractable
3) Longevity of spacecraft components becomes more critical
4) Non-protected orbit transfers increases exposure time to:
    a. Orbital debris
    b. Radiation belts
5) The calculations required are more demanding and must be readily accomplished.

There are significant trades with respect to staging, propellant mass fraction vs. I_{sp}, and available payload as shown in Figure 3 First Stage Propellant Mass Fraction Vs. I_{sp}, Figure 4 Second Stage Propellant Mass Fraction Vs. I_{sp}, and Figure 5 Payload Vs. First & Second Stage I_{sp}.

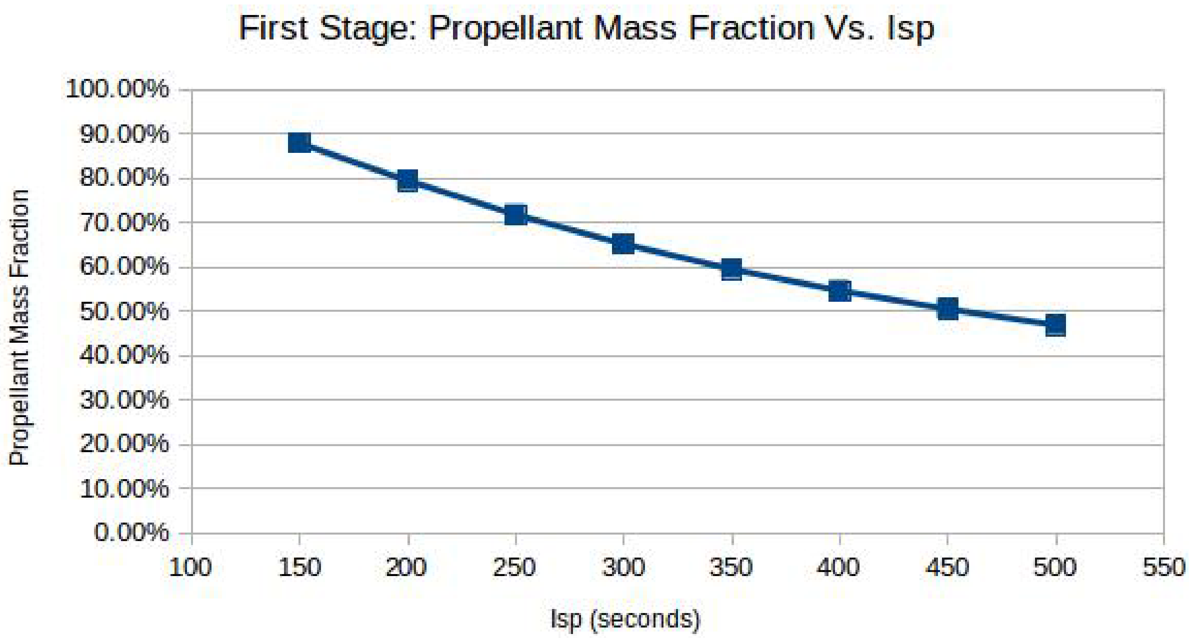

Figure 3. First Stage: Propellant Mass Fraction Vs. Isp

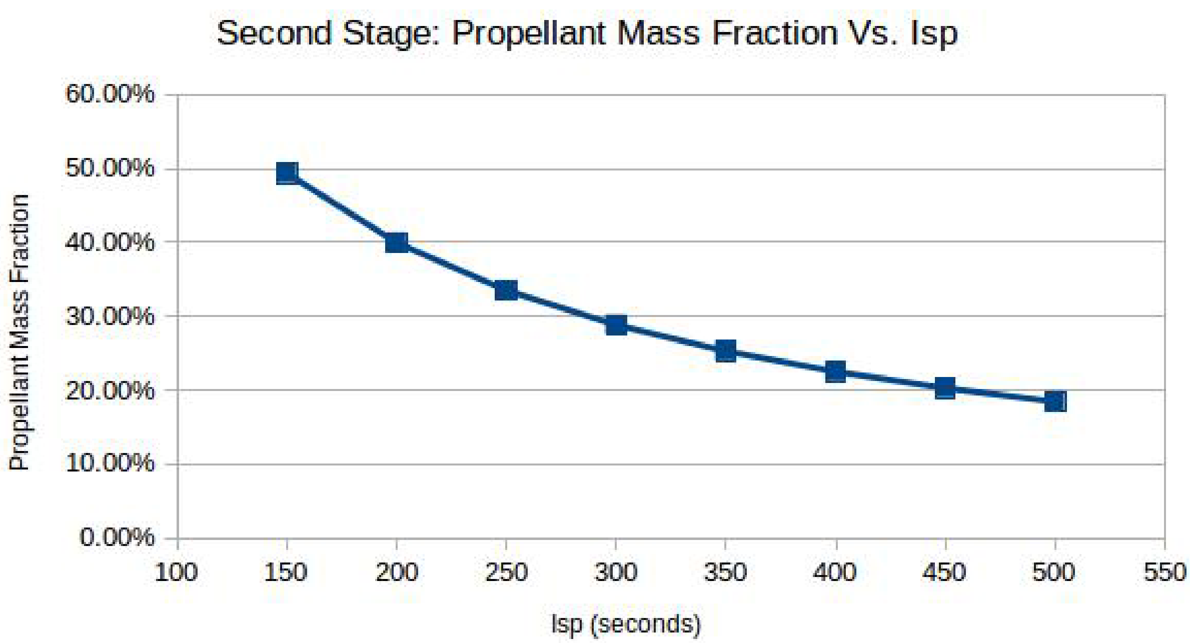

Figure 4. Second State: Propellant Mass Fraction Vs. Isp

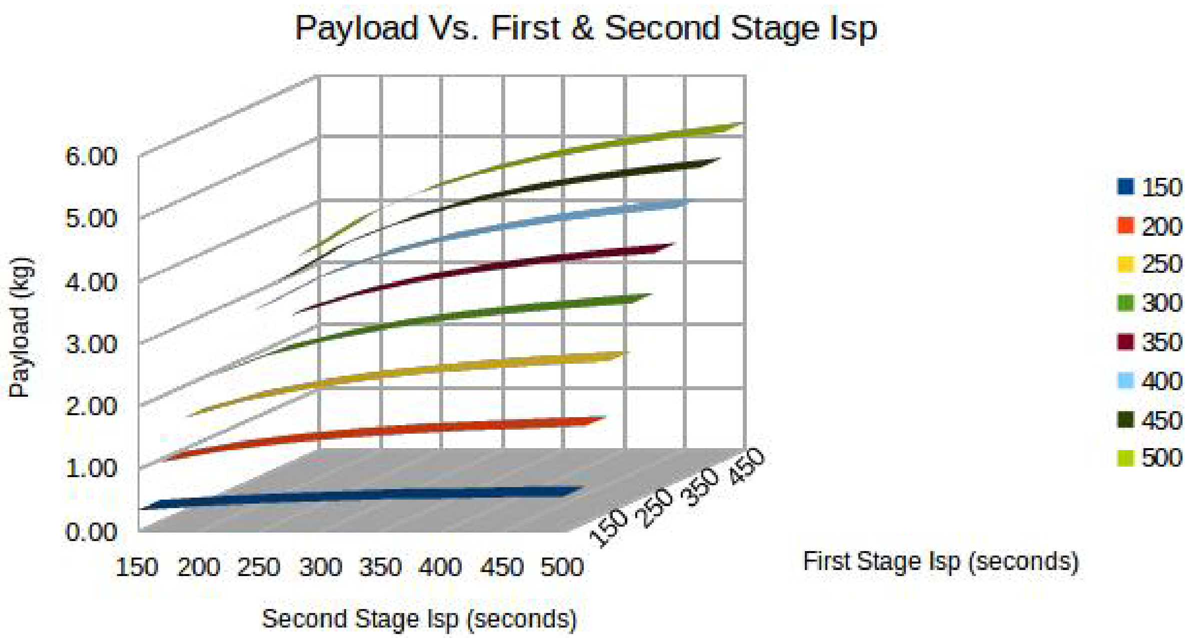

Figure 5. Payload Vs. First & Second Stage I_{sp}

There is an intersection between orbital dynamics and art as shown in Figure 6. ISEE 3 Maneuvers from Launch to Halo Orbit to Comet Exploration.[1]

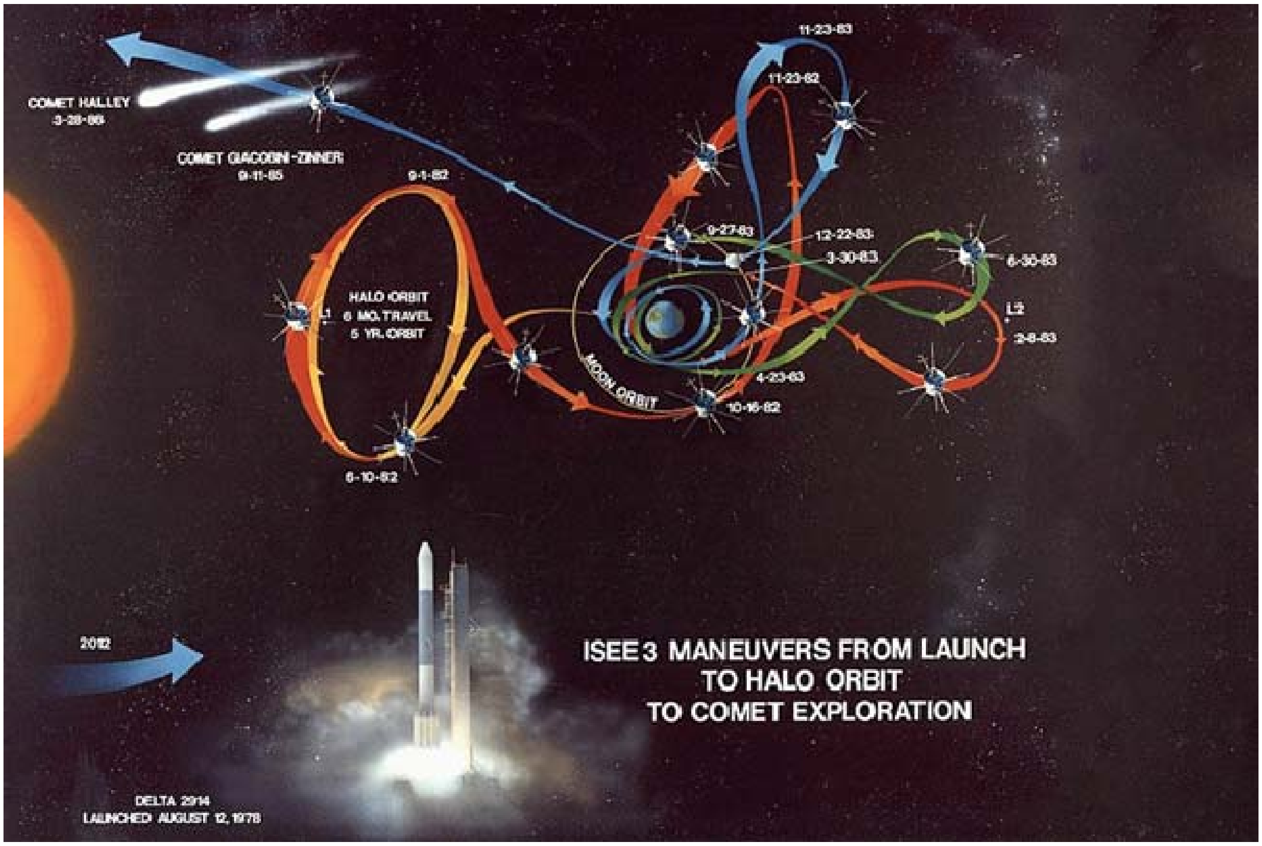

Figure 6. ISEE 3 Maneuvers from Launch to Halo Orbit to Comet Exploration

C. ACS Notional Trajectory

In order for Team ACS to successfully take on the NASA CubeQuest Challenge Deep Space Derby and Lunar Derby as one mission with a single 6U spacecraft it was known that some alternative to classic Hohmann trajectory solutions would be required. The Team ACS CubeQuest Challenge registration package set out the vision of what needed to be done in general terms but the viability of the mission depended on getting a first order trajectory calculation that closed with non-negative margins for the spacecraft budgets (e.g., mass, volume, power, etc.). For the CubeQuest Challenge Ground Tournement–1 (GT-1) Team ACS submitted a first order trajectory calculation that closed with non-negative spacecraft margins using conventional minimum energy trajectory solutions and a notional approach to alternate minimum energy solutions that held the promise of trajectory refinement which could be mined for required design and payload margin. The total mission delta-V required for the spacecraft using Hohmann and bi-elliptic trajectories (i.e., the conventional minimum energy trajectory solution space) was calculated to be ~8.401 km/s, requiring propellant mass fractions on the order of ~80-90% leaving little to no appreciable design or payload margin. As the GT-1 judges aptly noted in their review, the viability of the mission was clearly in question.

D. ACS Baseline Trajectory Calculations

One of the key items of guidance coming out of the GT-1 exercise was the criticality of developing a baselinable trajectory calculation that made the most effective use possible of alternate minimum energy trajectory solutions. To support this effort Team ACS recruited Dr. Edward Belbrono with Innovative Orbital Design, Inc. a widely published expert in orbital dynamics to assist in the development of the trajectory calculations.

The Alpha CubeSat baseline trajectory propulsion requirements resulting from this collaboration is as shown in Figure 6 Alpha CubeSat Baseline Trajectory.[5]

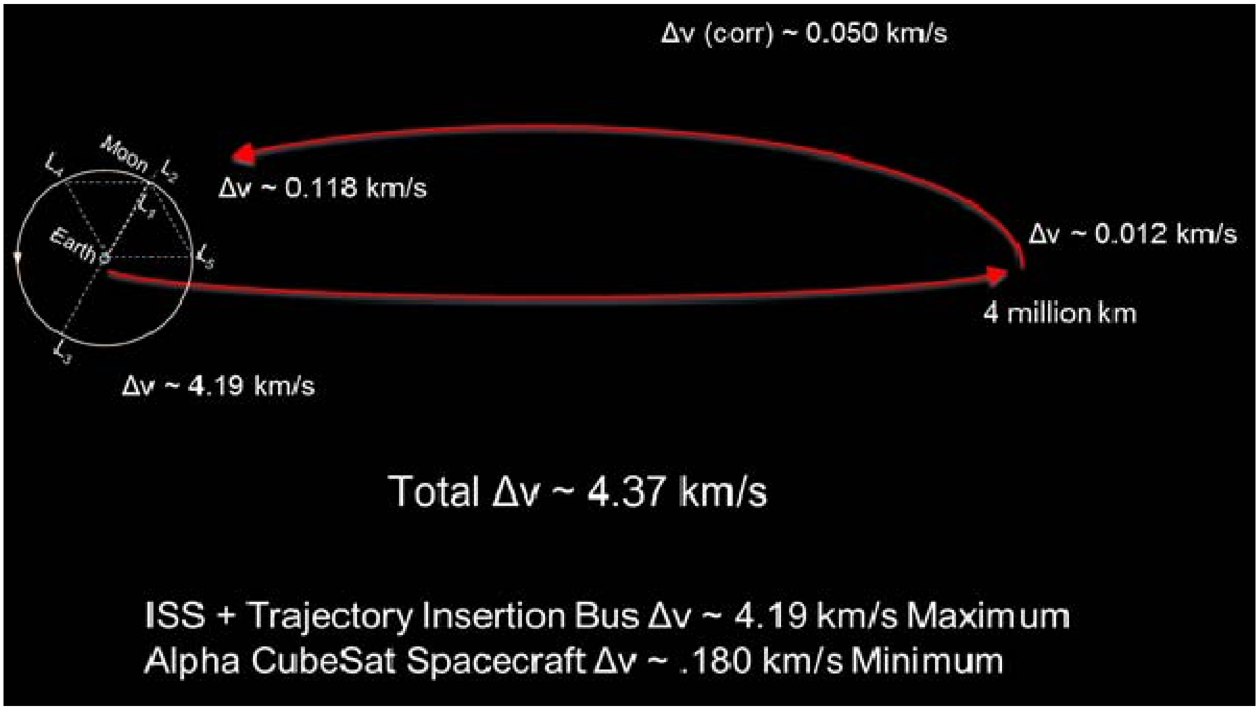

Figure 6. Alpha CubeSat Baseline Trajectory

The details of the trajectory calculations are as:

1) Commercial Cargo Transport to ISS
   a. Δv_{ISS} to reach ISS is not booked against the ACS mission.

2) ISS ➔ Trajectory insertion point via Launch Service Provider Trajectory Insertion Bus
   b. Δv_{E} is 4.19 km/s (maximum)

3) Alpha CubeSat Trajectory Makeup Propulsion to 4+ million km
   c. $\Delta v_{\text{Deep Space Trajectory Insertion}}$ is ~0.0 km/s (minimum)

4) Alpha CubeSat Deep Space (4+ million km) Maneuver
   d. $\Delta v_{\text{Lunar Trajectory Insertion}}$ is ~0.012 km/s (minimum)

5) Alpha CubeSat Trajectory Correction Budget
   e. $\Delta v_{\text{Correction Budget}}$ is ~0.05 km/s (minimum)

6) Alpha CubeSat stable lunar orbit injection
   f. $\Delta v_{\text{Lunar Orbit Injection}}$ is ~0.118 km/s (minimum)

Accordingly, the minimum required for the Alpha CubeSat Spacecraft $\Delta v_{Mission}$ = .180 km/s

The Lunar Orbit Manifold trajectory as shown in Figure 7. Lunar Orbit Manifold calculation details are as follows:

1) Earth Escape to 4 million kilometers
    a. R_p ~ 4.5E4 km, Δv ~ 4.19 km/s, e ~ 0.98, R_a ~ 4E6 km, time of flight ~ 166 days
2) Enter Lunar Manifold, target lunar periapsis ~ 500 km
    a. Δv ~ 0.012 km/s
    b. Achieves plane change at the Moon, desired lunar inclination, other lunar arrival conditions
3) Enter lunar elliptical orbit, 500 x 40000 km
    a. Δv ~ 0.0 km/s
    b. Ballistic capture into highly elliptical orbit with NO delta-V
    c. Ballistic capture region is called a Weak Stability Boundary
    d. (See references)
4) Lunar Manifold trajectory passes near Earth-Sun L_2 on a halo orbit
    a. Approaches on $W^+(L_2)$ stable manifold, departs on $W^-(L_2)$ unstable manifold
5) Lunar orbit apoapsis reduction, 500 x 40000 km to 500 x 10000 km
    a. Δv ~ 0.118 km/s, total time of flight ~ 315 days

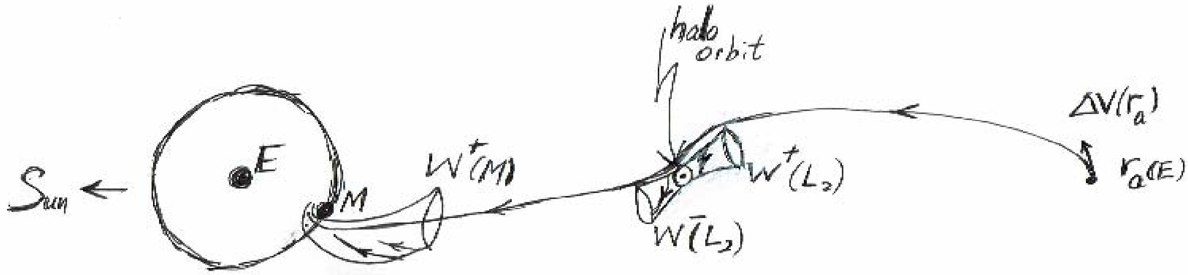

Figure 7. Lunar Orbit Manifold

The ACS propulsion analysis shows that the trajectory proposed is tractable and it was adopted as baseline. The use of Weak Stability Boundaries and ballistic escape and capture trajectories that take advantage of Sun-Earth and potentially Earth-Moon Libration Points to achieve trajectories and orbits of interest, radically reduces the delta V requirements.

Using a combination of long-term low-thrust, high-I_{sp} electric and multiple impulse high-thrust, low-I_{sp} chemical propulsion systems and the alternate minimum energy trajectories offers new mission opportunities.

E. Concept of Operations

The ACS concept of operations is shown in Figure 8 Alpha CubeSat Concept of Operations and can is outlined below:

1) Commercial Cargo Pressurized "Softpack" launch & stow
    a. IVA unpack & final assembly
    b. CYCLOPS JEM Airlock IVA ➔ EVR Transition
    c. EVR handoff to Mobile Servicing Centre (MSC)
2) Commercial Cargo Unpressurized Cargo launch & stow
    a. EVR unpack & final assembly
    b. EVR handoff to Mobile Servicing Centre (MSC)
3) Support services
    a. EVR MSC relocate & position for deployment
    b. MSC SPDM Deployment RAM + Starboard + Zenith Bias
    c. Final proximity checkout services (e.g., imaging, communications, navigation & power)
    d. Optimized access to alternative minimum energy trajectories
    e. Single & Multi-use Trajectory Insertion Buses
    f. Opportunities for Low Cost Earth Applications, Space Operations, and Space Exploration Missions

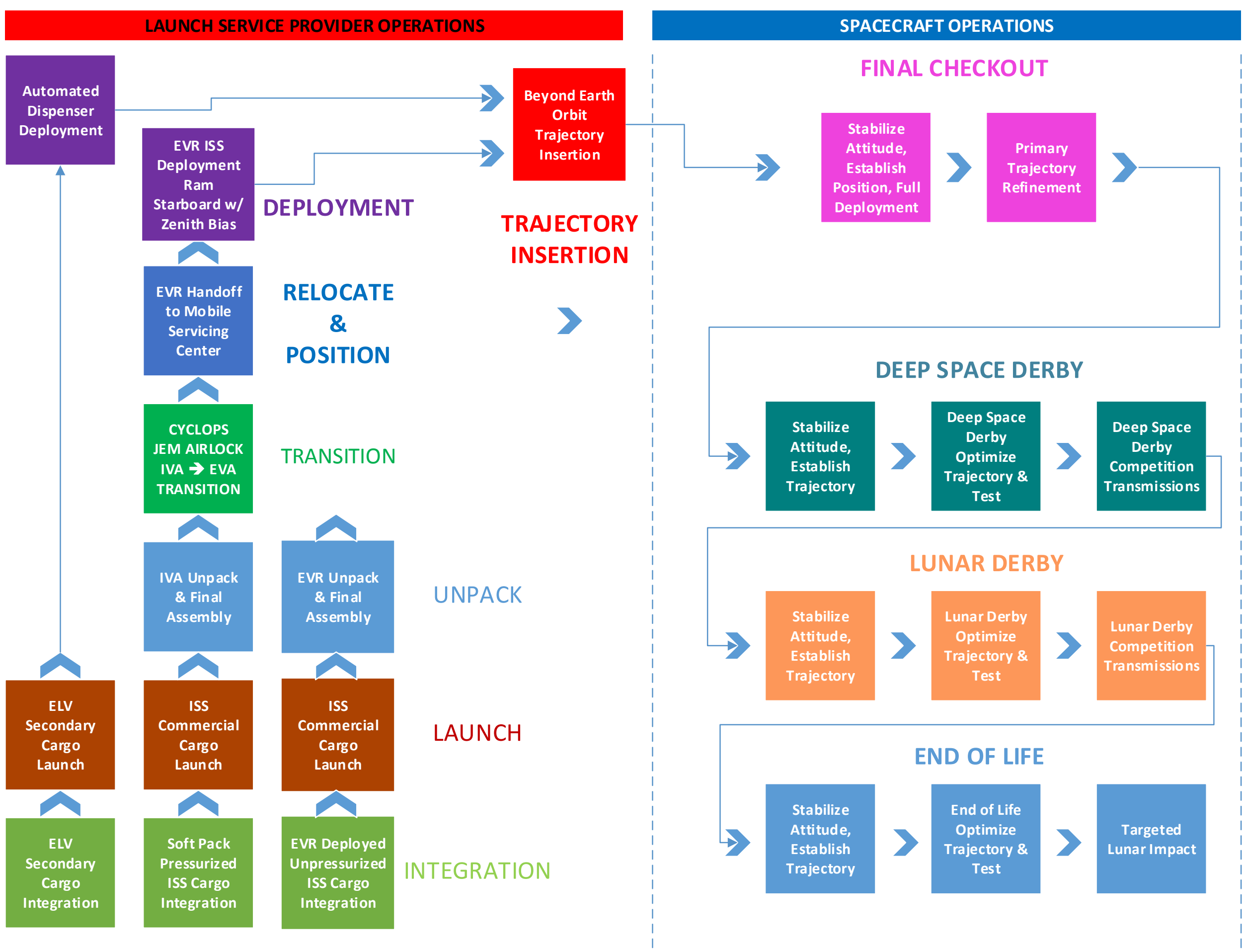

Figure 8. Alpha CubeSat Concept of Operations

The ISS coordinate system is shown in Figure 9. International Space Station Coordinate System. Current payload release operations for LEO destination are focused on Aft release with a Nadir (Deck) bias. The proposed payload operations for co-orbiting spacefraft and beyond Earth orbit destinations are focused on Ram release with a Zenith (Overhead) bias to mitigate the possibility of collision with ISS.

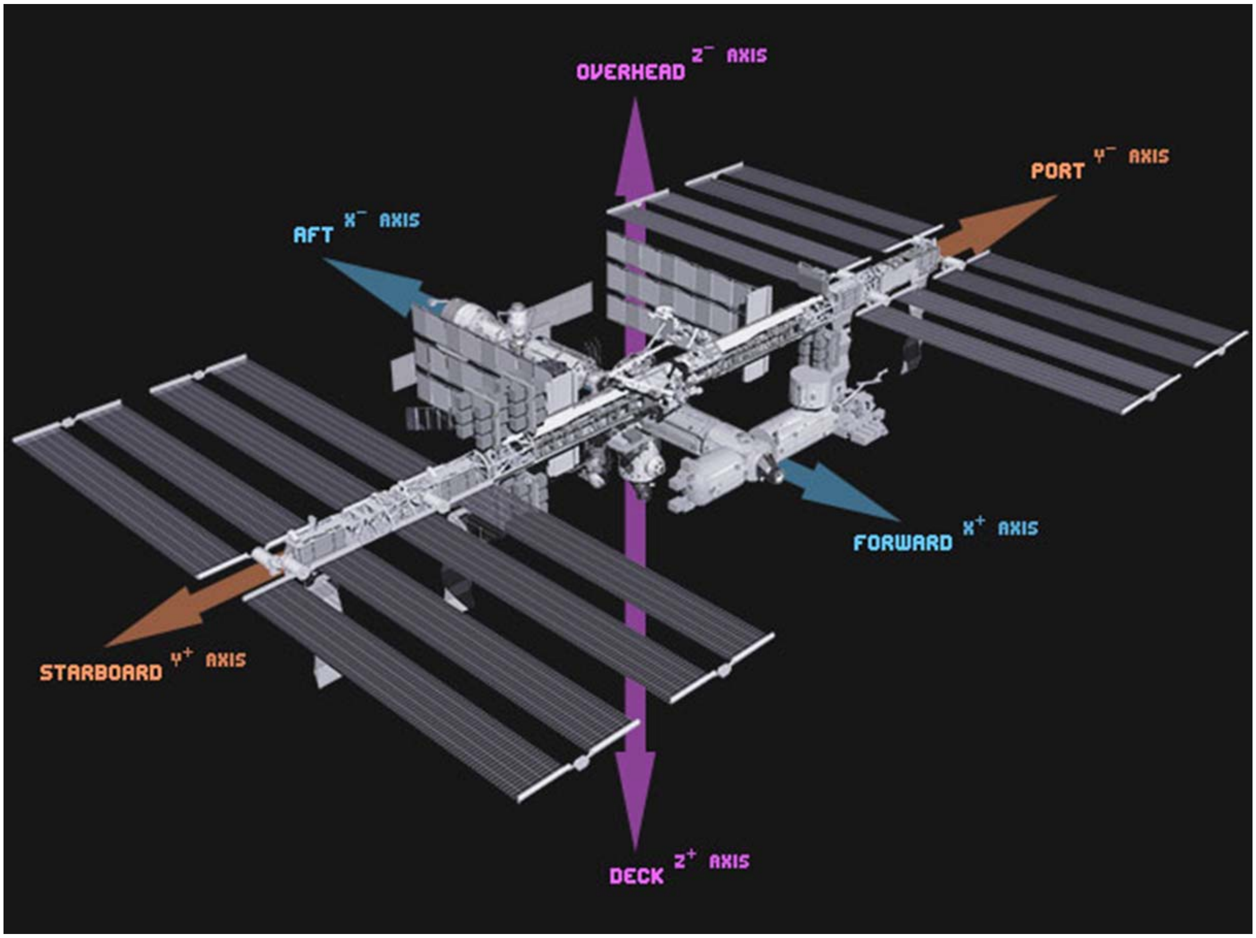

Figure 9. International Space Station Coordinate System

The CYCLOPS (a.k.a, Space Station Integrated Kinetic Launcher for Orbital Payload Systems - SSIKLOPS) Japanese Experiment Module (JEM) Airlock EVR Deployer Payload Volume is show in Figure 10 CYCLOPS JEM Airlock EVR Deployer Payload Volume. Until the eagerly awaited commercial airlock from Nanoracks, Inc. is delivered to the station all payloads that are delivered as pressurized cargo to ISS must pass through either the JEM airlock or through the EVA airlock with the crew in contingency situations.

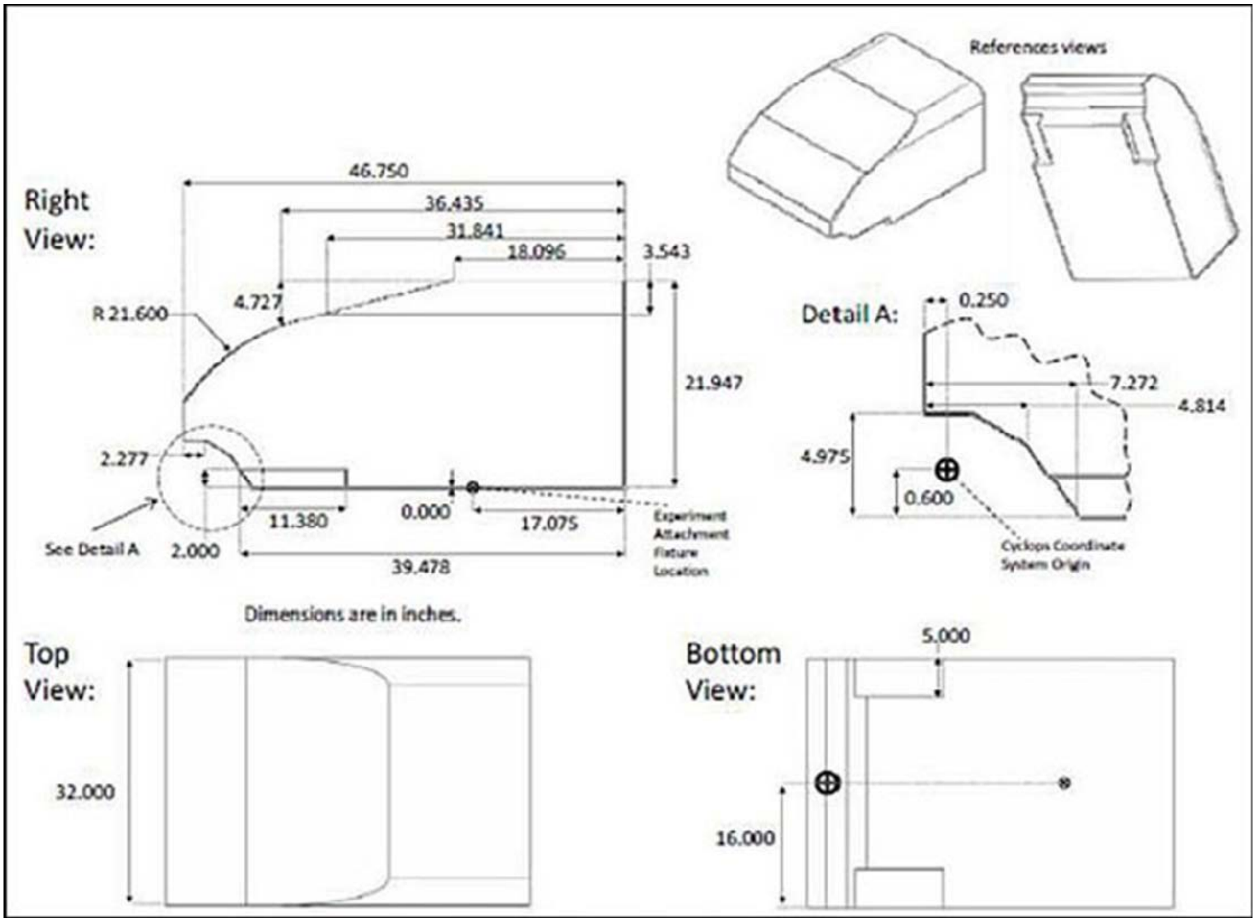

Figure 10. CYCLOPS JEM Airlock EVR Deployer Payload Volume

The Deep Space Insdustries, Inc. 3U flight test article incorporating their COMET-1 water fueled thruster is shown in Figure 11 Deep Space Industries 3U Flight Test Article Concept Art. The use on non-toxic readily available resources from terrestrial and non-terrestrial sources (i.e., insitu Resource Utilization -- ISRU), including the possibility of harvesting fuel solid, liquid, and gaseous fuel from an evolved Integrated Waste Management are emerging commercial opportunities.

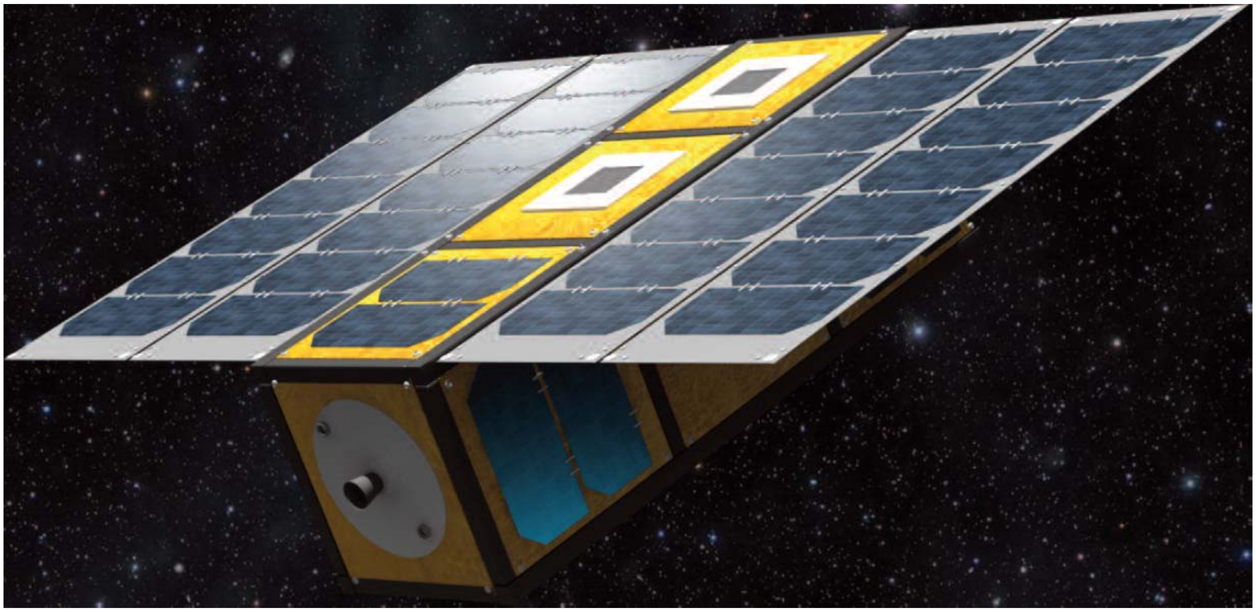

Figure 11. Deep Space Industries 3U Flight Test Article Concept Art

The Alpha CubeSat 6U Flight Test Article is shown in Figure 12 Alpha CubeSat 6U Flight Test Article Concept Art. It is anticipated that Alpha CubeSat will be one of the first beyond Earth orbit payloads to be launched from the ISS.

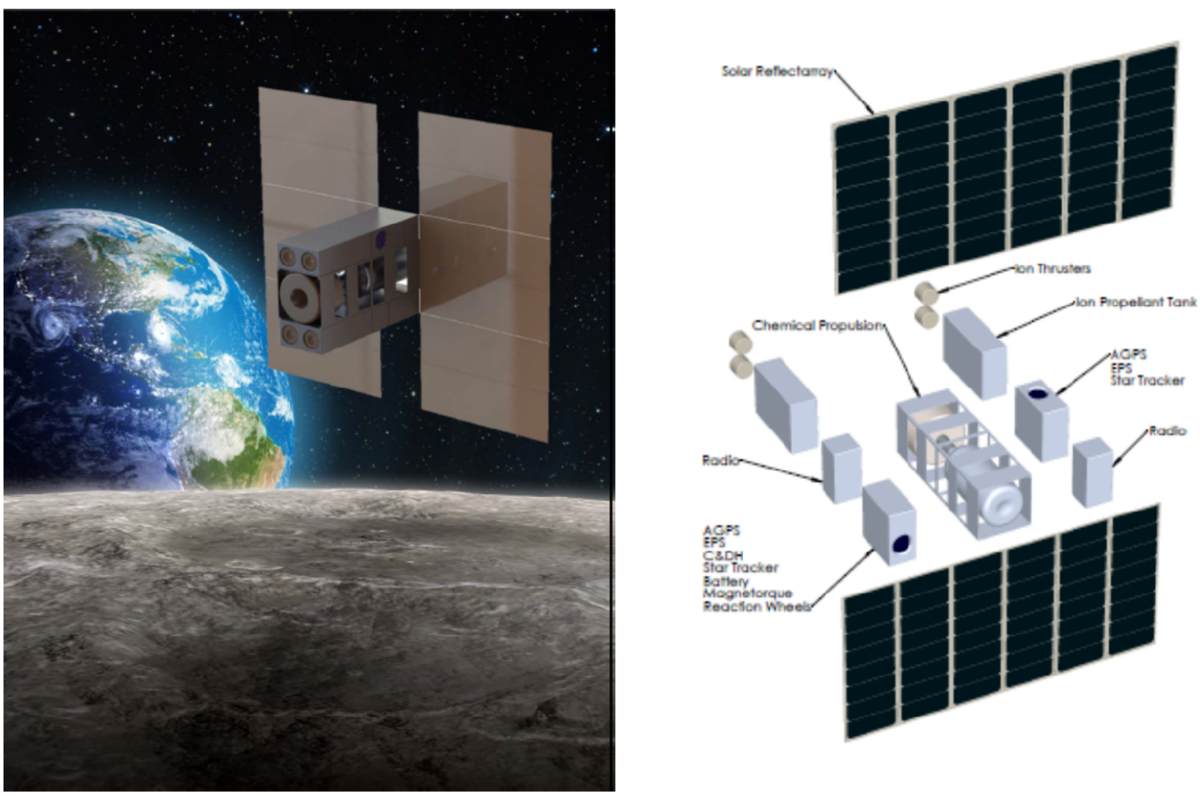

Figure 12. Alpha CubeSat 6U Flight Test Article

F. What is the relevance of the problem to NASA and others?

This work is part of an XISP-Inc proposed commerical Propulsion Test Bed mission which would be an Annex to an overarching Space Act Umbrella Agreement under negotiation between NASA Headquarters and XISP-Inc, as well as an in-place NASA ARC Space Act Agreement for Mission Operations Control Applications (MOCA). This mission seeks to leverage and/or develop alternate minimum energy trajectory solutions and innovative propulsion systems to bring a range of concepts that have been studied for decades to fruition.[10-11]

ACS is a recognized competitor in the NASA Cube Quest Challenge. A commercial Propulsion Test Bed mission using cubesat flight test articles requires the cooperation of NASA, industry, academia, and international partners.[12]

The work will result in a near term demonstration of a beyond Earth orbit mission launched through ISS, and provide a test bed to allow for the rapid iteration of designs and experiments.

The ISS is an extraordinary resource that can be leveraged to dramatically lower the cost of beyond Earth orbit technology development, demonstration, and deployment. As shown in Figure 13 Typical ISS EVR Operations, the set of EVR resources available to support operations including the Mobile Service Centre (Mobile Base Transporter + Mobile Base Structure + Space Station Remote Manipulator System), the Special Purpose Dexterous Manipulator (SPDM, aka Dextre), the JEM Remote Manipulator System (JEM RMS), the JEM Small Fine Arm (JEM SFA) are very capable systems. For example the SSRMS was designed to be capable of berthing a fully loaded Space Shuttle to the ISS.

Establishing ISS as a viable transportation node using small scale systems could allow experimentation and validation of components required to accommodate larger spacecraft, and reduce the cost, schedule and technical risk associated with the development, demonstration, and deployment of larger systems.

Although the initial experiments with ISS and cubesats would be small scale, there are near term applications for range of deep space missions including lunar and asteroidal assay work.

A primary mission of XISP-Inc is to develop cooperative arrangements with different parts of NASA and different industry partners. The early implementation of a beyond Earth orbit transportation capability on ISS, could enhance or enable a myriad of lower cost missions.

G. What is the proposed solution?

The use of the ISS as an evolving transportation node is an opportunity to apply ISS resources to the development of a Propulsion Test Bed and demonstrate how existing and enhanced infrastructure can provide a means to incrementally mature the technology base.

XISP-Inc has brought together an innovative partnership of interested parties to accomplish technology development work in this area including both government, commercial, university, and non-profit sectors. Many formal letters of interest have been submitted to NASA and/or XISP-Inc and are available on request.

This mission starts with the design and implementation/prototyping of a parametric model for unbundled power systems for spacecraft propulsion and/or sustained free flyer/surface operations in conjunction with the NASA ARC Mission Control Technologies Laboratory and other interested parties.[10] This work has provided an opportunity to craft a viable basis for establishing a confluence of interest between real mission users and the technology development, demonstration, and deployment effort. This could lead to a range of mission fight opportunities that can make efficient and effective use of beamed energy for propulsion and/or sustained operations.[11] Already, several potential research opportunities have emerged that could make use of a combination of resources currently available or that can be readily added to ISS.

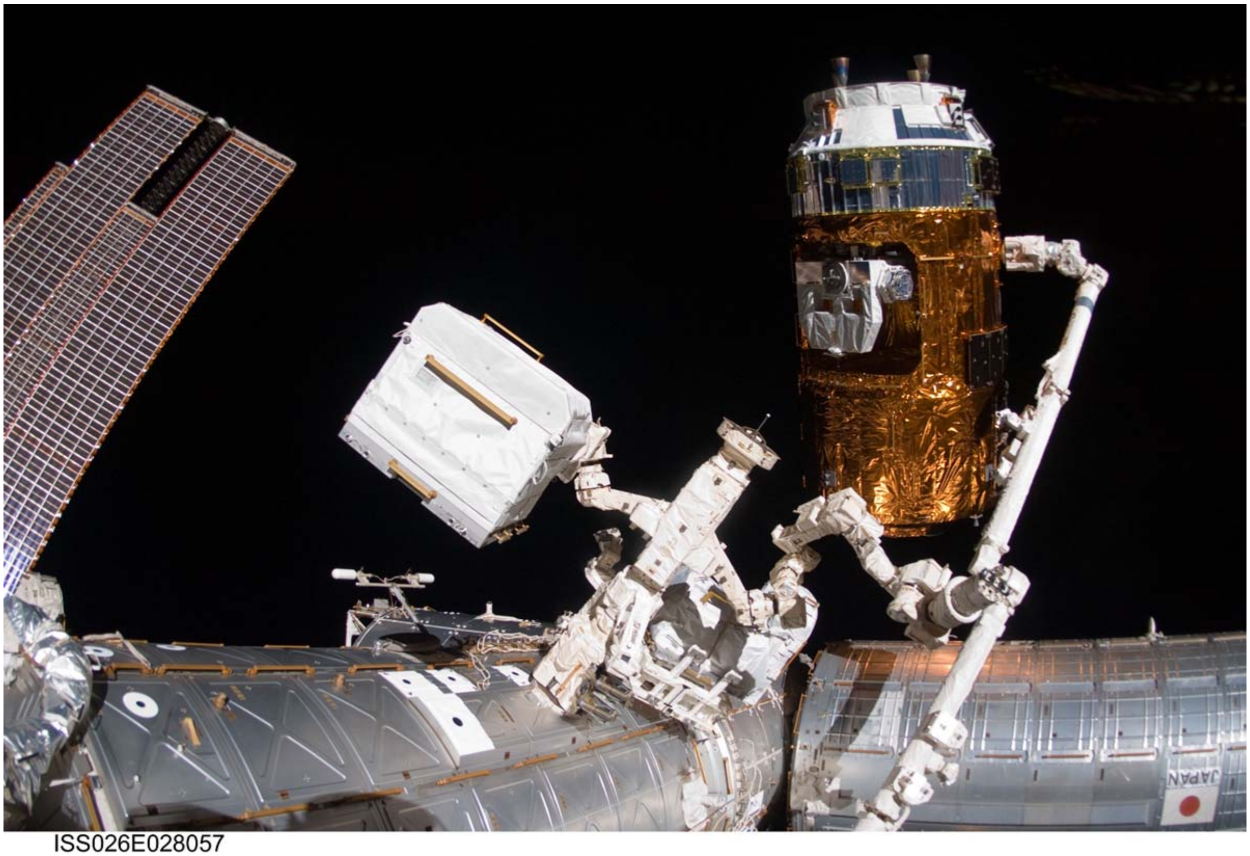

Figure 13. Typical ISS EVR Operations

III. Experiment Outline

The scope of this mission is outlined below.

A. Experiment Objectives

The experiment objectives that we have defined for this work are:

1) Support the development, demonstration, and deployment of advanced propulsion technologies and the use of alternate minimum energy trajectories.
2) Demonstrate the successful use of ISS as a beyond Earth orbit transporation node.
3) Reduce the cost, schedule, and technical risk associated with the use of the advanced propulsion technology and alternate minimum energy trajectory calculation to better address the mission challenges for new spacecraft and/or infrastructure.

B. Experiment Description

This experiment set will provide an alternate low cost launch option for beyond Earth missions.

This experiment is an opportunity to craft viable technology demonstrations that will establish the basis for a confluence of interest between real mission users and the technology development effort.

C. Technology Development

For the purposes of this work we have defined the scope of the technology development involved to include:

1) Knowledge Base on Radiant Energy Beaming
    a. Significant Actors/Interested Entities
    b. Intellectual Commons
    c. Prior Art
        i. Patents & Patents Pending

    ii. Trade Secrets
  d. Known Unknowns
2) End-to-End State Models
  a. Spacecraft Systems-of-Systems
    i. Mission operations control
3) Flight Test Articles
  a. DSI (3U) Spacecraft
  b. Alpha CubeSat (6U) Spacecraft
4) Flight Support Equipment
  a. Trajectory Insertion Bus
  b. Spacecraft Deployment Flight Support Equipment
  c. Spacecraft Recovery Flight Support Equipment

D. Technology Demonstration

For the purposes of this work we have defined the scope of the technology demonstation involved to include:

1) Test Beds
  a. Propulsion Test Bed

2) Flight Test Article & Flight Support Equipment Interfaces
  a. Modular Small Space Craft (e.g., DSI (3U), Alpha CubeSat (6U), etc.) Interfaces
  b. Trajectory Insertion Bus Interfaces
  c. Spacecraft Deployment Interfaces
  d. Spacecraft Recovery Interfaces

E. Technology Deployment

For the purposes of this work we have defined the scope of the technology deployment involved to include:

1) Team ACS
2) Beyond Earth Orbit Deployment Platform – The mission objective is to support the use of one or more ISS trajectory insertion bus by directly or indirectly providing a propulsion augment using a radiant energy beam from the ISS.

IV. Technological Challenges

There are significant safety considerations associated with the operation of a propulsion test bed, in any location. Building and operating a propulsion test bed on-orbit provides both some unique advantages and disadvantages.

The ready access to the intended operation environment (e.g., hard vacumn, temperature extremes, etc.) is a clear advantage.

The absence of convection and atmospheric blast effects, may provide an additional margin of safety.

The use of toxic and/or highly energetic mono and bi propellants is not suitable for ISS IVA handling and EVA/EVR handling will require very carefully orchestrated and validated procedures. The transition to non-toxic, throttable systems is anticipated to be a key area of test bed research interest.

The increased cadence of operations associated with using the ISS as a transportation node will require an evolution of operational procedures.

Most if not all test bed and deployment operations will have to be conducted using ExtraVehicular Robotic (EVR) systems

V. Mission Team

The following organizations, entities, and/or individuals have notified XISP-Inc of their interest in cooperation/collaboration with respect to this mission:

A. Commercial Entities

1) Xtraordinary Innovative Space Partnerships, Inc. - Gary Barnhard, et.al.
2) Deep Space Industries, Inc - Daniel Faber, et.al.
3) Center for the Advancement of Science In Space (CASIS) – David Zuniga, et.al.

4) Nanoracks Inc. – Chad Brinkley, et.al.
5) EXOS Aerospace – John Quinn, et.al.
6) Innovative Orbital Design – Dr. Edward Belbruno

A. Universities:
1) University of Maryland Space Systems Lab – David Akin, et.al

B. Government Agencies:
1) NASA Headquarters Human Exploration & Operations Mission Directorate
    a. Advanced Exploration Systems Division, Jason Crusan, et.al.
    b. Space Communications and Navigation Office, Jim Schier, et.al.
2) Multiple NASA Centers will have some cooperating role – NASA ARC, et.al.

C. Non-profit Organizations:
1) Space Development Foundation
2) National Space Society

D. Consultants/Advisors:
1) Joseph Rauscher

Multiple other commercial, educational, and non-profit organizations have expressed substantive interest in cooperation/collaboration with respect to this mission and are actively negotiating their potential role with XISP-Inc.

VI. Next Steps

XISP-Inc is the founding sponsor of Team ACS and has an evolving set of commercial mission recognized by NASA. NASA is participating through a combination of in-place (NASA ARC) and proposed (NASA HQ) Space Act Agreements. Formal request for support is under review with CASIS. NASA direct support to accelerate and/or add additional milestones when opportunities emerge is being negotiated.

Additional partners/participants are being sought in the commercial, academic, non-profit, and government sectors.

Opportunities for international cooperation leveraging the ISS Intergovernmental Agreement are being explored and developed. Use of ISS helps ensure that this is an international cooperative/collaborative research effort.

1) Design and implement a propulsion testbed environment for ISS
    a. Testbed will provide the common infrastructure required
2) Safety protocols required for each mission stage must be defined
    a. Experiments need a known path to flight
3) Each experiment will start with the defined operations and safety protocols augmented as needed based on any mission unique aspects added
4) The possibilities for final assembly and checkout support need to be actualized by meeting real mission requirements

VII. Conclusion

Multiple solutions exist for using ISS as a beyond Earth orbit transportation node in theory, in practice we need to test & optimize alternatives

1) We need to learn how to scale to larger systems
2) We need to create opportunities for collaboration
3) We need to find ways to do more with less resources
4) On-orbit final assembly and checkout needs to be move from theory to practice

We need to lower the perceived cost, schedule, and technical risk of accomplishing all of the above.

This is an opportunity to forge a bridge between technology development, demonstration, and deployment that is mission enhancing and/or mission enabling in many instances.

This is a new way of doing business, that we need to learn to leverage . . .

"Once you're in low Earth orbit you're halfway to anywhere."
– Robert Heinlein

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