Technical Proposal

Part 1: Table of Contents

Part 2: Identification and Significance of the Innovation

The Problem

Systems of systems state models are N-Dimensional interaction problems (i.e., a potentially arbitrary number of objects interacting in an arbitrary number of ways), a class of problems for which the generalized solution space is typically computationally intractable in any time frame. Space automation, autonomy, and robotics present a subset of these problems that exacerbates the situation by requiring near real-time solutions in many instances. Solving these challenges requires the ability to structure and order complex knowledge sets in both a computationally tractable manner and in a framework coherent and accessible to human understanding. Fundamentally, reality is neither a convenient problem nor solution space.

The Proposed Innovation

The proposed innovation is to develop near real-time state model extensions, using the proposed XISP-Inc Crosslink Protocol (XLINK) shown in Figure 2-1, to the NASA Ames Mission Control Technologies (Open MCT) software platform, in support of one or more Technology Development, Demonstration, and Deployment (TD^3) missions. The objective is to create an extensible implementation tool set for near real-time state models that can be applicable to multiple TD^3 missions.

The Relevance of the Proposed Innovation to the Subtopic H6.03 Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration

The proposed innovation (aka near real-time state model extensions) is part of an intelligent autonomous agent cognitive architecture that is both open and modular such that it can feasibly be certified for use on ISS, Cislunar, and deep space missions to interact both with the mission control operators, the crew, and most if not all of the spacecraft subsystems.

It is anticipated that such a cognitive agent with access to all relevant data (onboard and otherwise accessible) and communications, could continually integrate this dynamic information and advise and assist the crew and mission control on a shared control basis. Relevant interfaces that support multiple modes of interaction including text, speech, and animated images can be added using the Xlink protocol. It is anticipated that such an agent could respond to queries and recommend to the crew, mission control, and autonomous control systems with courses of action and direct activities that take into account all known constraints, the state of the systems, availability resources, risk analyses, and goal priorities.

These capabilities can support future human and robotic spaceflight missions for which the locus of control must necessarily be mutable (e.g., due to communication lag and interruptions in service due to distance, positioning, and/or unanticipated events). Such novel artificial intelligence capabilities as proposed can serve as a foundational technology for space automation and robotics. They can allow for control to be shared on a seamless basis between crew, ground control, and autonomous control systems. Such shared control capabilities would augment all controlling authorities' ability to manage spacecraft operations including spacecraft and systems health, crew health, maintenance, consumable management, payload management, training, as well as activities such as food production and recycling.

It is anticipated that such systems will reduce the cognitive loads on the crew as well as perform many tasks that would otherwise require scheduling crew time. In addition, this such cognitive computing capabilities will be necessary in many circumstances to respond to off-nominal events that overload the crew; particularly when the event limits crew activity, such as high-radiation or loss of atmospheric pressure events.

Such systems must implement a plug-in/plug-out modular hardware and software architecture that allows modules to be dynamically be added, removed, and enhanced in support of virtualized functions which have defined Quality of Service requirements (i.e., performance, availability, and security).

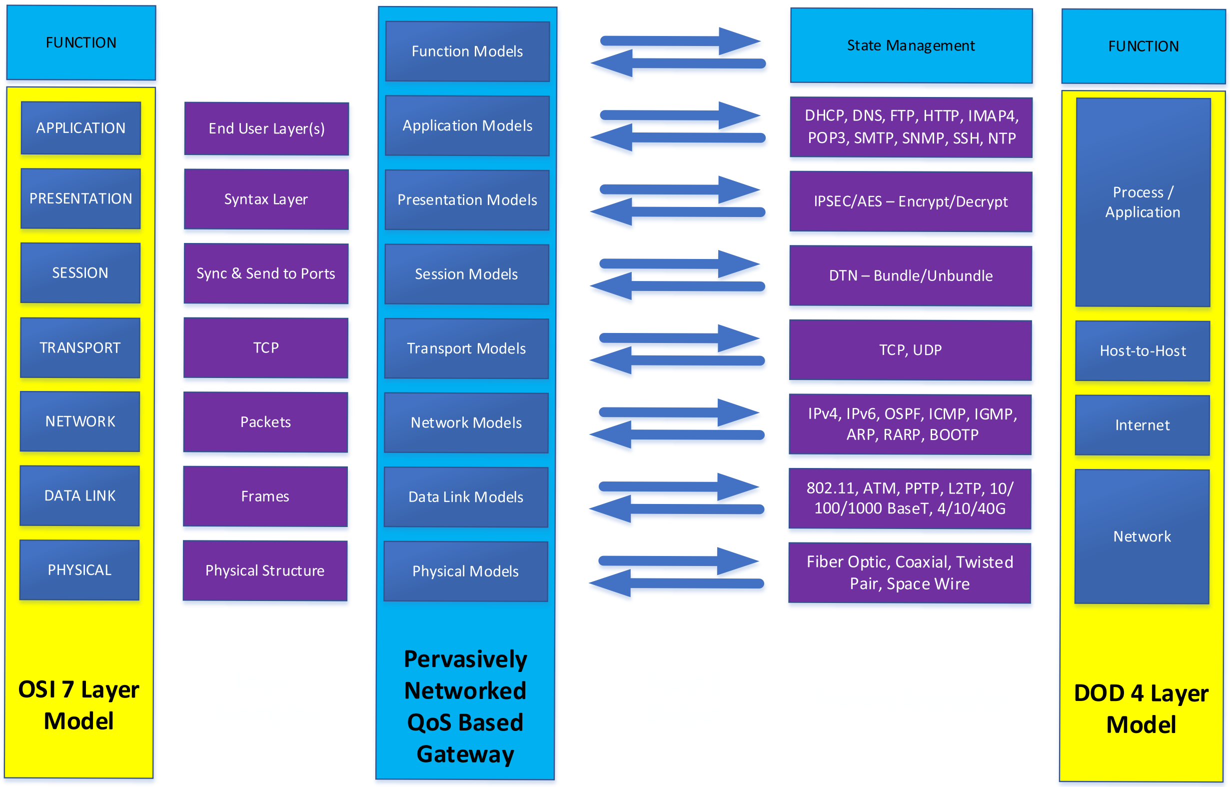

Figure 2-1 XISP-Inc Crosslink Protocol (XLINK)

The XISP-Inc proposed approach postulates that any given system of systems can be understood as a set of supported functions that can be modeled as a process flow problem involving a series of telemetry/command/payload/ancillary internal and external data streams, a layered hierarchy of models bound to physical systems and/or useful, and taxonomy of characterizable flows across the internal and external interfaces. The "Crosslink" (XLINK) protocol captures the metadata glue used to link the functions, data streams, models, and characterizable flows together in a tractable manner. The models in this case are transforms that specify when, how, and why a state transition can occur at a given level. The models are layered in order to allow for knowledge specification at level of abstraction that makes the sub-problem tractable. Models may have one or more inference engines ranging from classic if/then rule parsers, to Bayes theorem instances for probabilistic data, to hypothesis and test for fuzzy inferences, to neural networks, advanced pattern recognition algorithms, minimum set covering probabilistic heuristics, and a whole host of discipline transforms. If the framework created is robust enough the overall "state model" can be refined both iteratively and recursively with the relative value of each transform to driving the allowed state transitions to determinacy calculable. The transforms can then be ordered based on the required input data and the efficacy of the output. This allows for a prioritization and allocation of resources to achieve satisfactory and sufficient answers first, with refinement possible as resources permit.

The emphasis of proposed efforts will be on analyzing and demonstrating the feasibility of various configurations, capabilities, and limitations of a cognitive architecture suitable for crew support on deep space missions which necessitates a mutable locus of control with respect to both automation and autonomy.

The software engineering of a cognitive architecture will be documented and demonstrated by implementing a prototype goal-directed cognitive agent in this case a near real-time state model that interacts with an ISS simulation, experiment hardware (simulated spacecraft systems), autonoma, and humans.

For Phase I, a preliminary cognitive architecture, preliminary feasibility study, a cognitive agent prototype that supports a human operating a simulated complex system that illustrates a candidate cognitive agent architecture, and a detailed plan to develop a comprehensive cognitive architecture feasibility study will be created.

The cognitive architecture will be designed for implementation as a set of virtualized functions with defined Quality of Service (QoS) requirements. It will be capable of supporting multiple processes executing on multiple processors, in order to meet the expected computational loads as well as be robust to processor failure. The cognitive architecture developed will be capable of being certified for crew support on spacecraft and will be open to NASA with interfaces open to NASA partners who develop modules that integrate with other modules on the cognitive agent in contrast to proprietary black-box agents.

The proposed research program while anticipated to be tractable is at best on the bleeding edge of the state-of-the-art. Demonstrating a cognitive architecture that supports one or more practical applications in a tractable manner that can at least provide satisfactory and sufficient control authority with a mutable locus of control is a technology development challenge.

Accordingly, rather than treat this is an abstract problem XISP-Inc proposes to use this effort to augment the development of near real-time models in support of the XISP-Inc integrated ISS TD^3 mission set [Figure 2-2] under an existing Space Act Agreement with NASA and an evolving set public-private partnerships.

More specifically:

Team Alpha CubeSat (ACS) NASA Cube Quest Challenge Entry
- Operations of a 6U Tech Dev Cube Sat

➔ Virtual Operations Center

Space-to-Space Power Beaming (SSPB)
- Effective use of radiant energy beam components

➔ Cislunar Electrical & Ancillary Services Utility - Lunar Power & Light Company

Interoperable Network Communications Architecture (INCA)
- virtualized function compute modules which are thermally and radiation managed, dynamically allocable, support multi-core processors, as well as fault tolerant memory and storage

➔ Testing Delay/Disturbance Tolerant Networking (DTN) with real world requirements

➔ Pervasively networked DTN gateway/QoS Router

➔ Space Based Automated Telco Central Office Testbed

Systems Control Through Advanced Algorithms (SCTAA)
- improve microgravity, decrease propellant use, and facilitate operations
- Demonstrate adaptive control using state models
- Multi-vehicle synchronization & payload control

Advanced Vision and Task Area Recognition (AVaTAR)
- Framework for supporting a mutable locus of control between teleoperation and autonomy on a shared control basis

  ➔ Dramatic improvements in speed, efficiency, and safety for EVR and combined EVA/EVR tasks

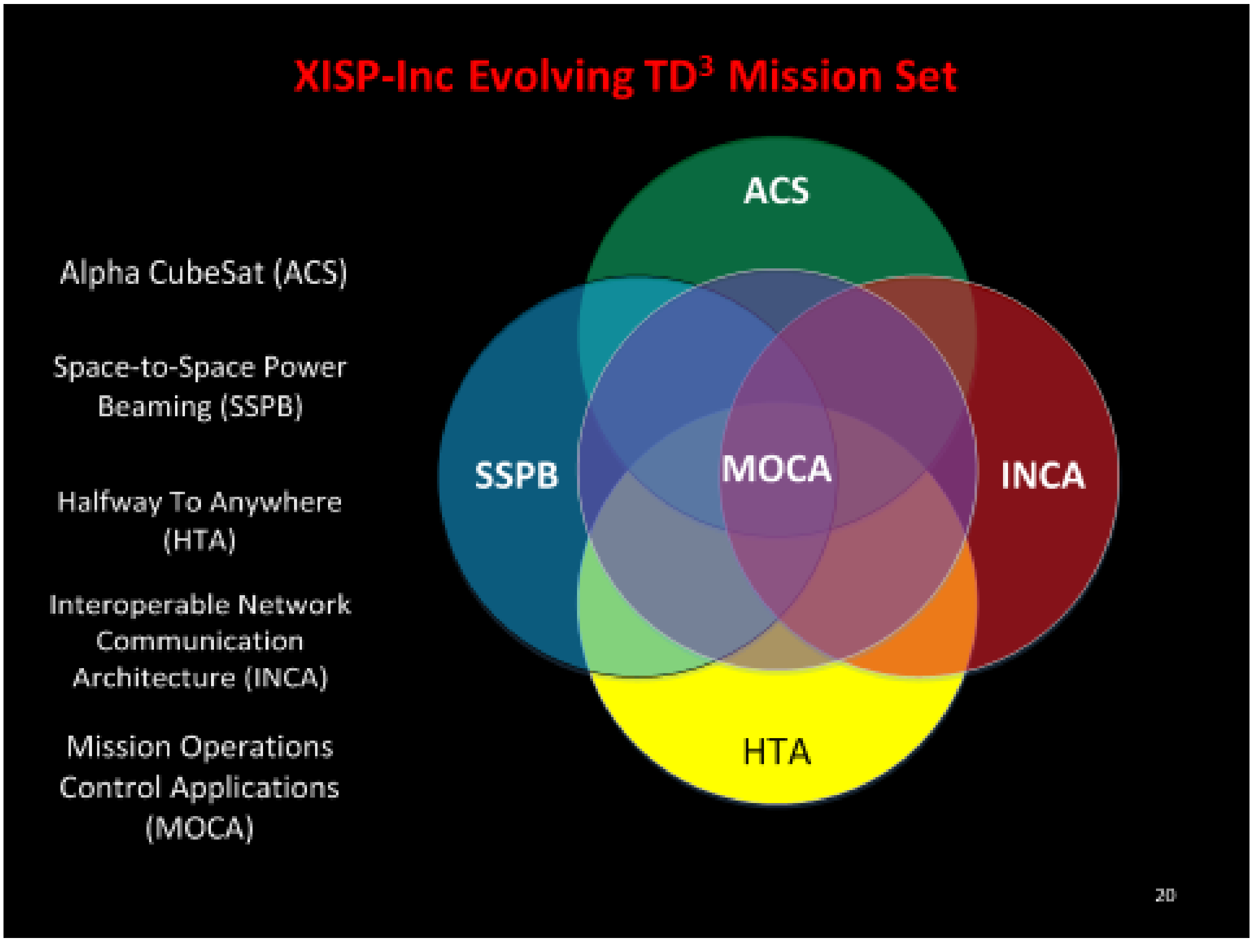

Figure 2-2 XISP-Inc Evolving TD^3 Mission Set

XISP-Inc has brought together a truly innovative partnership of interest 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 implement/prototype 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. 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 work can expand further opportunities for the international cooperation and collaboration, including:

- Extra Vehicular Robotics (EVR)/Systems of Systems Automata – Teleoperation to Autonomous Operations;
- Intra Vehicular Robotics (IVR)/Systems of Systems Automata – Earth control to full automation and/or autonomy from Earth;
- Interaction with novel environments -- emergency conditions, exploration rovers, etc.;
- Supporting transportation to as well as living and working in Low Earth Orbit, Cislunar space & beyond;
- Implementing the Advanced Vision and Task Area Recognition (AVaTAR) near real-time state model (autonomic nervous system) and dynamic world modeling capability using current technology for use with EVR & IVR systems (e.g., DEXTRE, Robonaut, Spheres) on the International Space Station.

This mission proposes to further develop and demonstrate the use of NASA Ames Mission Control Technologies software (Open MCT) as an extensible implementation tool set for near real-time state models. We address the characterization, optimization, and operation of near real-time models being developed as part of the XISP-Inc integrated ISS TD^3 mission set under an existing Space Act Agreement with NASA and an evolving set public-private partnerships.

Open MCT is an open source framework for developing web-browser-based systems for visualizing and analyzing telemetry data, as well as formulating and processing command streams. The advanced parametric state models proposed will generate system status in near-real-time, even over low-bandwidth and high-latency connections. Such models can be used to provide rapid fault detection, autonomous operation, and other applications that could benefit from complete near-real-time information of a remote system's state.

Part 3: Technical Objectives

The MOCA initial mission objectives are:

1) Defining and prototyping parametric state models for integrated end-to-end mission operations control applications.
2) Implementing the parametric state models for technology development and demonstration mission prototypes, test and flight articles.
3) This effort includes the incremental, iterative, and recursive development of near real-time state models of all the supported mission components operating within the MCT framework/environment

Part 4: Work Plan

<u>Making MOCA real</u>

XISP-Inc has hypothesized that in order to make near real-time state models real for a significant number of applications the order of the problem to be solved must be reduced to something tractable. The proposed approach involves:

- Breakup problem space into many sub-problems suitable for parallel processing
- Focus on the sub-problems that matter
- Use boundary conditions, initial conditions, symmetry, known geometry, established datums, etc. to further reduce complexity

The key is to propagate constraints as rapidly as possible.

A mutable locus of control is required between:

- Teleoperated and Autonomous Operations
- Ground and Inflight Operations
- Scheduled and Dynamic Operations
- Defined and Sensed Environments
- Referenced/Predicted/Sensed Geometry
- Toggled and Shared Control

This necessitates near real-time state models of the involved systems and the environment

N-Dimensional interaction problems do not have to be intractable.
With appropriate metadata, transforms can be applied.

- Data is a set of ordered symbols
- Data in context is information
- Information in perspective is knowledge
- Knowledge in reflection is wisdom

Problems of interest can be recast and structured as:
(Items (Attributes (Values))) -- LISP transform

They can then be modeled as a set of process flow problems.
Inference driven constraint propagation can then be applied to reduce the generalized solution space to a computationally tractable scale.
The structure and ordering of knowledge makes a very real difference . . .

- Systems-of-systems can be bounded as a finite set of state transitions
- Systems can be modeled as a set of flows across defined interfaces
- A taxonomy of flows can be defined as either energy, mass, or information and then further subdivided into individual types as shown in Figure 4-1 Sub-System Flow Taxonomy
- Each type of flow can be defined by a specific set of qualitative and quantitative attributes, independent of the source and terminus
- *Each set of characterized flows can be associated with corresponding states and allowable transitions.*

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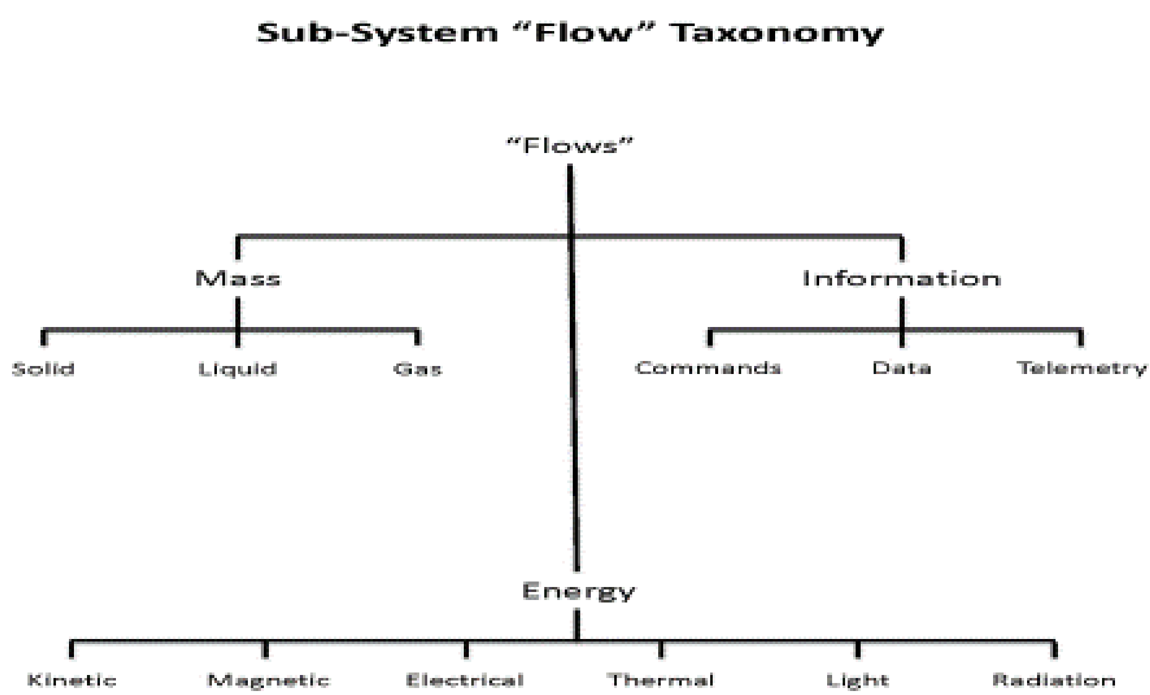

Figure 4-1 Sub-System Flow Taxonomy

<u>MOCA initial products for supported missions*</u>

1. Development of a paper model and individual element protocode (see Figures 4-2, and 4-3)
2. Development of functioning individual element models and an end-to-end model protocode;

Alpha CubeSat Electrical Power System (EPS)

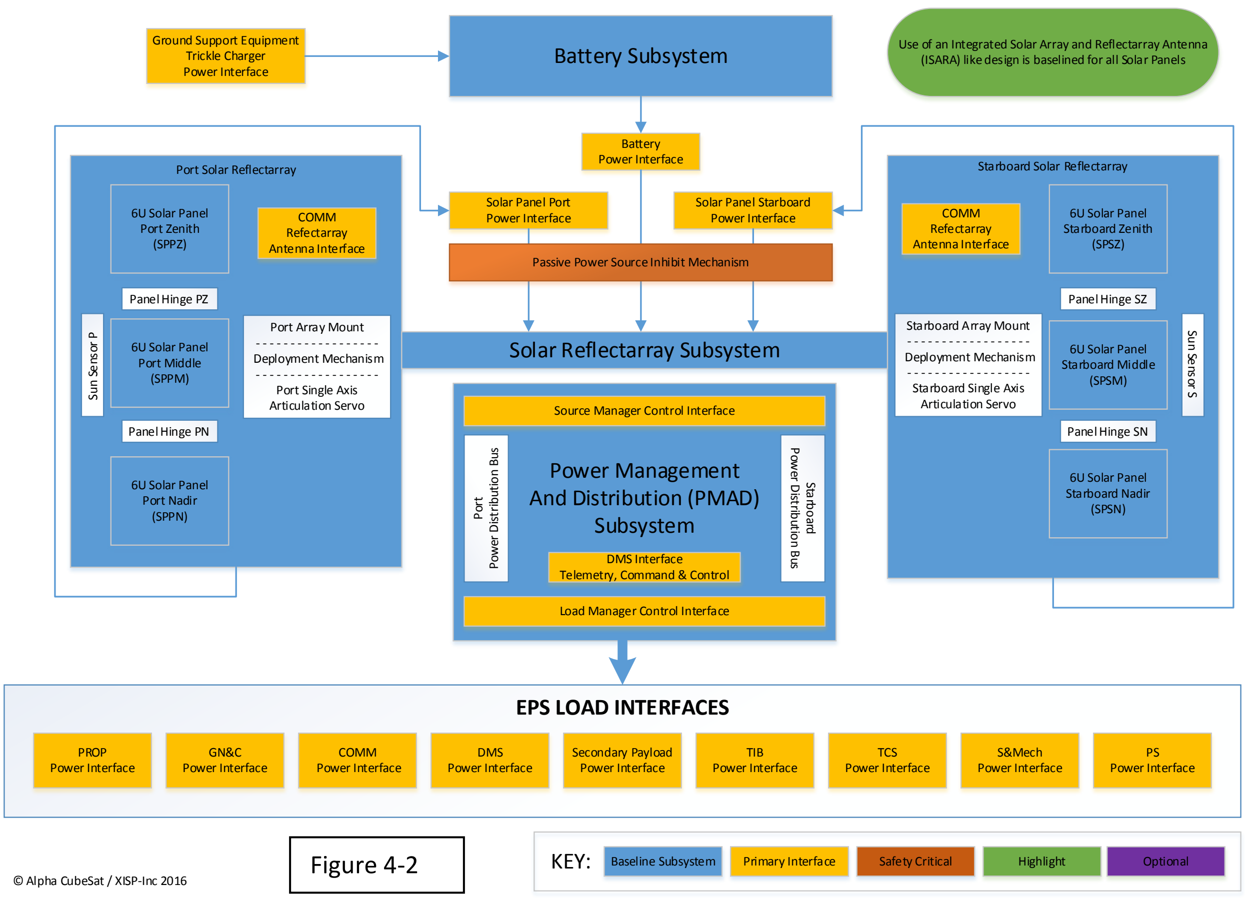

Figure 4-2

System Telemetry Status

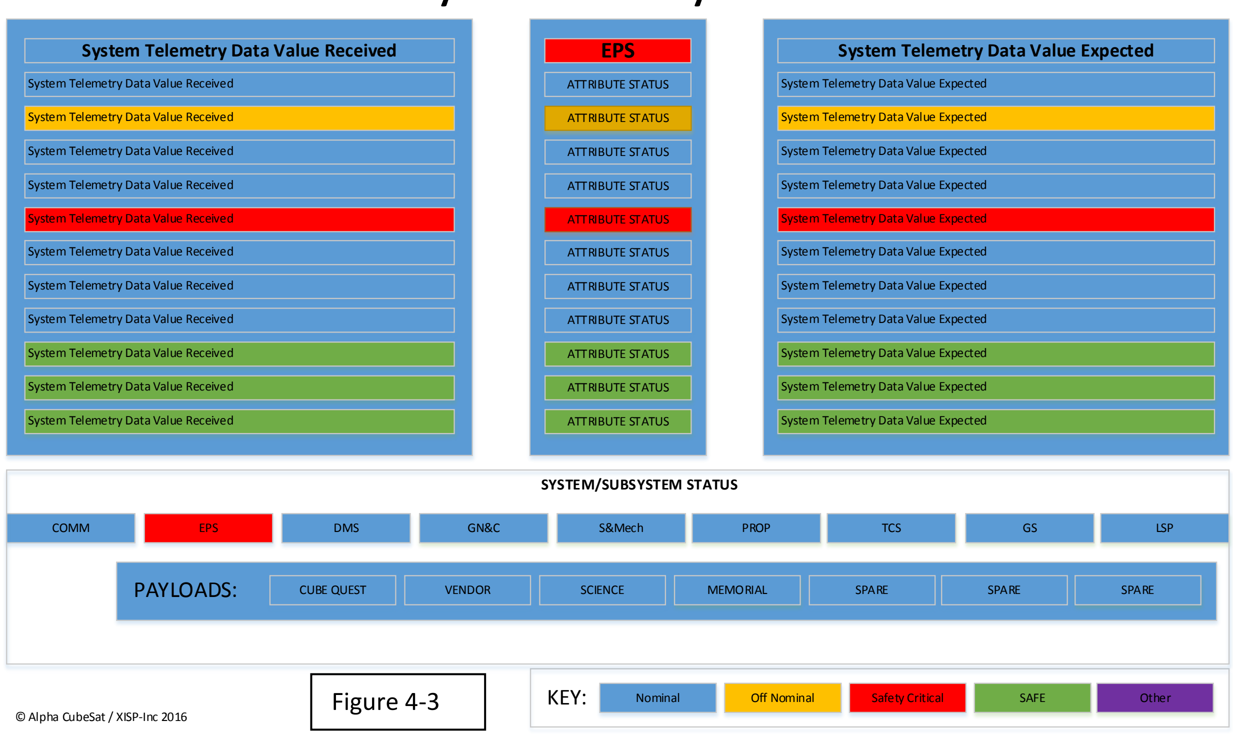

Figure 4-3

3. Optimization of individual element models and a functioning end-to-end model;
4. Testing of the optimized end-to-end model and individual element models in mixed modes (protoflight hardware and software with simulation as needed).

* MOCA progress for each supported mission to date has been driven by the status and schedule of each mission and the availability of resources. By providing direct funding to MOCA progress can be made independent of the supported missions' ability to directly allocate funds to the MOCA effort prior deliverable functionality.

For the purposes of this work we have identified initial products for each supported mission. The experiment objectives that we have defined for this work are:

- MOCA extended activities will focus on actual on-orbit demonstrations and flight testing the efficacy of the near real-time parametric state models developed for the supported missions.
- Follow-on activities will focus on assessing, reviewing, and establishing the efficacy of applying the near real-time parametric state modelling tools to other current and future technology development missions.

MOCA Technology Development

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

1) Knowledge Base on Mission Control Technologies
    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. System/Subsystem
        i. Characterize the system/subsystem in a near real-time state model
        ii. Optimize the system/subsystem for performance based on application
        iii. Operationalize the system/subsystem by defining and encoding the performance envelope and operating rules.
    b. Spacecraft Systems-of-Systems
        i. Mission operations control

MOCA Technology Demonstration

For the purposes of this work we have defined the scope of the technology demonstration involved with applying MOCA to:

1) Radiant Energy Beam Management
    a. Characterization of the radiant energy beam
    b. Optimization of the radiant energy beam
    c. Operationalize the radiant energy beam
2) Test Bed Operations
    a. Near Field/Far Field Test Bed
    b. Loosely Coupled Modular Structures Test Bed
    c. Propulsion Augment Test Bed
    d. Platform Infrastructure Technology Test Bed
3) Rectenna Design
    a. Differentiation and performance characterization by size
    b. Differentiation and performance characterization by type
    c. Differentiation and performance characterization by build method

4) Flight Test Article & Flight Support Equipment Management Operations
    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. Logistics Carrier Augmentation Interfaces

<u>MOCA Technology Deployment</u>
For the purposes of this work we have defined the scope of the technology deployment involved to include:

1) Team Alpha CubeSat (ACS) NASA Cube Quest Challenge
   a. NASA recognized team in good standing.
   b. Successfully completed PDR, pressing to CDR for this fall.
   c. Currently 95%+ volunteer effort supported by XISP-Inc.
   d. System-of-systems view with drill down.
      i. systems => subsystems => components => interfaces => flows

2) Space-to-Space Power Beaming (SSPB)
   a. NASA recognized XISP-Inc commercial mission.
   b. Flight articles based on ACS & BitSat design from DSI.
   c. Public/Private implementation team forming up.
   d. CASIS integration support, Commercial Cargo, and ISS resource allocation requests in development.
   e. End-to-end space-to-space radiant energy beaming characterization.

3) **Interoperable Network Communications Architecture (INCA)**
   a. NASA recognized XISP-Inc commercial mission.
   b. Flight articles based on ACS & BitSat design from DSI.
   c. Public/Private implementation team forming up.
   d. CASIS integration support, Commercial Cargo, and ISS resource allocation requests in development.
   e. Near real-time characterization of the Quality of Service (Performance, Availability, and Security) for a single defined function is the critical design point. If it can be accomplish for one function it can be accomplished for multiple functions.

4) **Systems Control Through Advanced Algorithms (SCTAA)**
   a. Ongoing technology development effort aligned with the NASA Payload Opportunities Program.
   b. EXOS Aerospace is an XISP-Inc teammate cooperating and collaborating on XISP-Inc missions (e.g., MOCA, SSPB, INCA, and AVaTAR).
   c. Near real-time state model of the star tracker data acquisition, state data processing, and Reaction Control System command string generation for precision pointing.

5) **Advanced Vision and Task Area Recognition (AVaTAR)**
   a. Nascent mission opportunity which could leverage near real-time state modeling capabilities that meet real mission requirements as a foundational technology for evolving space automation and robotics capabilities.
   b. Near real-time state model of DEXTRE and dynamic world model of the task area and its intersection with the environment.

The XISP-Inc enhanced MCT is intended to provide virtual control centers for all supported missions.

<u>Phase I Deliverables</u>:

1. Preliminary cognitive architecture,
2. Preliminary feasibility study,

3. Cognitive agent prototype that supports a human operating a simulated complex system that illustrates a candidate cognitive agent architecture, and
4. Detailed plan to develop a comprehensive cognitive architecture feasibility study.

Phase I Staffing:

1. Gary Barnhard, Principal Investigator, Mission Technical Lead (41+ years and specialized experience -- computer/robotics/space), 458 hours (half time for six months)
2. Engineer 2 - Aerospace Systems Engineer (10-20 Years or equivalent with programming experience) 1064 hours (one to three staff, part time)

Phase I Travel:

1. *Mid Phase Collaboration* -- Location From: Cabin John, Maryland Location To: Mountain View, California
   Number of People: 2 Number of Days: 5
   Purpose of Trip: Face-to-face collaboration work session with NASA Mission Control Technologies Lab and other interested parties
2. *End of Phase Review* -- Location From: Cabin John, Maryland Location To: Mountain View, California
   Number of People: 2 Number of Days: 5
   Purpose of Trip: Face-to-face review/work session with NASA Mission Control Technologies Lab and other interested parties.

Part 5: Related R/R&D

This work can support a range of technology development missions on International Space Station (ISS) and subsequent flight opportunities that can make efficient and effective use of near real-time state models and the enhanced Open MCT Web Software suite. Open MCT is a next-generation mission control framework being developed at NASA's Ames Research Center in Silicon Valley, in collaboration with the Jet Propulsion Laboratory. Software based on Open MCT is being used for mission planning and operations in the lead up to the Resource Prospector mission at NASA's Ames Research Center, and as a data visualization tool at the Jet Propulsion Laboratory.

The MOCA mission development work has been presented in various forms to the:

- NASA Future In Space Operations (FISO) Colloquia June 22, 2016
- AIAA Space 2016 Long Beach, CA – Paper and Presentation September 13, 2016
- ISS R&D Conference 2017, Washington, DC – Presentation July 19, 2017

As a NASA grantee in NASA Graduate Student Researchers Program in conjunction with the NASA Goddard Space Flight Center and the University of Maryland, College Park Department of Aerospace Engineering, the proposed Principal Investigators work on the applications of knowledge based systems to the domain of space systems engineering constitutes prior art that is directly relevant:

- SPaCE-I: Spacecraft Preliminary and Conceptual Engineering I, UMCP Aerospace Engineering Department Technical Report TR 84-1 (Published thesis proposal)
- SPaCE-II: Spacecraft Procedures and Concepts Evaluator – 2, EER Systems -- (December 1986)

In addition, the proposed Principal Investigators professional work in the Space Station Program Documentation Tree is relevant:

- NASA GSFC Technology Development Missions, Space Station Mission Requirements Working Group Data Base submissions (co-author with David Suddeth).
- Robotic Systems Integration Standards (RSIS):
  - ⇨ Volume I Accommodation Requirements, SSEIC Technical Lead
  - ⇨ Volume II Interface Standards, SSEIC Technical Lead
- Mobile Servicing Centre Systems Requirements Document, SSEIC Technical Lead

- Special Purpose Dexterous Manipulator Systems Requirements Document, SSEIC Technical Lead

The proposed Principal Investigator is on the AIAA Space Automation and Robotics Technical Committee as well as the AIAA Space Colonization Technical Committee.

There are multiple other intersecting communities of interest with respect to artificial intelligence, large data processing, cognitive science, virtual reality, process control, and human factors that the Phase I work should be presented to for peer review.

Relationship with NASA

The NASA ARC Mission Control Technologies (MCT) Open MCT Web is the web based modular programming environment that is being enhanced by XISP-Inc to incorporate near real-time state model extensions.

This work is germane to the NASA ARC / XISP-Inc Non-Reimbursable Space Act Agreement on Management Operations Control Applications (MOCA) and the family of supported XISP-Inc commercial missions under development.

Relevance

This body of work 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.

This can lead to a range of technology development missions on ISS and subsequent flight opportunities that can make efficient and effective use of near real-time state models and the enhanced Open MCT Web Software suite.

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 readily extensible near real-time state modeling capability on ISS could prove to be enhancing if not enabling technology for a wide range of technology development, demonstration, and deployment missions. The ISS is an extraordinary resource that can be leveraged to dramatically lower the cost of space solar power technology development, demonstration, and deployment.

We have a unique opportunity to foster the development of space-to-space power beaming by leveraging ISS resources to create a space-to-space power beaming testbed environment driven by MOCA on and in the vicinity of ISS. 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 the bridge between technology development, technology demonstration, and technology deployment. 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.

Key Example – DEXTRE is missing something?

The Special Purpose Dexterous Manipulator (SPDM) aka DEXTRE was designed to have an Advanced Vision Unit (AVU). The AVU was to provide a near real-time state model of the systems-of-systems that made up the SPDM – effectively an autonomic nervous system. In addition, it would have the ability to dynamically build up a world model of an assigned task area and its intersection with the environment
The combination of these two capabilities with the appropriate sensors/cameras/tags/targets/interfaces and the as-built documentation of the International Space Station was intended to support a mutable locus of control between full teleoperation and full autonomy. The AVU was intended to allow the SPDM to effectively break dance with an EVA astronaut rather making paint drying seem like an exciting spectator sport.

Alas, it was estimated proximate to 1995 that implementing the AVU as intended would only take 25 times the anticipated available computational capacity of the International Space Station (ISS).
However, implementing the AVU using 2018 technology should and would be a much more straight forward proposition given . . .

- Multiple space qualified multi-core thermally managed processors
- Highly reliable registered Error Correcting Code (ECC) memory
- Solid state data storage systems
- Open source multi-threaded operating system amenable to near real-time operations
- Multi-fault tolerant virtualizable functions and a generalized control architecture designed for failure tolerance
- Pervasively networked environment with access to as-built configuration data and relevant ISS operations and environmental data

The same logic is applicable to any EVA/IVA robotics as well any advanced automated systems.

Part 6: Key Personnel and Bibliography of Directly Related Work

The proposed Principal Investigator's background includes:

WORK EXPERIENCE:

Xtraordinary Innovative Space Partnerships, Inc. (XISP-Inc) 5/2012 to Present – President/CEO

Responsible for defining and executing commercial Technology Development, Demonstration, and Deployment (TD^3) missions which leverage the extraordinary resources of the International Space Station along with other government, commercial, educational, and non-profit assets. XISP-Inc's objective is to form extraordinary innovative space public/private partnerships to further the development of innovative technology and applications, useful for space exploration and development as well as terrestrial markets. These efforts can serve to bridge the technology development "valley of death" as well as substantially mitigate (perceived and actual) cost, schedule, and technical risk associated with the short, mid, and long term applications of the technology. The current XISP-Inc commercial mission set includes: Space-to-Space Power Beaming (SSPB), Management Operations Control Architecture/Applications (MOCA), Interoperating Network Communications Architecture (INCA), Halfway To Anywhere (HTA), and the Alpha CubeSat (ACS). Further details on these missions and other nascent ones are available at http://www.xisp-inc.com.

Barnhard Associates, LLC (BALLC) 5/1983 to Present (inclusive of prior entities) – President/CEO

Systems architect/network engineer/consultant/licensed reseller providing computer systems engineering, consulting, and integration services for business, government, academic, and individual clients. Scope of work includes: custom and semi-custom solution development and fielding including all necessary hardware, software, integration, contracting, installation, testing, and support services. Work has included extensive involvement from initial requirements analysis/development, programming/integration, through fielded operations and support in a wide variety of environments from embedded computing to main frame systems.

National Space Society (NSS) 8/2004 to Present – Chairman of the Executive Committee/CEO emeritus

Served as the CEC/CEO 1/2005 - 4/2010; Executive Director 4/2010 – 1/2012; Board of Directors (2004-2008, 2009-2012 ex Officio, 2016-present); and multiple other positions. Responsible for the coordination and orchestration of the efforts of a diverse collection of space advocates ranging from non-technical volunteer enthusiasts, to highly qualified professionals spanning a wide range of disciplines drawn from industry, government, academia and the public at large. Activities of the Society range from space education, general space advocacy, fostering the development of national and international space policy, to broadening the opportunities and venues for cooperative action between organizations, agencies, companies, and individuals involved in space development. An integral part of the efforts of the NSS is fostering the ongoing investment in space endeavors across all sectors. This requires the strategic deployment of resources to engineer a synergistic outcome that maximizes both engagement and impact.

This is critically important since in most space flight projects the organizational challenges are at least as great as the technical ones.

Grumman Space Station Engineering & Integration Contract (SSEIC) 11/1987 to 3/1994 – Senior Space System Engineer

Automation & Robotics Lead Engineer for the Structures, Mechanisms & Robotics Branch of the Space Station Engineering & Integration Contract (SSEIC). Served as a recognized expert in robotic, space, and computer systems analysis/systems engineering. Key activities included: development, negotiation & documentation of the Robotic Systems Integration Standards (RSIS), Volume I: Robotic Accommodation Requirements, and Volume II: Robotic Interface Standards; analysis of collision detection & avoidance methods; development & assessment of fault tolerant system architectures; technical risk assessment/mitigation; and Space Station Robotics Working Group support as SSEIC Lead & Executive Secretary.

EER Systems 8/1984 to 11/1987 – Space Systems Engineer

Lead Space Systems Engineer/Task Manager for NASA Goddard Space Flight Center (GSFC) Space Station Systems Engineering & Integration Office CAE/CAD/Engineering Data Base support task. Responsible for design alternative generation, systems analysis, systems engineering/technical integration, technical data systems architecture, and specialized engineering support for space platforms, attached payloads, and robotic equipment. Supported the development and analysis of the Space Station Data System Requirements and the Space Station User Information System Requirements.

NASA Graduate Student Researchers Program 8/1982 to 8/1984 – NASA Graduate Student Researcher

NASA grantee conducting research in the application of knowledge based systems to the domain of spacecraft systems engineering. Worked in conjunction with the GSFC Data Systems Technology Office, the GSFC Advanced Missions Analysis Office, and the Advanced Earth-Orbital Spacecraft Systems Technology RTOP activity. Responsible for GSFC input to the Space Station Technology Development Missions Advocacy Group and member of the NASA Headquarters Space Station Task Force.

EDUCATION:

University of Maryland College Park -- Bachelor of Science Degree College of Engineering - 8/1982; Aerospace + Materials Science.
Graduate Work in Aerospace Engineering, Artificial Intelligence, Solar Physics, and Science Policy (1977-1990, ~68 Credits)

PUBLICATIONS:

Author and/or co-author and presenter of over fifty-two space related professional papers and/or technical presentations (2005 – present) to a wide range of professional fora sponsored by the AIAA, IEEE, IAC, NASA, AAS, DEPS, NSS, and CASIS as well as space media.

PROFESSIONAL BIOGRAPHY: Gary Pearce Barnhard

A self-described synergistic technological philanthropist, entrepreneur, and serial venture capitalist now serving as the President & CEO of Xtraordinary Innovative Space Partnerships, Inc. (XISP-Inc) a start-up company focused on International Space Station technology development work as well as Barnhard Associates, LLC, a systems engineering consulting firm and Internet Service Provider (Xisp.net) based in Cabin John, Maryland. He is a robotic space systems engineer whose professional work includes a wide range of robotic, space, and computer systems engineering projects. He received a Bachelor of Science in Engineering from the University of Maryland College Park in 1982 combining Aerospace Engineering, Materials Science, with graduate work in science policy, solar physics, and artificial intelligence/knowledge based systems. He served as a Space Systems Engineer and Information Systems Architect for EER Systems, and as a Senior Space Systems Engineer on the Grumman Space Station Systems Engineering and Integration Contract (SSEIC) responsible for advanced automation and robotic systems support. He was the Executive Secretary of the Space Station Freedom Program Robotics Working Group and received a NASA Group Achievement Award for the Robotic Systems Integration Standards Interface Design Review Team, as well as an Outstanding Support Award from the Canadian Space Agency Space Station Freedom Program Liaison Office. He is an Associate Fellow of the AIAA. He is a member of the AIAA Space Colonization Technical Committee and the AIAA Space Automation and Robotics Technical Committee.

He is a life member of the National Space Society (NSS) serving the society in many capacities and has received multiple awards including NSS Pioneering Space Award (2004); NSS Award for Excellence in (2005) & (2008). He was the Executive Director and co-founder of 1000+ member Space Interest Group MSFA/MASC (1977-1982) (L5 Society affiliate). Other space advocacy involvement includes: Space Development Foundation Founder/President/CEO, Space Studies Institute (SSI) Senior Associate, Planetary Society member, American Astronautical Society (AAS) member, Space Frontier Foundation (SFF) Advocate, and Students for the Exploration and Development of Space (SEDS) Alumni.

KEY EXPERIENCE SUMMARY:

In particular, my previous work on the Space Station Engineering and Integration Contract (SSEIC) that is highly relevant included serving as the Automation & Robotics Lead Engineer for the Structures, Mechanisms & Robotics Branch of SSEIC. I was the SSEIC recognized expert in robotic, space, and computer systems analysis/systems engineering responsible for evaluating all robotics (and most advanced automation) related Space Station Control Board (SSCB) Engineering Change Requests, writing the SSEIC opinion, jurying all SSCB opinions, and presenting the integrated decision package to the SSCB.

Key activities included: development, negotiation & documentation of the Robotic Systems Integration Standards (RSIS), Volume I: Robotic Accommodation Requirements, and Volume II: Robotic Interface Standards; analysis of collision detection & avoidance methods; development & assessment of fault tolerant system architectures; technical risk assessment/mitigation; and Space Station Robotics Working Group support as SSEIC Lead & Executive Secretary. These efforts required extensive negotiation/collaboration with NASA centers, industry, international partners, and academia.

I was responsible for definition, management, verifiability, and flow down of Program & System level requirements for advanced automation and robotics for the Space Station Program, SSEIC technical Lead and coauthor of the Systems Requirements documents for the Mobile Servicing Centre (MSC) and the Special Purpose Dexterous Manipulator (SPDM). I lead the team responsible, and received a NASA Group Achievement Award, for the development of the Robotic Systems Integration Standards (RSIS) Volumes I (Accommodation Requirements) & Volume II (Interface Standards), and I lead the Space Station External Utility Port Standardization project. I was a direct participant in requirements/interface negotiation, design assessment/review, and interdisciplinary problem resolution for all Space Station robotic systems/elements and Space Station Program level reviews.

Other prior work that is relevant includes: participant in the development and analysis of the Space Station User Information System Requirements, and the Space Station Data Systems Requirements, architect and lead engineer for the development of a master engineering database system and modeling tools for the support of multi-discipline systems engineering design analysis, concept development, and problem resolution. I also served as part of the Space Station Mission Requirements Working Group Technology Development Missions Panel responsible for the NASA GSFC Technology Development Missions, co-authored all NASA GSFC Space Station Mission Requirements Working Group Data Base submissions and supported the editing and review of all submissions.

Selected Presentations & Papers

1. Barnhard, G.P., "SPaCE-I: Spacecraft Preliminary and Conceptual Engineering I", UMCP Aerospace Engineering Department Technical Report TR 84-1, 1984 – published thesis proposal
2. Barnhard, G.P., "SPaCE-II: Spacecraft Procedures and Concepts Evaluator", EER Systems, December 1986.
3. Barnhard, G.P., "Turning good ideas into gold - blazing a trail through the technology development valley of death" – International Space Development Conference (ISDC) 2012 Washington, DC – Presentation May 26, 2012

4. Barnhard, G.P., "Near Real-Time State Models - a Foundational Technology for Space Automation and Robotics " Future In Space Operations (FISO) Colloquia – Presentation June 22, 2016
5. Barnhard, G.P., Faber, D., "Space-to-Space Power Beaming - A Commercial Mission to Unbundle Space Power Systems to Foster Space Applications", AAS/CASIS/NASA 5th Annual International Space Station Research and Development Conference 2016 San Diego, CA – Presentation July 12, 2016
6. Barnhard, G.P., Dahlstrom, E.L., Belbruno, E., "Halfway to Anywhere - Cislunar and Deep Space Cubesat Missions from ISS", AAS/CASIS/NASA 5th Annual International Space Station Research and Development Conference 2016, San Diego, CA – Presentation July 13, 2016
7. Barnhard, G.P., "Management Operations Control Applications (MOCA) Mission Update", AAS/CASIS/NASA 5th Annual International Space Station Research and Development Conference 2016, San Diego, CA – Poster Session July 13, 2016
8. Barnhard, G.P., "Interoperable Network Communication Architecture", AAS/CASIS/NASA 5th Annual International Space Station Research and Development Conference 2016, San Diego, CA – Presentation July 14, 2016
9. Barnhard, G.P. – "XISP-Inc Commercial ISS Space-to-Space Power Beaming Technology Development, Demonstration, and Deployment (TD**3) Mission" – IEEE Wireless in Space Extreme Environments (WiSEE) 2017, Space Solar Power Workshop, Montreal, Canada. – Presentation October 10, 2017.
10. Anzaldua, Al; Barnhard, Gary; Dunlop, David; Phipps, Claude – "A path to a commercial orbital debris cleanup, power-beaming, and communications utility, using technology development missions at the ISS", The Space Review November 6, 2017
11. Barnhard, G.P. – "Challenges of Power Beaming" – DEPS DE Science & Technology Symposium 2018, Space Solar Power Workshop, Oxnard, California – Presentation/Panel Discussion & Poster Session February 26-28, 2018

Part 7: Potential Future Applications and Relationship with Future R/R&D

MOCA is now a commercial mission that will be worked with NASA through a combination of established and proposed Space Act Agreements.

Reducing the number of perceived "impossible things that have to be accepted before breakfast"* is a way of incrementally disabusing people of unfounded notions.

** Allusion to "Alice in Wonderland" by Lewis Carroll. "Alice laughed: "There's no use trying," she said; "one can't believe impossible things." "I daresay you haven't had much practice," said the Queen. "When I was younger, I always did it for half an hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."*

Doing something real with the technology that is of demonstrable value can help to establish the confluence of interests necessary to mature the technology for more advanced applications.

Use of ISS helps ensure that this is an international cooperative/collaborative research effort.
An incremental investment in the development of near real-time state modelling capabilities that meet real mission requirements can serve as a foundational technology for evolving space automation and robotics capabilities.

This work can deliver:

- Reduced cost, schedule & technical risk
- Mission enhancing technology
- Mission enabling technology

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

The Phase I effort lays a foundation for a myriad of space automation and robotics applications of near real-time state models.

The inherent nature of the XISP-Inc Commercial mission set is that the technologies developed are relevant to both potential NASA and Commercial Applications. Examples based on the proposed missions to be supported and the anticipated applications to be developed include:

Alpha Cube Sat (ACS)

- ➔ Virtual Operations Center for ISS experiments, CubeSat's, and system infrastructure control

Space-to-Space Power Beaming (SSPB)

- ➔ Characterization, optimization, and operational management of radiant energy beam components for relay to co-orbiting systems, propulsion, and utility infrastructure

Interoperable Network Communications Architecture (INCA)

- ➔ Virtualized function compute modules which are thermally and radiation managed, dynamically allocatable, support multi-core processors, as well as fault tolerant memory and storage
- ➔ Pervasively networked Delay/Disruption Tolerant Networking (DTN) gateway/QoS Router
- ➔ Space Based Automated Telco Central Office Testbed

Advanced Vision and Task Area Recognition (AVaTAR)

- ➔ Framework for supporting a mutable locus of control between teleoperation and autonomy as well as ground vs. onboard on a shared control basis
- ➔ Dramatic improvements in speed, efficiency, and safety for EVR and combined EVA/EVR tasks

Halfway To Anywhere (HTA)

- ➔ Improvements in alternate minimum energy trajectory applications, propulsion, navigation, and situational awareness

The proposed innovation (aka near real-time state model extensions) is part of an intelligent autonomous agent cognitive architecture that is both open and modular such that it can feasibly be certified for use on ISS, Cislunar, and deep space missions to interact both with the mission control operators, the crew, and most if not all of the spacecraft subsystems.

Part 8: Facilities/Equipment

XISP-Inc was incorporated in the state of Maryland 30 November 2012. XISP-Inc's objective is to form extraordinary innovative space public/private partnerships to further the development of innovative technology and applications, useful for space exploration and development as well as terrestrial markets. XISP-Inc was founded by Mr. Gary Pearce Barnhard (proposed Principal Investigator).

This work requires an information technology rich environment (e.g., an extensive collection of readily configurable physical servers/workstations/laptops/embedded machines, virtual machines, wired and Wi-Fi networking, internet connectivity, state-of-the art engineering and visualization software, and a collaborative work environment). BALLC as a Value Added Reseller has access to a wide range of vendor and distribution channel resources and maintains extensive hardware, software, and integrated systems demonstration and development capabilities. BALLC/Xisp.net provides XISP-Inc with all of the above, in place and fully operational. Each of the anticipated MOCA supported missions has unique hardware and software requirements which they are responsible for providing.

Accordingly, XISP-Inc has the necessary instrumentation and facilities to be used to perform the proposed work and has included the same in the proposed overhead and G&A cost allocations. Access to any government furnished equipment or facilities is strictly optional.

XISP-Inc is located in Cabin John, Maryland just outside of Washington, DC and in a custom home office with over 1750 sq. ft. of the 6,400+ sq.ft. structure dedicated to business use. XISP-Inc has five fully equipped work areas (desk, one or more computers, tools, and phone), solid color printer, laser color printer/scan/fax machine, conference area, reference library, multiple white boards, and a multi-media room with 120 inch diagonal projection screen. The facilities include an extensive collection of readily configurable physical servers/workstations/laptops/embedded machines, virtual machines, wired and Wi-Fi networking, internet connectivity, state-of-the art engineering and visualization software, and multiple collaborative work environments. All workstations are on UPS systems and the primary server systems are supported by a 12 kW UPS and a 20 kW natural gas generator in addition to a dual commercial electrical service. Of particular note Xisp.net is the only publicly routed node on the Verizon FiOS network and has a nominally 1 gigabit symmetric fiber optic connection to the Internet that is effectively peered with Verizon. If needed, Verizon has also installed an eight fiber pair frame capable of scaling to 40 G symmetric.

Part 9: Subcontracts and Consultants

The MOCA effort is not anticipated to engage any subcontracts and/or consultants as proposed. All personnel charging to the MOCA effort are anticipated to be employees of XISP-Inc.

In addition, XISP-Inc anticipates substantial resources will be applied to one or more of the MOCA supported XISP-Inc commercial missions. The resources used for the implementation of the respective missions will be provided by XISP-Inc mission consortium participants. It is anticipated that the different missions will coordinate/collaborate on their efforts to make parsimonious use of available resources.

Part 10: Essentially Equivalent and Duplicate Proposals and Awards

As stated previously, XISP-Inc has a non-reimbursable NASA Space Act Agreement with NASA ARC (SAA2-402986) for work on Mission Operations Control Applications (MOCA) which is part of the XISP-Inc commercial mission set.

The XISP-Inc commercial mission development effort to date has been supported by Barnhard Associates, LLC (in excess of $1 million Cash and In-kind) and EXOS Aerospace & Technologies, Inc. (Consulting Customer, MOCA). To date neither NASA nor any other government agency has directly or indirectly funded the proposed MOCA effort.

XISP-Inc submitted a proposal ISS Space-to-Space Power Beaming (SSPB) to NASA Code OZ on January 20, 2017 for award under RESEARCH OPPORTUNITIES FOR ISS UTILIZATION NASA Research Announcement: NNJ13ZBG001N Soliciting Proposals for Exploration Technology Demonstration and National Lab Utilization Enhancements. The proposal was favorably reviewed by NASA but no direct NASA funding award was determined to be available for FY 2017.

On further review, action on the SSPB proposal as a commercial mission was referred by Code OZ to the ISS U.S. National Lab payload broker, Center for Advancement of Science In Space (CASIS). CASIS now has a pending resource allocation request for ISS resources, commercial cargo resources, integration support, as well as a contribution to mission development funding for XISP-Inc commercial mission set. The initial test case is anticipated to be the Space-to-Space Power Beaming (SSPB) mission. *It is anticipated that the SSPB will utilize MOCA to the extent that it is implemented*. The stated position of the NASA Associate Administrator for HEOMD is that XISP-Inc has met the bar for acknowledgment that that it now has a commercial TD^3 mission Space-to-Space Power Beaming which is going forward with the advice and consent of NASA. Furthermore, if sufficient progress is made with respect to the defined criteria NASA would consider direct funding participation. To date no direct or indirect funding has been provided to XISP-Inc for the SSPB mission other than by BALLC. The Principal Investigator is Gary P. Barnhard.

XISP-Inc has submitted a Space-to-Space Power Beaming Mandatory Preliminary Proposal to NASA Space Technology Mission Directorate (STMD) in response to UTILIZING PUBLIC – PRIVATE PARTNERSHIPS TO ADVANCE TIPPING POINT TECHNOLOGIES APPENDIX to NASA Research Announcement (NRA): Space Technology - Research, Development, Demonstration, and Infusion – 2018 (SpaceTech–REDDI–2018), 80HQTR18NOA01 APPENDIX

NUMBER: 80HQTR18NOA01-18STMD_001 AMENDMENT 4 on January 31, 2018. *It is anticipated that the SSPB will utilize MOCA to the extent that it is implemented.* To date no direct or indirect funding has been provided to XISP-Inc for the SSPB mission other than by BALLC. The Principal Investigator is Gary P. Barnhard.

XISP-Inc has a draft proposal being actively iterated with Department of Homeland Security Customs and Border Protection Mission for work germane to the XISP-Inc INCA commercial mission. *If this work moves forward it is anticipated that the SSPB will utilize MOCA to the extent that it is implemented.* To date no direct or indirect funding has been provided to XISP-Inc for the INCA mission other than by BALLC. The Principal Investigator is Gary P. Barnhard.

XISP-Inc has a draft proposal being actively iterated with the NASA Federal Credit Union for work germane to the XISP-Inc INCA commercial mission. *If this work moves forward it is anticipated that the INCA will utilize MOCA to the extent that it is implemented.* To date no direct or indirect funding has been provided to XISP-Inc for the INCA mission other than by BALLC. The Principal Investigator is Gary P. Barnhard.

The XISP-Inc Alpha Cube Sat (ACS) team is actively negotiating commercial sponsors and is *anticipated to utilize MOCA to the extent that it is implemented*. To date multiple individuals and entities have contributed (cash and in-kind) to the ACS mission development effort. No direct or indirect NASA funding has been provided to XISP-Inc. The lead systems engineer is Gary P. Barnhard.

The XISP-Inc Halfway To Anywhere (HTA) mission is actively negotiating commercial consortium participants and is *anticipated to utilize MOCA to the extent that it is implemented*. To date multiple individuals and entities have contributed (cash and in-kind) to the HTA mission development effort. No direct or indirect NASA funding has been provided to XISP-Inc. The Principal Investigator is Gary P. Barnhard.