Space Studies Symposium 2018
Collected Abstracts

In Presentation Order

In Alphabetical Order

Capstone Student Abstracts

MARTIAN METEOROLOGISTS: FORECASTING THE STORMS OF TOMORROW

Denise Buckner

Human habitation of Mars and other extraterrestrial bodies is a promising venture for the future of space exploration, and is an important goal of NASA and other space organizations. Currently, Earth based analog habitat studies provide vital research on life support systems and essential technical functions. For a Martian settlement to support sustained human presence, weather forecasting is of utmost importance; the Martian atmosphere can be volatile, and dust storms are a major concern to Extravehicular Activity (EVA) operations.

Weather balloons provide an ideal platform for forecasting, as they are low cost, user friendly, require no fuel, traverse high altitudes, support radio based payloads for instant information downlink, and can carry a wide variety of light, low cost, accurate sensors. Further, sensor arrays can be fabricated within the habitat, and weather data transmitted to the base station immediately, creating a sustainable, real time forecasting system.

This poster discusses a weather balloon EVA simulated by crewmembers in the Inflatable Lunar Martian Analog Habitat at the University of North Dakota in an attempt to prove the validity of extraterrestrial weather balloon operations and prepare for sustainability and autonomy in future habitation.

This EVA is a preliminary mission intended to explore feasibility of balloon operations and weather forecasting with a small, three member crew in a simulated Martian environment in the Inflatable Lunar Martian Analog Habitat at the University of North Dakota

For this mission, the crew fabricated a sensor based payload, then launched the instruments. One crewmember stayed inside the habitat to monitor weather data transmitted via HAM radio to the ground station. Meanwhile, two crewmembers exited the habitat in spacesuits, filled a weather balloon with helium, attached the payload, initiated contact between the payload and the ground station, and re- entered the habitat to track the balloon and downlink the data.

Mission Overview: This mission was designed to simulate an autonomous weather observation operation. Hardware and software were Earth based, but could operate in the Martian environment. Procedures and human performance were other key elements.

Farming and the Future of Off-Planet Colonization

Jennifer Russell

University of North Dakota, John D. Odegard School of Aerospace Sciences, Department of Space Studies

Abstract

Growing crops will be an essential undertaking if the aspirations to colonize either the Moon or Mars are to be successful and sustainable. The Lunar Mars Analog Habitat (L.M.A.H) has introduced the Plant Growth Module, currently in its second mission, and successfully grown crops, which have been integrated into a healthy diet for the crew containing essential nutrients and cancer fighting antioxidants, which are crucial to surviving off planet conditions. If humans desire the colonization of territories off the planet Earth, we will have to model our ancestors in that we will have to be able to grow our own food. In the long run, this may mean we will eventually have to modify crops to suit the conditions on the Moon, or Mars. In the meantime, experimenting within the analog habitat, we must be able to fulfill the most basic functions of survival and that involves farming. Although we cannot exactly replicate microgravity or low-pressure environments, we can still learn a great deal about growing plants and integrating them as part of a closed ecological life support system. This is the most important and exciting time of human exploration, we can't take everything with us, so being able to grow our own food in space is critical to our success as an off-planet species.

Taren Wang

Space Studies Department

Master's Thesis

2nd Year

Electrodynamic excavation of lunar regolith

Lunar dust is a promising target for in-situ resource utilization, potentially providing future space missions with propellant, life support consumables, and building material. However, the abrasive and adhesive qualities of regolith make it challenging to work with. Furthermore, traditional excavation methods (which rely on the weight of the excavator to break soil) are less effective in the low lunar gravity. This project proposes a novel excavator based on the electrodynamic dust shield, which uses embedded wire electrodes to levitate dust off a surface. By activating electrodes in sequence, dust may be transferred across the surface without moving parts. A swarm of small excavators could cover themselves in dust, levitating it into their collection bins, before moving to a drop off point and re-activating the original functionality of the dust shield to deposit their cargo. This process takes advantage of both dust adhesion and low gravity, potentially representing a new tool in space industrial operations.

Dinoflagellates (Bioluminescent Phytoplankton): A Study of Enzyme Kinetics in Microgravity

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Biochemical pathways in cells evolved under Earth gravity conditions. However, when exposed to microgravity environments, these pathways can differ due to alterations in protein conformation and concentration. Detailed study on how the microgravity environment affects enzyme kinetics remains largely unresearched. Here, we investigate enzyme kinetics of the bioluminescent pathway in Dinoflagellates. The Dinoflagellates are stimulated to trigger their bioluminescent pathway involving their luciferin-luciferase reaction during a microgravity flight. The intensity and wavelength of the light is measured and compared to a ground control. Bioluminescence was chosen for this study both to elucidate enzymatic pathway changes during microgravity exposure and as it pertains to a growing number of field including biomedical, biotechnical, and spaceflight applications.

I. Nomenclature

AIAA	=	American Institute of Aeronautics and Astronautics
ASGSR	=	American Society for Gravitational and Space Research
ASCAN	=	Astronaut Candidate
DINOs	=	Dinoflagellates
Dinonaut	=	Dinoflagellate Astronaut
DINOLAB	=	Dinoflagellate Experiment Flight NanoLab Assembly
ECLSS	=	Environmental Control Life Support System
NanoLab	=	Payload hardware in CubeSat form factor, measuring 10 cm x 10 cm x 20 cm
NASA	=	National Aeronautics and Space Administration
NoIR	=	Custom camera module that does not have an IR cut filter
UND	=	University of North Dakota

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Graphene Oxide Membranes for Terrestrial and Celestial Water Purification

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Abstract

Freshwater scarcity is becoming an increasingly global problem. Current technologies, such as reverse osmosis (RO) seawater desalination, help combat this problem, but new technologies will be needed to keep up with a growing population and a shifting hydrosphere. To that end, we present a compendious review of the literature and state-of-art of the research into graphene oxide (GO) membranes for both terrestrial and celestial water purification applications along with evidence that GO membranes are a serious contender to be that new technology. On Earth, GO membranes can reduce the specific power consumption of RO facilities by up to 76% by operating at reduced pressures while keeping high ion rejection. Beyond Earth, this energy savings can be applied onboard the International Space Station's (ISS) water reclamation system, significantly reducing specific power consumption by up to 96% through lowering the required water flux. Concurrently, mass reductions can be achieved for both the system and its expendable media of 46% and 99.95%, respectively. Additionally, future proofing the system can be achieved by restoring the flux of GO membranes to their nominal rates, increasing the supported crew from the current 6 members to 58 while still attaining energy savings of up to 16%.

Aquaporin Membranes for Water Purification on the International Space Station

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Abstract

The International Space Station (ISS) is continuously home to astronauts. The production of clean water, treatment of waste water, and CO_2 removal from air are all necessary for human presence. Current water purification systems on the ISS are energy intensive and utilize several operations which increase the likelihood of failure. Membrane technology for water purification offers the benefits of reduced energy requirements and fewer components compared to current methods. Although many membrane materials have been investigated, few meet the energy demand and rejection properties required for potable water. One material that is currently being investigated is aquaporin. Aquaporin are proteins embedded in the membranes of cells that selectively transport water into the cell interior. When formed into a film, aquaporin membranes are capable of high salt rejection at low energy intensity, making them a superior prospect for water purification needs on the ISS. While many membrane architectures have been studied, we propose a vesicle based approach to fabricate aquaporin membranes. We expect to find improved performance over other membranes.

CHARACTERIZATION OF REGENERAGED SILK MATERIAL FOR BIOMIMETIC SPINNING AND FILM CASTING

In preparation to future human exploration of deep space, the ability for materials to be repaired needing little to no human interaction, is a key element for upcoming mission technologies. This idea saves valuable time and energy that could direct focus towards other pressing aspects of exploration missions. There is an ever-increasing necessity for special lightweight, self-strengthening and multifunctional materials within the field of human space flight. These materials could be used for space suit, vehicle and habitat structures to survive long duration missions in the harsh environments of space. In this study through the ND Space Grant Consortium an investigation into biomimicry provides a framework for the development of flexible, light-weight, "smart" and biologically compatible sensor materials.

Natural silks produced by spiders and silkworms exhibit tailorable mechanical performance yet to be achieved synthetically. In earth's gravity, spiders can create a variety of mechanically robust (i.e., high tensile strength, high extensibility) silk fibers, each with unique characteristics which has been developed by an evolutionary niche and promoting survival for millions of years. This phenomenon is derived from a biological system that has been evolutionarily optimized. In efforts to harness this elusive promise of tailorable bio-material fabrication, a study was conducted to investigate 1) silk solution processing 2) silk spinning via a biomimetic spinning system 3) dispersions of carbon nanotubes into regenerated silk by spinning and casting to improve conductivity and strength. Resulting carbon nanotubes functionalized with carboxylic-acid (CNTC) and non-functionalized (CNTNF) were integrated into spinning and casting processes. Decreases in performance was observed in CNTNF constructs, however an increase was present in CNTC suggesting structural integration of silk proteins.

“Balloon Line Autonomous Instrument Using Nichrome Wire and Electricity”

Peter Henson

High altitude ballooning serves as a platform for scientists and engineers to experiment at extreme altitudes in the near-space environment. However, an operations challenge arises in being able to recover flown payloads in satisfactory locations. Having a simple system onboard to terminate the flight based on desirable latitude, longitude, or altitude data could ameliorate this issue. Nichrome wire, an alloy comprised of Nickel and Chromium metal, could be used as a resistance-heating blade to cut the line connecting the balloon to the payload train. A subsystem level design and its preliminary test results are presented here. To develop its technological readiness level, a test readiness plan is also evaluated to ensure its functional requirement milestones will be achieved.

Acetonitrile in Titan's Atmosphere from ALMA Radio Telescope Observation

Abstract

Titan is the largest satellite of Saturn and the only natural satellite that has significant atmosphere in the Solar System. Titan's atmosphere was first suspected by Joseph Comas I Solá in 1903 and confirmed by Gerard Kuiper in 1944 with detection of methane. The Cassini-Huygens mission arrived in Saturn's orbit in 2004 has primary mission to study about Saturnian system (Saturn and satellite). The prime Cassini-Huygens mission (2004–2008) has taught us a lot about the chemical composition of the Titan's atmosphere. The data we have acquired regarding the vertical profile, latitude distribution, and seasonal changes of various photochemical compounds has significantly increased our understanding of Titan's atmosphere. Extended monitoring of the seasonal variations of composition is a vital component to understand Titan's meteorology. This had also been a major motivation for extending Cassini operations up to Saturn's northern Summer solstice in 2017. ALMA (Atacama Large Millimeter/submillimeter Array) is an interferometer radio telescope at 5000 m altitude in Atacama, Chile, consisting of 66 antenna radio telescopes observing at millimeter and submillimeter wavelengths. Abundances of acetonitrile (CH_3CN) has been detected in Titan's atmosphere using ALMA data. The levels of CH_3CN were found increase from surface up to an altitude of 800 km . The ALMA data of CH_3CN are lower than Marten et al. (2002) showing seasonal variation in Titan's atmosphere.

Keyword: acetonitrile, Titan, atmosphere, Cassini-Huygens, ALMA

ABSTRACT

A massive impact event on (4) Vesta is believed to have created the Vesta family of asteroids (Asphaug, 1997). The rotational characteristics of the Vesta family provide important clues about this event, including its timing, the make-up of the resulting debris, the subsequent migration of members of the family into Earth-crossing orbits, and the deposition of the Howardite-Eucrite-Diogenite meteorites on the Earth's surface. This study conducted lightcurve measurements of ten V_p-type asteroids, drawn from an asteroid taxonomy defined by Carvano et al. (2010) and based on the Sloan Digital Sky Survey (SDSS) Moving Object Catalogue (MOC4). These measurements identified a range of asteroid rotation periods from approximately 2.5 to 9.5 hours, as well as a potential synchronous binary system, (15121) 2000 EN14. The lightcurve results were combined with those of other V/V_p-type asteroids available in LightCurve Database (LCDB; Warner et al., 2009), and matched with both WISE diameter/albedo (J. Masiero et al., 2011) and near-infrared spectroscopic (Hardersen et al., 2014-2018) data. This integrated approach identified a set of Vesta family asteroids with relatively fast spin rates, nearly spherical shapes, and loose aggregate compositions. These findings, combined with the non-Maxwellian shape of this population's spin rate distribution, highlighted the importance of thermal Yarkovsky-YORP effects on the evolution of the Vesta family.

Exploring Star Formation in Cluster Galaxies

Sandanuwan Kalawila,Wayne Barkhouse,Madina Sultanova

We describe our survey to map the star formation activity in cluster galaxies. A sample of galaxy clusters is observed using the KPNO 4m telescope. Redshifted H-alpha emission is observed using the narrow-band BATC filters. The continuum-subtracted H-alpha images allow us to constrain the star formation rate by measuring H-alpha luminosity. The impact of the cluster environment can be quantified using radial-dependent measures of the star formation rate. This will allow us to understand the mechanism responsible for the enhancement or quenching of star formation.

BinCat: a Catalog of Nearby Binary Stars with Tools for Calculating Light-Leakage for Direct Imaging Missions

Elias Holte[1,2], Dan Sirbu [2], Ruslan Belikov[2]

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Binary stars have been largely left out of direct imaging surveys for exoplanets, specifically for earth-sized planets in their star's habitable zone. Utilizing new direct imaging techniques brings us closer to being able to detect earth like exoplanets around binary stars. In preparation for the upcoming WFIRST mission and other direct imaging-capable missions (HabEx, LUVIOR) it is important to understand the expected science yield resulting from the implementation of these imaging techniques. BinCat is a catalog of binary systems within 30 parsecs to be used as a target list for future direct imaging missions. There is a non-static component along with BinCat that allows researchers to predict the expected light-leakage between a binary component and its off-axis companion (a value critical to the aforementioned techniques) at any epoch. This is accomplished by using orbital elements from the Sixth Orbital Catalog to model the orbits of the binaries. The software was validated against the historical data used to generate the orbital parameters. When orbital information is unknown or the binaries are purely optical the proper motion of the pair taken from the Washington Double Star catalog is integrated in time to estimate expected light-leakage.

Mars Games: Crew Psychosocial Support on the Journey to Mars and Beyond

In support of NASA's Behavioral Research goals, *Mars Games* - a team of simulated astronauts, current aerospace professionals, and their research colleagues - devised a study to improve work-rest scheduling, optimize leisure-related payloads, test and validate available stress-relief options, support astronaut self-care, and facilitate the psycho-social well-being of self-contained astronaut communities. With an eye towards successful long duration space habitability, the Mars Games study was deployed at HI-SEAS IV, the longest NASA-funded space simulation in history. In order to determine which activities best optimized the ratio of time to stress relief over the mission, Mars Games collected daily data on simulated astronauts' non-work time activity frequency and the stress-relieving effects of these non-work activities. We then integrated reports of resource limitations, media consumption patterns, individual activities, and group activity frequency. We found specific leisure activities that were consistently associated with lower stress across the team. We also identified between-individuals differences as well as evidence that preferred leisure modalities evolved over time. *Mars Games'* unique, crew-driven research revealed a previously unseen pattern of social behavior in "space". If integrated into future mission infrastructure, the results of this study could lead to significant improvements in astronaut mental health and morale before, during and after deployment in long-duration space missions and analogs.

Space Studies Symposium 3 Abstract

Title: Days on ‘Mars’

Presenter: Stefan Tomović

Analog missions that simulate operations in space are crucial in humanity’s quest to explore outer space. Simulated analog missions held at the Inflatable Lunar Mars Analogue Habitat (ILMAH) at the University of North Dakota will help researchers to address questions and concerns of humans traveling into deep space. The topic of this research is about the participation of the author as a crewmember during Mission IV, which was the fourth analog mission held at the ILMAH.

During the mission’s duration, the crewmembers had to perform daily tasks such as watering/harvesting plants, exercise and routine maintenance of the Habitat. Along with daily tasks, a number of experiments were integrated into the daily routine. The experiments entailed biomedical, and mental health experiments. The experiments focused on how the crew members were affected by living in a confined environment that resembled a deep space setting.

Mission IV had a plethora of Extra-Vehicular Activities (EVA) that were scheduled throughout the mission’s duration. During these EVA’s the crewmembers would perform tasks that would be done on the surface of Mars or the Moon. These EVA’s consisted up from setting up solar panels, and generators to power the habitat, among other tasks. Other EVA’s focused on exploring space from a telescope or launching a high-altitude balloon to take data samples of the atmosphere. The high-altitude balloon launch was the first ever balloon launch done during an analog mission while donning space suits.

Marissa Saad and Caitlin Nolby
S3 Conference
May 2018

Abstract

This study examines the confidence levels of space science pedagogy for eighteen North Dakota in-service teachers. The teachers completed a two-day professional development (PD) workshop at the University of North Dakota, conducting hands-on NASA-themed activities. A pre- and post-survey were administered prior to and following the workshop. These surveys revealed three statistically significant results: 1) after a workshop, teachers feel confident in teaching space science, $t(34) = 3.669$, $p < 0.001$; 2) teachers felt more confident teaching space science once they are aware of available educational resources, materials, and opportunities that can complement their teaching, $t(19.83) = 5.548$, $p < 0.001$; and 3) after a workshop, teachers feel more confident adapting other STEM lesson plans to cover space science topics, $t(33) = 3.237$, $p < .05$.

UND Lunabotics – Team Raptor

2017-2018 NASA Robotic Mining Competition

Team Members: Alec Herb, Anthony Tuttila, Bobby Munoz, Cody Kuntz, David Shutty, Elliott Gehl,

Elijah Kranz

Advisor: Professor Jeremiah Neubert

Team Raptor 2017-2018 NASA RMC

The NASA RMC (Robotic Mining Competition) is an annual competition where university teams compete in a robotic mining event. This year's team consists of seven mechanical engineering seniors, two computer science students, an electrical engineering student, and a number of underclassmen. Two of the team members are distance students living outside of North Dakota. The NASA RMC is a multifaceted competition with great value. The main focus of the competition is the mining event. In this event, each team builds a robot that is capable of mining simulated Martian resources. The main objective of this event is to mine, transport, and deposit more simulated icy regolith than other teams.

Each year Team Raptor modifies and improves previous years' designs to perform at a higher level than prior years. A significant rules change was enacted this year where only icy regolith is counted in the competition. This led to a major rebuild of our hopper and other systems. Our team also rebuilt the entire electrical system and implemented new sensors to increase capabilities.

In addition to the main competition, the team is also awarded points for other categories including outreach, social media, a verbal presentation and a written systems report. With this project, we are able to reach many different groups of people through our volunteering and social media. We would also like to thank all of our sponsors that helped make this competition a reality.

Kayla Daniels

The Importance of a Liquid Cooled Garment for Extravehicular Activity

The liquid cooling and ventilation garment (LCGV) is a lifeline for astronauts working in space. Without the use of the LCVG, astronauts would be subject to the extreme temperature swings of the outside environment and inevitably create a hostile environment within the extravehicular mobility unit (EMU). This paper will discuss the physiological and psychological reactions related to extreme body temperature changes. Furthermore, a discussion is provided detailing how different environments influence the thermal efficiency of the LCVG in relation to varying workloads. Two Personal interviews with former astronauts with extravehicular activity (EVA) time, as well as a literature review, will lend insight regarding how the LCVG interacts with the body in extreme environments. The findings revealed that without the use of the LCVG, astronauts are incapable of completing even the simplest mission tasks due to the extreme temperatures they encounter.

Development of Remotely Operated Sensor based Greenhouse for Planetary Habitat Research

Fnu Anamika, Pablo de León (Faculty Advisor)
University of North Dakota, Department of Space Studies

The Inflatable Lunar/Mars Habitat (ILMH) located at the University of North Dakota is an operational planetary base concept developed to perform simulations of lunar and Mars missions. The ILMH is also equipped with a rover and two NDX-2AT space suits to perform extravehicular operations. The ILMH is used to conduct planetary analog missions for up to four crew members. Four additional modules are being added to the ILMH under a current NASA EPSCoR grant. The additional modules will allow crew members to grow plants, conduct additional extravehicular activities (EVA), perform analysis on geological samples, and maintain human exercise and performance. The Plant Production and EVA modules have already been added to the ILMH in summer of 2017. The additional modules are being developed to mimic feasible extraterrestrial architectures, with the purpose of being tested and optimized on Earth. This paper will describe the engineering challenges of designing a remotely controllable plant sensor system for terrestrial use, from concept to design. The result is a self-sustainable sensor network for the Plant Production module with minimum or no human intervention to be used for extraterrestrial analog simulations. The entire system can be controlled from a remote location. The sensor data can help determine the optimal design of a greenhouse for upcoming missions to settle extraterrestrial bodies.

Keywords: ILMH, Greenhouse, Plant production, Sensor network, Extraterrestrial Analog Simulations

Benefits of Indoor Houseplant for toxic air removal in living module of Inflatable Lunar Martian Analog Habitat at the University of North Dakota

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Abstract:

Sansevieria trifasciata, commonly called as Snake Plant or Mother-in-law's Tongue is an ideal plant for indoor spaces because of its natural ability to purify the air. An interesting research program has been done by NASA using a few selected plants including the Snake plant for air purification and to curb "Sick Building Syndrome." The results have consistently shown that the plant removes toxins such as Trichloroethylene, formaldehyde, benzene and xylene. The plant purifies air by absorbing toxins through the leaves and produce adequate oxygen during night thereby also promoting the sleep factor in the human body. In this paper, three 6 inches snake plants are kept in the living core module where the crew members live and sleep. A TVOC (Total Volatile Organic Compound) sensor is placed near the plant which is monitored during pre and post mission to collect data of the toxic gases obtained. These data will be crucial to analyze the quantity of toxic substances present in the module and thereby serving as a preliminary study in the quality of sleep experienced by the crew members with the plant present during the mission.

Keywords: Snake plant, TVOC, toxic gas.

The Lunar Mars Analog Habitat (LMAH) missions serve the purpose of providing valuable information for human adaptation to restricted living space conditions. Among the studied effects of these conditions and associated activities have been the sleep cycles of the crew members. Crewmembers from the 30-day Mission III experienced changes in their circadian rhythm, where the sleep start time shifted to the 0300 – 0400 hour time range after Day 20[1]. Participants in Mission IV experienced similar symptoms with later sleep start and wakeup times. This was shown with one crewmember monitoring his sleep times using his personal Samsung S2™ smartwatch. The data obtained during the mission for this non-thesis project seems to indicate a similar trend that warrants investigation into causes of circadian rhythm shift and the relation of sleep quality to performance.

[1] Nelson, Travis. 30 DAY LUNAR/MARTIAN PLANETARY HABITATION ANALOG: SUBJECTIVE CREW ANALYSIS OF BEHAVIORAL HEALTH. 2011

William Elder

The Case for an On-Orbit Servicing Regulatory Framework

On-Orbit Servicing (OOS) of spacecraft to perform upgrades, life extensions, or disposal is on the cusp of commercial viability. Due to the proximity required for these operations, and the increased risk for accidents safety regulations are critical to preservation of the space environment as a global commons. As assessed through archival research, the current international space treaty regime and national licensing methods do not provide adequate levels of mission assurance. Critical gaps will be identified in this paper that restricts the commercial growth of OOS, and recommendations are made to create a new treaty and international regulatory authority to address these concerns. The proposed actions include resolving issues of ownership, liability, responsibility, and anxiety over the dual-use nature of OOS technology that could be used for space warfare. The planned organization is a blended model of the International Civil Aviation Authority (ICAO) and International Committee on Global Positioning Systems (ICG) with representative membership and explicitly defined authorities to adequately promote and regulate OOS activities. It performs critical oversight functions to deal with the aforementioned issues, and without these binding standards the commercial viability of OOS will suffer. Under these conditions the organization ensures the sustainable and responsible use of space to proactively prevent incidents that threaten its utility and mutual benefit to mankind.

Patrick Heuer

Active Removal of Orbital Debris

Abstract

With the 1957 launch of Sputnik 1, humans placed the first artificial satellite into Earth orbit. Although Sputnik 1 lasted less than three months in orbit, the technology was proven. Humans possessed the capability to place objects in orbit for extended periods of time. Since that day over 60 years ago, thousands of man-made objects circle the Earth every day. While space is infinitely vast, the particularly useful regions at specific distances from Earth is finite. Dozens of launches occur per year, occasionally with dozens of individual payloads. This continually depletes the regions of useful space. Additionally, the depletion is exacerbated by collision events between objects in space. Two such events, the 2007 Chinese ASAT test and the 2009 Iridium-Cosmos collision added over 5000 pieces of trackable objects. Collectively, these objects orbiting the Earth with no purpose are referred to as space debris. The proliferation of debris is managed by national and international regulations, but annual addition of debris out numbers the annual removal via deorbit and graveyard orbits. This paper answers whether the question, “Is active debris removal (ADR) necessary to preserve Earth orbit(s)?” Through analysis of the current trends and policies, and the potential effectiveness of ADR, it is concluded that ADR is required for the preservation of Earth(s) orbits.

Cislunar Missions and Architecture: The Driving Requirement for Nuclear Power in Space
Kyle L. Kirkpatrick

Abstract

The desire to explore space has prompted the scientific and engineering community to solve complicated design requirements and present innovative drive solutions to conquer the space environment. Every space mission will require an independent power source that will have to pass technical, social, policy and law scrutiny.

The purpose of this study is to examine current and proposed cislunar missions and architecture, determine power requirement options, and whether they would drive the need for the use of nuclear power over other types of power sources. Can a nuclear power source in cislunar space, to include the lunar surface, be technologically and economically feasible in that it provides a safe and internationally acceptable source of power for use by future lunar missions?

This research is not all inclusive, meaning it will only cover a fraction of the concepts, missions, and research into subcategories of solar and nuclear-based power systems that operate in cislunar space. Although there are other nuclear-based infrastructures in use or in concept, this research focuses on those that are designed to produce power.

Many variables are involved when designing a space mission, and the best solution for what type of power is recommended is heavily based on the type of mission being supported. The statement advocating that a nuclear power source for cislunar missions is technologically feasible and acceptable across the international community is, however, still valid. The area that presents as not feasible is on the side of economics. At this point, the use of nuclear powered systems is not economically feasible due to the massive costs entailed to restore the fraction of ^{238}Pu remaining to a viable amount through the regeneration of its production cycle. Until it is restored, solar power will be the dominating source of power in cislunar space.