

Abstracts book

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[1] ***Performance of Flight Compatible Microlith® Catalytic Oxidizer for Exploration Trace Contaminant Control***

Saurabh Vilekar (Precision Combustion, Inc.), Curtis Morgan (Precision Combustion, Inc.), Matthew Kayatin (NASA) and Jay Perry (National Aeronautics and Space Administration).

*Abstract*

Precision Combustion, Inc. and NASA Marshall Space Flight Center have been developing and testing prototype high temperature catalytic oxidizers based on PCI’s patented Microlith® technology to meet the requirements of future spaceflight exploration missions. Based on the demonstrated performance (17,000+ hours) of a subscale prototype, a next-generation prototype was designed to meet exploration contaminant load control demands while upgrading the prototype form and fit to match flight-compatible interfaces. Prototype design considerations intended to reduce power consumption, impacting process thermal and hydraulic performance, are discussed herein. We also report on the performance characteristics of the catalytic oxidizer.

[2] ***Material Compatibility Study of Coated Metals to Maintain Biocidal Silver in a Spacecraft Potable Water System***

Rogelio Garcia Fernandez (NASA JSC - Jacobs Technology Inc.), Stacey Marshall (NASA JSC - Aerodyne Industries), Niklas Adam (NASA JSC) and Dean Muirhead (NASA JSC - Barrios Technology, LTD).

*Abstract*

Ionic silver-based biocide is an option of strong interest for future exploration and has been baselined for several emerging spacecraft potable water systems. A challenge for the use of silver biocide remains the depletion of ionic silver on wetted materials of construction. Consequently, the design and/or selection of materials that can be used as the wetted system components need specific consideration. As part of the strategy to address this issue, a multitiered approach is being investigated that looks at combinations of conventional and non-conventional spacecraft treatment processes and materials. In this study, eleven chemically-resistant polymer coatings were applied as surface treatments onto coupons that were cut out from three types of conventional spacecraft-grade metals (Titanium Grade 2, Inconel 718, and 316L Stainless Steel). The coated metals were immersed in a static 400 parts per billion silver biocide solution at a surface-area-to-volume ratio of 2.0 cm^-1 and left to soak for predefined periods of time. The concentration of the solution in contact with the coated samples were then analyzed via inductively coupled plasma mass spectrometry, and the data used to determine the extent to which the coatings provided a barrier to silver loss. This paper summarizes the coating selection process, the configuration of the test, and the performance of each coating-metal combination as a mitigation to silver depletion. The preliminary results demonstrate that select coatings are proving effective at maintaining biocidal silver concentrations. The knowledge acquired through this investigation will be used to assess the feasibility of using these coatings as a robust strategy for maintaining biocidal silver in the water systems. Future studies are planned to assess the specific use of these coatings and to better understand the implications of utilizing this material approach in the future spacecraft potable water system designs.

[3] ***Regenerative Solid Oxide Stack for Energy Storage***

Saurabh Vilekar (Precision Combustion, Inc.), Christian Junaedi (Precision Combustion, Inc.), Kyle Hawley (Precision Combustion, Inc.), Eric Allocco (Precision Combustion, Inc.) and Jessica Rehaag (Precision Combustion, Inc.).

*Abstract*

Precision Combustion, Inc. (PCI), with support from NASA, continues to develop unitized, regenerative solid oxide stack system. The technology has been previously demonstrated for power generation with methane reformate and efficient co-electrolysis of H2O and CO2 for energy storage. Challenges and risks regarding carbon deposition and thermal management associated with internal reforming have already been addressed. Advantages include potential to provide high power density, improve reliability, and enable quick cycling between power generation and electrolysis. Durability over multiple cycles and several hundreds of hours of operation has been proven. Prior experimental validation comprised utilizing air on the oxidant side of the solid oxide stack. With NASA support, PCI is advancing stack validation and evaluation for air-independent operation to enable implementation of the regenerative stack technology in future NASA missions to the moon, near-Earth asteroids, and Mars. In this paper, we describe continued developmental efforts undertaken at PCI to experimentally demonstrate a regenerative solid oxide stack capable of air-independent operation for use in In-Situ Resource Utilization applications for future NASA lunar and/or Martian missions.

[4] ***JUICE (JUpiter ICy moon Explorer) Thermal Model Correlation and Final Flight Thermal Predictions***

Romain Peyrou-Lauga (ESA) and Gabriel Roca (Airbus Defence and Space).

*Abstract*

JUICE - JUpiter ICy moons Explorer - is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme. Planned for launch in 2022 and arrival at Jupiter in 2031, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa. The JUICE spacecraft will carry the most powerful remote sensing, geophysical, and in situ payload complement ever flown to the outer Solar System. The payload consists of 10 state-of-the-art instruments. JUICE spacecraft thermal control has to cope with a large variation of external environment during the mission (Sun flux from 3323 W/m² in the inner Solar System down to 46 W/m² in Jovian environment) and long eclipses of up to 4.8 hours. The JUICE thermal control is designed with the objective to minimize the impact of the external environment on the spacecraft through high efficiency Multi-Layer Insulation. Minimizing heating power demand especially during science and communication phases and minimizing hardware mass is a constant concern and solutions are found to build to a maximum extent a robust and passive thermal design supplemented by heaters. This paper will focus on the thermal model correlation after the Thermal Balance test and will present the overall final flight thermal predictions.

[5] ***Development of a Deployable, Freeze-Tolerant Condensing Radiator for Spaceborne Two-Phase Pumped Loops***

Thomas Conboy (Creare, LLC), Daniel Kromer (Creare, LLC) and Eric Sunada (Jet Propulsion Laboratory).

*Abstract*

Future space exploration missions require advanced thermal control systems (TCS) to dissipate heat from spacecraft, rovers, or habitats to external environments. These TCSs must be lightweight, reliable, and able to effectively control cabin and equipment temperatures under widely varying heat loads and ambient temperatures. In contrast to single phase pumped coolant loops, two phase pumped loops are very attractive for this application because of the uniform cooling temperature provided by the boiling coolant, low required pumping power, high heat transfer coefficients, and high thermal conductance. However, introduction of two phase flow can pose design challenges associated with flow management and dynamic stability. A condensing radiator technology is needed to enable future heat rejection systems with high turndown ratio, compatibility with freezing, and deployability, while balancing considerations unique to two phase flow condensation. To meet these performance requirements, Creare has developed a freeze tolerant, variable conductance radiator for deployable heat rejection in two phase pumped loop systems.

[6] ***Development and Application of a Novel Calorimetry Technique for the Study of Lithium-Ion Cell Thermal Runaway***

Steven Rickman (NASA).

*Abstract*

Lithium-ion battery technology is widely used and is attractive due to demonstrated specific energies in the 100-200 W-hr/kg range and specific powers as high as 500 W/kg. The excellent, mass-efficient energy storage capability of lithium-ion batteries has led to their use on many aerospace platforms. However, lithium-ion batteries can exhibit thermal runaway behavior wherein stored electrochemical energy is released rapidly as a result of thermal or mechanical failure, electrochemical abuse, internal or external short circuiting. A single cell undergoing thermal runaway within a battery has the potential to induce thermal runaway in adjacent cells if heat dissipation is not properly managed and can result in a catastrophic failure of the battery.

Designing batteries that are resistant to thermal runaway propagation requires an understanding of, not only, total energy yield but also the means by which that energy is liberated from the cell. While Accelerating Rate Calorimetry and other techniques provide total thermal runaway energy yield, they do not provide the fractional breakdown of energy liberated via conduction through the cell casing or that which is vented from the cell as hot gases and effluents. Such data are needed to inform battery thermal design and analysis.

To measure the total energy yield, the fraction conducted through the cell casing, and the fraction lost due to gases and effluents, NASA developed Fractional Thermal Runaway Calorimetry (FTRC). Two calorimeters have been developed and demonstrated, the Small format- and Large format-Fractional Thermal Runaway Calorimeters (S-FTRC and L-FTRC, respectively). The technique has been successfully applied to small- and large-format cells (2.4-3.5 Ah and >100 Ah capacity, respectively) and has given new insights into li-ion cell thermal runaway.

Development of the calorimeters is discussed and results from the initial thermal runaway testing campaigns are presented.

[7] ***Source Contaminant Control System Design, Operation, and Testing for the Trash Compaction and Processing System***

Janine Young (NASA), Gregory Pace (KBRWyle), Serena Trieu (NASA), Kevin Martin (NASA), Tra-My Justine Richardson (NASA), Steve Sepka (NASA) and Jurek Parodi (NASA).

*Abstract*

The Trash Compaction and Processing System (TCPS) aims to reduce volume, biologically safen, physically stabilize, manage effluents, and recover resources from astronaut trash in the International Space Station (ISS). This process involves heating the trash to high temperatures, which in turn releases gaseous contaminants. Effluent management scenarios involve releasing these gases back to the ISS cabin after processing and/or directly venting these gases out to space via the Vacuum Exhaust System (VES). Concerns for recovering the gases back to cabin are crew health, safety, and spacecraft environmental impact. The Heat Melt Compactor (HMC) at NASA Ames Research Center (ARC) serves as a test system that supports TCPS development by conducting risk reduction activities associated with an ISS flight demonstration. Previous gas effluent studies were conducted on the HMC. The results consisted of contaminants from the trash exhaust to exceed Spacecraft Maximum Allowable Concentrations (SMAC), which are selected airborne contaminants that can elicit toxicity symptoms to crewmembers via exposure. The Source Contaminant Control System (SCCS) aims to reduce that risk by converting the contaminants into carbon dioxide (CO2) and water (H2O) vapor. The SCCS is composed of a carbon adsorbent bed, to avoid catalyst poisoning, and a catalytic oxidizer (CatOx), which promotes oxidation of the contaminants to CO2 and H2O. In turn, the gases coming out of the SCCS should be compatible to the ISS cabin and systems such as the Trace Contaminant Control System (TCCS). Preparation for SCCS testing alongside the HMC Gen 3 are currently underway at ARC. The main objectives are to evaluate CatOx efficiency by CO2 conversion and characterize effectiveness of removal by comparing contaminant results before and after CatOx. This paper will report on the SCCS design, operation, and testing with results.

[8] ***The Collapsible Contingency Urinal (CCU) for Spacecraft***

Mark Weislogel (IRPI LLC), Ryan Jenson (IRPI LLC), Oleg Krishcko (IRPI LLC), Logan Torres (IRPI LLC), Adam Naids (NASA Johnson Space Center), John Graf (NASA) and Donald Pettit (NASA Johnson Space Center).

*Abstract*

The routine, hygienic collection and processing of urine aboard spacecraft remains difficult. This fact is perhaps as attributable to the myriad requirements of spaceflight life support as it is to the acute challenges of multiphase fluid physics in microgravity. In this paper we present the specification, development, flight demonstration, and certification of a Collapsible Contingency Urinal (CCU) for use aboard spacecraft. The passive device exploits recent advances in microgravity capillary fluidics research, combining robust superhydrophobic and superhydrophilic substrates that mimic gravity, where, in effect, droplets ‘fall’ and bubbles ‘rise.’ According to crew commentary, the device successfully delivers a method for clean, ergonomic no-moving-parts urine collection for females, which is in turn successfully adapted for males. The encouraging results provide a practical solution for CCUs aboard spacecraft as well as identify a design path forward for the myriad passive fluids management tasks ahead for space exploration. Directions for future CCU production are highlighted in summary.

[11] ***Development and Testing of a Two-Phase Mechanically Pumped Loop for Active Antennae***

Henk Jan van Gerner (NLR), Johannes van Es (NLR), Ramon van den Berg (NLR), Anne Tailliez (AIRBUS Defence and Space), Andy Walker (ADS France), Charlton Castro (AVS Added Value Solutions), Cristina Ortega (AVS Added Value Solutions), Mónica Iriarte (AVS - Added Value Solutions, Elgoibar), Romaine Kunst (NLR), Nuria Roldan (AVS – Added Value Solutions) and Christian Ortega Castañeda (AVS – Added Value Solutions).

*Abstract*

The satellite telecommunications industry is currently undergoing significant evolutions. Future communication satellites need to accommodate a rapidly growing demand in data transfer, combined with more flexibility. For example, there is a strong need for Very High Throughput Satellites capable of delivering up to Tb/s over wide coverage areas. This is only possible when an active phased array antenna is used. However, cooling of active antennas requires the use of a highly efficient thermal control system because it has many heat sources (from hundreds to several thousands), high local heat fluxes (20 W/cm² at evaporator interface), high overall dissipation (around 10 kW), and isothermal requirements on the amplifier chain. These conditions are very difficult to meet with current thermal control solutions (e.g. heat pipes or loop heat pipes), but require a two-phase mechanically pumped fluid loop (MPL). In a MPL, a pump circulates a fluid which evaporates when it absorbs the waste heat from the active antenna. In the IMPACTA project, a demonstrator for such a MPL is being designed and build. This paper describes the test results for the IMPACTA demonstrator. The demonstrator is able to cool a total heat load of 9.8 kW divided over 10 parallel branches with a better than 2°C spatial temperature uniformity over the heat sources. In an active antenna application, the heat load can be unevenly distributed over the different branches. Tests show that even in the extreme case when half of the branches are turned off and the other half are set to full power, no sign of dry-out or too high temperatures is observed, demonstrating the ability of the MPL to cool imbalanced payloads. The demonstrator was tested in 3 different orientations and the test results are similar for all orientations, indicating that the system is not sensitive to gravity effects.

[14] ***Benefits of the In-Orbit Thermal Correlation of the Solar Orbiter Spacecraft***

Scott Morgan (Airbus Defence and Space UK).

*Abstract*

Solar Orbiter, an ESA/NASA spacecraft launched in 2020, was designed to explore the Sun and heliosphere and investigate key questions about our star. To answer these questions, the spacecraft will fly within 0.28AU of the Sun, with a suite of remote and in-situ payloads, measuring solar wind, electromagnetic fields and energetic particles, as well as taking the nearest pictures of the Sun ever taken. This mission comes with a set of demanding thermal challenges that the spacecraft must overcome. In order to understand the thermal performance of Solar Orbiter in space, a set of in-flight thermal correlations were performed at several different distances from the Sun. The correlated thermal model was then used to simulate and predict an accurate thermal performance over the entire mission timeframe. This analysis proved very useful, and led to uncovering potential issues much earlier in the mission than would otherwise be possible with conventional operational monitoring. This allowed for detailed discussions and analysis by the involved parties, leading to a much deeper understanding of the potential problem, and ultimately much more informed decisions taken by the operations team, avoiding significant spacecraft risks. Further, the increased confidence in the thermal model enabled its use in predicting and justifying other thermal configuration changes on the spacecraft, significantly lowering operational risk. This paper is a presentation of the in-fight thermal correlations that were performed, as well as a discussion about the benefits of the process — including real in-flight examples.

[16] ***U.S. Spacesuit Knowledge Capture – Expanding Our Future***

Cinda Chullen (NASA), Vladenka Oliva (Jacobs), Gordon Andrews (Jacobs), Diana Rodgers (S&K Global Solutions) and Amy Ross (NASA).

*Abstract*

NASA is going to the Moon. And it will don a new spacesuit when it reaches its destination. NASA is partnering with industry to build the spacesuit and supporting systems (i.e., surface mobility tools) that astronauts will use on the Moon, starting with Artemis III. The Johnson Space Center’s (JSC) Extravehicular Activity and Human Surface Mobility Program (EHP) is managing this effort, and the U.S. Spacesuit Knowledge Capture (SKC) Program is expanding its scope to help. For 15 years, the SKC Program has collected, archived, and disseminated decades of spacesuit-related knowledge, as appropriate, to help NASA scientists, technicians, and engineers support space exploration. The SKC Program captures its knowledge by hosting and recording subject-matter expert (SME) lectures, interviews, and workshops. It also collects retired SMEs’ reports, drawings, and schematics containing legacy spacesuit knowledge. To build a technically capable spacesuit essential for future lunar exploration, spacesuit professionals borrowed much of their knowledge from legacy Extravehicular Activity (EVA) spacesuits. Most of the SKC Program’s captured knowledge has focused on legacy and current spacesuits. To support the EHP, the SKC Program is expanding its knowledge capture focus beyond the spacesuit and will seek to collect knowledge from other pertinent topics (e.g., lunar terrain vehicle and EVA tools). In 2007, the SKC Program began as an independent source, without funding. As demand for capturing essential spacesuit knowledge increased, consequently, the SKC Program’s funding increased. Expansion of the SKC Program was evident in 2019, when it seized the opportunity to capture the Exploration Extravehicular Mobility Unit (xEMU) buildup at JSC. In 2021, its collaboration with the xEMU Technical Community of Practice facilitated training and knowledge sharing with the xEMU team. In 2022, the SKC Program began supporting the EHP. This paper describes the SKC Program’s expansive evolution, plans to support the EHP, and more.

[17] ***Pressure Retarded Osmosis for Water Supply for Alkaline High Pressure Electrolysis***

Sebastian Markgraf (Airbus Defence and Space GmbH), Fabian Fremdling (Airbus Defence and Space GmbH), Walter Jehle (Airbus Defence and Space GmbH) and Martino Giobbio (Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS, Delft, the Netherlands).

*Abstract*

Water electrolysis for oxygen generation is an established process for supplying oxygen to manned space systems. A high pressure of the produced gases is beneficial for the storage and further processing. A direct generation at high pressure by a high pressure electrolyser might offer advantages such as increased system efficiency and reduced complexity compared to systems with external pressurization e.g. by compressors. Airbus Defence and Space is currently developing an alkaline high pressure electrolyser capable of generating oxygen and hydrogen at 100 bar. The current system design includes one feed pump, supplying water against the operational pressure, and one circulation pump for the electrolyte within the system. Since a potassium hydroxide solution is used as alkaline electrolyte, a high difference in concentration is present between the electrolyte and the water, which is fed to the system. By separating the electrolyte from the water supply via a suitable osmosis membrane, this concentration gradient can be used to establish a water transfer through this membrane. Consequently the feed pump can be replaced. The paper at hand gives an overview over the status of the corresponding developments at Airbus Defence and Space. A laboratory setup was deployed. First tests with different membranes showed promising results regarding the utilization of this process. In the lab, the transport of water through the membrane from ambient pressure into the electrolyte at up to 40 bar could be observed. Further parameters such as the long-term stability of the membranes in contact with the electrolyte and the inverse transport of the ions of the electrolyte have been investigated and the results are presented here.

[18] ***Chemical Challenge Tests on ISS Fire Cartridges***

Cristina Muko (KBR), Steven Beck (KBR), Edgar Hudson (JES Tech), Lawrence Barrett (Jacobs), Adam Korona (Jacobs), Emily Rabel (NASA), William Wallace (KBR), Spencer Williams (NASA) and Daniel Gazda (NASA).

*Abstract*

Following a confirmed combustion event onboard the International Space Station (ISS), crew members will don Emergency Masks, each fitted with 2 ISS fire cartridge filters. As the crew member breathes through the filters, combustion products in the cabin air are either filtered or catalyzed by the fire cartridge media to minimize crew exposure to harmful levels of contaminants. Rigorous certification, acceptance, and surveillance programs for the fire cartridges ensure that each lot meets stringent performance requirements throughout the service life of the cartridges. In accordance with the Quality/Acceptance Test Plan, multiple fire cartridges from each lot undergo chemical challenge tests involving one or more chemicals at specified concentrations. These tests are conducted at specific temperatures, humidity levels, and gas flow rates intended to mimic the worst-case conditions for fire cartridge performance. These challenge tests are conducted by the Environmental Chemistry Laboratory at the NASA Lyndon B. Johnson Space Center. Many of the challenge tests focus on carbon monoxide (CO), but other gases include hydrogen cyanide (HCN), hydrogen chloride (HCl), cyclohexane, acrolein, ammonia (NH3), and acetaldehyde. A fire cartridge is exposed to the test gas in a chamber at the specified conditions, and the outlet is monitored for breakthrough during the 2.5-hour test. This paper will briefly introduce fire cartridges and how they work and will then discuss details of the challenge gas delivery and exposure system, breakthrough monitoring methods, and discussion of issues that have arisen during the course of the test program. Although the focus of this paper will be on the challenge tests, a general summary of the performance of the fire cartridges will also be provided.

[19] ***Fabrication and Evaluation of an Oscillating Heat Pipe with Check Valves by Metal Additive Manufacturing***

Makiko Ando (Japan Aerospace Exploration Agency), Kousuke Tanaka (Japan Aerospace Exploration Agency), Atsushi Okamoto (Japan Aerospace Exploration Agency), Koutaro Matsushige (Nikkeikin Aluminium Core Technology Co., Ltd.), Kentaro Tanaka (Azuma Kinzoku Sangyo Co., Ltd.) and Shinya Okuma (Azuma Kinzoku Sangyo Co., Ltd.).

*Abstract*

An oscillating heat pipe (OHP) is an attractive thermal control device, which has high heat transport capability and enables heat transfer from narrow space. The Japan Aerospace Exploration Agency (JAXA) has developed an OHP with check valves (CVOHP) for space applications. The CVOHP successfully operated in the on-orbit experiment, and now we are at the stage of working toward practical use of the CVOHP. In this study, we focused on metal additive manufacturing as a fabricating method of the CVOHP, aiming at developing a CVOHP with thinner plate thickness, higher thermal performance, and ease of shaping complex structures. This paper describes the fabrication and evaluation of a prototype of additively manufactured CVOHP (AM-CVOHP) using AlSi10Mg powders by selective laser melting (SLM) in a powder bed. The flow channels including straight lines, turn sections, and check valves were fabricated without clogging. The thermal performance tests were conducted in a horizontal orientation. The test results indicated that the AM-CVOHP could operate effectively as a two-phase heat transfer device. The AM-CVOHP transferred heat up to 200W, and the effective thermal conductivity was in the range of 3,000 to 8,000W/mK.

[20] ***Spacecraft Scale Magnetospheric Protection from Galactic Cosmic Radiation***

John Slough (MSNW LLC).

*Abstract*

An optimal magnetic shielding configuration for significantly reducing astronaut exposure to Galactic Cosmic Radiation (GCR) on long interplanetary missions has been realized, and is referred to as the Magnetospheric Dipolar Toroidal Magnetosphere (DTM). This configuration was shown to have the singular ability to deflect the vast majority of the GCR including High Z Energetic (HZE) ions. This external (to the spacecraft) dipolar field is created by an array of unidirectional toroidal High Temperature Superconductor (HTSC) windings mounted externally on the surface of the toroidally-shaped spacecraft habitat. In this way the spacecraft directly supports the magnetic hoop forces generated by the toroidal currents and thereby significantly reduces the structural mass requirements for the shield. The magnitude of the toroidal currents are arranged poloidally to flow so as to maintain the spacecraft shell as a constant flux boundary where the poloidal flux  = 0 inside the spacecraft keeping the habitat field-free. As the dipole magnetic field is perpendicular to the spacecraft habitat in all directions, the DTM provides a deflecting shield to all the incoming GCR which is nearly isotropic. In addition, the DTM shields the HTSC magnets as well thus eliminating the secondary particle irradiation hazard, which can dominate over the primary GCR for shields with closed magnetic topologies. With DTM shielding it was found that both the structural and magnet mass as well as power requirements were significantly reduced. A 3-D relativistic particle cod was used to evaluate shielding effectiveness for the GCR spectrum encountered in space. Four topics that will be covered involve a direct comparison of the three principal efforts developed to date for shielding; They are: (1) Effectiveness of the magnetic shielding (2) Issues with secondaries; (3) Launch and space assembly (4) Advantages and other uses.

[21] ***A Study of the Kinetics of the CO Oxidation Catalyst in a Human Spaceflight Fire Cartridges as a Method to Understand and Predict Performance***

Adam Korona (Jacobs Engineering), Lawrence Barrett (Jacobs Engineering), Emily Rabel (NASA), Cristina Muko (KBR), Steven Beck (KBR) and Edgar Hudson (KBR).

*Abstract*

Fire Cartridges (FC) are an integral part of fire response on ISS, Orion and Gateway. When a pair of FCs are integrated with an Emergency Mask, they can be used to provide safe breathing air on these vehicles in a post-fire environment. The FCs have two primary mechanisms for removing contaminants from the air, an activated carbon (AC) bed which adsorbs the majority of fire byproducts, and a catalyst bed consisting of gold nanoparticles supported on iron oxide which oxidized CO to CO2 under near ambient conditions. While the FC catalyst has proven its ability to convert CO under relevant conditions, this paper attempts to address the apparent inconsistent performance of the catalyst seen in testing. Numerous variables effect the performance of the catalyst, including but not limited to: reaction environment, reactant gas composition, inert gas composition, catalyst age, and catalyst lot. This paper discusses the importance of these variables and attempts a fundamental mechanistic explanation for the effects of each variable. The fundamental mechanisms are then used to establish the magnitude of expected performance variability, which were validated against real test data of flight quality FCs.

[23] ***Thermal Modeling of a Novel Air-Cooled Temperature Swing Adsorption Compressor (AC-TSAC)***

Hannah Alpert (NASA Ames Research Center), Keith Peterson (NASA Ames Research Center), Tra-My Justine Richardson (NASA Ames Research Center), Quinton Dzurny (Georgia Institute of Technology) and G. P. Peterson (Georgia Institute of Technology).

*Abstract*

Contaminant removal technology, such as the Carbon Dioxide Removal Assembly (CDRA) on the International Space Station (ISS), is critical to Environmental Control and Life Support Systems (ECLSS), which enable humans to live and work in outer space. The CDRA includes an adsorbent bed, which absorbs CO2 from the cabin air and releases it to a Sabatier reactor for water production when thermally cycled. An effective system would heat and cool the adsorbent quickly and uniformly to maximize the amount of CO2 removed from the cabin and delivered to the Sabatier reactor. Air-Cooled Temperature Swing Adsorption Compressors (AC-TSAC) are promising for use downstream of the CDRA because they are a simple alternative to more mechanically-complex compressors, which are currently in use on the ISS. The current investigation addresses the thermal modeling of potential AC-TSAC designs. An initial thermal model was created and validated by comparing the model outputs to experimental data for the heating phase. Several design trades were conducted, including bed geometry (rectangular vs. cylindrical), bed structural material (i.e., the material that makes up the walls and shelves), and configuration of heat spreading elements within the bed. Also investigated is AC-TSAC performance sensitivity to the thermal conductivity of the adsorbent material and the heat pipes as well as the input power for heating. The results from these studies will inform the design of the next generation of the AC-TSAC, and the thermal modeling results will be further validated through testing.

[24] ***Characterizing Fit Factor of a One Size Fits-Most Emergency Mask using Subjects with Smaller Neck Circumferences***

Adam Korona (Jacobs), Emily Rabel (NASA (JSC)), Justine Wiles (NASA (JSC)), Matt Meyer (Jacobs), Alicia Ruiz (Jacobs) and Jeff Hahn (Jacobs).

*Abstract*

The Emergency Mask (EM) is an integral part of fire response on the International Space Station (ISS), Orion, and Gateway. The EM is a hood protection respirator sealing around the subject’s neck, with an additional nosecup covering the subject’s oral/nasal region. When integrated with a pair of air-purifying cartridges, the system can provide safe breathing air in a post-fire environment. Initially, the EM was certified as a one-size-fits-most respirator; however, a recent requirements scrub discovered that the initial requirement set did not include the neck circumferences of the smallest possible crew population. To investigate whether the requirements gap would pose a problem for the current EM design the project performed fit tests on eight subjects with neck circumferences smaller than the initial EM requirement. The test included subjects donning an EM and performing head movements in a tent filled with approximately 50,000 particles/cc of smoke particles. During these motions, particulate measurements are obtained from within the EM and compared with particulate measurements in the surrounding environment. This paper provides descriptions of the test hardware, methodology, and results, which have provided the rationale for designing and building an EM to accommodate subjects with smaller necks.

[25] ***Requirements Engineering Scorecard and the Next-Generation Space Suit***

Michael Cabrera (Jacobs Technology), Steve Simske (Colorado State University) and Julia Worrell (NASA).

*Abstract*

The objective for a NASA contractor, the performing organization in this case study, is to develop and deliver the next generation space suit to NASA, the customer in this case study, against a radically different level of customer expectation from previous years. In 2019, the administration had proposed a return to the moon, thus transforming and changing the system context of the current, next generation space suit in addition to pushing schedule expectations forward two years. The purpose of this dissertation will serve as a case study in two specific areas with qualitative and quantitative analyses regarding a new process and approach to (i) project lifecycle development and (ii) requirements engineering with the intent that if utilized, these tools may have contributed to improvements across the project in terms of meeting cost, scope, budget and quality while appropriately accounting for risk management. The procedure entails a research method in which the current state of the project, current state of the art and the identified systems engineering challenges are evaluated and iterative models are tempered through development by continual improvements by engineering evaluation of engineers on the project. The current results have produced (i) a prototype to project lifecycle development method via agile, Lean and Scrum hybrid implementations into a Traditional Waterfall framework and (ii) a prototype to requirements engineering scorecard with implementations of FMEA and quantitative analysis to determine root cause identification. Forward work includes customer, performing organization, INCOSE and PMI acceptance.

[26] ***Space Suit Portable Life Support System Thermal Control Valve Ball Design***

Ryan Ogilvie (NASA Johnson Space Center), Sean Miller (NASA Johnson Space Center) and Tessa Rundle (NASA Johnson Space Center).

*Abstract*

A Thermal Control Valve (TCV) has been in development for the Exploration Extravehicular Mobility Unit Portable Life Support System (xEMU PLSS). The xEMU PLSS TCV controls flow going to the liquid cooling and ventilation garment that the crew member wears during extra-vehicular activity to expel waste heat. A previous TCV version with a linear actuator and diverter valve has been tested to attempt to control the flow accurately. The previous valve has a non-linear flow response relative to valve position and has struggled to meet the setpoints desired for precise thermal control. While many diverter valve design variations have been attempted, all previous designs have had difficulty meeting set points. Additionally, high precision machining is required to create a metal-on-metal seal which has its own drawbacks and does not always meet requirements for internal leakage. This metal seal also requires stalling a linear actuator to load the seal in compression or tension which has caused sticking failures when stalled. A new approach and design for a TCV has been developed which uses a rotational ball to control flow and has demonstrated a much more precise and linear flow control. The design functions like a two-way ball valve with two Teflon seats that cradle and compress the ball for sealing. The ball outlet has a unique geometric design to create a set-able orifice like hole which is more predictable at controlling flow. Additionally, the Teflon seat performs much better for preventing internal leakage than the metal seal and prevents sticking by having a large range in which it is sealed without having to stall the actuator. This paper will review a new proposed xEMU PLSS TCV ball design and compare it with previous iterations of the design.

[27] ***Space Suit Portable Life Support System Oxygen Regulator History, Development, & Testing Results***

Ryan Ogilvie (NASA Johnson Space Center), Colin Campbell (NASA Johnson Space Center), Ioannis Hatziprokopiou (Mission Systems Division, Eaton), Robert Walz (Mission Systems Division, Eaton) and James Rogers (Mission Systems Division, Eaton).

*Abstract*

An oxygen regulator has been in development for the Exploration Extravehicular Mobility Unit (xEMU) Portable Life Support System (PLSS). The regulator provides the necessary oxygen pressure control for the crew member during prebreathe, Extra-Vehicular Activity (EVA), post EVA airlock operations, and Decompression Sickness (DCS) treatment. It has been over four decades since a new spacesuit oxygen regulator has been designed. The regulator and EMU that is presently used on the International Space Station (ISS) was developed for the space shuttle program without any significant changes made throughout its service life. The xEMU spacesuit oxygen regulator is based on the previous EMU Secondary Oxygen Pack (SOP). The new design integrates numerous improvements and changes including an innovative approach to regulator architecture, a more robust first stage pressure sensing mechanism, digital actuation control, and electronic pressure sensing. These upgrades replace manual control linkages, physical gauges, and enable infinitely variable pressure set points. The new setpoints can decrease prebreathe time and make in suit DCS treatment possible. Throughout its four iterations design concerns have been addressed, safety features have been added, and the envelope of the regulator designed to fit inside the xEMU PLSS package. This paper will review the history, design, testing, and lessons learned during the development of the xEMU PLSS Oxygen Regulator.

[32] ***Thinking Outside the Apollo Toolbox: Designing SAMPLERS - Spacesuit Attached Multi-Purpose Lunar EVA Retrieval System***

Samuel Stenzel (Wayzata High School).

*Abstract*

The tools that the astronauts used during the Apollo missions were designed over 50 years ago and may be inefficient, outdated, or problematic. The development of new geological tools is an important component of NASA's plans to return to the Moon by 2024 in a program called Artemis. NASA has outlined gaps that must be filled before launching a return to the Moon. One requirement was to explore the development of a harness that could be attached to a spacesuit to carry tools. Relevant recent literature finds few studies that have focused on spacesuit attached tools. This research study addresses a known gap and describes the process of designing, fabricating, and testing a spacesuit-attached multi-purpose Lunar geology sampling tool system to improve astronaut Extravehicular Activity (EVA) efficiency. The research and design method utilized a rapid prototyping process to create a tool system called SAMPLERS. The SAMPLERS prototype consisted of five main components. The details of each component and its design considerations, strengths, and issues are discussed. Hardware testing utilized a mixed method of qualitative and quantitative data collection. Test subjects evaluated the completed SAMPLERS prototype while wearing spacesuits in an analog Lunar environment at the University of North Dakota (UND) Human Spaceflight Laboratory. The objective and subjective data supported the advantages of a spacesuit-attached multi-purpose Lunar sampling tool, such as SAMPLERS. The results show SAMPLERS satisfied requirements and demonstrated it is worthy of consideration as a viable addition to the Artemis geology tool assortment.

[33] ***Exploration Helmet Permanent Anti-fog Study***

Kristine Davis (NASA) and Greg Trude (Air-Lock Inc).

*Abstract*

For the current Extravehicular Mobility Unit (EMU) spacesuit, an astronaut applies an anti-fog solution to the interior of the helmet bubble before each EVA. However, the anti-fog solution has been reported to cause eye discomfort during at least seven EMU EVAs when the anti-fog solution contacted the crew member’s eyes. During STS-100, astronaut Chris Hadfield reported the eye irritation temporarily blinded him during his spacewalk. In addition, the wipe on anti-fog solution is a consumable that needs to be accounted for and a supply launched for missions.

To solve this, the Exploration EMU (xEMU) pressure bubble investigated using a permanent anti-fog coating during Design Verification and Test (DVT) human in the loop (HITL) events. Chosen for previous use in Constellation Space Suit develop, HTAF-601, a water based permanent anti-fog solution, was tested. However, major issues have arisen with further HITL testing with the coating. Cleaning the helmet has been a challenge to avoid damaging the permanent anti-fog coating. NASA has completed a set of different methods for cleaning the anti-fog to try to document a preferred method. Even with using a very gentle cleaning method of flushing with distilled or DI water and dabbing at facial oils, the permanent anti-fog starts to delaminate consistently after 50 hours manned pressurized time (MPT). Finally, the HTAF-601 coating is being discontinued by the vendor.

Due to these issues, further investigation is being completed evaluating two solvent based anti-fog solutions: Exxene’s HCF-100 and FSI’s Visgard 106-94. Each coating will be evaluated on polycarbonate samples for application consistency, steam cycles (mimicking breath cycles), cleaning durability, haze, and light transmission. This study will determine if either coating is a viable option to pursue as a permanent anti-fog for spacesuit helmet applications.

[34] ***Initial Testing of the Exploration Extravehicular Mobility Unit (xEMU) in Lunar Environment Simulation at the Neutral Buoyancy Lab (NBL) in 2022***

Kristine Davis (NASA), Zachary Tejral (NASA), Tommy Keomany (NASA) and Linh Vu (MEI Technologies).

*Abstract*

Understanding how to effectively train for Extravehicular Activities (EVAs) for Artemis missions is critical. Tasked by the new Extravehicular Activity and Human Surface Mobility Program (EHP), a team of stakeholders from engineering and flight operations worked together to test the Exploration Extravehicular Mobility (xEMU) in the Neutral Buoyancy Lab (NBL) simulating the lunar environment. The NBL is a pool in which astronauts are typically trained to complete simulated International Space Station (ISS) EVA tasks in a neutral weigh-out. The overall focus for this test series was evaluating how well the NBL could be used as an effective simulated environment for Artemis lunar EVAs. New NBL support hardware was manufactured to support this test series and update the interfaces to be more representative of xEMU hardware such as a new NBL Portable Life Support System (PLSS) mock-up and umbilical, lights and cameras, and display and control unit (DCU). To simulate the 1/6th-gravity (1/6-g) environment, extra weights were added around the suit to create an accurate center of gravity representation. The Partial Gravity Weigh-out Stand (PGWS) predicted where and how much weight would be required for the 1/6th-G simulation and predicted the center of gravity placement. After the weigh-out attempt was completed, the suited participant would complete a set of directed tasks such as kneeling, object pick-up, and walking to evaluate the weigh-out. To create the lunar environment, sand, boulders, and ramps were added to the pool floor. Overall, the NBL was able to create an acceptable lunar landscape and ability to have two subjects work side by side in pressurized xEMUs which currently cannot be achieved in other test environments. Achieving a stable 1/6th-G lunar weigh-out and clear, consistent dual suit communications was a challenge for this series. Future work is planned to continue to improve this simulation environment.

[35] ***Ventilation Heat Exchanger/Flow Meter for xPLSS***

Michael Izenson (Creare Inc.), Adam Niblick (Creare LLC), Sheldon Stokes (Creare LLC) and Tessa Rundle (NASA).

*Abstract*

The flow meter / heat exchanger (FMHX) in the ventilation loop of the exploration EMU cools the ventilation gas and measures the ventilation flow rate. The heat exchanger transfers heat from the ventilation gas to the thermal control loop via a miniature shell-and-tube heat exchanger. The flow meters calculate the flow rate of gas through the ventilation loop based on the pressure drop across the heat exchanger core. Creare has delivered four design validation test (DVT) heat exchangers and five DVT flow meters to NASA JSC to support development of the exploration portable life support system (xPLSS). This paper describes the design and performance of the DVT units.

The heat exchangers are designed to cool the ventilation gas to a specified temperature with low pressure losses under the most challenging operating conditions. The measured performance of the DVT heat exchangers agrees well with design models and meets all performance requirements.

The flow meters use a MEMS thermal flow sensor to produce a signal that is proportional to a small bypass flow around the heat exchanger core. They are designed to achieve high measurement accuracy across the full range of xPLSS operating conditions. We calibrated the flow meters in a special-purpose flow facility that simulates operation in the xPLSS ventilation loop. Calibration testing shows that DVT flow meters produce digital output for vent loop mass flow that meets NASA’s accuracy requirements across the range of xPLSS operating conditions.

This paper reviews the design of the heat exchangers and flow meters and presents data from the final flow meter calibration testing, heat exchanger performance validation, and initial ground testing in NASA’s xPLSS.

[37] ***Establishing Standardized Test Methods for Evaluating Space Suit Gloves***

Robert Jones (NASA), Richard Rhodes (NASA), Morgan Abney (NASA NESC), Timothy Brady (NASA NESC), Shane McFarland (NASA), Joseph Settles (NASA), Chanel Stephens (NASA), Andrew Hoyle (NASA), Andrew Funk (NASA) and Stephanie Rodgers-Ahnen (NASA).

*Abstract*

The Artemis space suit glove environmental protection garment (EPG) will be the first line of protection used to shield the crewmember’s hands from the environments encountered during extravehicular activity (EVA). As the Artemis missions will include more extreme environments than those experienced on the International Space Station, development, verification, and validation of gloves poses three key challenges. First, there are no standardized tests defined to evaluate the durability of space suit gloves for the extreme lunar environments, particularly the permanently shadowed regions. Second, there is insufficient data on state-of-the-art glove performance in a lunar environment from which to compare new designs. Third, current ISS glove Thermal Micrometeoroid Garment (TMG) fabrics are unlikely to be sufficient to meet Lunar requirements. It is therefore necessary to define tests to evaluate if gloves can meet new, challenging requirements. This paper focuses on the development of a test procedure to characterize lunar EVA glove fabrics using ASTM standardized test methods and the design and validation of a new standardized test procedure for comparing abrasion resistance between fabrics in lunar-like conditions. The results of testing on twelve candidate EVA glove fabrics are presented.

[38] ***NASA Exploration Toilet On-orbit Results and Impact on Future Missions***

Melissa McKinley (NASA-JSC), Melissa Borrego (NASA), Cory Kaufman (Collins Aerospace), Jill Williamson (NASA-MSFC) and Kelly DeRees (NASA-JSC).

*Abstract*

The Universal Waste Management System (UWMS), which has the ISS operational nomenclature “Toilet”, was initially installed on the International Space Station (ISS) in 2020 with final installation completed in 2021. Technical progress continued to be made with each on-orbit operation that culminated in additional crew use of the UWMS on ISS. Additional problems were evaluated during troubleshooting and testing with the UWMS hardware using water and pretreat to simulate crew use. This paper summarizes the additional testing, troubleshooting and the results as well as characterizes the additional data obtained and summarizes the interpretation of the data to characterize the hardware’s operational nuances. Use of the hardware by crew is planned and will also be summarized. The paper will also describe the additional portions of the technology demonstration that were completed and the benefits that inform the Orion-installed UWMS unit and future manifesting of consumables for both Orion and ISS.

[40] ***Advancements in Logistics Reduction for Exploration Missions***

Melissa McKinley (NASA-JSC), Melissa Borrego (NASA), Patrick Fink (NASA-JSC), Anne Meier (NASA-KSC), Michael Ewert (NASA-JSC), Curtis Hill (ESSCA), Steven Sepka (NASA-ARC), Justine Tramy Richardson (NASA-ARC) and Evelyn Orndoff (NASA-JSC).

*Abstract*

Management of logistics on exploration missions includes both looking for ways to minimize the quantities, mass and volume of various consumables, supplies, spares and equipment as well as ways to minimize the crew time needed for locating and handling those items. Also included are ways to minimize the waste, handling and resultant products from the processes of maintaining a crew on these missions. The Logistics Reduction project encompasses technologies for management of waste, trash, autonomous logistics, and clothing. This paper provides a status of work in these areas including recent accomplishments and challenges encountered. Future objectives will also be covered along with the work currently in progress. Specifically, the paper will cover technologies in waste management, namely, the Universal Waste Management System (UWMS) or exploration toilet and work on an alternative waste collection container, the Alternate Fecal Canister. Trash management technologies work on the Trash Compaction and Processing System (TCPS) and Trash to Gas (TtG) is summarized with progress to date as well as information on how Jettison as an option is related. Progress and summary of recent accomplishment on the RFID (Radio Frequency ID) Enabled Autonomous Logistics Management (REALM) and the Autonomous Logistics (AL) technologies is detailed. Advanced Clothing System (ACS) and work in the area of Systems Engineering and Integration (SE&I) is also included. Status of the technologies, accomplishments and how the focus areas inform program decisions will be addressed.

[41] ***Silver Electrolysis for Disinfection of Spacecraft Potable Water: 2023 Update***

Phillip Hicks (Jacobs Technology), Niklas Adam (NASA), Rogelio Garcia Fernandez (Jacobs Technology) and Michael Callahan (NASA).

*Abstract*

Anodic dissolution of silver electrodes, or “silver electrolysis,” is being investigated as a means of introducing biocidal silver into potable water on exploration spacecraft. Last year’s paper reported a fault condition termed “electrode bridging,” in which silver deposits on interelectrode wetted materials, eventually bridging the electrode gap and providing an alternate conduction pathway that diminishes the silver output of the reactor. Since then, two strategies have been developed that prevent this fault from occurring: 1) increasing the frequency of polarity reversal and 2) separating the active surface of the electrode from the interelectrode wetted material. These strategies were tested independently, and in both cases, the reactor performed as expected with no occurrence of bridging for at least one crew-year equivalent of cumulative operation. Additional tests were conducted at varying levels of influent dissolved oxygen to better understand the nature of the cathode reaction and its impact on reactor performance. Results indicate that the primary cathode reaction is the reduction of dissolved oxygen, which could imply a dependence of reactor performance on dissolved oxygen concentration. However, it was found that at the typical oxygen concentrations anticipated for spacecraft processed water, the impact on silver electrolysis performance was negligible. Finally, multiphysics modelling of the reactor fluid mechanics and electrochemistry was undertaken to provide the capability to optimize the design of a future reactor prototype.

[42] ***Analyses of Blue Origin Blue Moon Lunar Landing Descent Engine Plume Effects***

William Hoey (Jet Propulsion Laboratory, California Institute of Technology), Maxwell Martin (Jet Propulsion Laboratory, California Institute of Technology), John Alred (Jet Propulsion Laboratory, California Institute of Technology), Carlos Soares (Jet Propulsion Laboratory, California Institute of Technology) and Mohammed Ababneh (Blue Origin, LLC).

*Abstract*

Powered landings onto airless bodies like the Moon generate rarefied gas dynamic environments composed of engine plume flows and surface materials including mobilized dusts. These induced atmospheres can cause harmful degradations of spacecraft performance. In particular, lunar dust can cause severe operational problems for human and cargo landing systems, astronauts, and deployed scientific observatories as was observed during the Apollo program. The need to understand and quantify the effects of plume-surface interactions during powered landings onto airless bodies has motivated the development of physics-based modeling approaches at NASA’s Jet Propulsion Laboratory. JPL incorporates inputs from Blue Origin and literature surveys of lunar regolith and applies computational fluid dynamics, direct simulation Monte Carlo, and Lagrangian particle-tracing simulation methodologies to model the plume exhaust flowfields generated by the Blue Moon descent engines during the final meters of landing, as well as the effects of that plume flow in eroding, entraining, and transporting lunar regolith to the descent element. The effects of dust deposition onto thermal control system radiators are of primary interest in this work, but other detrimental effects can include deposition onto landing sensors and optical systems during and after landing; damage induced by dust impact or subsequent abrasion within exposed lander cavities; and the performance degradation of solar arrays and scientific payload instruments. Plume interactions will also result in lunar dust clouds which may obscure visibility during landing, and may cause mechanical erosion of surfaces downstream of the plume-surface interaction.

[43] ***Evolution of the Next Exploration Toilet through Human-in-the-Loop (HITL) Testing***

Melissa Borrego (National Aeronautics and Space Administration (NASA)), Mary Walker (National Aeronautics and Space Administration (NASA)), Yvette Carmona (KBR Wyle Services, LLC (JES Tech)), Alexandra Eifert (KBR Wyle Services, LLC (AEGIS Aerospace)), Alisa Marshall (KBR Wyle Services, LLC (Leidos)) and Melissa McKinley (National Aeronautics and Space Administration (NASA)).

*Abstract*

Human waste collection in space is a unique and necessary function that all crewmembers must perform. The variability in how each crewmember uses the toilet to urinate and defecate introduces complexities and challenges with regards to overall hardware design. Because of this variability, it is important to consider crew inputs in all aspects of a toilet design especially with regards to crew interfaces that could impact overall waste collection. Access to crew feedback is essential to the design process and should be considered early and often through the various design phases. In 2020, NASA started a project for the Human Landing System (HLS) program to develop a Government Furnished Equipment (GFE) toilet option. The project is known as the Lavatory On-Orbit (LOO). During the early development of the LOO, the project team conducted several crew evaluations to collect and summarize valuable crew feedback on system design, function, and overall usability to influence the next design iteration. Because every person could use the system differently in space, it was extremely important to collect and analyze the data in a very methodical manner to appropriately influence the design based on the evaluation results. Establishing a standard process ensures consistent data collection from one evaluation to another, helps to maintain privacy for each test subject’s inputs and removes any potential bias from test subject to test subject. To date, the team has completed four crew evaluations on prototypes for the different LOO hardware. This paper will summarize the methodology used to conduct the evaluations as well as how data was collected and analyzed. The paper will also provide details on each of the evaluations and how the design was updated based on the results.

[45] ***From Waste to Water - An Integrated System to Recover Potable Water from Urine and Condensate***

Ingrid Helgeland (Aquaporin A/S), Maja Bender Tommerup (Danish Aerospace Company), Jason A. Ogden (Danish Aerospace Company) and Jörg Vogel (Aquaporin A/S).

*Abstract*

The Water Recovery Unit (WRU) is based on an open loop triple circulation system with two-stage filtration and the start of its development has been reported at ICES 2018 and 2019. Here, we identified several challenges. The first stage, based on forward osmosis (FO),separating water from the contaminated urine/condensate mix, suffered from precipitation and storage challenges which lead to lower water recovery and reduced system lifetime. The second stage was designed as a vacuum assisted membrane distillation (MD) process and was challenged by low water flux and shorter than required membrane lifetime. Throughout the past years we worked on an improved design and integrated several upgrades to both stages.This includes a concept for better waste storage, improved water recovery and improved water recovery sub-system that will enable us to produce water in sufficient quantity and quality. Despite the improvements to the complete system all components are still designed to be lightweight and easy to operate with the only external connection to the unit to be power and the supply of contaminated water.

[47] ***Benefits of Trash-to-Gas versus Jettison of Waste via Trash-Lock for Mars Transit***

Thomas Chen (NASA Johnson Space Center), Michael Ewert (NASA Johnson Space Center) and Joel Olson (Southeastern Universities Research Association, NASA Kennedy Space Center).

*Abstract*

Human exploration missions to Mars pose difficulties due to the significant waste that will be generated during transit, which will need to be carried along or disposed of in some fashion. Waste removal from the spacecraft decreases the spacecraft’s mass as well as the associated logistic items necessary for storing the waste. A mission propellant analysis was performed to highlight the mass benefits that may be accessed via waste removal. The propellant mass savings were determined for different waste removal rates (2.9 – 11.6 kg/day) with the highest removal rate leading to the greatest propellant savings of 7,785 kg for an 850-day round-trip mission. Due to these benefits, two methods for waste reduction were studied for the 850-day Mars mission: Trash-to-Gas (TtG) and physical jettison via a trash-lock. The trash-to-gas methods considered were combustion, steam reforming, and pyrolysis, which convert waste into ventable gases (e.g., CO2, CO, CH4, etc.). Combustion and steam reforming require a co-reactant (O2 and/or H2O). Therefore, additional processing units or integration with the spacecraft’s environmental control and life support system (ECLSS) are required to facilitate recycle of the pertinent species. In contrast, pyrolysis is a purely thermal degradation process, which can operate as a standalone system; however, a lower percentage of waste is gasified with pyrolysis. The study herein compares standalone TtG (e.g., Advanced Organic Waste Gasifier, Plasma Pyrolysis, etc.), integrated TtG-ECLSS (e.g., Orbital Syngas Commodity Augmentation Reactor, Incineration/Gasification, etc.), and physical jettison. Each system’s mass, volume, power, and cooling requirements were compared via an equivalent system mass (ESM) analysis to ascertain potentially promising technologies that can achieve efficient waste removal while minimizing their own spacecraft load. This study highlights the advantages and disadvantages the different waste management technologies and provides recommendations on the promising technologies based on the ESM metric and propellant mass savings.

[48] ***Assessing Technical Risk of Tailoring Space Vehicle Thermal Vacuum Testing***

John Welch (The Aerospace Corporation).

*Abstract*

Tailoring requirements for spacecraft environmental tests is necessary to ensure that the effectiveness of these tests is consistent with program risk posture expectations and to meet program cost and schedule constraints. A vehicle thermal vacuum test is one of the most costly and time-consuming of prelaunch tests, so it is not surprising that cycle reductions below the four cycles commonly conducted across industry are often proposed. In this paper, technical risks with such reductions are discussed qualitatively and quantitatively as they affect test effectiveness. The impact of inclusion of a vehicle thermal cycle test is also discussed. The vehicle thermal vacuum test remains an essential verification of mission performance requirements and should not be deleted for any priority space program.

[51] ***Development of an efficient alternative to recovery O2 from metabolic CO2 via electrolysis operated at ambient temperature and driven by a highly selective catalysis***

Jesus Dominguez (Jacobs JSEG IG), Cara Black (NASA Marshall Space Flight Center), Brittany Brown (NASA Marshall Space Flight Center), Wilaiwan Chanmanee (University of Texas at Arlington), Brian Dennis (University of Texas at Arlington), Lorlyn Reidy (Jacobs JSEG), Shannon McCall (Jacobs JSEG), Kaitlin Oliver-Butler (NASA Marshall Space Flight Center), Kagen Crawford (NASA Marshall Space Flight Center), Kenneth Burke (NASA Glenn Research Center) and Joseph Fillion (Jacobs Space Exploration Group (JSEG)).

*Abstract*

The current State of Art (SOA) on oxygen recovery onboard the Environmental Control and Life Support System (ECLSS) at the International Space Station (ISS) is a complex, heavy, and power-consuming system that recovers approximately 50% of the oxygen (O2) from metabolic carbon dioxide (CO2). For future long-duration beyond low Earth orbit (LEO) missions, O2 recovery systems will need to be highly reliable, and efficient, and recover a minimum of 75% O2 from metabolic CO2. An alternative technology development effort currently underway at NASA Marshall Space Flight Center (MSFC) has the potential to significantly increase O2 recovery currently limited to 50% (Sabatier) and reduce the complexity of ECLSS O2 recovery. MSFC and the University of Texas in Arlington (UTA) have jointly designed and fabricated a microfluid electrochemical reactor (MFECR) that operates at ambient conditions and utilizes a proprietary catalysis highly selective on reducing CO2 to ethylene (C2H4) at the cathode while O2 is generated at the anode. The MFECR would replace three pieces of hardware for future ECLSS architectures: the current CO2 Reduction Assembly (CRA) (Sabatier reactor), the Plasma Pyrolysis Assembly (PPA), and the Oxygen Generation Assembly (OGA). It is designed to interface directly with the CO2 Removal Assembly (CDRA) and the Water Processing Assembly (WPA) to supply CO2 reactant and water replenishment respectively. This is expected to substantially improve the sustainability of the ISS ECLSS and reduce requirements on power and weight. Here, we discuss the current development and evaluation efforts on different alternatives on not only the configuration and setup of the MFECR at an Engineering Design Unit (EDU) scale but also the selection of component materials.

[52] ***Extraterrestrial Mining Via Two Coupled Thermal-Driven Phenomena***

Jesus Dominguez (Jacobs JSEG/IG), Cara Black (NASA Marshall Space flight Center), Brittany Brown (NASA Marshall Space flight Center), Paul Hintze (NASA Marshall Space flight Center), Shannon Mccall (Jacobs JSEG) and Kagen Crawford (NASA Marshall Space Center).

*Abstract*

Two-coupled thermal-driven phenomena, the Marangoni effect and thermal fractional decomposition under high vacuum, observed by the authors could lead to an extraterrestrial mining operation that would significantly reduce mechanical operation and allow in-situ product extraction directly from the mineral without the necessity of either mineral beneficiation or use of terrestrial precursors. Thermal Marangoni effect alone and coupled with fractional decomposition have been corroborated through paths of 10 and 13 inches respectively on molten JSC-1A lunar regolith simulant. These two coupled phenomena (self-transportation via the Marangoni effect and fractional decomposition at a higher temperature) present a novel and valuable potential for extraterrestrial mining as the observed outcome will be more prominent on extraterrestrial surfaces under higher vacuum and reduced gravity. A comprehensive 3D model built by the authors demonstrated to be a crucial tool to determine the right location of the sample to optimize the gradient temperature along the wall of a long tubular crucible enhancing the Marangoni effect as surface tension (the driving force for the thermal Marangoni effect) depends on the temperature gradient.

[53] ***Development of a Multi-Gas Microsensor Array for the Exploration Portable Life Support System***

James Makel (Makel Engineering Inc.), Richard Kokoletsos (Makel Engineering Inc.), Darby Makel (Makel Engineering Inc.), Ryan Ogilvie (NASA Johnson Space Center) and Sepehr Bastami (NASA Langley Research Center).

*Abstract*

The Portable Life Support System (PLSS) of the Exploration Extravehicular Mobility Unit (xEMU) requires sensors capable of measuring the major constituents of the gas stream. These major constituents include oxygen, carbon dioxide, and water vapor. The sensors must operate across a wide range of flow and pressure conditions and introduce very low pressure drop in the ventilation loop. The sensors must operate with low power and occupy a small volume. This paper reports the development of a compact, low power, multi-parameter astronaut life support sensor (M-PALSS). M-PALSS consists of an array of low-power chemical microsensors for oxygen, carbon dioxide, water vapor, and pressure. M-PALSS includes custom electronics to control the sensors and is packaged in a custom housing that meets the volume and shape requirements for service in the PLSS.

[56] ***Comprehensive 3D Multiphysics Model on Electrochemical Recovery of O2 from metabolic CO2 at the International Space Station (ISS)***

Jesus Dominguez (Jacobs JSEG/IG), Cara Black (NASA Marshall Space Center), Brittany Brown (NASA Marshall Space Center), Wilaiwan Chanmanee (University of Texas at Arlington), Brian Dennis (UT Arlington), Kaitlin Oliver-Butler (NASA Marshall Space Center), Kagen Crawford (NASA Marshall Space Center), Shannon McCall (Jacobs JSEG), Kenneth Burke (NASA Glenn Research Center), Joseph Fillion (Jacobs Space Exploration Group (JSEG)) and Lorlyn Reidy (NASA Marshal Space Center).

*Abstract*

The International Space Station (ISS) is presently equipped with an elaborate, heavy, and high-power consuming system that recovers approximately 50% of O2 from metabolic CO2 as part of the atmospheric revitalization (AR) at the ISS habitat. Future long-duration missions will require a more sustainable and efficient system capable of yielding a minimum of 75% O2 recovery to reach the self-sufficiency required for long-duration space missions beyond Earth’s low orbit. A Microfluidic Electrochemical Reactor (MFECR) technology development effort is currently underway at NASA Marshall Space Flight Center (MSFC) to not only increase significantly current O2 recovery efficiency, improving self-sufficiency on AR at the ISS habitat and future long-duration missions, but also reduce system complexity. The authors have developed and deployed a comprehensive 3D multiphysics model that thoroughly replicates the actual configuration and fluid/material domains of the MFECR. The coupled physics in this multiphysics model include multicomponent-multiphase electrochemical-driven reactions, non-ideal mass transport mechanism, free and porous flow, heat transfer, CO2 solubility on alkaline electrolyte, water condensation on porous medium, and DC electrical current generation along with Joule heating effect. This model is aimed to conduct qualitative benchmark on three different MFECR layouts, one without serpentine paths (plain) and two with serpentines leading to four and twelve paths respectively. Once experimental data is generated via a test matrix of 200 tests, the model will be validated to conduct MFECR process optimization and revalidate the qualitative benchmark on three different MFECR layouts.

[57] ***Additively Manufactured Heat Pipe Performance and Modeling***

Payton Batliner (The Aerospace Corporation), Alex Pagano (The Aerospace Corporation), John McHale (The Aerospace Corporation), Natalie Walsh (The Aerospace Corporation), Jacob Rome (The Aerospace Corporation), Xueyong Kevin Qu (The Aerospace Corporation) and Glenn Bean (The Aerospace Corporation).

*Abstract*

Additively manufactured (AM) heat pipes enable more direct integration with a spacecraft’s structure than conventionally designed heat pipes. Application of AM heat pipes could improve spacecraft thermal control through the elimination of interface thermal resistances and could increase heat transport efficiency due to optimized heat pipe paths and fewer geometric constraints. This could be particularly beneficial for cubesats, where physical space to integrate thermal control devices is often very limited. Previous work demonstrated the ability of an aluminum-methanol AM heat pipe to operate in reflux mode with an internal temperature gradient 89% lower than that of the uncharged pipe. Building on this work, thermal performance tests are carried out for an Inconel-water AM heat pipe. The heat pipe is tested in a horizontal orientation, allowing the capillary pumping capabilities of the AM heat pipe to be evaluated. Test configurations include the heat pipe either charged (filled) with water or empty (uncharged) to determine the increase in conductance along the pipe due to the two-phase heat transfer within the heat pipe. In addition to this, numerical predictions from our Python model are compared to the experimental results.

[58] ***Exploration Extravehicular Mobility Unit (xEMU) Pressure Garment System (PGS) Cycle Testing Overview and Results***

Christine Flaspohler (NASA) and Richard Rhodes (NASA).

*Abstract*

With the development of NASA’s next generation spacesuit, the hardware life expectations for the new spacesuit required evaluation. The Exploration Pressure Garment Systems (xPGS) team designed and performed a test series to assess the new hardware against the life requirements. The Extravehicular Mobility Unit (EMU) is used today on the International Space Station (ISS) and has a cycle life requirement, which was previously validated by performing isometric joint cycle testing. The Isometric joint cycle model for the EMU is based on analysis of previously performed Extra-Vehicular Activities (EVAs). The xPGS includes new designs for suit components and a new operating environment, the lunar surface. As a result, the requirements for the life cycle of the suit had to be developed and tested with these new operations in mind. Cycle requirement and testing for the xPGS suit utilized functional tasks in lieu of isometric cycles to understand the life of the suit more realistically. Manned cycle testing of the xPGS was conducted by performing repetitions of a series of tasks that reflect predicted Lunar EVA operations. The test series utilized a gravity offload system to simulate Lunar gravity environment. Cycle testing concluded in October of 2022 after 30 test dates throughout the fall of 2022 with lessons learned that will be critical for future spacesuit design. Specific lessons learned with regards to suit performance and test methodology are provided.

[59] ***Testing the Exploration Conops(Excon) Mockup Suit in Lunar Analog Environments in 2022***

Zachary Tejral (NASA), Zachary Fester (NASA), Christine Flaspohler (NASA), Tommy Keomany (NASA), Kristine Davis (NASA), Trevor Graff (Jacobs Engineering) and David Coan (The Aerospace Corporation).

*Abstract*

Understanding how to effectively train for Extravehicular Activities (EVAs) for Artemis missions is critical. Developing high-fidelity simulation environments is important for Artemis mission preparation. Because the actual Lunar exploration environment cannot be fully replicated on Earth, it is paramount to determine where and how to properly train the Artemis team. The overall focus for this test series was developing the capability to perform Artemis simulated EVAs in high-fidelity, full-scale environments. This test series was broken into 3 distinct tests titled after the EHP integrated test team: Joint EVA Test Team (JETT). The test locations are planned to serve as Artemis training sites and were selected because of their relevance to the expected Artemis Lunar terrain. JETT1 was conducted near Kilbourne Hole by El Paso, Texas and focused on hardware development and checkout. JETT2 was conducted in the Icelandic Highlands and began the transition towards EVA concept operations (con-ops), risks and technology. JETT3 was conducted near SP Crater by Flagstaff Arizona and focused on simulating the Artemis III mission with a simulated Houston based Flight Control Team (FCT) and a Science Mission Directorate (SMD) science team. All three JETT tests utilized the Excon mockup space suit. The Excon mockup suit is a light-weight, unpressurized Exploration Extravehicular Mobility Unit (xEMU) simulator. While it cannot replicate the feel of working within a pressurized suit, it does introduce similar volume constraints and some of the mobility programing to simulate the user experience in the xEMU. Overall, the JETT testing was able to create a simulated Lunar EVA and have two subjects perform full scale operations in line with Artemis III mission expectations. Future work is planned to continue to improve the simulation quality of Lunar EVA simulations.

[60] ***Actively Controlled Louver for Human Spacecraft Radiator Ultraviolet (UV), Dust, and Freeze Protection***

Darnell Cowan (NASA).

*Abstract*

This paper examines the use of actively controlled louvers to attenuate UV and dust, as well as mitigate freezing concerns for human spacecraft radiators during Artemis missions. Artemis missions to the lunar orbit or surface will expose the radiators to high energy UV radiation and dust, which will degrade the radiator’s coating emissivity and consequently reduce heat rejection performance. In addition, subfreezing environmental temperatures during transit to lunar orbit and nighttime on lunar south pole can rupture coolant tubes, reduce heat rejection performance, and worst-case scenario result in a Loss of Mission (LOM). Louver technology would be a promising solution to maintaining radiator performance and integrity for Artemis missions, but heritage louvers are passively controlled. This technology needs maturing to active control, or motor actuation, to achieve faster thermal response times. Actively controlled louver design considerations are discussed in this paper. The analysis that follows shows actively controlled louvers can attenuate high energy UV radiation and dust, as well as protect the coolant from freezing.

[62] ***EMU Ventilation Loop Simulation and Assessment of Contamination of the EMU Sublimator Hydrophilic Coating***

Alex Wickham (Reaction Systems, Inc.), Colin Campbell (NASA Johnson Space Center), Michael Humbert (Collins Aerospace) and David Wickham (Reaction Systems, Inc.).

*Abstract*

Controlling moisture is a critical function performed in the spacesuit during extra vehicular activity (EVA) missions. Currently, this function is carried out by a sublimator, which is coated with a hydrophilic material. Tests have shown that siloxane compounds can off-gas from the helmet absorption pad extender (HAP-E) and helmet absorption band (HAB) when they are at elevated temperatures, and initial testing indicated that siloxanes could damage the hydrophilic coating. Therefore, more representative testing was needed. Important test considerations were source and destination kinetics, system geometries, scrubbing efficacy by the activated charcoal from the MetOx canister, and other benefits that derive from active condensation occurring on the hydrophilic coating during exposure. A ventilation loop, which was originally constructed to test hardware for control of CO2 and trace contaminants under EVA conditions, was modified to conduct the siloxane off-gassing tests. A vacuum compatible acrylic chamber was installed to simulate the suit volume. A steel beaker located in the chamber contained the HAP-E and HAB materials and was heated with two band heaters. The flow exiting the chamber passed through a LiOH cannister, which contained carbon beds to simulate their function in the MetOx. The flow then was directed into a smaller volume that contained a coupon, which was coated with the hydrophilic material and was maintained at 50°F. Moisture was injected upstream of the suit volume simulator to maintain the dew point between 55°F and 65°F. The pressure was controlled to between 3.8 and 4.4 psia, and the flow was held at 6 acfm. The system was run for an equivalent of 25 10 h EVAs, where the HAP-E/HAB materials were changed out after each EVA. The effect of the potential off-gassing on the coupon was measured after each EVA period.

[63] ***Analysis of the Solid Products from the OSCAR and the AOWG Trash Processing Systems***

Anne Meier (NASA), Mahmoud Matar Abed (University of Minnesota), Stacy Carrera (Pioneer Astronautics), Joel Olson (Southeastern Universities Research Association) and David Rinderknecht (NASA).

*Abstract*

Two trash conversion systems that process space logistical trash for conversion into gases and liquids have minor solid product formation consisting of primarily high carbon ash, inorganic salts and aluminum metal flakes. These solid products necessarily comprise part of the system output because the thermal degradation processes intentionally operate at temperatures below aluminum vaporization and do not convert all solid inorganics or carbon-based compounds into gaseous compounds (i.e. CO2 or CH4). The two systems included the Orbital Syngas/Commodity Augmentation Reactor (OSCAR) combustion system funded by the NASA Space Technology Mission Directorate (STMD) located at NASA’s Kennedy Space Center, and the Advanced Organic Waste Gasifier (AOWG) steam reforming system developed by Pioneer Astronautics in Lakewood, Colorado, and funded by the NASA Small Business Innovation Research (SBIR) Exploration Systems Development Mission Directorate (ESDMD). OSCAR residual solids were collected from suborbital flight and ground-based laboratory testing, while all AOWG samples were collected from ground testing. This report discusses the solid product characterization, including elemental analyses performed with scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS), and surface chemistry performed with x-ray photoelectron spectroscopy (XPS). A particle size analysis was performed with sieves, followed by SEM analyses. These analyses were performed to elucidate what high value products can be extracted or utilized from the solid products for follow on infusion into chemical feedstocks, manufacturing additives, or in-situ construction-based material needs.

[64] ***xPLSS Structural Backplate Design, Manufacture, and Test Overview***

Sarah Hargrove (NASA), Sean Miller (NASA) and Alicia Baker (Jacobs/NASA).

*Abstract*

NASA Johnson Space Center (JSC) has been developing and building a new detailed design of the Exploration Extravehicular Mobility Unit (xEMU) space suit to support future International Space Station (ISS) and Lunar Artemis missions. The Exploration Portable Life Support System (xPLSS) of the xEMU contains some clever new technologies to meet the requirements to provide Extra Vehicular Activity (EVA) capability on the ISS and the Moon. The suit must interface with and fit through ports and airlocks of at least three vehicles: ISS, Human Landing System (HLS), and Gateway. The first partial xPLSS experimental flight unit called SWME EXPRESS Rack Flight Experiment (SERFE) that was a rack-deployed thermal control system payload on the ISS for two years (2020-2022). The first complete assembly of the xEMU was built as a Design Verification Test (DVT) unit (2022); similar to but more extensive than an Engineering Development Unit (EDU). The xPLSS Backplate serves not only as the structural backbone of the xPLSS and SERFE systems but also contains innovative design features to reduce the: mass, complexity, parts count, number of seals (and therefore leak potential), and outer dimensions of the entire assembly. This paper provides an overview of these new design features, manufacturing processes, system interfaces, and SERFE/DVT test results of the Backplate as part of the xPLSS/xEMU.

[68] ***Mitigation of Silver Ion Loss from Solution by Polymer Coating of Metal Surfaces, Part V, and Related Developments***

John Vance (NASA AMES RESEARCH CENTER / KBR) and Lance Delzeit (NASA).

*Abstract*

Ionic silver (Ag+) biocide is a leading candidate to provide residual microbial control in spacecraft potable water systems but suffers from rapid concentration loss due to interactions with the metallic containers and tubing. One approach to mitigate this is the coating of metal surfaces with an inert barrier film. In previous reports, we have described our investigations addressing Ag+ loss mitigation and adhesion performance of parylene barrier coatings on coupons of several metal alloys and 316L tubing under static immersion, including tubing with fittings subject to several assembly/disassembly cycles. In such conditions, parylene-C and -AF4 coatings have shown excellent Ag+ loss mitigation and mixed long-term adhesion performance, depending on parylene species and substrate surface chemistry/structure. Testbed systems were developed to investigate the performance of parylene-C barrier coatings, under more challenging and realistic conditions, in order to evaluate potential suitability for use. In Part V of this series, we report on the current operational configuration of the Bellows Testbed and experimental Ag+ loss mitigation performance with Parylene-C coating on a 316L edge-welded bellows under long-duration cyclic operation. Significant improvement in Ag+ retention over bare metal was observed during extended operation (26 weeks, nearly 2000 bellows cycles). In addition, we report limited continuation work with parylene-C coated coupons (with total immersion duration of 3 years) and tubing with fittings for Ag+ loss mitigation, and Ag+ compatibility with rigid PEI and PVDF engineering polymers. Finally, we report on Ag+ loss mitigation experiments with thermal CVD hard coatings (Dursox™ and Dursan™) on 316L and on compatibility experiments with PEU elastomer.

[70] ***A Cryogenic CO2 Scrubber with an Integrated Switchable Heat Pipe***

Weibo Chen (JPL), Luis Fonseca Flores (JPL) and Scott Roberts (JPL).

*Abstract*

Human missions to explore Moon, Mars, and beyond will require reliable, compact air revitalization systems. Using a cryogenic separation system to sublimate CO2 in the processed air steam and thus remove it from the air flow is a very attractive approach for long-duration missions because it eliminates the need for consumable adsorption systems. The required cryocooling power to achieve the target CO2 removal rate for a spacecraft with four crewmembers is quite high, more than tens of Watts below 125 K. A critical need for this technology is a cryogenic CO2 scrubber with an integrated heat transport mechanism to efficiently transfer heat to a remotely located active or passive cooler during the collection phase, and to thermally disconnect from the cooler during the regeneration phase to eliminate the need for two separate cryocoolers. To meet this need, we are developing a CO2 scrubber with a built-in cryogenic liquid trap switchable heat pipe to connect the scrubber with a cooler. The scrubber has enhanced heat transfer surfaces to collect CO2 snow. The enhanced surfaces are directly cooled by evaporation of heat pipe working fluid, instead of relying on thermal conduction cooling to minimize temperature gradients on the enhanced surfaces. The enhanced surfaces also have features to promote a uniform air flow and minimize impact of channel clogging as CO2 accumulates. The design of the scrubber and switchable heat pipe is built on JPL’s experience in additive manufacturing of two-phase thermal devices with porous media. This paper discusses the design of the scrubber and the switchable heat pipe, as well as the test setup and preliminary test data for the proof-of-concept switchable heat pipe.

[71] ***Capacitively-Coupled Contactless Conductivity Detection (C4D) for In-Line Ionic Silver Monitoring***

John Vance (NASA AMES RESEARCH CENTER / KBR), John Abdou (KBR) and Lance Delzeit (NASA).

*Abstract*

Effective techniques for the in-line concentration measurement of ionic silver (Ag+) biocide are desired to ensure nominal dosing. The electrolytic conductivity change produced by chemical dosing of ca. 200-400 ppb Ag+ (~0.25-0.50 µS/cm) into highly-purified potable water is linearly related to the concentration dosed, and could serve as a useful proxy. In a previous work, the potential compatibility issues associated with conventional (wetted-electrode) conductivity measurement of dilute Ag+ solutions, as well as potential mitigations were discussed. An alternative approach, capacitively-coupled contactless conductivity detection (C4D), was also proposed. C4D uses electrodes placed outside an inert, insulating material, with dielectric polarization, enabling the production of an electric field and resultant current across the analyte solution that is monotonically related to its electrolytic conductivity. In this work, a systematic investigation of the performance of a COTS C4D instrument with 1/16” (1.59 mm) outer diameter flow tubing (eDAQ Pty. Ltd., Australia) for electrolytic conductivity measurement in the range of interest (~0.1-6.0 µS/cm) is reported. A series of test apparatuses were constructed to flow analyte solution of well-controlled conductivity through the C4D instrument by pumping of a mixture of two electrolyte solutions. The effects of excitation frequency and analyte conductivity range on instrument response were predicted based on theory and characterized experimentally. Analyte conductivity changes on the order of 0.05 µS/cm (equivalent to 40 ppb Ag+) were reliably resolved, but experimental difficulties prevented completion of satisfactory calibration curves spanning the entire 0.1-6.0 µS/cm range. Instrument response was found to be similar with both NaCl and AgNO3 solutions. A passive side-stream system for integration with a practical spacecraft water processing system was demonstrated, and the potentially deleterious effects of two-phase flow (entrained bubbles) on flow reliability and measurement accuracy were considered.

[72] ***On-orbit Thermal Performance of the JWST Mid-Infrared Instrument***

Bryan Shaughnessy (RAL Space), Tim Grundy (RAL Space), Samuel Tustain (RAL Space), Mireya Etxaluze (RAL Space), Bret Naylor (JPL) and Mark Weilert (JPL).

*Abstract*

Authors Bryan M. Shaughnessy(1), Tim Grundy(1), Samuel Tustain(1), Mireya Etxaluze(1) Bret Naylor(2) and Mark Weilert(2).

1 RAL Space, STFC Rutherford Appleton Laboratory, UK 2 Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Abstract The James Webb Space Telescope (JWST) observatory was launched on the 25th December 2021. This was followed by a commissioning phase of about six months, where the observatory deployed to its final configuration and transferred to its L2 orbit location, whilst cooling science components and instruments down to their cryogenic operating temperatures.

The Mid-Infrared Instrument (MIRI) is one of four scientific instruments on the JWST observatory. It provides unique capabilities to probe the deeply dust-enshrouded regions of the universe, investigating the history of star formation both near and far.

The MIRI is the coldest instrument on the observatory. Its thermal design is driven by requirements to cool an Optics Module (OM) to below 16 K and detectors within this to below 7 K with a stability of <10 mK over 1000 seconds. The OM is accommodated within the passively cooled Integrated Science Instrument Module (ISIM). The instrument temperatures are achieved by a combination of thermal isolation from the ISIM and active cooling by a dedicated cryocooler.

This paper summarises briefly the thermal design and pre-launch thermal verification of the instrument. It goes on to report the MIRI thermal performance through the commissioning phase, and concludes with lessons that can be applied to future similar missions.

[73] ***Solid Waste Ultrasonic Drying Performance under Zero Gravity Condition and the Impact on Material Bioactivity***

Ayyoub Momen (Ultrasonic Technology Solutions), Connor Shelander (Ultrasonic Technology Solutions), Jonathan Bigelow (Ultrasonic Technology Solutions) and Tra-My Justine Richardson (NASA).

*Abstract*

Our study aims to investigate the drying performance of direct contact ultrasonic drying for bagged human solid waste under zero gravity conditions. Unlike the conventional thermal drying methods, direct contact ultrasonic drying does not use substantial heat to evaporate water. It, therefore, is not bound by the high energy input required for water vaporization. Using piezoelectric transducers, this novel drying method mechanically removes water by shaking the object rapidly (on a micron-scale). By partially bypassing the evaporation process, the technology demonstrates a much higher efficiency and drying speed on bagged human solid waste. In this paper, we will report the ultrasonic drying performance of the simulated feces on multiple piezoelectric transducers across a membrane under zero gravity conditions. We will also report this process's impact on the inoculated samples' biological activities. This study's result could help design a better, lighter, and more compact solid waste management system for ISS and other space applications.

[74] ***V-HAB Atmosphere Modeling and Simulation for a Crewed Polar Sortie***

Amrita Singh (University of Colorado Boulder), Trayana Athannassova (University of Colorado Boulder), James Nabity (University of Colorado Boulder) and Claas Olthoff (Airbus).

*Abstract*

Habitats beyond Low Earth Orbit (LEO) must include a robust and reliable Environmental Control and Life Support System (ECLSS) to meet the environmental and metabolic needs of the crew with minimal support from Earth. The University of Colorado Boulder HERD Graduate Project team designed an ECLSS for a notional Human Landing System (HLS). The proposed ECLSS will support two or four crewmembers on the lunar surface during a 6.5-day surface sortie or 31.8-day extended surface stay, the latter with resupply from preplaced assets. Modeling and simulation of the system-level dynamics during these mission scenarios is necessary to verify and validate the ECLSS design. The Virtual Habitation modeling and simulation tool (V-HAB) has been under development at the Technical University of Munich since 2006 to dynamically simulate life support systems and their interactions with crew metabolism. Firstly, this work presents a V-HAB system-level model of the HERD team’s HLS ECLSS, supported by the development and validation of two new component-models within the V-HAB tool: a lithium hydroxide bed for carbon dioxide removal and a Nafion membrane for humidity control. Secondly, a V-HAB crew model for a 6.5-day Polar Sortie mission simulates varying crew metabolic loads from nominal and extravehicular activities over the course of the mission. Finally, we integrate the system-level ECLSS model with the crew model to assess the ability of the proposed HLS ECLSS to maintain crew health and support crew activities throughout a Polar Sortie.

[75] ***Considerations For Waste-to-Base Future Research Paths***

Steven Sepka (NASA), Michael Ewert (NASA), Jeffrey Lee (NASA (retired)) and Andrew Shapiro (HeroX).

*Abstract*

Developing innovative technologies to reprocess low value waste into high value base products will enable a new “Waste-to-Base” (WtB) capability leading to innovative approaches to space mission design. Systems engineers and mission architects will work together under a new paradigm in logistics planning. Equipment, components, packaging,storage, and structures will be understood not only by functional requirements, but also in terms of useful lifetimes and materials of construction. The advent of a new technical discipline- reprocess engineering - will grow from the intersection between chemical, mechanical, and systems engineering, mission design, and logistics planning. A crowdsourcing approach was employed to gather low Technology Readiness Level (TRL) concepts into workable solutions for issues in trash management, CO2 processing, foam reprocessing, and fecal processing. The results of the crowdsourcing activities are summarized along with a discussion for future technology development work.

[77] ***Alternate Approach to Multi-Layer Insulation Modeling to Reduce Node Count***

Hume Peabody (NASA-GSFC) and Chris Evans (NASA-GSFC).

*Abstract*

For models with a limitation on the overall node count, the typical approach to Multi-Layer Insulation (MLI) modeling may generate nodes that are necessary for the analysis, but do not represent components of particular interest. This leaves fewer nodes that can be utilized to model components of greater importance than the MLI. A common approach to modeling MLI is to include a separate MLI node representing the outer layer of the insulation and a radiative coupling based on the area multiplied by an effective emissivity. Therefore, wherever insulation is included, one node is needed for the underlying surface and another node for the insulation. Since many spacecraft and instruments include MLI covering a sizable portion of their designs, this may result in a considerable number of nodes being used for MLI. An alternate method to MLI modeling was developed that eliminates the MLI node, while still preserving the effect of the insulation for the underlying surface, thereby increasing the available nodes that could be used elsewhere in the model. This approach relies on preserving the baseline reflectivity, while reducing the absorptivity (based on the blanket effective emittance) and including a transparency. An inactive second surface is placed just behind the base surface that fully absorbs any energy that is transmitted without including its effect in the model. In essence, this approach applies only the energy that makes it through the blanket to the underlying surface. This method was tested out on the Roman Space Telescope model in local areas in preparation for its use in the generation of a launch model, which is constrained in the allowable node count. This paper documents the performance of the method and presents a comparison between the One-Node MLI method and the traditional two node MLI approach.

[78] ***A Simulated Air Revitalization Task to Investigate Remote Operator Human-Autonomy Teaming With Communication Latency***

Jacob Kintz (University of Colorado - Boulder), Young-Young Shen (MDA Ltd.), Savannah Buchner (University of Colorado - Boulder), Allison Anderson (University of Colorado - Boulder) and Torin Clark (University of Colorado - Boulder).

*Abstract*

Future crewed missions to deep space will involve communication latency that makes Earth-based mission control infeasible. Autonomous systems may be able to remedy some of the challenges presented by this lack of real-time mission control. While communication latency’s impact on human-human teaming has been studied, less understood is how latency impacts humans in supervisory control roles as they work with autonomous systems. We have developed a human-autonomy teaming task in which experiment participants act as remote operators communicating with an autonomous system onboard a deep space habitat with a simulated 10-second round-trip communication delay. This magnitude of communication delay is understudied but could be encountered on future lunar missions utilizing Gateway, or on deep space missions as approaching crews communicate with autonomous systems onboard distant habitats. Such autonomous systems will likely have a high level of autonomy as they maintain habitats during periods of dormancy, operating independent of Earth-based control. Motivated by this future scenario, the simulated autonomous system in our task can have a high level of autonomy as it maintains simulated air revitalization systems onboard the habitat (CO2 removal, O2 generation, trace contaminant removal), consulting with the remote human operator only when issues arise. This paper presents the motivation for our task, a discussion of previous work investigating human-autonomy teaming and communication latency, a description of the task’s design and operation, and brief examples of past use and future work.

[79] ***Prototype of Loop Heat Pipe with Electrohydrodynamic Conduction Pump for Active Shutdown Function***

Masahito Nishikawara (Toyohashi university of technology), Takeshi Miyakita (Japan Aerospace Exploration Agency), Genki Seshimo (Toyohashi university of technology), Hiroshi Yokoyama (Toyohashi university of technology) and Hideki Yanada (Toyohashi university of technology).

*Abstract*

Loop heat pipes (LHPs) are attractive devices to passively cool the electronic devices in spacecraft. The LHP operation needs to be shut off in some cases, for example, lunar rovers on cold nights, so that the temperature of the electric devices does not decrease too much. Some techniques have been developed for LHPs capable of heat switching in either active or passive ways. We develop a new active technology. To control liquid flow in the liquid line of the LHP, an electrohydrodynamic (EHD) conduction pump is placed in it. The EHD pump operates so that liquid flows in the reverse direction against the normal LHP flow. The pressure developed by the EHD pump overcomes the capillary pressure developed in an evaporator, and then the LHP operation stops. The advantages of using the EHD pump to control LHP operation are a low pressure drop during normal LHP operation, low power consumption, and no moving parts, although electric power and high voltage are needed. To demonstrate our proposal, an EHD conduction pump has been developed and evaluated to obtain pump characteristics with varying applied voltages. EHD simulations were conducted to design the pump, including the electrode configuration. Because EHD pumps can work only with dielectric liquids, R134a was chosen as the working fluid. When an appropriate high voltage was applied to the EHD pump incorporated into the liquid line of an LHP, the LHP was shut down successfully.

[80] ***Is Direct Methane Removal in Human Space Flight Required?***

Bettylynn Ulrich (Northrop Grumman).

*Abstract*

Environmental Control and Life Support (ECLS) is a major part of human space flight and habitation. Great care is taken to ensure an environment not only capable of supporting human life, but also one that is comfortable. One aspect of that habitable and comfortable environment is controlling trace contaminants in the atmosphere. The document the National Aeronautics and Space Administration (NASA) uses to govern the levels of specific compounds considered trace contaminants is the Spacecraft Maximum Allowable Concentrations (SMAC) for Selected Airborne Contaminants (JSC 20584) which is publicly available on the internet. While more attention is given to ammonia (NH3), propylene glycol (C3H8O2), and other physically toxic compounds, one of the most difficult atmospheric trace contaminants to remove directly is methane (CH4). Many technical papers have discussed the process of direct CH4 removal – what is required and potential future techniques to mature. This paper explores how to determine whether CH4 removal is required and the advantages or disadvantages associated with its implementation.

[82] ***Leaky Waveguide Solid Sorbent Desorption System Overview***

Chris Delnero (Lockheed Martin Space), Clifton Courtney (Lockheed Martin Aeronautics), Arun Bhattacharyya (Lockheed Martin Space) and Kevin Payne (Lockheed Martin Space).

*Abstract*

Metabolic CO2 removal using zeolite 13X has successfully been utilized on the International Space Station (ISS) for over two decades. The current ISS habitation CO2 control system, Carbon Dioxide Removal Assembly (CDRA), and the next generation currently under test, 4-bed CO2 Scrubber, both utilize electrical resistance heaters embedded in an axial canister packed with zeolite 13X to thermally desorb CO2 and parasitic water. Microwave energy, coupled with rough vacuum, has recently been shown to require 30-50% less energy, and ~50% faster desorption times, of zeolite 13X than traditional electrical heaters but still faces challenges of uneven microwave energy distribution. This work will provide an overview of the design, preliminary analysis, and build status of a sorbent desorption approach that utilizes a patent pending leaky waveguide configuration that results in even sorbent energy deposition and lower absorption phase pressure drop. This system is expected to provide higher frequency absorption/desorption cycles, lower overall system mass, and produce a higher purity of collected CO2 than traditional heater desorption approaches.

[83] ***Spacecraft Water Analysis with Nanopore (SWAN)***

Zehui Xia (Goeppert LLC), Brian DiPaolo (Goeppert LLC), David Niedzwicki (Goeppert LLC) and Vanya Buvac (Goeppert LLC).

*Abstract*

To provide a fast, simple and reliable way of identifying unwanted constituents present in the water systems aboard ISS and potentially other spacecraft (e.g., Artemis Gateway Outpost), we aim to develop a robust, portable and easy-to-use sensor system based on solid-state nanopore technology, a.k.a. SWAN. The current water monitoring capability in the ISS is only limited to electrical conductivity, total organic carbon and selected ions of iodine and silver. Any other analyte must be brought back to Earth. The maintenance of safe living conditions in ISS is important in order to support the scientific activities of the crew, and to ensure their unharmed return to Earth upon mission completion. The solid-state nanopore system presents an inherently single-molecule sensor system that works on the principle of pore occlusion by the molecule which then can be registered as a change of the electrical current. Each analyte establishes its unique electrical signal upon passing through the nanopore of tailored characteristics. Previously we reported the detection of mercury and lead using 2-5 nm- diameter and 20-nm thick nanopores at concentrations down to 5 nM and 0.5 nM, respectively, both of which are below both EPA requirements and SWEGs. We continued to mature the sensor platform and successfully used it to detect diethyl phthalate (DEP), a desirable small organic analyte (~1 nm) to NASA for water monitoring purpose, without tedious sample prep and heavy use of organic solvents which are required in the typical mass spectroscopic methods on earth. This direct detection of the naked molecule is enabled by innovative ultrathin (< 5 nm) and ultrasmall (~ 1.5 nm) nanopores. SWAN will allow the detection of low-concentration analytes in water and is thus a promising tool for a miniaturized analytical laboratory for future NASA missions, together with other analytical tools available.

[85] ***Two Phase Capillary Evaporator Characterization for an Ammonia Cooling MPL Dedicated to Highly Dissipative Electronic***

Benjamin Lagier (IRT Saint Exupery Toulouse (AIRBUS Defence and Space)), Frédéric Boudesseul (IRT Saint Exupery Toulouse (THALES Alenia Space)) and Laure Baert-Authier (IRT Saint Exupery Toulouse (EPSYL)).

*Abstract*

Highly dissipative electronic components are more and more common on current telecommunication spacecraft due to digitalization of payload architectures. This trend comes with new thermal management challenges both in terms of total heat to reject and power densities at component level. 2Φ MPL are cooling system already used in commercial spacecraft and intended for high capacity cooling and efficient heat transfer coefficients. At dissipative component level, a portion of coolant fluid is vaporized in an evaporator, classically circular tubes interfaced with the hot source. The vapor mass fraction is constantly increasing until outlet of evaporator. A serial connection, between different evaporators, is the usual approach to prevent potential issues with parallel flows: branches dry out or flow instabilities. This classical architecture shows limitations in terms of high heat flux density handling, pressure drop generation and flow rate needs.

The solution characterized in this work consists of a novel evaporator architecture for an ammonia 2Φ MPL performing a flow separation (vapor and liquid apart) and achieving very high heat transfer coefficient at a high heat flux density (up to 30 W/cm2) on a 4cm² surface. It consists of a 3 ports evaporator: the inlet subcooled liquid flows through it with very limited pressure drop (< 100 Pa) and a portion of the flow is withdrawn through capillary structures, vaporized and exit through a dedicated vapor port. These structures are made of grooves engraved directly onto the evaporator aluminum baseplate and an LHP-like capillary PTFE wick. This solution enables, at a global system level, parallel and series mounting of several evaporator units with a limited impact on performances. Indeed, pressure drops of the vapor branch are handled directly by capillary forces, leaving only single-phase liquid pressure drop variation handled by the pump itself.

[87] ***Characterization of Microbes Present in Purge Pump and Separator Assembly Ground Testing***

Kristen Saban (NASA George C. Marshall Space Flight Center), Yo-Ann Velez Justiniano (NASA George C. Marshall Space Flight Center), David Long (NASA George C. Marshall Space Flight Center), Peyton Herrneckar (NASA) and Eric R. Beitle (Jacobs ESSCA).

*Abstract*

Microbiology is a growing sector in the field of human spaceflight development. Microorganisms have been observed and studied on crewed missions and space stations. The presence of microbes has potentially detrimental effects on crew health and hardware structure and maintenance. These effects are especially present on flight hardware involved with human wastewater, such as the Water Recovery System (WRS) of the International Space Station (ISS). The Urine Processor Assembly (UPA) of the WRS was recently updated to include the Purge Pump and Separator Assembly (PPSA). The PPSA improves the purge capability and therefore overall performance of the UPA. This paper details microorganisms present within three PPSA pumps after ground testing. Ground microbial testing and decontamination are essential for preventing further system contamination during flight technology demonstrations. The microbial characterization from these pumps includes qualitative and quantitative descriptions of bacterial and fungal species present. DNA sequencing, genome assembly, and identification were performed using Nanopore MinION and KBase. All three sampled pumps showed microbial growth. Bacteria were identified in both the Burkholderia and Ralstonia genera. This work has implications for the viability of urine processor technology against biofouling for longer duration spaceflight missions where hardware replacement is infeasible.

[88] ***Methane Pyrolysis Enables Closed-loop Oxygen Recovery - Brassboard Evaluation***

Amanda Childers (Honeywell Aerospace), Stephen Yates (Honeywell Aerospace) and Mark Triezenberg (Honeywell Aerospace).

*Abstract*

Methane pyrolysis is an essential element for a closed-loop ECLS system that incorporates a Sabatier system, since this system converts carbon dioxide and hydrogen to methane and water, and the hydrogen value of the methane must be recovered to complete closure. Methane pyrolysis converts methane, at high temperature, to carbon and hydrogen. The hydrogen is required by the Sabatier reactor to completely convert the available carbon dioxide, and there are a number of re-use opportunities for the carbon. In this paper, we describe the construction and operation of a full scale brassboard methane pyrolysis reactor before it was provided to Marshall Spaceflight Center for further evaluation. The system converted methane at a 1.45 SLPM scale to carbon and hydrogen with 50-80% conversion and >95% selectivity. The effects of temperature, and substrate design were important to obtaining reliable conversion. In addition, experiments in which a feed simulating the output from a Sabatier reactor were also completed. A second generation Flight Like Advanced Materials Reactor, with similar scale but using light weight and more durable materials will also be described.

[89] ***Human Landing System ECLSS Research and Design***

Cody Bahan (University of Colorado, Boulder), Nathan Foote (University of Colorado, Boulder), Kathleen Laughton (University of Colorado, Boulder), Adam Oswald (University of Colorado, Boulder), Aanshi Panchal (University of Colorado, Boulder), Chad Pflieger (University of Colorado, Boulder), Samuel Trux (University of Colorado, Boulder), Stuart Tozer (University of Colorado, Boulder) and James Nabity (University of Colorado, Boulder).

*Abstract*

A Human Landing System's (HLS) Environmental Control and Life Support System (ECLSS) supports and satisfies the physiological needs of the crew. The National Aeronautics and Space Administration (NASA) developed five Design Reference Missions (DRMs) for the Artemis program, driving the HLS system design. For this graduate student project, the team designed elements of an ECLSS to support two DRMs. The first DRM (001) plans for a crew of two on a 6.5-day sortie mission with at least four Extravehicular Activities (EVA). In the second DRM (002), four crew members embark on a 31.8-day surface mission with pre-placed surface assets. Additionally, ECLSS capabilities were addressed with a unique DRM that confines a crew of four within the HLS during a 6.5-day surface stay.

An astronaut's day-in-a-life schedule was developed to estimate the crew's metabolic outputs based on the NASA Human Integration Design Handbook (HIDH) for the 95th percentile American male. After identifying these requirements, trades were performed within critical ECLS subsystems (pressure, temperature, humidity control, and atmospheric revitalization). Subsequently, the team constructed functional subsystem designs, analyzed failure modes, and developed system redundancies. Estimations of mass, volume, and power were derived from high technology readiness and commercially available technologies. The final design, accompanied by the risk and failure analysis concludes that the system can support the crew during the chosen missions. Future work includes constructing physical test beds and developing simulations to further validate the design.

[90] ***Analysis of CDC Bioreactor Internal Thermal Measurements and Sample Coupon Temperatures***

Eric Beitle (Jacobs Space Exploration Group), Connor Murphy (Jacobs Space Exploration Group), Yo-Ann Velez Justiniano (NASA George C. Marshall Spaceflight Center) and Darla Goeres (Center for Biofilm Engineering, Montana State University).

*Abstract*

The Center for Disease Control and Prevention (CDC) bioreactor is an integral laboratory tool for the Environmental Control and Life Support Systems (ECLSS) biofilm formation and growth research program. Critical to this research is the need to adjust and maintain various surface temperatures of the coupons housed within the CDC Bioreactor. The purpose of this study was to provide quantitative temperature gradient information when the CDC Bioreactor was operating according to several process scenarios. Two primary process parameters were evaluated. For the first set of test parameters, the liquid level was maintained at 350 mL, with an inlet flowrate of 0.1 mL/min, 1 mL/min, 10 mL/min. The liquid was allowed to gravity drain out of the outlet spout. For the second set of test parameters, the liquid level within the reactor was maintained at 550 mL, with an inlet flow of 0.1 mL/min, 1 mL/min, 10mL/min and draining intermittently controlled to 0.8 mL/min to maintain the 550 mL level. Due to the placement of the thermocouple in the reactor, a difference in temperature occurred between the coupon surfaces and target Bioreactor temperature when operated according to the first set of test parameters. When the reactor was operated according to the second set of parameters, which resulted in the thermocouple being submerged, the temperature gradient was eliminated. The results demonstrated minimal temperature gradient between the top and bottom coupon surfaces for coupons placed in a single rod within the CDC Bioreactor for both sets of test parameters evaluated. The collection of this information helped to explain previous ECLSS biofilm formation test runs, along with providing guidance on best operating practices for future ECLSS experiments. The placement of the thermocouple also helps to explain the challenge of achieving and maintaining bulk liquid temperatures when biofilm is grown according to the standardized methods.

[92] ***ANITA-2 – the Advanced Multicomponent Air Analyser for ISS – First Year of Operation, Hardware Behaviour, Expected Lifetime and Reliability as well as Future Updates for ANITA-3.***

Lukas Pfeiffer (OHB), Michael Gisi (OHB System AG), Eckart Göhler (OHB), Roland Seurig (OHB System AG), Armin Stettner (OHB System AG), Atle Honne (SINTEF), Kristin Kaspersen (SINTEF), Jens Thielemann (SINTEF), Anders Erik Liverud (SINTEF ICT), Pierre Rebeyre (ESA) and Kari A. Bakke (SINTEF).

*Abstract*

The ANITA2 (Analysing Interferometer for Ambient Air) instrument is a trace gas analyser designed to operate onboard the ISS to monitor the cabin atmosphere. ANITA2 can detect more than 35 of the most important trace gases in parallel. The advantages of an ANITA-type instrument include high sensitivity, accuracy, precision, and time resolution of the measurement data, as well as no consumption except electrical power and no production of waste. This also makes ANITA a steppingstone into the future, as a precursor system for crewed stations, bases, and exploration missions, including the (Deep-Space) Gateway and to/on the Moon and Mars. ANITA-2 has been built in a contract between ESA, OHB and SINTEF, launched to the ISS in December 2021 and commissioned in Q1 of 2022. Since then ANITA-2 is monitoring the ISS gas environment on board the ISS. This paper shows the final flight hardware, describes the accommodation on board the ISS and discusses the performance of the Payload on board the ISS compared to a Ground Model. On board data of performance, opto-mechanical sensitivity, stability and reliability are shown and discussed. From this data an estimate is drawn of the expected lifetime of the life limited items. Additionally, a description of the operations concept is given and current on orbit activities are being discussed.

Developments points of for the ANITA hardware are discussed and possible future applications identified.

[94] ***Status of ISS Biofilm Management Testing for the Water Processor Assembly***

Yo-Ann Velez Justiniano (NASA George C. Marshall Space Flight Center), Iulian Cioanta (Sanuwave), Eric R. Beitle (Jacobs Space Exploration Group), Connor P. Murphy (Jacobs Space Exploration Group), Cary McGhin (Sanuwave) and John Jackson (Sanuwave).

*Abstract*

Biofilm growth is a significant concern for NASA's current and future water systems. The International Space Station (ISS) Water Processor Assembly (WPA), which produces potable water from a combination of humidity condensate and urine distillate, has suffered from biofouling incidents. In recent years multiple technologies have been tested to combat this biofouling. Temperature treatments, coated surfaces, and nutrient filters have been tested in-line with bioreactors simulating similar conditions to the wastewater tank. Results from testing indicate that microbial growth persists through multiple conditions, and thus other tests were required to further understand treatment performance. Other plans to tackle biofilm include prototyping an impedance biosensor configuration, developing plasmid treatments, and a shockwave tank. Future testing of these technologies is being discussed to determine a final biofilm treatment regiment for water systems.

[95] ***ANITA2 – the Advanced Multicomponent Air Analyser for ISS – Gas Measurement Results From the ISS Air in 2022***

Atle Honne (SINTEF), Kristin Kaspersen (SINTEF), Kari Anne Hestnes Bakke (SINTEF), Anders Erik Liverud (SINTEF), Jens T. Thielemann (SINTEF), Brian Elvesæter (SINTEF), Michael Gisi (OHB System AG), Lukas Pfeiffer (OHB System AG), Armin Stettner (OHB System AG), Eckart Göhler (OHB System AG), Roland Seurig (OHB System AG) and Pierre Rebeyre (ESA).

*Abstract*

The ANITA2 (Analysing Interferometer for Ambient Air) instrument is a trace gas analyser designed to operate onboard the ISS to monitor the cabin atmosphere. ANITA2 can detect more than 40 of the most important trace gases in parallel. The advantages of an ANITA-type instrument include high sensitivity, accuracy, precision, and time resolution of the measurement data, as well as no consumption except electrical power and no production of waste. This also makes ANITA a steppingstone into the future, as a precursor system for crewed stations, bases, and exploration missions, including the Lunar Gateway and to/on the Moon and Mars. After a successful operation of ANITA1 for 11 months onboard the ISS in 2007 and 2008, the ANITA2 instrument was built in a contract between ESA, OHB and SINTEF and launched to the ISS in December 2021. ANITA2 started its regular operation on March 9, 2022, and it is at the time of writing monitoring 44 gas compounds in the ISS air. This paper covers ANITA2's gas analysis through the commissioning phase on the ISS and the following in-flight air analyses. After start-up, several off-nominal conditions were detected and handled through an updated calibration, which was uploaded to ANITA2 on the ISS for autonomous air monitoring. The updated calibration could also be applied offline to all previously measured spectra, to produce high-quality gas data from the entire period of operation. In addition to the updated calibration for use on the ISS, a semi-local ISS gas scenario was defined, to cover the observed gas variations plus smaller margins than the general scenario of the very robust main calibration. This calibration, which has further improved precision and detection limits for the gases present, was applied offline as basis for air analysis reporting to ESA and NASA.

[96] ***CDC Bioreactor Configuration Method for Volume Level Control with Controlled Inlet and Outlet Flow***

Connor Murphy (Jacobs Space Exploration Group), Eric Beitle (Jacobs Space Exploration Group) and Yo-Ann Velez Justiniano (NASA George C. Marshall Space Flight Center).

*Abstract*

Environmental Control Life Support Systems and other microbiological biofilm studies often utilize small scale bioreactors. Among these options are the popular BioSurface CDC bioreactors, currently being utilized by Marshall Space Flight Center groups researching the impact of biofilms on life support systems. After a recent experimental regime, it was determined additional equipment could be added to augment the capabilities of the bioreactors. Previous research configurations such as ASTM E3161 – 18 relied on an outlet stream gravity draining from a side drain port located above sampling coupons. This limited applications to experimental conditions with a controlled inlet and uncontrolled outlet flow. With the introduction of a small single pole single throw (SPST) reed float switch, a peristaltic pump connected to the outlet drain and a chassis controller, the bioreactor is able to maintain a set level. The modification allows additional variables to be tested, including highly adjustable fill and flush cycles, bioreactor volume, draining and filling control. Once the configuration modifications were implemented through the installation of the new equipment, data was collected to ensure the stability of the level measurements. As the level control switch is a float switch, consideration was taken into account for effects of internal stirring speed, along with effects of inlet and outlet flow rate. Data presented in this study will illustrate the stability and effectiveness of the configuration changes in equipment made to the bioreactor. These configuration changes are proving an effective control method to conduct biofilm mitigation techniques for ECLSS hardware research. The controlled level capabilities allow for a constant drip feed flow rate into the bioreactors, a key aspect of the biofilm mitigation testing.

[97] ***Status of ISS Water Management and Recovery***

Jill Williamson (NASA), Hieu Luong (The Boeing Company), Kristina Robinson (The Boeing Company) and Jonathan P. Wilson (NASA).

*Abstract*

Water management on ISS is responsible for the provision of water to the crew for drinking water, food preparation, and hygiene, to the Oxygen Generation System (OGS) for oxygen production via electrolysis, Waste & Hygiene Compartment (WHC) and Toilet for flush water, and for experiments on ISS. This paper summarizes water management activities on the ISS US Segment as of March 2023 and provides a status of the performance and issues related to the operation of the Water Processor Assembly (WPA) and Urine Processor Assembly (UPA), and the Brine Processor Assembly (BPA).

[98] ***An Investigation into the Effect of Liquid Accumulation on Thermo-Physiologic State using an Advanced Moisture Model Coupled with a High Resolution Human Thermal Model***

Timofey Golubev (ThermoAnalytics, Inc.), Mark Hepokoski (ThermoAnalytics, Inc.), Kevin Ward (W. L. Gore and Associates), Joel Coffel (W. L. Gore and Associates) and Hee Jong Song (NASA Johnson Space Center).

*Abstract*

A physics-based mathematical model for simulating heat and moisture transport on the skin and within clothing was developed to improve the accuracy of human thermal modeling predictions. In a previous study, a set of sweating hotplate experiments was specifically created to obtain test data for model validation. The clothing moisture model was subsequently coupled with a human thermal model and tested by simulating human experiments described in the open literature, which served to verify the model’s ability to predict whole body thermo-physiologic state in work-rest cycles during which sweating was known to occur. In this study, a human subject test was specifically designed to validate the model’s ability to predict local and whole body sweat evaporation and accumulation on the surface of the body. The human subject test incorporated twelve clothed male subjects of moderate physical fitness, ages 18-30, which were prescribed a work-rest cycle in a climate-controlled chamber (25 °C, 50% RH). Two activity levels were considered during the active stage (4 MET vs. 6.5 MET), and two sets of ending ambient conditions were considered for the final rest stage (25 °C vs. 15 °C, 50% RH). Model predictions were compared to the measured local skin temperatures, core temperatures, and whole body sweat losses. In general, the model was able to reproduce the trends observed in the human subject trial, but more importantly, provided insight into how dynamic changes in liquid content can impact the evolution of local and whole body thermo-physiologic state. This study demonstrates the ability of an advanced moisture model to capture distinct physics attributable to moisture accumulation, allowing for increased accuracy in predicting human thermal state and for interpreting the results of measurements derived from human subject tests.

[100] ***Development and Testing of a New Partial Gravity Urine Processor Design and Urine Pretreatment***

Jill Williamson (NASA), Colton Caviglia (NASA), Yo-Ann Velez Justiniano (NASA), Chelsea McCool (ESSCA) and Chelsi Cassilly (ESSCA).

*Abstract*

The Planetary Urine Processor (PUP) is a proposed urine distillation system for lunar or planetary applications, taking advantage of local gravity for phase separation as well as the movement and storage of waste feeds and product water. The PUP utilizes a stationary evaporator with an integrated disposable bag to process urine and capture remaining precipitates. This system aims to increase water reclamation percentage, reduce resource requirements, and enhance reliability/maintainability due to lower system complexity over the existing water recovery system used on the International Space Station (ISS). This paper focuses on the hardware development and testing efforts and the associated urine pretreatment development work.

[101] ***Ground Testing of an Oxygen Concentrator in a Simulated International Space Station (ISS) Cabin Environment***

Laura Soto (NASA), Katerina Lewis (NASA) and Jeffrey Sweterlitsch Ph. D. (NASA).

*Abstract*

The method for supplying medical oxygen to respiratorily-compromised astronauts on the International Space Station (ISS) and in future Orion missions consists of drawing oxygen from high pressure oxygen tanks. An Oxygen Concentrator Module (OCM) is a device that pulls in ambient air and separates out the nitrogen, resulting in a high concentration oxygen source. This technology has the potential to eliminate resupply and oxygen-enrichment issues associated with using high pressure oxygen tanks and become an alternative technology to support medical oxygen operations for future exploration missions. In this study, we test the long-term performance of a Commercial Off-the-Shelf (COTS) OCM in a simulated ISS cabin environment. Humidified air, carbon dioxide, and fifteen representative trace contaminants are continuously injected through a enclosed test chamber where the OCM is challenged. This study included the first successful demonstration of the Trace Gas Injection System (TGIS), which reliably and continuously produced ISS levels of trace contaminants, carbon dioxide, and humidity in an enclosed environment. The TGIS is a new and unique ground capability with significant implications for Test Readiness Level (TRL) advancement of COTS items and Government Furnished Equipment (GFE). This study demonstrated that the tested OCM reliably delivers enriched oxygen mostly at desired performance specifications. This study also demonstrated that the OCM does not inadvertently concentrate trace gases in its oxygen product stream, as detectable concentrations of trace contaminants in the oxygen product stream were at all times below the simulated ISS levels.

[103] ***Carbon Dioxide Removal by Ionic Liquid System (CDRILS): Ground Prototype Testing and Trace Contaminant Removal Integration***

Rebecca Kamire (Honeywell Aerospace), Stephen F. Yates (Honeywell Aerospace), Phoebe Henson (Honeywell Aerospace), Matthew J. Kayatin (NASA), Jack Ford (Honeywell Aerospace), Emir Rahislic (Honeywell Aerospace), Mark Triezenberg (Honeywell Aerospace), Meghan Pipitone (Honeywell Aerospace), Eric Pope (Honeywell Aerospace) and Nathaniel Gressly (Honeywell Aerospace).

*Abstract*

The Carbon Dioxide Removal by Ionic Liquid System (CDRILS) utilizes a continuously recirculated ionic liquid sorbent and hollow fiber membrane contactors for carbon dioxide removal from air. The CDRILS ground prototype was operated under varied process conditions to optimize performance and meet a 4-crew scale carbon dioxide removal rate of 4.16 kg/day at a carbon dioxide partial pressure of 2 mm Hg. Humidity and thermal management at scale, ongoing durability trials, and tests of updated components are key demonstrations that inform refined designs of the upcoming CDRILS flight demonstration unit. In addition, CDRILS has demonstrated trace contaminant removal from simulant cabin air without impact on the CDRILS carbon dioxide removal performance. Removal of trace contaminants from cabin air reduces the contaminant load within the cabin. Benefits to other systems that interface with the cabin air are also achieved. However, trace contaminant removal by CDRILS results in contaminant delivery to the CDRILS carbon dioxide and water condensate product streams, which may in turn be delivered to a Sabatier reactor or Water Processor Assembly. The relative partitioning of the contaminants between the two streams and impacts on downstream systems are evaluated.

[104] ***Integrated Testing of the Air-Cooled Temperature Swing Adsorption Compression System (AC-TSAC) and 4-Bed Molecular Sieve (4BMS)***

Jonathan Wells (KBR / NASA Ames), Kelby Gan (KBR / NASA Ames), Arisa Waddle (ESSCA) and Grace Belancik (NASA Ames).

*Abstract*

The Air-Cooled Temperature Swing Adsorption Compression system (AC-TSAC) is a solid state, sorbent based compressor and storage device, intended to replace the CO2 Management System (CMS) on board the International Space Station (ISS). The CMS consists of a mechanical compressor and a set of accumulator tanks. The AC-TSAC is an important technical option in the air revitalization process, and takes low pressure carbon dioxide (CO2) from a CO2 removal system (like the 4 Bed Carbon Dioxide Scrubber, 4BCO2) and stores and pressurizes it for use in the Sabatier reactor. AC-TSAC is appealing for this role due to its lower weight, power usage, and improved reliability (no rotary parts) compared to the CMS. To prepare for this operating environment, AC-TSAC and 4BMS (the ground development unit for 4BCO2) were connected at MSFC for integrated testing of the two systems. Results from integrated testing with one of the current state of the art flight demonstrations for CO2 removal showcases AC-TSAC ability to deliver pressurized CO2 in a more flight-like scenario. Eight different integrated test scenarios were run for 24 hours each representing different scenarios that may be encountered on ISS, a lunar base, or in Mars transit. Integrated test data will allow for system redesign into a more flight-like configuration.

[108] ***Demonstration of Paragon’s ISRU Propellant Production Subsystem Electrolyzer and Electrolysis Assembly***

Jordan Holquist (Paragon Space Development Corporation), Connor Joyce (Paragon Space Development Corporation), Robert G Rivera (Paragon Space Development Corporation), Philipp Tewes (Paragon Space Development Corporation), Timothy Myles (Giner, Inc.), David Markham (Giner, Inc.), Thomas Ebaugh (Giner, Inc.), Meagan Rich (Giner, Inc.) and Jason Willey (Plug Power).

*Abstract*

To better sustain long term lunar activities, in-situ resource utilization (ISRU) has been proposed for processing the regolith-bound water-ice to provide fresh water, breathable oxygen, and rocket propellant for lunar exploration missions. However, the water-ice is found concurrently with other typically volatile species that would contaminate and degrade downstream processing systems. Paragon Space Development Corporation®, along with their partner, Giner, Inc., has been developing the ISRU-derived water purification and In-situ Hydrogen Oxygen Production (IHOP) subsystem to collect, purify, and process water-ice from permanently shadowed regions (PSRs) on the lunar surface to generate hydrogen and oxygen, incorporating state-of-the-art technologies for water-based ISRU. The primary water purification component of the IHOP subsystem concept is Paragon’s Ionomer-membrane Water Processor (IWP) technology that can selectively transport water vapor through the membrane while rejecting contaminant components. The water electrolysis is accomplished by Giner’s lightweight, proton exchange membrane (PEM) aerospace electrolyzer optimized for ISRU applications. This paper presents results, analysis, and discussion of experimental investigations to demonstrate the performance, endurance, and robustness of the electrolyzer, along with initial demonstration of the electrolysis assembly of the IHOP subsystem. The first build of the electrolyzer stack was tested for a cumulative runtime of 6,000 hours to verify long-term durability and performance. A second build was put through four freeze-thaw cycles with performance testing before and after each cycle to show robustness through non-operational environmental conditions experienced on the Moon. Further, the electrolyzer balance of plant assembly was built and tested. Results met the nominal electrolyzer subsystem performance requirements. The integrated IHOP subsystem will be demonstrated with both water purification using a simulated lunar volatile contaminant load and water electrolysis of the resulting water operating together in future testing.

[109] ***Thermal Design and Control of the Main Electronic Box in Titan Environment for the DraMS Instrument***

Daniel Bae (NASA GSFC), David Steinfeld (NASA GSFC), Franklin Robinson (NASA GSFC) and Samuel Nichols (ATA Aerospace).

*Abstract*

The Dragonfly Mass Spectrometer (DraMS) is an instrument on the Dragonfly mission operating on the surface of the Titan, the Saturn’s largest moon. Titan's atmosphere is nitrogen rich and has surface atmospheric pressure of 147 kPa and temperature of 94 K. Since electronics cannot survive at these extreme temperatures, significant thermal isolation is needed between the electronics and the Titan atmosphere to maintain the components above their survival temperatures. However, the main electronic box (MEB) for the DraMS instrument dissipates significant amount of heat over small volume and a conventional conductive cooling approach cannot be used without significant mass additions. Instead, a fan cooled approach was chosen. Conditioned room-temperature air, supplied by the Dragonfly lander, will flow directly over the MEB’s boards during DraMS operational scenarios. A cooling air manifold is designed with the help of computational fluid dynamics (CFD) simulations to effectively distribute the flow over the actively cooled boards. Since the fan will operate at denser-than-Earth pressures on Titan but Earth-like pressures during ground testing, a thermal test was performed to verify the fan’s thermal performance (at varying levels of pressure) and compared against CFD predictions. This test was performed with a 3-D printed mockup of the MEB with heated metallic plates to simulate the circuit boards. This paper will discuss the analytical CFD work and the thermal tests performed to aid the development of the DraMS thermal/mechanical MEB design.

[110] ***Progress on the Organic and Inorganic Modules of the Spacecraft Water Impurity Monitor, a Next Generation Complete Water Analysis System for Crewed Vehicles***

Stuart Pensinger (NASA Johnson Space Center), Michael Callahan (NASA Johnson Space Center), Evan Neidholdt (KBR), Aaron Noell (Jet Propulsion Laboratory), Nathan Oborny (Jet Propulsion Laboratory), Byunghoon Bae (Jet Propulsion Laboratory), Valeria Lopez (Jet Propulsion Laboratory), Bruce Hancock (Jet Propulsion Laboratory), Marianne Gonzalez (Jet Propulsion Laboratory), Margie Homer (Jet Propulsion Laboratory), Stojan Madzunkov (Jet Propulsion Laboratory), Murray Darrach (Jet Propulsion Laboratory) and Richard Kidd (Jet Propulsion Laboratory).

*Abstract*

The Spacecraft Water Impurity Monitor (SWIM) is a joint collaboration to develop an instrument platform that will perform in-flight measurements and deliver a more complete picture of water quality to decision makers. For exploration missions, returned water samples will not be an option, so spacecraft and habitats will need to be equipped with advanced water monitoring capabilities. Eventually, missions to the moon, Mars, and beyond should be equipped with analytical capabilities roughly analogous to those found in terrestrial labs. Based on what we know about current and future spacecraft environments, SWIM will seek to provide enhanced analytical capability that enables NASA to confidently send astronauts on distant missions without the possibility of returned water samples.

The SWIM architecture can be broken down into an Organic Water Module (OWM) and an Inorganic Water Module (IWM), independent of each other but can be flown together if desired. An integrated system may share some commonality, e.g., single sample injection, sampling consumables, waste, etc. Each of these main modules can be broken down further into separation (if required) and detection modules. Additionally, each separation module can be paired with one or more detection modules depending on mission, spacecraft, customer needs, and size / mass / power constraints.

This paper discusses the research and development progress toward the goal of a total water analysis system. For OWM, one of the analysis techniques that the SWIM team have been developing is a liquid-injection gas chromatograph mass spectrometer system; these systems are the workhorses of analytical chemistry laboratories world-wide. For IWM, the team is exploring a number of technologies ranging from traditional liquid chromatography technologies (e.g., ion chromatography, capillary electrophoresis) to flight-heritage technology such as ion-specific electrodes.

[111] ***Small Satellite Validation of a Simulation Approach for Assessing Dynamic Temperatures in Orbit***

Corey Packard (ThermoAnalytics, Inc.), Timofey Golubev (ThermoAnalytics, Inc.), Daniel Woodford (ThermoAnalytics, Inc.), Madison Rosiek (ThermoAnalytics, Inc.) and Zachary Edel (ThermoAnalytics, Inc.).

*Abstract*

Small satellite launches have proliferated as an economically-efficient approach for space access. Accurately predicting satellite temperatures during orbit is of interest to the satellite community due to a high rate of thermal failure combined with limited means of thermal control due to size, weight, and power constraints. Primary contributors to this radiation-dominant simulation problem include optical surface properties and orbit altitude, which impacts view factors. Additionally, the photovoltaic (PV) panel power output and internal components such as circuit board assemblies and battery cells must be considered, since the PV panels charge the battery pack, which powers the electronics.

To address this simulation need, we developed an automated approach for dynamic orbit thermal prediction. TAITherm, a comprehensive heat transfer simulation software, uses an explicit 3D geometric representation of a satellite to automatically create the radiation and conduction nodal networks necessary for transient thermal simulation. Thermal and optical properties are used as inputs for conduction and radiation, respectively; similarly, space environment, solar position, and solar irradiance boundary conditions are also collected via simple user inputs. CoTherm, a simulation process automation tool, handles the dynamic positioning of the satellite as it orbits the Earth.

In this paper, we detail this dynamic orbit thermal simulation methodology and describe a successful validation of this approach via comparison to published results for a representative 3U CubeSat. We then demonstrate the integration of PV power yield predictions, which depend on temperature, incident angle and radiation degradation. We also incorporate a battery pack using equivalent circuits, include charging of the battery cells from the PV panels, and show how electronic circuit board assemblies can be used in assessing power budgets. This study lays the groundwork for thermal predictions of battery packs, interior electronics, exterior surfaces, and solar panels of an orbiting satellite.

[116] ***Status of the Four Bed Carbon Dioxide Scrubber ISS Technology Demonstration 2022-2023***

James Knox (Knox Analytical Solutions Inc.), Gregory Cmarik (Jacobs Space Exploration Group, NASA/MSFC/ES62) and John Garr (NASA Johnson Space Center).

*Abstract*

The Four Bed Carbon Dioxide Scrubber flight demonstration is presently operating onboard the International Space Station. After being launched in August and activated in September 2021, the system has been removing metabolic CO2 from the cabin as a supplement and replacement for other CO2 removal systems, specifically the two Carbon Dioxide Removal Assemblies. This paper describes on-orbit operations and changes (including installation of the Calnetix blower) during 2022 and early 2023. Performance of the system especially as affected by changes in the on-orbit configuration will be described. System reliability, software changes, and ongoing efforts will be summarized.

[119] ***Four Bed Carbon Dioxide Scrubber Engineering Development Unit Cabin Air Inlet Testing***

James Knox (Knox Analytical Solutions Inc), Gregory Cmarik (Jacobs Space Exploration Group, NASA/MSFC/ES62) and Arisa Waddle (Jacobs Space Exploration Group, NASA/MSFC/ES62).

*Abstract*

This paper reviews a test series conducted on the Four Bed Carbon Dioxide Scrubber Engineering Development Unit, a ground test analog for the Four Bed Carbon Dioxide Scrubber Technology Demonstration currently operating on the International Space Station. For this test series conducted in mid-2022, an alternate FBCO2 inlet air location (direct from the cabin) was evaluated. This paper presents test results, rationale for observed performance changes, and possible ramifications for the flight FBCO2 Scrubber.

[120] ***Theoretical Approach to Quantify Effects of Lunar Dust Deposition on Radiator Performance for Moon Exploration Missions***

Philipp B. Hager (European Space Agency), Adrian P. Tighe (European Space Agency), Fabrice W.S. Cipriani (European Space Agency) and Francesca McDonald (European Space Agency).

*Abstract*

In this paper a set of theoretical equations is presented which allow the conversion between lunar dust deposition rates and the modification of thermo-optical properties of radiators for lunar surface missions. This work is supporting the early design phases of the European Large Logistics Lander (EL3) also known as Argonaut. Lunar dust and its effect on thermal control hardware is a large unknown when designing hardware for lunar surface missions. There are natural and artificial dust levitation and transport processes such as landing or roving vehicles or naturally occurring electrical charge differences. These cause the dust to move across the surface of the Moon and deposit. The smallest fraction of the sharp-edged small dust particles easily deposits on and adheres to technical surfaces, such as radiators or MLI. Literature on dust deposition is based on flight data and hence linked to natural lunar regolith, whereas the literature on radiator thermo-optical property modification is mostly based on tests performed with lunar dust simulant (LDS) materials. For both dust deposition and property modification, literature is scarce. The particle size distribution, density, particle shape and thermo-optical properties of the natural and dust simulants differ and impact the conclusions. Solar absorptivity of radiators is more affected than its infrared emissivity. The modification factor for the solar absorptivity varies from 1.1 to almost 5 for natural lunar dust deposition ranging from 140-840 µg/cm2, but depends on type of radiator coating, and radiator substrate. The same dust coverage rate of 25% can lead to modification factors for solar absorptivity that range from 1.4 @ 1790 µg/cm2 to 2.6 @ 840 µg/cm2, depending on the applied conversation from natural lunar dust to LDS. The conducted study is meant as a first steppingstone toward design guidelines for thermal engineers for ‘dusted end-of-life’ properties for thermal control coatings.

[121] ***NASA Advanced Space Suit Pressure Garment System Status and Development Priorities 2023***

Shane McFarland (NASA), Richard Rhodes (NASA) and Don Campbell (KBR/NASA-JSC).

*Abstract*

This paper discusses the current focus of NASA’s Advanced Space Suit Pressure Garment Technology Development team’s efforts, the status of that work, and a summary of longer term technology development priorities and activities. The Exploration Extra-vehicular Activity Mobility Unit (xEMU) has been the team’s primary effort over the past several years. ICES papers in 2022 detailed the design of the xEMU pressure garment components. This paper outlines the design updates to the xPGS since that time. More notably, this paper documents the various tests executed with the xPGS to evaluate its performance, durability, and acceptability for microgravity and Lunar missions. An overview of ongoing and planned xEMU testing and training is provided. The PGS team’s transition from xEMU development and testing, to supporting the Exploration Extravehicular Activity Services (xEVAS) vendors is discussed. In addition, technology development efforts in coordination with the EVA and Human Surface Mobility Program (EHP), the NASA Engineering Safety Council (NESC) and the Small Business Innovation Research (SBIR) Program will be discussed in the context of supporting sustaining EVA operations on the Lunar surface over the coming decade. Finally, a brief review of longer-term pressure garment challenges and technology gaps will be presented to provide an understanding of the advanced pressure garment team’s technology investment priorities and needs.

[122] ***Thermal Design of the Hyperspectral Instrument of the CHIME Mission***

Victor Cleren (ESA) and Niels Schibilla (OHB).

*Abstract*

The CHIME mission is the hyperspectral component of the European Union’s Earth Observation programme, Copernicus.

The CHIME mission consists of 2 satellites carrying as payload Hyperspectral Imagers (HSI). Each HSI is a high-performance pushbroom imaging spectrometer type of instrument recording ~130 km of swath at a 30 m x 30 m ground sampling distance. The spectral sampling interval is less than 10 nm, covering a continuous spectral range from 400 nm to 2500 nm. A high performance Three Mirror Anastigmat (TMA) type telescope with wide-band coated optics collects the light reflected from the ground and images it to three highly linear radiometric responsive and almost distortion-free spectrometers attaining very good spectral stability. All optical units are mounted to a torus-like carbon fiber (CFRP) optical bench structure providing the necessary line of sight stability. The electro-optical back-end is based on passively cooled Teledyne CHROMA-D digital readout detectors, cooled down to cryogenic temperatures.

The main objectives of the thermal control system are to 1) cool the detectors of the three focal planes down to 170 K, 2) maintain the optical pathway by keeping the temperature of the optics and the structure highly stable at 20 °C and 3) remove the heat from the detector acquisition electronics. Cooling the focal planes is a particular challenge, which is achieved passively by a baffled cryogenic radiator. The radiator is connected to the focal planes via a thermal chain using graphite thermal straps and ethane heat pipes.

CHIME will support a broad range of new and improved Copernicus services and applications, such as sustainable agricultural management, raw material and mineral resources management, food security and biodiversity monitoring. The satellite and its instrument have both passed their PDR (Preliminary Design Review) in 2022. The first CHIME satellite is planned to be accepted for flight in 2028.

[123] ***Highly Thermally Conductive Hybrid Carbon Fiber Polymer Composite for Radiator Application***

Jin Ho Kang (NASA Langley Research Center), Keith Gordon (NASA Langley Research Center), Darwyn Ward (NASA Interns, Fellows, and Scholars (NIFS) Program Intern, NASA Langley Research Center), Grace Belancik (NASA Ames Research Center), Pranav Jagtap (KBR Wyle Services, LLC / NASA Ames Research Center) and Godfrey Sauti (NASA Langley Research Center).

*Abstract*

Carbon fiber (CF) reinforced polymer composites have been used for aerospace structures because they have low mass, high specific strength, high specific stiffness, and low life-cycle maintenance compared to aluminum alloys. However, due to their relatively low thermal conductivity, pristine CF polymer composites fail to provide effective heat flow for certain applications such as heat exchange systems and radiators. The technology described in this paper provides novel CF polymer composites that possess high thermal conductivity by incorporating pyrolytic graphite sheets (PGS). The thermal conductivities of novel hybrid PGS/CF polymer composites were measured to be about 13 to 36 times higher than that of pristine CF polymer composite, and about two times higher than that of aluminum alloy 6061. This new material with sufficient thermal conductivity is applicable to composite radiators of heat exchange systems.

[124] ***Legume Crop Testing for Space***

Lashelle Spencer (Amentum), Jennifer Gooden (Amentum), Aaron Curry (Amentum), Takiyah Sirmons (Leidos Innovations Corporation), Raymond Wheeler (NASA) and Matthew Romeyn (NASA).

*Abstract*

Long-duration missions beyond low-Earth orbit will encounter challenges in maintaining adequate nutrition and acceptability in the food system. In situ production of fresh produce can supplement nutrient deficiencies in the prepackaged diet. Currently there is a relatively small number of crops that can be reliably grown in space for space crop production efforts. Recent challenges with Veggie plant growth technical demonstrations, such as interveinal chlorosis and necrosis of Tokyo Bekana Chinese cabbage when grown under elevated CO2 (~3000 ppm) and narrow-band LED lighting, have highlighted the necessity to conduct rigorous ISS-relevant crop screening on the ground. Additionally, crops should be selected to address specific nutritional deficits as identified by the Human Research Program, with an emphasis on having a diversity of crops to meet nutritional requirements and crew acceptability. To achieve this, the concept of Crop Readiness Level (CRL) has been developed to gauge readiness of crops for spaceflight applications. This includes assessing environmental compatibility, food safety considerations, relevant nutritional analysis, and sensory analysis. Recent testing at Kennedy Space Center has focused on the advancement of a variety of legumes along the CRL. Five varieties of peas (Pisum sativum) ‘Tom Thumb’, ‘Royal Snap’, ‘Yellow Snap’, ‘ES Thick Pod 404-51-2’ and ‘ES Thick Pod 404-52-2-1’ and three varieties of bean (Phaseolus vulgaris); ‘Antigua’, ‘4921 snap’, and ‘Velour Purple’ were grown under 300 µmol m-1 s-1 PPFD from LED lights, 3000 ppm CO2, and 23°C to simulate an ISS environment. Crops will be harvested and yield, baseline nutritional analysis (Vitamins B1, C, K; elemental analysis; proximate analysis) and sensory evaluation will be performed. These baseline data are essential to selecting candidate crops for future missions in addition to assessing crop production hardware and changes in environmental conditions on future crop performance and nutritional quality.

[125] ***Novel Microgreen Crop Testing for Space***

Lashelle Spencer (Amentum), Jennifer Gooden (Amentum), Aaron Curry (Amentum), Takiyah Sirmons (Leidos Innovations Corporation), Raymond Wheeler (NASA) and Matthew Romeyn (NASA).

*Abstract*

Long-duration missions beyond low-Earth orbit will encounter challenges in maintaining adequate nutrition and acceptability in the food system. In situ production of fresh produce can supplement nutrient deficiencies in the prepackaged diet. Currently there is a relatively small number of crops that can be reliably grown in space for space crop production efforts. An intriguing area of new investigation is into novel types of microgreens that have the potential to be sources of calories, fat, carbohydrates, and protein. These sources of nutrition are not obtainable in significant quantities with current pick and eat crops. Many microgreen cultivars are also sources of nutrients of interest, such as Vitamins B1, C, K and elements such as potassium. Microgreens should be selected to address specific nutritional deficits as identified by the Human Research Program, with an emphasis on having a diversity of crops to meet nutritional requirements and crew acceptability. To achieve this, the concept of Crop Readiness Level (CRL) has been developed to gauge readiness of crops for spaceflight applications. This includes assessing environmental compatibility, food safety considerations, relevant nutritional analysis, and sensory analysis. Recent testing at Kennedy Space Center has focused on the advancement of a variety novel microgreens along the CRL. These varieties were grown under 150 µmol m-1 s-1 PPFD from LED lights, 3000 ppm CO2, and 23°C to simulate an ISS environment. Crops will be harvested and yield, baseline microbiological, nutritional analysis (Vitamins B1, C, K; elemental analysis; proximate analysis) and sensory evaluation will be performed. These baseline data are essential to selecting candidate crops for future missions in addition to assessing crop production hardware and changes in environmental conditions on future crop performance and nutritional quality.

[126] ***METimage Visible and Infrared Detectors End to End Co-Alignment Verification at Cryogenic Subsystem Level***

Raphaël Naire (Airbus Defence and Space GmbH), Anja Bergs (Airbus Defence and Space GmbH), Theresa Bonenberger (Airbus Defence and Space GmbH), Robert Schweikle (Airbus Defence and Space GmbH), Heiko Joos (Airbus Defence and Space GmbH), Bernhard Dorner (Airbus Defence and Space GmbH) and Klaus Werner Kruse (Airbus Defence and Space GmbH).

*Abstract*

METimage is a cross-purpose, multi-spectral optical imaging radiometer for meteorological applications. It measures thermal radiance emitted by the Earth and solar backscattered radiation in 20 spectral bands from 443 to 13345nm with one visible and two infrared detectors accommodated on the Cryogenic Subsystem. One of the key requirements of the instrument is the pointing and spatial co-registration of the infrared and visible detectors, mainly achieved at subsystem level. This paper presents the challenging development and verification approach of this subsystem until delivery of the first Proto-Flight Model end of 2022. The whole sequence had to be drastically adapted because of major programmatic constraints with the target to achieve the detectors co-alignment at the first attempt. The selection method used to re-visit the development risks after the withdrawal of the Engineering Model by shuffling the verification and qualification activities on the Structural-Thermal Model and the introduced Proto-Flight Model is enlightened in details: First, the maximized use of heritage technologies and the early verification by test of innovative design features for a subsystem accommodating both cold and warm optics are described. Afterwards, a specific focus is put on the achievement of the co-alignment requirement with the basis alignment using a smart alignment breakdown of the components reference focal planes. It provides a flexible parallel integration of the warm and cold optical assemblies to cope with another constraint: the late delivery of a central optical part. Finally, the cryogenic co-alignment verification approach in the Vacuum Chamber is described from detectors data generation using dedicated electronic and Optical Ground Support Equipment until image post processing and detectors spatial localization. The full multi-disciplinary engineering activities, development and testing have been performed at Airbus Defence and Space premises in Friedrichshafen. METimage is a German Space Agency (DLR) Customer Furnished Instrument for the EUMETSAT MetOp-SG Satellite A.

[127] ***Automated Carbon Formation Reactor Facilitates Closed-Loop Oxygen Recovery to Enable Long-Duration Manned Missions***

Mary Powell (pH Matter LLC), Chris Holt (pH Matter LLC), Paul Matter (pH Matter LLC), Travis Hery (pH Matter LLC), Toby Baumgartner (pH Matter LLC), Jacob Goldman (pH Matter LLC), Carolyn Weiser (pH Matter LLC), Charlie Wiswesser (pH Matter LLC), Elek Kayuha (pH Matter LLC) and Makenzie Holt (pH Matter LLC).

*Abstract*

Future NASA missions have a critical need for improved process technologies for life support loop closure to enable extended manned exploration missions beyond Earth’s atmosphere. A crucial component in life support loop closure is removing carbon dioxide produced by the crew in the cabin atmosphere and chemically reducing it to recover the oxygen. pH Matter is developing a fully automated carbon formation reactor (CFR) that will be a key component in a Series Bosch system that has the potential to achieve near 100% oxygen recovery, making it attractive for lunar and inter-planetary missions. The pH Matter CFR uses carbon monoxide from a reverse water gas shift reactor and converts it into solid carbon. This carbon can then be used for other oxygen recovery processes on the lunar or Martian surface, such as the carbothermal reduction of regolith. pH Matter’s unique CFR design enables continuous automated operation at the four-crew member scale with limited crew intervention, easy removal of the carbon product, and low resupply mass for replacement of the CFR catalysts.

[128] ***A Methodology for the Systematic Review of Space Architecture Concepts***

Annika Rollock (Aurelia Institute), Danielle DeLatte (Aurelia Institute) and Ariel Ekblaw (Aurelia Institute).

*Abstract*

The vast majority of space vehicles and habitats have been launched and operated by nations for scientific and exploratory purposes. Consequently, their form has been shaped by the constraints posed by the scientific and diplomatic needs of the mission as well as the physical limitations of their launch and operation. These constraints have resulted in a homogenous appearance of space architecture, with either a single monolithic hull or a central, cylindrical axis with branching, pressure-cylinder modules. Recently, an influx of private investment in space has resulted in low-cost access to orbit and an emerging space services economy that has in turn led to a surge of interest in commercial space habitat design. With an increasingly diverse pool of spaceflight participants, the design of these future space habitats must evolve past the ‘orbital laboratory’ to instead accommodate a wide range of participants and reasons for spaceflight.

This work presents a space habitat assessment methodology and systematically reviews space habitat concepts throughout modern history, including flight-proven spacecraft, ideas from NASA competitions over four decades, technical workshops, industry concepts, terrestrial analogues, and notable, credible designs from science fiction. Ninety concepts were collected and characterized based on figures of merit such as pressurized volume, occupancy, location, structural geometries, and purpose. From this broad search, gaps between current capabilities and future-leaning designs are identified for research and development. Broad categories of trends and opportunities are identified for the space architecture community–namely, determining the technologies needed to enable the next generation of space habitats. This paper presents the foundation of a space architecture database collected from concepts across the field, analyzes the resultant technology gap, and proposes R&D workstreams for meaningfully democratizing access to space via in-space infrastructure that can scale up habitat occupancy.

[129] ***Novel Methods for Modeling Thermochromic Variable Emissivity Surfaces***

Derek Hengeveld (Redwire) and Jonathan Allison (Air Force Research Laboratory, Space Vehicles Directorate).

*Abstract*

Thermochromic variable emissivity material (VEM) optical properties (i.e., emissivity and absorptivity) vary in response to material temperature. As a result, these VEMs can provide passive, adaptable heat rejection and temperature regulation for spacecraft thermal engineers. In the future, it is anticipated that these types of materials will become mainstream; however, a significant barrier to their adoption is the lack of means to accurately model VEM behavior using traditional tools. Traditional spacecraft thermal modeling assumes constant surface properties which do not accurately capture the unique variable emissivity nature of VEMs. To overcome this challenge, novel VEM modeling methods were developed in Thermal Desktop. Methods include Radiation Conductor, Dynamic SINDA (Systems Improved Numerical Differencing Analyzer), and Radiation Database. Details of each method are provided with examples of implementation and results.

[130] ***Testing and Evaluation of Spacecraft Thermal Isolators for SmallSats***

Isaac Foster (Air Force Research Laboratory), Trevor Bird (Blue Halo), Derek Hengeveld (Redwire) and Steven Lockyer (Redwire).

*Abstract*

Thermal isolation is a common practice in spacecraft to limit conductive heat transfer through mechanical interfaces and introduce temperature gradients between components. A typical application is battery mounting where isolation can help sustain moderate battery temperatures while minimizing required survival heat. There are many common types of thermal isolation including tension band or cable systems; bipod, flexure, or strut structural isolation; and low thermal conductivity thermal isolators. Of these, thermal isolators are the easiest to implement and cheapest; therefore, they are often found in less-expensive SmallSat applications. Performance of thermal isolators is dependent on many parameters, including material type, size and application, and contact pressures. Unfortunately, handbook values for these types of interfaces are limited and as a result, thermal designers/analysts are often left with broad estimations and higher than acceptable uncertainty. Because of this, thermal teams must often test these interfaces which is costly and time-consuming. In this work, we developed a model to evaluate a broad range of thermal isolator designs. To validate this model, we developed a modular and robust test bed. The details of this testbed are provided along with results from heat leak (i.e., tare test) testing. We tested a custom design low thermal conductivity isolator at various temperatures and summarized the steady-state results. Results were compared to the developed model. The goal of this work is to provide SmallSat thermal designer/engineers with better tools to evaluate thermal isolators.

[131] ***Novel Vapor Chambers for Heating and Cooling of Advanced Sorption Systems***

Haley Myer (Advanced Cooling Technologies) and Michael C. Ellis (Advanced Cooling Technologies, Inc.).

*Abstract*

The Carbon Dioxide Removal Assembly (CDRA) is a subassembly of the Environmental Control and Life Support (ECLS) system on the International Space Station (ISS). The function of the CDRA is to remove CO2 from cabin air, ideally turning it into a useful resource such as water or methane. This is accomplished using a sorbent material, zeolite, to adsorb and desorb CO2. Zeolite has a highly porous molecular structure, and CO2 can favorably bond within these pores at certain temperatures and pressures. This molecular bonding process is exothermic during CO2 adsorption and endothermic during CO2 desorption. Thus, the zeolite material on the CDRA must be heated and cooled to very specific temperatures for the most efficient desorption and adsorption of CO2, respectively. The current CDRA operates most effectively when the sorbent bed is cooled to 20°C for adsorption and heated to 220°C for desorption. The zeolite material has poor heat transfer characteristics, making a well-designed thermal management system a priority on the CDRA. Under a NASA Phase I SBIR program, Advanced Cooling Technologies (ACT) has developed an additively manufactured (AM), titanium-water, grooved vapor chamber to heat and cool the zeolite material in the CDRA. ACT’s proposed thermal management system is designed to heat and cool the zeolite to these specific temperatures at faster rates and more uniformly than the state-of-the-art design, which utilizes a cartridge heater and aluminum fin. ACT’s titanium water vapor chamber design has additional benefits over the state-of-the-art such as reduced size, weight, and power (SWaP) and adaptability to future sorbent materials.

[133] ***Limiting Oxygen Concentrations of Burning PMMA Cylinders under External Radiant Heating and Subatmospheric Pressure***

Christina Liveretou (University of California, Berkeley), Charles Scudiere (University of California, Berkeley), Jose Rivera (University of California, Berkeley), Carlos Fernandez-Pello (University of California, Berkeley), Michael Gollner (University of California, Berkeley), Sandra Olson (USRA; NASA John H. Glenn Research Center) and Paul Ferkul (USRA; NASA John H. Glenn Research Center).

*Abstract*

This work considers the effect of ambient pressure and an external radiant flux on the limiting oxygen concentration (LOC) for flames spreading downward over the surface of cylindrical samples of black polymethyl methacrylate (PMMA). The objective is to determine the effect of an external radiant flux on the LOC of combustible solid materials in environments expected in future spacecraft cabins. The experimental apparatus and testing methodology is a combination of the LOI and LIFT test apparatuses. The radiant heating ranges from 0 to 3.3 kW/m^2 and the ambient pressures tested from 100 kPa to 40 kPa. An upward forced flow of a mixture of oxygen and nitrogen with a velocity of 10 cm/s is used to determine the LOC of the PMMA as a function of ambient pressure and external heat flux. Results show that increasing the ambient pressure or external radiant flux increases the flame spread rate and decreases the LOC of the PMMA. Correlating the LOC data in terms of the partial pressure of oxygen and the ambient pressure shows that the LOC occurs at an approximately constant oxygen mole fraction that depends weakly on the ambient pressure and radiant flux. The combustion mechanisms leading to this result are discussed based on simple equations and phenomenological arguments. The data from this work will be compared with data from experiments to be conducted in the International Space Station (ISS) under the SoFIE-MIST project, to provide further understanding of the effect spacecraft environments on the LOC of materials. The results will give further insight into the flammability of materials, particularly at subatmospheric ambient pressures, such as in spacecraft, aircraft, and high-altitude locations.

[135] ***Thermal Performance of the Perseverance Rover During Mars Surface Operations***

Bailey Cassler (Jet Propulsion Laboratory, California Institute of Technology) and Emma Nelson (Jet Propulsion Laboratory, California Institute of Technology).

*Abstract*

On July 30, 2020, NASA launched the Perseverance rover as part of the Mars 2020 (M2020) mission. On February 18, 2021, the rover landed on the surface of Mars in Jezero Crater at a latitude of 18.5°N. As of the writing of this paper, the rover has completed over 790 sols of surface operations, more than one full Martian year. Landing occurred during the Martian spring in the Northern Hemisphere (Ls=5 deg), and the rover has since operated through the summer, fall, and winter seasons. While the rover was originally designed to support a surface mission of 1003 sols, Perseverance has been integrated as part of the planned Mars Sample Return (MSR) Campaign to bring samples back from the surface of Mars to Earth for the first time. Understanding the thermal performance of the rover is essential to ensuring the longevity of Perseverance to perform this mission. This paper discusses the thermal performance of the rover from landing to present, including predicted versus actual performance, nominal operations, incidents and anomalies, and long-term trending data that will be used to improve energy usage for activities requiring thermal support in the future.

[136] ***Demonstration and Model Validation of Freeze Distillation as a Purification Step for Lunar Water Processing***

Connor Joyce (Paragon Space Development Corporation), Jordan Holquist (Paragon Space Development Corporation), Alex Ruble (Paragon Space Development Corporation), Robert Rivera (Paragon Space Development Corporation) and Timothy Moeller (Paragon Space Development Corporation).

*Abstract*

Since the observation of direct evidence of water-ice in the permanently shadowed regions (PSR) on the lunar surface, in-situ resource utilization (ISRU) has been proposed for processing the regolith-bound water-ice to provide fresh water, breathable oxygen, and rocket propellant for lunar exploration missions. However, the water-ice is found concurrently with other typically volatile species that would contaminate and degrade downstream processing systems. Cold trapping of liberated water vapor and the purification of collected water are integral stages within ISRU architectures, but the technology to accomplish these critical water processing steps in the lunar PSR environment remains under-developed. To fill this identified ISRU gap, Paragon Space Development Corporation® has been maturing the patent pending ISRU Collector of Ice in a Cold Lunar Environment (ICICLE) Cold Trap technology which simultaneously collects and purifies water vapor from lunar ice collected from a wide range of potential lunar ice mining techniques. To predict and demonstrate water collection performance as part of this “freeze distillation” process, Paragon developed a spatial-temporal frost deposition model for low-pressure (<600 Pascal), temperature-controlled water-ice collection, and built an ICICLE development test article which allows for the measuring of frost deposition at the same conditions. This paper presents results of an experimental investigation into frost collection and aspects of freeze distillation using these tools, including the description and demonstration of the process, measurement of the growth profile of frost at lunar mining conditions, and validation of the model as a function of temperature, pressure, and water vapor concentration. The presented results inform next steps for advancement of the technology and demonstrate efficacy of ICICLE as a key step in lunar water processing.

[137] ***Update of the Ground-Based Liquid Amine Horizontal Contactor Test System***

Tiago Costa (NASA), Lisa Chu (NASA), Lawrence Barrett (NASA), Grace Belancik (NASA) and Jason Samson (NASA).

*Abstract*

As NASA continues to pursue longer durations of crewed space flight missions, the importance of a robust carbon-capture system is becoming more evident. Currently, NASA relies on a packed bed of zeolite pellets to remove carbon dioxide from the International Space Station cabin air. While this is a proven technique, NASA and the Environmental and Life Support System community are continuously looking for alternatives that are lighter, take up less volume, draw less power, and are more reliable. One method being investigated is a system using a liquid amine to absorb carbon dioxide from the cabin air stream. Because the liquid must be in contact with cabin air in a microgravity environment, possible exposure to crew must be mitigated. This can be achieved with the use of V-shaped channels which use capillary action to keep the liquid contained within the channel. Since amount of CO2 removed is a function of sorbent surface area, the contactor liquid surface area will need to be designed and sized to account for the CO2 removal requirements per crew member. Ground-based test data to date has evaluated vertical contactor channels, which have a delta from microgravity performance due to the gravity effect in the vertical orientation. Therefore, a new horizontal channel contactor design, operable in any gravity or absence thereof, was built and tested. An analytical model of this new design was also developed in Aspen Custom Modeler. Both tools will be used to further understand the fluid characteristics, CO2 absorption, and scale up requirements for the overall liquid amines CO2 removal system.

[138] ***Coatings for Space-Based Systems: Impacts of Plasma Processes***

Richard Clergereaux (CNRS - Laplace), Veronica Orlandi (CNRS - Laplace), Myrtil Kahn (CNRS - LCC), Gregory Navarro (CNES - Spaceship) and Alexis Paillet (CNES - Spaceship).

*Abstract*

Plasma assisted processes have become more and more important in surface treatments applied to different domains. For example, thin metallic films, dielectric layers or hard coatings with functional properties related to the material structure and composition are widely used in different fields of applications. Nowadays, multifunctional coatings are also highly required. For example, sustainable activated filters, protective layer to reduce system ageing, as well as combined superhydrophobic, anti-fouling and resistant coatings are expected in various terrestrial applications. Nanocomposite thin films i.e. coatings of matrix-embedded nanoparticles are potential candidates as they are exhibiting multifunctional properties related to the matrix and the nanoparticles and, especially, their concentration, size, shape, and distribution in the coating. Different plasma strategies are developed. This presentation aims to review different plasma assisted technologies to form innovative coatings and their potential impacts for space-based systems with a specific focus on safer-by-design methods.

[139] ***TuMag Optical Unit Thermal Control for a Stratospheric Balloon-borne Mission***

Alejandro Gonzalo (Instituto Nacional de Técnica Aeroespacial (INTA)), Manuel Reina (Instituto Nacional de Técnica Aeroespacial (INTA)), Antonio Sánchez (Instituto Nacional de Técnica Aeroespacial (INTA)), Ana Fernández-Medina (Instituto Nacional de Técnica Aeroespacial (INTA)), María Cebollero (Instituto Nacional de Técnica Aeroespacial (INTA)), Hugo Laguna (Instituto Nacional de Técnica Aeroespacial (INTA)), David Escribano (Instituto Nacional de Técnica Aeroespacial (INTA)) and Alberto Álvarez-Herrero (Instituto Nacional de Técnica Aeroespacial (INTA)).

*Abstract*

The Tunable Magnetograph (TuMag) is an imaging tunable spectropolarimeter designed to study solar magnetic fields at high spatial resolution. It measures the state of polarization of light at three selected spectral solar lines: the Fe I at 525.02nm and 525.06nm, and the Mg I b2 at 517.27nm. TuMag is part of the post-focal instrumentation of the SUNRISE III mission whose first launch attempt was carried out from Kiruna (Sweden) in July 2022. The correct science performance of the instrument is strongly determined by the thermal stability of critical subsystems during observations. Elements such as the polarization modulator based on Liquid Crystal Variable Retarders, the LiNbO₃ etalon used to scan the spectral lines, or the three narrow bandpass filters with a ~1.5 Å FWHM mounted on a filter wheel, are required to operate within a tight temperature set-point. TuMag Thermal Control System (TCS) will guarantee the correct operational temperature for the aforementioned sub-systems at the time that provides a cooling mechanism for the detectors and minimizes thermo-elastic deformations across the optical path. It combines active and passive strategies in an architecture that profits from the unit location within the balloon gondola, which leaves only its top surface opened to the outer space. The thermal environment of a stratospheric flight is similar to that in LEO and hence typically driven by radiation. However, the presence of a 5 mbar rarefied atmosphere is shown to have an undesired effect in the thermal control performance of some of the internal elements. This impact was assessed during the thermal ground testing with the fully integrated Optical Unit, prior to its delivery to the platform. The expected TCS performance is currently being compared to the real data retrieved during the brief SUNRISE III first flight.

[140] ***PFPU – Microgravity Precursor Food Production Unit development status***

Giorgio Boscheri (Thales Alenia Space Italia), Giovanni Marchitelli (Thales Alenia Space Italia), Thomas Fili (Thales Alenia Space), Christel Paille (European Space Agency), Irene Karoliussen (NTNU Samforsk), Achim Gerstenberg (NTNU Samforsk), Øyvind Mejdell Jakobsen (NTNU Samforsk) and Kai Arne Kristiansen (NTNU Samforsk).

*Abstract*

So far, several technical issues related to the development, implementation and operations of food production system for space applications were identified. They include food quality prediction, food safety, integration strategy as well as microbial contamination, humidity and nutrient delivery management. Thus, considering the amount of issues and their respective criticalities, the cost-conscious development of a food complement production unit for space application requires a step-by step approach based on a modular technological demonstrator. PFPU is a study of a modular food complement production unit demonstrator, aiming at a statistically representative production of edible tuberous plants in micro-gravity. The study is performed within the MELiSSA framework under contract with the European Space Agency. It is carried on by an Italian and Norwegian consortium led by Thales Alenia Space Italia. The PFPU systems breadboard has been designed, built and tested. This paper describes the PFPU development status, the test campaign key results and the associated roadmap.

[141] ***Towards Personalized Digital Twin as Clinical Decision Support Tool for Astronaut Medication : a Review of Literature.***

Laure Boyer (MEDES/CNES), Samuel Baroudi (ExactCure), Sylvain Benito (ExactCure), Matthieu Basset (ExactCure), Alexis Paillet (CNES), Anne Pavy-Le Traon (MEDES), Audrey Berthier (MEDES) and Frederic Dayan (ExactCure).

*Abstract*

The 6-month missions aboard the International Space Station demonstrate that microgravity and confinement lead astronauts to use drugs to prevent and treat disorders associated with this unusual environment. Deep-space exploration missions, towards the Moon and Mars, generate new challenges, in particular the need for increased autonomy with limited equipment. As the distance from Earth prevents evacuation and real-time telemedicine with medical teams, the development of a clinical decision support software to guide astronauts in their medicine intake is of interest. The objective of this work is to gather the necessary information to develop a personalized digital twin to simulate drug exposure for astronauts, based on their personal characteristics and physiological adaptations related to spaceflight. This work provides foundation for the development of a modeling strategy to adapt existing terrestrial pharmacokinetic models for astronaut use. To do this, a list of high-priority drugs has been created, based on the most encountered health problems during spaceflight and potential needs. In addition, spaceflight-induced physiological adaptations based on data from spaceflight and analogous terrestrial models (bed rest, dry immersion) were collected. Such clinical decision support software will allow astronauts to autonomously monitor and personalize their medication intake, ensuring greater safety of use by taking into account their personal characteristics (e.g., age, weight, genetic polymorphism). This is especially critical when taking emergency drugs and those with a risk of exposure related adverse events. It also helps to limit the consumption of medications to what is strictly necessary, a real asset considering the complexity of terrestrial resupply. In the perspective of the Artemis space mission, the opportunity to collect new pharmacological data will allow a better understanding of the needs of astronauts.

[142] ***Development of Parabolic Flight Experiment to Measure the Volume of Gas Bubbles Detaching from Substrates in a Liquid as a Function of Buoyancy, Gravitational Force and Substrate Surface Energy***

Jadon Kaercher (Texas A&M University), Justin Roskamp (Texas A&M University), Samantha DeNicola (Texas A&M University) and Bonnie Dunbar (Texas A&M University).

*Abstract*

In 1g Earth gravity, buoyancy is the dominant force in liquid-solid systems whereas in a microgravity environment, surface tension is the dominant force. However, in a relative partial gravity environment, such as on the Moon or Mars, the transition between buoyancy and surface tension is largely unexplored. Understanding how two-phase systems, such as liquids and gases, behave in partial gravity when in contact with solid surfaces is fundamental to characterizing heat and mass transfer in the design of life support systems, cryogenic fuel management and In Situ Resource Utilization (ISRU). The Aerospace Human Systems Lab (AHSL) previously developed and published an isothermal CFD model which predicts the volume of a gas bubble at detachment from a solid substrate surface submerged in a liquid as a function of buoyancy and the gravitational force, from 1 g to microgravity. The model considered four different substrate materials commonly used in experiments and life support systems: quartz, polycarbonate, aluminum and stainless steel. These materials represent a wide range of material wetting, or surface energy, properties. The model predicts that bubble volume at detachment is non-linear with gravitational acceleration and is unique to each solid substrate’s surface energy. The CFD model was validated at 1g using an AHSL designed experimental device (FLUIDS-1), which measured the volume of an air bubble in distilled water at the moment it detached from the four material substrates. To verify the CFD model at Lunar and Martian gravity levels (1/6th g and 3/8th g, respectively), the AHSL designed and built FLUIDS-2 to fly on a parabolic flight at those acceleration levels, testing multiple substrates simultaneously. The design of the experimental devices, results from 1g validation testing and preliminary results for a flight scheduled in May 2023 will be discussed.

[143] ***CO2 Capture with Supported Ionic Liquid Membranes for ECLSS and ISRU: Progress, Performance, and Potential***

Bharath Tata (University of Colorado), Cody Bahan (University of Colorado) and James Nabity (University of Colorado Boulder).

*Abstract*

Ionic liquid sorbents are attractive for spaceflight applications due to their low volatility and high tunability for long-duration, low-maintenance, and task-specific performance at reduced pressures. Typical ionic liquid-based gas separation systems involve contacting an ionic liquid flow with gas flows at two separate stages to enable continuous operation: one stage for selective absorption of the target gas species and one for desorption. One promising configuration is a supported ionic liquid membrane (SILM) – a porous membrane filled with an ionic liquid sorbent. SILMs allow for continuous in-line separation without a liquid flow. Instead, there are two gas flows – the feed gas mixture flows over one side of the membrane, where it contacts the supported liquid sorbent, and the liquid then releases the captured target molecule into the gas phase on the other side of the membrane. This continuous absorption-desorption process reduces process complexity and power requirements. Here, using the ionic liquid 1-butyl-3-methylimidazolium acetate and expanding upon previously published data, we explore the CO2 separation and mass transfer performance of SILMs using different polypropylene and nylon membrane supports in both flat sheet and hollow fiber configurations.

[147] ***ECLSS Technology Roadmap at Spaceship FR***

Gregory Navarro (CNES), Marie-Christine Desjean (CNES) and Alexis Paillet (CNES).

*Abstract*

The lunar ambitions of NASA's Artemis program spell out multiple crewed missions to the Moon and later to Mars. The recently published ESA Terrae Novae 2030+ exploration strategy roadmap aims to enable Europe’s participation in the first crewed exploration mission to Mars. Yet, missions to deep space still pose significant challenges in terms of Environmental Control and Life Support System (ECLSS) technologies. The ECLSS approach adopted in the current ISS spaceflight program relies heavily on terrestrial resupply and maintenance capabilities. This approach is not suitable for a future Moon and Mars missions which will impose the management of considerable amounts of resources (e.g. metabolic consumables, hygiene items, clothing, etc.) in complete autonomy from Earth. This paper aims to present the ECLSS Roadmap of Spaceship FR project. Since 2018, the objective of Spaceship FR team at CNES (Centre National d’Etudes Spatiales - FRANCE) is to develop innovative technological bricks for the future Moon and Mars bases. SpaceShip FR project is bringing together technologies and skills and building the required partner networks with academia, laboratories and industries. Bricks relative to ECLSS can be used to develop a circular life support system with the highest degree of autonomy. Thus producing oxygen, water, food, and potentially biomaterials, for the astronaut crew from the wastes generated during their mission. Through the studies on going, we can find CO2 trapping thanks to new generation of solid fiber, a combination of urine recycling, food and bioplastic production thanks to a bioreactor, an autonomous vegetable growing chamber, water purification system based on photocatalyst.

[149] ***Definition of a Reusable Lunar Habitat to Extend Exploration Range***

Gregory Navarro (CNES), Alexis Paillet (CNES), Sebastien Barde (CNES) and Marie-Christine Desjean (CNES).

*Abstract*

The lunar ambitions of NASA's Artemis program outline multiple crewed missions to the Moon and later to Mars. A compact shelter able to sustain life for the typical duration of the missions, which could be deployed autonomously and reused either during the same mission or from one mission to the next, would greatly ease this purpose and expand the area of exploration. The aim of the Spaceship FR team at CNES (Centre National d’Etudes Spatiales - FRANCE) is to define this new habitat concept. This paper aims to presents the results of the concurrent design approach and the development logic for this habitat. Three different updates will step the development to achieve a shelter habitable by a crew. This logic makes it possible to meet different needs and to integrate more and more complex equipment. The first version of the shelter will be a charging station for a rover to power it and protect it during the lunar night. It will permit the feasibility of deployable pressurized structures, environmental and thermal control, dust mitigation and a new generation of batteries to be demonstrated. The second version will serve as a warehouse and possibly a greenhouse. It will allow the feasibility of radiation and micrometeoroid protection, airlock, equipment transfer and first level of ECLSS and autonomous supervision to be demonstated. The third version will be a shelter consistent with the safety requirements with human in the loop integration. These different types of shelters can offer complements to the different Artemis missions from 2028 as the shelter will be brought to the Moon by EL3, the European Large Logistic lander, when this item is available for space flight. They will also allow to demonstrate the proper functioning of innovative technological bricks integrated before their transfer to a future Mars mission.

[151] ***Improvement in Radiative Exchange Factor Calculations Using New GPU Dedicated Hardware***

Daniel Navajas Ortega (IDR/UPM), Javier Piqueras Carreño (IDR/UPM), Ignacio Torralbo Gimeno (IDR/UPM), Isabel Pérez-Grande (IDR/UPM) and David González Bárcena (IDR/UPM).

*Abstract*

The aim of this work is to test the applicability of new GPUs, with dedicated hardware to accelerate raytracing computations, for calculating radiative exchange factors of thermal models.

Radiative exchange factors (REFs) are used to model the net exchange of thermal energy by radiation between two surfaces. While there are analytical solutions for simple configurations, for general thermal models most REFs are calculated numerically. Montecarlo raytracing algorithms are typically used to this end.

Raytracing algorithms simulate the radiation thermal energy transportation phenomena by emitting, tracing, and bouncing energy particles (usually called rays) between the different surfaces that make up the thermal model. The thermo-optical properties of the surfaces determine the interaction between the rays and the model.

Although raytracing algorithms are conceptually simple, to obtain accurate solutions a large number of rays need to be traced, which is a process extremely expensive computationally. However, because each ray can be considered independent, the simulation is also easily parallelizable, and therefore very suitable to be computed by a GPU, especially the new ones with built-in raytracing capabilities.

To do so, a multi-platform software has been developed. The software is able to handle general geometry and better exploit the computing capabilities of the GPU by using triangular meshes internally. The conversion between the internal representation of the geometry and the geometrical thermal model is handled automatically.

The result is a code that can calculate all REFs of a complex thermal model much faster than commercially available software where only the CPU is used. The software has been tested with the thermal model of the PHI instrument of the ESA Solar Orbiter mission. In the same machine, with single GPU, and using 10E6 rays per surface, the developed code can calculate the REFs around 2 to 3 orders of magnitude faster than ESATAN-TMS.

[152] ***Space Rider Re-entry Module Thermal Transient Uncertainty Analysis: Metholodogy and Results***

Gianni Pippia (Thales Alenia Space Italia), Maria Chiara Berva (Thales Alenia Space Italia), Massimo Bertone (Thales Alenia Space Italia), Corrado Guglielmo (Thales Alenia Space Italia), Andrea Ferrero (Thales Alenia Space Italia), Giovanni Chirulli (ESA) and Egidio Collavo (ESA).

*Abstract*

Space Rider is an uncrewed orbital spaceplane that will provide the European Space Agency (ESA) with affordable access to space. Within the thermal analysis campaign of its Reentry Module (RM), a sensitivity analysis has been performed to determine the Uncertainty of Flight Prediction (UFP) for both on-orbit operations and vehicle Entry, Descent and Landing (EDL). Different approaches were followed for each mission phase. Orbital analysis (quasi steady state) is guided by ECSS standards and heritage of past programs. EDL uncertainty analysis concerns a transient phase consisting of consecutive sub-phases with very different characteristics: preparation to deorbit, coasting, re-entry, descent and post landing. EDL temperature deviations are time variant and propagate through concatenated sub-phases. A detailed study matrix was set up to define the different parameters to be modified: dedicated investigations were then executed to determine specific parameter variations. No ECSS standard is directly applicable, due to the transient nature of this phase. Variations related to environment (general orbit, aerothermal and air for EDL), physical parameters and TCS performances were considered. The UFP was evaluated with a “classical” approach as sum of random error and modeling error. For the transient phase two different methodologies were developed and compared to determine temperature deviations. Analyses results were compared to investigate: 1) difference between peak temperatures of sensitivity and nominal case (close to a classical approach); 2) instantaneous difference between temperatures resulting from sensitivity analysis and nominal case, both time-dependent. Peak UFP resulted conservative and able to envelope time-dependent UFP. The latter methodology is less practical, hence it is preferred for validation purposes and for local analyses on critical items (e.g. exceeding temperature design limits). The approach presented in this paper could be considered for a possible (ECSS) standardization, applicable first to Earth re-entry missions, then extendable to other planetary missions having different atmospheres.

[153] ***The Thermal Balance/Thermal Cycling Test of Euclid***

Marco Gottero (Thales Alenia Space Italia), Andrea Ferrero (Thales Alenia Space Italia), Roberto Bogiatto (Thales Alenia Space Italia), Daniele Stramaccioni (European Space Agency), Alex Short (European Space Agency), Giorgio Costa (Thales Alenia Space Italia), Renato Martino (Thales Alenia Space Italia), Simone Ferrero (Thales Alenia Space Italia) and Gianni Pippia (Thales Alenia Space Italia).

*Abstract*

Euclid is a medium-class mission in ESA's Cosmic Vision programme. It will investigate the evolution of our Universe over the past ten billion years using a visible to near-infrared telescope to survey red-shift and weak lensing of galaxies over 35% of the sky. This will enable us to improve cosmological models and better understand the role of dark energy and dark matter. ESA selected Thales Alenia Space as the Euclid Prime Contractor, with overall responsibility for manufacturing the satellite. Airbus Defence and Space Toulouse was selected as a Sub Contractor, responsible for designing and building the Payload Module (telescope). The focal plane instruments were provided by two nationally funded consortia (VIS and NISP). In 2022 a thermal balance/thermal cycling system test was conducted on the Proto Flight Model (PFM) of the spacecraft in order to verify the thermal design which had previously been qualified through an Structural Thermal Model (STM) test campaign in 2019. Euclid was operated under vacuum throughout the PFM test campaign in order to verify functionality of the fully integrated spacecraft under flight-like conditions. Specific tests were also conducted to complete the verification of Euclid scientific instruments in the final configuration and to conclude on several issues which had arisen during an earlier Payload Module level end-to-end test. To allow the achievement of instrument testing objectives, special care and dedicated solutions had to be put in place in terms of test setup and parameters. This paper will describe all aspects of the Euclid system level thermal balance/thermal vacuum test, with special focus on its peculiar points.

[154] ***Unfolding the Universe with the James Webb Space Telescope: Combining Art, Science, and Technology for Public Outreach***

Elaine Stewart (NASA), Ashley Zelinskie (Ashley Zelinskie Studio LLC) and Maggie Masetti (ADNET SYSTEMS Inc).

*Abstract*

“Unfolding the Universe: First Light” is an art exhibition focused on the science of the James Webb Space Telescope, created by artist Ashley Zelinskie with the assistance of the James Webb Space Telescope team, and first shown in New York City in October of 2022. The exhibition featured a variety of artistic media, including VR and holographic works, 3-D printed sculptures and large-scale serigraphs, and was combined with a series of weekly talks from scientific and engineering experts that worked on the James Webb Space Telescope. Additionally, the VR platform was used in months preceding the exhibit to highlight talks from the Webb team and artwork from featured artists in a virtual gallery. Science-inspired artworks and art exhibitions are an under-explored form of science communication, and present a unique opportunity to engage new audiences in discussions of STEM topics. This paper examines various aspects of the Unfolding the Universe Exhibition, including the use of new media, the use of an artistic forum for science & engineering presentations, and the nature of collaboration between government team members supporting the Webb project, academia and a private artist. It concludes with future lessons for science outreach and science communication to the public.

[156] ***Roles of Human and Robotic Agents Toward Operating a Smart Space Habitat***

Xiaoyu Liu (Purdue University), Amir Behjat (Purdue University), Shirley Dyke (Purdue University), Dawn Whitaker (Purdue University), Julio Ramirez (Purdue University) and Ilias Bilionis (Purdue University).

*Abstract*

To construct and operate a deep space habitat, for example, on Mars, is an ambitious goal but bound to happen for future space exploration. This mission represents a grand challenge that will require the application of the highest technologies we have. Countless questions are to be answered. One of the most challenging questions is the roles of humans and instead of/or robots to operate the space habitat? There may not be a definite and decisive answer to this problem in the short term depending on the critical technologies involved in human life support and robotic autonomy. However, by quantitatively comparing a human and a robot for designated mission tasks, evidence can be found to support later strategy and to encourage research in directions relating automation and human machine interaction. For such purposes, two independent parallel scenarios, in this paper, are formed to compare the mission success with a human agent (HA) and a robot agent (RA). In each scenario, HA and RA are scheduled appropriately to carry out a series of tasks to maintain the space habitat in a safe and functional status. The tasks include to repair subsystems, e.g., power, structure, etc. in terms of reacting to emergencies. Meanwhile, the default daily activities of HA and RA are also modelled, e.g., sleeping of HA, recharging of RA, etc. Most importantly, to evaluate the actual performance of HA and RA, we have included an independent research scientist in the study. The research scientist, of which the model inherits from HA, exists in both the scenarios for HA and RA, and is solely to generate research outcome. The outcome generate by the research scientist is the metric utilized to compare the performance of the agents, besides the equivalent costs to engage HA and RA.

[157] ***Design, Development, and Testing of Peristaltic Suit: Active-Dynamic Compression and Physiological Sensing Intra-vehicular Activity Spacesuit for Cardiovascular Deconditioning***

Irmandy Wicaksono (MIT), Ali Shtarbanov (MIT), Esha Ranade (MIT), Rebecca Slater (MIT), Dava Newman (MIT) and Joseph Paradiso (MIT).

*Abstract*

Prolonged exposure to microgravity is known to cause various acute health risks, including muscle atrophy, bone loss, cardiovascular deconditioning, and orthostatic intolerance. Due to the absence of gravitational force, bodily fluid hydrostatic pressure gradients vanish, and blood distribution shifts from the astronaut's legs toward their upper body. Consequently, it is imperative to provide continuous medical check-ups and interventions for astronauts and crewmembers throughout their long-term journey in outer space and also after their return to Earth. This paper presents the design, development, and preliminary parabolic flight testing of Peristaltic (PS) Suit. PS-Suit is an active bioelectronic intra-vehicular activity spacesuit that could simultaneously perform wireless multi-modal monitoring of vital signs, including heart electrical activity, respiration, blood flow, and oxygen level and exert controlled, spatiotemporal and peristaltic pressure through five textile-based compression sensors and five pneumatic chambers integrated across the bodysuit. Integrating physiological and physical sensing and pneumatic actuation systems in the PS-Suit (1) facilitates closed-loop and timely intervention for astronauts to regulate their cardiovascular dynamics and (2) enables researchers to study the direct influence of active-dynamic compression in micro to hypergravity conditions on various cardiovascular and physiological markers. In the end, we tested and evaluated a functional prototype of the PS-Suit during a parabolic flight campaign to investigate the response of heart-rate and blood pulse arrival time to applied gradient compression and changes in gravitational force.

[158] ***3D Printed Wicks for Loop Heat Pipes***

Rohit Gupta (Advanced Cooling Technologies, Inc.), Chien-Hua Chen (Advanced Cooling Technologies, Inc.) and William G. Anderson (Advanced Cooling Technologies, Inc.).

*Abstract*

This paper describes the development of 3D printed wicks for loop heat pipes. This work is part of an overall effort by Advanced Cooling Technologies, Inc. to develop 3D printed loop heat pipes as a low-cost, rapidly-manufacturable alternative technology to standard loop heat pipes for future high-performance small spacecraft. The wicks were built using laser powder bed fusion of standard 316L SS powder. The build parameters were varied by controlling a custom variable called the energy density to produce an assortment of wicks with different capillary metrics, i.e., porosity, permeability, and maximum pore radius. The variation in the capillary metrics, determined using a combination of capillary flow porometry and mercury intrusion porosimetry, was studied with respect to the energy density. The pore distribution was also studied by analyzing in detail the intrusion curves acquired during mercury intrusion porosimetry. The results from this study can serve as general guidelines for building future 3D printed wicks for loop heat pipes with the desired capillary performance.

[159] ***Operating Characteristics of Cryogenic Loop Heat Pipes at Different Filling Pressures***

Takeshi Yokouchi (Institute of Fluid Science,Tohoku University), Xinyu Chang (Institute of Fluid Science), Kimihide Odagiri (Japan Aerospace Exploration Agency), Hiroyuki Ogawa (Japan Aerospace Exploration Agency), Hosei Nagano (Department of Mechanical System Engineering, Nagoya University) and Hiroki Nagai (Institute of Fluid Science).

*Abstract*

A cryogenic loop heat pipe (CLHP) is a two-phase heat transport device for cooling equipment in cryogenic operating temperature regions, such as infrared detectors. Long-distance heat transport using a CLHP can decouple the heat source from the cryocooler, reducing the effects of vibration from the cryocooler. It is expected to improve the attitude control of the satellite and enable high-precision observations using optical instruments. In this study, a gravity-assisted CLHP has been designed, and its operational characteristics have been determined. The transport distance of the CLHP was 2m. In this report, we investigate the operating characteristics of the CLHP by changing the filling pressure of the CLHP. In addition, a one-dimensional thermal-mathematical model simulating the gas reservoir specific to the CLHP was constructed to investigate the effect of the filling pressure on the operating characteristics. In this study, the filling pressure was varied between 2.9 MPa and 3.4 MPa in 0.1 MPa increments. As a result, the maximum heat transport capacity was 25 W at 2.9 MPa-3.2 MPa and 30 W at 3.3 MPa-3.4 MPa, indicating that the heat transport capacity tends to increase as the filling pressure increases. The operating temperature increased with increasing filling pressure, with a maximum difference of 4.2 K. The effect on the operating characteristics was confirmed.

[160] ***The Development of Carbon-Based Sorbent Monoliths – a Review***

Marek A. Wojtowicz (Advanced Fuel Research, Inc.), Joseph E. Cosgrove (Advanced Fuel Research, Inc.), Michael A. Serio (Advanced Fuel Research, Inc.), Andrew E. Carlson (Advanced Fuel Research, Inc.) and Cinda Chullen (NASA).

*Abstract*

The NASA objective of expanding the human experience into the far reaches of space requires the development of rapidly regenerable life support systems. Activated carbon has been historically used to adsorb various trace contaminants (TCs), water, and, under some conditions, also CO2. In addition, porous materials have been used as supports for liquid absorbents, e.g., porous polymer-supported liquid amines for CO2 control. In most applications, the porous sorbent, such as activated carbon, is utilized in the form of a packed bed of granular material, which, in spite of effective sorption properties, is associated with the following potential drawbacks: (1) high pressure drop, which in turn leads to high fanpower requirement and inefficient vacuum regeneration; (2) poor heat transfer; and (3) sorbent attrition and dust generation. To address the above sorbent deficiencies, the concept of structured (monolithic) sorbents was put forward. The scope of this review paper is limited to the development of carbon-based sorbent monoliths used in life-support systems. The focus is on carbon sorbent monoliths meant for TC control, but limited results of efforts to use structured activated carbon for CO2 control are also reported

[162] ***A System-Level Spacecraft Thermal Model Reduction Method Applicable to Transient Analysis***

Toshihiro Shibukawa (ArkEdge Space Inc.) and Shinichi Nakasuka (The University of Tokyo).

*Abstract*

In spacecraft thermal design, Thermal Mathematical Models (TMMs) play an essential role to evaluate thermal performance in-orbit. However, typical detailed TMMs have a high calculation cost, while many iterations running these TMMs are required in thermal design processes, such as uncertainty analysis, feedback from hardware design, and model correlation using thermal vacuum test data and in-orbit data. Therefore, shortening analysis time for TMMs is essential to reduce time and cost required for thermal design. Creating reduced models is one approach to deal with this problem. Generally, there are two approaches in creating reduced models: model-based and data-driven. Past studies on spacecraft thermal design reduction methods mainly focus on either component-level, model-based reduction or system-level, data-driven reduction. This study presents a model-based reduction method that is applicable to system-level thermal models, based on connected component decomposition algorithms. To make decision of which nodes to be fused in an automatic process, analysis results from the original model, under typical case sets, are used. By this approach, the reduced model preserves physical properties, allowing it to be used in both static and transient cases, and realize application to hardware design, thermal vacuum test correlation, and software-in-the-loop simulations for operation testing and planning. For evaluation of this reduction process, the actual thermal model used for ONGLAISAT, a 6U CubeSat developed by the University of Tokyo, was utilized. Even for CubeSat level models with only less than 1,000 nodes, this reduction process showed a reduction rate of around 0.6 to 0.7, shortening analysis time, while displaying a maximum of just several degrees celsius in temperature difference between the original model and the reduced model. This displayed that an effective system-level reduced model can be created using this method.

[163] ***XROOTS ISS Tech Demo of Aeroponics and Hydroponics Nutrient Delivery in Microgravity***

John Wetzel (Sierra Space), Robert Morrow (Sierra Space), Guillermo Tellez (Sierra Space) and Daniel Wyman (Sierra Space).

*Abstract*

The eXposed Root On-Orbit Test System (XROOTS®) is a payload integrated with the Veggie hardware for experimentation aboard the International Space Station (ISS). XROOTS grows plants in the microgravity environment of the ISS to evaluate nutrient delivery and recovery techniques such as aeroponics and hydroponics over the course of a full plant growth cycle, from germination to maturity. XROOTS was designed so multiple independent growth chambers can be used in parallel to evaluate alternative water and nutrient supply and recovery methods and configurations during operations. XROOTS allows for root zone and crop observation through video and still images, and short periods of crew observations. As a middeck locker equivalent (MLE) sized payload, XROOTS is mounted to the EXPRESS Rack below the Veggie lighting module. XROOTS was launched on NG-17 in February 2022 and installed the end of April. Sierra Space monitored and controlled payload operations from our Payload Operations Center (POC) in Madison, WI. Operations were conducted over a six-month period, with individual experiments lasting between 10 and 80 days. Results of each investigation provided insight for subsequent investigations. XROOTS demonstrated the feasibility of using aeroponic and hydroponic techniques for plant growth in microgravity. Results of these tests will help optimize design and performance of hydroponic systems for large scale plant production in space.

[165] ***Improving Harness–based Partial Gravity Simulators by Implementing Engineering Systems Modeling***

Alvin Harvey (Massachusetts Institute of Technology), Nicole McGaa (Massachusetts Institute of Technology) and Dava Newman (Massachusetts Institute of Technology).

*Abstract*

The unique gravitational environments of the Moon and Mars present challenges for many aspects of human spaceflight. Harness-based Partial Gravity Simulators (H-PGS) that rely on mechanical systems to offload subjects from Earth gravity are an accessible, ground-based technology that can train astronauts and inform researchers of the physiological, psychological, and operational effects of reduced gravity on human subjects. The fidelity of H-PGS impacts the validity of astronaut training and research, necessitating constant improvement to such systems to meet the needs of upcoming crewed missions. Currently, there is no formal design and diagnostic model for H-PGS or standardization in subsystem identification and nomenclature, and there is limited literature on the study of subject-harness interactions. The lack of an organized approach to understanding H-PGS as a collection of dynamic subsystems limits the ease of the design cycle for greater simulation usability and fidelity for future space mission operations. To initiate structured understanding, a systems-based model of H-PGS was developed using literature on notable H-PGS and their designs. The model distinguishes and organizes subsystems to be generalizable to most H-PGS and other harness-based systems. Several aspects of usability and fidelity often disrupted by H-PGS are described. Possible impacts on usability and fidelity by each H-PGS subsystem are preliminarily identified. The model was validated following the design iterations of the Moonwalker Partial Gravity Simulator as a case study. Structured descriptions and examinations of possible interferences of each H-PGS subsystem reveal the significance of the harness subsystem, which encourages its centrality in future development. The model’s applicability to the Moonwalker demonstrates its potential usefulness in understanding current and future H-PGS designs and contributes a benchmark for future studies characterizing subsystem influences on usability and fidelity. Overall, this proposed model can act as a customizable design and diagnostic tool for researchers developing and using H-PGS.

[168] ***The Mk-7 Gravity Loading Countermeasure Skinsuit: Evaluation of Insole Pressure and Load Distribution***

Ciarra Ortiz (Georgia Institute of Technology), Rachel Bellisle (Massachusetts Institute of Technology), Alvin Harvey (Massachusetts Institute of Technology), Katya Arquilla (Massachusetts Institute of Technology) and Dava Newman (Massachusetts Institute of Technology).

*Abstract*

The Gravity Loading Countermeasure Skinsuit (GLCS or “Skinsuit”) is an intravehicular activity suit for astronauts that simulates the effects of Earth’s gravity to combat muscle atrophy and spinal elongation through the application of axial load on the body using material tension. Currently, the Mark (Mk)-7 GLCS provides approximately 30% bodyweight loading, and a quantitative analysis was performed to understand and characterize the loading profiles. In this study, the pressure distributed across the insole was analyzed during locomotion in suited and unsuited conditions. The spatial load distribution over the sole of the foot was measured to identify any over- or under-pressurization compared to typical 1 g insole loading, which provides crucial sensorimotor feedback to foot mechanoreceptors. A pilot study was conducted on one participant wearing the Skinsuit on the Moonwalker, a partial gravity simulator, to investigate the load generated by the GLCS while running for 60-second intervals in 0.17 g, 0.38 g, and 1 g. An insole pressure-sensing system measured insole pressure distribution across multiple gait cycles, separated by heel strikes. To examine foot profile loading, pressure on the toes, metatarsals, midfoot, and heel were extracted from recorded insole data measurements. While this study is limited to one participant, the initial results show that the GLCS increases insole loading compared to unsuited conditions, supporting the goal of reloading the body towards 1 g loading conditions. The results of this study assess the Skinsuit’s ability to return some load onto the participant when experiencing differing partial gravities and determine how close the GLCS is to approaching a load equivalent to Earth’s gravity.

[169] ***Break-Even Point Analysis of In Situ Resource Utilization for Mars Settlement by SpaceX Starship***

Hiroyuki Miyajima (International University of Health and Welfare).

*Abstract*

The Artemis program, which includes the lunar orbital platform Gateway and lunar landing, is underway. In addition, space agencies and private companies are making plans to land on the Moon in search of water resources that they can utilize to produce drinking water and propellant. There have been various studies on manned flights to the Moon and Mars using in-situ resources, and most of them found the utilization of Mars’s resources to be generally positive, despite some technical difficulties. The Mars settlement plan announced by SpaceX in 2016 envisions the use of only Martian resources. On the other hand, studies of the utilization of lunar resources have been very mixed, with both positive and negative findings. In situ resource utilization has different break-even points and technical difficulty levels depending on the size and nature of the mission. In this report, we discuss the break-even point for multiple scenarios consisting of SpaceX Starship and in-situ resource utilization for a lunar and Mars mission by changing the system mass and lifetime. A sensitivity analysis was performed to estimate a feasible system mass and lifetime for liquid oxygen production on the lunar surface based on current data in terms of in-situ resources and rocket reuse. As a result, liquid oxygen production on the lunar surface may increase the initial mass in low Earth orbit if there is an insufficient quantity of water that can be excavated on the lunar surface or if the number of Starship flights to the lunar surface is extremely low. Therefore, the system mass must be reduced, the lifetime must be long enough (i.e. more than 10 years), or both.

[170] ***Dynamic Simulation Study on the Effect of Airtightness on the Sensitivity of Air Composition Monitoring in SPACE FOODSPHERE***

Hiroyuki Miyajima (International University of Health and Welfare), Yoshitoki Tanaka (JGC Corporation), Hidekazu Tsuda (JGC Corporation) and Soichi Mori (JGC Corporation).

*Abstract*

In 2021, the Ministry of Agriculture, Forestry, and Fisheries selected the SPACE FOODSPHERE Association as the contractor for a Japanese government-led strategic project called “Development of a Highly Resource-Recycling Food System That Supports Long-Term Stays on the Moon, etc.” In the same year, the writers of this paper, SPACE FOODSPHERE Association members, launched a conceptual design study of a ground-based test facility comprising a crop/microalgae/meat cultivation area, a habitation area, a resource recycling facility, and an environmental control area. In the ground test facility, it is important to measure changes in gas composition as accurately as possible over a long period, but the results will differ greatly if gas leaks out of the facility or flows into it from outside. Therefore, using dynamic simulation, this study analyzed the effects of a change in gas composition in the facility over a span of one year. The results of various specified leakage ratios were compared to determine the airtightness performance required for the experimental threshold. The results identify the relationship between air tightness and the air composition and capacity of the environmental control life support system as well as that between air tightness and the accumulation rate of trace components.

[171] ***Sooting Behavior in Concurrent and Upward Burning of Cylindrical PMMA-samples***

Christian Eigenbrod (University of Bremen, ZARM), Florian Meyer (University of Bremen, ZARM), Hans-Christoph Ries (University of Bremen, ZARM) and Jan Heissmeier (University of Bremen, ZARM).

*Abstract*

IR videography has proven useful for tracking the position of the pyrolysis front under a flame propagating upward in 1g. Since PMMA burns with low soot formation in 1g conditions, the radiation density of the gases above the sample is very low and the flame is hardly visible. As a result, the surface can be easily followed and the temperature at the pyrolysis front can be determined. The phenomenological definition of the pyrolysis front remains difficult. In experiments on concurrent propagation along cylindrical PMMA samples under µg conditions during the Sounding Rocket flight TEXUS 57, it was shown that the drastically increased soot production compared to terrestrial conditions leads to a significantly increased radiation fraction by the gas phase above the sample. Here, pyrolysis front temperatures were determined to exceed 450 °C and include a significant radiative fraction of soot formed between the flame and the sample. This also sheds light on the significantly elevated local temperatures under µg conditions, which can lead to self-sustaining burning of some materials in microgravity that are inflammable or extinguishing on ground– this despite the overall reduced mass burn rate observed in microgravity. The paper compares pyrolysis front velocities in upward configuration (1g) along cylindrical PMMA samples with diameters of 5, 20, and 25 mm with concurrent propagation (µg) of the same samples. Both the 1g and µg experiments were performed in hypoxic exploration atmosphere (70 kPa, 26.5% O2). While the 1g experiments were subjected to buoyant convection only with a typical but averaged flow velocity of 20 to 30 cm/s, a forced inflow between 20 and 30 cm/s was set for the µg experiments. Soot formation was also analyzed in the microgravity tests.

[172] ***Swarm Habitat: Lava Tube Base Design with Non-Orthogonal Modular Coordination of The Truncated Octahedral Modules***

Takashi Mizuguchi (Keio University) and Yashushi Ikeda (The University of Tokyo).

*Abstract*

Swarm Habitat is a concept for building a long-term, rational lunar base inside the lava tube, which has been pointed out as highly habitable but has been little explored. The development of a permanent base involves two types of issues: interior design issues, such as a comfortable interior for the long-term crew and a translation paths of travel that facilitates movement and emergency evacuation even in low gravity, and architectural scale issues, such as ease of construction in an unexplored area and transportation from the landing zone to the construction site.This paper attempts to solve these two problems by using modules that can reconfigure themselves autonomously and cooperatively like Swarm and their modular coordination.Swarm Habitat is designed from the perspective of the shape of the module and the interaction of its configurations. The orthogonal configuration of cylindrical modules, which has been used in many previous studies, is not suitable for construction in a 3-dimensional terrain of a lava tube, due to the increased exposed area, difficulty in transportation to the site, and difficulty in moving the interior space under lunar gravity. Therefore, a module with the truncated octahedron is adopted as a module shape that is more like a sphere, which is easy to roll and can be connected in multiple directions in a non-orthogonal manner.The four modules, the smallest in configuration, "crawl" around the terrain by changing their configuration, "slide" into the lava tube, and "flock" together to form the final module. The final 100-module base is constructed by "combining" them. The non-orthogonal configuration allows the crew to jump and move through pressurized space.The mainstay of Swarm Habitat is that it can establish modular coordination while sequentially adapting to the lunar gravity environment and the irregular site.

[175] ***Hybrid Life Support System Full Scale Testing: Integrated Bioreactor-Desalination Long Term Testing***

Ghaem Hooshyari (Texas Tech University), Arpita Bose (Texas Tech University), Jessica La-Grenade (Texas Tech University), Siddhi Kad (Texas Tech University), Michael Callahan (NASA) and William Jackson (Texas Tech University).

*Abstract*

As space habitats are developed in reduced gravity environments, life support systems will be able to evolve to harness the gravity present enabling a wider diversity of treatment systems that can be more robust and reduce consumable mass. Hybrid life support systems that combine biological regenerative processors with physio-chemical systems are one system that could provide such benefits. In this effort, gravity-dependent bioreactors were tested for extended periods for their capacity to treat space-based greywater and urine + flush water (U+F), separately. Effluent from the greywater biological reactor was further processed using a small-scale low-pressure reverse osmosis (RO) unit. Effluent from the urine biological reactor was desalinated using a static distillation system. Our objectives were to demonstrate if 1) the bioreactor could be used as the RO recycle tank, reducing the system mass and volume; and 2), if operating the urine bioreactor to produce NO3- instead of NO2- as the oxidized NH3 product would improve distillate quality. Using the greywater biological reactor as the RO system recycle tank reduced the life of the prefilter and RO membrane but had no effect on water quality. Operating the urine bioreactor to produce NO3- did reduce NOx- carryover to the distillate. Our results support the ability to use biological pretreatment in concert with desalination systems to eliminate the need for storage tanks, brine processing, reduce system mass and complexity, consumable mass, and provide robust systems.

[182] ***Anthropocentric Habitation of Mars Through Parametric Design***

Chi Lan Huynh (Sasakawa International Center for Space Architecture), Erin Quigley (Sasakawa International Center for Space Architecture), Logan Miller (Sasakawa International Center for Space Architecture) and Christopher Hisle (Sasakawa International Center for Space Architecture).

*Abstract*

Mars has been a central subject of the space exploration discussion for decades. The Red Planet is an atypical destination, offering humanity a location to study the rudimentary stages of microbial life, as well as implement a greater understanding of how the evolution of the planet's surface can influence the future of our civilization. Conditions on Mars are severe, yet livable. The proposed mission ARES (Architectural Research Expedition of Space) seeks to capitalize on the habitable aspects that the planet offers and develop a sustainable solution regarding humanity's first manned mission to Mars. Comprised of autonomous and human-centered operations, ARES is a thirteen-year expedition with the intent of establishing and constructing a permanent, self-sustaining colony. A system of three interconnected phases enables ARES to accommodate an initial crew of seven after the proposed site, Valles Marineris, has been readily prepared. Innovation in the 3D printing processes will provide a higher standard of living that limits the effects of radiation while establishing a suite of necessary amenities. This, in conjunction with several preconstructed temporary habitats and greenhouses, provides a system through which Martian crews can conduct a plethora of scientific studies while maintaining a healthy psychological and physiological state. The projected outcome of the mission will see an environmentally protected Martian colony that is prone to expansion and additional crewed missions to Mars.

[183] ***Development of a Damageable ECLSS and Interior-Environment Virtual Testbed Model to Simulate Future Resilient Deep Space Habitats***

Seungho Rhee (Purdue University), Zoe Noble (Purdue University), Jaewon Park (Purdue University), Amanda Lial (Purdue University), Laura Collazo Carballude (Purdue University) and Davide Ziviani (Purdue University).

*Abstract*

The Environmental Control and Life Support Systems (ECLSS) ensure inhabitable interior environments for the crew members in extraterrestrial spacecrafts and future habitats. ECLSS is interconnected with other subsystems (e.g., power systems), sensors, and environmental conditions to generate breathable air, recover/reutilize wastewater and solid waste as well as regulate temperature, pressure, and humidity within the habitat. To enable the design of future resilient deep space habitats, physical aspects of ECLSS, control algorithms, and both faults and damage scenarios must be accounted for. To this end, a physics-based ECLSS model has been developed and coupled with an Interior-Environment (IE) model which is able to represent multi-zone habitat architecture. This paper will primarily focus on two ECLSS sub-systems namely the Active Thermal Control System (ATCS) and Interior Pressure Control System (IPCS). The ATCS encompassing a heat rejection loop (radiator-based) and a heat pump system based on a vapor compression cycle is designed to meet heating/cooling loads within the habitat to maintain the desired indoor temperature setpoint. The heat sink loop is not included in the conventional ECLSS model, but it has been considered as a sub-system of ECLSS due to the close interactions and possible damage scenarios that can affect the thermal management of the habitat. The IPCS controls the interior total pressure by using an air supply line connected to a storage tank and safety valves. Additionally, breathable air generator model is combined with ATCS to control air quality and concentration. The behavior of coupled ECLSS and IE model has been verified under both nominal condition and damage scenarios that result in damage propagation on the components of ATCS and IPCS. Results of various cases with different initial damaged component will be compared. The results of analyses are presented and discussed along with future development plans.

[184] ***Numerical Analysis of Lunar Dust in Support of the Habitat and Logistics Outpost***

Owen G. Brown (Northrop Grumman), James C. Eblin (Northrop Grumman), Luis M. Bermudez (Northrop Grumman) and Zach Turner (Northrop Grumman).

*Abstract*

The NASA Artemis program aims to send humans back to the Moon for the first time since 1972. To achieve this goal, NASA and its commercial and international partners are constructing the Lunar Gateway, a facility that will support scientific research and surface landings on the Moon and help prepare astronauts for future missions to Mars. The Habitat and Logistics Outpost (HALO) module, a critical component of Gateway, is currently under development by NASA and Northrop Grumman. HALO will serve as the first Gateway habitable module where crew members will live and work in the cis-lunar environment. Designing a one-of-a-kind spacecraft orbiting the Moon requires careful consideration of crew safety and comfort. In this paper, we present the results of flow modeling and simulation performed as part of the design of the environmental control and life support system for HALO. Detailed computational fluid dynamic analyses of cabin flow and the effects of a simulated lunar dust seeding event on the cabin environment, examining the spread of dust parcels are presented. Our results cover multiple scenarios, including visiting vehicles, fan speeds, crew operations, and environmental changes. It is shown that the designs provide satisfactory mixing within the module and demonstrated efficient lunar dust removal.

[187] ***XR Testing Framework for Human-System Interaction Design Validation***

Vittorio Netti (Sasakawa International Center for Space Architecture), Albert Rajkumar (Sasakawa International Center for Space Architecture) and Olga Bannova (Sasakawa International Center for Space Architecture).

*Abstract*

The current standard for human-system integration testing for the development of space hardware makes large use of high-fidelity mockups to test operational scenarios and human interactions with the hardware. This process is iterated at different development stages with the utilization of large amounts of time and resources.

Immersive technologies can help overcome those limitations by minimizing the dependency on physical prototyping of assets and help condense the iterative evaluation/implementation process optimizing the transition from design to human-in-the-loop testing.

In this study, we present the current development stage of a XR testing framework to be used in Human-System Interaction design validation. This study has been developed at Sasakawa International Center for Space Architecture’s immersive laboratory as a breakthrough towards the implementation of those technologies in space hardware testing.

To validate the framework we used the Lunar Surface Infrastructure, a pilot project developed at SICSA and sponsored by The Boeing Company. The purpose of this project was to design a minimal lunar infrastructure that allow 4 astronauts to carry out an exploration class mission on the lunar surface of a 14 days duration. The scopes of the project included the design of a Class I pre integrated habitat, an unpressurized teleoperated/autonomous rover and the development of surface operations scenarios (ConOps).

The XR testing framework makes use of the Task Load Index by NASA (TLX) to assess the task workload and the System Usability Scale (SUS) to study the usability of the immersive technology system for these applications.

A test campaign will take place in the firsts months of next year, using the XR assets of the Immersive Laboratory at SICSA. The data will be collected and used to evaluate the current habitat and rover design using the proposed testing framework.

[189] ***Proposal for a testing standard for Planetary Construction technologies with ISRU***

Vittorio Netti (Sasakawa International Center for Space Architecture) and Tara Bisharat (Sasakawa International Center for Space Architecture).

*Abstract*

A fundamental part of ISRU construction research is to establish a useful metric to compare and evaluate the different technologies from the available sources, addressing the differences in the data presented across the selected publications. Earth-based testing with In Situ materials can be conducted in two possible ways: with original materials sourced from the Moon and Mars surface or through simulants fabricated from soil analysis. The only tests we have been able to perform on original material is on lunar regolith, mainly from the 360kg of lunar regolith and rocks brought back from the Apollo missions, but recently also from the Chang'e 5 lander. As for Mars, there is currently a Martian sample return mission planned for 2026, but at the moment the only manufacturing experiments have been performed on simulants.

Analyzing the current literature, it is possible to find a common problem that affects this kind of research: different tests performed on simulants and samples across the decades cannot be easily compared. Different research groups with different equipment and different methodology to analysis have produced a great deal but inconsistent amount of data and results.

This paper proposes a testing standard for Planetary Construction technologies with ISRU.

[191] ***Upward Flame Spread over a Thin Fabric in Normoxic Atmospheres***

Maria Thomsen (Universidad Adolfo Ibañez), Luca Carmignani (University of California Agriculture and Natural Resources), Priya Garg (University of California, Berkeley), Carlos Fernandez-Pello (University of California, Berkeley), Michael Gollner (University of California, Berkeley), David Urban (NASA) and Gary Ruff (NASA).

*Abstract*

The influence of environmental conditions on the flammability of combustible solids is of importance to spacecraft fire safety. In a manned spacecraft the environment is maintained at a normoxic condition, which is the combination of ambient pressure and oxygen concentration that results in a partial pressure of oxygen equal to that of normal atmosphere at sea level. Future spacecraft will have atmospheres with reduced pressures and increased oxygen concentrations at normoxic conditions (Space Exploration Atmospheres - SEA), designed to reduce preparation time for extravehicular activities. This paper presents experimental results on upward spread of flames over a flat thin cotton fabric under normoxic conditions. Experiments are conducted with ambient pressures ranging between 100 and 60 kPa and oxygen concentrations between 21% and 35% by volume. Additional experiments are carried out with a fixed oxygen concentration of 21% (ambient air) and a pressure ranging between 100 and 60 kPa. Results show that moving to normoxic environments with reduced pressure and increased oxygen concentration increases the flammability of the fabric and the flame spread rate. Low pressures with 21% oxygen concentration, on the other hand, led to a decrease in flame spread rate. Normoxic conditions also showed a greater increase in distance between the outer flame and the fuel bed at lower pressures. During the experiments, O2, CO, and CO2 were measured in the combustion products, and were used to calculate the heat release rate at different pressures and in normoxic conditions. The results show that as the cabin environment transitions to normoxic conditions with higher O2 concentrations, the heat released by the flame also increases. The data presented here provides information about the flammability of spacecraft materials in future SEA in support of the NASA research, yielding insight for future designs when considering fire safety in spacecrafts.

[194] ***Evaluation of Buoyant Flow Velocity Induced by Centrifugal and Coriolis Acceleration During Downward Flame Spread Over Thin Wire in a Centrifuge***

Yusuke Konno (Hokkaido University), Shoryu Ishikawa (Hokkaido University), Nozomu Hashimoto (Hokkaido University) and Osamu Fujita (Hokkaido University).

*Abstract*

Centrifuges are effective devices for observing physical phenomena in various gravitational fields. This study discusses the effectiveness of observing flame spread phenomena along the solid materials in centrifuges as a basis for spacecraft fire safety. Flame spread tests are carried out on the ground in the present study. Thin wires which consist of a metallic core and polymer insulation are used as test samples. A sample is supported vertically in a chamber at 120 mm apart from the axis of rotation. The upper end of the sample is ignited by a hot wire and subsequent downward flame spread under varied centrifugal force is observed. A spreading flame leans to the radial direction due to centrifugal force, but also to the circumferential direction due to the Coriolis force. By measuring the flame tilt angle, we attempt to predict the buoyant flow velocity affecting the spreading flame, based on the scale analysis at the location of sample. The buoyant flow velocities obtained in this study are similar to those reported in previous studies, indicating the validity of analysis method. Those results show that the centrifuge can be used not only to investigate the material flammability under arbitrary gravitational field, but also to evaluate the buoyant flow velocity that affects the flame spreading along the solid materials.

[196] ***Development of CO2 Reduction-Water Electrolysis Tandem Device as a Full-Scale Model***

Asuka Shima (Japan Aerospace Exploration Agency), Masato Sakurai (Japan Aerospace Exploration Agency), Yoshitsugu Sone (Japan Aerospace Exploration Agency), Hironori Nakajima (Kyushu Univ.), Mitsuhiro Inoue (Univ. of Toyama) and Takayuki Abe (Univ. of Toyama).

*Abstract*

This study describes an advanced tandem reactor for environmental control and life support systems (ECLSS). The reactor consists of a low-temperature (220°C) Sabatier reactor producing water and methane (CH4) from carbon dioxide (CO2) and hydrogen (H2) and a thermally coupled water electrolysis cell with a proton exchange membrane (PEM). The Sabatier component generates heat energy used to operate a tandem water electrolyzer and is thermally self-sustaining. A previous, subscale reactor generated 1 L/min of hydrogen (H2) for the Sabatier reaction and achieved 93 % CO2 conversion. The model electrolyzer used in this study currently generates H2 at 3.6 L/min, which the Sabatier reactor can use to convert 1.58 L/min of CO2 to CH4 as much as possible.

[198] ***Sublimation Cooling Technology for CubeSat Thermal Control***

Janine Moses (University of California, Davis) and Stephen Robinson (University of California, Davis).

*Abstract*

Small, inexpensive satellites called CubeSats are commonly used for conducting academic and commercial space research. Typically, there is no thermal control system to dissipate heat from the CubeSat avionics, which can limit onboard computing and payload power. Sublimators are a small-volume, passive thermal control technology with a proven 60-year flight history which may allow CubeSats to fly more powerful computers and conduct more complex experiments. Sublimators utilize water, a consumable; their size and passive nature is especially useful for CubeSat missions with volume constraints and short durations. Even with flight history, there are aspects of the heat and mass transfer processes in sublimation cooling which are not fully understood. Both historical and current modeling efforts make assumptions which require further exploration. This paper proposes CubeSat sublimation cooling technology, reviews past and current sublimator applications, and discusses the knowledge gaps and shortcomings of past sublimator uses and models. A UC Davis sublimator model is introduced with an initial analysis which addresses the assumptions often found in literature. Further, the overall thermal control system for a CubeSat with a sublimator is described, along with an initial sublimator sizing procedure and example.

[199] ***Spaceflight Exercise and Textile Laundering Machine for Improved Human Health***

Andrew Arends (University of California, Davis) and Stephen Robinson (University of California, Davis).

*Abstract*

Without a precedent to laundering clothes off-Earth, a preliminary solution space is required to develop a spaceflight laundry machine capable of operating in various gravity fields. With this paper's proposed solution space, human exercise to power a vibration agitation bladder, a closed-loop hydraulic system, and a wastewater sensor suite provide a desirable environment for quantifying waste-mass transfer away from textiles while reducing textile damage. Bond Graph Theory is used to evaluate how human power affects system and cleaning performance because it is amenable to the large variety of machine configurations humans can set and to the coupling expected within the different subsystems. Bond Graph simulation results reveal preliminary performance metrics, sensor types and placements, and the hardware significantly impacting the spaceflight exercise and textile laundering machine's performance. Last, this paper's methodology provides structure in maturing the machine's Spaceflight Technology Readiness Level beyond its current s

[200] ***Flight Environment HEPA Filter Testing for Lunar Dust Removal Capability***

Andrew Walcker (Paragon Space Development Corp), Juan Agui (NASA), Zach Turner (Northrop Grumman), Robert Green (NASA), Gordon Berger (NASA) and Craig Wadlington (Paragon Space Development Corp).

*Abstract*

Lunar dust is an abrasive compound that can cause critical damage to hardware and crew. The mechanical and chemical makeup various from typical earth dust due to weathering effects. Current space missions require extensive air filtration of lunar dust to ensure mission success; as such filtration testing is paramount in verifying the dust-removal capabilities of the system. Previous testing at NASA GRC consisted of two stages: testing a flat high efficiency particulate air (HEPA) media sheet at various pressure ranges (Stage 1) and testing a pleated HEPA filter at different humidity and dust levels (Stage 2). This testing was done to buy-down risk when testing the flight-qualification HEPA filter for the proposed Stage 3 test. Stage 3 testing consisted of using a flight-ready HEPA filter thereby determining the performance characteristics to verify programmatic requirements. This includes measuring lunar dust loading vs. pressure drop performance and determining a maximum capacity based on the allowable pressure drop, determining the HEPA filter efficiency utilizing two separate methodologies, and assessing if the lunar dust caused the HEPA filter to experience any damage. Additionally, dust removal from the HEPA filter was performed using a vacuum to determine if the filter life can be prolonged. These test results will aid the program in verifying programmatic requirements and ensuring risk buydown before this HEPA filter takes flight.

[204] ***Vehicle Modeling during the Burning of Cotton Samples in the Saffire IV and V Experiments***

Justin Niehaus (NASA) and John Brooker (NASA GRC).

*Abstract*

Predicting the transport of combustion products and heat during a spacecraft fire can help design a safer vehicle and mission. The Saffire project has provided data on the spread of large fires in a microgravity environment within Northrup Grumman’s Cygnus vehicle after a resupply mission to the ISS. Solid materials, including cotton-based samples were ignited to study flame spread and the effect a fire has on a vehicle. Sensors were placed within Cygnus that measured carbon dioxide concentration and temperature. A model of the Cygnus vehicle was developed using inlet and outlet data of Saffire and the descent phase cargo configuration photos. The initial gas phase volume of the model did not match volume measurements provided by the release of CO2, likely due the porous nature of the trash and cargo in Cygnus. Holes were placed in the model cargo to match the experimental volume, providing a better prediction of species transport. Surface heat transfer was calibrated to match the closest remote sensor to the Saffire IV outlet, (RS3) in the forward port standoff, providing a better prediction of the temperature throughout the vehicle.

[206] ***Preliminary Study of Moisture Absorption and Desorption in CO2 Removal System***

Masato Sakurai (JAXA), Asuka Shima (JAXA), Kentaro Hirai (JAXA), Chiaki Yamazaki (JAXA), Shotaro Futamura (JAXA), Satoshi Matsumoto (JAXA) and Hideki Saruwatari (JAXA).

*Abstract*

Removing CO₂ and conserving water efficiently in a spacecraft are crucial. Dehumidifying methods are necessary. This study examined the effects of heating temperature, air flow rate, humidity, and desorption time on absorption time. The ability of Zeolite and CSX-250 to absorb and desorb moisture was clarified by experiment. The experiments showed the potential of CSX-250 to maintain the dew point temperature needed for effective CO2 removal.

[207] ***The Trash Compaction Processing System (TCPS) Technology Demonstrations Science Objectives and Requirement Definitions***

Tra-My Justine Richardson (National Aeronautics and Space Administration), Steve Sepka (NASA), Kevin Martin (NASA), Michael Ewert (Johnson Space Center), Melissa McKinley (NASA-JSC), Jeffrey Lee (NASA), Gregory Pace (KBR Wyle), Douglas White (Stellar Solutions, Inc), Janine Young (KBR Wyle Labs) and Serena Trieu (Logyx LLC).

*Abstract*

Throughout the Next STEP Phase A and Phase B, the Trash Compaction Processing System (TCPS) is being developed for a technology demonstration on the International Space Station in 2025. For Phase A, two contractors built the proof-of-concept hardware. One contractor was chosen to build the TD hardware for Phase B. Both Phase A lesson learned and risk reduction activities at Ames Research Center were used to write the TD science objectives, scope, and requirements. The work at ARC aims to retire technical risks and provide design data to TCPS developers and the ISS system integrators. This paper will summarize the lessons learned from the proof-of-concept hardware and the risk reduction activities and how these lessons learned form the TD requirement matrix.

[208] ***Design, Build, Test of a CO2 Removal Testbed and Twin Robotically Manipulable Testbed: Sensing Degradation and Performing Maintenance with Robot/Human Teaming***

Daniela Ivey (M.S. Student- Mechanical & Aerospace Engineering Department, University of California Davis), Ulubilge Ulusoy (PhD Student - Department of Astronautical Engineering, University of Southern California), Samuel Eshima (PhD Student - Smead Aerospace Engineering Sciences, University of Colorado Boulder), Tammer Barkouki (PhD Student - Mechanical & Aerospace Engineering Department, University of California Davis), Ayush Mohanty (PhD Student - H. Milton Stewart School of Industrial & Systems Engineering, Georgia Institute of Technology), Monica Torralba (M.S. Student - Mechanical and Aerospace Engineering Department, University of California Davis), Christopher Lindbeck (PhD Student - Aerospace, Transportation & Advanced Systems Lab, Georgia Tech Research Institute), Stephen Balakirsky (Chief Scientist - Aerospace, Transportation & Advanced Systems Lab, Georgia Tech Research Institute) and Stephen Robinson (Professor, Director - UC Davis Center for Spaceflight Research, University of California Davis).

*Abstract*

The NASA-sponsored “Habitats Optimized for Missions of Exploration” (HOME) Space Technology Research Institute is creating a foundation for smart deep-space habitats that can both sustain human residents and sustain themselves without human residents. A vital element of any human-rated mission is the Environmental Control and Life Support System (ECLSS), composed of multiple subsystems, including an Air Revitalization subsystem that maintains a breathable atmosphere. Tracking performance, identifying performance degradation, predicting remaining useful life of components, and performing maintenance on such a critical system are paramount to creating a safe, habitable environment and are thus key research areas within HOME. This paper outlines the design, build, and test of two new testbeds at UC Davis. The first, ZeoDe (Zeolite Capacity Degradation), is a chemically functional CO2 removal testbed that generates degradation data for prognostics through the introduction of humidity into the system. The introduction of humidity can occur in a space habitat due to leaks or other faults. Humidity build-up within the system leads to CO2 removal capacity degradation of the sorbent. Thus, the study of sorbent degradation is of paramount importance to any zeolite-based CO2 removal system deployed on future spacecraft. The maintenance of such a system is equally important. The second UC Davis testbed, RobInZeN (Robotically Interactive ZeoDe twiN), is a non-functional ECLSS testbed designed for the physical manipulation by robots and humans of its components for task execution. It is modeled after ZeoDe, with additional design changes to allow maintenance practices for both humans and onboard robotic agents. These two testbeds will allow HOME to investigate sensor criticality, degradation physics, detection sequences, and maintenance plans for a degraded ECLSS CO2 removal unit in both autonomous robotic tasks and integrated robot/human teaming scenarios.

[209] ***Integrating Real-Time Environmental Data into an Educational Web Interface***

Meridith Greythorne (Over the Sun, LLC), Gregory Ross (Over the Sun, LLC), Ian Castellanos (Over the Sun, LLC), Grant Hawkins (Over the Sun, LLC), Ezio Melotti (Over the Sun, LLC), Ryan Meneses (Over the Sun, LLC), Kai Staats (Over the Sun, LLC) and Gretchen Hollingsworth (Barrow Arts & Sciences Academy).

*Abstract*

Modern, educational computer simulations can aid in advancing students’ engagement with STEAM topics (Science, Technology, Engineering, Arts and Math), as well as enable the integration of on-line teaching tools with a more standard curriculum. One current educational simulation, SIMOC (A Scalable, Interactive Model of an Off-world Community; ICES 2021) provides an interactive model of a Mars habitat. There are substantial complexities to living off-world, principally Environmental Control and Life Support Systems (ECLSS), which SIMOC incorporates as an integral part of its simulation. A new version of SIMOC, developed in part by an Arizona State University software engineering capstone team, has coupled live instrumentation and data collection with the educational web interface hosted by National Geographic. The sensor array includes CO2, temperature, pressure, and relative humidity, which populate the existing SIMOC dashboard with live readings as components of a simulated life support system. This paper describes how real-life data can be provided to citizen-scientists, establishing a tangible interface between simulation and real-world systems. As described in this publication, the integration of real-world data into SIMOC will offer new and exciting opportunities for students to connect with concepts of interplanetary travel and habitats. This paper details the components integrated into SIMOC such that current and future classrooms may perform hands-on experimentation through use of in-classroom sensor arrays, and describes in-depth a classroom experience implementing this system with local sensors.

[210] ***Multifunctional Sorbent (MultiSORB) Devices for Carbon Dioxide Removal***

Tra-My Justine Richardson (National Aeronautics and Space Administration), Keith Peterson (National Aeronautics and Space Administration), Tane Boghozian (Analytical Mechanics Assoiates Inc.), Hannah Alpert (National Aeronautics and Space Administration), Sander Visser (Analytical Mechanics Associates, Inc.), Gurpreet Klar (Analytical Mechanics Associates, Inc.), Alexander Schmitt (Guardian of Honors), Gabriella Sandoval (Guardian of Honors), Cameron Ojeda (NASA Volunteer Internship Program) and Quinton Dzurny (Georgia Tech).

*Abstract*

The Environmental Control and Life Support System on the International Space Station uses solid adsorbent systems to remove contaminants from spacecraft cabin air. These solid adsorbent systems use commercial off-the-shelf adsorbent pellets with predetermined characteristics such as adsorption capacities, thermal conductivities, and pellet shapes and sizes. The Multifunctional Sorbent (MultiSORB) project aims to develop sorbent lattices with custom adsorbent paste formulations and lattice designs with embedded heaters and sensors to reduce system mass, volume, and power consumption. The MultiSORB production process employs additive manufacturing with paste formulations to fabricate adsorbent beds with customized air flow channels and desired pressure drops. Advanced heaters or heat transport systems such as heat pipes and vapor chambers can improve temperature ramp rates and uniformity within adsorbent beds. This enhanced thermal performance leads to lower power consumption and an increased capability for rapid cycling, resulting in reduced system volume. This paper will introduce the MultiSORB concept alongside alternative sorbent technologies and discuss preliminary results for MultiSORB paste formulations, lattice designs, and heater technology.

[211] ***Ecosystem Modeling and Validation using Empirical Data from NASA CELSS and Biosphere 2***

Grant Hawkins (Over the Sun, LLC), Ezio Melotti (Over the Sun, LLC), Kai Staats (Over the Sun, LLC), Atila Meszaros (Over the Sun, LLC) and Gene Giacomelli (University of Arizona).

*Abstract*

Plant productivity varies widely based on the growing conditions. Controlled Environment Agriculture (CEA) commercial production systems such as greenhouses routinely outperform open field agriculture by 10 times or more per unit area and per unit time by optimizing every resource: available light, atmospheric conditions, space, labor, nutrients and water, and by eliminating soilborne diseases, harmful pests and fungi. Dozens of mathematical and computer models of plant growth have been developed to explain and/or predict yield from growing conditions using discrete processes or functional structures, and their outputs are validated against one or more empirical studies. Validation data are typically selected based on the intended application of the model; for example, models for open-field agriculture will incorporate the range of conditions likely in the regions where a particular crop is grown and calibrated to experiments on that crop. In this study, we extend the Scalable, Interactive Model of an Off-world Community (SIMOC) with a highly generic plant growth model that incorporates 22 different plant species and validate it against two high-profile and dissimilar experiments: NASA’s Controlled Ecological Life Support System (CELSS) and the Biosphere 2 Intensive Agricultural Biome (B2-IAB). Despite a difference in yield of >10x, our model predicts the outputs of both to be within range of experimental results, and the system-level behaviors of the B2 experiment are replicated by the simulation as well. Applications of this model include holistic cost-benefit comparison of widely dissimilar agricultural practices, optimization of long-term Biological Life Support Systems (BLSS), and public education.

[213] ***Development and Characterization of Additive Manufacturing Flat Loop Heat Pipe Evaporator***

Javier Corrochano (Arquimea Space), Francisco Romera (Arquimea Space), Carlos Galleguillos (FADA-CATEC), Antonio Periñán (FADA-CATEC), Fernando Lasagni (FADA-CATEC), Marco Gottero (Thales Alenia Space Italia) and Stéphane Lapensée (ESA-ESTEC).

*Abstract*

This work aims to show the results of the development of a novel ammonia flat Loop Heat Pipe (LHP) stainless steel evaporator manufactured by a combination of Additive Manufacturing (AM) technologies. Firstly, the materials and processes were validated by several tests performed at sample level. The results of this phase revealed that AM technology can manufacture porous stainless steel 316L primary wicks with porosity of 40% and pore diameter of 4.5 µm. Proof and burst tests showed that the flat stainless steel 316L compensation chamber manufactured by selective laser melting technology can withstand up to 200 bar without deformation. In addition, these AM stainless steel 316L materials showed good weldability and excellent chemical compatibility with ammonia. Finally, X-Ray Computed Tomography (CT) has been established as the preferable Non-Destructive Testing (NDT) method for analyzing the manufactured SLM components and flaw detection. For the second phase of the project, the AM flat evaporator was integrated in a technological loop and submitted to a thermal test campaign. The results revealed that the LHP works in a stable way up to 236 W without dry-out in a wide range of temperature sink conditions. The flat AM LHP evaporator combines the advantages of thermal control based on LHPs with the low cost and short production time of AM technologies. Thus, it can be considered as a promising alternative to conventional cylindrical evaporators for cooling applications.

[217] ***Evaluation of Thermal System Based on Flight Result of Nano Moon Lander OMOTENASHI***

Junji Kikuchi (Japan Aerospace Exploration Agency (JAXA)), Tomihiro Kinjoh (Japan Aerospace Exploration Agency (JAXA)), Yuki Akizuki (Japan Aerospace Exploration Agency (JAXA)), Toshihiro Osada (Shinwa Space Inc.) and Tatsuaki Hashimoto (Japan Aerospace Exploration Agency (JAXA)).

*Abstract*

OMOTENASHI is a CubeSat that was launched by a NASA SLS rocket in November 2022. Its mission was to demonstrate that a CubeSat can make a semi-hard landing on the Moon. The 6U-size spacecraft weighs 12.6 kg, and consists of an orbiting module, a rocket motor for deceleration on the Moon, and a surface probe as the landing module. Tight resource constraints of CubeSat impose the difficulty of mounting a heater and a radiator. The passive thermal control which is the prominent design feature of OMOTENASHI breaks through technical difficulties. In the mission sequence, the heat input changes greatly on orbit and when approaching the moon. In addition, the moon temperature cannot be predicted as a sunshine or shade. Therefore, the spacecraft is coated with APTEK2711 which white paint has high emissivity and reflectivity. This paint can be maintained small changes in temperature even when affected by radiation and albedo from the moon surface. OMOTENASHI established communication with the ground station approximately 30 minutes after SLS separation. In this moment, the solar cells were unexpectedly facing away from the Sun and rotating fast. From the temperature monitoring, the temperature of the spacecraft is gradually decreasing. Then, attitude control was performed by gas jets, but the battery voltage was sharply dropped. As the result, the transmitter turned off due to lack of battery voltage and the communication has not been restored yet. Based on the estimated trajectory, there is the possible that the solar cells will be able to generate power and communications will resume after March 2023. In this paper, the flight result of the thermal status during the first ground station pass is reported. Furthermore, based on the estimated trajectory, the future thermal status of the spacecraft is also evaluated.

[218] ***Reduction and Correlation of Lumped Parameter Method for Thermal Models in Steady-State Conditions***

Ignacio Torralbo Gimeno (IDR/UPM), German Fernandez-Rico (Max Planck Institute for Solar System Research), Javier Piqueras-Carreño (Universidad Politécnica de Madrid) and Isabel Perez-Grande (Universidad Politécnica de Madrid).

*Abstract*

The reduction of thermal mathematical models is often carried out manually, being very time consuming and error-prone. A combination of two methods for reducing and correlating the reduction results is presented. The first step consists in the reduction of the thermal model applying a matrix method, based on the manipulation of the conductive couplings matrix. A new model with the characteristics of a lumped parameter thermal model is obtained. The scope of the method — the scale of the reduction — is limited by the temperature differences between the detailed and reduced models, as well as by the differences in the heat flows across the model interfaces. This limitation is overcome by the application of the second method, for the correlation of the detailed and reduced models results. The correlation method is based on Jacobian matrix formulation and Moore-Penrose pseudoinverse, which allows the obtaining the value of the model parameters — conductive couplings — that yield correlated results. The combination of both methods in a pipeline allows the reduction and correlation of the thermal models, with little intervention of the engineer.

[220] ***Microbial Electrochemical Technologies for Regenerative Life Support Systems***

Amanda Kay Luther (Redwire Space NV), Jean-Romain Bautista Angeli (University of Ghent), Dries Demey (Redwire Space NV), Korneel Rabaey (Hydrohm) and Jolien De Paepe (Hydrohm).

*Abstract*

Life Support Systems are essential for human survival in manned spaceflight. As we head towards longer journeys Regenerative Life Support Systems (RLSS) must advance to avoid major payload requirements. Physicochemical life support systems developed thus far for the International Space Station (ISS) include water recovery and regeneration of carbon dioxide to oxygen, but do not yet include nutrient recovery nor food production. RLSS aim to integrate physicochemical technologies with key bioprocesses known on Earth to recycle waste, water, and air with minimal external inputs. Microbial Electrochemical Technologies (METs) are themselves integrated technologies, consisting of one or two microbial processes integrated into an electrochemical cell. These technologies utilize microorganisms that have the ability to use solid electrodes (directly or indirectly) as an electron acceptor or donor for their energy metabolism. The technology is flexible and offers efficient use of energy and resources, making it a good candidate for RLSS. MET can be operated for different purposes depending on catalyst selection, membrane selection, and operational configuration. Coupled to water electrolysis, it can minimize chemical input e.g., by acid and/or base production. Oxygen or hydrogen production can be coupled to the biochemical process, and these processes are directly controllable via electric current. The microorganisms used in MET tend to have low biomass yield, which translates to less waste and lower maintenance, and finally, the technology is compatible with reduced gravity as gas sparging is avoided. Challenges include long term maintenance and stability. Stability depends on a thorough understanding of both fluid and microbial behaviors and a dynamic control system to match. This paper will provide an overview of how MET can contribute to RLSS, provide a current state of the art for this purpose, and highlight a recent demonstration of an MET applied for CO2 recovery featuring a dynamic control system.

[221] ***Digital Twin for Astronaut Orthopedic Care: A Feasibility Study***

Laure Boyer (MEDES/CNES), Léo Fradet (Philomec), Rohan-Jean Bianco (Philomec), Alexis Paillet (CNES) and Audrey Berthier (MEDES).

*Abstract*

Deep space exploration missions will require crews to be more Earth-independent while, at the same time, extending their exposure to the hazards of spaceflight. Microgravity induces bone degradation, with a bone mineral density loss each month, in addition to muscle atrophy. Missions to planetary surfaces will introduce partial gravity after a prolonged microgravity flight, as well as new stressors that may have physiological repercussions. With a weakened bone/muscle structure, the increased risk of fracture during the execution of tasks may jeopardize the success of the mission. The need for increased autonomy with limited equipment for health monitoring emphasizes the development of digital tools in order to follow the evolution of astronaut health, to anticipate possible physiological disorders and to test countermeasure strategies. The long term objective is to develop a digital tool ("digital twin") for monitoring and for personalized diagnosis of the astronaut's osteoarticular health in order to limit the risk of fracture, and to evaluate bone health during long-duration flight. A musculoskeletal finite element model of the lower limb, which can measure the zone of bone density loss due to microgravity exposure, was used to simulate femoral loading following foot to ground contact for walking and running, under either Earth or artificial gravities similar to the ARED system. The Von Mises stresses in the proximal femur were measured to evaluate the average mechanical solicitation generated by each simulated physical activity, and to compare bone solicitation between Earth and artificial gravities. This highlighted the abilities of these simulation results to correlate with observed bone density loss. The value of the proposed solution, in the long run, lies in its ability to test and recommend a personalized countermeasures program necessary to maintain the musculoskeletal health of astronauts.

[222] ***Long Term Material Circulation Control and Handling Repair Order in ALSS by Hierarchical Approach***

Masakatsu Nakane (Nihon University) and Hiroyuki Miyajima (International University of Health and Welfare).

*Abstract*

An Advanced Life Support System (ALSS) achieve life support in the ultimate environment by regenerating materials in the system. Because of their complexity of material circulations in ALSS, it is difficult to control whole-system material circulations and to handle on abnormal situations. Because of this, we had proposed hierarchical and autonomous circulation control methodology and had constructed automatic order determination system to deal with failure machines. In this paper, we calculated material circulation for 360 days with several machine failure events. As results, is was confirmed that our hierarchical procedure was useful.

[224] ***Assessing the Recycling Potential of Cupriavidus necator for Space Travel: Production of SCPs and PHAs from Organic Wastes***

Pierre Joris (TBI - INSA de Toulouse), Eric Lombard (TBI - CNRS), Gregory Navarro (CNES), Alexis Paillet (CNES), Nathalie Gorret (TBI - INRAE) and Stephane Guillouet (TBI - INSA Toulouse).

*Abstract*

Nowadays on the international space station, more than twelve replenishments per year are necessary to supply food, spare parts and scientific experiments and to take out wastes. But as it is envisaged to go longer in space, those replenishments won’t be possible anymore because of the distances involved. The astronaut life support system must be capable of continuously transforming wastes into valuable compounds. Two production types have been identified as critical and could be completed with a unique microorganism like Cupriavidus necator. As microgravity leads to fast muscle loss single cell proteins (SCPs) could be used as protein rich food for the crew. In addition, disposing of a sufficient amount of construction materials to build an advanced habitat will not be possible only by space goods transported from Earth to Mars. C. necator is well known for its ability to produce polyhydroxyalkanoate biopolymers (PHAs). By coupling the life support system to a 3D-printer, astronauts could be provided by an unlimited amount of construction materials. Moreover, based on life support system design, waste streams have been identified: urea coming from the crew’s urine and volatile fatty acids (VFAs) coming from a first step of anaerobic waste digestion. So, the objective of this work was to compare the effect of carbon sources (glucose vs VFA mix vs individual VFAs) on the biomass composition for SCP and PHA productions. Because life support systems function continuously as loops, continuous culture have been chosen. The total transformation of the carbon source into high SCP or PHA content biomass has been achieved. The best VFA composition for those applications have been identified.

[227] ***Thermal Control System Design and On-Orbit Validation for the 6U CubeSat SPHERE-1 EYE***

Kazuki Takashima (The University of Tokyo), Shingo Nishimoto (The University of Tokyo), Yuki Kusano (The University of Tokyo), Kazuki Toma (The University of Tokyo), Toshihiro Shibukawa (The University of Tokyo), Shinichi Yokobori (The University of Tokyo), Akihiro Ishikawa (The University of Tokyo), Shuhei Matsushita (The University of Tokyo), Ryu Funase (The University of Tokyo) and Shinichi Nakasuka (The University of Tokyo).

*Abstract*

In recent years, there has been an increase in smallsats and CubeSats performing complex missions in near-Earth and deep space environments. These complex missions require smaller sizes and higher performance in subcomponents, resulting in higher power densities and more difficult thermal design. In an Earth-orbiting satellite, the direct sunlight and eclipse phases repeat. This cycle is particularly intense for LEO satellites, and it is crucial to design satellites that take care of both the cold and hot sides. Generally, equipment keeps within its allowable temperature range through passive thermal control, such as changing surface characteristics or designing internal thermal paths. If it is still difficult to deal with, active control is performed by turning on heaters or changing the power status of equipment. The Intelligent Space Systems Laboratory (ISSL) at the University of Tokyo has developed two Earth-orbiting 6U CubeSats with a versatile bus system. One is SPHERE-1 EYE, whose mission is to capture images at will by general users. The other is ONGLAISAT, whose mission is to perform Earth remote sensing using Time Delay Integration (TDI) technology. This paper introduces the design of the thermal control system, including the hardware and software of SPHERE-1 EYE. A thermal design description of SPHERE-1 EYE, including requirements, thermal hardware accommodation, and thermal control algorithms in software, is presented. It also describes the checkout procedures for thermal hardware during a limited pass time and on-orbit thermal condition, including initial temperature control by battery heater and checkout status of temperature sensors.

[229] ***Advanced Adsorbents for Ammonia Control in Enclosed Environments***

Charles Cummings (QinetiQ) and Edward Harris (QinetiQ).

*Abstract*

Exposure to gaseous contaminants in the enclosed atmosphere of a submarine may pose a hazard to health. Ammonia (NH3) is one such gas which originates from the carbon dioxide removal system and physiological activity. Within the enclosed environment of a submarine the continuous Maximum Permissible Concentrations (MPC) are lower than UK Workplace Exposure Limits (WEL) to ensure that health is not comprised. NH3 levels on-board are monitored and maintained within permitted levels using selective adsorbents. This paper details the laboratory evaluation of advanced absorbents for NH3 removal. Adsorbents for NH3 prepared in-house and commercial alternatives were evaluated under dynamic flow conditions. Results indicate that the in house materials have substantially greater NH3 adsorption capacity and would be suitable for deployment on submarines. An alternative passive NH3 removal system using a thin film of sorbent on an inert substrate has been investigated. Using developed testing methodology the effect of film loading on NH3 removal will be presented. Based on the results of laboratory tests the predicted performance of an on-board system is discussed.

[230] ***Evaluation of Long-Term Microbial Regrowth in Slosh Water Tanks from the International Space Station***

Luke Roberson (NASA), Jason Fischer (Amentum), Daniella Saetta (University of South Florida), Carolina Franco (Amentum), Christina Khodadad (Amentum), Mary Hummerick (Amentum), Cory Spern (Amentum), Daniel Yeh (University of South Florida) and Melanie Pickett (University of South Florida).

*Abstract*

The NASA Launch Services Program (LSP) maintained the SPHERES-Slosh experiment aboard the International Space Station (ISS) between 2013 and 2019. The purpose of the Slosh experiment was to examine how liquids move inside fuel tanks in a microgravity environment. These tanks were similar to water storage tanks planned for use aboard future space systems, where large dormant periods between crew-use will provide similar conditions for biological growth or chemical leaching. The water within the SLOSH tanks remained undisturbed for over five years after testing concluded, providing a unique sample for stored water under microgravity conditions without prior protocols for microbial control such as sterilization or addition of biocides. The Slosh storage tanks were returned to Kennedy Space Center (KSC) aboard SpaceX CRS-18 mission in November 2019. Upon return of the tanks, the water within each tank was analyzed to determine how the water chemistry and biology changed during its tenure in microgravity. The data obtained and described within this publication provided a basis and reasoning for planning water storage and purification treatment methods aboard ISS, Gateway, and future space habitats. Results demonstrated that low microbial concentrations were present within the water, as expected since no biocide treatment was employed, yet no extensive biofilm formation was observed after 5 years even in the presence of microbial food sources such as the polycarbonate structure and food color additives. This experimentation demonstrates that future biofilm studies should be performed on this type of experimental setup with proper controls aboard ISS to examine microbial regrowth to improve microbial control within space water systems.

[231] ***Design of Space Music Hall as a Module of Low Earth Orbit Space Station***

Kazuki Toma (University of Tokyo), Shuto Takashita (University of Tokyo) and Shinichi Nakasuka (University of Tokyo).

*Abstract*

In recent years, new space stations in low Earth orbit have been considered and developed by several private U.S. companies to replace the International Space Station (ISS), which is scheduled for decommissioning in 2030. Elsewhere, China is building its own space station. In the future, when more people will stay in orbit for longer periods of time, the following demands are expected to arise: (1) a place for orbiters to relax and unwind, (2) a place for communication, and (3) a place for new cultural activities of humankind. We believe that a facility for public entertainment and cultural activities in space satisfies these demands, and designed a crewed module in space that functions as a place for cultural activities such as a concert and live performance. Our design provides the following attractiveness:(1) audience placement and stage performances that do not exist on the ground, taking advantage of microgravity in a low-earth orbit and (2) a view of the earth through a huge window that does not exist on old space stations. In this paper, the feasibility of these facilities in view of environmental control, structure and human safety is studied and planning how to operate it in orbit is also considered.

[233] ***Passive Deployment Mechanisms for Minimal Composition of Lunar/Martian Base Camp Implanted into Lava Tube***

Jun Sato (The University of Tokyo), Saneyuki Kawabata (The University of Tokyo), Tomohiro Yokozeki (The University of Tokyo), Kazuya Saito (Kyushu University), Masato Sakurai (Japan Aerospace Exploration Agency), Yasuhiro Awata (Japan Aerospace Exploration Agency) and Nao Hoshinouchi (Japan Aerospace Exploration Agency).

*Abstract*

Lava tubes on the moon and Mars are considered favorable sites to implant a habitation module due to their protected environment from enormous temperature gaps, radiations and meteorites. In the initial steps of Lunar/Martian habitation, a quickly deployable base camp is beneficial in preparing for a permanent human presence. Envisioning quick establishment of the base camp implanted into a lava tube on the moon or Mars, the habitation module and related infrastructure should be composed as a minimum. The habitation module is installed inside the lava tube, while solar power modules are installed on the ground surface. A cable lift suspended from an overhang connects the bottom of the lava tube and the ground surface for transporting humans or supplies. Cramped spaces inside the habitation module apply to dense vegetation that contributes to providing oxygen and food, absorbing carbon dioxide. Derived from a transportation and installation scenario in which humans arrive through a final transport, each component comprises semi-passive deployment mechanisms for its primary structures. Affiliated external structures are developed in addition to the deployable structures of the habitation module for an envelope and an embedded floor that were developed in the past. The overhang comprises a tensioning structure to cantilever from the cliff. Releasing rails are ejected, and adjustable footings touch down on bumpy terrain during the deployment of the habitation module and the overhang. The adjusting mechanism for the footing is developed using levers with a migratable junction.

[234] ***Plasma Activated Water: A Technology for Acid Generation and Space Crop Production***

Ryan Gott (Oak Ridge Associated Universities), Kenneth Engeling (NASA), Joel Olson (Southeastern Universities Research Association), Misle Tessema (NASA), Jason Fischer (Amentum), Carolina Franco (Amentum), Bruce Link (Southeastern Universities Research Association) and Christina Johnson (Oak Ridge Associated Universities).

*Abstract*

As humanity returns to the moon and onward to Mars, sustainable space travel becomes essential for cost and independence from Earth. Astronaut activities in low Earth orbit resupply consumable materials and can require alternative technologies if transportation of chemicals is deemed hazardous. Plasma technology and applications are able to generate commodities that assist in achieving Earth independence. Plasma interaction with water generates acid in-situ using on-board resources of electricity and breathable air without the need for large infrastructure. At Kennedy Space Center, researchers have shown that plasma is able to produce nitric acid, and therefore nitrates, in a plant-usable form in water. In this report, the team presents results on acid generation in g/kW-hr as well as provides results on plasma activated water for plant growth assistance. Plasma was generated utilizing DC, AC, and pulsed power supplies in order to determine optimizing parameters for generation of this useful commodity.

[236] ***Using Virtual Reality to Envision Deployment of Spacesuit-Compatible Augmented Reality Displays for Lunar Surface Operations***

Jacob Keller (Jacobs/NASA JSC), Lanssie Ma (KBR Wyle/NASA Ames), Matthew Noyes (NASA JSC), Daren Welsh (KBR Wyle/NASA JSC), Lauren Brady (METECS /NASA JSC), Joseph Vacca (Tietronix/NASA JSC), Forrest Porter (Tietronix/NASA JSC), Skye Ray (Jacobs/NASA JSC), Paromita Mitra (NASA JSC) and Matthew Miller (Jacobs/NASA JSC).

*Abstract*

The National Aeronautics and Space Administration (NASA) aims to land crew on the lunar surface to establish a sustainable presence and develop operational concepts for future long-duration missions. New technologies will be necessary to extend planning and execution capabilities for lunar surface activities. NASA’s Joint Augmented Reality Visual Informatics System (Joint AR) is one such technology. Joint AR is a suitmounted augmented reality (AR) display and computes system which facilitates unprecedented information exchange and data visualization capabilities between mission support operators and suited crew. This paper describes challenges associated with developing AR technology for an envisioned work domain by applying a sociotechnical lens to the iterative testing and development of novel AR technology through virtual reality (VR). A VR testbed was established to simulate a representative lunar surface environment, enabling a series of three human-in-the-loop (HITL) tests evaluating AR navigation interfaces for exploration extravehicular activity (xEVA). Our findings identify several considerations for future Joint AR design and testing efforts, including challenges with data overload, attentional demands, and environment-related perceptual challenges. Tradeoffs and potential approaches are discussed to mitigate these challenges and improve future Joint AR testing fidelity.

[237] ***To Biocide or not to Biocide? Exploring the "No Biocide" Option in Spacecraft Potable Water Systems***

Mary Lou Nadeau (Aerodyne Industries LLC), Audry Almengor (JES Tech), Dean Muirhead (Barrios Technology), Mark Ott (NASA Johnson Space Center) and Michael Callahan (NASA Johnson Space Center).

*Abstract*

Residual biocide has been used to protect against microbial growth in spacecraft potable water systems since the Gemini program. Iodine, the biocide currently used on the International Space Station (ISS) has a long history of use but presents a few challenges for exploration: it must be removed using a consumable absorbent before crew consumption and is known to lose its biocidal concentration due to interactions with wetted components, especially during periods of dormancy. Biocidal silver is being considered for exploration missions as it is safe for crew consumption, but it too has challenges with proper material design to maintain sufficient disinfection residuals. An idea proposed by some in the Environmental Control and Life Support System (ECLSS) community has been that the biocide does not provide a true barrier against microbial growth, and therefore, perhaps the challenges of maintaining a residual biocide in the system could be best overcome by removing the biocide altogether. In this argument, they point to the regenerative water treatment system on the ISS which produces high purity water that theoretically meets the microbiological requirements before the iodine is added. Exploration water processing systems are expected to have similar water processing capabilities. This paper will discuss the role that residual biocide may play in controlling microbial growth and presents perspectives on the potential risks associated with removing it from exploration water systems.

[238] ***MMX Rover: Thermal Control Design and Validation of a Rover on Phobos Martian Moon***

Maxime André (CNES).

*Abstract*

The MMX (Martian Moons eXploration) mission led by JAXA will lift off in 2024 to study Mars’ moons Phobos and Deimos. In this context, CNES and DLR provide a low-cost and lightweight rover – 29 kg in a 50 x 50 x 25 cm box powered by solar arrays – that will be carried by the spacecraft to Phobos. The rover is jettisoned to the surface, autonomously uprights and deploys itself. It then carries out its technical and scientific objectives analyzing the Phobos soil using an infrared radiometer (MiniRad), a Raman spectrometer with laser (RAX) and its cameras to study the mechanical action of the wheels into the regolith. Despite the rover’s limited weight and energy, the rover development plan is similar to a NanoSat approach. The rover embarks flight proven hardware, electronics from CubeSat recent heritage and some new technologies with low TRL. The rover experiences a changing thermal environment with external temperatures varying between -130 °C and +50 °C with low heating power allowed (<2W) to thermally control battery, motors and avionics. Environment is similar to the Earth’s Moon with large amount of thermal cycling due to the day-night cycle of 7.65 hours on Phobos and with craters and rocks at its surface. Due to the jettisoning, the rover bounces and rolls on the regolith with a complex dust impact. The thermal control system (TCS) is based on an efficient thermal insulation both radiative and conductive with the environment and a careful management of heat leaks especially through the harness (more than 1 000 wires). The 9 thermal zones are thermally controlled using MLI, paints, thermal straps, heaters and thermal switches. This paper focuses on the rover TCS design, constraints and objectives as well as its validation by testing including in particular heat leakage characterization tests through harnesses.

[239] ***Design Process intended to protect xEMU components from Lunar Dust***

Thomas Stapleton (Innovative Aerospace LLC), Cinda Chullen (NASA), Kelsey Bloom (Jacobs Technology), Otis Walton (Grainflow Dynamics, Inc.), Beichuan Yan (University of Colorado, Boulder) and Saikat Chakraborty Thakur (Auburn University, Auburn).

*Abstract*

The xEMU is being developed to supply astronauts with a safe environment during terrestrial exploration. Lunar dust has been identified as one of the greatest challenges to the xEMU during lunar exploration. Fine, glass like dust particles proved detrimental to Apollo hardware operation and has the potential to cause significant performance degradation to manned flight hardware. Lunar Dust Mitigation Devices (LDMD) were designed, fabricated and tested in fulfillment a NASA SBIR Phase I to protect xEMU venting components, during lunar exploration (EVA/IVA), from the threat lunar dust particles presented against six xEMU venting component operations. A structured approach was developed, during a SBIR Ph II, to better understand how electrostatically charged lunar dust could impact dust protection designs. Following preliminary fluid and magnetic force analysis a complex simulation tool will be developed to predict the cohesive strength of lunar dust to LDMD surface and the ability of xEMU component purge gas to clean these surfaces. The cohesive analysis will be based on lunar dust triboelectric/adhesion properties, predicting cohesive forces between the dust and LDMD surfaces. Developed code will then be coupled within an existing ParaEllip3d-CFD, coupled Computational Fluid-Dynamics and Discrete Element Method (CFD/DEM) simulation model. This integrated tool intends to predict if the purge gases offer adequate shearing forces to clean LDMD surface of lunar dust. LDMD designs will be modified to enhance the self-cleaning approach and prototypes will then be fabricated. Testing at Auburn University intends to challenge LDMD prototypes by replicating Dusty Plasma, which contains electrostatically charged, simulated lunar dust as floats in clouds above the lunar surface. Ideally, results from this testing will validate the prediction models offer a guide to allow the design of LDMD, and other protection devices, to be effective.

[240] ***Design for Custom Shaped Spacesuit, and Optimizing the Fit of Spacesuit Hard Upper Torsos***

Will Green (University of North Dakota), Pablo De Leon (University of North Dakota), Jesse Rhoades (University of North Dakota) and Han Kim (Leidos, Inc).

*Abstract*

The next era of human spaceflight will see the return of astronauts to the lunar surface, requiring frequent planetary EVAs by an astronaut corps in diverse body shapes and sizes. Future suits must be designed to accommodate the growing and changing population of astronauts, and provide optimal fit, comfort, and mobility. The torso of the spacesuit is a critical component in determining the fitment and function of a suit system. This paper presents a design framework for generating custom shaped Hard Upper Torsos (HUTs) from a 3-dimensional body scan. In this framework a principal component (PC) analysis was performed on a 3D body scan database of the general population. A set of clusters was statistically identified, each of the which represents a distinct torso shape and size. The computer design of the HUT geometry was manually adjusted for optimal fit for each cluster. The obtained HUT geometries were processed for PC analysis and statistically modelled, so that an arbitrary torso shape can predict a HUT geometry hypothetically yielding an optimal fit. While this technique constituted a custom sizing scheme, a “standard” sizing scheme was additionally built, in which a discrete number of HUT sizes (small, medium, large, etc.) was identified for maximum accommodation of the population. To determine the improvement of fit, 3D printed mockups were fabricated for the standard and the custom shaped HUT, based on the 3D body scan of test volunteers. The perceived fit and comfort was assessed by a structures survey. Mobility was measured by patterns and ranges of the upper extremity motions. The testing and data analysis is currently in progress, and the details will be presented in the full manuscript.

[241] ***Planetary and Lunar Environment Thermal Toolbox Elements (PALETTE) Project Final Results***

David Bugby (Jet Propulsion Laboratory, California Institute of Technology), Jose Rivera (Jet Propulsion Laboratory, California Institute of Technology), Quynhgiao Nguyen (NASA Glenn Research Center) and Stephanie Mauro (NASA Marshal Space Flight Center).

*Abstract*

This paper summarizes the technology development advancements made at the conclusion of the three-year JPL PALETTE project, which was funded by the NASA Game Changing Development (GCD) Program. The project goal was to ensure that a full “palette” of flight-ready (high TRL) thermal “toolbox” elements is available so that engineers are able to create passive, ultra-isolative thermal designs for science instruments on a variety of carriers in lunar/planetary extreme environments. PALETTE was structured to meet the need by increasing thermal toolbox element TRL via four design/build/test efforts (Tasks 1-4) and four analysis/study efforts (Tasks 5-8). Task 1 targeted the development of thermally-switched enclosures (TSE) featuring a thermal switching system that links a reverse-operation DTE thermal switch (ROD-TSW) to a propylene miniaturized loop heat pipe (mini-LHP). Task 2 sought the development of an affordable parabolic reflector radiator (PRR) for lunar instruments operating at low-to-mid latitude sites. Task 3 focused on the development of an ultra-low effective emissivity (e\*) multilayer insulation known as “spacerless” MLI (SMLI). Task 4 involved the development of low conductance thermal isolators (LCTI) made from 3D-printable Ultem 9085/1010 and machinable Ultem 1000. Prototype test results for Tasks 1-4 will be summarized in the paper as will the analyzed architectures and the ranking results generated from Tasks 5-8, the four analysis/study tasks. Task 5 focused on optimizing gimbaled optical instruments, Task 6 on optimally combining thermal transport/storage/switching to achieve new capabilities, Task 7 on instrument feed-through (wire/aperture) heat loss minimization, and Task 8 on instrument scalability, extensibility, and planetary use. Also presented in this paper are current plans/opportunities for PALETTE technology mission infusion. These opportunities include two that are currently manifested and several that are still in the planning stages. The two manifested missions are the Farside Seismic Suite (FSS) and the (lunar farside-based) Lunar Surface Electromagnetic Experiment (LuSEE-Night).

[242] ***Supporting Exploration Missions by Enabling Exploration Mission System Software***

Matthew Miller (Jacobs/NASA JSC), James Montalvo (KBR Wyle/NASA JSC), Ben Feist (Jacobs/NASA JSC), David Charney (Jacobs/NASA JSC), David Rynearson (Jacobs/NASA JSC), Jackie Vu (Jacobs/NASA JSC), Katie Heinemann (KBR Wyle/NASA JSC), Trey Davis (KBR Wyle/NASA JSC), Stephen Lin (KBR Wyle/NASA JSC), Omar Baig (KBR Wyle/NASA JSC) and Cameron Pittman (Jacobs/NASA JSC).

*Abstract*

Future exploration missions will consist of a multitude of data sources, systems, and operators collaborating to complete mission objectives. Presently, NASA is instantiating the contractual mechanisms, such as the Exploration Extravehicular Activity Services (xEVAS) and Human Landing System (HLS) contracts, to produce these mission assets. Architectural planning is also underway to establish the networking protocols and infrastructure to digitally create and connect mission elements, such as LunaNET. However, without new horizontally integrated data systems, these advancements will be limited in their ability to get mission data appropriately integrated into the plan, train, fly, explore workflow of the flight operations workforce. Here we describe several mission system software development efforts underway that are designed to support human spaceflight missions. This paper describes the current iterations of a suite of tools to support EVA procedure authoring and execution, and mission context creation for both International Space Station (ISS) and Artemis missions. These tools have been developed iteratively and continue to be used in present-day ISS operations on orbit and in several NASA facilities such as the Neutral Buoyancy Lab (NBL) and Artemis field testing. These solutions demonstrate how software development can be aligned with ongoing operations development activities to discover the features that best support both current and future human spaceflight missions.

[243] ***Cryogenic Thermal Test Setup for ARIEL FGS Instrument***

Piotr Osica (Spacive Sp. z o.o.), Karolina Wielgos (Spacive Sp. z o.o.), Agata Białek (Space Research Centre of the Polish Academy of Sciences (CBK PAN)), Markus Czupalla (FH Aachen - University of Applied Sciences) and Cezary Gąsowski (Spacive Sp. z o.o.).

*Abstract*

The Atmospheric Remote-sensing and Infrared Exoplanet Large-survey (ARIEL) is a space observatory and the fourth medium-class (4M) mission of the European Space Agency's (ESA) Cosmic Vision programme. One of the instruments on board ARIEL is Fine Guidance System (FGS). This optic sensor provides high-precision pointing information for the telescope which is an input to its attitude control system. Spacive Sp. z o.o. is responsible for the design of the thermal test setup in the thermal vacuum chamber for the the Space Research Centre of the Polish Academy of Sciences (CBK PAN), which is responsible for the development of the FGS instrument. In this paper we are presenting design of the test setup in the Thermal Vacuum Chamber, which requires maintaining different interfaces with stable temperature of 30K and 90K for the FGS instrument and supporting electronics. Moreover, we presents the results of numerical vibration and thermal analyses, which enabled us to estimate needed power of the cooling device.

[244] ***Thermal Technology Advancements for Extended-Duration Lunar Operation***

David Bugby (Jet Propulsion Laboratory, California Institute of Technology), Jose Rivera (Jet Propulsion Laboratory, California Institute of Technology) and Stephanie Mauro (NASA Marshall Space Flight Center).

*Abstract*

The desire for extended-duration robotic exploration of the moon without radioisotopes has highlighted a need for improved thermal capabilities. Described in this paper are ten innovations to enable multi-day/night operability/survivability of lunar instruments/systems. Extended-duration lunar operation is highly challenging due to the 50-100 K temperatures during the (15 Earth-day) lunar night and the 350-400 K temperatures (at low-to-mid latitudes) during the (15 Earth-day) lunar day. The innovations and the reasons why they’re needed are as follows: (1) thermally-switched enclosure (TSE), which houses the instrument/system and (using innovations 2-5, 8-9 below) passively transitions from daytime thermal coupling to nighttime thermal isolation; (2) parabolic reflector radiator (PRR), which provides a low sink temperature during lunar day at low-to-mid latitude sites; (3) spacerless MLI (SMLI), which is a low e\* MLI concept involving nested double-aluminized Mylar layers hung from tension cable supports without spacers; (4) low conductance thermal isolator (LCTI), which conductively isolates systems from carriers and subsystems from each other; (5) reverse-operation DTE thermal switch (ROD-TSW), which is a high ON/OFF ratio, fully passive thermal switch used within the TSE; (6) extended duration ROD-TSW (ES-ROD-TSW), which is an extended-stroke version of the ROD-TSW for non-vacuum (or vacuum) environments; (7) miniaturized ROD-TSW (mini-ROD-TSW), which is needed for highly compact thermal-switching applications; (8) miniaturized loop heat pipe (mini-LHP), which transports heat from the TSE internal housing to the radiator with high conductance and minimal cross-sectional area; (9) Vectran tension cables (VTC), which provide conductive isolation and structural support; and (10) lunar magnetometer thermal enclosure (LMTE), which is the TSE for a future JPL lunar magnetometer. These ten advancements were developed at JPL under the PALETTE, ARTEMIS-T, and ROD-TSW projects. PALETTE is funded by NASA GCD, while ARTEMIS-T/ROD-TSW were funded by JPL. Also introduced in the paper are a few related future advancements.

[246] ***Numerical Study of Carbon Dioxide Transport Problem for the Open and Lower Airflow Space in the ISS Module***

Chang Son (The Boeing Company), Nikolay Ivanov (New Technologies and Services), Evgueni Smirnov (New Technologies and Services) and Denis Telnov (Peter the Great St.Petersburg Polytechnic University).

*Abstract*

The current contribution deals with the problem of possible high level of the carbon dioxide concentration when a crewmember works near or inside an open rack where the airflow is less than in the cabin. The Computational Fluid Dynamics (CFD) model considers the U.S. Laboratory with a port rack open. A crewmember is modeled as a localized source of the carbon dioxide. The paper presents examination of the ability of the current U.S. Laboratory ventilation scenario to prevent potentially dangerous carbon dioxide bubble formation near a crewmember staying at the same position for a long period. The focus of the discussion is on the carbon dioxide spatial/temporal variations with respect to working crewmember safety and comfort.

[248] ***The LIFETM Habitat (Large Integrated Flexible Environment) Air Revitalization System Development***

Sam Moffatt (Sierra Space), Mark Mentink (Sierra Space), Michael Martinez (Sierra Space), Jacob Fischer (Sierra Space), Matt Hurr (Sierra Space), Adam Marten (Sierra Space) and Abolfazl Shakouri (Sierra Space).

*Abstract*

The Air Revitalization System (ARS) within the LIFETM Habitat (Large Integrated Flexible Environment) is designed to maximize both technical and operational component readiness to reduce overall development and schedule risk. LIFE ARS draws on over a decade of Sierra Space experience in both regenerative and open-loop Environmental Control Life Support Systems (ECLSS) technologies. The system design centers on providing ultimate mission flexibility to allow versatility within the habitat design and extensibility towards future habitat configurations. LIFE ARS consists of three primary assemblies: the Temperature and Humidity Control Assembly (THCA), the Regenerable CO2 Removal Assembly (RCR), and Gaseous Trace Contaminant Control Assembly (GTCR). These assemblies form the core of the ARS and perform the majority of the critical air management functions within the vehicle. Because of the criticality and complexity of these assemblies, a rapid prototype/engineering development program was initiated. The prototypes produced during this program are intended for function, but with emphasis on incorporating flight-like components and interfaces wherever possible considering cost and lead-time. An overview of the prototype designs and initial test data are reported herein.

[249] ***Numerical Validation of ISS Columbus Crew Alternative Sleeping Area Ventilation with an Improved Configuration***

Chang Son (The Boeing Company), Susan Snyder (The Boeing Company), Amy Caldwell (The Boeing Company), Nikolay Ivanov (New Technologies and Services), Evgueni Smirnov (New Technologies and Services) and Denis Telnov (Peter the Great St.Petersburg Polytechnic University).

*Abstract*

The objective of the Computational Fluid Dynamics (CFD) study is to analyze the airflow and carbon dioxide concentration in the cabin of the International Space Station (ISS) Crew Alternative Sleeping Area (CASA) installed in an overhead rack of the Columbus module. The paper presents examination of the CASA ventilation scenario for the new plenum configuration with the aft and forward return grilles installed in comparison with the initial configuration. The focus of the discussion is on the velocity magnitude and carbon dioxide spatial/temporal variations with respect to sleeping crewmember safety and comfort. The computational data obtained allowed concluding that there is no considerable risk of stagnant zones formation within the CASA cabin with and without the improved configuration. Velocity distribution in Columbus satisfies the cabin air velocity requirements with one diffuser tapped into the CASA. The carbon dioxide concentration values within the cabin also satisfied the requirements.

[250] ***Optimal PV and Battery Sizing for a Space Microgrid Near the Lunar South Pole Considering ISRU, Habitat and Water Subsystem Power Demand***

Diptish Saha (Aalborg University), Najmeh Bazmohammadi (Aalborg University), Juan C. Vasquez (Aalborg University) and Josep M. Guerrero (Center for Research on Microgrids (CROM), Energy Department, Aalborg University).

*Abstract*

The size and mass of the payload substantially affect the cost of space missions. The aim of this paper is to investigate the optimal mass and size of the photovoltaic (PV) array and battery in a PV-battery-powered lunar microgrid (MG) at 15 highly illuminated candidate sites near the lunar south pole. It is assumed that PV arrays are installed on top of towers with a height of 10 m. The methodology to estimate the PV output power at each candidate site using the illumination time-series profile is presented. On the consumption side, the power demand profiles of ISRU and wastewater subsystems are determined using the estimated oxygen and water consumption profiles of the habitat with four crew members. The closed-loop model of water management includes the interaction of ISRU, wastewater filtration system, and the crew habitat. The power consumption profile of the crew habitat is generated considering different power-consuming components in the habitat as well as the daily schedule of the crew members. Organizing different loads in a multi-microgrid system is also investigated. Finally, a criterion, mass-per-unit-load (MPUL), is used to compare different sites and select the best location with the minimum PV-battery system mass that can serve the highest power demand.

[251] ***Silver Foam: A Novel Approach for Long-Term Passive Dosing of Biocide in Spacecraft Potable Water Systems – Update 2023***

Tesia Irwin (The Bionetics Corporation), Angie Diaz (Amentum), Jennifer Gooden (Amentum), Mary Hummerick (Amentum), Wenyan Li (Amentum), Nilab Azim (NASA Kennedy Space Center), Deborah Essumang (NASA Kennedy Space Center) and Michael Callahan (NASA Johnson Space Center).

*Abstract*

A spacecraft water disinfection system that suitable for extended length space exploration, should prevent or control the growth of microbes, prevent or limit biofilm formation, and prevent microbiologically influenced corrosion. In addition, the system should have minimal maintenance requirements, be chemically compatible with all materials in contact with the water, be safe for human consumption, and be suitable to be shared across international spacecraft platforms and mission architectures. Ionic silver is a proven broad-spectrum potable water biocide under investigation for future exploration missions. The competing technology for dosing silver ions in future water systems is based on actively dosing the ions via electrolytic production. Several challenges with this approach have prompted additional investigations into alternative dosing techniques. Controlled-release technology is an attractive option for developing a high-reliability passive silver dosing device. This paper describes the continued development of a nanoparticle/polyurethane (NP/PU) composite foam for the controlled release of silver ions, and is intended to build upon the 2022 International Conference on Environmental Systems (ICES) paper number 97. This paper provides the technical background and performance test results of ongoing long-term silver ion release testing, microbial check valve (MCV) function, and disinfection function during system dormancy from the silver chloride (AgCl) NP/PU composite foams. The ultimate goal of the project is to develop a stable and reliable passive dosing silver ion release device for use in future spacecraft potable water systems.

[252] ***Mitigation of Biofouling in Plant Watering Systems Using AgXX, a Novel Surface Treatment***

Tesia Irwin (The Bionetics Corporation), Wenyan Li (Amentum), Angie Diaz (Amentum) and Mary Hummerick (Amentum).

*Abstract*

The development of plant growth systems with high yield and low maintenance for food production is a key focus area for NASA. One of the remaining technical challenges is keeping the plant watering systems clean without affecting plant growth, requiring consumables, or demanding crew time. Plant watering systems, such as the one onboard ISS, provide a nutrient rich environment for biofilm formation. Frequent maintenance is necessary to prevent biofouling, which currently requires crew time and mechanical means of cleaning. Better solutions are needed. The current ISS practices for biofilm mitigation in the water recovery and distribution system include the use of biocides (silver ion or iodine) along with regular maintenance (e.g. flushing, filter replacement). These biocide-based strategies could be problematic for plant watering systems, such as Ohalo, Exploration Garden, and APH, due to incompatibilities of the biocides with plants. We propose the application of AgXX, a novel antifouling surface treatment that meets the above requirements. This paper will report on an initial study that was completed to determine whether AgXX would be effective in a plant nutrient solution, and whether or not it would negatively impact plant growth in an aquaponics-type system.

[253] ***Drop the Base: Biological, ISRU-Based Aleatory Construction System for Martian Habitats***

Monika Brandić Lipińska (Hub for Biotechnology in the Built Environment, Newcastle University), Martyn Dade-Robertson (Hub for Biotechnology in the Built Environment, Newcastle University), Meng Zhang (Hub for Biotechnology in the Built Environment, Northumbria University) and Lynn J. Rothschild (NASA Ames Research Center).

*Abstract*

The prospect of establishing human habitats on Mars presents numerous challenges due to its distance from Earth and the Sun. These include limited access to building materials and machinery, communication lags, and difficulty in obtaining energy. Moreover, Mars' unique environmental conditions, such as different gravity levels, lack of a breathable atmosphere, and the need for protection from radiation, pose additional obstacles. Therefore, developing habitats on Mars requires a reinvented construction process that can address these extreme conditions. One of the alternative approaches for extraterrestrial construction is the use of biological materials. These materials could be brought from Earth and grown in situ for the construction of surface habitats and other structures. We propose the biofabrication strategy for stabilizing regolith using mycelium. This approach focuses specifically on building in resource-limited conditions. It takes into account the use of biomass, water, and oxygen when creating structural components, and the assembly process when it comes to energy consumption and the need for robotic operations. The work explores the creation of in situ-grown mycelium-based regolith composites. Due to lower gravity eliminating the risk of crushing, the resulting components could be literally dropped and aleatorily assembled based on their geometry. A structural system consisting of stacked components containing living matter could meld together through a biological process known as bio-welding, resulting in a solid structure that would serve as a protective habitat shell. The paper discusses the challenges of biological manufacturing for building on Mars, including the complexity of biological material synthesis. It also presents the developments towards a biological aleatory construction system that would work in reduced gravity conditions, allowing the construction of extraterrestrial habitats with minimal energy and additional resources.

[255]  ***NASA Crew Health & Performance Capability Development for Exploration: 2022 to 2023 Overview***

Andrew Abercromby (NASA), Grace Douglas (NASA JSC), Kent Kalogera (NASA), Karina Marshall-Goebel (NASA), Jeffrey Somers (NASA), Rahul Suresh (NASA), Moriah Thompson (NASA), Scott Wood (NASA), Ralph Fritsche (NASA), Emma Hwang (KBR), Justin Yang (Aegis Aerospace) and James Broyan (NASA).

*Abstract*

Radiation, reduced gravity, distance from earth, isolation and confinement, and habitation within artificially created and controlled life support environments are hazards that present risk to human space explorers. These hazards necessitate development of new technologies to protect crew health and performance during future long-duration missions to the moon and Mars. NASA’s System Capability Leads coordinate with agency experts, programs, and exploration architecture teams to identify and prioritize technology investments in support of future missions. This paper describes progress over the past year in CHP technology development, ground testbed development, ground-based testing, parabolic flight testing, and on-orbit technology demonstrations. Technology maturation progress and future plans are described in the following capability areas: crew health countermeasures; spacesuit physiology and performance; food and nutrition; radiation protection; and exploration medical capabilities.

[256] ***Portable Tunable Laser Spectrometer (PTLS) for Human Exploration: Update on Lasers and Mesh Networking***

Lance Christensen (Jet Propulsion Laboratory, California Insititute of Technology), Kamjou Mansour (Jet Propulsion Laboratory, California Insititute of Technology), Alexander Hart (Northern Illinois University), Benedito Fonseca (Northern Illinois University), Yuebin Ning (Norcada Inc.), Simon Wingar (National Research Council Canada), Nakeeran Ponnampalam (Norcada Inc.), Tran Tran (Norcada Inc.), Rachel Rae (Norcada Inc.), Graham McKinnon (Norcada Inc.), James Gupta (University of Ottawa), Ghasem Razavipour (National Research Council Canada), Weihong Jiang (National Research Council Canada) and Pedro Barrios (National Research Council Canada).

*Abstract*

We report on the development of a wireless network of sensors that measure spatial and temporal distributions of carbon dioxide, oxygen, and water vapor in human habitable vehicles for NASA exploration needs. Each sensor is a hand-held, portable tunable laser spectrometer (PTLS). Toward this goal, we report on realization of first-ever, high-reliability mid-infrared tunable diode lasers emitting at 2683 nm for measurement of carbon dioxide and water vapor. These lasers are a critical component of PTLS. We describe the development, verification, and validation of these lasers which demonstrate achievement of requisite reliability and traceability needed for critical applications. We also describe advancement of wireless network system software enabling individual PTLS sensors to be incorporated into a network distributed throughout a human habitation vehicle like ISS for monitoring trace gases oxygen, carbon dioxide, and water vapor.

[257] ***Testing Fit, Mobility, and Comfort of the Exploration Pressure Garment Subsystem (xPGS)***

Richard Rhodes (NASA), Christine Flaspohler (Jacobs Technology) and Shane Mcfarland (NASA).

*Abstract*

The Exploration Pressure Garment Subsystem (xPGS) is an anthropomorphic spacesuit that allows crewmembers to conduct work in space. Key aspects of the crew’s ability to do work are the fit, comfort, and mobility of the spacesuit. NASA designed and executed a test series to evaluate the performance of the xPGS in multiple environments and with test subjects from across the anthropometric requirement range. The fit, mobility, and comfort testing was organized into three separate test series: Mobility Test Series #1 - xPGS Fitchecks; Mobility Test Series #2 - Vendor down selection; and Mobility Test Series #3 - xPGS Range of Motion (ROM)/xEVA Functional Task Performance. Each test series had specific objectives and was conducted in series. Mobility test series #1 focused on conducting fitchecks in a 1-g laboratory environment with test subjects from across the anthropometric requirement range. The objective of the test series was to verify a comfortable and functional fit for all test subjects, evaluate reach to key controls and tools, and evaluate nominal and off-nominal donning and doffing. Mobility test series #2 focused on down selecting the various suit softgoods and boot options to the final configuration that would be used for data collection in mobility test series #3. Mobility test series #3 involved both isolated and functional tasks performed in circuits to evaluate the suit’s performance. Test subjects were surveyed on their comfort and level of effort throughout task performance. The fit, mobility, and comfort testing of the xPGS was completed in May of 2022 with excellent feedback and results. Specific lessons learned from the suit’s performance, simulation quality, and test methodology will be provided.

[258] ***Integration of a Photobioreactor into the MaMBA Facility as Part of a Human-centered Life Support System***

Paul Große Maestrup (Center of Applied Space Technology and Microgravity (ZARM), University of Bremen), Ksenia Appelganc (Business Psychology and Human Resource Management, University of Bremen), Saurabh Band (Sustainable Communication Networks (ComNets), University of Bremen), Florian Stechmann (Center of Applied Space Technology and Microgravity (ZARM), University of Bremen), Vera Hagemann (Business Psychology and Human Resource Management, University of Bremen), Anna Förster (Sustainable Communication Networks (ComNets), University of Bremen), Cyprien Verseux (Center of Applied Space Technology and Microgravity (ZARM), University of Bremen) and Christiane Heinicke (Center of Applied Space Technology and Microgravity (ZARM), University of Bremen).

*Abstract*

One of the most important components of a habitat for long-duration missions to Mars is the life support system (LSS), which will most likely include bio-regenerative elements. Since the lives of the crew members depend on the LSS, it is important that they can trust it. Therefore, a human-centered LSS that can be well understood and controlled by the crew is required. In this interdisciplinary work between space engineering, electrical engineering and psychology, the air revitalization component of a human-centered LSS, a photobioreactor (PBR), is being designed. This PBR is integrated into the Moon and Mars Base Analog (MaMBA) facility at the Center of Applied Space Technology and Microgravity (ZARM) in Bremen as part of a future LSS prototype. The PBR, as well as the MaMBA facility, are equipped with multiple sensors which are monitoring various environmental parameters. To provide sensor information to the crew in a preprocessed and user-friendly way, we are designing a graphical user interface (GUI) that can also be used for interaction with the PBR. All three components together, the MaMBA facility, the PBR and the GUI can then be used to test and determine human-factor-related constraints on the operation of a LSS under realistic conditions. This work presents the preliminary design of both the PBR and the GUI and gives first results on the operation of the PBR.

[259] ***International Space Station as a Testbed for Exploration Environmental Control and Life Support Systems – 2023 Status***

Alesha Ridley (NASA), Christopher Brown (NASA), John Garr (NASA), Lynda Gavin (NASA), David Hornyak (NASA), Katherine Toon (NASA), Paul Caradec (Leidos Innovations Corporation) and Allen Williams (Leidos Innovations Corporation).

*Abstract*

Human exploration missions beyond low earth orbit, such as NASA’s Artemis Program, present significant challenges to spacecraft system design and supportability. A particularly challenging area is the Environmental Control and Life Support System (ECLSS) that maintains a habitable and life-sustaining environment for crewmembers. NASA is utilizing the experience gained from its current and prior spaceflight programs to mature life support technologies for exploration missions to deep space. The intent is to establish a portfolio of life support system capabilities with proven performance and reliability to enable human exploration missions and reduce risk to success of those missions. As a fully operational human-occupied platform in microgravity, the International Space Station (ISS) presents a unique opportunity to act as a testbed for exploration-class ECLSS, such that these systems may be tested, proven, and refined for eventual deployment on deep space human exploration missions. This paper will provide an updated status on the testbed development including hardware and ISS vehicle integration progress to date as well as future plans for efforts to design, select, build, test and fly Exploration ECLSS on the ISS.

[260] ***Increased Oxygen Recovery Using Plasma Pyrolysis Technology and Electrochemical Hydrogen Separation***

Kagen Crawford (NASA Marshall Space Flight Center), Cara Black (NASA Marshall Space Flight Center) and Travis Quillen (Jacob Space Exploration Group).

*Abstract*

Currently on the International Space Station, approximately 50% of the oxygen (O2) for the crew is recovered from metabolic carbon dioxide (CO2). Maximum O2 recovery is required to reduce resupply mass for long-duration manned missions. O2 recovery is constrained by the limited availability of reactant hydrogen (H2) from water (H2O) electrolysis, and Sabatier-produced methane (CH4) is vented as a waste product resulting in a continuous loss of reactant H2. The Plasma Pyrolysis Assembly (PPA) has the potential to substantially increase O2recovery by post-processing the Sabatier-produced methane to recover H2. The PPA decomposes CH4 into predominately H¬2 and acetylene (C2H2). A separation system is needed to purify the H¬2 from the PPA stream before it is recycled back to the Sabatier reactor. Two sub-scale electrochemical H2 separation systems, developed by Skyre, Incorporated, were delivered to NASA for evaluation. This report details the results of Phase I testing and evaluation of the C2H2 removal systems.

[263] ***Using Effluent from a Hybrid Anaerobic Membrane Bioreactor Treating Fecal Waste for Hydroponic Fertigation of Pak Choi***

Alexandra Smith (University of South Florida), Talon Bullard (University of South Florida), Daniella Saetta (University of South Florida/ NASA), Jason Fischer (NASA/ LASSO), Katrina Haarmann (University of South Florida), Flaubert Nascimento Akepeu (University of South Florida), Luke Roberson (NASA) and Daniel Yeh (University of South Florida).

*Abstract*

Challenges for future deep space ECLSS will include providing potable water, supplying nutritious food, and managing wastes generated by the crew. With next to no readily available resources to sustain human life on the Moon and Mars, nothing can be considered a waste, and every resource, including all organic wastes generated by the crew (e.g., fecal), should be deemed for recovery and reuse. Fecal waste aboard the International Space Station (ISS) is currently treated as solid waste and not recycled in any capacity. The high-water content (fecal material being ~75% water), complexity, and the presence of pathogens make fecal waste difficult to stabilize and process. However, fecal material contains considerable fractions of carbon, nitrogen, phosphorus, and minerals which after stabilization, can be recovered and used as plant fertilizer. There is considerable research about growing food in Lunar and Martian greenhouses but a major limitation for plant growth will be continuously supplying fertilizer salts. Recognizing the need for a bioregenerative approach to fecal waste, an organic processor assembly (OPA) unit was developed through collaboration between the University of South Florida and NASA’s Kennedy Space. OPA is a hybrid, physical-biological treatment technology that couples an anaerobic bioreactor with a tubular ultrafiltration membrane. OPA is designed to treat and recover resources from the solid organic waste stream of a crew of four astronauts on an early planetary base. Aspects of OPA’s long-term operations and water quality treatment analysis were presented at ICES 2022. This conference paper will present preliminary research regarding the downstream use of OPA’s nutrient-rich effluent, produced from an actual fecal influent, in supporting the growth of extra dwarf bok choy from germination to maturity. Overall, OPA1 is an enabling technology demonstrating its potential to minimize fecal storage volume and assist in waste management, while additionally offsetting fertilizer demand.

[264] ***NASA’s PACE Ocean Color Instrument Thermal Design Evolution: from Goddard’s Instrument Design Lab Through Flight Development***

Kan Yang (NASA Goddard Space Flight Center), Deepak Patel (NASA Goddard Space Flight Center) and Wes Ousley (Vertex Aerospace).

*Abstract*

NASA’s Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, set to launch in 2024, seeks to provide data continuity for the ocean color, aerosol and cloud measurements acquired by NASA’s on-orbit Earth Science observatories since the 1990s. It will accomplish this through its Ocean Color Instrument (OCI), an optical spectrometer being developed for hyper-spectral measurements in the ultraviolet-to-near-infrared band between 340 nm and 2260 nm. Although OCI’s instrument architecture will provide greater insight and resolution than its predecessors in this wavelength range, the engineering required to achieve this also poses a greater challenge. In thermal engineering, this translates to a more complex thermal control approach to address high heat dissipations, stringent stabilities, the volume of heat that requires transport, and changing thermal environments due to tilting of the entire instrument ±20° twice per orbit. This current work explores how the PACE OCI instrument design has evolved from its initial conception in NASA Goddard’s Instrument Design Laboratory (IDL) to the current iteration of its flight design. The IDL studies explored three separate instrument configurations and two spatial resolutions per configuration, which were then down selected to a single instrument type and spatial resolution for flight instrument development. OCI subsequently went through major project milestones, including Preliminary Design Review (PDR), Critical Design Review (CDR), Pre-Environmental Review (PER) and Pre-Ship Review (PSR), with significant design updates along the way. This paper aims to provide a comprehensive account of OCI’s thermal control architecture evolution and the engineering drivers that have shaped it, with the goal of identifying trends spanning the full instrument development timeline to inform and advance future instrument thermal designs.

[265] ***Environmental Control and Life Support (ECLS) System Options for Mars Transit and Mars Surface Missions***

Zach Bryant (Jacobs Space Exploration Group), Andrew Choate (Jacobs Space Exploration Group) and David Howard (NASA Marshall Space Flight Center).

*Abstract*

The NASA led Artemis campaign will take humanity back to the Moon and serve as an analog for continued deep space exploration to Mars. Artemis utilizes crewed vehicles and habitats on both the Lunar surface and in Lunar orbit. The exploration of the Lunar surface and buildup of a basecamp is meant to be a “Mars forward” approach to testing and refining new technologies and techniques for living and working far outside of Low Earth Orbit (LEO) and preparing for future Mars missions. The Lunar Surface Habitat is planned as a primary element for long duration crew habitation on the Moon and will be the primary testbed for ECLS system hardware in a partial gravity environment. The Mars Transit Habitat will be the crew vehicle for the roundtrip from Earth to Mars and spend a significant amount of time docked to the Gateway outfitting and testing its systems prior to making the first Mars mission transit. The Mars Transit Habitat will utilize closed loop ECLS system technologies while a Mars Surface Habitat could use either open loop, closed loop, or a mix of both. Better understanding the needs of both these system architectures operating for extended periods in the Lunar environment and outside LEO will help to establish the ECLS system architecture for the future Mars surface mission. There are many aspects to consider such as length of crew stay, level of autonomy and dormancy between crewed missions, power requirements, system mass, and overall system reliability and maintainability. Other considerations will include Mars gravity vs. Lunar gravity, Mars atmospheric pressure vs. hard vacuum, and possible use of in-situ resource utilization.

[266] ***Inspiring Future Generations to Pursue Careers in Space***

Michael Wales (Blue Origin), Laurinda Bellinger (Blue Origin), Kristen Yip (Blue Origin), Riza Mae Mold (Blue Origin), Barret Schlegelmilch (Blue Origin), Violet Days (Blue Origin), Amalaye Oyake (Blue Origin) and Charles Njoka (Blue Origin).

*Abstract*

In 2021, the global space economy reached $469 billion dollars, up 9% from 2020 and expected to reach $1 trillion by the year 2040. With the United States (U.S.) accounting for approximately half of the current global space industry, it is essential that US produces a strong STEM (science, technology, engineering, and math) work force. Unfortunately, U.S. students at the pre-college level (K-12) perform below average in math and science on the international scene; the U.S. ranks 38 out of 71 in math and 24 out of 71 in science in the latest PISA rankings (Programee for International Student Assessment). Additionally, the U.S. STEM labor force has disparities with a lower proportion of Women, Blacks, Hispanics, and Native Americans workers than the proportion of these groups in the U.S. population. To help fill these educational and demographic STEM gaps, Blue Origin founded Club for the Future, a non-profit organization whose mission is to inspire future generations to pursue careers in STEM and to help invent the future of life in space. Additionally, Blue Origin has internal employee groups that parallel demographic-specific professional societies and Veterans groups. This paper will discuss U.S. educational gaps and disparities in the STEM field and ways that Blue Origin is combating this through public outreach and employee engagement. This includes space-focused curriculum, community engagement, mentoring programs, and partnering with local STEM clubs.

[267] ***SERFE PLSS Component Lessons Learned from ISS***

Alicia Contreras-Baker (NASA/Jacobs), David Westheimer (NASA) and Chane Sladek (NASA/Jacobs).

*Abstract*

NASA has been developing a new spacesuit, called the Exploration Extravehicular Mobility Unit (xEMU) for over a decade. This spacesuit is under development to support missions to the International Space Station (ISS) and also to the Moon. Improvements in the life and robustness of the Portable Life Support System (PLSS) has been a major objective of these efforts. The Suit Water Membrane Evaporator (SWME) was chosen as the technology to provide cooling to the xEMU and has undergone several iterations of development over this period. An ISS flight experiment centered around the SWME and other thermal control loop (TCL) technologies was developed and was under test in an ISS EXpedite PRocessing of Experiments to the Space Station (EXPRESS) rack from November of 2020 to August of 2022. In addition to the SWME, The SWME EXPRESS Rack Flight Experiment (SERFE) contains several technology demonstrations from the xEMU project and demonstrated their performance in micro-gravity and over an extended duration. In addition to the SWME, these included two dissimilar water pumps, custom check valves, custom bypass relieve valves, a custom thermal control valve, development pressure and temperature sensors, and the Thermal Loop Controller. This paper presents PLSS component lessons learned after return of the SERFE flight unit in August of 2022. The SERFE team took the flight unit apart and handed hardware components over to hardware owners to see how parts of the TCL managed after almost 2 years on the ISS and 25 simulated EVAs (Exploration Extravehicular Activity) on orbit. The team performed inspection, testing, and analysis and provided lessons learned on PLSS components for NASA’s prototype spacesuit. This analysis included how well SWME maintained its heat rejection capability, as well as looked at the robustness of the other TCL hardware.

[268] ***Compatibility between Exploration EVA System and Exploration Spacecrafts***

Christine Kovich (NASA JSC Extravehicular Activity and Human Surface Mobility Program (EHP), (Mail Stop DI)/The Aerospace Corporation) and Caitlin Meyer (NASA JSC Extravehicular Activity and Human Surface Mobility Program (EHP), (Mail Stop DI)/NASA).

*Abstract*

Over the life of the Extravehicular Mobility Unit (EMU), numerous products detailing “how to build Extravehicular Activity (EVA) System hardware”, “how to interface with EVA System hardware” and “how to design hardware EVA will access and utilize” were generated to provide interoperability between a suited crewmember and the specified vehicle’s EVA task. Since the inception of these products, some have continued to receive updates due to the necessity of an on-going program while others remained unchanged for years and have led to discrepancies between the current accepted values and those considered outdated. For EVA-suited crewmember tasks beyond Low Earth Orbit (LEO), new vehicles need a single consolidated location for the best practices and lessons learned from the EVA Community. This paper outlines what common EVA compatibility design requirements are expected of an Exploration spacecraft that has interactions between the vehicle and an EVA suited crewmember for and an approach for standardizing EVA compatibility across various vehicles at various destinations. The approach of standardization allows for flexibility by tailoring the applicability to meet the EVA tasks required for that vehicle’s operation beyond Low Earth Orbit. This paper will also describe the broad difference between microgravity and partial gravity EVA compatibility and how those requirements were identified and will be informed.

[269] ***Thermal Control Design for Deep Space Optical Communication (DSOC) Docking Mechanism High-Output Paraffin Actuator***

Rogelio Rosas (Jet Propulsion Laboratory, California Institute of Technology), Kristen MacNeal (Jet Propulsion Laboratory, California Institute of Technology), Marcus Wilkerson (Jet Propulsion Laboratory, California Institute of Technology), Gregory Agnes (Jet Propulsion Laboratory, California Institute of Technology), Joel Johnson (Jet Propulsion Laboratory, California Institute of Technology), Arthur Na-Nakornpanom (Jet Propulsion Laboratory, California Institute of Technology), Brenda Hernandez (Jet Propulsion Laboratory, California Institute of Technology) and Luis Fonseca Flores (JPL).

*Abstract*

Deep Space Optical Communication (DSOC) is a technology demonstration laser communication payload riding on the Psyche spacecraft that will demonstrate data transmission via laser up to 2.76 AU (probe to sun). The payload achieves fine acquisition and tracking control by utilizing Lorentz force actuators to perform dual functions: mechanical isolation from the bus to provide a stable floating platform for the optical assembly, and fine-grain pointing and tracking of the optical uplink receiver. To satisfy a Psyche requirement, during DSOC off periods, the floating platform is mechanically docked to the stationary side using a pair of Docking Mechanisms (DMs). During an optical pass the optical platform must be undocked by the DMs which each utilize a High-Output Paraffin (HOP) actuator to perform the undocking function. The DMs need to be in the undocked phase for up to 8 hours without any interruption or dithering of the HOP pin. Dithering must be prevented because this could cause disruptions to the pointing of the optical assembly. Spacecraft bus voltage on-board is static so changing the power output by varying voltage to the HOP is not possible. This is critical due to strict paraffin temperature limits; thus, a pulse-width modulation (PWM) heating scheme was developed to achieve the desired power output. This PWM was then adapted and implemented in Psyche Flight Software (FSW). The flight unit DMs were tested successfully meeting all Verification & Validation requirements using this method for all temperature and voltage ranges. The DMs have been proven to work for 8+ hours in thermal vacuum, which is required for compliance of DSOC Project Level 1 requirements. This paper describes the development of the algorithm from inception to the final Psyche flight software implementation.

[270] ***Atlas of Habitats Beyond Earth. Architectural Solutions for Space Applications***

Giacomo D'Amico (Mediterranea University of Reggio Calabria) and Marina Tornatora (Mediterranea University of Reggio Calabria).

*Abstract*

The development of Space Architecture demonstrates how human settlement on planets beyond Earth is no longer science fiction, but a challenge to develop a specific architectural way of thinking, both technologically and conceptually. Ongoing research and design provide architects with new opportunities to experiment with orbital and planetary habitat spatial solutions, extending some architectural concepts to extreme environments such as the Moon and Mars. This paper describes a study conducted as part of a thesis with the purpose of tracing a path of research and design reflection through eighteen case studies selected from some of the extra-terrestrial habitat solutions proposed so far and attempts to develop the first Atlas of habitats beyond Earth. It is structured for constructive, morphological, and settlement types through examination, redesign, and comparison, with the aim of consolidating and defining characteristics necessary to structure a thinking process. The study also develops a design hypothesis for a settlement on Mars that tries to respond to the challenges in outer space environments while also reflecting on ‘living in Space’, a synthesis of consciousness and technology, while making use of Artificial Intelligence throughout the whole settlement process, from surveying and construction to living and maintenance. The lack of oxygen, the atmosphere, thermal excursion, cosmic radiations, micrometeorites, and the reduced sound propagation, are some of the factors that influence formal decisions made in a city concept that is no longer only thought of as a survival strategy in extreme environments. Rather, they serve as a constitution based on the ideas expressed by Paolo Soleri in the city of Arcosanti, Arizona, that propose critical models in the face of rampant consumerism, alternative expressions of a futuristic and sustainable architecture that dialogues with the environment without abandoning the founding architectural principles.

[271] ***Conceptual Design for the Advancement of Mechanical Counterpressure Spacesuits***

Michelle Kostin (Imperial College London).

*Abstract*

With expected increased demand for extravehicular activity in future exploration missions, the superficially simple nature of mechanical counterpressure (MCP) spacesuits holds significant appeal while promising numerous advantages. While traditional gas-pressurized suits have proven reliable for many decades, MCP’s skin-tight garments have the potential to offer significant improvements in mobility, dexterity, level of exertion and safety. Numerous unsolved design challenges exist which have prevented the adoption of this technology. This paper discusses work undertaken towards engineering solutions for some of these issues, prioritizing the demonstration of viability in experimental conditions. By considering mechanical components rather than material properties, this project investigates a way to achieve the generation of the large tensions required for a functional MCP suit. The concepts are examined in the context of comfort and donning speed for such a spacesuit. Garment adjustability is also considered to address concerns surrounding changes to body shape during long-duration missions, as well as providing better performance and reduced production costs.

[272] ***Evaluation of Lunar Dust Dispersion with Computational Fluid Dynamics Discrete Phase Modeling***

Abigail Baukus (KBR) and Rachel Sturtz (Jacobs).

*Abstract*

Lunar regolith dust is an unavoidable hazard that will accumulate in suits, cabins, and equipment over trips to the lunar surface. This is important in systems like Gateway, as too much lunar dust brought in from missions could pose a hazard to the crew onboard. However, we currently know very little about exactly how much dust could end up on Gateway, from where, and the properties of the dust itself. To aid in this understanding of what lunar dust could look like on Gateway, a computational fluid dynamics (CFD) model of the Gateway HALO module was developed in ANSYS Fluent. Discrete phase modeling was used to track the movement and fates of lunar dust particles in the cabin, accounting for ventilation flow and monitoring which outlet vents and ports experienced the highest dust loads. Because there are so many unknowns related to lunar dust, this model investigated the effects of several variables, including dust drop location, particle size, particle density, and total mass injected. This analysis can be used to inform dust loading on dust-sensitive visiting vehicles and filter design.

[274] ***Integration and Validation of Mushroom and Algae into an Agent-based Model of a Physico-chemical and Bioregenerative ECLSS***

Sean Gellenbeck (University of Arizona), Joel L. Cuello (Department of Agriculture and Biosystems Engineering, University of Arizona, Tucson, Arizona, USA), Barry Pryor (University of Arizona), Kai Staats (Over the Sun, LLC) and Chuck Gerba (University of Arizona).

*Abstract*

Research on bioregenerative life support systems has focused on individual subsystems that often struggle to produce all the required consumables to support the crew. Different biological systems (e.g., algae, higher plants) perform differently and approaches that integrate multiple types of organisms such as BIOS, MELiSSA, and the Lunar PALACE have seen greater success. Furthering this integrative trend, the modeling and design a Fully Integrated Bioregenerative Life Support System (FI-BLSS) utilizing separate yet connected biologically based subsystems was completed to enhance closure and optimize system output. The project sought to integrate mushroom and aquaculture subsystems to provide additional sources of edible biomass (especially proteins) with focus placed on maximizing the remediation and recycling of inedible biomass.

The project had three sequential goals, the first two of which are described in this paper. First, a review of existing published literature informed the conceptualization and modeling of the system at multiple levels. Second, mushrooms and algae were modeled and validated through a series of experiments. These experiments examined the two cultures individually to inform a program, which was then used to design a combined system to provide validation. Agent-based modeling was selected for this project due to its direct relationship with the expected operational interfaces.

The model developed through this research can accurately evaluate an integrated bioregenerative life support system. It is envisioned for use by future researchers, educators, and the public to further the research and as part of an existing outreach tool. This tool is supported through a collaborative effort between the National Geographic Society and the developers of the agent-based modeling program Scalable, Interactive Model of an Off-world Community (SIMOC). SIMOC has already been used in several classrooms and the results of this research project will expand and enhance the existing tool and outreach effort.

[277] ***Development of Challenge Aerosols for Testing Filters in Spacecraft Air Revitalization Systems***

Robert Green (NASA), Gordon Berger (USRA), Benjamin Sumlin (USRA), R. Vijayakumar (USRA) and Juan Agui (NASA).

*Abstract*

The common means for reducing particle concentrations in air in enclosed spaces, including in space habitats, are source prevention and particle removal by air filters. While air filtration and testing is a well-established discipline and industry, testing and classifying filters according to commonly used standards rely on a test aerosol that is often arbitrary and chosen for the convenience of the test method. In space habitats, the particle size distributions are expected to be quite different than the particle size distributions prescribed in test standards, due to the partial or low gravity environment affecting sedimentation of large particulates like hair or cloth fibers, or the introduction of planetary dust to the pressurized volume. This means that the efficacy of the filter will be quite different in the space habitat than specified according to a prevailing standard. This paper will present some initial work in development of a “composite” challenge aerosol to bound the measured and reported particle sizes reported for the International Space Station (ISS), and for expected particulate matter in a Lunar lander, habitat, or orbiting platform susceptible to the intrusion of Lunar dust. Application of this test aerosol is expected to yield filter efficiencies and loading effects closer to what one can expect on these spacecraft and be useful in determining filter lifetime and replacement cycles.

[278] ***New Equipment and Techniques for Steep and Vertical Terrain Access in Planetary EVA Operations***

Nate Ball (Atlas Devices), Daniel Walker (Atlas Devices) and Gino Kahaunaele (Atlas Devices).

*Abstract*

The Artemis missions usher in an exciting new era of surface Extravehicular Activities (EVAs) as humanity returns to the Moon. With Artemis III candidate landing regions located near permanently shadowed regions at the Lunar South Pole, surface EVAs that could yield the retrieval of ice and other scientifically rich samples could be in range for the first time. But physical access to such sites presents challenges due to the steep and vertical terrain inherently involved. Adaptation of terrestrial mountaineering equipment to enable such access has been proposed and tested before with promising results, using harnesses, suit analogs, climbing ropes and winches of various designs. In these tests, subjects have successfully traversed steep terrain by rappelling or being lowered downward on ropes and by being winched back up. Recent advances in powered rope climbing technologies add to the viability of these approaches with portable devices that are adaptable Lunar or Martian use. In recent tests we have shown such devices to work well for these operations by conducting a 230 m suited rappel and ascent by two personnel into and out of Nevada’s Lunar Crater using custom load rated xEMU simulators. However, suited rappelling introduces new ergonomic and mobility considerations outside the typical requirement space for planetary suits; namely, that the suit must suspend the crewmember within it while rappelling in addition to the suit being borne by the crewmember while walking on the surface. Changing from walking to rappelling can result in a significant shift downward of the crewmember within the suit if unaddressed, leading to reduced mobility and situational awareness. This paper presents approaches and test results for suit modifications that enable on-the-fly adjustments of the crewmember’s position within the suit that yield improved comfort, mobility and awareness in surface EVA operations including walking, sitting, climbing, and rappelling.

[281] ***Survey of Microbial Community in Bioreactors Used for Bioregenerative Water Purification***

Daniella Saetta (University of South Florida), Jason Fischer (Kennedy Space Center), Talon Bullard (University of South Florida), Alexandra Smith (University of South Florida), Cory Spern (Kennedy Space Center), Anirudha Dixit (Kennedy Space Center), Christina Khodadad (Kennedy Space Center), Daniel Yeh (University of South Florida) and Luke Roberson (NASA).

*Abstract*

Bioregenerative water purification systems are promising ECLSS technologies because they allow for complete recovery of water and nutrients for sustainable planetary base operations. These systems use a consortium of microbes to treat complex waste streams that have generally been ignored thus far, such as fecal and food waste. However, the microbial community structure of the bioreactors is largely unknown. The main goal of this paper was to survey the microbial community of four distinct bioreactors to provide a deeper understanding of the bioreactors in terms of treatment and operational hazards. The survey encompassed four types of aerobic and anaerobic bioreactors with real and ersatz influents, giving a wide picture of the microbial community across a wide range of conditions. We used shotgun metagenomics to provide a comprehensive analysis of the community constituents, which included bacteria, viruses, archaea, and eucarya. The study sampled two identical anaerobic membrane bioreactors (one with canine fecal waste influent and one with an ersatz influent), a suspended aerobic membrane bioreactor (with real human urine as its influent), and a photo−membrane bioreactor (with anaerobic membrane bioreactor effluent as its influent). This is the first study of its kind to study the microbiome of bioreactors designed for early planetary wastewater treatment. Results show a high level of diversity among the samples, with higher DNA densities in the samples from the reactors with real fecal and urine influents. Overall, this conference paper will detail how the bioreactor conditions affected the microbial community structure and how the community structure influences the wastewater treatment process.

[283] ***Plasma Abatement of Volatile Organic Compounds.***

Joel Olson (Southeastern Universities Research Association), Ryan Gott (NASA Kennedy Space Center), Shayla Wilhelm (Southeastern Universities Research Association), Kenneth Engeling (NASA Kennedy Space Center), Caiden Campbell (NASA OSTEM Intern) and Ray Pitts (NASA Kennedy Space Center).

*Abstract*

One difficulty with crewed space operations is the potential for the contamination of the spacecraft habitable volume from volatile organic compounds (VOCs) that may be present. One possible VOC abatement process is to apply a plasma to the contaminated gases. Plasmas provide high energy electrons and ions that are capable of breaking down gaseous organic species generally into smaller compounds. To explore plasma VOC abatement, the authors constructed a plasma gas system that recirculates a particular VOC-laden gas mixture through a plasma torch. This allows for the periodic collection of aliquots of gaseous samples for subsequent analyses via gas chromatography mass spectrometry, designed to quantify the remaining VOC materials. The VOCs evaluated included 100 ppm of acetone, benzene, ethanol, and pentane in a background of carbon dioxide. The plasma conversion of all analytes followed first-order rate kinetics, and VOC elimination was observed after 10 min or less of treatment for all analytes measured. Additionally, it was observed that the plasma caused the conversion of CO2 into oxygen and CO.

[285] ***Low Temperature, Durable Siloxane/Epoxy Nanocomposite Coating for Drastic Reduction in Lunar Particulate Adhesion***

Lauryn Baranowski (TDA Research, Inc.), Denis Kissounko (TDA Research, Inc.), Matt Peppel (TDA Research, Inc.), Amrita Singh (University of Colorado Boulder) and James Nabity (University of Colorado Boulder).

*Abstract*

Lunar dust is the fine powder of the moon's surface regolith. The dust particles can be highly charged due to solar irradiation, and the dry lunar environment helps these particles hold their static charge and adhere to surfaces. Lunar dust degrades both spacesuits and equipment. In this project, we developed a composite coating offering excellent passive dust mitigation. We used a specially selected cryogenic resin and incorporated functional additives to lower the surface energy and improve the abrasion resistance of the coating. We produced a low viscosity, sprayable formulation that can be applied to a variety of substrates. It demonstrated good coating adhesion on nylon, aerospace aluminum, Kapton, and Teflon via a tape test; all substrates had 5A tape adhesion. Additionally, the inclusion of additives designed to improve abrasion resistance increased the pencil hardness of the coating and reduced the coating mass loss in our sandblasting test. These properties are retained even after five cycles of cryogenic shock. The coating does not negatively impact either the solar absorptivity or thermal emissivity of the four substrates tested. Testing in air with a lunar dust simulant (Exolith Labs LMS-1D) has demonstrated over 90% reduction in dust adhesion versus an uncoated substrate. We constructed a rotating drum apparatus to test the dust adhesion under vacuum. The initial results support our conclusions that the coating is highly effective at reducing lunar dust simulant adhesion.

[286]  ***Exploration Extra-Vehicular Mobility Unit (xEMU) Composite Hard Upper Torso (CHUT) Development***

Shridhar Yarlagadda (Center for Composite Materials, University of Delaware), David Roseman (Center for Composite Materials, University of Delaware), Joseph Cipriani (Center for Composite Materials, University of Delaware), Nicholas Shevchenko (Center for Composite Materials, University of Delaware), John Tierney (Center for Composite Materials, University of Delaware), John Gillespie Jr (Center for Composite Materials, University of Delaware), Mohan Parthasarathy (Altair Engineering), Richard Rhodes (NASA), Daniel Kim (NASA) and Jeremy Jacobs (NASA).

*Abstract*

The xEMU is the Exploration Mobility Unity or space suit designed for microgravity (cislunar and low earth orbit (LEO)) and lunar surface operations. This suit design allows crewmembers to perform extravehicular exploration, science, construction, maintenance, and contingency operations while unattached to a vehicle for life support in pressure and thermal environments that exceed human capability. The xEMU provides life support, environmental protection, and communications capabilities to the EVA crewmember while allowing sufficient mobility and visibility to perform dexterous EVA tasks. The effort documented in this paper, addressed the design, analysis, manufacturing, full-scale test article testing and validation for a Composite Hard Upper Torso (CHUT) unit. Design and analysis of the CHUT was based on measured B-basis properties of the selected S-glass/epoxy composite, and established final geometry, composite layup and interface details that met requirements. A complete manufacturing and assembly protocol was established for the CHUT starting from composite layup in the tool, to final assembly of all interface metal hardware prior to delivery to NASA for suit integration. Full-scale CHUT test articles underwent static and fatigue pressure testing (2 lifetimes), impact testing at critical stress locations for tool drop/microgravity scenarios, followed by post-impact fatigue testing. Effect of manufacturing defects was evaluated by manufacturing a full-scale CHUT with 0.375”/0.5” defects at critical stress locations, followed by static and life-cycle fatigue testing. In all cases, the CHUT design met or exceeded mass, structural, interface and functional requirements. Two (2) complete CHUT articles were delivered to NASA for full-scale suit integration and testing.

[288] ***Dormancy Protocol of Electro Oxidation Membrane Evaporator for Urine Processing and Water Recovery***

Tatsuya Arai (Oceaneering Space Systems), John Fricker (Oceaneering Space Systems) and George Sparks (Oceaneering Space Systems).

*Abstract*

The Electro Oxidation Membrane Evaporator (EOME) is a NASA-funded advanced technology for processing wastewater electrochemically. EOME creates powerful oxidants from the salts in urine that break down organic compounds in the urine. Waste heat from the process is advantageously used to evaporate water from urine, and then the water vapor is condensed and collected for final processing before reuse. This paper describes work performed in 2022 to develop and demonstrate dormancy protocols for EOME shutdown prior to habitat dormancy and for restart upon return months later. The protocols were developed with special regard to minimizing operational crew time and consumables. The proposed protocols require adding a single 40 gram dose of acid to the wastewater on departure day, operating EOME normally for several hours, then draining the wastewater from EOME and powering off the system. Upon return to the habitat, after collection of several liters of urine in EOME, EOME is powered on and operated normally. The tests representing these protocols successfully demonstrated that EOME performance was retained after the 164-day dormancy.

[290] ***PESTO: An Agile Computational Solution for ECLSS Simulation and Control for the Gateway Air Revitalization System***

Jonathan Anthony (Paragon Space Development Corporation) and Gregory Doidge (Paragon Space Development Corporation).

*Abstract*

Paragon is developing the Air Revitalization System (ARS) for the Habitation and Logistics Outpost (HALO) module, as part of the Lunar Gateway. ARS controls temperature, humidity, CO2, and trace contaminant concentration. Additionally ARS supports two major off-nominal modes for cabin depressurization and fire recovery. For mass and power efficiency, ARS is designed as a tightly coupled multiple-input multiple-output (MIMO) system, where every actuator impacts multiple process variables.

Following a trade study, Paragon did not identify a cost-effective commercial tool that could meet the modeling requirements for the integrated performance of ARS which included flow dynamics, thermal transfer, and integration of existing submodels. Instead, Paragon has internally developed the Paragon ECLSS Simulation Testbed in Octave (PESTO) to tackle this complex task.

In its current state, PESTO includes a computational model describing the integrated performance of ARS within the HALO module, including preexisting submodels for humidity control and heat exchanger performance as well as an iterative flow network solver. PESTO also includes a flight-like control algorithm for ARS which addresses the inherent instability risk of the coupled ARS hardware design. The physics model and control algorithm are joined together in the PESTO framework that includes multiparameter scenario generation to span the full control envelope, as well as automated requirement checking. The simulation runs as a multicore process, enabling Paragon to quickly iterate on hardware and software design by parallelizing the execution of hundreds of scenarios.

This paper describes selected details of the PESTO framework including the physical ARS model and the ARS control scheme. Results for selected scenarios are presented and discussed. Paragon currently assesses that the physical model satisfactorily represents the hardware, and that the control solution provides acceptable control performance. Due to its success, Paragon is beginning to expand PESTO to support other projects as well.

[292] ***Brine Processor Assembly: A Year of Successful Operation on the International Space Station***

Stephanie Boyce (Paragon Space Development Corporation), Connor Joyce (Paragon Space Development Corporation), Patrick Pasadilla (Paragon Space Development Corporation), Philipp Tewes (Paragon Space Development Corporation), Jonathan P. Wilson (NASA MSFC), Jill Williamson (NASA MSFC) and Katherine Toon (NASA JSC).

*Abstract*

Paragon Space Development Corporation developed a Brine Processor Assembly (BPA) as a technical demonstration for the International Space Station (ISS), which has now been operating continuously for 18 months. BPA recovers water from urine brine produced by the ISS Urine Processor Assembly (UPA) via forced convection of cabin air coupled with a patented membrane distillation process. An ionomer-microporous membrane-based bladder retains the liquid brine while water vapor pervaporates into the cabin, for collection as humidity condensate. This paper will discuss progress to-date on BPA performance. As of May 2023, 22 full operational runs have been completed, recovering nearly 400 L of water from urine brine. This represents a cost savings of over $40 Million from the mass of water that has not needed to be launched to or discarded on ISS, minus the cost of consumables (bladders and odor filters). On orbit telemetry has been used to further refine the thermal model for more accurate predictions of water recovery. Water recovery operations continue to align closely with ground test results, and the added exhaust filter has performed well in eliminating nuisance odor. Several dewatered bladders have been returned to Earth to assess the inner membrane pore wetting, confirm dewatered weight, as well as to assess dewatered brine concentration and composition at Marshall Space Flight Center (MSFC). By increasing overall water recovery on ISS, BPA demonstrates a critical capability needed to close the water processing technology gap identified in NASA’s Water Recovery Technology Roadmap. The continued on-orbit operations of BPA contribute significant knowledge and understanding to the most efficient methods to recover water and inform best practices for future implementation of Paragon’s water reclamation technologies. This technology achieves an essential capability to enable human exploration of deep space.

[294] ***Multi-layered 3D Printed Mars Habitat Proposal, Analysis of Habitability Requirements and Autonomous Building Technologies from the NEST Team’s Design at the NASA Centennial Challenge***

Jose-Miguel Armijo-Vielma (Georgia Institute of Technology), José Hernández Vargas (KTH Royal Institute of Technology) and Priyanka Naidu (New York City Architecture Biennial).

*Abstract*

The NEST project was one of the top thirty finalists of the 2015 NASA 3D Printed Habitat Challenge, to propose habitat construction ideas using additive manufacturing based on in situ resources utilization (ISRU) and promoting sustainable housing solutions. NEST stands for Nested Environment Settlement Technology, which highlights the most important aspect of the proposal: distinct layers that progressively create adequate environmental conditions for human habitation. However, current advancement of space research has updated life support considerations and construction knowledge. Specifically, a Mars habitat floor plan configuration and 3D printing for the exposed shell. This paper presents an analysis of the multi-layered approach considering the current advancements in autonomous building technology. It is shown that the multi-layer approach is a feasible solution for providing an incremental building scheme with redundant layers and enhanced living conditions. This updated research presents an opportunity for further development of multi-layered solutions as a way of combining habitability requirements with current automated construction technology for space and Earth settlements.

[296] ***Design of a Trash Compaction & Processing System (TCPS) for Waste Management and Logistics Reduction in Long Duration Spaceflight***

Joseph Klopotic (Sierra Space), Daniel Wyman (Sierra Space), Zachary Petrie (Sierra Space) and John Wetzel (Sierra Space).

*Abstract*

The Trash Compaction & Processing System (TCPS) being developed by Sierra Space for long duration missions compresses, sterilizes, and recycles water from crew-generated standard trash. TCPS assists in solving complex logistical challenges for spaceflight by reducing needed volume for trash storage and consumable launch mass. Functions include compressing the waste into a more manageable tile, sterilizing the tile, recovering and recycling water from the waste, and the processing and cleaning of any gaseous byproducts. Sierra Space has leveraged our previous developmental systems to develop an integrated TCPS for use in the International Space Station (ISS) as a technology demonstration for future long-duration missions and capabilities. Numerous interfaces and systems onboard ISS will be used to verify the capabilities of TCPS for operation in future vehicles and missions, where resources in cooling, water management, and gas release may differ. This paper summarizes the design of the TCPS flight system, the concept of operations, and requirements of the flight system

[297] ***Scale Up and Coupling of the MOXIE Solid Oxide Electrolyzer for Mission-Scale Lunar and Martian Applications***

Michele Hollist (OxEon Energy), Joseph Hartvigsen (OxEon Energy), Jessica Elwell (OxEon Energy), S. Elangovan (OxEon Energy), Tyler Hafen (OxEon Energy) and Jenna Pike (OxEon Energy).

*Abstract*

The successful, repeated operation of MOXIE on the Mars Perseverance Rover has made In-Situ Resource Utilization (ISRU) a reality. Since developing the Solid OXide Electrolysis (SOXE) stacks for the Mars 2020 MOXIE program in 2017, the OxEon team has made significant advancements in both the scale and capabilities of the technology with the support of a NASA NextSTEP ISRU, SMTD Tipping Point, and SBIR award. Newer variants of the SOXE stack have a five-fold increase in cell area and a 6.5-fold increase in cells per stack, for a stack scaled 33-times the 0.5% scale of the device in MOXIE. Six of these OxEon mission-scale SOXE stacks will produce 30 tons of propellant oxygen to fuel a MAV in the 19-month window between landing an unfueled MAV pre-supply mission and the next launch opportunity for the first crewed Mars Mission, meeting target requirements for a return mission. The mission-scale SOXE stack utilizes an interconnect specially designed to allow for a sealed anode perimeter and internally manifolded collection of the 99.9%+ pure O2 produced during operation. Additionally, OxEon has investigated a combination of materials to improve redox tolerance of the nickel-based cathode and demonstrated this advancement in operational stability in scaled up stack systems. Demonstration systems have been built and tested with the mission-scale stacks, under relevant test conditions, for both Lunar and Martian applications. A breadboard system for the production of propellant H2 and O2 from Lunar ice will be tested in a cryo-vac chamber at JSC in 2023. A second, mission-scale stack demonstration system, for the production of O2 and CH4 from Martian H2O and atmospheric CO2, will be tested at JPL in December of 2022, before additional testing at JSC in 2023.

[298] ***Trades, Architecture, and Design of the Joint Augmented Reality Visual Informatics System (Joint AR) Product***

Paromita Mitra (NASA), Matthew Miller (Jacobs/NASA JSC), Briana Krygier (NASA), Sarosh Nandwani (NASA), Matthew Noyes (NASA), Vishnuvardhan Selvakumar (Purdue University), Amanda Smith (KBR Wyle/NASA JSC) and Tyler Garrett (NASA).

*Abstract*

Future expeditions will enable exploration and study of the planetary surfaces of the Moon and Mars by performing extravehicular activity (EVA) operations. Present-day International Space Station (ISS) EVA operations require an intricate and tight choreography of crew, space suits, tools, systems, and flight teams to plan, train, and execute with limited advanced informatics. Additionally, EVA operations, aside from the Apollo Lunar surface missions, have predominately focused on maintenance and construction tasks where success criteria are clearly measurable. However, future exploration missions expect to enable crew to carry out scientific objectives in increasingly Earth-independent ways. In this paper, the Joint Augmented Reality Visual Informatics System (Joint AR) characterizes the design space for developing a modular augmented reality (AR) device for a spacesuit form factor that can support crew decision-making for EVA. This paper highlights the project’s experience with a product-focused management style and use-case centered systems engineering approach to iteratively design, build, and test. The Joint AR product features were defined via trade studies and market analysis of previous EVA display efforts, various AR components such as optics, commercial AR systems, light engines, data interfaces, graphics engine software and analog test beds. We outline the defining architectural design decisions, including safety criticality considerations, suit mounting interfaces, computer architectures, and partnership contracting mechanisms. The outcomes of these studies, architecture decisions, and management requirements result in a recommended design which is the Joint AR product. We discuss the evolution, development of these system components, and what work remains. We hope to share a unified understanding of various design decisions and how they impact the future of crew members’ access to data during Lunar and Martian EVAs. This ongoing effort can enable a community-wide discovery process toward realizing necessary AR features and capabilities for future missions.

[300] ***Mission-Scale MOXIE Development Driven Prospects for ISRU and Atmosphere Revitalization***

Joseph Hartvigsen (OxEon Energy, LLC), Michele Hollist (OxEon Energy), Jessica Elwell (OxEon Energy, LLC), S. Elangovan (OxEon Energy) and Gerald Voecks (JPL).

*Abstract*

The Mars Oxygen ISRU Experiment (MOXIE) was a first of its kind demonstrations of in-situ resource utilization technology to produce propellant and breathable oxygen from the Mars ambient carbon dioxide. The use of Lunar and Martian resources represents a significant opportunity to reduce the cost of launch from Earth, enabling propellant production for space refueling, and allowing for life support of manned missions to the Lunar and Martian surfaces. Since developing the Solid OXide Electrolysis (SOXE) stacks for the Mars 2020 MOXIE program in 2017, the OxEon team has made significant advancements in scale and capabilities within NASA NextSTEP ISRU, SMTD Tipping Point, and SBIR projects. Newer variants have a five-fold larger cell area and a 6.5-fold increase in cells per stack, for a stack scaled 33-times the 0.5% scale of the device in MOXIE. Six of these OxEon mission-scale SOXE stacks will produce 30 tons of propellant oxygen to fuel a MAV in the 19-month window between landing an unfueled MAV pre-supply mission and the next launch opportunity for the first crewed Mars Mission, meeting target requirements for a return mission. OxEon has built and demonstrated systems with mission-scale stacks for both Lunar and Martian applications. A system for the production of propellant H2 and O2 from Lunar ice was successfully tested in a Mines cryo-vac chamber in 2022. Another mission-scale demonstration system demonstrated production of O2 and methane from Martian H2O and atmospheric CO2 at JPL in 2022. The Mars mission-scale system combines CO2-steam co-electrolysis with a methanation reactor. Aligned with the DOE and Naval Research Laboratories target production of liquid fuels with a Fischer-Tropsch synthesis back-end in place of methanation. This work will be presented showing the advantage of a -CH2- product (Fischer Tropsch) over a CH4 product (Sabatier) for ECLSS recovery of oxygen from respiration byproducts.

[301] ***Feasibility Testing of a Thermal Dispersion Flowmeter with External Signal Conditioning for Health Monitoring of Liquid and Gas flows***

Diego Mugurusa (Collins Aerospace), Nicholas Van Derzee (Collins Aerospace) and James Davis (Collins Aerospace).

*Abstract*

Spacecraft environmental and thermal control systems have liquid and air loops that include instrumentation to monitor the health of the prime mover (pump or fan). This instrumentation often includes temperature of the fluid flow, pressure rise of the pump or fan, and/or flow rate. In terrestrial and aircraft applications, there are many flowmeter technologies available, all requiring signal conditioning electronics to provide the required power or electrical signal to the sensing element and to convert the sensor output signal into a useable format, such as a linear analog or a digital output. The high radiation environment and stringent electronic part quality requirements typical of long life and/or mission critical space applications are a barrier for entry for many commercially available sensors with built-in signal conditioning electronics. Furthermore, the high non-recurring cost coupled with extremely low production quantities make a challenging business case for development and certification of new space hardened electronics, resulting in a very limited supply base and heavy reliance on re-use of legacy designs.

Thermal dispersion flowmeters are an interesting technology for space applications because the sensing element has very simple electrical interfaces, consisting only of a heater and a pair of resistance temperature detectors (RTDs). These interfaces are readily available in many spacecraft and subsystem controllers, offering the opportunity to eliminate the signal conditioning electronics in the sensor and instead allocate the signal conditioning function to the space hardened subsystem controller. A proof-of-concept test was conducted at Collins Aerospace to evaluate the feasibility of interfacing a thermal dispersion flowmeter directly with a space hardened fan/pump motor controller. The flowmeter was tested in Water and Air at flow rates relevant to current and future environmental and thermal control systems. This paper describes the concept and theory of operation, presents the test results, and provides recommendations for future implementation.

[302] ***Orion LAMS Laser Absorption Spectrometer for Human Spaceflight – Artemis 3 Flight Unit Build and Test Results***

Jason Pohly (Romach Technologies), Lance Christensen (Jet Propulsion Laboratory, California Institute of Technology), Kamjou Mansour (Jet Propulsion Laboratory, California Institute of Technology), David Roe (Dynetics), John Vaughan (Dynetics) and Cody Erb (Dynetics).

*Abstract*

The Orion Laser Air Monitor System (LAMS) is a tunable laser spectrometer that will monitor oxygen, carbon dioxide, and water vapor levels in the Orion Multipurpose Crew Vehicle (MCPV) cabin and in the space suit loop. LAMS, designed to be small, lightweight, and low power, can nonetheless accurately measure a wide dynamic range of analyte concentrations over relatively wide pressure and temperature ranges despite not using gas pumps, flow, or pressure controllers. Additionally, the LAMS hardware and electronics are capable of meeting stringent Crit-1R requirements for human life support. This paper is a follow-up to the 2020 ICES paper which covered flight unit build and testing results for the Artemis 2 mission. This paper covers design updates, flight unit build, and test results of the LAMS units for the Artemis 3 mission.

[305] ***Modeling of Gateway Environment Control and Life Support Systems as a Means to Investigate the Subsystem and Integrated Architecture Performance***

Lawrence Barrett (Jacobs), Rachel Sturtz (Jacobs) and Madelyn Hutchinson (Jacobs).

*Abstract*

As human spaceflight evolves and develops, the technology the crew relies on for life support must become more advanced than at any point in NASA’s history. Nowhere is this more apparent than the Gateway, where lessons learned from ISS are being applied in the design and production. Some of these technological improvements are proven in flight configuration, or have a heritage of proven flight hardware, but many are of a lower technology readiness level. Due to the unpredictable nature of the metabolic byproducts (CO2, H2O, and heat), even proven technologies can fail to meet requirements for crew safety. Detailed modeling of individual components excels in proving component level requirements are met, but fails to verify system or architecture level requirements. This paper expounds upon an effort to take a number of detailed component level models of the Gateway ECLSS and integrate them into a larger architecture model known as the Gateway Integrated ECLSS Model (GIEM). The GIEM is then used to study how the subsystems work synergistically to meet environmental requirements, as well as investigate how changes at the component level effect the Gateway stack as a whole.

[307] ***Integrating Hands-on Learning Modules into a Course on Life Support Systems***

James Nabity (University of Colorado Boulder).

*Abstract*

An Environmental Control and Life Support System (ECLSS) meets the environmental and metabolic needs of the crew. Specifically, the ECLSS must provide a breathable atmosphere, potable water, food and waste management, and consider the need for crew safety. The system must also remove contaminants from the atmosphere, collect and treat both solid and liquid wastes, and control temperature and humidity. A graduate level course at the University of Colorado Boulder entitled “Spacecraft Life Support Systems” teaches students the first principles behind regenerable and non-regenerable physicochemical ECLSS technologies that have enabled human spaceflight. Students study atmosphere revitalization processes, the means for temperature and humidity control, water reclamation and treatment, waste handling and the reuse of materials, along with food and nutrition. These lessons are put into practice via hands-on learning modules that challenge student teams to explore novel technological approaches to environmental control and life support through computational modeling and simulation or laboratory experimentation. In this paper, these learning modules are described with examples to illustrate the type and range of problems suitable for implementation into a 16-week semester, graduate level course.

[308] ***Demonstration of an Electrochemically-Driven Multi-Cell Stack Using Shorted Anion Exchange Membranes for Spacecraft Cabin Air Revitalization***

Marco Colin Martinez (University of Delaware), Stephanie Matz (University of Delaware), Brian Setzler (University of Delaware) and Yushan Yan (University of Delaware).

*Abstract*

Cabin CO2 removal remains a major obstacle for long-duration, manned deep space missions. The incumbent CO2 removal technology for spacecraft air revitalization—Carbon Dioxide Removal Assembly (CDRA)—requires frequent and costly maintenance. Numerous potential substitutes are being considered, including solid and liquid sorbents as well as cryogenics. This work proposes an alternative CO2 removal technology harnessing the alkaline environment surrounding an anion exchange membrane to separate CO2 from air. The electrochemically-driven CO2 separator (EDCS) is a low-cost, compact device that has been experimentally demonstrated to continuously and effectively separate CO2 at various concentrations (400-5000 ppm) and moderate temperatures using only a small hydrogen stream to power separation. The only products from the EDCS are a CO2-depleted air stream and a CO2-concentrated stream contaminated with unreacted hydrogen and pure water. This paper reports the design and first demonstration of the multi-cell EDCS stack prototype using carbon-composite, or “shorted,” anion exchange membranes. A 100 cm2, 2-cell EDCS stack has been demonstrated successfully at more demanding conditions than required in spacecraft air revitalization. At ambient conditions (420 ppm, 30 oC), the 2-cell EDCS stack has been shown to capture 80% of incoming CO2 while consuming less than 1.8 H2 per CO2 (mol/mol). Furthermore, based on single-cell work at relevant conditions for spacecraft air revitalization, a 100 cm2, 136-cell stack (3. L, 13.6 kg) would be sufficient to remove CO2 for a six-person crew (6.24 kg/day) operating at a temperature of 40 oC; for comparison, an EDCS of this size would be less than 10% the volume and less than 20% of the mass of the desiccant/adsorbent beds of the CDRA on the International Space Station.

[311] ***Status of the Advanced Oxygen Generation Assembly***

Kevin Takada (NASA), David Hornyak (NASA), John Garr (NASA), Steven Van Keuren (S&K Global Solutions, Inc.), Christine Faulkner (Jacobs Technology, Inc.) and Abdelrahman Elsherbini (Collins Aerospace).

*Abstract*

Future Exploration missions will require an Oxygen Generation Assembly (OGA) to electrolyze water to supply oxygen for crew metabolic consumption. The system design will be based on the International Space Station (ISS) OGA but with added improvements based on lessons learned during ISS operations and technological advances since the original OGA was designed and built. The goal of these improvements will be to reduce spares mass and crew maintenance time while increasing reliability. Over the past year, the team has performed additional design reviews, testing and analysis in an effort to optimize upgrade efforts and achieve the best value that meets Exploration mission requirements. Upgrades that will be incorporated include: redesign of the electrolysis cell stack, redesign of the hydrogen dome, replacement of the hydrogen sensors, redesign of the recirculation loop deionizing bed, and incorporation of recirculation loop nitrogen purging and water flushing. The ISS OGA will be upgraded to an Advanced OGA (AOGA) configuration and its operation demonstrated in a relevant flight environment.

[312] ***NASA Environmental Control and Life Support Technology Development for Exploration: 2022-2023 Status***

Walter Schneider (NASA), Arthur Brown (NASA), Chris Allen (NASA), Melissa McKinley (NASA), Imelda Stambaugh (NASA), Alesha Ridley (NASA), Daniel Barta (NASA) and Daniel Gazda (NASA).

*Abstract*

NASA is pursing Environmental Control and Life Support technology developments and hardware upgrades to support Gateway, lunar surface, Mars transit, and Mars surface missions. This paper will highlight 2022-2023 progress of the technologies and how they are maturing on the path to ground testing and demonstration in microgravity. Technologies NASA is trading, new developments, and particular challenging issues will be highlighted. Technologies addressed in this paper are in the areas of atmosphere revitalization, water recovery and management, waste management, and environmental monitoring.

[313] ***Carbothermal Reduction System Overview and Developments in Support of the Artemis Program and a Commercial Lunar Economy***

Brant White (Sierra Space Corporation) and Nathan Haggerty (Sierra Space Corporation).

*Abstract*

Sierra Space has continued to develop the carbothermal reduction system to create oxygen from lunar regolith, optimizing the system to process highlands regolith in support of the Artemis program. Continuous carbothermal processing of GreenSpar250 highlands simulant has been demonstrated in a largely autonomous laboratory system. Production of CO & CO2 has been demonstrated in excess of the target production key performance parameter using direct optical energy at the power level and distribution anticipated in the final lunar application. The system does not require consumables due to the innovative handling methods employed for the melted material. Regolith handling processes were validated to transfer the simulant through a pressure boundary, meter and flow the simulant through the system using various protected mechanisms, and to remove the processed material from the reactor. Optical interfaces were successfully protected from dust and other materials. A new proprietary valve design was tested which showed exceptional resistance to wear from the abrasive regolith simulant material. This valve design was tested for over 10,000 cycles with virtually no change in the overall leak rate, and total leakage of 1 +/- 0.5 SCCM at a pressure differential of one atmosphere. Sierra Space believes this valve design can be easily scaled and utilized for other processes requiring regolith or dust tolerant pressure seals, including crew air locks. Current work is underway to test these aforementioned processes in a thermal vacuum chamber at NASA Johnson Space Center to advance the carbothermal and regolith handling systems to technology readiness level six (TRL 6) for an anticipated Commercial Lunar Payload Services (CLPS) mission.

[315] ***Review of Human Thermoregulation Models, Validation Methods, and Selected Responses to Gravity Dose Analogs***

Maddie Haas (Texas A&M University) and Bonnie Dunbar (Texas A&M University).

*Abstract*

As crewed spaceflight exploration expands through the Lunar Artemis program and future Mars missions, it is essential to develop an understanding of how varying gravity dose impacts human physiology to support both life support system design and crew health and performance. Since modeling is becoming increasingly important for physiological simulation and life support system design, including for the design of Extravehicular Activity (EVA) Liquid Cooling and Ventilation Garments (LCVGs), it is equally important to ensure that the computational models in development are validated with empirical data. Human computational thermal models, although in use since the 1960s, are primarily based on 1g data and have been validated through experimental and comparative analytical studies. On Earth, there are multiple gravity analogs that are used to measure physiological changes in humans based on gravity dose, including tilt tables, lower body negative pressure, and short and long arm centrifugation, along with bed rest studies. In this paper, a systematic review of published literature on methods and analog experiments used to validate human computational thermal models is presented. Also presented is published research conducted to generate germane physiological data related to gravity dose, focusing on thermoregulation and heat rejection. In summary, this review assembles a body of known thermoregulation computational model validation methods and published empirical data on physiological changes due to gravity dose, which could be used in combination to validate future human computational thermal models in variable gravity environments.

[317] ***Lunar Environment Monitoring Station TRL-6 Thermal Vacuum Test and Results***

Ethan Burbridge (Vertex Aerospace, LLC), Mehdi Benna (University of Maryland, Baltimore County) and Mitchell Hamann (AMU Engineering).

*Abstract*

Thermal vacuum testing of the Lunar Environment Monitoring Station (LEMS) concluded successfully in early 2022 thus concluding the development effort and elevating the system to a Technology Readiness Level (TRL) of six (6). As a survive-the-Lunar-night package supporting a suite of instruments, LEMS required careful accounting of available power from on-board batteries and extreme thermal isolation from the environment. Battery tests were conducted prior to system TVAC to measure power available at low current draw and temperatures from -30°C to 30°C to determine that 953.6 Whr were available for electronics and 1200.4 Whr were available for heat dissipation. At 0.0045 °C/day, thermal vacuum test standards like GSFC-STD-7000b for thermal balance criteria were impossible to achieve due to temperature rates of change orders of magnitude smaller than the measurement sensitivity of temperature sensors. LEMS employed an alternative thermal balance criteria based on power available in the LEMS system design and measurement uncertainty of heat flows and thermal mass for a temperature rate of change of 0.062°C/hr. Consideration was also given to the test set up regarding temperature sink plates, mounting interfaces, and thermal radiation insulation to accurately measure heat flows from LEMS. With measurement uncertainty included the total nighttime heat dissipation was measured to be 1199.8 Whr confirming that the package can survive the Lunar night.

[318] ***Workload Measurements in the EDEN ISS Greenhouse during the 2021 Antarctic Overwintering Mission***

Conrad Zeidler (German Aerospace Center) and Jess Bunchek (German Aerospace Center).

*Abstract*

From January 2018 to February 2022, the EDEN ISS project investigated technologies for plant cultivation and operation procedures for planetary surface greenhouses. The EDEN ISS space analog test facility was located near the German Neumayer Station III in Antarctica. For the fourth and final overwintering expedition from 2021 to early 2022, a tenth person joined the Neumayer Station III overwintering team as the dedicated on-site operator of the EDEN ISS greenhouse, supported by an interagency collaboration between DLR and NASA. For this final mission of the EDEN ISS Antarctic campaign, 790 g/m2/day fresh produce was grown within the 12.5 m2 plant cultivation area of the EDEN ISS greenhouse – comparable to production in prior missions. As in previous years, operator workload was assessed using the NASA Task Load Index to investigate which tasks/procedures could be facilitated in terms of workload, how workload changed over the course of the mission, and how workload could be reduced in the future. In this paper, we present the results of the NASA Task Load Index measurements conducted from 4 October 2021 to 26 December 2021. Detailed workload measurements are presented with respect to specific recurring tasks, e.g., daily/weekly/monthly routines, harvesting, and pruning, as well as workload on a daily, weekly, and monthly basis. The measurements show that there is a need to reduce the workload of the on-site operator in a space analog greenhouse. These studies provide valuable insight for operating future greenhouses on the Moon and Mars, which should already be included in the planning phases of such space missions.

[319] ***Practical Lunar Surface Site Selection Criteria to Optimize Habitat Environmental Control***

William O'Hara (Blue Origin LLC) and Jennifer Matty (Blue Origin, LLC).

*Abstract*

Site selection criteria for a lunar habitat requires the consideration of a variety of factors ranging from view of the sun to proximity to spacecraft landing sites. All of these driving factors are traded against each other to arrive at candidate landing sites, as recently highlighted in NASA’s site selection for the Artemis III mission. Selecting sites amongst the desolate, diverse and shadowy terrain of the south pole is a challenge likely not seen since the placement of McMurdo Base in the Antarctic or the placement of homesteads in the days of the western expansion in the United States. While not obvious, one class of considerations for site selection criteria has to do with reducing habitat environmental risks. Specifically considering temperature control, radiation mitigation and dust mitigation as hazards and systems design challenges, we strive to find solutions that minimize cost, mass and complexity. Surface construction and regolith moving, shielding and environmental systems are candidate solutions we target for developing efficiencies. To that end, we looked at how topographic features on the lunar south pole can be used to optimize habitat environmental control by minimizing the need for heavy machinery or complex systems. While these are ultimately traded against other priorities, it is important to consider them and their relative importance and practicability. The candidate site selection criteria resulting from this assessment are discussed in this paper.

[320] ***Nanoporous Silica as a Regenerable Sorbent for Potential Integration into NASA’s Trace Contamination Control System***

Evgueni Kadossov (XploSafe LLC), Nick Materer (Oklahoma State University), Allen Apblett (Oklahoma State University), Shoaib Shaikh (XploSafe), Mallikharjuna Komarneni (XploSafe), Michael Teicheira (XploSafe), Cinda Chullen (NASA), John Hostetler (Axiom Space) and Kelsey Boom (NASA).

*Abstract*

Development is underway for the next generation of spacesuits called the Extra-Vehicular Mobility Unit (xEMU). The Exploration Portable Life Support Subsystem (xPLSS) is a vitally important component of the xEMU that is also being developed. The xPLSS is tasked with the maintenance of a breathable atmosphere that is free of noxious volatile molecular species. The purification system that removes contaminants present in the ventilation system is the Trace Contamination Control System (TCC) which is a component in the ventilation loop of the xPLSS. Acid-impregnated activated carbon is the current state of the art for trace contamination control. As this sorbent is non-regenerable consumable, there is a significant impact of logistics on future missions. The primary trace contaminants that must be removed by the sorbent include ammonia, carbon monoxide, formaldehyde, and methyl mercaptan. XploSafe has developed and demonstrated the technical feasibility of a vacuum-regenerable sorbent that could be integrated into the TCC. XploSafe’s sorbent media was exposed to 7-day Spacecraft Maximum Allowable Concentrations of the 18 trace contaminants that are present within the xPLSS breathing loop. The trace contaminants were exposed to the sorbent columns individually and in mixtures at relative humidities of 40% and 85% and temperature of 22 °C). Adsorption breakthrough volumes and capacities were measured along with regeneration capacity for the sorbent tested with these trace contaminant analytes. Prototype TCC holder design considerations including the required sorbent mass and sorbent holder volume are also discussed.

[321] ***NextSTEP Appendix A Modular ECLSS Effort Lessons Learned***

James Clawson (NASA HQ (Stellar Solutions, Inc)), Daniel Barta (NASA), Walter Schneider (NASA), Marlon Cox (NASA) and David Howard (NASA).

*Abstract*

The first appendix under NextSTEP-2, Appendix A, focused on developing deep space habitation concepts, engineering design and development, and risk reduction efforts leading to a habitation capability in cislunar space. Collins Aerospace, formerly UTC Aerospace Systems (UTAS), was awarded a Phase 1 and subsequent Phase 2 contract to “develop concepts that group ECLS systems into logical modules maximizing the use of common components and the development of unique methods and design concepts that support in-flight maintenance and repair for future exploration systems.” This effort developed and matured a modular palletization concept to enable standard rack interfaces, post-launch outfitting, and decoupling of structural supports that withstand launch environments from those needed for lower on-orbit loads, Collins also assessed numerous architecture trades, including the use of condensing and noncondensing heat exchangers, the ability of modular units to accommodate various habitat volumes and thermal loading, and the most appropriate order and timing of delivery of regenerative ECLSS hardware to orbital habitats. Collins additionally developed software approaches for distributed/modular command, control, and communication systems and innovative Bayesian fault detection and isolation techniques. Finally, the effort explored advanced maintainability and supportability concepts including the definition of maintenance units (MUs) in place of the traditional Orbital Replacement Units (ORUs), increasing parts commonality to reduce the number and type of spare parts, the use of augmented reality to guide crews during maintenance and repair procedures, and how crews would prepare for and recover from long durations of habitat dormancy. Now that the NextSTEP Modular ECLSS effort has come to a close, it’s important to summarize the work accomplished under this effort and identify the lessons learned and where they can be leveraged to improve NASA’s broader program of ECLSS technology development and demonstration and ultimately how they can increase the performance of future surface and orbital habitats.

[322] ***Updated Analysis of Particulate Data from the Airborne Particulate Monitor ISS Payload***

Claire Fortenberry (Universities Space Research Association/NASA Glenn Research Center) and Marit Meyer (Northrop Grumman).

*Abstract*

Future long-duration lunar and deep space missions necessitate improved air quality monitoring to maintain crew health and comfort, especially as new aerosol sources (e.g., lunar dust) pose novel risks and challenges. The Airborne Particulate Monitor (APM) payload constitutes the first effort to monitor particulate matter concentrations on the International Space Station (ISS). In an effort to obtain per-person particle emission rates, the APM was deployed in two locations on the ISS during crew handover periods wherein the crew complement was elevated. Although monitoring efforts have not been completed, preliminary analysis of crew handover data demonstrate that high filtration rates keep particle concentrations very low, even during high-activity handover periods. Weeks-long deployments of the APM demonstrate that particle concentrations, while generally low, depend primarily on local activities, such as exercising or vacuuming. Here, we present analysis of the most recent APM data and discuss directions for future particulate monitoring efforts.

[324] ***Test Bed for Evaluation of Sorbents Used in the Exploration Portable Life Support System***

Nick Materer (Oklahoma State University), Evgueni Kadossov (XploSafe), Allen Apblett (Oklahoma State University), Mallikharjuna Komarneni (XploSafe), Shoaib Shaikh (XploSafe), Michael Teicheira (XploSafe), Cinda Chullen (NASA) and Kelsey Bloom (NASA).

*Abstract*

The Trace Contamination Control (TCC) system is a component in the oxygen ventilation loop of the Exploration Portable Life Support System (xPLSS) which removes contaminants generated by the crewmembers’ metabolic processes. XploSafe has developed a vacuum regenerable nanoporous silica sorbent for the TCC system to advance xPLSS technology, resulting in increased mission capability, durability, and extensibility. To investigate the effectiveness of our silica-based nanoporous regenerable sorbent, XploSafe constructed a recirculating test bed that mimics the environment within the xPLSS by providing the concentrations of the trace contaminant analytes at the operating temperature, humidity, pressure and flow rates of the xPLSS. The system uses quick connect flanges and a bypass loop to allow quick removal and replacement of sorbent beds without having to purge the trace contaminant gas stream. In addition, two minutes or longer pressure swing cycles across the TCC sorbent bed can be programed. Contaminant removal efficiency across the sorbent beds is quantified by periodically measuring gas concentrations in the circulated stream using an automated sampling loop which incorporates a combination of real-time sensors and a vapor capture system connected to a thermal desorption unit combined with a gas chromatograph/mass spectrometer to separate and analyze contaminates for near real-time quantification. By monitoring the decrease in contaminant contents with time, the sorption capacity and rate constant of the evaluated sorbent medias can be determined and compared. This system will be used to test individual sorbent columns or fully assembled TCC units with the currently deployed nonregenerable sorbent or our regenerable sorbent media.

[327] ***A Decision Support System for Extravehicular Operations Under Significant Communication Latency***

Timothy McGrath (JES Tech), Jason Norcross (KBR), Brianna Sparks (National Aeronautics and Space Administration), Fernando Figueroa (National Aeronautics and Space Administration), Jon Morris (D2K Technologies), Federico Piatti (D2K Technologies) and Jeffrey Somers (National Aeronautics and Space Administration).

*Abstract*

Within the next few decades, humanity hopes to perform extravehicular activities (EVAs) on the surface of Mars; however, several technical and operational challenges must first be overcome. Foremost among these challenges is managing a significant two-way communication latency between Earth and Mars. Current and historical paradigms of EVA operations have required near-real-time communication between the crewmember(s) performing an EVA and an Earth-based mission control.

Next-generation operational paradigms for supporting deep space exploration will necessitate a distributed decision authority system, including delayed Earth-based mission control, the on-planet extravehicular crewmember(s), and intermediate mission support from intravehicular crewmember(s) within real-time communication range. This latter group is of particular interest: they must provide operations support without the plentiful resources available to mission control on Earth.

For this purpose, NASA is developing the Personalized EVA Informatics and Decision Support (PersEIDS) software platform. PersEIDS is designed to bolster operator situational awareness and offload operator workload by automating the tracking and projection of consumables usage over an EVA timeline, providing real-time probabilistic safety assessments of an EVA timeline given consumables constraints, and recommending alternative EVA timeline(s) when the active timeline is not expected to be completed under consumables limits.

The PersEIDS concept of operations, use cases, and models will be presented. A limited version of PersEIDS was demonstrated during a three-day-long study where each day a roughly four-hour-long simulated Martian EVA was performed in virtual reality at the NASA Johnson Space Center. The first day was a control trial without PersEIDS support; the second and third days represented different levels of decision support provided by PersEIDS to the intravehicular crewmember acting as mission control. With PersEIDS support, the IV crewmember was able to manage the mission to completion faster and with more remaining consumables; however, additional testing is required to understand confounding factors, e.g. training bias.

[328] ***Ultrasonic Clothes Washer/Dryer Combination for Moon, Mars, and ISS Applications***

Ayyoub Momen (Ultrasonic Technology Solutions), Jonathan Bigelow (Ultrasonic Technology Solutions), Connor Shelander (Ultrasonic Technology Solutions), Justin Ellis (Ultrasonic Technology Solutions), Dennis Chertkovsky (Ultrasonic Technology Solutions), Michael Ewert (JSC NASA) and Melissa McKinley (NASA).

*Abstract*

Our study aims to investigate the effectiveness of an ultrasonic-based combo garment washing and drying system for space applications. Our system leverages our technological innovations in direct-contact ultrasonic fabric drying in combination with ultrasonic fabric washing. The main objective of this investigation is to gauge the effectiveness of washing and drying textile garments ultrasonically. In this paper, we will report the results of experiments conducted to assess the effectiveness of washing clothes ultrasonically, including ultrasonic intensity testing, stain removal testing, and fabric degradation testing. This study's outcome could lead to the production of an Ultra-Fast Ultrasonic Washer/Dryer Combination unit that would reduce clothing resupply costs for crewed missions to the moon, Mars, and the ISS.

[329] ***Modeling Characterization of Smoke Particle Transport and Fate in Lunar Gravity***

Claire Fortenberry (Universities Space Research Association/NASA Glenn Research Center), David Urban (NASA Glenn Research Center) and Gary Ruff (NASA Glenn Research Center).

*Abstract*

Spacecraft fires present one of the most dangerous scenarios threatening crew safety for future lunar and deep space missions. Spacecraft fire detection strategies are challenged by transport phenomena unique to reduced gravity environments. To date, spacecraft fire detection studies have focused on microgravity systems, but, as NASA plans to return to the Moon, more research is needed to evaluate optimal fire detector placement in lunar gravity. This placement must consider a balance between the buoyant flow towards the ceiling due to lunar gravity and the cabin air filtration. Here, we present results from a study to evaluate smoke particle transport from an early-stage fire in lunar gravity. This model, built in COMSOL Multiphysics, combines turbulent flow, heat transfer, and particle transport from a simulated material overheating (pre-flame) event under varied temperature conditions. Particle velocities are tracked in lunar gravity and compared to results from terrestrial gravity calculations to evaluate timescales for buoyant transport. Results suggest that in lunar gravity, small (~1 µm) particles travel upward at velocities similar in magnitude to average air velocities on the ISS. However, maximum smoke plume velocities are dependent on fuel configuration and location, and smoke particle transport must be evaluated considering particle properties like size, density, and morphology. Finally, we consider a hypothetical ventilation strategy with a low-velocity forced flow applied from ceiling air supplies to floor air returns. Under the tested conditions, the upward flow of a buoyant lunar smoke plume may enable strategic placement of smoke detectors on ceilings of future lunar spacecraft cabins depending on the cabin ventilation velocity, air filtration, and habitat design.

[332] ***Experimental Comparison of Two-Phase Heat Spreaders for Space Modular Electronics***

Sai Kiran Hota (Advanced Cooling Technologies, Inc.), Kuan-Lin Lee (Advanced Cooling Technologies, Inc.), Greg Hoeschele (Advanced Cooling Technologies, Inc.), Tanner McFarland (Advanced Cooling Technologies,Inc.), Srujan Rokkam (Advanced Cooling Technologies, Inc.) and Richard Bonner (Advanced Cooling Technologies, Inc.).

*Abstract*

Standardized form factor electronics cards promote inter-operability across various applications on land and in space. However, current cards might be less reliable due to thermal management bottlenecks. Conventional approaches for cooling electronics cards involve using conduction based thermal heat spreaders, which are limited in performance. So, to improve thermal management of these electronics, high thermal performing, two-phase based heat spreaders are gaining attention. Among these two-phase heat spreaders, embedded heat pipe has achieved high maturity, while, pulsating heat pipes (PHPs) are in nascent stages. In an ongoing SBIR Phase II program funded by NASA, Advanced Cooling Technologies, Inc. is developing a PHP heat spreader for standard 3U form factor electronics thermal management. A prototype PHP was fabricated by 3D printing approach with aluminum as the base plate. Performance of the PHP was determined and compared to a HiK™ plate, which is a copper-water embedded heat pipe heat spreader of same form factor. The experiments were performed on an assembled platform with one central evaporator and two edge condenser configurations. The evaporator was a 1-inch x 1-inch aluminum block with two cartridge heater inserts. A copper tube pressed aluminum cold plate was used as the condenser. Influence of operating parameters such as operating temperature and orientation were determined.

[333] ***Culture-Independent Fungal Profiling for the International Space Station using Nanopore Sequencing: Method Development***

Hang Nguyen (JSC NASA (JES Tech)), Sarah Stahl-Rommel (JSC NASA (JES Tech)), Marie G. Sharp (JSC NASA (KBR)), Christian L. Castro (JSC NASA (JES Tech)) and Sarah Castro-Wallace (JSC NASA).

*Abstract*

Microbial monitoring of the International Space Station (ISS) environment is a crew health requirement that encompasses both bacterial and fungal identification. Currently, culture-based methods are used for sample collection, and these samples must be returned to the laboratory for analysis. The use of culture and the need for sample return to Earth results in a bias toward culturable organisms and causes a significant delay between sample collection and delivery of final data (weeks to months), respectively. Recently, advancements in molecular technology have aided a broad range of applications, including medical, industrial, and basic sciences. Additionally, increases in portability and ease-of-use of molecular platforms have provided point-of-use capabilities demonstrated by the miniPCR thermal cycler and the MinION sequencer (Oxford Nanopore Technologies). These devices have been applied to, and validated for, the identification of bacteria onboard the ISS. Building on this work, a spaceflight-compatible fungal workflow has developed. Molecular-based fungal analysis is complicated by low biomass, difficult-to-lyse spores, debate regarding the region for taxonomic assignment, and the lack of bioinformatic pipelines and curated-databases. To overcome these difficulties, primers yielding an ~ 2 Kb amplicon were validated against a wide range of fungal isolates. The current spaceflight method was substantially optimized, bioinformatic pipeline was created, and refinements to the UNITE database were implemented. To compare this optimized method to the current culture-based standard, 41 sample sets (82 total swabs, held in tandem) were evaluated. Parallel fungal profiles were obtained between the two methods, with the culture-independent method revealing increased diversity. Further validation has also performed with the launched DNA on board the ISS using the fungal flight compatible method. The addition of this method to the already established bacterial process fulfills the crew health identification requirement. Moreover, the implementation of this method onboard ISS will enhance our understanding of its unique fungal microbiome.

[334] ***Multi-Sensor 3D Data Visualization in Virtual Reality for Planetary Science and Mission Operations***

Ferrous Ward (MIT), Cody Paige (MIT), Jess Todd (MIT), Don Derek Haddad (MIT), Jennifier Heldmann (NASA Ames), Darlene Lim (NASA Ames), Dava Newman (MIT) and Ariel Ekblaw (MIT).

*Abstract*

The MIT Resource Exploration and Science of our Cosmic Environment (RESOURCE) project aims to bridge the operations gap between current uses of VR as a training tool and future uses as an immersive interface for mission support operations and science. We describe the development of “digital twin” field sites within a VR environment from several low cost and commercially available sensors for photography, LiDAR, combination LiDAR-RGB, and photospectrometry. Three-dimensional point-cloud datasets of rocky outcrops were taken from Marblehead, Massachusetts and Svalbard, Norway. These sites were selected for the presence of features across multiple scales and fidelity as analog sites for a terrestrial space environment. They contain large landscape features like hills, depressions or permafrost features (>>1m scale), boulders (~1m scale), small rocks (~10cm), and small scale geologic features such as veining or fracturing (<1cm). These data were collected using a Velodyne LiDAR, Sony digital photography camera, DJI aerial drone, and Hamamatsu mini-spectrometer. Depth models were reconstructed with Open3D and AliceVision/Meshroom. These models were aligned and exported to a VR-capable file format. Geologic data was manually checked for key feature presence, and the point clouds were compared for distance accuracy and feature matching with the photogrammetric model in CloudCompare. Finally, the aligned models and point clouds were rendered in the Unreal 5 VR game engine. As part of this work, we discuss the data collection techniques for dense LiDAR point clouds, as well as handheld and aerial drone photogrammetry. We also discuss considerations for data resolution and rendering capability for a VR interface that can be used for either mission planning or for real science analysis. The low cost and flexibility of the acquisition hardware allows for high extensibility both on Earth for remote sensing, but also in deep space for science targets and mission analytical tasks.

[335] ***Development of Flight Demonstration Hot Reservoir Variable Conductance Heat Pipes for Microgravity Testing and Future Lunar Landers and Surface Systems***

Kuan-Lin Lee (Advanced Cooling Technologies Inc.), Calin Tarau (Advanced Cooling Technologies Inc.), Ramy Abdelmaksoud (Advanced Cooling Technologies Inc.), William G. Anderson (Advanced Cooling Technologies Inc.), Chirag Kharangate (Case Western Reserve University) and Yasuhiro Kamotani (Case Western Reserve University).

*Abstract*

The lunar landers and rovers require a reliable tight passive thermal control technology due to their exposure to the ambient’s harsh temperature conditions such as the lunar night where the temperature drops to about -280˚F (-173.3˚C) and lasts for a continuous 14-day period. Advanced Cooling Technologies Inc. (ACT) has devised and demonstrated a hot reservoir variable conductance heat pipe (HR-VCHP) to be an ideal passive variable thermal link between the payloads and the radiator for such lunar landers since HR-VCHP can offer much tighter thermal control capability when compared to a regular cold-biased reservoir VCHP. Under NASA Small Business Technology Transfer (STTR) program, ACT and Case Western Reserve University (CWRU) further matured this technology by introducing a novel fluid management feature that enables a non-condensable gas (NCG) flow to generate inside the device. This flow can maintain the moisture level of the reservoir and lead to more reliable VCHP operation in space. Two flight demonstration units (FDU) of HR-VCHPs with NCG flow are under development: one for microgravity testing on International Space Station (ISS) and another one for lunar lander thermal control applications. The FDU for microgravity testing is made from copper where the working fluid is water while the HR-VCHP for the future lunar landers is made from aluminum where the working fluid is ammonia or propylene. This paper will present a compact HR-VCHP prototype description, reliability testing results, and the development status of two FDUs.

[336] ***Design of an Augmented Reality User Interface for Lunar Extravehicular Activity Operations***

Michael Fornito (Embry-Riddle Aeronautical University), Nicholas Lopac (Embry-Riddle Aeronautical University), Graydon Russell (Embry-Riddle Aeronautical University), Joseph Demartini (Embry-Riddle Aeronautical University), Riley Flanagan (Embry-Riddle Aeronautical University), Lea Miller (Embry-Riddle Aeronautical University) and Miranda Young (Embry-Riddle Aeronautical University).

*Abstract*

Embry-Riddle Aeronautical University’s Spacesuit Utilization of Innovative Technology Laboratory (ERAU S.U.I.T. Lab) has developed an augmented reality (AR) heads up display for lunar astronauts as part of the 2021 and 2022 NASA SUITS challenge. This system, called the Augmented Lunar Exploration and Extravehicular Interface (ALEXEI) aims to support lunar EVA operations by providing astronauts with critical, procedural, navigational, and scientific information in an innovative and novel fashion. As NASA prepares for the return to the lunar surface with the Artemis missions, they have identified a spacesuit user interface as a current technology gap. The Exploration Extravehicular Mobility Unit (xEMU) is NASA’s next generation lunar spacesuit and is being developed with the future of heads up displays in mind. The student team from the ERAU S.U.I.T. Lab has designed ALEXEI with lunar EVA operations and astronaut performance at the center of design. The system runs on the Magic Leap One AR headset, and uses a tactile controller combined with head-tracking for input control. ALEXEI organizes EVA information into screens located on the periphery of the user and separates the major elements of EVA into separate applications. These applications include Vitals, Tasks, Navigation, Science, Settings, Telemetry Stream, and Communication. The features provided by these applications satisfy the requirements of the NASA SUITS challenge and aim to provide novel solutions for displaying useful EVA information to lunar astronauts. The ALEXEI system underwent limited human in the loop at NASA’s Johnson Space Center. EVA subject matter experts tested and evaluated ALEXEI and provided largely positive feedback. Standout features included the multiple navigational aids, user preference considerations, and tactile control input system. The overall ALEXEI framework has been validated as a concept and is a starting point for continued development to maximize situational awareness on future lunar EVAs.

[337] ***Demonstration of Ice-Extraction and Ice-Collection System for Lunar Ice Miners***

Kuan-Lin Lee (Advanced Cooling Technologies,Inc.), Sai Kiran Hota (Advanced Cooling Technologies, Inc), Quang Truong (Advanced Cooling Technologies, Inc.), Mojtaba Edalatpour (Advanced Cooling Technologies, Inc), Srujan Rokkam (Advanced Cooling Technologies, Inc.) and Kris Zacny (Honeybee Robotics).

*Abstract*

Mining water-ice in the permanent shadow region of the moon opens opportunities for In Situ Resource Utilization (ISRU) since it is a valuable resource for lunar exploration activities. To realize an efficient water-ice mining system, Advanced Cooling Technologies, Inc. in collaboration with Honeybee Robotics, is developing an advanced thermal management under an ongoing SBIR Phase II funded by NASA. The thermal management system consists of two-principal components: 1. Thermal corer; and 2. Volatile cold trap tank. The thermal corer is an improved drill auger developed by Honeybee Robotics incorporating minichannels to facilitate regolith heating for ice-sublimation. Volatile cold trap tank is a chamber with variable conductance heat pipes (VCHP) integrated to a radiator panel. The VCHP’s aid in effectively collecting ice. A prototype thermal corer, 17.3 cm long and with 5 cm internal diameter was 3D printed with stainless steel. Ice-extraction demonstration experiments were performed to determine the performance of the thermal corer with the heat transfer fluid flowing through the thermal corer at different temperatures for certain time. During the experiments, the concentration of the ice in the regolith was 5%. Likewise, a VCHP based cold trap tank was designed and fabricated. Currently, thermal characterization of the cold trap tank is being performed to determine the performance of the ice-collection by modulating the heat transfer modes of the VCHP from fully active condenser for 100% heat rejection to diode mode.

[338] ***Hybrid Thermal Control System for Extreme Thermal Environments***

William Johnson (NASA Marshall Space Flight Center), Kayla Daniel (NASA Marshall Space Flight Center), Kenton Roberts (NASA Marshall Space Flight Center), Greg Schunk (NASA Marshall Space Flight Center) and Jeffery Farmer (NASA Marshall Space Flight Center).

*Abstract*

NASA’s return to the moon brings about many challenges, including issues with survival on the Lunar surface. In order to be sustainable, assets such as landers, rovers, and habitats must be usable for more than a single mission duration. One of the key challenges with sustainability is designing adequate thermal control systems that allow for surface systems to survive both during the day and the Lunar Night. Marshall Space Flight Center (MSFC) has been developing a hybrid thermal control system that can be utilized for various surface assets that must survive in extreme lunar environments. This scalable system is targeted for human-rated systems and utilizes a combination of a pumped fluid loop (PFL) and a loop heat pipe (LHP) with thermal control valve (TCV). Pumped fluid loops have a long history of use in human rated systems. They can collect large amounts of waste heat and transport it over long distances in rovers, habitats, and other systems. By utilizing a non-toxic working fluid in the habitable volume the PFL is easily serviceable by the crew and does not pose a risk during any unexpected leaks or failures. The addition of a LHP for the exterior heat transport and rejection adds several benefits to the system for extreme environment survival. The quantity of LHPs can be tailored to optimize heat rejection for different systems and allows for large radiative surfaces. By utilizing a TCV in combination with the LHP, there can be high heat transfer during the daytime with minimal heat transfer during the night. The TCV passively controls the amount of heat transfer through the LHP based on the environmental tempera-ture. A prototype system has been tested in benchtop and thermal vacuum conditions. Results are presented showing the turndown ratio and power consumption compared to a traditional systems.

[342] ***Pathway to Successful Inclusion of Tribal Colleges and Universities (TCUs) in the Johnson Space Center (JSC) Small Business Innovation Research (SBIR) / SBIR Technology Transfer (STTR) Program***

Doug Goodman (Jacobs), Kathryn Packard (NASA) and James Whittington (JETS/JSC).

*Abstract*

In 2015, the authors began an outreach plan to Minority Serving Institutions (MSIs), particularly targeting Tribal Colleges and Universities (TCUs), which were overlooked at that time. Since then, the Johnson Space Center (JSC) Small Business Innovation Research (SBIR) team has visited 15 TCUs across 10 states and 11 reservations. This outreach is the most extensive of its kind within the agency. Two separate papers have been written about the trajectory and impact of that outreach on the SBIR Technology Transfer (STTR) program, where colleges and universities that partner with small businesses compete for Federal research dollars. In the 2021 STTR Solicitation, Navajo Tech University (NTU) became the first TCU in the history of the NASA SBIR program to receive an STTR Phase I award. In 2022, they then became the first TCU to receive a Phase II award, which totals $750,000 combined for the college and the partner and has a 2-year lifecycle. This paper will elaborate on the history of JSC’s outreach activities, the strategies utilized (and focusing on the benefits of the SBIR program to reservations), and the lessons learned that led to the more productive TCU engagement and the contract award. The paper will also show how we and NASA SBIR modified presentations to adjust to JSC outreach experiences. The paper will recommend how other Federal programs can engage these communities in STEM contracts. These lessons learned and strategies will benefit companies and Government agencies who want to implement similar outreach and public engagement plans within their programs.

[346] ***Comparative Analysis for EMU Fleet Latent Loading Characterization in Support of US EVA 80 Failure***

Noah Andersen (HX5, LLC (JETS2)).

*Abstract*

During United States Extravehicular Activity 80 (US EVA 80), water was observed in the helmet of an Extravehicular Mobility Unit (EMU) during cabin repressurization. One of the primary mechanisms that can cause water in the helmet of an EMU is integrated performance induced sublimator carryover. The sublimator is a heat exchanger that removes heat and humidity from the ventilation loop. Water vapor is condensed from the gas and removed by slurper holes in the sublimator. Sublimator carryover is caused by the inability of the EMU sublimator to remove all of the condensed water vapor, resulting in liquid water entering the helmet. To determine if sublimator carryover was a likely cause of the US EVA 80 failure, a comparative analysis of numerous historical EVAs was conducted to calculate the total latent load (total water vapor generated by the crewmember) for numerous historical EVAs and ground tests using the Systems Improved Numerical Differencing Analyzer EMU (SINDA EMU) model. The analysis showed that US EVA 80 was associated with a comparatively high latent load when compared to other EVAs that did not present water in the helmet. Further, this analysis showed that other historical EVAs which had visible water in the helmet were also associated with higher latent loads. This analysis provides evidence that the likely cause of the US EVA 80 water in the helmet event was not the failure of an individual component, but rather sublimator carryover caused by excessive production of water vapor by the crewmember. The evidence from this analysis agrees with results from the Test, Teardown, and Evaluation (TT&E) of the EMU which did not show any failure of individual components of the EMU that would lead to water in the helmet.

[347] ***Extravehicular Mobility Unit System-Level Model (SINDA EMU) Usage for Operational Mitigations in Support of US EVA 80***

Noah Andersen (HX5, LLC (JETS2)) and Bruno Miranda (HX5, LLC (JETS2)).

*Abstract*

During United States Extravehicular Activity 80 (US EVA 80), water was observed in the helmet of an Extravehicular Mobility Unit (EMU) during cabin repressurization. Through a comparative analysis and Test, Teardown, and Evaluation (TT&E) of this EMU, the most likely cause of the US EVA 80 water failure was determined to be sublimator carryover caused by a comparatively high latent load (water vapor production by the crewmember). High latent load can be reduced by the crewmember adjusting the thermal control valve (TCV) setting on the EMU to prevent the onset of significant sweating. To reduce the risk of high latent load leading to water in the helmet, a potential warning system was developed using the Systems Improved Numerical Differencing Analyzer EMU model (SINDA EMU). The goal of this warning system is to alert the crewmember when they are producing a high latent load and recommend adjustment of the TCV to increase cooling. This warning system was designed to ensure high risk conditions are avoided while simultaneously preventing a system that warns the crewmember too frequently. Theoretical tests of the warning system through modeling calculated that if the warning system were used during US EVA 80, the total latent load could have been reduced by up to 33% which would have significantly reduced the risk of water in the helmet. This analysis also investigated the effectiveness of the warning system on EVAs that occurred after US EVA 80.

[348] ***Development of a Variable Conductance Cold Plate for Spatial and Temporal Isothermality Across Power Scales***

Elizabeth Seber (Advanced Cooling Technologies) and Michael Ellis (Advanced Cooling Technologies, Inc.).

*Abstract*

For low-earth orbiting satellites, environmental conditions rapidly change throughout the course of a single orbit. These changes affect the radiative heat sink of these satellites, and in turn, rapidly alter the temperatures of sensitive onboard instrumentation. As such, there exists a need for a thermal control system to maintain such instrumentation at a uniform and consistent temperature despite environmental changes. Such a thermal system must also be low in size, weight, and power if it is to be adopted into LEO satellites. Through a NASA Phase II SBIR, ACT has developed such a thermal system, consisting of a variable conductance cold plate (VCCP) to provide spatial and temporal isothermality to mounted electronic components. The technology builds on ACT’s experience with passive two-phase devices, specifically variable conductance heat pipes (VCHP) and vapor chambers, which address spatial isothermality. Temporal isothermality is handled by the VCHPs, which are charged with a working fluid at saturation conditions and a non-condensable gas (NCG). During operation, vapor that is generated from the VCHP’s evaporator moves to the condenser. As the heat load/sink temperature changes, the working fluid seeks to operate at a higher temperature. This increases pressure as the working fluid exists at saturation conditions. This increase pushes back the NCG and opens more condensing area. As the opposite occurs, NCG pushes forward and blankets a portion of the condensing area of the VCHP. As the condenser surface area changes, the conductance of the heat pipe varies, which allows the VCHP to carry heat at a higher rate and mitigate the effects of heat load or sink temperature changes. ACT has tested two subscale versions for different power levels, charged with either acetone or ammonia, and expanded this technology to a cold plate boasting a heat collection surface area of 0.5 m2.

[349] ***The Roles of Plants in a Commercial Space Habitat***

Robert Morrow (Sierra Space), John Wetzel (Sierra Space), Samuel Moffatt (Sierra Space), Matthew Bair (Sierra Space) and Laura Kelsey (Sierra Space).

*Abstract*

As “Commercial Space” becomes established, the need to generate additional revenue as a commercial entity may significantly expand the role of plants in long duration space missions. Salad crop production has been considered for inclusion in habitats such as space stations and Mars transit habitats to provide nutrient supplementation, increase diet variety and food acceptability, and provide a source of crew recreation. However, new habitat concepts, such as Orbital Reef, would have an increased emphasis on meeting commercial goals that may include space tourism, research, exploration, a remote supply depot, an industry base (including biomanufacturing), and site for consumer productions including entertainment, media, and advertising. Tourism, for example, may require high-level hospitality for adventure tourists who represent a source of significant revenue to such commercially financed stations. Providing a high-end guest experience in any setting includes, among other things, elevated dining experiences and enhanced accommodations. Fresh salad crops can enhance even high-quality prepacked food by providing more complex tastes and improved presentation. Candidate plants beyond general salad crops studied to-date would be selected to achieve a broader array of characteristics such as increased flavors (herbs), sweetness, spiciness (peppers, radishes), textures (mouthfeel) and aromas, and vibrant colors (garnishes). Plants can also improve “quality of life” by making accommodations more pleasant through incorporation of live plant stands into social interaction volumes (lounges, dining areas). Even small non-edible plantings for aesthetic reasons might be feasible. Growing edible and ornamental plants in space presents technical challenges including development of efficient microgravity subsystem technologies, containment of plant debris and microbial contamination, maintenance of system cleanliness, and food safety. Aesthetic improvements for a crop production system can be accommodated without impacting functional performance, and might include modified culture subsystems for specific aesthetics, modified housings for plant visibility, and improved noise reduction.

[350] ***Thermal Vacuum and Vibration Testing of the Differential Thermal Expansion Thermal Switch***

Stephanie Mauro (NASA MSFC), Jeffery Farmer (NASA MSFC), David Bugby (JPL) and Jose Rivera (JPL).

*Abstract*

The Extended Stroke, Reverse Operation, Differential Thermal Expansion Thermal Switch for Extreme Variable Environments was described in the previous ICES paper: ICES-2021-412, ‘Extended Stroke and Miniaturized Reverse-Operation DTE Thermal Switches’. This thermal switch (TS) uses materials with both positive and negative coefficients of thermal expansion (CTE) arranged in concentric cylinders so that the TS operates passively, opening a gap between interfaces to create a low thermal contact when cold, and closing the gap between interfaces to create a high thermal contact when hot. This paper details the testing of the TS at Marshall Space Flight Center including the pre-vibe thermal vacuum cycle test, vibration test, post-vibe thermal vacuum cycle test, and long duration thermal vacuum cycle test. The pre- and post-vibe thermal cycle and the long duration cycle test tested to hot and cold plateau initial temperatures of 40 °C, and -173 °C, respectively. The pre- and post-vibe tests required plateau holds of at least 2 hours, whereas the long duration cycle test required plateau holds of at least 20 hours. The tests each used a rate of temperature change of < 2 °C/min when transitioning between plateaus. The data collected from each thermal test is compared to show the operation of the TS both before and after the vibration test to GEVS levels, and throughout the long duration cycle test. From the data collected, the total conductance through the TS interfaces is calculated for both on (TS closed – during hot plateau) and off (TS open – during cold plateau) configurations, and the turndown ratio is also calculated. Challenges and lessons learned from the testing are also discussed.

[351] ***Cold Trap Carbon Capture Filter for Carbon Fines Management – In-laboratory Performance and Efficiency Results***

Juan Agui (NASA) and Gordon Berger (USRA).

*Abstract*

Carbon dust management is vital to the continuous operation of the Plasma Pyrolysis Assembly (PPA), which supports the Carbon Dioxide Reduction Assembly (CRA) on the ISS. A developmental filter system known as the Cold Trap Carbon Capture Filter is being prototyped and tested to determine its performance under different challenge aerosols. The filter system employs particle separation through high-speed inertial impaction, centrifugal forces and tortuous flow paths combined with media filtration to remove carbon particulates from the PPA effluent flow. Tests were performed focused on the collection efficiency of the filter system subjecting it to ISO (International Organization for Standardization) Fine Test Dust (FTD) and carbon black. The collection efficiency of the filter system depended on the collective efficiencies of its three filter stages. Efficiencies were measured gravimetrically by determining the accumulated dust mass in each filtration and separation stage. The test data indicated that about 76% of the dust is captured in the first two stages of filtration with ISO FTD. However, the carbon dust was only collected to about 41% collection efficiency. Pressure drop rise with particle loading was gradual to moderate for the first two filter stages in the main filter housing. There was almost no rise in pressure drop across the HEPA filter with ISO FTD loading, but a noticeable pressure drop rise with carbon loading. Improvements in internal filter design can help increase dust holding performance of the system. This paper will report on the experimental technique and results of a series of tests to assess the simulated performance of the filter system.

[352] ***Developing a Hybrid Spacesuit Simulator as a Research Tool for Assessing Extravehicular Activity Relevant Workload***

Yayu Monica Hew (KBR Inc), Bradley Hoffmann (KBR Inc), Zachary Wusk (KBR Inc), Karina Marshall-Goebel (NASA Johnson Space Center) and Jeffrey Somers (NASA Johnson Space Center).

*Abstract*

Conducting human tests in a pressurized spacesuit is limited by availability, cost, and manpower; however, pressurized spacesuits are not always needed depending on the objectives of testing, including the development and testing of new informatics capabilities. The Human Physiology, Performance, Protection & Operations Laboratory (H-3PO) at NASA is developing a Hybrid Spacesuit Simulator (HS3) to support testing and characterization of human performance during analog planetary exploration extravehicular activities (EVAs). The goal of HS3 is to create a low-cost, modular, and unpressurized spacesuit simulator as a research tool that provides relevant physical and cognitive workload approximations with EVA-like immersion. HS3 consists of a soft outer suit, thermal control, gloves, boots, helmet, and integrated bioinformatics and communications. Baseline HS3 assessments were performed during 3-hour EVA simulations in two different subjects (DEMO1 and DEMO2) that included traverses at variable resistances and geological sampling activities. Liquid cooling garment (LCG) temperature, mean skin temperature, heart rate, motion capture, and metabolic rate were collected during each 3-hour simulated EVA. During DEMO1 and DEMO2, baseline metabolic rates at rest were 836 ± 327 BTU/hr and 869 ± 207 BTU/hr and increased to 2124 ± 548 BTU/hr and 2269 ± 559 BTU/hr, respectively, during 500m traverse. Average inlet LCG temperatures were 29.57 ± 6.62 °C and 25.63 ± 6.48 °C for DEMO1 and DEMO2 with increased outlet LCG temperatures of 33.53 ± 6.62 °C and 29.21 ± 4.79 °C, respectively. Overall, HS3 will enable future studies to characterize EVA tasks, human performance, and test future EVA capabilities in analog test environments without the need for pressurized suited environments.

[355] ***Integrated Computational Fluid Dynamics and Thermal Desktop Thermal Modeling for Assessment of the EMU in Support of ISS EVA 80***

Blain Lancaster (NASA JSC/JETS), Abigail Baukus (NASA JSC/KBR), Kambiz Andish (NASA JSC/JETS), Anthony Hanford (NASA JSC/JETS) and Noah Andersen (NASA JSC/JETS).

*Abstract*

Following the reports of water accumulation in the Extravehicular Mobility Unit (EMU) helmet during the ISS US EVA-80, various efforts for mitigation and further understanding of this phenomenon have been undertaken with the goal of prevention and to ensure crew safety in future EVAs. In support of this goal, a combination of Thermal Desktop thermal modeling and Computational Fluid Dynamics (CFD) has been performed in order to characterize the performance of the EMU components, specifically those within the ventilation/cooling water loops. This modeling effort evaluates the dry/wet gas pressure drop and flow distribution through gas and liquid flow paths using CFD, as well as a two-phase flow assessment of condensation production and water separation/removal performance using an integrated Thermal Desktop model of important EMU ventilation loop components. The models assess this overall thermal-fluid performance in comparison with previous existing models and design points, with the potential to evaluate worst case scenarios and historical EVAs.

[356] ***EMU CO2 Washout Comparative Assessments for the HAB/HAP-E in Support of EVA 80***

Moses Navarro (NASA), Abigail Baukus (KBR Wyle Services), Monica Mah (NASA) and Noah Andersen (JACOBS).

*Abstract*

After water was reported in the Extravehicular Mobility Unit (EMU) helmet during ISS US EVA 80, mitigation strategies were created to attempt to arrest the motion of any droplets that enter the helmet for future Extravehicular Activities (EVAs). This included adding absorbent materials into the interior of the helmet. But before a mitigation strategy can be implemented, it must first be proven to be safe. Towards this aim, a computational fluid dynamics (CFD) model was developed to assess the effect that the absorbent material has on the concentration of carbon dioxide in the EMU helmet. Within a small, closed volume such as a helmet, some amount of the carbon dioxide produced by the suit-wearer will be re-inhaled before being cleared from the oral-nasal region. The ability of the suit to remove carbon dioxide is referred to as CO2 washout. Pathological levels of inhaled CO2 (hypercapnia) are associated with dizziness, fatigue, and headaches. The CFD model was built in ANSYS Fluent and adapted to assess CO2 washout in a variety of scenarios grouped into three categories: ventilation cases, varying metabolic rates, and varying sorbent material configurations. The presence of the sorbent material did not prove detrimental to CO2 washout in the helmet.

[358] ***Evaluation of Alternative Liquid Sorbents and Additives for Spacecraft CO2 Capture***

Grace Belancik (NASA Ames Research Center), Lisa Chu (Barrios Technology), Tiago Costa (KBR Wyle) and Mathangi Soundararajan (KBR Wyle).

*Abstract*

Long-duration missions to the Moon and Mars require robust life support systems capable of dormancy and high-reliability operation. Liquid sorbents, specifically primary amines, have been used with success on submarines for CO2 removal and are therefore being evaluated in a microgravity-tolerant design. In addition to microgravity, other criteria are pivotal in optimizing the liquid sorbent. The current baseline sorbent, an aqueous diglycolamine solution, was selected for its low vapor pressure, high CO2 uptake rate and capacity, relatively long shelf life, and moderately low toxicity compared to the most common CO2 liquid sorbent monoethanolamine. An ongoing effort to replace monoethanolamine with more efficient and less toxic alternatives in flue gas systems is currently underway. From additives to improve kinetics or stability, such as carbonic anhydrase or piperazine, to newly created sorbents such as amino acid ionic liquids, a range of comparison studies have been published. This paper describes the application of the promising results of those studies to the specific spacecraft CO2 capture environment. An initial capacity experiment was performed on a variety of sorbent solutions to determine the most promising candidates. The performance of each sorbent or mixture of sorbent and additives was compared to the diglycolamine baseline performance. The results of this study show that the selection of optimal liquid sorbent will be a trade between CO2 capture kinetics to reduce system size, stability to reduce spares mass, and toxicity to minimize mass of containment.

[359] ***Producing Air Revitalization Sorbents from Spacecraft Waste Biomass***

Oscar Monje (ESC / Air Revitalization Lab), Joshua Finn (NASA) and Orlando Melendez (NASA).

*Abstract*

Repurposing spacecraft waste biomass improves the logistics of waste disposal and the resupply of expendable activated carbon used in air revitalization ECLS. Several bioregenerative technologies (bioreactors, algal reactors, and crop production systems) produce C wastes that can be converted into activated carbon used for trace contaminant control. Activated carbon can be produced by a two-step process: 1) biochar formation using slow pyrolysis, and 2) activation with steam or with chemical agents. The activated carbon produced must have similar NH3 and dichloromethane removal capacities as the SOA impregnated activated C (i.e. Barnabey Sutcliffe Type 3032) used for trace contaminant control on ISS. The feasibility of methods for producing biochar and impregnated activated carbon from inedible plant biomass and algae is presented and discussed. The NH3 removal capacities of plant and algal biomass derived sorbents were compared to capacities of two commercial acid-treated sorbents. This proof-of-concept effort opens an avenue for repurposing spacecraft C wastes towards the production of sorbents used for ECLS air revitalization architectures.

[360] ***Alternative Treatment of Crew Wastewater Using a Hybrid Membrane Technology***

Talon Bullard (USF), Daniella Saetta (NASA/USF), Alexandra Smith (USF), Katrina Haarmann (USF), Flaubert Akepeu (USF), Ana Ferret (USF), Celia DeVito (USF), Benjamin Hoque (USF), Robert Bair (USF), Melissa Collins (Forward Designs LLC), Mark Fehrenbach (Forward Designs LLC), Paul Long (Forward Designs LLC), Jason Fischer (NASA/Aetos Systems, Inc.), Luke Roberson (NASA) and Daniel Yeh (USF).

*Abstract*

Environmental Control and Life Support Systems (ECLSS) of future long-duration, deep-space human exploration missions should aspire to meet the following guiding principles: 1) perform robustly and reliably, 2) minimize consumables which are hazardous and/or require frequent resupply, 3) avoid the generation of hazardous byproducts, and 4) preserve opportunities for waste resource recovery in mature phases of the mission. As a water source, urine is difficult to treat due to its high nitrogen concentration, tendency for high pH, propensity to off-gas ammonia, and high mineral content. At the same time, urine contains a plethora of nutrients which should be preserved as fertilizer when crop production is needed. The current state-of-the-art technology, the urine processing assembly (UPA) aboard the International Space Station (ISS), meets the first guiding principle. The incorporation of bioregenerative elements into next-generation water management, combining microbiology with physicochemical processes, has the potential to address all the guiding principles. A Suspended Aerobic Membrane Bioreactor (SAMBR) with biological nutrient removal (BNR) capabilities was developed by the University of South Florida and Kennedy Space Center. Intended for partial gravity habitat, SAMBR serves as a hybrid alternative to current water treatment technologies to support closing the resource recovery loop. With its modular and flexible design, SAMBR’s operation can be customized to meet treatment requirements (nitrogen removal, conversion, or recovery) as dictated by mission scope. This proceeding presents preliminary research pertaining to: 1) design challenges in maximizing hydraulic throughput while minimizing mass and volume of the assembly; 2) capabilities for treating high nitrogen waste under steady and non-steady state conditions; and 3) measured performance parameters such chemical oxygen demand (COD), nitrogen conversion, nutrients, turbidity, and system throughput. Future research and development pertaining to further optimization on system safety, reliability, and expanded treatment capabilities will also be presented.

[361] ***Final Report of the COSPAR Meeting Series on Knowledge Gaps in Planetary Protection for Crewed Missions to Mars***

J Andy Spry (SETI Institute), Bette Siegel (National Aeronautics and Space Administration), Elaine Seasly (National Aeronautics and Space Administration), J Nick Benardini (National Aeronautics and Space Administration) and Sarah Wallace (National Aeronautics and Space Administration).

*Abstract*

The international scientific community has, through a Committee on Space Research (COSPAR) meeting series, participated in a seven-year review of knowledge gaps in planetary protection for crewed missions to Mars. This meeting series first identified a prioritized list of knowledge gaps that, if addressed, would permit development of an implementable planetary protection policy for the initial crewed Mars mission. Next, a consideration of the available venues (ground, LEO, deep space, planetary surfaces) yielded a roadmap of potential future investigations needed to close the knowledge gaps. Finally, the meeting series evaluated topic-specific measurements that are essential to establishing the figures of merit needed for hardware engineering design requirements. The three main topic threads considered within the meeting series were: microbial and human health monitoring; natural transport of terrestrial biological contamination on Mars, and; technologies and operations for contamination control (of spacecraft systems). Participants at the meeting series included engineers, scientists, managers and various subject matter experts from space agencies, academic and research institutions, commercial companies and other government departments. This paper provides a detailed summary review of the findings of the meeting series, including descriptions of the basis for each of the figures of merit (where they were identified), and considerations of how planetary protection implementation and policy for crewed missions may progress from the current state of the art.

[362] ***Data Collection in Svalbard, Norway to Test the use of Virtual Reality for Lunar and Planetary Surface Exploration***

Cody Paige (Massachusetts Institute of Technology), Don Derek Haddad (Massachusetts Institute of Technology), Ferrous Ward (Massachusetts Institute of Technology), Jessica Todd (Massachusetts Institute of Technology), Gordon R. Osinski (University of Western Ontario), Ariel Ekblaw (Massachusetts Institute of Technology) and Dava Newman (Massachusetts Institute of Technology).

*Abstract*

As part of MIT’s work with the Resource Exploration and Science of our Cosmic Environment (RESOURCE) project with NASA Ames and the Solar System Exploration Research Virtual Institute we are testing both the scientific and operational usefulness of a virtual reality environment for local, small-scale (< 5 m) geological analysis for Lunar and planetary surface exploration missions. Specifically, we are testing a virtual reality (VR) environment developed using a low-cost commercial off-the-shelf combination LiDAR/RGB camera for geological exploration. We incorporate local environmental data such as temperature, luminosity, humidity, and wind. The data was collected in Svalbard, Norway, from three locations near Longyearbyen. The sites were selected based on their distinct geological features including 1) a riverbed in a glacially carved valley (<10 cm-scale features), 2) the base of a recent glacial retreat (last 100 years, 10-50 cm) and 3) a permafrost feature (>1 m). This data is rendered in VR and will be used to assess scientists’ abilities to answer questions about the relevant local geology for differing feature scales (<10 cm, 10-50 cm and >1 m). The VR environment will be compared to a traditional desktop application in 2-dimensions and geological field notes taken on an app developed by the University of Western Ontario for geological field work. Here we discuss the data collection techniques used in Svalbard as well as the lessons learned from this field work. Data processing techniques are presented, as well as the final VR rendering capabilities developed for this work. The low cost of the technologies provides an opportunity to develop immersive environments not only for Lunar and planetary surface exploration, but also for remote or environmentally sensitive locations on Earth where research is lacking and human presence should be minimized.

[365] ***Nuclear Data Needs for GCR Shielding Models***

Lawrence Heilbronn (University of Tennessee).

*Abstract*

Fundamental nuclear data, such as differential and total cross sections, are critical in the development and improvement of calculational tools used to predict the dose and risk from exposure to galactic cosmic rays (GCR). Those tools include complex Monte Carlo transport codes as well as 3-dimensional analytical codes, all of which rely on an accurate description of the nuclear interactions between the incoming GCR ion and the target nuclei it strikes. As shielding thickness increases, calculations indicate that secondary light ions such as protons, deuterons, tritons, 3-He, 4-He and neutrons become the dominant source of the radiation field behind the shielding. When comparing predictions of doses and particle fluences behind thick shielding between several different codes, differences up to 20 percent or more are observed, mostly due to the prediction of secondary light ions from GCR interactions. The range of GCR ion species and energies along with the range of shielding materials presents creates a potentially large set of differential and total reaction cross sections to consider when improving code predictions. The available data base of measured cross sections will be presented, along with recommendations for additional cross section measurements needed to reduce uncertainties and improve the accuracy of radiation transport models used for GCR shielding.

[368] ***Utilizing Gaps and Performance Measures to Inform NASA Environmental Control and Life Support Systems and Crew Health and Performance Technology Decisions***

James Broyan (NASA-HQ), Andrew Abercromby (NASA) and Alexander Burg (Bryce Space and Technology).

*Abstract*

Human spaceflight is a complex endeavor requiring multiple capabilities for transportation, crew health, scientific goals, and safe return to Earth. The difference between spaceflight proven capabilities and those needed for future exploration architectures is defined as a capability gap. Capability gaps are not technology specific. Each capability gap may be closed with a range of technologies that have unique benefits and challenges. Determining what a capability’s relevant and distinguishing key performance parameters (KPPs) are for a mission is critical. Mass, power, and volume are always constrained and defining these in a way normalized by performance is very important. KPP definitions for reliability, dormancy, and integration needs are hard to define but also critical. Outside of technical considerations, the programmatic factors of the estimated time to develop the technology and how the technology validation objectives are matured are strong considerations in which technologies should be pursued and how they should leverage earlier mission elements before the longer duration missions. The Environmental Control and Life Support (ECLSS) and Crew Health and Performance (CHP) capability areas are decomposed to high level gaps. KPPs should be technology agnostic. They can be used to both compare technologies and measure progress of technology development over time. KPPs help define when the gap is closed, and the core mission objectives can be accomplished. Proposed technology improvements to enhance a capability should balance improved KPPs and against investments in other capabilities that are not yet closed. A selection of gaps, KPPs, and validation objectives and their formulation, current state, and how they inform capability roadmap planning are discussed.

[370] ***Two-Phase Thermal Switch for Lunar Lander and Rover Thermal Management***

Nathan Van Velson (Advanced Cooling Technologies, Inc.), Jeffrey Diebold (Advanced Cooling Technologies, Inc.), David-Paul Schulze (Advanced Cooling Technologies, Inc.), Calin Tarau (Advanced Cooling Technologies) and William Anderson (Advanced Cooling Technologies, Inc.).

*Abstract*

The 14-earth day long lunar night poses a significant challenge to the thermal management of future lunar landers and rovers. For these vehicles to operate for long durations on the lunar surface, the on-board electronics must be maintained above their survival temperatures during the lunar night. Thermal switches are among the passive thermal management technologies that may be utilized for helping lunar vehicles survive the lunar night while minimizing the use of electric power for survival heating. Thermal switches are designed to minimize heat transfer in the OFF condition, and to maximize it when in the ON condition. In this work, a passive thermal switch design with high turndown is developed for lunar landers and rovers. This thermal switch design utilizes a sealed flexible bellows containing a two-phase working fluid. The switching mechanism is passively actuated by the temperature of the heat source. At low temperatures, the vapor pressure within the bellows is low, and the bellows is not in contact with the heat sink, restricting heat transfer through the switch. At higher temperatures, the increased vapor pressure causes the bellows to expand and come in contact with the heat sink, allowing more effective heat transfer through the switch. The actuation temperature is determined by the balance of forces on the bellows. A coupled thermal-mechanical model has been developed to illustrate the dynamic performance of the two-phase thermal switch. Several thermal switch prototypes were fabricated and tested for concept demonstration and model validation, and trade studies for enhancing the ON/OFF conductance ratio were performed. Finally, a prototype thermal switch with high ON/OFF ratio was developed and tested for a small lunar rover application.

[371] ***Heat Balance Model to Inform Requirements for Martian Spacesuit Architectures***

Gabriella Schauss (University of Colorado Boulder) and Allison Anderson (University of Colorado Boulder Bioastronautics).

*Abstract*

Limitations of our current spacesuits may pose operational challenges during Martian surface exploration. Alternative pressure systems, such as mechanical counter pressure (MCP), may provide potential advantages to overcome these limitations, but development and demonstrated capability is lacking. Progress has been stalled in the development of novel spacesuit architectures due to a lack of informed design requirements. It has been identified that research in the field of thermoregulation and heat transfer for MCP is a critical stepping stone in the road map to making MCP a feasible technology for spaceflight. Thermal modeling has been an effective method to analyze designs for gas pressures (GP) spacesuits in the past as well as used in other high performance safety industries. Past research has explored alternative heat rejection technologies and material layups for exploration thermal systems, but do to not considering sex, body segmentation, and garment architectures. In addition, some thermal modeling has used software which is not readily accessible. Improving the fidelity of human thermal models allows for rapid development and comparison of thermal requirements across alternatives spacesuits such as MCP. In this research, thermal models are developed to analyze novel spacesuits and evaluate the effects of architecture and thermal properties on local skin temperature of a female simulated astronaut. Models evaluated hot and cold conditions of a Martian day in the summer and winter for the constant metabolic rate of 400 W. This work builds on past research by adding gender and body segmentation, increasing the model fidelity and allowing for both segmented and layered spacesuit architectures evaluation. Future results can be used to inform designs and develop requirements for life support systems that can be tailored to operational tasks, environment, and gender specific considerations to minimize consumables as well as provide a comfortable environment for our future astronauts.

[372] ***BBTherm: A High-Fidelity Analysis Tool for Estimating the In-Vacuum Thermal Conductance Across Ball Bearings***

Christopher Bertagne (The Aerospace Corporation), Christopher Ye (The Aerospace Corporation), Natalie Walsh (The Aerospace Corporation), John McHale (The Aerospace Corporation) and Yoshimi Takeuchi (The Aerospace Corporation).

*Abstract*

In this paper, we present BBTherm, a newly developed high-fidelity thermal analysis tool capable of characterizing the thermal behavior of arbitrary ball bearings operating at low speed and in vacuum. BBTherm includes advanced features such as automatic geometry generation, adaptive mesh refinement, as well as the ability to conduct parametric sensitivity studies to assist with the early phases of component- and system-level design. After describing the overall architecture of the tool, we demonstrate the core capabilities with two example trade studies that investigate the behavior of both unlubricated and lubricated bearings. In both cases, the predictions from BBTherm are then compared with a low-fidelity model from the literature. BBTherm represents a significant improvement over previous analysis capabilities and will be useful to thermal analysts in a variety of bearing-related design and analysis efforts going forward.

[373] ***Evaluation of a New Commercial Catalyst for CO Oxidation for Environmental Control and Life Support Applications***

Sudheera Yaparatne (Department of Civil and Environmental Engineering, University of Maine, Orono, ME 04469), Madison McCarthy (Department of Civil and Environmental Engineering, University of Maine, Orono, ME 04469), Louis Nicoloro (Department of Civil and Environmental Engineering, University of Maine, Orono, ME 04469), Neil Fisher (Department of Civil and Environmental Engineering, University of Maine, Orono, ME 04469), John Graf (Johnson Space Center, Houston, TX, 77058, USA), Lawrence Barrett (Jacobs JETS Contract, Houston, TX, 77058, USA), Oageng George (Jacobs JETS Contract, Houston, TX, 77058, USA) and Onur Apul (Department of Civil and Environmental Engineering, University of Maine, Orono, ME 04469).

*Abstract*

The Contingency Breathing Apparatus (CBA) and Orion Smoke Eater Filter (OSEF) are equipment designed to clean up particulates and harmful gases released during a fire event onboard the Orion Multi-Purpose Crew Vehicle (MPCV). CO oxidation catalyst currently used in CBA and OSEF is developed by TDA research. In this study, a commercially available Au-Titania-based catalyst was evaluated for its CO oxidation ability. The possibilities of using Au-Ti catalyst for CO oxidation and comparison to TDA catalyst are expected in this study. The experimental setup was designed to measure the CO concentration accurately and control the gas flow rates, relative humidity (RH), and temperature at desired levels. The CO oxidation efficiency was measured in a fixed-bed reactor under different gas hourly space velocities (GHSVs), i.e., 1.1×10^4 h^-1 -1.1×10^5 h^-1. The catalyst performance was tested at 0 °C, 12 °C, 22 °C, 25 °C, and 35°C temperatures and 15%, 50%, and 85% RH levels at an initial CO concentration of 1000 ppm. At lower GHSVs (1.1×10^4 h^-1 and 2.7×10^4 h^-1), more than 97% CO removal was achieved at 0 °C near the catalyst. Higher GHSVs (1.1×10^5 h^-1) drastically diminished the CO oxidation percentage to ≈66% due to less contact time of reactants with the catalyst. Increasing temperature near the catalysts demonstrated increased activity of the catalysts, and this change was more apparent at higher flow rates. The reaction kinetics confirmed the Arrhenius relationship with respect to the temperature dependence on reaction rates. At low GHSVs, a significant difference was not shown in the CO removals for different RHs. Higher GHSVs reduced the CO removal percentage from 79.7% to 66.4% when RH was changed from 15% to 85%, respectively. Temperature fluctuation near the catalyst, catalyst poisoning, and catalyst regeneration were also monitored in this study.

[376] ***Spacecraft Carbon Dioxide Deposition Full-Scale System: Design, Analysis, Build and Test***

Pranav Jagtap (NASA Ames Research Center), Grace Belancik (NASA Ames Research Center), Michael Schuh (NASA Ames Research Center), Tiago Costa (NASA), Kelby Gan (NASA Ames Research Center) and Jason Samson (NASA Ames Research Center).

*Abstract*

The Carbon Dioxide Deposition (CDep) system is being developed for long-duration human space exploration toward the Moon, Mars, and beyond. It selectively deposits CO2 onto a cold surface directly from cabin air via phase change temperatures of air constituents. The cold surface is generated using flight-proven and highly reliable Stirling cryocoolers. The system also utilizes air-to-air heat exchangers to minimize its power draw, making it more efficient. The full-scale system is currently under development at NASA Ames Research Center. The system operates cyclically with two circuits that alternate deposition/sublimation processes for continuous CO2 removal. Each circuit consists of a single cooler to precool the air, two heat exchangers to improve the system's efficiency, and three coolers to generate a cold surface where CO2 will be deposited. The cold surface (finhead) was designed and 3D printed to achieve critical characteristics such as a large surface area, low mass, low pressure drop, and ease of manufacturing. System modeling is concurrently being developed in Modelica to predict system performance and optimize the full-scale system's design. This paper will detail the latest design, analysis, build, and planned testing of a full-scale CO2 deposition system ground test unit.

[383] ***Microbial Mayhem: Microbial Growth Potential in CO2 Removal Systems Designed for Long-Duration Spaceflight***

Nico Whitlock (KBR Wyle, NASA Ames Research Center, Moffett Field, CA 94035) and Grace Belancik (NASA Ames Research Center, Moffett Field, CA, 94035).

*Abstract*

Crewed missions that venture into deep space require extremely robust life support systems. Amongst these systems is the CO2 removal system, which helps ensure the recirculation of breathable air to crew. To travel to Mars, a new CO2 removal system is needed. Two candidate systems are in development at the NASA Ames Research Center (ARC): Liquid Amine CO2 Removal (LACR) and CO2 Cold Surface Deposition (CDep). Engineering constraints are important in the design process, but biological problems must also be considered; Microbial growth has been detected on a multitude of surfaces on the International Space Station (ISS) and has been shown to cause problems on several occasions due to biofilm formation inhibiting system performance. Should the new CO2 removal system be susceptible to microbial growth, its performance could be hindered and crew health threatened on future long-duration missions. To investigate this possibility, existing relevant literature was thoroughly reviewed for these two ARC candidate systems. The results show that both systems have components that are potentially susceptable for problematic microbial growth. Therefore, wet lab testing to measure performance degradation was designed using dry and wet biofilm-forming species that have been found on the ISS. Further testing was devised to determine the quantity and species of microbes most likely to enter a CO2 removal system by determining the efficiency of charcoal-HEPA filters that filter incoming air. This work will inform the design and preventative measures that NASA will take to avoid problematic microbial growth in future CO2 removal systems.

[385] ***Baseline Assumptions and Ersatz Waste Streams for Partial Gravity Habitats with Mobile Female and Male Crew***

Dean Muirhead (Barrios Technology), Stacey Marshall (Aerodyne Industries, Jacobs JETS Contract), Leopoldo Romero (Jacobs Technology), Niklas Adam (NASA) and Michael Callahan (NASA).

*Abstract*

Effective and reliable water management and recovery systems will be required to sup-port human missions beyond the low Earth orbit (LEO) of the International Space Station (ISS). Lunar and Mars surface missions will introduce new challenges to managing water and associated waste streams from mobile crew members who will be living in up to six shelters in extreme environmental conditions under a range of gravity conditions. A review of baseline assumptions for the human activities and associated air and water cycles in and between the transit vehicle, orbiting station, lander-ascent vehicle, surface habitat, pressurized rover, and suits is conducted. The paper reviews ersatz formulations and water flow rates for the main liquid water waste streams of urine, humidity condensate, hygiene, and laundry. Emphasis is placed on the metabolic emissions partitioning between the six habitat elements and the lunar exosphere during a design reference mission scenario.

[388] ***Dragonfly: Thermal Control System Design Overview***

Gary Holtzman (The Johns Hopkins University Applied Physics Laboratory LLC), Jane He (The Johns Hopkins University Applied Physics Laboratory LLC), Robert Coker (JHU/APL), Hui Liu (The Johns Hopkins University Applied Physics Laboratory LLC), Dahway Lin (The Johns Hopkins University Applied Physics Laboratory LLC), Bruce Williams (The Johns Hopkins University Applied Physics Laboratory LLC), Elisabeth Abel (JHUAPL) and Carl Ercol (The Johns Hopkins University Applied Physics Laboratory LLC).

*Abstract*

Dragonfly is a NASA New Frontiers mission that will send a rotorcraft lander to Titan, Saturn’s largest moon. Titan has low gravity and a dense atmosphere, making flight an ideal way to traverse its surface. The atmosphere of Titan is mostly nitrogen, like Earth, and the pressure at the surface is similar, about 1.5 times Earth pressure. The lander Thermal Control System (TCS) will use the atmosphere that Titan generously provides to distribute heat from its Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to the lander’s internal components, which are insulated from the extrmemely cold Titan temperature of 94 K. Lander external components will be designed to survive the Titan environment, and preheated as necessary for operation. During cruise to Titan, a pumped fluid loop will maintain spacecraft components, the lander, and its MMRTG within allowable flight temperatures. The performance of the lander TCS as well as all components exposed to the Titan environment will be verified with testing on Earth in a Titan-relevant environment. This paper will provide an overview of the the preliminary thermal design and introduce the topics of the lander thermal system modeling, CFD analysis, testing and validation, and lander component and system environmental testing and verification.

[389] ***Dragonfly: Lander Thermal System Modeling***

Robert Coker (JHU/APL), Gary Holtzman (The Johns Hopkins University Applied Physics Laboratory LLC), Jane He (The Johns Hopkins University Applied Physics Laboratory LLC), Hui Liu (The Johns Hopkins University Applied Physics Laboratory LLC), Dahway Lin (The Johns Hopkins University Applied Physics Laboratory LLC), Bruce Williams (JHU/APL) and Elisabeth Abel (JHUAPL).

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[390] ***Dragonfly: Lander Thermal Testing***

Dahway Lin (The Johns Hopkins University Applied Physics Laboratory LLC), Bruce Williams (JHU/APL), Gary Holtzman (The Johns Hopkins University Applied Physics Laboratory LLC), Jane He (The Johns Hopkins University Applied Physics Laboratory LLC), Robert Coker (JHU/APL), Hui Liu (The Johns Hopkins University Applied Physics Laboratory LLC) and Elisabeth Abel (JHUAPL).

*Abstract*

Dragonfly is a NASA New Frontiers mission that will send a rotorcraft lander to Titan, Saturn’s largest moon. Titan has low gravity and a dense atmosphere, making flight an ideal way to traverse its surface. The atmosphere of Titan is mostly nitrogen, like Earth, and the pressure at the surface is similar, about 1.5 times Earth pressure. The lander Thermal Control System (TCS) will use the atmosphere that Titan generously provides to distribute heat from its Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to the lander’s internal components, which are insulated from the extrmemely cold Titan temperature of 94 K. Lander external components will be designed to survive the Titan environment, and preheated as necessary for operation. This paper will provide an overview of the lander thermal testing and verification plan for the thermal design, and additional component testing, such as for the lander mobility motors and thermal trim device.

[392] ***Dragonfly: Lander Computational Fluid Dynamics (CFD) Thermal Analysis on Titan Surface***

Hui Liu (The Johns Hopkins University Applied Physics Laboratory LLC), Jane He (The Johns Hopkins University Applied Physics Laboratory LLC), Gary Holtzman (The Johns Hopkins University Applied Physics Laboratory LLC), Bruce Williams (JHU/APL), Dahway Lin (The Johns Hopkins University Applied Physics Laboratory LLC), Robert Coker (JHU/APL) and Elisabeth Abel (JHUAPL).

*Abstract*

Dragonfly is a NASA New Frontiers mission that will send a rotorcraft lander to Titan, Saturn’s largest moon to study prebiotic chemistry and habitability. Titan’s low gravity and dense atmosphere will allow Dragonfly to carry its science payload and fly on Titan. The atmosphere of Titan is mostly nitrogen with 1.5 times Earth’s atmospheric pressure, 94 K surface temperature, and 14% of Earth gravity. The convection phenomena on Titan’s surface are complex and different from Earth. This paper will present the CFD validation methodology using test data simulating Titan’s conditions, evaluate the Lander preliminary thermal design using CFD and propose optimization approaches for the Lander detailed thermal design.

[396] ***Implementing a Biorobotic Spacesuit Glove Solution to Optimize Crew Performance for Planetary Surface Operations***

Danielle Carroll (University of Colorado Boulder), Spencer Dansereau (University of Colorado Boulder), Taylor Tvrdy (University of Colorado Boulder), Allison Anderson (University of Colorado Boulder) and Stephen Robinson (University of California Davis).

*Abstract*

Fifty percent of NASA astronauts suffer nail bruising and delamination injuries with prolonged use of the pressurized spacesuit glove, either in simulation at the Neutral Buoyancy Laboratory, or during EVA operations on the International Space Station, and even more crewmembers report significant hand and forearm muscle fatigue as an impediment to extending EVA duration. As we move toward long-duration missions to the moon and Mars with extensive surface exploration components, recurring nail delamination injuries will pose a serious threat to crew health, and premature muscle fatigue will likely continue to curb EVA mission duration and impair crew resource management if left unmitigated.

We addressed current spacesuit glove shortcomings by developing a biorobotic solution, driven by electromechanical actuators and incorporating principles of biomimicry to closely follow the human hand flexor pulley system. Our early work demonstrated the feasibility and utility of a lightweight, 3D-printed fingertip cap and phalangeal frame, along with a force augmentation system that can maintain agility and dexterity while reducing muscle fatigue. We incorporated a soft hand exoskeleton with rigid fingertip caps and flexible silicone phalangeal frames to offload pressure from the fingertips to a location with more redundant blood supply via guided carbon-fiber tendons, while also allowing for augmentation of palmar and phalangeal flexion.

Most recently, we have explored the implementation of electromyographic (EMG) sensors and feedback control systems, borrowing concepts from prosthetic hand devices while preserving the novelty and medically-inspired nature of our design. The next iteration of our design incorporates EMG sensors to unobtrusively trigger the mechanical assist provided by the soft hand exoskeleton. Integration of EMG also offers a mechanism to validate the effectiveness of our technology in mitigating hand fatigue and reducing the risk of musculoskeletal injury and nail delamination, in support of scientific exploration of lunar and Martian surfaces.

[398] ***Design, Modeling, and Initial Characterization of a Subscale Variable Conductance Radiator for CO2 Deposition System in Deep Space Transit***

Alexander Sarvadi (University of North Texas), Huseyin Bostanci (University of North Texas), Cable Kurwitz (Texas A&M University) and Grace Belancik (NASA Ames Research Center).

*Abstract*

Deep space, long-duration human exploration missions require critical technical advancements in areas such as air revitalization, since resupply is not accessible and resources including mass, power, and volume must be minimized for all subsystems. NASA is currently conducting research on a CO2 capture technique that involves using cryogenic coolers to create cold surfaces. By cooling cabin air to extremely low temperatures, CO2 is deposited onto these surfaces. This process is performed in a continuous, cyclic manner to demonstrate concept of operation. However, since the implementation of cryogenic coolers results in high power consumption, alternative methods are needed to achieve energy efficient air revitalization systems. As Mars transit missions provide a capability to view deep space at low temperatures, utilizing radiators for heat rejection is emerging as an opportunity to complement or replace cryogenic coolers for CO2 deposition. This study focuses on the Variable Conductance Radiator (VCR)-based CO2 deposition system that mainly features two internal CO2 capture/recovery panels and one external heat rejection panel (radiator). The closed-loop system circulates a working fluid between two panels: the CO2 capture panel and the heat rejection panel. The CO2 capture panel is maintained at approximately 130K, allowing CO2 from the cabin air to be deposited on it. The heat rejection panel, exposed to the deep space environment at around 4K, dissipates the heat absorbed from the air stream. The two internal panels operate alternately; while one panel involves circulating working fluid to maintain a cold surface for CO2 deposition, the other one involves stagnant, non-condensable gas and is heated for CO2 sublimation. A subscale, VCR-based CO2 deposition system is investigated to demonstrate its feasibility for deep space applications. Initial efforts include developing the design geometry and performing analytical and numerical analysis to evaluate various design parameters for the external heat rejection panel (radiator).

[399] ***Design and Performance Maturation of Regenerable Trace Contaminant Control for Removal of Ammonia and Other Trace Constituents***

Christian Junaedi (Precision Combustion, Inc.), Kyle Hawley (Precision Combustion, Inc.), Codruta Loebick (Precision Combustion, Inc.) and Sinead Flanagan (Precision Combustion, Inc.).

*Abstract*

The Trace Contaminant Control System (TCC) is a component in the ventilation loop of the Portable Life Support System (PLSS) which removes contaminates present in the ventilation system. These trace contaminants, introduced into the ventilation loop via crew metabolic processes, off-gassing of spacesuit materials, and by-products of the processes contained within the suit, such as by the CO2/H2O removal system (e.g., Rapid Cycle Amine beds), would accumulate without the TCC and pose a threat to the crewmember. They are traditionally removed using non-regenerable activated carbon. Although effective, the downside of using the current state-of-the-art is a bulky system with low regeneration capability, a reliance on consumables, significant power consumption, and consequently high associated life cycle operating cost. This provides a logistics impact to future missions.

Precision Combustion, Inc. (PCI) has been designing and evaluating a compact, vacuum-regenerable sorbent bed for effectively removing a broad range of trace contaminants, meeting NASA’s target performance requirements, which can be integrated with the Exploration PLSS CO2/H2O removal system. Both the primary trace contaminants as well as other species that threaten to exceed the 7-day Spacecraft Maximum Allowable Concentration (SMAC) levels were addressed. These sorbents with different properties were combined in the modular Trace Contaminant Control (TCC) bed, tailored to the requirements and in suitable proportion. Our approach is based on PCI’s proven sorbent nanomaterials that have high surface area on a structured support, enabling a compact, modular, and vacuum-regenerable TCC device. TCC hardware prototypes were designed, and their performance was evaluated after integration with a CO2/H2O removal system in a closed-loop ventilation test rig. In this paper, we plan to highlight the TCC bed engineering and the resulting specifications, including life cycle and environmental testing at the anticipated operational conditions. Future optimization based on the test data and sorbent performance will also be summarized.

[400] ***Preliminary Investigation of Vortex Phase Separator-Based Spacecraft Cabin Air Dehumidification Subsystem for CO2 Removal***

Chirag Byanjankar (University of North Texas), Alexander Sarvadi (University of North Texas), Huseyin Bostanci (University of North Texas), Cable Kurwitz (Texas A&M University) and Grace Belancik (NASA Ames Research Center).

*Abstract*

Cabin atmosphere revitalization, more specifically CO2 removal, is a key technology to pursue long-duration, crewed space missions. The ISS currently uses the Carbon Dioxide Removal Assembly (CDRA) that employs desiccant (silica gel) and solid sorbent (zeolite) to remove humidity and CO2 from cabin air, respectively. However, CDRA has challenges with high reliability and low maintenance requirements. Air dehumidification is an important process for state-of-the-art and emerging technologies since it helps provide higher CO2 removal efficiency and purer CO2 downstream product. The desiccant in CDRA degrades over time, causes substantial reduction in water removal capacity, and would require an additional energy cost for regeneration. A promising technology to perform successful dehumidification in support of new CO2 removal systems is the Vortex Phase Separator (VPS). The VPS operation in microgravity relies on creating and maintaining a liquid vortex, which offers centrifugal acceleration in replacement of gravitational acceleration, within a right circular cylinder. Warm and humid air enters the VPS, breaks into very small bubbles, and passes through cold liquid desiccant. Rapid, direct heat and mass exchange between the liquid and gas phases facilitates high water absorption and/or condensation capability, and allows for high throughput per unit energy consumed. This preliminary study investigates the VPS for cabin air dehumidification as part of NASA’s spacecraft CO2 removal systems under consideration. A prototype microgravity VPS system was designed, built, and tested to separate water vapor from a warm, humid air stream to characterize its performance using water and ionic liquid (IL) in the separator. Experiments with 77 SCFH airflow rate and 200 ml IL charge demonstrated the VPS capability to reduce up to 45% of water content in a humid air stream.

[402] ***Excess Water in Astronaut Helmet During EVA on ISS: Mitigations with Flight Demonstrations***

Mark Weislogel (IRPI LLC), John Graf (NASA), Logan Torres (IRPI LLC), Oleg Krishcko (IRPI LLC), Paul Dum (NASA), Colin Campbell (NASA) and Tessa Rundle (NASA).

*Abstract*

Following a second crew report of excess water inexplicably accumulating in the helmet during EVA-80 on March 23, 2022, NASA initiated an aggressive effort to identify, mitigate, and/or eliminate all sources of the potentially life-threatening water. Our narration highlights demonstrations of microgravity flow expectations using terrestrial scale models, mitigations to dangerous water migration within the helmet, low-g two-phase flow separations for the flow entering the helmet, and an investigation of the nature of liquid carry-over from the EMU condensing heat exchanger source. Fast-to-flight demonstrations of each aspect of the work are carried out during hands-on crew interaction with flight scale hardware on ISS during the 2022-2023 timeframe. The results of the tests are described with a focus on the rarely observed, and thus rarely studied, large length scale air-driven wall-bound droplet and rivulet two-phase flows in microgravity. The success of the mitigations and directions for continued work is discussed in summary.

[403] ***Ionic Liquids for a Regenerable Carbon Formation Reactor: Reactor Design Study and Ionic Liquid Parameterization***

Kaitlin Oliver-Butler (NASA Marshall Space Flight Center) and Mitchell Woolever (University of Colorado, Boulder).

*Abstract*

For oxygen recovery, the Bosch process holds the promise of theoretical complete oxygen and process hydrogen recovery, and it is a subject of interest for air revitalization systems for travel beyond low-earth orbit. However, the Bosch process generates a solid carbon product that causes issues with pressure and interferes with the catalyst; dealing with the carbon and renewing the catalyst poses high up-mass or resupply needs for any Bosch reactor, making it unfeasible at its current state of development. Marshall Space Flight Center (MSFC) has studied the use of ionic liquids (IL) to renew the catalyst required by the reactor to address the issue of high resupply need. An ionic liquid can be used to digest catalyst material out of the carbon fouling and then electroplate it onto a substrate, which would then be ready for use in another carbon formation reaction. This cycle can then be repeated as necessary, ideally within a single reactor. Towards this end, this conference paper reviews prior proof-of-concept work completed by MSFC, and then it defines the reactor design problem for a single reactor that can be used for both carbon formation reactions and ionic liquid-based catalyst renewal. IL selection considerations are detailed. Empirical parameterization studies on the selected IL are presented with discussion on how it informs design choices and creates tradeoffs. This paper concludes with a discussion on challenges in reactor design and an outline of future work.

[408] ***Ceramic Oxygen Generator: A Method for Extracting High Pressure, High Purity Oxygen from Spacecraft Cabin Air.***

John Graf (NASA Johnson Space Center), Dale Taylor (American Oxygen), Jon Tylka (NASA White Sands Test Facility) and Jeff Sweterlitsch (NASA).

*Abstract*

Ion Transport Membranes (ITMs) are ceramic membranes permeable to oxygen and only oxygen. They are capable of extracting pure oxygen from air, or other gaseous process streams that contain oxygen. For several decades, ITMs have been the subject of research: particularly for the supply of ultra-high purity oxygen and as a method for providing oxygen to zero emission power plants. ITMs have not been put into widespread practice. ITM devices have not been qualified for human spaceflight, and they have not been used to supply medical oxygen to hospitals. ITM oxygen generators have not seen widespread use because previous ITM systems suffered low production rates and high energy consumption. NASA, in partnership with American Oxygen, has developed a ceramic oxygen generator (COG) with substantially higher oxygen production rates, and substantially lower energy consumption than earlier systems. Three key elements are essential to increased production and improved energy efficiency: the cell stack, the thermal management system, and the oxygen delivery system. This paper describes recent improvements in these three elements, along with results of testing that demonstrates unprecedented system level performance. Two forms of this technology are in development: one form produces oxygen at pressures up to 1 MPa, another version produces oxygen at pressures as high as 20 MPa. The prototype described in this paper is designed for 1 MPa operations, but advances in cell stack manufacture, thermal management, and oxygen delivery apply to high pressure applications.

[414] ***Test and Evaluation of the Next Generation Blower for FBCO2 Scrubber***

Kaitlin Oliver Butler (NASA Marshall Space Flight Center), Jim Knox (Jacobs Technology, Inc.), Rasish Khatri (Calnetix Technologies), Octavio Solis (Calnetix Technologies) and John Garr (Johnson Space Center).

*Abstract*

The four-bed carbon dioxide (FBCO2) scrubber was deployed on the ISS in late 2021 as a technology demonstration. The system was launched with a Honeywell blower that, while performing well, is no longer supported by the manufacturer with no available spares. Thus, NASA contracted with Calnetix Technologies to develop a next-generation, magnetic-bearing blower to meet FBCO2 demands and deliver the flowrates required for effective CO2 scrubbing. The first flight blower assembly was tested by Marshall Space Flight Center (MSFC) in the summer of 2022 and installed in FBCO2 in February 2023. This paper presents the blower performance ground testing results, with details on the test plan and test setup provided. The performance data is used not only to qualify the blower for use in FBCO2, but also to create a model for use in predictions of on-orbit performance based on available telemetry data. The paper concludes with discussions on test limitations and early FBCO2 performance data with the new blower installed.

[417] ***Carbon Dioxide Adsorption Process of 3D Zeolite-13X Structures: A Numerical Study***

Noah Agata (North Carolina State University), Priom Agrawal (North Carolina State University), Joseph Cesarano (Robocasting Enterprises), Michael Niehaus (Robocasting Enterprises LLC), Tra-My Justine Richardson (Ames Research Center) and Sajjad Bigham (North Carolina State University).

*Abstract*

Existing carbon dioxide removal systems for life support in space environments rely on sorption beds packed with desiccant beads. Their performance and efficiency are limited by high pressure drop penalties, mal-distribution of the air within the packed bed, and poor thermal conduction during the adsorption and regeneration processes. Additively manufactured 3D zeolite-13X structures could potentially optimize flow paths and thermal characteristics, thereby improving adsorption and regeneration rates. However, there is limited information available in the open literature about the adsorption characteristics of 3D zeolite-13X structures. Here, detailed rod-level 3D numerical simulations are conducted on 3D-printed zeolite-13X lattice structures to reveal the underlying adsorption physics. Particularly, the present study focuses on the interconnected effects of inlet air velocity, adsorption rate, and the utilization ratio of a zeolite lattice structure at the breakthrough time. The results suggest that the inlet air velocity needs to be carefully designed for a given 3D-printed zeolite lattice structure to simultaneously optimize the sorption rate for a rapid adsorption process and breakthrough time for maximum utilization of the zeolite media. The above understanding is important to design advanced 3D-printed zeolite structures for future carbon dioxide removal systems.

[418] ***Ejectors as a Contingency for Waste and Odor Collection in Microgravity***

Cory Kaufman (Collins Aerospace), Matthew Pearson (Raytheon Technologies Research Center) and Yasmin Khakpour (Raytheon Technologies Research Center).

*Abstract*

Waste collection in microgravity has been extensively studied for over 50 years culminating in the design and implementation of the latest technology called the Universal Waste Management System (UWMS). However, toilets are generally zero fault tolerant to function. This means a small space vehicle with only one toilet would be left without waste collection assistance in the event of a system or component failure. Collins Aerospace has demonstrated a small and effective method for assisting in waste collection for contingency scenarios. The design is compact, lightweight, and can be utilized by either male or female crew members to collect urine and possibly manage odor during defecation. The preliminary performance testing of this technology in a 1g environment will be discussed in this paper as well as any modifications necessary for use in a microgravity environment.

[420] ***Feasibility of an Optical Sensor to Monitor Toilet Pretreat Quality***

Cory Kaufman (Collins Aerospace), Robert Youngquist (QPhysics Inc), Tracy Gibson (NASA), Mark Nurge (NASA) and Upendra Singh (NASA).

*Abstract*

Processing urine is a critical function on the International Space Station (ISS). It provides a sizeable portion of the water used on ISS stored in the Potable Water Bus (PWB). Yet processing of urine is a sensitive undertaking. The urine must be collected, stabilized, and stored to inhibit molecular breakdown, organic growth, or solid precipitation. The stabilization process mixes a strong acid with the urine which must be carefully balanced to achieve the desired urine stabilization, but also to minimize the corrosive properties of the mixture at higher acid concentrations. A precise method for mixing and monitoring the urine pretreat acid in real time is vital to protecting waste processing hardware and maintaining water recollection capabilities on ISS. This paper discusses the data, testing, and analysis around using an optical sensor for measuring fluid transmittivity in order monitor the pretreat quality being mixed with crew urine.

[421] ***1st International Space Ecology Workshop - Research Needs & Roadmap to the Future***

Christine Escobar (Space Lab Technologies), Patrick Grubbs (Spring Institute for Forests on the Moon), Frieda Taub (University of Washington), Jane Shevtsov (Propagule Space Ecology Institute), Sherri Damlo (University of Florida) and Stephen Lantin (University of Florida).

*Abstract*

Self-sufficient life support systems will be crucial for meeting the physical and mental health needs of crew during long-term, deep space exploration missions and for maintaining a permanent human presence in space. Closing the material loop with food production and waste recycling is necessary to reduce reliance on Earth resupply. Closed ecological systems (CES) can utilize a combination of biological, ecological, and physicochemical processes to support human life. A space habitat can be considered an artificial ecosystem in which human beings exchange energy and material with other system components and their extraterrestrial environment. The inaugural International Space Ecology Workshop was held on October 22, 2022, to promote and organize CES research internationally and to reignite interest in the ecological systems approach to space life support. This workshop brought together engineers, space biologists, and ecologists to discuss the past, present, and future of CES that could enable indefinite, sustainable human exploration of space, as well as sustainable living on Earth. Specific workshop goals were to review research needs and knowledge gained to date, connect active professionals in the field, and plan next steps for closing knowledge and technology gaps. This paper summarizes the proceedings and a Space Ecology Roadmap for prioritizing and guiding future action.

[423] ***The FY2022 Development Status of CO2 Removal System for ISS Demonstration***

Chiaki Yamazaki (Japan Aerospace Exploration Agency), Kentaro Hirai (Japan Aerospace Exploration Agency), Shotaro Futamura (Japan Aerospace Exploration Agency), Satoshi Matsumoto (Japan Aerospace Exploration Agency), Hideki Saruwatari (Japan Aerospace Exploration Agency), Ayako Yamamoto (Chiyoda Corporation), Hidetoshi Nakagami (Chiyoda Corporation), Mutsumu Nagase (Chiyoda Corporation), Tomohiro Kinoshita (Research Institute of Innovative Technology for the Earth), Naomi Yoshino (Research Institute of Innovative Technology for the Earth) and Katsunori Yogo (Research Institute of Innovative Technology for the Earth).

*Abstract*

The Japan Aerospace Exploration Agency (JAXA) is developing a CO2 removal system to strengthen core life-support technologies for future crewed space missions. The ISS demonstrator of the CO2 removal system (DRCS) is being developed as one of the activities demonstrating Gateway’s CO2 removal system (CDRS) and is scheduled to be launched in FY2023. This paper reports the results of the DRCS Bread Board Model test and the Proto Flight Model's development status.

[426] ***A Localized Compute Platform to Support EVA Software Applications***

Michael Vandi (Celestial Systems), Larysa Paliashchuk (Celestial Systems) and Ashish Upadhyay (Celestial Systems).

*Abstract*

The increasing demands and complexity of EVAs require a total reexamination of existing technologies. Astronauts on spacewalks are not equipped with appropriate technologies compatible with human anatomy interaction. With the advent of NASA’s Artemis missions, we have an ideal opportunity to innovate existing EVA technology and equip astronauts for a new era of permanent space exploration. Our paper introduces CelestialOS, a heads-up display interface that can be retrofitted with a spacesuit helmet bubble to help astronauts communicate better, monitor crewmembers’ biometric data with safety alerts, and access mission instructions collaboratively. The main infrastructure consists of a micro-projected display, a wireless compute unit that performs computationally intensive tasks, and a voice-operated exchange interface to control the compute unit and display. Multiple compute units can be configured to interact with each other and construct a localized compute network. We utilize Liquid Crystal on Silicon (LCoS) micro displays for reflective multimedia projection on the spacesuit helmet bubble. This infrastructure can be used as a platform to develop and deploy software solutions to help astronauts during EVAs. Ultimately, CelestialOS provides an execution environment like an operating system that allows space agencies and enterprises to build different EVA software applications for astronauts in space.

[429] ***Embedded Pulsating Heat Pipe for Improved Heat Spreading in CFRP Equipment Panels for Satellites***

Johannes van Es (Royal Netherlands Aerospace Centre NLR), Edwin Bloem (Royal Netherlands Aerospace Centre NLR), Roel Benthem (Royal Netherlands Aerospace Centre NLR), Adry Van Vliet (Royal Netherlands Aerospace Centre NLR), Ronald Klomp (Royal Netherlands Aerospace Centre NLR) and Gunnar Sieber (European Space Agency (ESA)).

*Abstract*

To avoid hot spots on satellites for equipment mounted on Carbon Fibre Reinforced Polymer (CFRP) panels, there is an increasing demand for improved heat spreading. A technology investigated in this paper is embedding a Pulsating Heat Pipe inside a CFRP sandwich panel. A PHP is a meandering tube partly filled with Ammonia effectively achieving an enhanced conductive value above 10,000 W/m/K along the length of the tubing. Although the physics behind the operation of a PHP is not yet fully understood, it can be constructed based on experimental experience available at the Netherlands Aerospace Centre.

The paper describes the design, performance analysis, and manufacturing process of an Engineering Model (EM) of a 0.8 m2 PHP panel. It concludes with performance tests done in a representative environment, achieving TRL 4 to 5. The EM panel has PAN based HT carbon fibre composite face sheets, a carbon foam layer with an embedded pulsating heat pipe tube supported by an aluminium honeycomb. The test programme included leak testing, proof pressure testing, pressure cycle testing, burn-in testing, performance testing in various orientations, and thermal tests in vacuum.

In ambient conditions the PHP performed according to expectations with a heat spreading capability > 300 W/m2. However in vacuum the PHP did not operate at all. This unexpected failure is presented including the root cause investigation. The paper ends with an outlook on further research and potential applications.

Proposed paper sections: 1. Background info on PHP panel 2. Panel design process 3. Panel manufacturing process description 4. PHP EM panel and test set-up 5. Test results summary 6. TV test anomaly and root cause investigation 7. Summary & recommendations

[430] ***Ammonia Loop Heat Pipe with Thin Evaporator Fabricated by Additive Manufacturing***

Hosei Nagano (Nagoya Univ), Satoshi Kajiyama (Nagoya Univ), Kazuhiro Nakazawa (Nagoya Univ), Takeshi Tsuru (Kyoto Unibv) and Yuki Akizuki (Japan Aerospace Exploration Agency).

*Abstract*

The next-generation X-ray observation satellite "FORCE" is being developed for launch in the early 2030s. To achieve low-noise and high-sensitivity X-ray observations with the CMOS detector on this satellite, the operating temperature must be kept low. FOr the thermal design, following conditions are required: (1) a heat source temperature is -25°C or lower, (2) a maximum heat transport capability is 10 W, (3) a temperature difference between the heat source to the heat sink is 5°C or lower, and (4) the thickness of the LHP is 3mm or less. In this study, we proposed an ammonia loop heat pipe with flat evaporator that can operate in low-temperature environments which is fabricated in 3D printer. In the full paper, design, fabrication, and test results at room temperature and low temperature will be presented.

[431] ***Assessment of HAB Particulate Tracing in EMU Helmet in Support of EVA 80***

Abigail Baukus (NASA) and Colin Campbell (NASA).

*Abstract*

After water was reported in the Extravehicular Mobility Unit (EMU) helmet during International Space Station US Extravehicular Activity 80 (ISS US EVA-80), mitigation strategies were created to attempt to arrest the motion of any droplets that enter the helmet for future EVAs. This included adding absorbent materials into the interior of the helmet. Before a mitigation strategy can be implemented, however, it must first be proven to be safe. Towards this aim, a computational fluid dynamics (CFD) analysis was done tracing the paths of particulates potentially generated by the absorbent material. The objective was to characterize the risk these particulates pose for inspiration and eye irritation by tracking what percentage of particulates contact the suit-wearer’s face, eyes, or mouth. The model consisted of a human mannikin head and torso inside the EMU suit and helmet. The software used was ANSYS Fluent, with discrete phase modeling enabled to generate and track the particulates within the ventilation flow of the helmet.

[432] ***EMU Helmet Free Water Transport Assessment for the HAB in Support of EVA 80***

Abigail Baukus (NASA) and Colin Campbell (NASA).

*Abstract*

After water was reported in the Extravehicular Mobility Unit (EMU) helmet during International Space Station US Extravehicular Activity 80 (ISS US EVA-80), mitigation strategies were created to attempt to arrest the motion of any droplets that enter the helmet for future EVAs. This included adding absorbent materials into the interior of the helmet. To assess the effectiveness of this strategy, a computational fluid dynamics (CFD) model of a human mannikin head in the EMU helmet was used to track water droplets and quantify how much water is likely to be caught by the absorbent material. A combination of engineering judgment, tests, and CFD results were used to develop the expected path of droplets in the helmet, to account for the simplifications necessary in modeling two-phase flow.

[433] ***Design and Optimization of a Test Setup for Low Thermal Conductance Measurements***

Natalie Walsh (The Aerospace Corporation), Christopher Ye (The Aerospace Corporation), Christopher Bertagne (The Aerospace Corporation), Yoshimi Takeuchi (The Aerospace Corporation) and John McHale (The Aerospace Corporation).

*Abstract*

Bearings are essential to rotational spacecraft components so a proper understanding of bearing behavior is necessary for reliable spacecraft operation. Characterization of bearing thermal conductance provides accurate temperature predictions, which are important to a successful design so that critical mechanical fit is maintained, and lubricant degradation and migration is avoided. The Aerospace Corporation’s Bearing Thermal Test facility has provided valuable bearing conductance data, but its test method has proven to be complex and takes multiple months to complete. A static “Ball-on-Flat” test is being developed to simplify bearing conductance testing, specifically for low-speed bearings where dynamic effects are not considered. This test consists of a single, lubricated ball between two “flats.” Two heat flux meters with embedded thermocouples capture the thermal gradient across the experiment, which is used to calculate the conductance across the ball and two flats. These test results are used to characterize the conductance of a complete bearing with a correlation factor determined by Aerospace’s BBTherm tool. Initial path finding tests showed that the measurements have high uncertainty because the low thermal conductance of the ball causes the setup to be insulative, with very little temperature differences between thermocouple readings. This paper describes the use of regression analysis and Kuhn-Tucker necessary conditions to optimize the heat flux meter dimensions and thermocouple spacing to reduce the measured conductance uncertainty. The use of uncertainty analysis in the experimental design will allow the test to provide agile and accurate thermal characterization of various ball and lubricant combinations.

[434] ***Trade Study Considerations for Fire Detection, Suppression and Remediation Systems for Commercial Space Missions***

Marit Meyer (Northrop Grumman) and Bettylynn Ulrich (Northrop Grumman).

*Abstract*

With the upcoming retirement of the International Space Station (ISS) and NASA’s Moon to Mars campaign, NASA is actively building the United States space economy by engaging private industry in the design of vehicles and missions for human space flight. The future successes of commercial space endeavors rely on the ability to procure proven and effective life support equipment in the marketplace. Budgets and schedules for typical missions do not allow for individual companies to design and build flight hardware for all required systems in-house. They must rely either on re-creating NASA heritage designs (assuming that the design calculations, drawings, reports, and analyses are available through official resource requests) or purchasing commercially available systems that have been demonstrated on the International Space Station. The latter would be considered at Technology Readiness Level (TRL) 9 as they have been proven successful in an operational mission environment. The available alternatives can be expanded by procuring lower TRL systems (potentially as low as TRL 5), which require longer lead times and carry additional risks that may be reduced by extensive testing. This paper outlines a trade study methodology to identify and rank available hardware options for commercial space entities, in this case, for fire detection, suppression and remediation. This is a subset of the comprehensive Environmental Control and Life Support Systems (ECLSS) trade studies that have been done by Northrop Grumman. While this approach creates a suite of optimized hardware alternatives, the final choices for a given program will depend on the use case, priority, and budget of each individual mission or program.

[435] ***Recent Major Constituent Analyzer Performance on the International Space Station***

Ben Gardner (Collins Aerospace), Stephen Denson (Collins Aerospace), Mark Huffman (Collins Aerospace) and Tyler Zimmerman (Collins Aerospace).

*Abstract*

This is the latest installment in our series of presentations describing the performance of the Major Constituent Analyzer (MCA) onboard the International Space Station (ISS). The MCA is a mass spectrometer-based system for monitoring six major atmospheric constituents and is an integral part of the Environmental Control and Life Support System (ECLSS). The MCA has accumulated an extensive history of performance data that can be used to drive improved design and performance requirements for both the MCA proper and for future atmosphere monitoring systems.

This paper discusses the latest performance of the MCA on orbit during 2018 through 2022 years, with particular attention to ion source filament current and lifetime, response drift, and sensitivity drift. Expected component lifetimes, impact to logistics and ISS support, and implications for future missions going forward will be discussed.

[437] ***International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events 2022***

Steven Balistreri (The Boeing Company) and John Cover (NASA).

*Abstract*

Nov 20th, 2022 marks the 24th anniversary of the beginning of construction of the International Space Station (ISS). The ECLS system is constantly changing to meet the needs of current missions and future exploration. The ISS has become the laboratory that was always envisioned, allowing for an ever-growing class of exploration level technologies that will propel the stage forward as humanity advances beyond Low Earth Orbit (LEO). This paper will review the past year, and look towards the future for each U.S. ECLS subsystem. The impacts, challenges, and successes related to the intermingling of incumbent and cutting edge technologies are summarily discussed in this paper.

[440] ***Multi-criteria Optimization of Two-phase Thermal Control System of Space Vehicle***

Gennadiy Gorbenko (Center of Technical Physics LLC), Rustem Turna (Center of Technical Physics LLC) and Artem Hodunov (National Aerospace University«Kharkov Aviation Institute»).

*Abstract*

This paper presents an algorithm for optimizing the heat rejection system of a satellite two-phase thermal control system, with a focus on designing condensers and the thermal-hydraulic network. The heat rejection system is based on a radiation panel with heat pipes, and various performance indicators are used for optimization. Optimization is recommended at different levels of the hierarchy, including at the level of elements and systems, as well as the entire thermal management system. Through computational and theoretical research, a heat rejection system concept is proposed that utilizes traditional elements for loops with a single-phase liquid coolant. This system can be fully tested on the ground without a mandatory flight experiment and is operable at high saturation pressures and temperatures (up to 85°C on ammonia). The proposed system shows promise for improving the efficiency and reliability of satellite thermal management systems.

[442] ***iSTEM to Know NASA Outreach Program at Purdue University Fort Wayne***

Dawn Whitaker (Purdue University) and Marteze Hammonds (Purdue University Fort Wayne).

*Abstract*

Purdue Fort Wayne (PFW), a campus of Purdue University in Fort Wayne, Indiana, is a public university with an approximate enrollment of 5,600 undergraduate and 700 graduate students of which approximately 400 are underrepresented minority students (URM) in STEM majors. Over the past decade the fall-to-fall retention rate of URM students has declined. These students are often first generation college students and typically have a lower GPA than non-URM students. With collaboration and funding from the Indiana Space Grant Consortium, the PFW Office of Diversity, Equity, and Inclusion initiated a project to introduce NASA and aerospace-related STEM content to 40 undergraduate students from underrepresented populations within a program year. The Indiana Space Grant Consortium (INSGC) is part of the National Space Grant College and Fellowship Project, a NASA Office of STEM Engagement program primarily focused on science and engineering education, research and public outreach efforts. The goals of the iSTEM project were to leverage interest in aerospace and space habitats to increase retention, support college STEM majors to consider entering the STEM workforce and/or a career with NASA, and enhance the presentation skills and professional development of students through presentation and communication workshops. A curriculum was developed by the project staff/faculty utilizing NASA STEM Education content and centered around aerospace careers/education including a robust overview of NASA missions and research. Through the use of guest speakers including life support system researchers and Indiana aerospace industry representatives and by virtual/in-person visits to NASA-related facilities, the students gained first-hand knowledge of the scope of NASA’s work.

[445] ***First Principles Modeling of the Thermal Amine Scrubber Flight Experiment’s Chemical Performance***

Lawrence Barrett (Jacobs Engineering).

*Abstract*

The removal of atmospheric CO2 from a spacecraft is of particular importance to NASA’s mission, and is an area of continual study and technological advancement. One of the more recent advancements has been with reusable sorbents being regenerated with a combination of heat and vacuum. One such technology is the Thermal Amine Scrubber (TAS) flight experiment currently on board the ISS, though several are currently flying or preparing to fly. A model was created of the TAS to predict chemical performance, using fundamental chemistry and physics based principles rather than empirical relations. Since physical laws are true across all conditions, such a model enables greater model accuracy outside the bounds of test data, and allows for virtual testing of the hardware at conditions that are prohibitively difficult or expensive to actually test. This paper details the model’s development, operation, and correlation to data from the flight unit. The model is then compared to a data set taken from the flight unit under different flow, CO2 partial pressure, and bed configuration conditions, resulting in only a 2% error. The equations and principles laid forth in this paper are applicable to a wide range of thermally regenerated sorbents, and additional models of a similar nature would allow for potentially the most straightforward and direct method of comparison of technologies available to date.

[447] ***Design of Working Fluid Venting System for Mechanical Pumped Fluid Loop Heat Rejection System for Mars Missions***

Pradeep Bhandari (Jet Propulsion Laboratory).

*Abstract*

In several Mars missions flown by JPL, a mechanically pumped loop utilizing Freon-11 as the working fluid is utilized for thermal control of the spacecraft components during cruise. The fluid loop controls temperatures of components within the cruise stage as well the entry vehicle’s lander or rover. During entry into the Mars atmosphere, the cruise stage needs to be separated from the entry vehicle, which requires the tubing connecting the two stages to be severed. Just cutting the tubing, without venting the freon in a controlled manner, would lead to a random direction and speed of the effluent fluid. The impulse from this would create a significant and non-deterministic nutation of the entry vehicle, which could jeopardize its entry. To avoid that impact, the Freon is vented in a very carefully controlled direction and speed to ensure that the direction of the vent vector passes along the center of gravity of the entry vehicle or is canceled by opposing nozzles. An innovative scheme of using the pressurized gas to “piston out” the Freon was designed and implemented in these missions. Additional concerns with the vent nozzle not freezing up due to the sublimation of the liquid Freon while escaping into the vacuum of space were investigated and mitigated in this design. A detailed fluid-thermal-impulse model was created to predict the resultant thrust profile and total impulse imparted on the spacecraft. This paper will describe the basic design, the corresponding design & analysis to assess and predict its performance, the trade -off of design concepts, and its implementation for flight usage.

[448] ***Design of an Actively Shuttered Dust-Resilient Radiator for Lunar Applications***

Andrew S. Gibson (ESR Technology), Angel Iglesias (Almatech SA), Dominic Bailes-Brown (ESR Technology Limited), Martin Humphries (Spacemech Limited), Simeon Barber (Space Science Solutions Limited) and Philipp Hager (European Space Agency).

*Abstract*

The design of radiators for the lunar surface must consider detrimental effects of lunar dust in terms of thermal performance, as well to the reliability of the mechanism. Radiator function is influenced by extreme temperature variations, where thermal cases must consider IR heating from the surface during the Lunar day as well as heat losses during the Lunar night. The overall challenge for the development was to maximize the range of functionality across a wide variety of lunar locations, while focusing on polar scenarios.

In early stages, a thermal analytical model was developed in Python to study thermal shutter performance of 2 variants according to lunar latitude and orientation of the radiator, as it was required to maximize the shutters’ usefulness. The trade-off resulted in the selection of the thermal shutter approach versus a louvered radiator concept, with the shutter favoured for lower mass and higher field of view and reliability.

The actively shuttered design enables closure of the radiator to minimize heat losses at night and is also intended to protect from contamination during radiator during events and phases of the day with high expected dust deposition, such as the passing of the day/night terminator, landing, or activities of astronauts, rovers or robotic equipment.

The paper describes progress made following one year of development, focusing on status. Results of component level breadboarding and an overview of the design of an Engineering Model unit will be covered, highlighting thermal design choices, risk mitigation activities and thermal capabilities predicted for this device as well as the mounting approach. The mechanism design will be described demonstrating the dust-resilient approach, suitable for lunar landers (EL3), rovers and other longer duration lunar surface applications.

[449] ***Simulation-Based Assessment of Hazardous States in a Deep Space Habitat***

Luca Vaccino (Purdue University), Kenneth Pritchard (Purdue University), Mohsen Azimi (Purdue University), Shirley Dyke (Purdue University) and Alana Lund (University of Waterloo).

*Abstract*

The progression of the Artemis missions is bringing us nearer to extraterrestrial surface habitation and the realization of a sustainable living environment in deep space. This requires that we improve our capability in the design and evaluation of a variety of protocols to mitigate and manage a variety of hazards. Given the near impossibility of in situ testing, computer simulation is a suitable tool for this task. The Resilient Extra-Terrestrial Habitats institute (RETHi) has developed a Modular Coupled Virtual Testbed (MCVT) to simulate measures to enhance resilience in an extraterrestrial smart habitat (SmartHab). MCVT is composed of several subsystems with damageable/repairable components, and is capable of modeling different disruption scenarios. Micrometeorite impact, fire, moonquakes, and nuclear leakage are included along with typical environmental disturbances such as dust accumulation and solar flux. For each of these disruption scenarios, the location, onset time, and intensity can be specified by the user. The order and the rate of the repair are also user-defined. Consequently, the effect of the damage propagates through different components and subsystems, potentially rendering the habitat unlivable. The goal of this paper is to investigate the use of the MCVT for studying a resilient SmartHab. By altering the initial conditions, certain input parameters, and repair prioritizations across several simulations for different disruption scenarios we demonstrate some scenarios in which simulation is an effective tool to support design. In the end, the lessons learned and the conditions that contribute to placing the SmartHab in an unsafe or unrecoverable state are identified, alongside with the best-practice emergency responses. These results form a framework for future studies into resilient SmartHab design via similar methods.

[450] ***Ionic Liquid-based CO2 Control of Plant Growth Chamber Atmospheres***

Felix Nitschke (Technical University of Munich) and James Nabity (University of Colorado Boulder).

*Abstract*

Control of carbon dioxide (CO2) remains important for human spaceflight. Long-term continuous exposure to elevated CO2 concentrations (> 2,000 ppm (0.2 kPa)) has been hypothesized to adversely affect crew performance and contribute to crew physiological issues (headaches, vision impairment, and intracranial pressure). Open plant chambers such as the Russian Lada and NASA’s Veggie unit have utilized the cabin CO2 to sustain photosynthesis, however dynamic changes in CO2 levels can adversely affect gas exchange and plant growth as the plants adapt to the new CO2 levels. A closed plant growth chamber with independent control of CO2 can establish conditions ideal for photosynthesis and thereby reduce stress on the plants. In this paper, we describe a CO2 control system that uses an ionic liquid membrane contactor for selective transport of CO2. A blower circulates the plant growth chamber atmosphere through the contactor. Red, blue, and green light-emitting diodes illuminate plants which dynamically alter the CO2 level within the growth chamber; plants remove CO2 during the light cycle and respire CO2 when it’s dark. When the plant growth chamber CO2 level is low, the control system scrubs CO2 from a simulated CO2-laden cabin atmosphere and delivers it to the plant growth chamber to maintain the desired set point. If the chamber CO2 level is higher than the set point, then the control system reverses the direction of transport by scrubbing CO2 from the plant growth chamber atmosphere and rejecting this CO2 to the cabin. A model was developed with the V-HAB virtual habitat modeling and simulation tool to characterize CO2 control over a broad range of operating conditions and demonstrate feasibility for control between 1,000 and 2,000 ppm (0.1 and 0.2 kPa).

[451] ***Lunar SmartHab Mission Operations and Crew Day-In-The-Life***

Kenneth Pritchard (Purdue University), Luca Vaccino (Purdue University), Xiaoyu Liu (Purdue University), Dawn Whitaker (Purdue University), Shirley Dyke (Purdue University) and Brian Joyal (Veridiam, Inc.).

*Abstract*

Toward the goal of developing realistic models and conducting useful trade studies, researchers, including those in the Resilient ExtraTerrestrial Habitat Institute (RETHi), depend on a shared notional understanding of how a smart planetary habitat (SmartHab) might look and operate. Models must originate from a baseline reference architecture for all mission characteristics. This project qualifies some general assumptions made about the daily activities and objectives of a SmartHab’s crew. It provides crew schedules to represent agent actions and availability through a day-in-the-life (DITL) but refrains from defining a concrete mission architecture that might infringe on simulation flexibility . Researchers and designers can use these DITL schedules and the content of this paper as a contextual reference point to inform future projects.

[452] ***Space Hands-on Training at the University of Stuttgart: from Microalgae to Docking Maneuvers***

Gisela Detrell (Institute of Space Systems - University of Stuttgart).

*Abstract*

The University of Stuttgart places great value in providing the students a unique opportunity to put in practice the concepts taught in theoretical lectures. Therefore, research and teaching at the Institute of Space Systems (IRS) are highly linked. A practical training module, “Selected hands-on training for space”, has been offered for nine years, and its content is always being adapted to the current institute research. The courses offered over the years are linked to life support and energy systems (use of microalgae for oxygen and food production, electrolyzers and fuel cells), mission analysis, use of Earth observation satellite data and the most demanded by our students, the spacecraft maneuvering. Here, the students have the opportunity to carry out docking maneuvers with a full-scale Soyuz simulator. The students participate in two of the offered courses over one semester and are evaluated through a report, presentation or exam. After successful completion, this allows them to obtain three ECTS (European Credit Transfer System) for the space specialization in the aerospace engineering Master. This module is very popular, and the places offered are filled in a matter of hours, as soon as registration opens. Unfortunately, the number of places is limited, due to the resources required, both in terms of material and tutoring staff. The university, the faculty of Aeronautics and Geodesy, and the institute itself provide the necessary means to offer this module. This paper presents the different training courses from our institute and their link to the current research. Student’s feedback from the current semester (Winter 2022/23) is included.

[453] ***SCAMPI Project: Design of an Aquatic Closed Ecological System for Microgravity***

Tarek Ben Slimane (The Spring Institute for Forest on the Moon), Costanza Torchia (The Spring Institute for Forest on the Moon), Patrick Grubbs (The Spring Institute for Forest on the Moon), Jorge Galvan Lobo (The Spring Institute for Forest on the Moon), Alvaro Ropero (The Spring Institute for Forest on the Moon), Jorge Alberto Rodriguez (The Spring Institute for Forest on the Moon), Joshua Smith (The Spring Institute for Forest on the Moon), Anatole Berger (The Spring Institute for Forest on the Moon) and Solène Roche (The Spring Institute for Forest on the Moon).

*Abstract*

Long-duration crewed space missions require bioregenerative life support solutions to improve mission sustainability and resiliency in the harsh environment of space. Understanding the impact of the space environment on Earth ecosystems is a critical next step in developing such solutions. This manuscript presents the experimental design of the SCAMPI Project (Saltwater Crustacean, Algae, and Microbe Population Investigation), a student mission to investigate the effect of microgravity and increased radiation on a multitrophic aquatic closed ecological system. The team is developing a custom payload, consisting of a sealed aquarium and instrumentation suite, to be integrated into the ICE Cubes facility onboard the International Space Station. Remote monitoring will collect data and imagery on the biotic and abiotic factors within the closed environment, informing a digital twin simulation that is being developed concurrently. This experiment will be the latest in a short list of ecosystem-scale experiments to fly in space, and address fundamental knowledge gaps including microbial community dynamics in microgravity. Ultimately, SCAMPI will provide data to inform the design of future closed ecological life support technologies by validating the hypothesis that Earth's ecosystems can function nominally in the space environment. The experiment is currently being built as a part of ESA’s PETRI program and anticipates launching in early 2025.

[454] ***Developing an Integrated Logistics Infrastructure for Lunar Surface Habitats***

David Akin (University of Maryland).

*Abstract*

The Artemis program is building up to a return to human lunar exploration, with the goal of extended and eventually permanent human lunar surface habitation. While this effort builds on almost 25 years of permanent human habitation at the International Space Station, logistics resupply will be uniquely different on the lunar surface, due to both substantial gravity and the greater challenge of logistics transport. While ISS resupply is accomplished with 6-8 dedicated cargo missions per year for a cumulative annual cargo mass of approximately twenty metric tons, there is an open question of the optimum number and size of resupply missions for a lunar surface base. Logistics for human habitats will remain primarily focused on the use of pressurized modules to protect the resupply items from vacuum and temperature extremes, as well as to simplify the process of bringing the logistics into the habitat for use.

This paper focuses on technologies for establishing a robust logistics infrastructure for upcoming surface habitats and bases. Following a review of potential lander vehicles with their associated payload mass and volume limits, it identifies a set of candidate scales for incoming logistics elements, from full habitat modules to dedicated ISS-type logistics modules to small multi-unit logistics elements capable of being manipulated by EVA astronauts or robotic systems. Tasks for the logistics system will include offloading landing vehicles, which may include elevated payload decks, transporting the logistics elements up to a kilometer from the landing site to the base, berthing the pressurized module to the habitat, and systems for offloading cargo from the module’s interior and transporting it internally to designated storage sites. Developmental testing includes the use of underwater simulation of human and robotic logistics tasks ballasted to replicate lunar gravity conditions.

[455] ***Ionic Liquid Parameter Prediction Leveraging Quantum Structure Property Relationships***

Mitchell Woolever (University of Colorado Boulder), James Nabity (University of Colorado Boulder), Ronald Cook (MDI LLC) and Eric Fox (NASA MSFC).

*Abstract*

U.S. Space Exploration Policy denotes the critical importance of establishing an outpost on the Moon to provide the foundation for human missions beyond cislunar space. However, launching spare components and systems from Earth will likely be cost prohibitive, so the single most important development that is required for enhancing, and in some cases enabling, sustained human presence on the Lunar surface is having the capability to extract metals, oxygen, and water from the Lunar regolith. Ionic Liquids (ILs) are noteworthy for their host of unique chemical properties: a relatively large temperature range in the liquid phase, negligible vapor pressures, thermal and chemical stability, wide voltage window, and many have low toxicity. Furthermore, their coupled organic and ionic nature make them excellent solvents for a wide range of materials. In particular, acidic ionic liquids show the potential to enhance oxygen and metals production from regolith via dissolution and electrolysis. Furthermore, given their organic composition, the physical and chemical properties of ILs can be fine-tuned by modifying their ion structures and combination. Relative abundance changes with sample location, but the principal metals of interest for In Situ Resource Utilization (ISRU) in the Lunar regolith are iron, aluminum, magnesium, calcium, and titanium. However, an IL has yet to be identified that reliably dissolves titanium dioxide or silicon dioxide. Manufacturing and testing even a relatively small subset of the million theoretically stable IL anion/cation combinations for mineral digestion performance analysis is time and cost prohibitive. This paper will discuss a software process pipeline and corresponding analysis setpoints for a method to determine quantum structure property relationships (QSPR), which relate IL molecular structure to chemical function. Using QSPR, hundreds or even thousands of ILs could be assessed for efficacy in regolith ISRU and beyond.

[458] ***Successful Testing of Advanced Space Habitat***

James Kirwan (ILC Dover), John Lin (ILC Dover), Beth Schaepe (Sierra Space), Gerard Valle (Sierra Space), Matthew Morgan (ILC Dover) and Shawn Buckley (Sierra Space).

*Abstract*

Commercial Space is an ecosystem which is rapidly evolving with advanced space habitats and broad interest in habitation development opportunities. Addressing this growing space economy requires the on-orbit presence of multi-use environments, similar to the International Space Station. One of these advancements is maximizing the livable volume of the space habitat without the burden of multiple launches or heavy lift capabilities, which is addressed by use of softgoods. Softgoods provide the benefit of an expandable volume once on orbit but minimal packed-size while launched, creating a significantly better volume-to-weight ratio. This enables support functions for diverse payload, governmental and civilian human visitors, on orbit in various scenarios including robotic, human tended, and autonomous/remote operations. In order to support a variety of user case functions in the manner in which customer bases are accustomed, the ecosystem of services should be scalable. The ability to scale and evolve on orbit habitation is a key discriminator in the advancement of space exploration.

ILC Dover and Sierra Space have successfully tested multiple Ultimate Burst Pressure (UBP) subscale softgoods space habitats, a significant milestone towards manned flight qualification. The UBP tests verify the structural integrity of the system at or above a 4.0 factor of safety requirement at maximum operating pressure (15.2 psi) and demonstrates repeatability in the design across test units with both units exceeding the required 182.4 psig (operating pressure x 4 = 60.8 x 3 = 182.4 taking into account the 1:3 sub-scale factor) , averaging 198 psig internal pressure before failure. This paper discusses the system architecture, concept of operations, rationale for testing approach, and test results gathered.

[459] ***A Constellation of Dreamers: Advancing Space Exploration through Democratization***

Daniella Ngarambe (The Spring Institute for Forests on the Moon), Patrick Grubbs (The Spring Institute for Forests on the Moon), Anatole Trepos (The Spring Institute for Forests on the Moon), Florent Bourlette (The Spring Institute for Forests on the Moon), Tarek Ben Slimane (Ecole Polytechnique) and Louise Fleischer (The Spring Institute for Forests on the Moon).

*Abstract*

The New Space industry gives us an opportunity to prioritize a new generation of space exploration, driven less by military and state needs and more by commercial and private interests. Despite progress, space remains inaccessible to many, with only six nations sending astronauts to space in 2021. To prevent underrepresented demographics from being excluded, the Spring Institute aims to democratize space creating opportunities for engagement for individuals from diverse nationalities and disciplines - and to do it in such a way that enables them to return their knowledge and experience to their homes. We do so by creating and collaborating on projects, proposals, and grants; as well as hosting events like hackathon challenges with local organizations, universities, and governments to encourage action in communities. Some of The Spring Institute’s goals being to generate usable data for citizen science initiatives, leveraging their network and skills imparted by these collaborations. By championing the strength and resilience afforded by a diverse community of scientists, engineers, artists, and dreamers, The Spring Institute for Forests on the Moon will accomplish its objective of building a functional ecosystem in a lunar environment. We hope to inspire generations to continue looking towards the stars that are our shared cultural heritage.

[461] ***Check Valve Anomaly Investigation for the Mars 2020 Spacecraft***

Jennifer Miller (NASA JPL), Pradeep Bhandari (JPL), Keith Novak (Jet Propulsion Laboratory), Razmig Kandilian (NASA JPL), Kaustabh Singh (Jet Propulsion Laboratory), Paul Karlmann (NASA JPL), Mohamed Abid (NASA JPL) and Jacqueline Lyra (Jet Propulsion Laboratory/).

*Abstract*

Following launch of the Mars 2020 spacecraft July 30, 2020, a fault response safely re-configured the operational pumps for the cruise heat rejection system as a result of a larger-than-expected system temperature gradient. Further analysis and investigation determined the cause to be a stuck open check valve downstream of one of three pumps, allowing re-circulation through the pump itself and a reduced system flow rate. An in-flight characterization test confirmed the cause and cleared the check valve issue, returning the system to its as-designed flow rate. This investigation described here documents performance with and without re-circulation, possible causes for the check valve issue, characterization results, and improvements for future missions.

Note: This abstract previously submitted by Jackie Lyra and withdrawn. Being resubmitted for publication for 2023 conference.

[464] ***Development and Testing of Crew Interfaces for an Advanced Unpressurized Exploration Rover***

Charles Hanner (University of Maryland), Nicolas Bolatto (University of Maryland), Daniil Gribok (University of Maryland), Spencer Quizon (University of Maryland), Rowan Quintero (University of Maryland), Ian Welfeld (University of Maryland) and David Akin (University of Maryland).

*Abstract*

Although revolutionary in its impact on lunar exploration, the Apollo Lunar Roving Vehicle (LRV) had only rudimentary navigation capabilities, and crew controls were essentially limited to go/stop and turn right/turn left. After more than five decades, rovers supporting the Artemis program will have vastly increased capabilities, and a corresponding need for more detailed and complex crew interfaces. The VERTEX rover has been developed at the University of Maryland as an field test analogue of concepts such as the Lunar Terrain Vehicle, and incorporates advanced capabilities such as active suspension, variable deck height and angle, reconfigurable payload interfaces with multipurpose electronic interfaces, and advanced controls including teleoperation and autonomous driving modes. This paper details the development and human factors evaluation of controls, displays, and restraint systems for the VERTEX rover, based on both laboratory and field testing. While advanced robotic systems are often controlled from graphical user interfaces including touch screens, the extremes of lighting on the lunar surface and effects of regolith on pressure suit gloves drive designers to greater use of discrete and dedicated control interfaces and single-function displays easy to read in both bright sunshine and darkness. Extensive human factors testing was performed to examine potential layouts for the comparatively large number of discrete displays and controls, without impacting rover ingress/egress in spacesuits. Display and control layouts are also inherently impacted by crew seating and restraints, and a focused effort was made to move beyond the unsatisfactory simple seat belts of the Apollo LRV to restraint systems which are easier to engage and release in a spacesuit. The seat design itself is strongly driven by the portable life support system, and the VERTEX seat system was optimized to accommodate a number of different backpack designs and sizes to support external test objectives.

[465] ***Calibration and Performance of the Spacecraft Atmosphere Monitor, an Air Constituent Monitor for Human Spaceflight***

Murray Darrach (Jet Propulsion Laboratory (JPL)), Byunghoon Bae (Jet Propulsion Laboratory (JPL)), Dejian Fu (Jet Propulsion Laboratory (JPL)), Vachik Garkanian (Jet Propulsion Laboratory (JPL)), Margie Homer (Jet Propulsion Laboratory (JPL)), Richard Kidd (Jet Propulsion Laboratory (JPL)), Cecile Jung-Kubiak (Jet Propulsion Laboratory (JPL)), Hannes Kraus (Jet Propulsion Laboratory (JPL)), Frank Maiwald (Jet Propulsion Laboratory (JPL)), Stojan Madzunkov (Jet Propulsion Laboratory (JPL)), Charles Malone (Jet Propulsion Laboratory (JPL)), Dragan Nikolic (Jet Propulsion Laboratory (JPL)), Mina Rais-Zadeh (Jet Propulsion Laboratory (JPL)), Tina Tillmans (Jet Propulsion Laboratory (JPL)), Fang Zhong (Jet Propulsion Laboratory (JPL)) and Jurij Simcic (Jožef Stefan Institute, Ljubljana).

*Abstract*

The Spacecraft Atmosphere Monitor (S.A.M.) is a miniaturized gas chromatograph mass spectrometer (GC/MS) instrument for monitoring the cabin atmosphere for human spaceflight missions. The first Technology Demonstration Unit (TDU1) operated successfully aboard the International Space Station (ISS) from August 2019 to July 2021. The second unit, TDU2, will be delivered to ISS in 2023. While on-station, TDU2 will continuously monitor the major atmospheric constituents and, on command, perform analysis of the cabin atmosphere for trace organic volatiles. The S.A.M. TDU2 uses the same quadrupole ion trap mass spectrometer (QITMS) sensor as in TDU1, but includes a MEMS preconcentrator, gas chromatograph, and microvalve system. Its miniature, ruggedized form factor allows the S.A.M. to be aisle-deployed to monitor the cabin in different locations and during activities such as exercise and sleep.

[466] ***Development of ARGOS Offloading Assessments and Methodology for Lunar EVA Simulations***

Sarah Jarvis (NASA/Aegis Aerospace), Richard Rhodes (NASA), Linh Vu (NASA/Aegis Aerospace), Garima Gupta (NASA/Aegis Aerospace), Elizabeth Benson (NASA/KBR), Han Kim (NASA/Leidos) and Sudhakar Rajulu (NASA).

*Abstract*

The Active Response Gravity Offload System (ARGOS) at NASA Johnson Space Center (JSC) is an analog environment that can offload pressurized suited subjects at various gravity levels. The suit is suspended from a robotic overhead crane by a cable connected to the suit via a gimbal with an adjustable pivot point. There has been increased interest in providing lunar pressurized suited training at ARGOS in preparation for lunar missions. Determination of the appropriate gimbal pivot point location for a given subject is vital for a high-fidelity and functional lunar simulation. Interactions between the pivot point location and center of gravity (CG) can result in righting moments that may lead to artificially stable or unrealistically challenging configurations. Changing the pivot point location is time consuming and repeated adjustment can result in significant loss of valuable pressurized suited time. This paper aims to share the knowledge obtained from the offloading characterization efforts during pressurized suited testing at ARGOS and document the ongoing process to define an appropriate pivot point location through iterative quantitative and qualitative assessments. The human-spacesuit CG locations for the ARGOS lunar simulation were estimated using a 3D body scan and density model combined with spacesuit hardware CAD and specifications. Early pilot testing of the gimbal revealed that setting the pivot point coincident with the modeled CG location was not always possible due to the current gimbal design, and small shifts forward and aft had noticeable effects on subject stability. Fifteen subjects performed a series of CG-related tasks in the xEMU spacesuit to assess simulation acceptability. Through iterative testing, this task list evolved to streamline the process needed to efficiently identify a suitable pivot point for a given subject. The developed methodology will be critical to determine pivot point selection for astronaut training in the xEMU ARGOS environment.

[469] ***Cyclone Sub-Micron Particulate Separator***

Matthew Haggerty (Mainstream Engineering Corporation), Matthew Emmons (Mainstream Engineering Corporation), Andrew Wagner (Mainstream Engineering Corporation) and Michael Cutbirth (Mainstream Engineering Corporation).

*Abstract*

A hygienic environment for deep space exploration vehicles is vital to the health and functionality of crew members and the hardware. Previous missions have shown the pervasive problem of fine particulate including obscuring optical systems, scratching surfaces, and potential long-term health impacts. The current International Space Station (ISS) Environmental Control and Life Support (ECLS) system architecture employs traditional High-Efficiency Particulate Air (HEPA) filters to combat sub-micron particles, but these require frequent cleaning and ultimate replacement as particles embed within the filters and are unable to be removed. As missions return to planetary bodies, particulate becomes an even larger challenge as frequent migration of crew members to and from the vehicle will cause sub-micron lunar regolith particles to permeate throughout the pressurized cabin. Mainstream Engineering has been developing a cyclone-based system for sub-micron particulate capture that integrates with the central HVAC system. In this work, we present our computational fluid dynamics (CFD) model development, rapid prototyping process, and validated system design to achieve an in-place regenerable system with high-efficiency sub-micron particle collection and a comparable pressure drop to HEPA filters. The results of this work can aid in the reduction of consumable filtration devices and provide a longer service life than the filters that are currently in use on deep space exploration vehicles.

[470] ***SWIM: Progress Report on the Organics Detection from Water***

Dragan Nikolic (Jet Propulsion Laboratory), Stojan Madzunkov (JPL) and Jurij Simcic (Jet Propulsion Laboratory).

*Abstract*

Jet Propulsion Laboratory (JPL) is developing a Quadrupole Ion Trap Mass Spectrometer (QIT-MS) suited for detecting ppm and ppb levels of organics within the liquid sample. The QIT-MS sensor is of the same heritage as one used in Spacecraft Atmosphere Monitor (S.A.M.). However, the pumping system, introduction of the sample, and operational architecture and procedures are different. We present our progress in this new instrument development and illustrate its ruggedized design by injecting 98% concentrated sulfuric acid that has the potential as a solvent for biochemistry. Using ruggedized QIT-MS to detect organic species dissolvable in water is straightforward and directly supports Spacecraft Water Impurity Monitor (SWIM) technology development.

[472] ***DAVINCI EDU Descent Sphere Thermal Insulation Test Results and Model Correlation***

Rommel Zara (Vertex Aerospace/GSFC) and Evan Alexander (Vertex Aerospace/GSFC).

*Abstract*

The Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) Mission will send an approximately 1-meter diameter probe into Venus to take detailed measurements of the Venus atmosphere and surface to answer questions about terrestrial planet formation and evolution, including the role (if any) of oceans. This probe, called the Descent Sphere, contains five science instruments and avionics that, as a system, must survive and operate thru the extremely challenging environment of the Venus atmosphere with pressures and temperatures reaching 90 bars and 465°C respectively. To mitigate the influence of this environment, the Descent Sphere design utilizes passive thermal control methods that include a 1-inch thick, high temperature MLI, and a 2-inch thick mat insulation to minimize the internal radiative and convective heat leaks from the very hot outer shell. To characterize the performance of the MLI and mat insulations, an engineering development unit (EDU) Descent Sphere was fabricated and tested at an industrial furnace where the predicted transient temperatures were simulated (up to 465°C), data collected, and subsequently a thermal model was correlated. The resulting correlated thermal model reduced uncertainties in the MLI and mat insulation performance and provided increased confidence in the flight predictions and design margins.

[474] ***Artemis-I - Development and Testing of Radiation Mitigation Strategies for Crewed Missions***

Janet Barzilla (Leidos, Civil Group Integrated Missions Operations), Ramona Gaza (Leidos, Civil Group Integrated Missions Operations) and Nicholas Stoffle (Leidos, Civil Group Integrated Missions Operations).

*Abstract*

The Space Radiation Analysis Group (SRAG) at Johnson Space Center developed a variety of radiation monitoring devices, space weather tools and crew exposure tracking products that were successfully tested during Artemis-I. These include vehicle area monitoring using the Hybrid Electronic Radiation Assessor (HERA) as the prime environment monitor for flight operations on Orion; Crew Active Dosimeter (CAD) as a precursor for crew worn dosimeters and tested during Artemis-I Science Payloads research (e.g., Commander Moonikin Campos, BioExpt-1 and the international collaboration Matroshka AstroRad Radiation Experiment - MARE); space weather Scoreboard interface hosting prediction model outputs (collaboration with Moon to Mars Space Weather Analysis Office and Community Coordinated Modeling Center at Goddard Space Flight Center); Acute Radiation Risk Tool (ARRT) predicting biological impacts during an energetic solar particle event using as input onboard radiation instrumentation; Mission operation tools to monitor real-time telemetered data and allow efficient 24/7 console operations support in preparation for the first crewed lunar mission (including daily communications with the Flight Control Team (FCT), internal and external collaborators). The current paper will present an overview of the Artemis-I radiation protection technology and tools, radiation measurements and data using the International Space Station (ISS) as testbed for these technologies, and preliminary Artemis-I data.

[475] ***An Experimental Study on Low Pressure Frost Formation for Lunar Polar Water Capture***

Beau Compton (NASA Glenn Research Center), Timothy Krause (Universities Space Research Association) and Leah Struchen Deans (NASA Glenn Research Center).

*Abstract*

In-situ resource utilization (ISRU) is a vital component of NASA’s mission to the Moon and beyond, as the extraction of resources from the environment can reduce payload weight and the frequency of resupply missions. Since the discovery of water in the regolith of the permanently shadowed regions (PSR) of the Moon, its extraction and transport has become an area of increasing interest for NASA. One proposed method is heating icy regolith to free the water before desublimating and transporting it as ice in a tanker. However, little is known regarding the dynamics of frost growth at low pressures, and an understanding of the heat transfer process is required to properly size the heat exchanger for the tanker. To investigate this phenomenon, a cold plate was placed in a vacuum chamber with water vapor directed at its surface. The chamber pressure (300 and 500 Pa) and cold plate temperature (–18 to –5 °C) were kept below the triple point and varied throughout the experiment to examine their impact on frost layer heat transfer. As water flowed into the chamber and deposited on the cold plate surface, the heat flux and temperature were measured along with the frost layer thickness and/or mass. Density calculated at the conclusion of each test suggests the frost layer is denser than that of frost grown at atmospheric pressure. The results demonstrate unexpected density and heat transfer characteristics and require development of a new model of frost growth for lunar conditions.