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CHASE – Commercial Human Spaceflight Expeditions

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"Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand." – A.Einstein 1931

Abstract

In the 2021 Fall term, the ASTE Studio focused creative efforts on how commercial human spaceflight in the United States could catalyze space activity around the globe and steer the future of human spaceflight. With an eye on NASA's Gateway and Artemis projects, the CHASE project cast the net wide, to seek out synergies and collaborations sans policy limitations. By starting to explore the future of governmental and commercial activities in low Earth orbit, on the International Space Station, and evolving outward to encompass cislunar space and our Moon, the USC CHASE project imagined and created potential concepts that we feel are worthy of further investigation.

Topics explored included Commercially focused Utilization of the International Space Station, Uses of a Human-tended Geostationary Space Station, Evolution and Uses of an Advanced Cislunar Communications Infrastructure, Importance of Establishing a sturdy Earth-Moon Logistics Channel to support 21st century cislunar traffic and a permanent human lunar surface presence. A scientific exploration mission for the Artemis lll crew to retrieve solar activity records to help build a much more complete solar behavior model over geologic time that can inform Climate Change on Earth and also explore the interior of a lunar lava tube, a concept for a Robot scout assistant rover for lunar surface crew in EVA, and Crew safety and rescue Infrastructure establishment before commencing Artemis missions that can also be used in case anomalies arise are proposed as well as the evolution of nuclear power systems for lunar applications.

Several American space companies are sprouting that continue to broaden human spaceflight capability and expand CHASE allied engineering capacity needed to grow and mature this fully homegrown space industry ecology. Powered by the plummeting costs of components and methods like advanced additive manufacturing, a wide stable of launchers and private spacecraft are entering the space activity domain once considered the monopoly of governments.

Commerce is the lifeblood of modern civilization. Healthy competition and agility, ingenuity and innovation are the drivers of economics and profit in this sector. We must continue to encourage real space commerce, especially human space activity, beyond the NASA vendor-buyer model. Fundamental economic sense drives all successful commerce. A sustainable business model requires a profit motive. [Profit = Revenue – Cost] is a fundamental formula for all sensible commerce. Monitoring and minimizing environmental impact is a prime concern in the fragile vacuum and weightlessness of Space.

All these CHASE related activities, both domestic and around the globe bode well for the US to remain the beacon of the free world and at the forefront of space activity. Human space activity in particular, makes us the nexus for global cooperation and collaboration. That is a good sign for 21st century civilization, progressing step-by-step to build a peaceful, equitable and glorious future for humanity in space and on Earth.

Synopses of visions created in the CHASE concept studio are presented. Recommendations are made. Welcome to USC ASTE527 2021 CHASE Graduate Space Concept Synthesis Studio dear colleagues, where architectural and engineering minds work together to imagine the "what can be" of human spaceflight.

1. Introduction

Imagination is that precious faculty which distinguishes our species from Nature's other magnificent creatures. We use our imagination in creative ways to survive, live and thrive. We use our imagination to create tools to discover the laws of Nature and to invent and create things of value to us.

The ASTE 527 Space Concept Synthesis Studio has two main purposes; to unleash and exercise unbridled imagination and creativity in our participants and to provide creative input to our nation's civil and commercial space programs. Our studio promotes Ideation, that vital front-end activity that precedes concepts, eventually leading to the realization of useful products. Creating preliminary concepts worthy of further investigation for Space activity is the focus of our graduate studio in Astronautical Engineering.

In particular, Human Space Activity, or Human Spaceflight as it is known in inner circles, is one critical arena of technological progress that is vital to our species survival. The sciences involved, both theoretical and applied, the technologies, both directly used and related, point to redefining and continually refining systems that allow humanity to survive and thrive with minimal impact on the surrounding environment. The Reduce, Reuse and Recycle paradigm has always been a crucial aspect of human space activity. Therefore, space activity has direct implications for humanity and our biosphere, seeking efficient and sustainable ways to interact and live with Nature, cleanly, affordably and sensibly.

This 2021 Fall term, we chose to focus our creative efforts on how commercial human spaceflight in the United States could catalyze space activity around the globe and steer the future of human spaceflight. With an eye on NASA's Gateway and Artemis projects, the CHASE project cast the net wide, to seek out synergies and collaborations sans policy limitations. By starting to explore the future of governmental and commercial activities in low Earth orbit, on the International Space Station, and evolving outward to encompass cislunar space and our Moon, the USC CHASE project imagined and created potential concepts that we feel are worthy of further investigation.

Vital technologies with critical implications for space operations in general and human spaceflight in particular are racing along in this early 21st century. They include the imminent arrival of fully reusable heavy-lift rockets and spacecraft, nuclear power and propulsion, advanced robotics, secure, interference-free-space laser communications and rapid advances in molecular and cell biology-genetic engineering. Each of these technologies impact not only human spaceflight but life and living on Earth as well.

In the following CHASE presentation synopses, a sustainable collaborative future for ISS operations and a graceful end-of-life to that facility is sought. How to mitigate the growing threat to ISS posed by orbital debris is addressed. In an effort to provide more comfortable, socially and culturally acceptable ambience for crew on-orbit, imaginative visions for food production and service, lively green spaces as well as accommodations for culturally relevant and attractive space tourist applications are discussed.

Technologies exist today that were not available in the past to be able to provide our astronauts timely support in case anomalies appear that require speedy external intervention or crew extraction. Since emergency and rescue of Gateway and Artemis crew are not yet detailed, and because flight times to the Moon are not quick enough using current transportation technologies, an emergency and rescue way-station in geostationary orbit with multiple potential applications is proposed. Lunar suborbital logistics vehicles can drastically shorten delivery times to locations of interest and robotic rovers can assist crew during lunar surface EVA. Emergency support and timely rescue capability for Artemis crew on the lunar surface from low lunar orbit is discussed.

Optical communication forms the backbone of terrestrial communication networks today. Deep space laser communications is gaining ground rapidly as satellites routinely use optical links to provide secure, reliable and interference-free ultra-broadband communications. Extending laser communications across cislunar space is proposed for the numerous cislunar missions and spacecraft operations that are planned in the near term as well as for local lunar surface networks, thereby easing demands or obviating the need for engaging the aging Deep Space Network that is already taxed and oversubscribed with interplanetary and far space mission communication needs. Moreover, the tie-in of such an optical space network to the existing terrestrial optical network would provide the globe with a versatile communications infrastructure that could also attract many more partners to NASA's Artemis Accords.

Ultra-high bandwidth links offered by optical communications expand and make possible vastly superior applications in automation, autonomy and robotics aided by advances in machine learning and artificial intelligence. Free space laser links in excess of 650Mb have already been tested between the Moon and Earth and terabit and gigabit applications are in use on Earth today. High fidelity virtual presence with tactile feedback loops for astronaut crew in EVA and qualities like proprioception for agile robots and cobots as well as massively parallel applications in real time like very long baseline optical interferometry across the entire cislunar domain become possible at such data rates. This will allow robust and reliable monitoring of cislunar traffic, provide crew support and alerts regarding situational awareness and the operational environment in real time including early warning, and enable timely and accurate coordination and control of large fleets of spacecraft and assets.

CHASE activities have accelerated in the last four years. A new US administration has taken the helm in 2021 and a new NASA administration is in place. The new administrator, Senator Bill Nelson who has flown on STS-24 as a mission specialist has been nominated by unanimous consent of the Senate to be the NASA administrator. Sen. Nelson brings decades of space and science policy experience and has chaired the space subcommittee in the House. He is an ardent advocate for Climate Change mitigation. Both administrator Sen.Nelson and associate administrator Col.Melroy know human spaceflight first hand, having flown on missions. Moreover, both witnessed the fast-paced execution of Apollo program and cherish the legacy of Apollo and the impact those missions have had on our nation and the world.

Today, the National Space Council is seated with new members and advisory bodies are active. A new branch of the defense forces, the Space Force, is being shaped to be a global force with an agenda to share the space domain responsibly, equitably and peacefully. Social, cultural, spiritual and civic responsibility issues are being raised globally, on par with ecological awareness and sensitivity in space activity, starting with the issue of crowding assets and artificial debris in Earth orbital and cislunar space.

Space activity, especially human space activity, has now blossomed from open-ended exploration missions to one focused on utilization. Climate Change is high on the agenda for the current US administration and is reflected in current NASA priorities including the recent first meeting of the newly seated National Space Council chaired by our honorable Vice President Mme. Kamala Harris.

Geologic records provide conclusive and verifiable scientific evidence that our planet has had many makeovers since life evolved here. Geologic evidence suggests that mother Earth knows how to take care of herself. The question is not whether Earth can take care of itself but "Can we, Homo Sapiens, as a species, take care of ourselves, or face extinction?" Climate Change is wreaking havoc around the globe. The fragmenting and melting icecaps, rising sea levels, hurricanes, cyclones, tornadoes, fires and those drought and deluges caused by extreme weather patterns are taunting us at our doorstep, literally.

The sun plays a role in climate change. Lacking an atmosphere, the dormant Moon has been exposed to direct solar activity over several billion years. It is quite possible that solar activity records are imprinted on the Moon that are unavailable on Earth or elsewhere in solar proximity because of dynamic weathering processes. Careful astronaut-assisted scientific exploration of certain regions of the Moon could help retrieve such samples for careful analyses in order to build a much more reliable and direct solar activity model, spanning geological time. Such information would be far more complete and reliable than the sliver of proxy data we have accumulated on Earth to date. Such data can be invaluable to build much better climate change models and also help to better predict solar behavior.

Space Tourism is now reality. 2021 saw the first private human spaceflight missions by ordinary citizens and space tourism is now ramping up to be a lucrative industry. The experience options available to the non-astronaut citizen range from ground-based simulations and stratospheric gondolas to suborbital and orbital expeditions. Even lunar orbital missions are planned in the near term. Two new batches of NASA astronauts are in training for ARTEMIS lunar landing mission. The ARTEMIS ACCORDS, a set of principles put forth by the agency to enhance global collaboration for lunar activity is actively garnering the support and gaining more partners and signatories, clearly signalling that common purpose and goals require adhering to common responsibility among participants as we move to explore a far more fragile environment of the Moon. The 2024 goal of returning humans to the Moon with commercial assets at the core of such an architecture still remains a possibility.

A new law was enacted last year to preserve our space artifacts as species cultural heritage on the Moon and in Space. The International Space University has been a strong enabler for multilateral policy discussions, recruiting and educating promising leaders in global space activities. And nongovernmental space advocacy citizen groups like the National Space Society, The Planetary Society, and the international Moon Village Association are active, and many others are sprouting, to provide valuable feedback to space agencies through public participation events, active dialogs and discussion.

Welcome to USC ASTE527 Graduate Space Concept Synthesis Studio dear colleagues, where architectural and engineering minds work together to imagine the "what can be" of human spaceflight.

The CHASE is on ….

Figure 1. USC CHASE – Commercial Human Spaceflight Expeditions project logo

2. GAIA BLUE: The Next Generation International Space Station

Since its deployment in 1998, the International Space Station (ISS) has served as a symbol of human ingenuity, kickstarting humanity's permanent presence in space and beyond. However, despite its name the ISS isn't very "international", with only five entities aboard – the USA, Russia, Japan, the EU, and Canada – other nations are limited in how they can participate. Such a policy limits space advancements and has caused countries like China to construct their own space stations in direct competition to the US when tensions are at an all time high. Furthermore, the US plans to decommission the ISS in the next 10 years, relying on the private sector to construct new LEO stations. Such an action will be detrimental to the US – it will eliminate the US's LEO presence in the short term, and countries such as Russia and China will have more time to build up their presence in space. Other nations will turn to Russia and China for access to LEO, and the US will suffer a great set back while its private sector struggles to establish the infrastructure needed for a new LEO station. Instead of decommissioning the ISS, this presentation seeks to present an alternative solution – a rethinking of US space policy and a transformation of the ISS into a true international station called Gaia Blue, where the ISS's lifespan will be extended indefinitely. NASA will transfer management of the ISS to the University of Southern California, where its renowned Space Engineering Research Center (SERC) will serve as the new headquarters for the Gaia Blue, similar to the NASA partnership with the Space Telescope Science Institute at Johns Hopkins University for the management of Hubble. Such a transfer of management relieves NASA of the ISS, allowing the organization to focus on ARTEMIS and its other programs, which is one of the main reasons why NASA wants to decommission the ISS. USC's world-wide connections and private funding will allow Gaia Blue to flourish, and private companies/nations will be able to work with USC to gain access to Gaia Blue. In addition, USC is one of the largest employers in Southern California and has experience handling a large work force. Without NASA overhead costs, USC will be able to cut operational costs, and funding will come from both NASA and companies/nations wishing to be a part of Gaia Blue. Overtime, SERC will evolve into a consortium that partners with other universities/private entities to manage Gaia Blue. As for the new station itself, Gaia Blue will add new manufacturing, research, and tourism modules to the current ISS configuration, promoting manufacturing of experimental drugs & materials, research in climate change, geology, & biology, and tourism for those who seek to vacation in space. With the expansion of the ISS into Gaia Blue, the new station will be equipped with state-of-the-art nuclear reactors and hydrogen fuel cells to power itself, phasing out solar panels to reduce drag. It will also be outfitted with a new, powerful propulsion system for station-keeping. By transforming the existing ISS infrastructure into Gaia Blue, the US maintains its dominance in LEO orbit while simultaneously promoting international cooperation through USC. Moreover, through the Gaia Blue initiative, the ISS can become a truly global project with all nations involved, self-sustained by private enterprise and private astronauts, with new and exciting manufacturing, research, and tourism capabilities in LEO orbit [Figure 2].

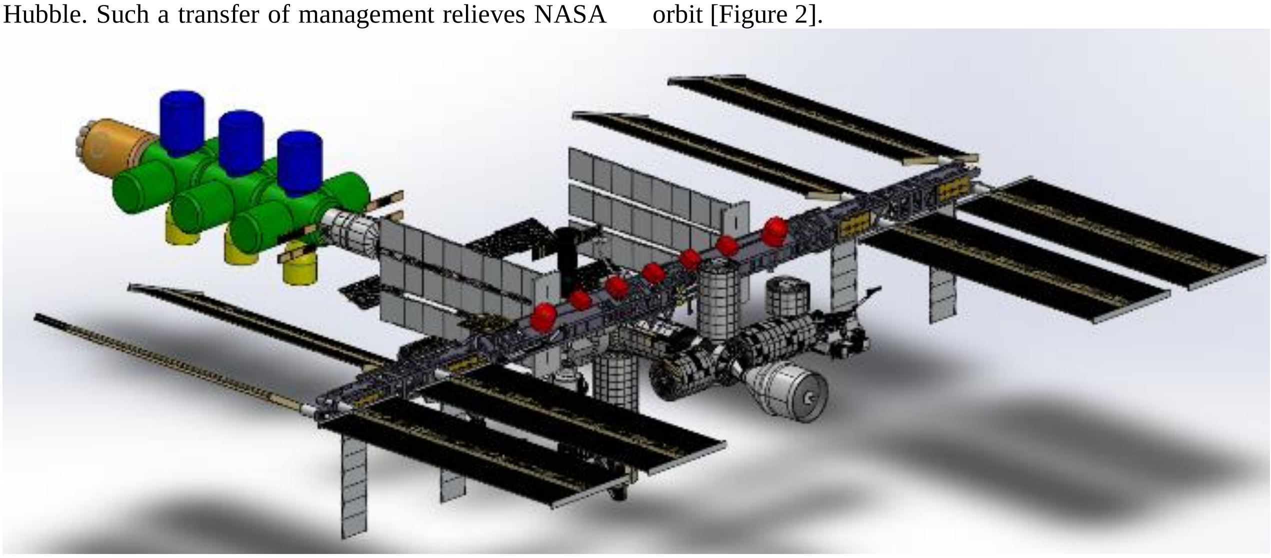

Figure 2. GAIA BLUE modifications to the International Space Station

3. A Taste of Earth: The Galaxy Garden

As space exploration and technology continues to develop, long-term travel and exploration have become more feasible goals towards human expansion. Within this ambition, commercial spaceflight has opened the doors towards achieving space tourism that include liveable, practical habitats and environments for people to enjoy while being in space. Amongst the different environments that one could experience in outer space, the need for the connection to earth and the home planet is essential for not only mental but physical health. The ISS has already experimented with the growth of lettuce and the effect of space on the taste buds, so by developing a Galaxy Garden on the ISS we could use the same method and apply it to other systems of spaceflight. The Galaxy Garden focuses on the use of sustainable systems to grow more food in space and as space tourism continues to develop, humans will need the sustenance and nutrients to have the energy to thrive and live in the extraterrestrial environment. The use of aeroponics, aquaponics, vertical farming and oxygen harvesting will all help establish the garden that gives a reminiscence of life back on earth. It will also give the tourists and workers a new hobby and a place to escape the emptiness of space. Gardening will mentally benefit the crew by reducing stress, depression and anxiety and increase the sense of community for the members. Overall, the Galaxy Garden will provide a Taste of Earth being far from home [Figure 3].

Figure 3. The Galaxy Garden provides an essential piece of humanity to Earth's astronauts, fresh food.

4. Farah Flight – A Wedding in Orbit

Farah Flight is an event space in orbit, inspired by middle eastern weddings. The middle east perfected the art of celebrations. One must ask themselves to what extent are they willing to push the ceiling for extravagant weddings. This event space is called Farah because it means wedding in the Egyptian dialect but also means happiness in the Persian Gulf region. Farah Flight is created to celebrate one's milestone in life. whether it be a wedding, an anniversary, a promotion, etc.

Farah Flight will host a maximum of 15 people including two staff members. Where guests can choose whether to dock at the International Space Station or the world's first luxury hotel; The Aurora Station. The event space is a unique zero-gravity experience for those who wish to disconnect from the world and reflect on their life achievements and goals.

The importance of this event space is to attract high profile individuals and accelerate the attraction of outer space tourism. This relates to CASH as it is the first step to catch some traction on social media and the traditional news. Once celebrities and high-profile individuals want to spend their money and time in outer space, celebrating while broadcasting to the public. Farah Flight can help advertise the unique experience and ceremonies it has to offer. The experiences of zero-gravity food and beverages that will be surrounding the guests in hand-held pods and many possibilities with exploring zero gravity decorations and florals.

Finally, the entertainment industry will have access to Farah Flight for film production and advertisement. The entertainment industry is very familiar with space travel and has been promoting the experience of space tourism through films, restaurants, hotels, etc. [Figure 4].

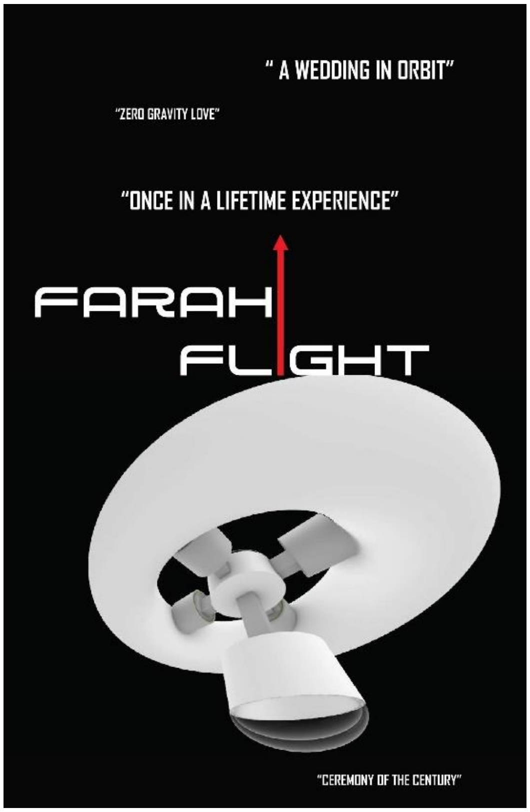

Figure 4. Farah Flight, a luxury celebration of love and space.

5. C.H.E.F. in Space - Creating Human Experience through Food in Space

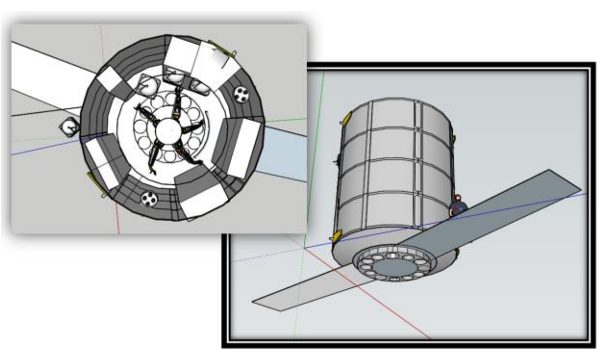

Figure 5. C.H.E.F. in Space module

The Artemis mission has motivated further advancements and developments in the Space arena. There has been an increase in private space companies, sprucing up to innovate and produce space products. NASA (National Aeronautics and Space Administration) and CSA (Canadian Space Agency) has sanctioned the Deep Space Food challenge, calling all food innovators around the world to take on the challenge of developing novel food production technologies that can support long-duration missions. The challenge is slated to complete by 2024, which is the same timeline as Artemis's plan of returning astronauts to the Moon.1 This was part of the motivation for the C.H.E.F. in Space project with a goal to serve gourmet food that provides space travellers an exceptional dining experience. It addresses the challenges of creating a more palatable meal, providing nutritious and tasty food, and catering to individual's caloric needs.

The concept architecture presented here is part of promoting commercial human spaceflight expeditions (CHASE). It is part of the overall plan of converting the ISS (International Space Station) into a hotel that accommodates space tourists. Food is a necessity for any type of trip travelers embark on. Historically, space food is limited to pre-packaged meals that are prepared to either be rehydratable, thermostabilized, irradiated, or introduce intermediate moisture.4 Other courses are packed in clear, flexible pouches that are ready to eat with no preparation required. Cooking methods in ISS are also limited to using microwave oven, convection oven, or hot water to heat or cook the food.5 Astronauts are provided a set menu for their journey. There are still concerns about the palatability of the food, which affects food intake and leads to underconsumption of food by astronauts. This is evident from the weight loss that astronauts experience during space flight. Food tastes different in space and based on the conditions that astronauts may experience in space, it could change their appetite for certain foods.2

The concept of C.H.E.F. in Space is to create an exceptional dining experience and produce gourmet food that can be tailored to cater individual's needs on the day of meals being served. It proposes a food technology system that prepares, cooks, and serve the food in an automated fashion. The use of a pressure cooker concept is introduced to cook food per astronauts' or space tourists' request in a shorter period of time. A mixture of preserved food, raw ingredients from the Galaxy Garden, and spices are processed to go into the pressure cooker concept. With the use of tele-robot arms, the finished dish along with some supplements are plated on a serving dish [Figure 5]. A separate presentation on this CHEF topic is included at this IAC in Paris.

6. Space Waste Management: Using Lasers for Debris Mitigation

In the past, space has only been accessible to government entities; presently, the space industry is going through a commercialization phase, where private companies are launching high value government assets, fielding proliferated LEO constellations for internet connectivity across the globe and successfully accomplishing commercial human spaceflight. However, with every great opportunity comes a great challenge: protecting assets, including humans, from collision with orbital debris. There are millions of high energy orbital debris, in various size and orbits, being tracked by the U.S. Space Surveillance Network. This number is expected to continue to grow as more assets are injected into orbit. If appropriate measures in space waste management are not immediately undertaken, accidental, unintended collisions between objects and high value assets will create a cascade effect known as the Kessler Syndrome (or Effect), making the orbital regime unusable. The threat is real and the risk to astronauts is already increasing. One way to tackle this challenge is by vaporizing smaller pieces of debris or displacing larger orbital debris into perturbed orbits to re-enter Earth's atmosphere using high power lasers.

The proposed SWM concept utilizes both ground-based lasers and space-based lasers to deorbit orbital debris in Low Earth Orbit (LEO). For both the ground-based and space-based lasers, the technology is based on the "DE-STAR" concept, where a modular phased array of kilowatt class lasers is used to achieve a highly focused directed energy beam to "sweep" orbital debris. The flexible, modular phased array laser design concept would be leveraged to attach a laser cannon to the ISS to deorbit threatening debris that appear in the path of the ISS. The concept of attaching a deorbit laser in space has been proposed before and is known as the Coherent Amplification Network (CAN) laser. Through the combination of using multiple ground-based laser stations all over Earth and supplying high value assets, such as the ISS, with space-based lasers, this is a simple yet achievable path to reduce orbital debris in the near future. Advancing this technology is a path to field lasers to vaporize debris along the tracks of high value assets in all orbits, such as the ISS and cislunar vehicles. Reducing orbital debris in all orbits increases the safety of commercial human spaceflight in LEO, cislunar vehicles, and future human spaceflight missions to Mars and beyond. Merits and current policy limitations notwithstanding, Earth and orbit-based directed energy lasers show promise for orbital debris mitigation and should be pursued to make space activity safe for crew and high value assets.

Figure 6. Space Waste management leverages ground and space-based lasers for debris removal in LEO.

7. ASCENDERS: ISS Gaming Platform

Participation in Human Space Flight is an idea that has captured the hearts and minds of many would be astronauts since the beginning of the space race in the 1950s. With sub-orbital flights set to cost on the order of $200,000, real space flight experiences will continue to remain frustratingly out of reach for all but a select few government astronauts and the considerably wealthy. In carrying out its core mission of space exploration, NASA's budget will continue to remain fixed while its mission objectives will continue to expand. To meet this challenge NASA must find opportunities to partner with the commercial sector in ways that are both financially sound and further its strategic objectives. ASCENDER's is a novel business and governmental partnership that aims to simultaneously be a commercially viable next generation gaming platform, remotely operated space vehicle research and development testbed and, a tool to inspire the next generation of space flight professionals. Combining commercial off the shelf gaming technology (flight simulator controls modified for spacecraft thrusters, virtual reality goggles and, in later versions full motion simulation) with a communications uplink to thousands of gaming satellites (modeled on the 1.3 kg CubeSat) stored in a new support module attached to the ISS, a platform for the next generation of remote in space entertainment is created. Gone are the days of satellites being the sole purview of research scientists. With ASCENDERs a platform is created for the common man to be awed and entertained in space. Rented time on an ASCENDER provides for actual in space satellite races, exploration of variable 3D mazes, simulated laser tag shoot outs and earth watching all at the customers leisure. In developing the capacity to execute this gaming platform the commercial industry would provide improvements to the communications bandwidth of the ISS and NASAs overall communications architecture, an added capability that would directly impact NASAs ability to communicate with its GATEWAY and ARTEMIS programs. Once commercial viability is established NASA could begin to charge rent for commercial utilization of its core infrastructure on the ISS. Beyond profitability, ASCENDERS also provide the opportunity for NASA to continue its telerobotic research and development activities begun in 2013 by allotting a portion of the gaming satellites for NASA space ROV mission operations development and through observation of how gamers choose to employ their space craft. NASA could also choose to provide opportunities for chosen gamers to participate in actual NASA's activities for example by supporting Astronauts on a spacewalk. In doing so the ASCENDERs platform creates connections between the Agency and its next generation of aerospace engineers, software developers, scientists and astronauts [Figure 7].

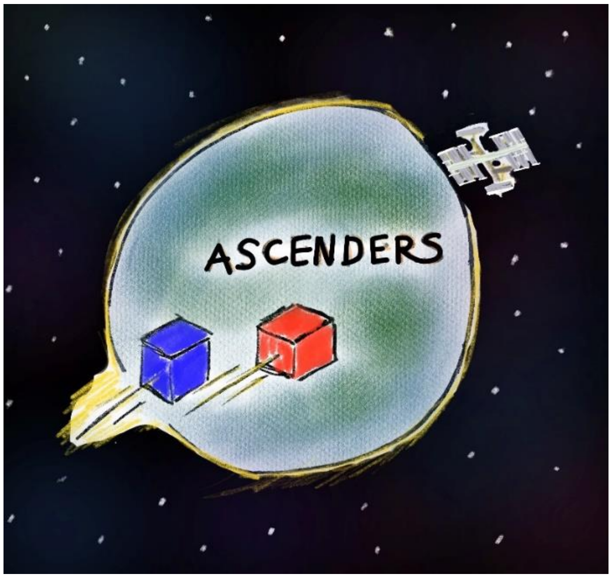

Figure 7. ASCENDERS logo.

8. CITADEL – Cislunar Telecommunications Architecture Development Logistics

A focus of expanding human activity beyond the familiar near-Earth arena is the commercial utilization of the much larger volume of space between the Earth and the Moon – the cislunar domain. The architecture to support this lucrative new realm of commercial activity, though, is not yet in place. CITADEL, an acronym for Cislunar Telecommunications Architecture Development Logistics, provides a method to establish the supporting architecture for commercial human spaceflight expeditions, particularly within this domain. With its backbone in laser optical technology, CITADEL aims to provide a stronghold of communications to enable not only the commercial development of the cislunar space in the near future but continued human space activity even beyond the Moon.

In order to successfully pursue commercial endeavors in the cislunar realm, situational domain awareness (SDA) over the region needs to be established first. This awareness will "create a safe, stable, secure, and sustainable environment for space activities", in accordance with the National Space Policy of 2020 [1,2]. CITADEL pitches the establish of critical end-to-end situational domain awareness over the cislunar domain through three main points: 1) leveraging three-body problem dynamics in the Earth-Moon system, 2) utilizing laser optical communications technology, and 3) utilizing existing and planned communications architectures from all different players within the aerospace industry: civil, commercial, academic, defense, and even international partners.

Firstly, CITADEL promotes leveraging the three-body dynamics of the Earth-Moon system in order to develop necessary cislunar logistics. As a primary distinguishing factor from operating in near-Earth space, three-body dynamics pose unique challenges to SDA, but they also enable unique architectures to be established. Multiple families of periodic orbits originate from the five equilibrium points emitted from the three-body problem. The most familiar periodic orbits are the planar Lyapunov orbits or the Halo orbits, but there are a vast number of others that may be of interest for communications architectures depending on the necessary line-of-sight and time-of-flight requirements. Some of these orbits sweep out large volumes of space, providing periodic access to both the Earth and the Moon.

Secondly, CITADEL promotes the use of laser optical communications technology that has been in development over the last decade or so. Since its first technology demonstration in 2013 with NASA's Lunar Laser Communication Demonstration (LLCD) flown aboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite, laser optical communications has instigated a "paradigm shift in future space communications" [3]. This technology boasts revolutionary downlink and uplink rates, 10 to 100 times faster than those of current state-of-the-art radio frequency capabilities, enabling the transmission of high-resolution images and videos [4] on a terminal that weighs less, uses less power, and occupies less space [5]. In addition to increased data transfer rates, laser optical communications transmits at a much higher frequency thus allowing more data to be encoded in each transmission. All of these capabilities are critical not only for space missions as they generate and collect more data, but for cislunar operations as well, from tracking manned or unmanned payloads to potential search and rescue operations.

Thirdly, CITADEL promotes the use of existing and planned communications architectures from all players in the aerospace industry, including but not limited to civil, academic, commercials, and even international partners. By taking advantage of the technology already in place or in development, especially leaning into a commercial path, the implementation of laser optical communications in support of greater cislunar development logistics is streamlined. It will be an evolutionary path to quickly adopt optical communications technology by taking advantage of commercial ventures to fund and implement. Overall, cislunar optical communications will comprise an amalgamation of interoperable terminals, creating wide access to SDA capabilities as a service. Examples of architectures that may fit into the picture include the newest generation of SpaceX Starlink satellites, which are fitted with optical terminals, for Earth-end coverage and NASA's LunaNet for Moon-end coverage. In between these could include optical communications satellites placed in periodic orbits of interest by a commercial entity or academia-based satellites with optical payloads such as USC's own DODONA, and these are by no means the only potential options to create a full end-to-end communications architecture.

Other reasons for pursuing the cislunar logistics development framework set forth by CITADEL include the increasing obsolescence and limitations of the Deep Space Network. The Deep Space Network (DSN) at its current state has limited bandwidth in its capability to accommodate the unique challenges of cislunar communications and providing the necessary logistics for expanded human space activity; it is already a limited resource taken up by many other missions and radio frequency transmissions are not the ideal path forward to transmit the massive amounts of data that will be generated. The difficulty to secure funding in order to make technology upgrades and implement new technologies underscores the benefit of leaning commercial instead to provide these services on a much more compact timeline.

CITADEL also has the potential to help the entire communications world, not just that of space exploration and utilization, through elevating global broadband to a new level by integrating with a global terrestrial optical network. Those connected to this optical communications network will benefit from greater connectivity on the ground in addition to low-cost, secure, and interference-free space communication capabilities, a privilege afforded to those who agree to the Artemis Accords.

In summary, CITADEL puts forth a framework for developing the necessary communications logistics to enable successful and sustainable human activity in the cislunar domain. Rooted in revolutionary laser optical communications, CITADEL provides the foundations for space exploration and development between the Earth and the Moon by leveraging the unique dynamics of the realm and leaning heavily into collaboration between partners from many different sectors. CITADEL can support commercial human spaceflight expeditions in cislunar space, with the potential for providing the foundation for expeditions beyond the Moon as well.

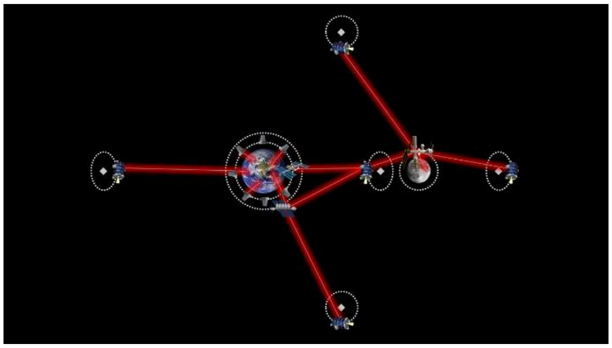

Figure 8. CITADEL architecture concept.

9. SERVO: Space Emergency Response Vehicle Outpost

The next major milestone that has been targeted for human spaceflight is NASA's Artemis program to return humans to the moon. The current plan proposes to build the Gateway in Lunar orbit that can support crew, followed by building a permanent base on the surface of the Moon. The Gateway is proposed as a human-tended platform that could provide critical support to the lunar base, but this outpost also requires resupply and constant upkeep to maintain.

Meanwhile, in Earth orbit, the International Space Station is expected to be decommissioned in the next few years, and commercial space companies are looking to establish their own human presence in the same LEO regime. All of these stations require the capability to support human life, as well as being able to respond to contingency scenarios with the overarching priority to keep the crew safe. Since it takes approximately 3 days to reach the moon using conventional chemical propulsion, and the LEO regime requires specific launch times to align trajectories to reach the LEO stations, having another capability in Earth orbit that can respond and support emergencies on a shorter timeline is important to safely maintain human presence in space.

The Space Emergency Response Vehicle Outpost (SERVO) concept architecture is proposed as an alternative, or additional option to Artemis Gateway. SERVOs are GSO based, crewed stations that support both LEO and Lunar emergencies and can fulfill many of the needs that the Gateway is proposed to meet in its lunar orbit. These include providing a staging point for deep space exploration, supply transportation, and vital support for long-term human presence in space, at a much lower risk factor and on a quicker timeline than having this same staging point in lunar orbit. Primarily intended to function as a depot of emergency supplies such as human food, propellant, and backup hardware, SERVO will also allow for commercial companies to establish a presence more easily in space, with its lower development cost and ability to support a wide range of smaller scale missions.

SERVO would initially be launched as a pilot program, where one module is designed and assembled in LEO, and over the course of time boosted up to GEO via additional module deliveries. Once in GEO, this station would stay in a fixed location relative to earth (Geostationary orbit) which would guarantee continuous communication access. To maintain functionality as an emergency response station, SERVO would be outfitted with multiple types of docking adapters, including but not limited to the Dragon and Orion crew capsules. This would open SERVO up to being able to support docking functions with any of the crewed modules designed to dock with the ISS (which is what a lot of commercial companies are looking at in the near future). Having the ability to dock with Orion supports contingency scenarios on proposed Artemis mission trajectories to the Moon and showcases the capability of SERVO to grow as technologies evolve. Additionally, since the ESA Service Module has limitations in how low of lunar orbit it can support the Orion Capsule, having the ability to meet with a SERVO adds another emergency response option than just rendezvousing with Gateway at the planned time.

An example of a contingency scenario that took place recently would be the ISS collision threat with space debris. The astronauts had to take shelter in their crew modules and assess damage afterwards. If SERVO had been available to support, an example of a response to this contingency would be that the astronauts could've vacated temporarily for the collision and stayed at the SERVO. Upon assessment of damage, if there were any parts that could use repairs or additional patching, SERVO would have those supplies readily available, rather than having to wait for the next launch or making do with what was available on the ISS.

SERVO does not require new technology to implement. This design utilizes existing technology that has been validated and used for the ISS, and also provides a testbed for advancements intended for the Lunar Gateway and future deep space missions. Additionally, our current international choices of launch vehicles are able to delivery crew and supplies directly to GEO, as opposed to lunar orbit, so repairs and resupply trips would be already attainable even prior to full operational capability of SERVO.

Another benefit of SERVO is the ability for it to evolve over time. Once the pilot program has been executed successfully, this design allows for more SERVOs to be launched to support different GSO locations around the globe. A future capability that could be pursued as well would be in aiding with 'recycling' of decommissioned space assets that pose an orbital debris threat in graveyard orbits beyond currently loitering GSO. Boosting the SERVO to slightly past GSO would allow it to be in a 'lagging' orbit that services different parts of the GEO orbit regime over time. This would mean astronauts on the station could characterize the orbital debris and previously decommissioned satellites in that regime, and harvest parts that may be able to be repurposed or collect debris to be burned up on reentry. This additional scope would be further down the line in development of SERVOs and is intended to showcase the growth opportunity, as the primary purpose and driver for developing this concept is to provide infrastructure in orbit to support emergency scenarios in both LEO and Lunar orbits.

SERVO is a concept that is rooted in current technology but envisioned for how the future in space will evolve. This concept will allow for quicker development timelines that also push for new ways to utilize existing technology in many fronts – driving for a regular commercial presence in space while also meeting the basic infrastructural needs to maintain human presence in space. This concept also easily expands into higher end commercial tourism opportunities that have been considered before and dropped due to high-cost barriers, such as space hotels in GEO. Starting with the primary need to support emergency scenarios and building up to the commercial tourism aspect of making visits to space a vacation will allow for that cost barrier to come down naturally as more companies provide capabilities to support space travel [Figure 9].

Figure 9. SERVO crewed GEO station.

10. Buzzcraft: Evolution of Cislunar Cycler

As part of the Artemis program, NASA intends to have boots back on the moon by 2024, with help from the Gateway station in Lunar orbit. However, questions persist about the physiological consequences of prolonged exposure to deep space radiation on the human body. Furthermore, there is currently no cislunar infrastructure in place to aid with rescue missions in the event of catastrophe on the lunar surface, nor is there a reliable logistics channel and communications link to the moon.

Buzzcraft is an alternative proposal to the Gateway station that seeks to address both of these issues. Buzzcraft will evolve over the course of 4 stages between 2022 and 2024. The first stage is a Dragon and Orion module docked together in Low Earth orbit containing a plant and animal laboratory (PAL). PAL's initial phase in LEO within Earth's magnetosphere will serve as a control for study of biological tissue taken from plants and animals in the capsule. After this initial phase, PAL will move into phase 2: Geostationary orbit where it will be beyond the protection of Earth's magnetosphere and the biological tissue will be exposed to deep space radiation for prolonged periods of time. PAL will be relatively accessible in GSO for rack changeouts and collecting tissue samples. Phase 3: PAL will move back into LEO where other modules will be clustered with help from international partners. After the modular assembly of the constituent modules into Buzzcraft, Buzzcraft will be placed into a free-return cislunar orbit. PAL will be attached to Buzzcraft to continue the biological studies, and other modules will carry cargo, landers, and people into cislunar orbit. Once in this orbit, Buzzcraft will be a critical piece of cislunar infrastructure and will aid the Artemis mission in carrying payloads to the moon. This would eliminate the need for Gateway altogether.

The architecture of BuzzCraft is composed of already existing commercial space technology, both human rated and non-human rated, including SpaceX's Dragon capsule, and Falcon Heavy launcher, as well as Boeing's Unity connection module. As a result, the first phase of Buzzcraft could be launched as soon as 2022. Further modules can be supplied by international partners such as the ESA, JAXA, and CSA [Figure 10]. A separate presenation of the BuzzCraft concept is in the proceedings of this IAC in Paris.

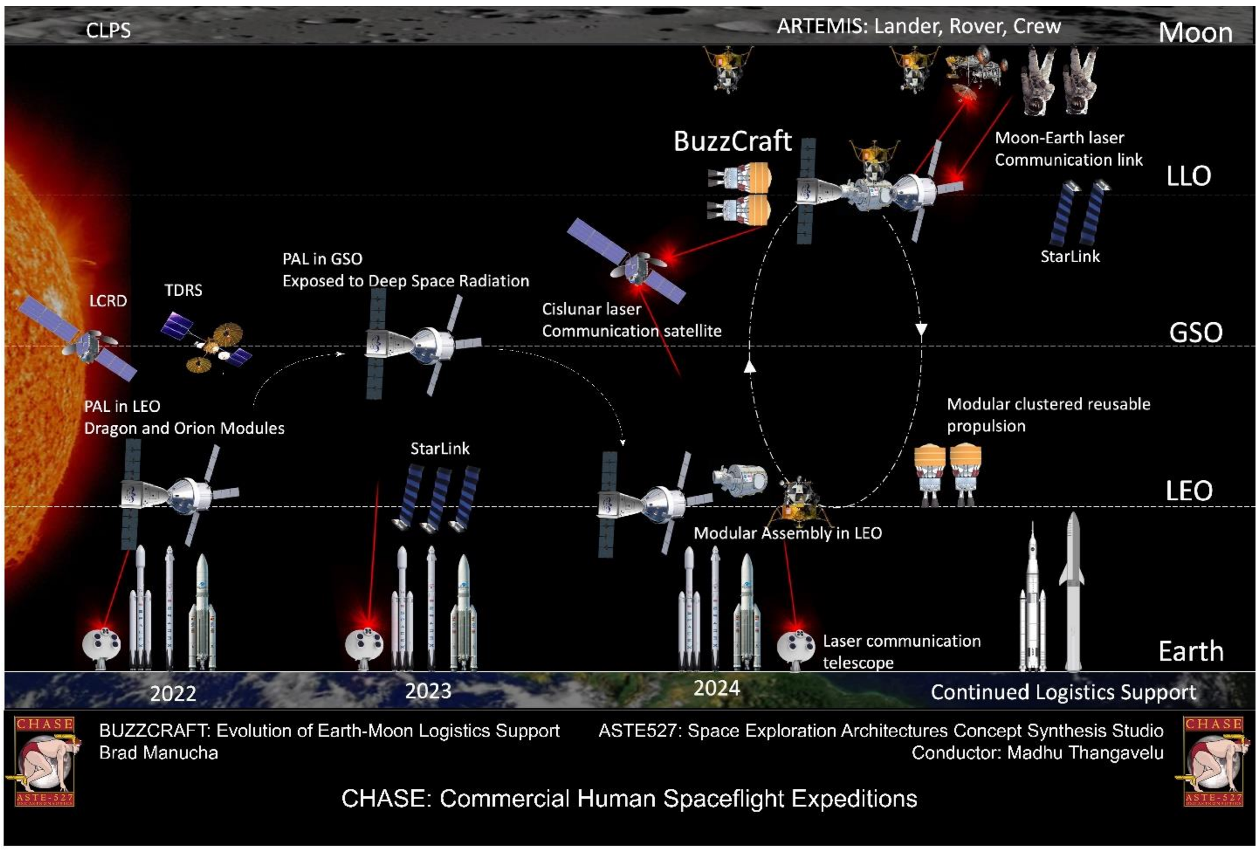

Figure 10. BuzzCraft Cislunar cycler concept of operations.

11. IGLOO: Finding Space in Space

Space is no longer a scientific playground where discovery and testing reign; it is a frontier to be settled. As humans spend more time in space, space architecture needs to shift priorities towards long-term human comfort while maintaining the level of safety necessary to survive beyond Earth's atmosphere. Projects like using virtual reality to visit Earth or a "happy suit" meant to adapt the environment to the astronaut improves crew lives, but they are still temporary escapes from prolonged stays in a cramped environment. Human priorities needs to be incorporated from the beginning.

A effective way to improve the living space for astronauts is to increase volume and sequester a module from the scientific endeavors on station. Using the Halley VI Antarctic station as inspiration, a community module can accomplish both goals.

A community area in a space station must foster social engagement and comfort. Social engagement comes from a few necessary characteristics, such as a kitchen and a reconfigurable open space that the crew can make their own. In addition, the module must utilize amenities following the latest research on an environment's effect on crew psychology by using thoughtful colors, adaptive lighting, and a deliberate layout.

With regards to layout, this presentation contemplates an alternative inflatable configuration: the igloo. The igloo is characterized by a flat floor, a half-dome inflatable shell, and 500 cubic meters of hidden storage underneath the floor. While a flat floor is hardly a requirement in microgravity, it is useful in terms of creating a familiar space and helping maintain a sense of balance through a well-defined "ground". The half-dome creates more than enough room with over 1900 square feet of floor space and 20 feet of head room while using half the material needed for an inflatable cylinder design like NASA's TransHab. Underneath the floor, two long half-cylinders create hidden storage and keep the community module organized.

Long-term human habitation in space is already a reality, but it is limited by design. Inflating beyond our limitations in space will make space sustainable not only for our science, but also for our species [Figure 11].

Figure 11. IGLOO open space habitat concept.

12. R2S2: Lunar Robotic Remote Sensing Scout

Space Policy Document 1 calls for the U.S. to lead commercial and international partners in returning humans to the Moon "for long-term exploration and utilization" [1]. The Moon Village Association shares this vision and adds on the importance of sharing information between these partners to facilitate cooperation [2]. This call is being answered by the NASA Artemis program, which plans to lead commercial and international partners towards establishing a sustained human presence on the Moon [3-5]. The USC CHASE initiative proposes the Robotic Remote-Sensing Scout (R2-S2) to assist lunar EVA crews for Artemis III and following crewed lunar missions. R2-S2 is a versatile robotic rover intended to dramatically reduce the risk associated with lunar EVA missions.

R2-S2 has two primary modes of operation: 1) Teleoperated mode and 2) Autonomous crew-assist mode. In teleoperated mode, the lunar crew remotely operates R2-S2 from inside their lunar habitat to assess the safety of planned EVA crew missions (mission recon) or to conduct some tasks that would otherwise require a crewed EVA (remote exploration and inspection). For EVA mission recon, the teleoperator directs R2-S2 to the desired mission destination while gathering valuable sensor data that will aid in determining mission safety. In autonomous crew-assist mode, R2-S2 provides support alongside the crew during EVA excursions. In this mode, R2-S2 livestreams EVA operations to Earth, carries tools,

and performs specific tasks when commanded by the crew (sample collection, telescoping, microscopy, in-situ sensor readings). R2-S2 also carries spare oxygen tanks and suit repair materials for contingency scenarios.
As shown in the pictures above, R2-S2 comes in two configurations such that it may accommodate either equatorial or polar missions. The main differences between the two configurations are the solar panel placement, wheel width, and battery pack insulation.
R2-S2 will be a commercial and international effort led by NASA, and all data collected will be shared with those commercial and international partners. The Artemis program poses challenges and risks that have not been faced before. R2-S2 aims to help mitigate those risks as much as possible to ensure the safety of the crew and facilitate productivity on the lunar surface [Figure 12].

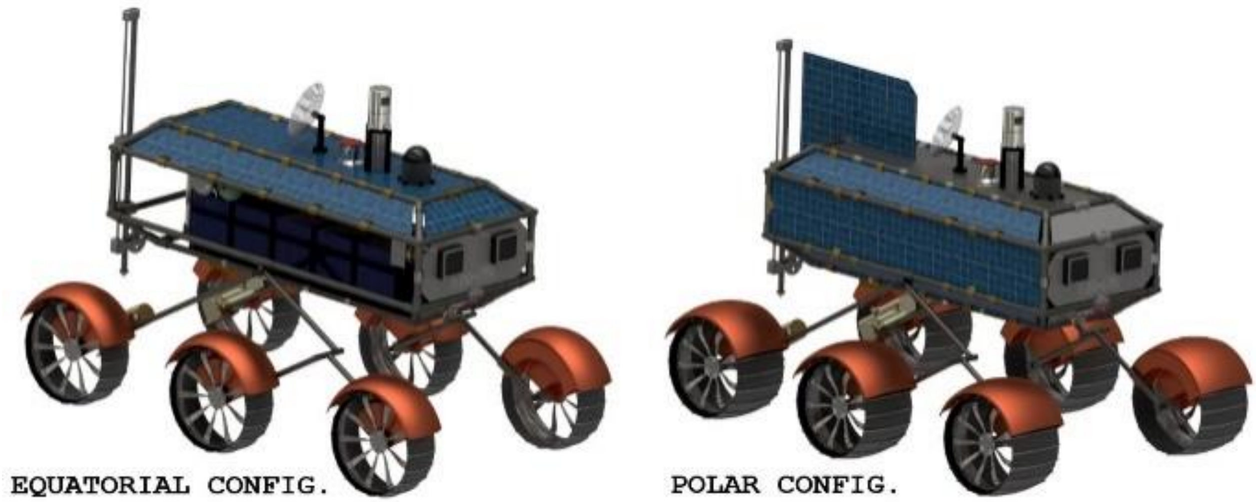

Figure 12. R2S2 rover concepts shown in both equatorial and polar configurations.

13. Helios-Lune Tranquilitatis: Artemis III Exploration Mission & Retrieval of Solar Activity Records

Helios-Lune Tranquillitas (HLT) is a proposal for a commercial Artemis III lunar exploration mission to the Mare Tranquillitatis pit crater. HLT has a primary mission objective of obtaining samples to be returned to Earth for analysis from two locations within the crater: the sunlit wall and talus pile. The samples will be collected using a tailored, mission specific version of the Axel Rover (Axel) (Kerber, Nesnas, & Keszthelyi, 2018), developed to rappel into a lunar pit. Axel is controlled by Artemis lll crew using real-time telerobotic systems from the cabin of the lunar lander or HLT's pressurized rover. The unique mission location and sampling strategy allows for solar activity record (SAR) data to be analyzed from the sample layers upon return to Earth. SAR imprinted on the long dormant Moon can provide critical data about solar behavior over geological time that is vital to building a reliable Climate Change model for Earth (Crawford, 2021). HLT's secondary objective is observation and scientific exploration of the lunar pit crater, through utilization of the rover's onboard scientific payloads including wide and narrow lens cameras, ground penetrating radar, a spectrometer and three-dimensional laser scanning capabilities.

The mission strategy overview to obtain the samples is as follows: the HLT lunar lander touches down on the moon's surface a few miles away from the Tranquillitatis pit. Once landed, a pressurized electric rover is deployed and is driven by the crew from the landing site to a set location near the rim of the pit crater. On arrival, Axel is readied by being tethered to the electric rover and thereafter begins to rappel into the crater, clearing debris on its downward descent. Once descent is complete, observation and experimentation through use of Axel's scientific payloads, including sampling of the talus pile commence. When this stage is complete, Axel ascends on the debris-cleared path towards the lunar surface, pausing at specified intervals to collect the remaining pit wall samples by drilling.

The mission is designed to align with US Space Policy goals and objectives to advance progress through a "robust, innovative and commercial space sector" (Federal Register, The National Space Policy, 2020) as well as "extending human economic activity in deep space" (Federal Register, The National Space Policy, 2020) (Marburger, 2006) by facilitating science-driven exploration on the moon. Moreover, the mission aligns with the Artemis program's objectives (NASA, 2020) as the Tranquillitatis pit is a prime location for initial study aimed at revealing ancient SAR data as well as lava studies that provide insight into past lunar planetary processes.

HLT is a Commercial Human Space Exploration (CHASE) mission. Thus, all stages of mission development can be open to company applications through worldwide tender, promoting international scientific collaboration and cooperation. Research proposals for sample data analysis and experimentation can be submitted by academic institutions and commercial space companies. Once obtained, data from the mission and results from sample analysis can be sold to public and private space sector companies, educational institutions, and other interested parties [Figure 13]. A separate presentation of the HLT concept architecture is included in the proceedings of this IAC in Paris.

Figure 13. Helios-Lune exploration concept. Image Credit (Left to Right): NASA, Axel Rover (Kerber, et al., 2018), LROC M144395745L M126710873R

14. SO-LEV: Sub-Orbital Lunar Excursion Vehicle

In the coming decades, NASA's Artemis program promises to return humans to the surface of the Moon. An important component of the Artemis program is the Commercial Lunar Payload Systems program (CLPS). NASA will contract commercial companies to deliver payloads to the lunar surface with privately developed landers. After completing their delivery, most of these landers will remain on the lunar surface and will not return to Earth. SO-LEV proposes to reuse lunar landers as suborbital vehicles after completing their delivery. Extraterrestrial flying vehicles are a rising area of research. Just within the past few months, NASA-JPL's Ingenuity Mars helicopter has demonstrated the concept on the surface of Mars. On airless bodies where rotorcraft cannot be used, rocket propelled vehicles could perform a variety of functions.

Artemis Base Camp will be located at the lunar south pole, a location pockmarked by craters and mountains. Traversal of the harsh terrain will be critical to the success of NASA's primary scientific interest for Artemis, locating and mining lunar ice. A suborbital hopper would be an ideal supplement for ground-based rovers, performing aerial reconnaissance of the planned mission routes and aiding in search and rescue when needed. It could also quickly and efficiently explore inside deep craters, reducing risk on the human and rovers. A manned version of the SOLEV would also expand the effective exploration range of the Artemis program, allowing crew and cargo to travel from the equator to the poles in just thirty minutes using about 3 km/s of delta-V, which is around the same amount of delta-V required to land on the moon itself.

Modularity is key to the design of SO-LEV. All vehicles come equipped with a propulsion and landing module, which carries the consists of propellant tanks, landing struts, thrusters, and avionics. The thrusters are throttleable to provide both fine adjustments for attitude control as well as ascent, descent, and hovering capability. Customers will be able to design and attach their own payload with scientific instruments, cargo, or crew capability, and interface them directly with the SO-LEV platform. The lower module will also house the sensors required for autonomous navigation. SO-LEV will make use of high resolution optical cameras for terrain relative navigation, a technology pioneered by the recent Mars 2020 mission [Figure 14].

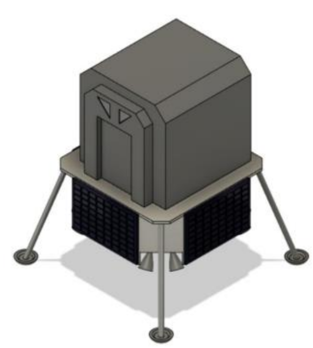

Figure 14. SOLEV lander concept.

15. Soteria – Rescue from Lunar Orbit

The NASA Gateway and Artemis reference missions have not yet articulated emergency or rescue mission strategies in any detail. Crew safety and assured crew return as well as mission success are top rung priorities. The Soteria concept architecture derives its name from the Greek goddess of safety and salvation, deliverance, and preservation from harm.

As lunar exploration increases, and the cadence of crewed missions become more frequent, there will be larger numbers of people exposed to the risk of an anomaly, accident or emergency that will require external intervention ranging from crew support to crew extraction. Even if the individual probability of an emergency is lower due to improved technology and procedures, the overall rate of accidents is likely to go up due to increased activity on the Moon.

The Soteria concept proposes an emergency and rescue architecture that would deliver supplies or extract crew from the lunar surface, should the need arise. By deploying Soteria ahead of lunar surface activity, crew safety for Artemis and commercial crews on the lunar surface is established. Traditional approaches have focused on abort as the primary way to mitigate emergencies, but there are alternate approaches that improve safety and mission flexibility. Leaving the lunar surface via an abort results in mission failure in many scenarios. A mission failure may be avoided if timely assistance can be rendered. In addition, some types of emergencies are not easily mitigated by an abort, such as a solar flare, critical medical event, or an anomaly encountered when a crew is not near an ascent vehicle.

The Soteria concept architecture proposes dispatching emergency supplies to the surface from the Lunar Gateway. Emergency supplies are delivered on an as-needed basis using a Commercial Lunar Payload Services (CLPS) derived lander. The lander can deliver supplies in one to three hours flight time, depending on the phasing of the orbit. The Lunar Gateway would be in a Low Lunar Orbit (LLO), with the orbital inclination to pass over the crews on the surface mission. The Lunar Gateway could provide coverage for multiple crews, leveraging emergency supplies. Multiple stations can be used to reduce the average flight time.

By locating the emergency supplies in lunar orbit, several benefits are achieved. A broader variety of emergency supplies can be provided, improving overall safety. Landed mass is much lower, which can reduce overall launch costs. For expeditions with crewed rovers, the rover can be much smaller and lighter, permitting the expedition to travel more quickly.

The Soteria concept accomplishes crew extraction by using a small ascent vehicle the scale of a CLPS lander. The ascent vehicle would be carried along with the surface expedition so it is always available. The proposed Soteria concept can be tailored for a range of lunar orbit, lunar surface and cislunar emergency missions as well [Figure 15].

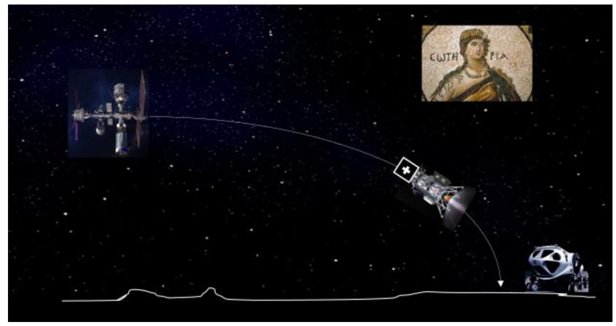

Figure 15. Soteria shelter concept.

16. N.U.K.A. – Nuclear Utilization with Kilopower Applications

A new and ambitious plan for a return to the Moon requires an equally ambitious approach to solving the challenges on the surface. As the first nation to unlock the power of the atom, there is no better opportunity to usher in a nuclear-powered future than to merge this compelling technology with the Artemis program. There are many unique factors that make the lunar surface the ideal location to incorporate nuclear energy into the lunar infrastructure, including its lower gravitational force and worry-free waste spaces. The applications of nuclear power to base operation, long-distance trips across the surface, and more make it a reliable and footprint-efficient way of providing power independently of the Sun. This technology will only become more relevant as the human presence on the Moon increases over time as new techniques for energy storage and high-speed transportation become possible. It will become clear that the fuel which ignites the possibilities of the future may be found in the core of the atom.

Figure 16. NUKA concept logo.

Conclusion

As the ASTE527 graduate Space Concept Studio enters its 30th year of creating concept architectures focused on visioneering a vibrant future for human space activity, this 2021 studio worked on human spaceflight projects described above that could be formulated with private space sector at the core with potential for extensive international collaboration.

Unlike the aspirations of humanity for Mars settlements, open-ended discovery and exploration quests at further destinations that are mostly science and technology development driven, activities on the Moon and cislunar space are policy driven. Several nations have projects or programs for lunar missions in this decade. It is in this immediate region between the Earth and the Moon that freedom and peace and free world values we cherish can continue to bloom, expand outward and flourish.

Several nations have space programs and ambitions to see people living and working at the final frontier. Only three nations today have the technology, the infrastructure and the operational capability to carry people into space, perform useful activities, and return them safely to Earth. The United States, Russia and China have national ambitions to lead our species into permanent human space occupancy.

American ingenuity is unique and on full display in this CHASE effort as SpaceX is the only private space company that is able to out-compete any and all global space agencies to safely carry crew and perform human space operations in orbit. SpaceX is the only entity on the globe that is ramping up aggressive technologies to bring human space activity on par with 21st century technologies and sustainable capabilities. They include reusable Earth-to-Orbit heavy lift launch vehicles, orbital spacecraft and autonomous operations for safe, economically sustainable lunar and interplanetary space missions.

Several American space companies are sprouting that continue to broaden human spaceflight capability and expand CHASE allied engineering capacity needed to grow and mature this fully homegrown space industry ecology. Powered by the plummeting costs of components and methods like advanced additive manufacturing, a wide stable of launchers and private spacecraft are entering the space activity domain once considered the monopoly of governments.

Commerce is the lifeblood of modern civilization. Healthy competition and agility, ingenuity and innovation are the drivers of economics and profit in this sector. We must continue to encourage real space commerce, especially human space activity, beyond the NASA vendor-buyer model. Fundamental economic sense drives all successful commerce. A sustainable business model requires a profit motive. [Profit = Revenue – Cost] is a fundamental formula for all sensible commerce. Monitoring and minimizing environmental impact is a prime concern in the very fragile vacuum and weightlessness of Space.

Healthy competition between very complex, lengthy and expensive government undertakings and a nimble private sector have yielded very successful results. Rapid growth of US Railways, the Airplane, the Internet and the Human Genome Project are some past examples. Human space activity is seeing similar engagement today with SpaceX and Blue Origin and Axiom among others acting as catalysts to spur on innovation and economics of access to Space and operations. Such concepts were discussed in this 2021 CHASE studio. Machine Learning and Artificial Intelligence aided by agile digital technologies are playing a big role in autonomy and automation to help drive down cost and reliability of complex space missions.

Despite the hype and ideology propaganda that fill our days with us vs. them politics, with masterful diplomacy, Russia, China and India could become true partners in civilian human space activities to accelerate our common species ambition to become a truly space-faring species. Commercial space activity may hold the key to bring nations together. Since multi-national and global corporations already work with adversarial nations with different philosophies and opposing ideologies of governance across continents, surely synergies exist that can be utilized with suave and creative diplomacy? Proactively pursuing such collaboration can reap peace dividends just as the Apollo-Soyuz orbital rendezvous helped thaw the cold war between rivals and eventually helped build the International Space Station.

From experience we know that competition is limiting. The competitive spirit binds us to the goal of winning over the rival. Pursuing excellence requires a completely different mindset. The pursuit of excellence makes you free to set new imaginative, creative and more ambitious goals without limits. The pursuit of excellence and the horizons of human spaceflight are limitless in the vast expanse of space.

In the 1960s, America had a firm and steady policy, a clear mandate and masterplan, and a focused goal for human space activity. It resulted in the Apollo project that is still considered the finest example of system architecting. Right now that policy seems centered around the International Space Station, and the agency has many competing constituencies, programs and diverse interests to balance as well. Since policy is based on ground truth and not on grand visions or aspirations, unless there is a new, concrete imperative supported by real mandate and hardware, the ISS will continue to remain the north star of our governmental program. The private space sector now has the momentum to change this established tradition. Commercialization is paving the path forward to sustainable ISS operations and management.

One way to change the two-decades old paradigm is to relieve NASA of ISS operations. Independent commissions have pointed out this fact. A new FFRDC-type setup can shift ISS operations and management to a world-class university like USC that has tremendous experience in space research and international affairs. Such a shift will allow NASA to pursue lunar return geared toward accelerating Mars expeditions with laser focus.

All these activities, aided by principles laid out in NASA's ARTEMIS ACCORDS are bearing fruit both domestic and around the globe. Such global alignment activities bodes well for the US to continue to remain the beacon of the free world and at the forefront of space activity. Human space activity in particular, makes us the nexus for global cooperation and collaboration. That is a good sign for 21st century civilization, progressing step-by-step to build a peaceful, equitable and glorious future for humanity in space and on Earth.

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"To the sculptor form is everything and is nothing. It is nothing without the spirit - with the idea it is everything."
- Victor Hugo, May 13, 1885.