Report on the Technical Sessions of the 32nd ASE Planetary Congress

Abigail Morgan Re

20 January 2020

Technical Session Coordinator

Dr. John-David Bartoe, Retired Astronaut

Table of Contents

Space Suit Developments for Future Exploration

Chair: Chris Hansen, Manager, NASA Extravehicular Office, USA

Organizer: Michael Lopez-Alegria, Retired Astronaut, Principal, MLA Space, USA

Space isn’t the Place: The Growing Space Debris Challenge

Chair: Alexander Alexandrov, Retired Cosmonaut, Advisor to the President of RKK “Energiya”, Russia

Organizer: Michael Lopez-Alegria, Retired Astronaut, Principal, MLA Space, USA

ABOVE THE FOLD

As Michael Lopez-Alegria, the panel host, retired astronaut, former US Navy Captain and President of MLA Space put it, the Apollo 11 lunar landing was ‘above the fold’. Those of you who grew up in this era will know exactly what this means. You may even have clippings of these newspaper articles saved in a scrapbook or pinned to a bulletin board (**Figure 1**). One of those clippings might read something like: “Twenty-four years from Trinity to Tranquility.”

You may remember listening to President Kennedy’s famous speech on a transistor radio: “There is no strife, no prejudice, no national conflict in outer space as yet. Its hazards are hostile to us all. Its conquest deserves the best of all mankind, and this opportunity for peaceful cooperation may never come again.” In a world where Burt the Turtle sang ‘Duck and Cover’, it would have been easy to agree with Kennedy’s statement, but hard to imagine the possibility of sending man to the moon.


The New York Times

MEN WALK ON MOON

ASTRONAUTS LAND ON PLAIN; COLLECT ROCKS, PLANT FLAG

Voice From Moon: ‘Eagle Has Landed’

A Powdery Surface Is Closely Explored

Figure 1: Picture of New York Times article (1969) reporting on Apollo 11 landing.

There is a generation out there though, a younger generation, a generation that now reads newspapers through online subscriptions and remembers the Apollo missions through retellings and the iconic launch of Music Television.

There is an even younger generation – this writer’s generation. A generation that has never known a day without human life in space as we come up on the 20th anniversary of continual human presence on the International Space Station. A space station where Americans and Russians work together and collaborate with other countries to study the long-term effects of microgravity, so that later, man and woman, together, can work more effectively in space.

Time passes, phrases change, technology develops, and older generations find it harder to connect to newer generations and vice versa. Still, the cultural and social impact of the National Aeronautics and Space Administration’s Apollo missions remains strong and continues to grow. It continues to inspire generation after generation and provides common ground upon which those generations can connect and relate to one another. Apollo connects not just past with present, and people with other people, but unites people with technology, science with the humanities, the government with commercial partners, and countries with other countries.

Wayne Hale, retired NASA flight director and director of Human Space Flight, launches the discussion by elaborating on the common phrase: “We might as well wish for the Moon.” It is a phrase many use today without second thought but “one of the things I think you have to know is that [back then] this phrase was what people used to describe the impossible. Something that would never happen, not in the whole history of mankind.”

Just over 10 years since the founding of NASA and less than seven years since Kennedy’s proposal, not just the United States, but the entire world, watched in awe as Neil Armstrong made “one small step for man, one giant leap for mankind.” To achieve this feat in such a short time span though, an incredible advancement in technology had to take place. These advancements ranged from the development of flight critical hardware, like the Apollo Guidance Computer, to even the miniaturization of filming equipment so that the mission could be recorded and experienced by the public. In this sense, Apollo not only achieved the impossible, but did so through the achievement of many other seemingly impossible events.

Dr. Tom Jones, retired astronaut and senior research scientist at Florida Institute for Human and Machine Cognition, explains that the Apollo Guidance Computer (**Figure 2**) was not only the first digital computer small enough to be used in human spaceflight, but was the first contract NASA would let into the Apollo program, making this piece of hardware revolutionary and perhaps “the keystone of the entire effort.” The development of this computer required 90% of the integrated circuits that the country was producing as a whole at the time, truly making Apollo a collaboration between NASA and outside sources.

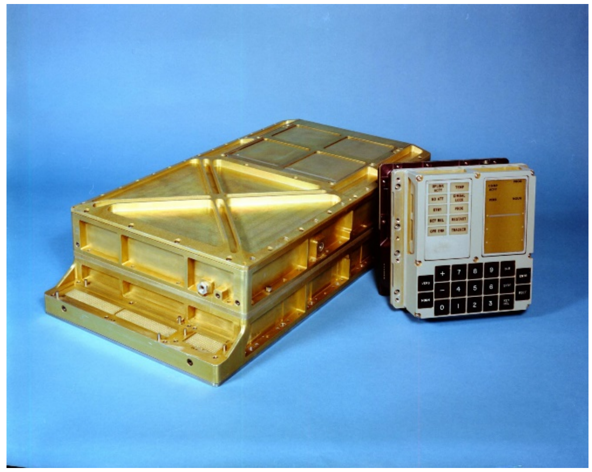

Figure 2: Apollo Guidance Computer.

The success of this development and collaboration at that time represented “everybody’s hope that we can work together and accomplish the seemingly impossible.” In light of this hope, people began to gain strength from the mission. People watched humanity come together as a whole to do something that before was not deemed possible, and they started to apply this to the challenges of everyday life, often using the phrase “If we can land men on the Moon, we can do X.”

But the impact of this computer goes beyond that. “There were no backup computers. There was just one computer in the command module and one in the lunar module. And so here for the first time you had a digital computer in space that was not only essential for mission success but was essential for the safety of the humans on board.” As Jones goes on to explain, “Human life relied upon this machine working to perfection,” and it introduced to those living in fear of thermo-nuclear war, the idea that people could really unite with technology rather than live in fear of it.

Even now, this computer continues to unite people, especially the younger generations, with the Apollo mission itself. Jennifer Levasseur, Museum Curator for the Department of Space History at the Smithsonian National Air and Space Museum, explains that “it is not only through the sharing of some of these artifacts like the Apollo Guidance Computer, it’s also through the visual media that was created.” And this is where we really start to see the unity of science and the humanities and “how space really does influence our daily lives…even today, I think. I mean you can go on a number of different fashion designer websites and see Apollo spacesuit sweatshirts and influences, and high end handbags that come from Apollo, so there’s been this really big movement, especially in the last few years of celebrating all that in really unique ways and I think it just speaks to the effect Apollo has had on us as a culture.”

Figure 3: Picture of Saturn 5 rocket projected on the Washington Monument in Washington D.C. (July 2019). The rocket was projected here as part of the Apollo 50th anniversary celebration.

America was particularly touched this July when a Saturn 5 rocket, the rocket that took us to the Moon, was projected on to the side of the Washington Monument in D.C (**Figure 3**). It was a provoking and moving experience for both those who had living memories of the Apollo launches and those who were seeing it for the first time. Jones had the pleasure of seeing this, and describes how the night sky, distant thunder, and theatrical steam rising from below, made the rocket, and Apollo's inspiration come alive again, particularly for "the young audience there, or people who hadn't remembered the moon landing 1st hand, they were awed and excited and overwhelmed, and enthusiastic in witnessing the replay of this historic event."

With a love for photography and space science and an academic background in history, Levarreur uses events like this one, to encourage children and young adults to follow their passions. She says that there are so many unique ways to play a role in spaceflight. There is not just one way to land a career in spaceflight and you have to be willing to think outside the box. "If you really care about it," she states, "you'll find a way."

For those interested in being part of the Apollo missions specifically, Levasseur enlightens us that there are still opportunities to contribute and make scientific discoveries. If you're interested in being a lunar geologist, for example, it is possible to get access to the samples brought back by Apollo astronauts (**Figure 4**). Jones goes on to explain that some of the most exciting findings are happening right now! Only within the last 10 years has our technology been advanced enough to measure water in samples brought back from Apollo 15, 16 & 17. This finding is ultimately leading us back to the Moon on Artemis!

Figure 4: Picture of moon rock lab at Johnson Space Center in Houston, Texas where samples from Apollo are stored. These samples continue to be analyzed for scientific discoveries and play a large role in public outreach.

Artemis, the twin sister of the Greco-Roman god Apollo, is the name of NASA's next lunar exploration project. The space race reignites as NASA strives to meet President Trump's goal of putting the first woman on the moon by 2024. This challenge will help us learn more about long duration mission outside of Earth's orbit, preparing us to send humans to Mars and beyond. Similar to Apollo, Artemis, continues to inspire unity amongst us. Despite huge advancements in technology that allow us to send accurate instruments into space in place of humans, Artemis aims to combine the strengths of both people and technology to make the most of our exploration efforts. Hale explains how "having a human on-site is very powerful. Robotics and human space flight go together. They are not separate. They complement each other."

Figure 5: Apollo 17 Astronaut and Cosmonaut pose for a symbolic picture at the docking point of Apollo and Russian Soyuz while in orbit around Earth.

Despite the great cultural and social impact of the Apollo missions, and the potential of similar impact with future missions, many Americans are disinterested in continuing the space program. As NASA and their international partners prepare for the launch of Artemis in the midst of wavering support, Hale asks us: "Are we going to self-destruct, or are we going to continue on?" The 1960's brought about the mental and physical challenges of war, the 2020's and beyond bring about similar challenges in the form of climate change, the decrease of natural resources, and an exponentially increasing world population. While Artemis will ultimately provide invaluable scientific discovery and technology advancement, it is unclear right now whether it and future missions will provide means to support life on another planet. By continuing on in our exploration of space, though, we avoid destruction in a challenging time with the construct unity, hope, and inspiration. "Where we joined the last Apollo with the Soyuz (**Figure 5**) is really indicative of where the future lies in that we are going on into the solar system and the stars together."

ADVANCEMENTS IN SPACE MEDICINE

What do radiation, altered gravity fields, the hostile and closed environment of spacecraft, isolation and confinement from the outside world, and the distance from Earth all have in common (**Figure 1**)? A panel assembled by retired astronaut Dr. Bonnie Dunbar discusses this question.

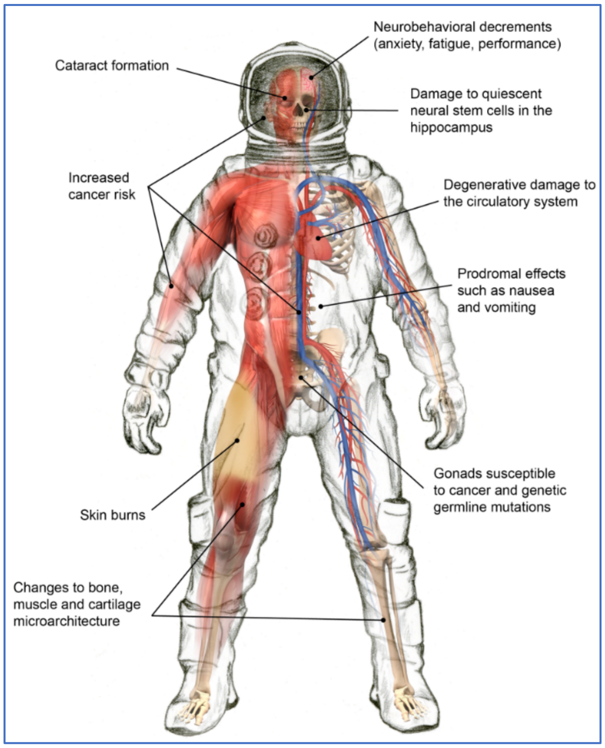

Figure 1: Depicts the main effects of spaceflight on the human body. Research in this area, however, is ongoing, thus this figure is not all encompassing.

Scientist in Residence at Space Center Houston, Dr. John Charles, explains that these are all medical challenges faced by future deep space crews: "one of the interesting aspects of these hazards is that they are all really manifestations of time." In other words, the longer the mission, the more the crew is impacted by these challenges.

Imagine being confined to your car for half an hour. It isn't so bad. Now imagine three hours, 10 hours, 30 hours. How about three years? Your legs start to go numb, you run out of water, food, and other supplies, and perhaps your mental health starts to decline. This is similar to what an astronaut will face when traveling in space for long periods of time. But Charles does not "believe that any of [these challenges] are insurmountable." Each concern will take deliberate attention but "with the proper support and preparation from those of us back on Earth," NASA and international partners should be able to send men and women to Mars.

Despite these hurdles, sending people to deep space is "a small investment up front that could really open up the solar system to us biologically." Charles explains that most planets have gravity fields similar to the Earth, Moon, or Mars. Therefore, if we understand Earth's gravity, the Moon's gravity and Mars' gravity, we basically understand the entire solar system. But until we put humans up in deep space for long periods of time, we do not know "if 1/6th [gravity] as found on the Moon is 5/6th as harmful as weightlessness or 1/6th as beneficial as Earth's gravity," and the same for Mars.

Medical Doctor, retired JAXA astronaut, and Vice President of Tokyo University of Science, Chiaki Mukai, shares similar thoughts on the importance of continuing space exploration on the International Space Station. Previously conducted studies show that many species have a threshold of 0.2 – 0.3 Earth's gravity. With a gravity of 0.16 of Earth's, the Moon falls below that threshold. Mukai suggests artificial gravity may be a way to support future crews living on the lunar surface for extended periods. In addition to exploring technology developments, Mukai encourages the continued exploration of various gravity fields. Earth is at 1G, but who's to say 1G is optimum. Currently, it is what we consider optimum, but as Charles explained, there could be a goldilocks gravity we just don't know about yet.

Also in support of continuing ISS research for the sake of enabling Moon and Mars missions is Oleg Kotov, who is a Medical Doctor, retired cosmonaut and Deputy Director of the Russian Institute for Biomedical Problems. Kotov has developed a matrix that defines the priority of space exploration technology. He says that the majority of this matrix is red, meaning the technologies needed most to fly to the Moon and stay there are the ones not getting enough attention. Making a greater effort to research these technologies using the LEO environment provided by ISS could ultimately make the trip to deep space safer for our crews.

Figure 2: AstroRAD vest on display mannequin.

Kat Coderre, an Advanced Program Engineer for Lockheed Martin, discusses one such technology aimed at protecting crews during long duration, deep space missions. The AstroRAD (**Figure 2**) is an international collaboration between Lockheed Martin and STEMRAD, an Israeli-based company. AstroRAD is worn as a vest by crew members and was designed using a selective shield algorithm. Its purpose is to mainly protect against the radiation caused by Solar Particle Events, but it was actually started as the StemRAD 360, which was created for first responders on Earth. The AstroRAD has been specifically designed to meet the need of female astronauts since they are at a higher risk for cancer during or after space flight due to increased exposure to radiation; however, the vest can be used effectively by both men and women. The first test of this vest in space is being conducted on ISS. This test will focus on the ergonomics of the vest, to ensure astronauts are able to comfortably wear this vest while simultaneously conducting other research. The vest will then be sent up on the Artemis missions to undergo the first spaceflight tests of its radiation dampening properties.

But even technologies like AstroRad cannot fully protect a crew in deep space. Andre Kuipers, Medical Doctor and retired astronaut from the Netherlands, goes into depth on some of the issues future deep space crews will face. He emphasizes the fact that these crews will have to be more independent than any crew has ever been before. For example, unlike crews on ISS, Mars crews will be unable to receive frequent resupplies of food, clothes, prescriptions and medical supplies. Because of an increased delay in communication time between Mars and Earth, Kuipers suggests each crew have a doctor on board. While many doctors, like Kuipers himself, have flown to the ISS to perform research, it is not mandatory to have a doctor on board the ISS at all times. This is because crew members can call down to mission control and can speak with flight


Figure 3: Astronaut Andre Kuipers on the International Space Station as he addresses a malfunction with the hatch.

surgeons stationed on the ground. With limited ability to communicate from Mars however, an experienced doctor would be required to perform emergency procedures. The benefit of doctors on board go beyond medical diagnosis, however. Kuipers recounts his experience on the ISS, during which he used his medical background to diagnose a problem with one of the module hatches by listening to the locking mechanism with his stethoscope (**Figure 3)**!

Health and safety are critical during a mission but so too is health and longevity after astronauts return home to Earth. Richard Jennings, Medical Doctor and Flight Surgeon, says that lots of time is put into studying the risks to astronauts on current and future missions. We have less data however, on how some of these risks may manifest themselves 20 to 30 years after an astronaut returns to Earth. On a playful note, Jennings point out that "most of us are going to get cremated or put in the ground…nothing good is every going to happen from there." On a more serious note, Jennings suggests autopsy could help us collect more of the data needed on post flight risks. This could lead to findings that could help provide optimum care to future crews both before and after exploration. Still, little is being done to facilitate this effort. Jennings talks about two Apollo astronauts who just recently died. Each astronaut was exposed to lunar dust for more time than any other astronauts, yet no studies were performed to better understand any connection between their death and the dust. As of July 2019, however, the integrated research plan was updated to include lunar dust as a serious threat: "You'd think the same program that carries [lunar dust] as a serious possibility would have liked to have just a little piece of the lung of those two people that were exposed to all that lunar dust…it costs nothing."

Dr. Sue Bloomfield, Professor at Texas A&M who works closely with Dunbar, elaborates on some of the issues Jennings pointed out. The Longitudinal Study of Astronaut Health (LSAH) is an active data base that collects information from annual exams. This program is limited, however, in that it is only active in the United States and Canada. Additionally, the transfer of data from medical providers to the program is a difficult and lengthy process that discourages use. Bloomfield and Dunbar are working together with industry consultants to customize an electronic personal health record (PHR) platform, the Retired Astronaut Biomedical Data Repository (RADAR), that will make transferring data from providers easy and convenient for the astronauts. They are in the process of conducting a feasibility study that will determine the interest level of retired and active astronauts and will help develop and test the platform.

Despite the difficulties faced in space and on earth for astronauts, Jennings holds an inspiring view: "I've always felt like humans can go do these things. Not that there aren't issues, but if you look at the success of the Mercury and Gemini and Apollo, Skylab and ISS, the Russian program, humans have pretty much done everything."

STANDING ON THE SHOULDERS OF APOLLO

Though the Saturn V no longer stands on the launch pad ready to take the Apollo crews to space, we continue to stand on the shoulders of Apollo. During this technical session, a distinguished group of Apollo crew members, flight directors and center directors talk about the mistakes, lessons learned, and successes of Apollo, and discuss how Artemis and future deep space missions can benefit from these events.

Right from the start, the Apollo program faced challenges and setbacks. George Abbey, JSC center director during the Apollo missions, addresses the fire of Apollo 1. He explains that the start of that fire and loss of the crew occurred due to a combination of variables that had not previously been identified as an issue. He remembers thinking that "it didn't look like we were going to land on the Moon by the end of the decade." To overcome this challenge, new materials that did not burn in oxygen had to be developed, tested and integrated into the spacecraft. In addition, a new hatch, one that opened quickly and outward, had to be designed and installed, and new wiring standards had to be developed and implemented.

But all of those challenges, and all of the improvements that came from overcoming them, eventually led to the success of many missions. Walt Cunningham, an Apollo 7 astronaut, explains that despite "a few problems here and there, or operational problems," Apollo 11 was declared 101% successful. "Even though it was scheduled for 11 days, I can't say that anyone was terribly confident that we were going to make it 11 days, [but] things were going so well on that mission that they added four more important mission objectives…and that was a good start for the Apollo program."

But as Gerry Griffin, one of the Apollo flight directors, points out: "Every flight we had had a problem, some were nagging, some were very serious like 13…" Fred Haise, the Lunar Module Pilot on Apollo 13, explains that the crew had to violate "specifications on certainly all the avionics and electronics" to power up the frozen crew module and return to Earth. Upon reentry, frozen water that had collected around the module's wiring melted. Haise believes that "those wiring standards [developed in reaction to Apollo 1], really saved us I think from suffering a wire short." But it wasn't just the engineers and crew that faced challenges. Griffin points out that Mission Control also had to be at its best, to help contribute to the safety and success of each mission.

Griffin explains that Mission Control was at its best when utilizing the strengths of every team member. At the time of Apollo 13, Griffin was working in Mission Control as a young engineer. He remembers working through problem after problem and finally coming to a solution with the help of his fellow engineers. When it came time to present the solution to upper management, Griffin said there was total silence as "these two young kids [told] them what we were going to do, and that we had figured it out." Finally, when Griffin had finished explaining his solution, Payne, the administrator of NASA at the time asked: "How can we help you?" And that, according to Griffin, was the secret to Apollo's success. The Apollo Mission Control "drove decisions down to the lowest possible point where the expertise was."

Going into the next generation of spaceflight and gearing up for the Artemis mission, the whole panel hopes that we remember the challenges faced by Apollo, and use the lessons learned and the success achieved to "stand on the shoulders of what we did in Apollo to get back to the moon."

FORWARD TO THE MOON

In an earlier technical session, *The Impact of Apollo, Today and Tomorrow*, we discussed the cultural and social impacts of Apollo. Those impacts include the unity of various countries, humans with robots, and past with the present. In this technical session, Forward to the Moon, panelists discuss similar impacts including the partnership of NASA, ESA, JAXA and CSA, the parallel use of humans and robots, and the blending of the present and the future, as we strive forward to the Moon.

Before March of this year, when the Vice President made his speech in Huntsville, Alabama, NASA was on track to return to the Moon in the 2028 time period. According to Dan Hartman, the panel chair, as well as the NASA Gateway Program Manager, the idea was to "establish kind of a commercial, international partnership. An innovative and sustainable program for exploration."

But now that idea is taking form much quicker than expected, as we work to reach the Moon by the new deadline of 2024. Hartman explains that it's hard to present Artemis' exact schedule because "we're just getting going, but I can tell you, the teams are working extremely hard to get procurements in place, get hardware manufactured…" The general plan however, as presented here in **Figure 1**, is to first have a crew orbit the moon on Artemis II, followed by Gateway support missions during which the construction of Gateway will continue in space, and then finally launch a crewed mission to the surface of the moon on Artemis III in 2024.

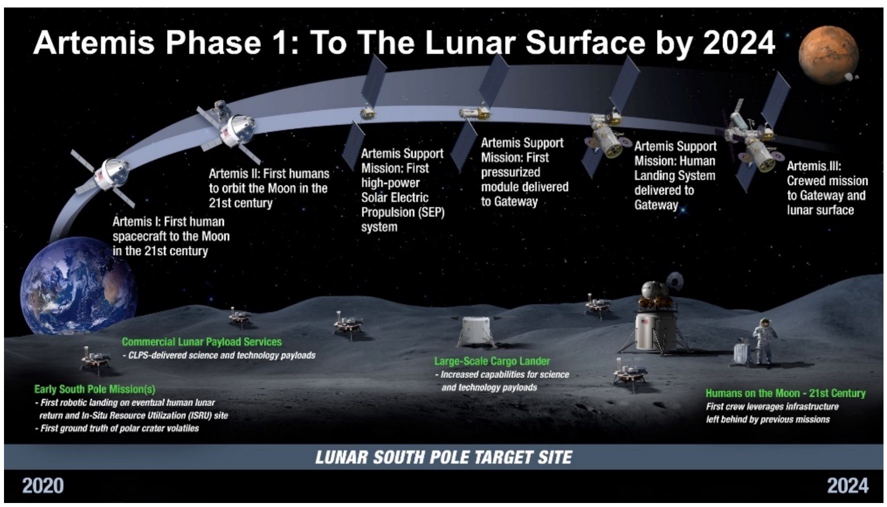

Figure 1: Proposed schedule for Artemis Phase 1.

Though Artemis' original schedule has been compacted by four years, Hartman expresses his confidence in our ability to meet this new mandate. This confidence is in part due to the knowledge learned and technology improved during missions like Apollo and in part due to the international partnerships that have formed in the last several years. The work done on the International Space Station, both in terms of science experiments and the actual construction of this flying laboratory, has really taught the international partners to "work, integrate, build, operate, sustain and overcome anomalies together."

Alexander Gerst, a German astronaut for ESA, looks at this cooperation from an interesting perspective. Rather than view international partnership as a necessity for exploration, he views exploration as a necessity to international cooperation: "It is the interaction of the international partners which is probably one of the most important components of why we do exploration."

Exploration, according to Gerst, is the collection and fostering of: information, innovation, interaction, and inspiration. You could call these the four I's, but exploration is anything but individual! It requires the help of international and private partners sharing technology to accomplish.

Though the coordination of robots, technology and humans, space exploration is perhaps a repeat topic at the congress, Gerst reiterates its importance and explains how it plays a role in ESA's exploration plan moving forward: "At ESA we recently combined the two directorates that we do exploration with, which are robotics and human, and we now put it into one directorate because we believe there is really no better way than doing it together." Humans alone, would be unable to explore as far and as deep as robots, and robots alone, would be unable to make the real-time decisions astronauts can make which makes human exploration critical.

Koichi Wakata, a JAXA astronaut, and the Director General of JAXA's Human Space Flight Technology Directorate, discusses JAXA's partnership with Toyota in the creation of a pressurized lunar rover that will help Artemis crews explore a greater area (**Figure 2**). Wakata explains, unsurprisingly, that this rover will remain on the Moon's surface as the crew returns to Earth. This rover, however, "will need to go autonomously to the next target," where it will be able to meet the next crew upon arrival.

Figure 2: Artist rendition of JAXA/Toyota rover to be used in the human exploration of the lunar surface.

CSA is also working to advance exploration technology. Canadarm 3 (**Figure 3**) is similar to Canadarm 2 in that it will help Artemis crews in the construction, repair, and upkeep of Gateway, in a similar fashion that Canadarm 2 helps on the ISS. Jeremy Hansen, an astronaut for CSA, explains that, despite experience in constructing Canadarm 2, the agency is experiencing interesting, and never before faced, challenges with Canadarm 3. He goes on to say that it is not the construction or design of the arm that pose the challenge, rather, "the latency of working out near the Moon, of dealing with the fact that we believe we're going to have to do operations when we don't even have communication with Gateway." It is similar to the challenges JAXA and Toyota face in the construction of the autonomous rover.

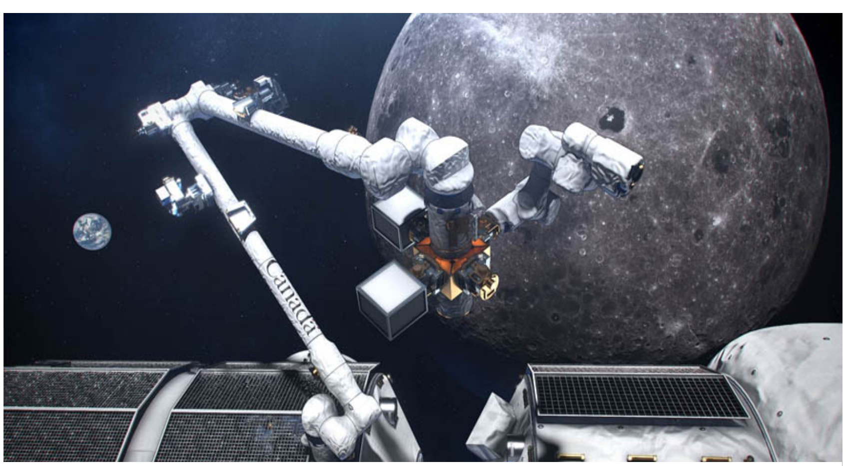
Figure 3: Artist rendition of Canadarm 3 to be used in the Gateway program.

Canadarm 3, will have to perform maintenance operations, even when no crew is on Gateway, which according to the panel, could be nine months of the year. To overcome this challenge, Hansen suggests integrating artificial intelligence into the new arm.

Along with that interesting challenge, Hansen discusses some of the challenges Canada faces as a whole, including the integration of food security and healthcare systems in northern, remote Canada. The Canadian government, specifically, has interest in advancing greenhouse technologies to support these regions. Hansen explains however, that “there’s also an interest for us long term for growing food in space, on the Moon, on Mars.” Making the most of the shared interest in growing food in remote places, CSA has “developed a neat little partnership…within provinces and at the national level, to go after these technologies to prove them on the planet, and then spin them into space.”

Programs and partnerships like these, not only open the way for technology developments, but helps promote the commercialization of space, which Wakata, says JAXA plans to do with its continued utilization of the ISS, despite its participation in Artemis.

In the international attempt to go forward to the Moon, JAXA is already developing the HTVX, “a new cargo transport vehicle that will supply the logistics to the space station [Gateway].” Wakata explains that the HTVX has more capability from both a mass and volume standpoint than the current HTV9. This will enable the vehicle to support operations in cis-lunar orbit.

Despite the development of HTVX and the development of some other technologies, including technologies that will advance the human habitation capabilities in the HALO module, “the government decision has not been made yet.” JAXA expects an official decision soon, on its ensured participation in the lunar program.

ESA, too, is participating in this program in substantial ways. In addition to providing the Orion Service Module, ESA hopes to contribute a new facility called Luna, here on Earth. Gerst describes Luna as “basically a Moon simulator with a regolith surface inside, allowing for technology tests and crew training.” It not only gives crew the opportunity to practice for EVAs, but includes “virtual reality equipment that allow testing of the technology that we will need on the Moon.”

This, along with other projects that are underway or in planning, helps ESA meet each one of their Exploration Cornerstones for the next three year funding period, as seen in **Figure 4**.

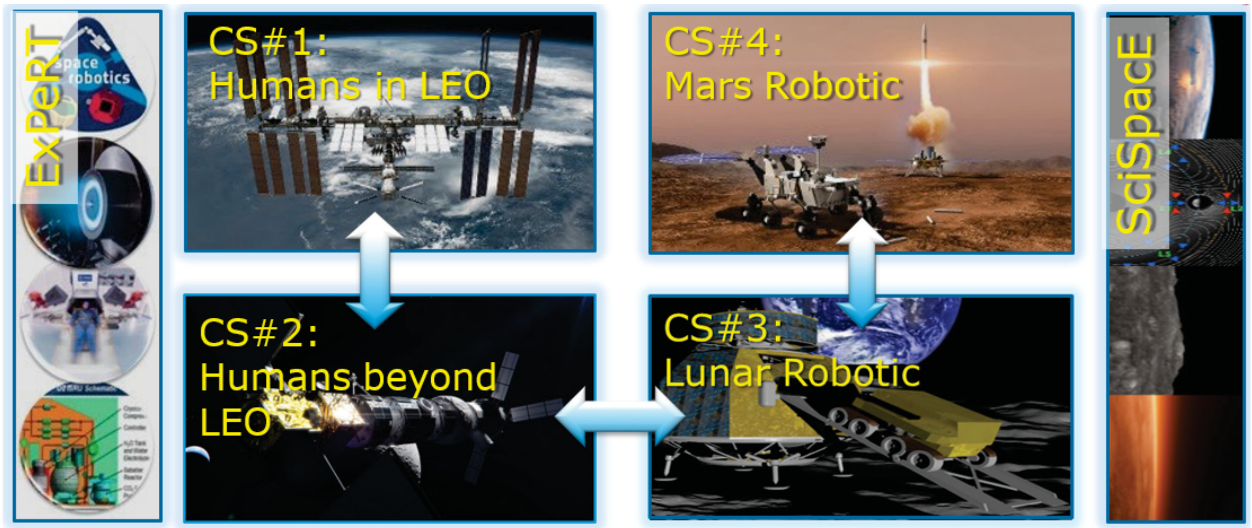

Figure 4: Graphic depicting ESA's exploration cornerstones for the next three-year funding period.

As ESA (habitation, communications, refuel, science airlock), JAXA (habitation system contributions, HTV-X contributions), CSA (external robotics & operations), and Roscosmos (discussions on crew airlocks integrated with science airlock) prepare for Gateway Phase II, NASA works with commercial partners such as Maxar Technologies, Jacobs, and Northrop Grumman to prepare Gateway Phase I. As mentioned by Wakata: "More participation by the private sector is very important for sustainable exploration." Some of the components being worked on right now are the Power & Propulsion Element (PPE), the Habitation and Logistics Outpost (HALO), Gateway Logistic Services (GLS), the Exploration Extravehicular Mobility Unit (xEMU), Landers, and Orion.

Hartman mentions that while discussion on the international and commercial contributions to Artemis and Gateway is ongoing, great progress has been made: "We're finalizing their contributions of what they will bring to the table and obviously the benefits that they're receiving."

Among several benefits of participating in Artemis, Hansen says, perhaps the greatest intangible benefit of these is the inspiration it brings to younger generations. As part of the Lunar Exploration Accelerator Program (LEAP), CSA is utilizing Canadarm 3 "to leverage the bold nature of going back to the Moon." He says that we need to engage our youth in our exploration efforts "to inspire them to carry on the next generation's exploration objectives."

On a similar note, Gerst closes, by reminding those of us present for the technical session and anyone watching online, that the Moon is only three days away: "A few hundred years back, that's how long it took with a horse cart to cross [the small] European countries. Nowadays, that's how quickly we can get to the Moon, and I think that is something that should tell us we're ready to go [back]."

THE NEXT 50 YEARS IN SPACE EXPLORATION

As discussed previously, NASA and their international partners plan to go forward to the Moon by 2024 given the President's mandate to create a sustainable exploration program. Taking advantage of this opportunity and the technology being developed to accomplish it, researchers excitedly form their science goals for the upcoming lunar missions.

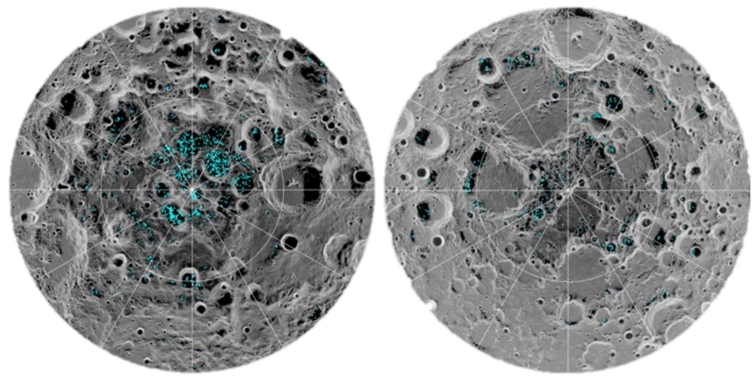

Figure 1: Ice (blue dots) depicted on poles of the moon appear to be more abundant in the cooler (darker colored) areas.

Dr. Brad Bailey, Program Scientist for NASA's Lunar Discovery and Exploration Program, explains that ice (**Figure 1**) is more abundant on the poles of the Moon. This, he explains, presents "a lot of exploration opportunities for sustained human presence." Finding this ice and exploring it, along with other natural resources available to us on the surface, is what will really enable NASA and others to send humans beyond Low Earth Orbit because it lowers the mass of initial and resupply launches. This in turn helps us learn more about the "radiation levels associated with planetary exploration by humans and robots and ultimately mitigation strategies and how to ensure the safety of our explorers moving forward."

While NASA plans to use the Moon as a steppingstone to Mars, Bailey explains that "the Moon is actually an incredibly valuable and interesting place to study from a science perspective." For example, it can tell us "about the inner solar system, the Earth and Moon impact history, overall planetary differentiation," Bailey says. Not all research is limited to the poles of the Moon, however. In the mid to low latitudes of the Moon phenomena like lunar swirls, magnetic anomalies, irregular mare patches, and volcanic activity can be studied by rovers.

Exploration like this is exactly what the Lunar Discovery and Exploration Program (LDEP) aims to enable prior to, during, and continuing after the Artemis missions. NASA plans to send a rover to the poles of the Moon in late 2022 to start answering questions necessary for human exploration. Bailey says that LDEP is also working with commercial partners on a program called the Commercial Lunar Payload Services (CLPS) that will open the door to commercial partners in which they will be able "to provide significant input into the overall Artemis program." The CLPS currently works with nine companies that can bid on future opportunities to send missions to the Moon. Bailey likens the program to FedEx or UPS: "we create an instrument package that we give to a commercial partner and then that commercial partner then takes it to the Moon for us," where astronauts can then deploy technologies and experiments on the surface. Ultimately, the CLPS and NASA's partnership with the private sector, will help speed up technology development and scientific discovery in an ideally sustainable manner.

“As we start expanding out to Mars, we need to think about having the kind of mobility we really want,” Dr. Ronald Litchford (Principle technologist, Game Changing Development Program, NASA office of the chief technologist), suggesting that nuclear power is the way to go. Unlike traveling to the Moon, traveling to Mars takes many months at a minimum with current chemical and solar propulsion technology. The need to cut down on this time, the panel explains, is what drives researchers to explore Nuclear Thermal Power (NTP) and Nuclear Electric Power (NEP). The development of nuclear power could also take us past Mars and out of our solar system. In terms of NTP versus NEP, Litchford explains that “NEP has much more promise [in terms of efficiency] but is at a much lower maturity state.”

Building off of Litchford’s comments on fast and efficient transportation, Dr. David Poston (Nuclear Design and Risk Analysis Group, Los Alamos Laboratory), makes an excellent point when he explains that nuclear power goes even beyond fast transit. It also has the capability to provide a reliable power source on the surfaces of both the Moon and Mars. Despite the obvious benefits to developing this technology, Poston explains that, “it’s hard to get Congress to fund something unless that thing you’re doing right then is going to give you some great benefit.” Even with proven benefit, however, social and political challenges still pose a great hurdle for researchers as special interest campaigns and media continue to instill the fear of radiation in humanity.

As discussed in previous technical sessions though, exploration requires us to take risks. And though NASA strives to mitigate the risks associated with space exploration and human space flight, a certain level remains necessary to reach the places we want to go, just as it was in the success of Apollo. Steve Bowen, NASA Astronaut and U.S. Navy Submariner, reinforces the success we could achieve with nuclear power when he says “we’re not talking milliwatts, we’re not talking watts, we’re talking kilowatts of power for science and exploration…and getting that stuff actually built and operating is really when you start to understand what you can do with it.” He goes on to explain that there is real hardware in labs right now, working to harness this power and overcome the technical, and hopefully, social and political challenges.

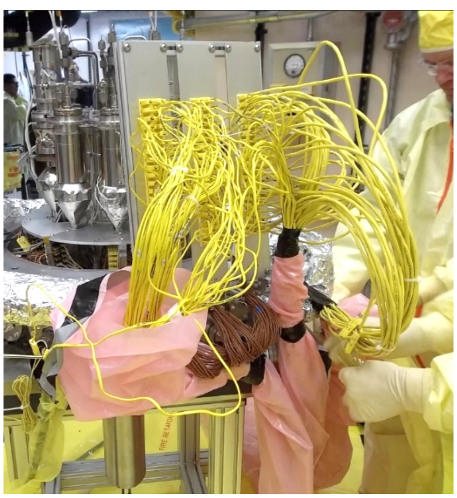

Figure 2: Test of KRUSTY reactor in the Los Alamos National Laboratory. In this test fuel maintained a temperature of 400 degrees Celsius. Results proved the simple, stable, passive behavior of the KRUSTY reactor.

In the Los Alamos National Laboratory, Dr. Poston and his team have “designed, built and tested a reactor. The first truly new reactor concept the United States has tested in 40 years.” He explains that the project, lovingly named the kilo-part KRUSTY program, after the Simpsons cartoon, is unique in that small, yet useful reactors are actually being produced (**Figure 2**). Though these reactors would need to be much larger for a Mars mission, the test models could provide beneficial here on both the Earth and on the Moon’s surface. As development and testing continues Poston says, “We need to keep taking small tests and for 80- million dollars we priced out the reactor and it could do the first NEP mission in the 100 kW surface system.”

More real tests are being done in other labs across the United States as well. Dr. Dennis Whyte (Nuclear Science and Engineering Professor and Director, MIT Plasma Science and Fusion Center) and his team are working on developing a magnetic faraday cage for a crewed flight to Mars. When fully assembled, hopefully within the next year and a half, the system will weigh about 10 tons, and will be about three meters high. This technology is being designed to allow astronauts to actually live inside of it. The magnet, Whyte explains, will be toroidal in shape and will spin, creating artificial gravity in order to replicate the effects of gravity on our gravity-dependent human anatomy. There will also be super conducting magnets imbedded in the outside of this structure. This system, as seen in **Figure 3**, will actually reduce the level of radiation experienced by the crew. Along with the faster transit times nuclear-electric propulsion will enable, Poston explains, this greatly reduces the risk astronauts face in terms of radiation and time away from home. While all of this may be hard to envision right now, Whyte reminds us that "this is not science fiction, this is happening in the laboratory right now."

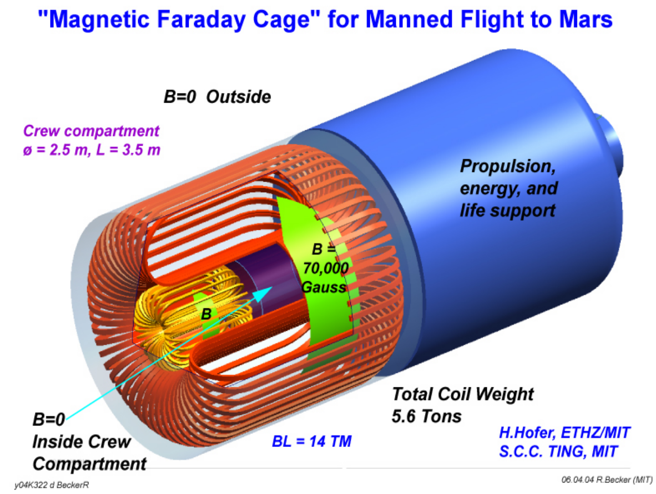

Figure 3: Theoretic design of Magnetic Faraday Cage used in human flight to Mars.

Across the globe in Saudi Arabia, new and exciting developments in the space industry are also taking place. "Many may not know that Saudi Arabia has been participating in space activities for over 40 years," Dr. Haitham Altwaijri, Supervisor of Space Research Institute, introducing Saudi Arabia's activities, starting with an experiment flown on STS-51-G, which astronaut Sultan bin Salman Al Saud flew on behalf of the Kingdom. Altwaijri compares this to Russia's Sputnik moment- the starting point of space exploration for them. After flying on NASA's shuttle mission in 1985, the Kingdom launched their first satellite, a communication satellite, into LEO in 1999. Now the Kingdom has about 16 satellites (remote sensing and communication based) orbiting our Earth. Just last year, in December 2018, Saudi Arabia established the Saudi Space Commission, which Altwaijri describes as their 'Apollo' moment. This commission was designed to "better organize and [help the country] better work with international agencies and universities and basically unlock economic and social benefit of the Kingdom and all of humankind." In other words, Altwaijri explains, the kingdom is very keen on fostering and expanding human capital and international partnerships with this Commission. The space agency has developed six key guidelines, pictured here in **Figure 4**. Utilizing these guidelines, the Saudi Space Commission has identified four main objectives listed as 1) Stimulate economic development and innovation, 2) Facilitate human capital development, 3) Foster international cooperation, and 4) Enhance national security; they have developed 18 different programs that will ultimately help the Kingdom achieve its goals. Each of these programs adhere closely to what the government and public has identified as useful and necessary, such as the improvement and development of new remote sensing and communication satellites.

Though Saudi Arabia does not currently have plans to travel with NASA and others to the Moon, the Kingdom's participation in space activities has greatly increased the number of Saudi students going into STEM fields and into the space industry. As suggested in previous technical sessions, the space industry needs to work hard to engage and encourage the younger generations so that exploration can continue later on. Like CSA and others, the Saudi Space Commission is helping us do just that. It is with great effort like this and contributions from international, governmental, and private sectors that humankind is able to explore deeper into space, and is able to achieve the things once deemed impossible.

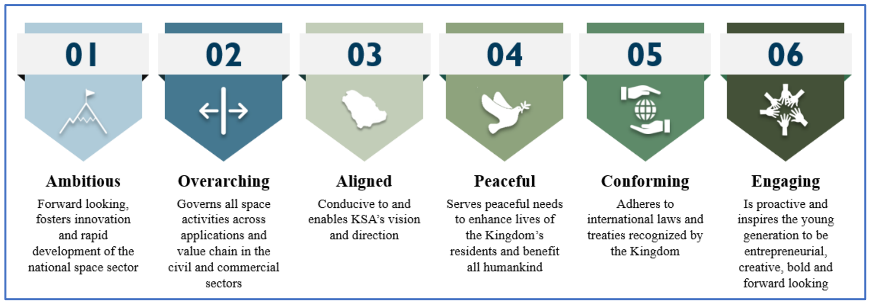

Figure 4: Key guiding principles of KSA's space program.

BUILDING THE FUTURE: DEVELOPING TECHNOLOGIES ON ISS

“Historically, the agency has used one program to feed another, through reducing risk and improving technologies during the first program. Mercury enabled Gemini enabled Apollo. So, we are using the ISS in a very similar way wherever that next destination, program, all of them, end up sending us,” introduces Dr. George Nelson.

In November 2020 we will be celebrating the 20th anniversary of continuous human presence onboard the International Space Station, but truly the program is just getting started. Now more than ever, experiments are being conducted in space that will help us develop the next generation of exploration technology and will help us ultimately to buy down risks associated with the human exploration of the Moon and beyond. Nelson explains that “the long duration missions are going to require capabilities that we didn’t have full confidence in some nine to 10 years ago, including just the vehicle itself.” But with the continued utilization of the ISS as a science laboratory and technology demonstration platform we increase our knowledge of fundamental microgravity science and increase the technology readiness level of the devices and vehicles needed to carry out the upcoming Gateway and Artemis missions. The best part of sending science and precursor missions to ISS, Nelson explains, is that it, “allows you to get [information] without putting your vehicle or your crew at risk.” NASA and their international partners have identified some of the following areas as research opportunities on ISS:

- Human Health & Performance
- Advanced life support systems
- Advanced power production and distribution
- Robotic tools, systems and operations
- Crewed spacecraft operation support tools
- Advanced communication/navigation systems
- Close proximity autonomous spacecraft systems
- Enabling space suit technologies
- Advanced habitats
- Cryogenic operations
- Thermal management

Figure 1: iROSA deployed over top of the ISS original solar arrays.

One such research opportunity led to the development of new solar arrays on the ISS. Eugene Schwanbeck, ISS Solar Array Project Manager, explains that these new solar arrays, iROSA (**Figure 1**), will “increase the power level of each array to what it was when it was new…each iROSA will produce more than 20 kilowatts of power, totaling 120 kilowatts of augmented power.” A smaller version of these solar arrays, ROSA, was tested back in 2017 and “demonstrated the mechanical capabilities of solar array deployment successfully.” Schwanbeck explains that his team was able to compare the scalable model predictions and on-ground test model to the prototype on

ISS. Being able to collect data from the prototype working in the relevant space environment was a major contributor to being able to develop the structural models. Overall, the ROSA “significantly improves the power density, stowage efficiency, and scalability,” and is a design that can be utilized for future spacecraft applications.

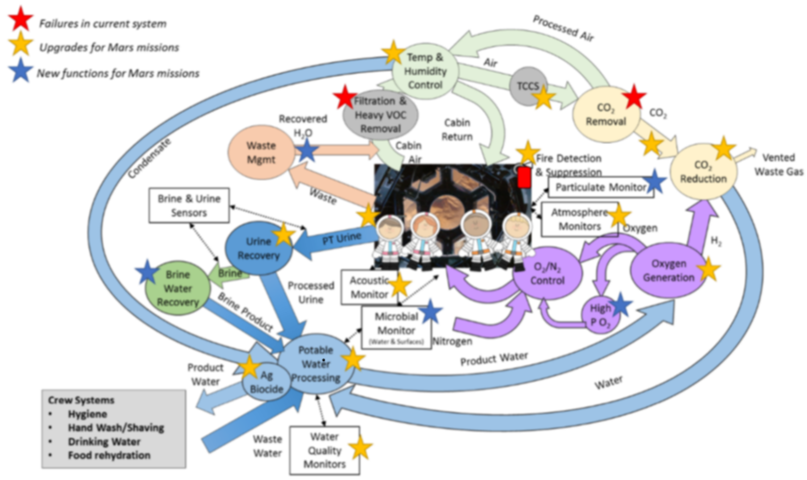

Figure 2: Graphic depicting the crew systems on ISS that are handled by ECLSS. Blue, yellow, and red stars represent the systems that need updating.

Laura Shaw explains that the ISS is essential for the development of the Environmental Control and Life Support System (ECLSS). For example, it has been found that human urine has a large concentration of calcium in space. Having the ECLSS tested in space helps researchers discover similar or corollary information that will lead to a better understanding of how tangent systems affect one another. The objective, Shaw says, “is to develop a capability portfolio.” In other words, Shaw and her team have been working on ECLSS long before the Gateway and Artemis missions were defined. The team, however, has anticipated future exploration missions, and is working to design a system that will support as many missions and destinations as possible. This of course, is a huge task. You can see in **Figure 2**, the number of ECLSS components that need updating, which, Shaw notes, is almost everything. Still, “ISS has given us a large body of experience in the area of life support systems and regenerative systems that we have, but a lot more needs to improve to go beyond Low Earth Orbit.”

Which is why Reinhold Ewald and his team at the Institute of Space Systems are working to design and test a hybrid life support system in the form of an algae based photobioreactor. This system is designed to recover O2 from CO2 and produce an onboard source of nutrition. The first test of this system was sent to the ISS to test the functionality of the system and study the stability of the algae in the space environment. Unfortunately, due to a device malfunction, data onboard the station was only collected for two of the planned 24 weeks. Still, valuable information was obtained in the form of growth kinetics, morphology, physiology, mutations, and information on the microbiome. Ewald believes this system has potential for future spaceflight as it reduces resupply mass and minimizes system mass compared to alternative life support systems, as you can see in the **Figure 3**. Not only does the proposed system help in this regard, it helps “close the loops by not throwing away what we are giving up in the toilet, but by

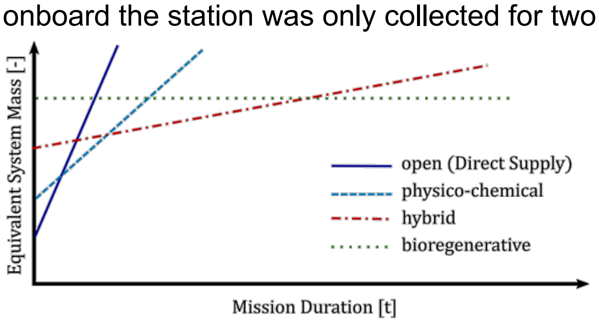

Figure 3: Graph shows that a hybrid system minimizes equivalent system mass.

reintroducing on the other end in order to feed biological stuff to the [algae].”


Figure 4: Current WHC on ISS.

Speaking of which, James Broyan, ASE Logistics Reduction Project Manager of the Crew and Thermal Systems Division at NASA Johnson Space Center, talks a little bit about the current waste collection system (WCS) (**Figure 4**), also known as Potty, and how updates to the current design are under development to support future missions. It is hard to believe that a single toilet system, something we use every day on Earth without thought, takes an entire research team and many years to develop. But believe it or not, this system has evolved greatly since the start of human space exploration, starting with diapers and developing into plastic bags, canisters, and full space toilets equipped with seats, lids, fans, and funnels. Development continues as teams work together to utilize human waste in the life support systems spoken about earlier. In addition, JIM explains, modifications to Potty continue to be made since earlier and current models “work well for some crew, but not all crew.” He explains that due to gender and individual preferences, space toilets are hard to design given the “wide variety of ways people use them.” Specifically, the team has seen a challenge in getting the design to accommodate simultaneous urination and defecation, especially with regard to the female astronauts. While some of this challenge has been technical, a surprising amount has been cultural: “Originally when we started, crew debriefs were basically gender specific, basically you had female people debriefing female crew and male people debriefing male crew, and most of our engineers who are designing potties are men, so you can see the immediate problem,” however; to fix this issue, debriefs are now mix gendered. The idea is not to design separate toilets for men and women, since that would increase the complexity and mass of the system, but instead design the best toilet that is maybe not perfect, but acceptable to as many crew members as possible.

Throughout its continuing development, Potty will need to address not just technical and cultural challenges, but international policy dilemmas. Kirk Shireman, ISS Program Manager, says that “the majority of the parts we buy are from Russia...[but] we have a law that says starting after December 2020 we cannot buy parts from Russia, so we actually need an act of Congress between now and December 2020 in order to make that toilet work.” Potty has also done an incredible job drawing media attention and catching the public’s interest in various Youtube videos and famous movies.

SPACES SUIT DEVELOPMENTS FOR FUTURE EXPLORATION

Just as new spacecraft, and new a rocket are being designed to take us to the Moon again, so too are new space suits. This new suit, the xEMU (**Figure 1**) builds off the current EMU suit and incorporates lessons learned from both our first landing on the Moon, and EVAs on ISS.

Despite the relatively new mandate to return humans to the Moon in 2024, an exploration suit, like the xEMU, has been in development for the last 15 years, mentions Chris Hansen. This suit is designed to fit greater than 90% of the population (both men and women).

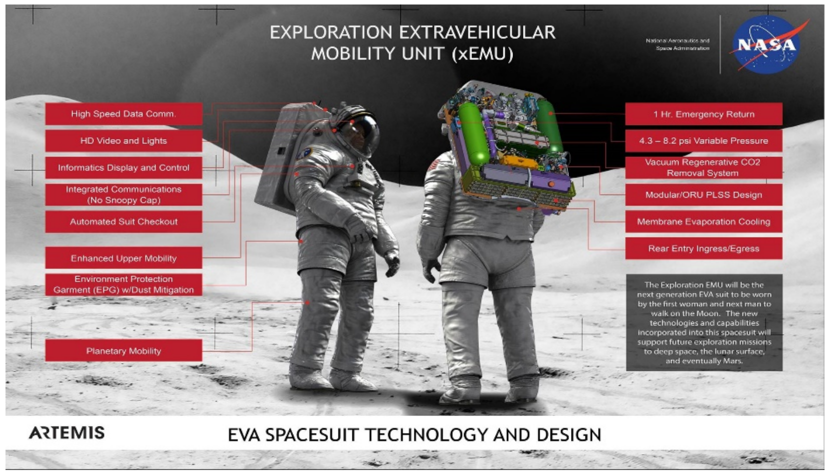

Figure 1: Labeled diagram of xEMU.

Astronaut Kate Rubins has been helping test the design here on Earth in the Natural Buoyancy Laboratory where over 20 runs have already been completed. One main difference between the EMU and the current xEMU design is a rear entry. In former suits, astronauts entered the suit from the waist, where the bottom half and top half connected. One reason for the rear entry design, Rubins mentions, is that it allows you to "have the torso much, much smaller because you don't have to accommodate getting your shoulders into the suit…" This design allows for both the smallest and largest of the current astronaut corps to utilize this suit in various configurations. The EMU comes in five sizes, mentions Hanson. In contrary, the xEMU will come in two to three sizes, with adjustable shoulders. The result, Rubins says, "is more like wearing a tank top," versus a t-shirt whose sleeves are too long and baggy on some and too short and tight on others. These adjustable shoulders not only help reduce the number of suits manufactured and sent to the Moon, they help improve flexibility and mobility within the suit. Rubins explains that unlike in former suits, she is able to raise her arm even above 90 degrees in the xEMU.

"We want a spacesuit that enables the astronauts to work on the moon like a geologist." This, in part with comfort and injury reduction, is the reason the xEMU design is focused around mobility, flexibility and agility. In addition to the flexible shoulders Rubins has tested, the suit has bottoms that allow the astronauts to bend down, look at rocks, and take samples. This is accomplished with a set of rotating bearings at the joints and waist.

Audience members, some of which are former Apollo astronauts, voice their concern that these suits allow enough mobility for astronauts on the Moon to get up if they fall. Of particular concern is an event rightly named 'turtling' that astronauts experience when they fall backward. One audience member likens this occurrence to a bug getting stuck on its back. While many video mashups from the Apollo missions portray this very event in a comical manner, Hansen assures us that the mobility of these suits is being specifically tested to eliminate this from occurring. Audience members also voiced concerns in regards to workspace volume. In other words, the amount of space the astronauts will have out in front of them to perform tasks.

Unfortunately, it seems that workspace volume is still limited, like it is in the current EMU. Rubins says that with some creativity though, tools could be attached elsewhere on the body (rather than the chest) to allow for more space. A test in the pool compared task completion times in both the EMU and xEMU upper torso. While the xEMU did not support faster times, it did not slow any tasks down.

Despite some of these challenges, “I think the other two really big improvements are communication and visibility,” says Rubins. The xEMU helmet shape (**Figure 2**) is different than that of the EMU. This difference allows for “a lot of lateral visibility,” eliminating the need for astronauts to turn their entire bodies to look in a certain direction, “so it saves a lot of effort for the whole EVA.” As for the communication component, Rubins said she was hesitant at first. This new design eliminates the need for the long trusted communication cap, also referred to as the Snoopy cap due its black ears and white headpiece. Instead, the speakers and mic booms are installed directly into the helmet. Rubins very quickly warmed up to the new design though after testing it in the pool: “it was really great not to have the comm-cap, you get this freedom of motion, you don’t have something on your ears for six hours, and you don’t have the chinstrap pulled right against your chin, and you don’t have mic booms that move out of position and screw up during the EVA.” This according to Rubins is just one of the elements “that reduce the fatigue and I think make an eight-hour EVA not a horrible thing.”

Figure 2: xEMU upper torso and helmet.

Overall, “this is a government design that has used a lot of contractors,” Hansen mentions, “but in the long run, we don’t want to be in the spacesuit production business. So very quickly I want a commercial company to come in with us as we build these first suits to figure out how to make them more producible, to make them easier to use, to upgrade the designs if we need to, to be able to take over production and sustaining of the suits very quickly starting in 2025.”

Dan Burbank, retired NASA astronaut and Senior Technical Fellow at Collins Aerospace, talks about the suits Collins Aerospace has been designing. Despite the increased flexibility and mobility associated with NASA’s rear entry design, Burbank says his designs are focused around the more traditional waist entry method. This, he explains, is not necessarily “the kind of suit any of us would want long term for excursions on the surface of the Moon or industrial scale resource extraction,” however due to mass restrictions within the lunar lander, might be type of suit necessary for these first few missions. Reducing the weight of the suits will also help astronauts perform their tasks on the surface of the Moon and has the potential to reduce injury. Unlike NASA’s xEMU that weighs between 200-300 lbs, the suits designed by Collins Aerospace, weigh about 164 lbs unladed. Burbank explains that the weight will increase some as necessary components are added, but Collins Aerospace strives to keep the weight below 190 lbs per suggestion of those who flew in the similarly sized Apollo suits.

But the different approaches to suit design begged audience members to ask if the suit designs were constrained by the right requirements. And the short answer is: ‘we don’t know.’ However, both NASA and their commercial partners do their best to set meaningful requirements based off past missions and future goals. Joe McMann explains that, “what can happen, and has happened in the past is that you get some unrealistic requirements. They don't look unrealistic at the time, but until you try and make them come alive in hardware… that is when you find out it's unrealistic."

Rubins has her own thoughts on what current requirements work and don't work: "right now we are working with this requirement that the gloves be resizable on board, and I think we've used that option once in the history of the program, so that drives a lot of bulk…" To overcome this, though, Rubins thinks that advances in material science and technology could help in the development of custom gloves. Despite the extra parts, pieces, and mass custom gloves would add, Rubins thinks "you are going to save so much over the life of the program in terms of reducing EVA time and getting tasks done…"

In conclusion, McMann, advises that designers and program planners to push back if they notice unrealistic requirements or notice if requirements are not being met.

SPACE ISN'T THE PLACE: THE GROWING SPACE DEBRIS CHALLENGE

In the last technical session of the ASE 32nd Planetary Congress, the conversation begins with the announcement of the planned launch of around 30,000 new satellites by SpaceX. These satellites will be contributing to an already crowded sky! Currently there are a little over 2,000 operational satellites in orbit, and over 500,000 pieces of space junk that include unused spacecraft parts, and fragmentations from parts that have collided and broken apart. Dan Oltrogge, Director of AGI's Center for Space Standards and Innovation, points out that only 60% of LEO payloads, 65% of LEO upper-stages, and 88% of GEO payloads are disposed of properly. A successful disposal of around 90-100% is required to maintain a safe space environment. Of the undisposed pieces and fragmentations, only about "four percent of LEO and four percent of GEO is tracked, so 96% we don't know anything about, and they're lethal," explains Oltrogge.

This untracked space debris is not just lethal to mission success, but to our friends up there on the ISS, as Ed Lu, Retired astronaut and Vice President of LeoLabs, puts it. While NASA and commercial entities spend a lot of time talking about and mitigating risks like radiation and muscle atrophy, a surprising 90% of risk to ISS once off the launch pad is space debris. That's 1/8 chance of experimentation ending on ISS and 1/60 chance that a crew is lost due to a collision with space debris… "and this is NASA's own figures. Is this acceptable?" asks Lu.

And the real answer of course, is no. To put the issue into perspective, former astronaut Mark Brown, Chairman of the ASE Committee on Space Traffic Management and Orbital Debris, explains that lethal debris is on the sub-millimeter scale. That is smaller than a grain of salt! "And that's because it is essentially a .22 [caliber] bullet traveling at 10 km/s, hitting aluminum and glass." And this is not just an 'if' scenario. It's not just 'when' either, it's "when it occurs next." The ISS solar arrays, even today, already have holes in them from previous impacts, and this is because this debris is extremely difficult to track.

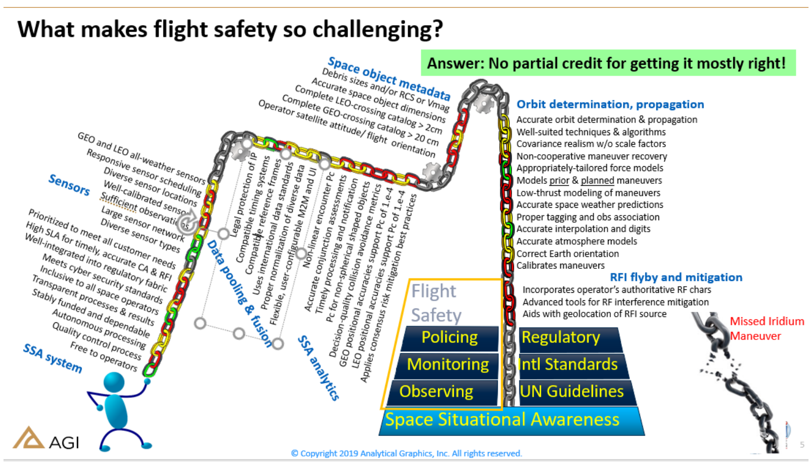

Figure 1: Major components that go into calculating collisions between space debris.

While formulas and programs are in place to do this, Brown says "we are getting a lot of bogus warnings in the system." This is because, as Oltrogge explains, there are major components, as seen in **Figure 1**, that go into 'calculating collisions'. "And an error in just one of those little elements makes the whole thing erroneous, we do not get partial credit for having a mostly good system." Due to this high level of difficulty, uncertainty and a lack of space laws and policy regarding the matter, it is difficult to take action. This is why, as stated at the 31st Planetary Congress in September 2018, "The international space sector should collaborate in order to keep the doors of space open and safe for everyone," as has been done similarly in the history of aviation and maritime operations.

Guidelines, approved by the United Nations, set the stage for the management of space debris, and encourage proper disposal of parts, however, "the key thing is the guidelines are voluntary, they are not legally binding…[and] the UN is very open about the fact that they're looking for individual states to solve the problem and bring them a solution, which brings it right back into our laps."

This is why ASE has drafted and submitted rules that dictate, in the event of an operational satellite collision, whose spacecraft moves first. However, Brown hopes that these rules "would [not] be the end solution but would be the beginning of the conversation."

As Lu puts it, "I think we all have an interest in the development of space for commerce, for science, for exploration and the principle issue that could derail all of that is space debris." Oltrogge, speaking on behalf of the Space Safety Coalition (SSC) explains his part in the beginning of this conversation: "The SSC is not a legal entity, it is simply a group that is getting together to create a best practices document and enhance it."

Despite this effort and other's efforts, Lu concludes, "There are big governance issues that are being understated, there are regulatory issues that are being understated, but the heart of all of this is we have got to track stuff before we can do anything about it."