Game Changing Development in Environmental Control and Life Support Systems

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Paragon Space Development Corporation specializes in environmental control and life support systems (ECLSS) for extreme environments. We develop equipment and technologies that enable life to safely flourish within and beyond the cradle of Earth. Having flown or participated directly in numerous life support experiments aboard MIR, the International Space Station (ISS), and the Space Shuttle we have seen firsthand the technological wonder that exists within these orbiting laboratories. However, despite the storied successes, these spacecraft, including the ISS, have not demonstrated the reliability, maintainability and long-duration in situ resource utilization required for prolonged deep space travel [1]. Before humans can safely progress beyond low earth orbit, game changing improvements must be realized in the areas of ECLSS closure, reliability, maintainability, and the fidelity of testing.

In its present configuration, ISS can achieve roughly 80% oxygen closure with its life support system, and varying degrees of closure in other areas [2]. In practice, this means material required to sustain life on the ISS must be delivered on a recurring, scheduled basis only to be consumed and discarded. Primary ISS life support subsystems such as the Water Processor (WP), Sabatier-based Carbon Dioxide Reduction Assembly (CRA), and electrolysis-based Oxygen Generator Assembly (OGA) all require significant consumable resupply mass to operate. As humans venture further from Earth this rapidly becomes a significant launch mass penalty while also reducing potential margins for abort trajectories. Reliable and in-flight-maintainable processes that enable life support system *closure* are needed. These include utilizing metabolic byproducts as a resource for the mission, maximizing Sabatier/Solid Oxide Electrolysis air-revitalization techniques, and enhancing water recovery via membrane diffusion. Game changing improvements in ECLSS closure are required if human space travel is to progress toward long duration, deep space missions with the safety required.

Once a crewed spacecraft departs low earth orbit and resupply or rescue becomes prohibitively complex and expensive, the reliability of life support systems is paramount. It is not enough to simply have a system in place that provides for life's basic needs. That system must be dependable without frequent repairs, calibrations or resupply. At present, the ISS is incapable of meeting this requirement. Much effort is required to replace worn components and troubleshoot malfunctions. Clearly, for long duration, deep space missions this is simply not a viable option. New, more reliable technologies for ECLSS are required if humans are to venture beyond low earth orbit frequently and safely. Achieving this goal requires limiting the number of moving parts in ECLSS hardware, minimizing complexity, eliminating multiphase flow whenever possible, and reducing susceptibility to corrosion and microbial fouling. Game changing advances in ECLSS reliability are needed for human spaceflight to push forward toward bolder objectives.

By definition the concept of long duration spaceflight implies there is ample opportunity for mishap. ECLSS reliability and substantial, if not total, closure is clearly required;

however, it is equally important to develop the ability to repair and maintain critical components in-flight when necessary. Equipment will fail, and when that happens the crew must have the ability to easily isolate and repair the offending hardware with tools and spares that are readily on hand. From the earliest phases of concept exploration, new ECLSS hardware must be designed with an eye toward in-flight repair under less than ideal conditions by fatigued, stressed, and non-expert personnel. Detailed planning for failure and facilitating maintenance is a game-changing concept required for ECLSS hardware to support life beyond low earth orbit.

Finally, no life support system is complete without rigorously comprehensive testing in the relevant environment(s). In many ways testing closed loop ECLSS in a truly relevant environment is unique because it is inherently dependent upon biological processes (i.e. the crew). In mechanical systems it is commonplace to accelerate testing by artificially aging equipment and components; however, this is often impossible with "biology in the loop" systems. Toxins build at a given rate, bacteria mutate at a given rate, biological fouling occurs at a given rate and there is frequently very little that can be done to accelerate one process without introducing error to others. For this reason, it is imperative to conduct full life cycle tests on advanced ECLSS systems. A system designed to provide life support for 5 years requires testing under realistic conditions for a minimum of 5 years. Achieving game changing advances in closed loop ECLSS necessitates full life cycle testing under realistic conditions.

The ISS ECLSS is a monumental state of the art achievement representing the single greatest advancement in ECLSS technology in the history of human spaceflight. This achievement naturally leads to the conclusion that incremental advancements in the subsystems of the ISS ECLSS architecture will provide the requisite reliability and maintainability for deep space missions, and that increasing levels of closure can be achieved simply with increased system power, mass, and complexity. However, documented reliability and maintainability issues with the ISS ECLSS architecture demonstrate that incremental improvements of current systems will not enable deep space missions.

Furthermore because testing of ECLSS must be done for full mission-length durations, relying on a single architecture carries a high risk that no ECLSS will be available to support a deep space mission when the other vehicle systems are ready. Game changing ECLSS development is needed if humans are to push beyond low earth orbit and pursue bolder dreams. We at Paragon encourage NASA to include Environmental Control & Life Support Systems as a major component in the Game Changing Development Program with a specific focus on increasing closure, reliability, maintainability, and scheduling realistic, long-term testing.

REFERENCES

1. ISS Status Papers, ICES 2002 – 2010, Consequello, Williams, and Genry.

2. Feasibility Demonstration of a Solid Oxide Electrolyzer with an Embedded Sabatier Reactor for Oxygen Regeneration, ICES 2007-01-3158, Christine Iacomini, et al.