Habitation Systems Concept Studies: Improving the Efficiency of Systems in Life Support & EVA Suits

Gabrielle M. Paris

Clackamas Community College

July 2019

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Life Support Systems: Air revitalization

An important consideration when creating air revitalization systems is the aerosols within the given environment. Aerosols are the "dust" particles that become suspended in the air, and include human skin, plastics, lint, and other microparticles, a lot of which can compromise a person's physical health. On Earth, these particles eventually fall onto the nearest surface due to gravity, but in a microgravity environment, these particles remain suspended in the air (Meyer, 2014, p. 2). The challenge that will be discussed is improving the air quality within enclosed microgravity and lesser gravity environments.

Background Research

One of the current issues on the International Space Station is the presence of microparticles in the air that the astronauts are breathing. A recent project to determine what makes up these "dust" particles is NASA's Aerosol Sampling Experiment (ASE). The ASE used both active and passive samplers to collect samples for extensive analysis on Earth. The passive sampler consists of five collection surfaces, each with their own storage unit to prevent cross-contamination, and the device is placed in front of a filter to collect samples on each surface for different amounts of time. The active sampler is an electronic device that pulls material into its collection surface with a mix of a fan and a large temperature gradient (Meyer, 2017, p. 3,4). In Table 1 of Marit Meyer's (2014) paper on aerosol sources, it was shown that the majority of particles in the ISS air consist of fiber lint and human exfoliation of skin and hair[1] (Meyers, 2014, p. 3). An updated list (Table 2 of the same article) showed that certain activities — such as

[1] The article considers that materials greater than 841μm will not pass through the air filters on the ISS.

vacuuming, 3D printing, and laser printing — produce significantly more particles per minute compared to human exfoliation (Meyers, 2014, p. 7).

Next Phase of Component

The next step would be to create a system that removes aerosols from an enclosed environment. It is important to note that the background resources have all been in the context of the ISS, which is an enclosed environment that has been recycling its air for approximately 16 years. To date, it is the only extra-terrestrial environment that humans live on, so any research pertaining to improving and maintaining human life in space is done there. A benefit to a surface colony (such as the Moon and Mars) is that there is a gravitational pull (albeit significantly less than Earth's gravity) which will affect the movement and suspension of particles in the air, so some of the filtration methods that are used on Earth can be used with modification to account for the different gravity; however, a microgravity environment is a little trickier due to particle suspension in the air.

For an enclosed environment with gravity, a system similar to present air sterilization methods on Earth. Since particles in the air would be affected by the body's gravity, ventilation ducts to filter out the particles would be sufficient in the air recycling process. For a microgravity environment, however, the issue of suspended particles remains. The proposed next step for reducing the number of aerosols in this kind of environment is to increase air circulation while cleaning.

Bridging the Gap

One method of sterilization (granted, a very simplified version of the process) involves passing used air through a filtration system, which removes particles from the system before allowing the air to continue into a given environment. This process, however, assumes that gravity is an influencing factor that is acting on the particles, that is, what is being filtered are the smaller particles while the larger particles accumulate on the ground. A variation of this system such that it can function in a lesser gravity environment is to have a series of filters on functionally the same type of filtration system. The filters would have different sized openings to separate larger particles from the smaller ones. The intent of this is to create “checkpoints” for dust particles, so instead of catching all of the dust at one entryway, it is caught at several points, that way there is a reduced chance of particles being pushed out of the filtration system.

A filtration process would not work in a microgravity environment, due to its dependency on gravity to separate larger particles from the smaller ones. A vacuum-style filtration system is already in use on board the ISS, but it does not efficiently collect all of the particles from the air. By increasing air circulation during cleaning, the added oxygen can push the particles around the space, which would increase the chance of the particles approaching the filtration system. The primary concern that comes up with this idea is the excess use of oxygen in a system with an already limited supply. Since using other gases would pose a potential hazard to astronauts, it would be feasible to use oxygen, and a way to remain more conservative with oxygen use is to only do this process when astronauts are cleaning with a vacuum. A way to keep aerosols from traveling to other parts of the enclosed environment, the modules could be sealed off while cleaning, either through airlock mechanisms or through an impermeable membrane that can be attached to the entryways.

Extra-Vehicular Activity: Space Suit Improvements

When the Space Race turned toward a competition to have humans walk on the Moon, the design of a space suit to protect astronauts from the hazards of space became just as important as the rocket that took them to the Moon. The suit had to maintain maneuverability for the astronaut while protecting them from radiation, particle impacts, and the cold vacuum of space. The challenge that will be addressed is how the current design for the space gloves can be modified for comfort and mobility in the context of working in an extra-vehicular environment.

Background Research

For astronauts to work in space, they need a suit that can sustain them in the vacuum of space, but also allows for astronauts to complete their work without excess difficulty. Several corporations, such as Perkin Elmer Corporation, David Clark Company, and B.F. Goodrich worked with ILC Dover and Hamilton Standard to design the components of a suit that satisfied these requirements (Thomas, 2016). NASA both mediated and oversaw quality checks to make sure that the suits that were being handed off met their requirements and provided the best safety to the astronauts who would be wearing them. Despite setbacks due to tensions between ILC and Hamilton, as well as redesigns to meet NASA requirements, the first EVA suits were tested in 1965 (First American Spacewalk, 2015).

The design of the EVA space suit has not really changed much since the Apollo Space Program, and with the current mission goal to establish a presence on the Moon and venture to Mars, future astronauts need more durable suits to sustain them. While parts can be modified for improved technical performance (such as the amount of oxygen per spacewalk), an astronaut must be able to perform tasks comfortably in the suit. According to the American Institute of Aeronautics and Astronautics, approximately half of the injuries sustained in EVA trainings were hand injuries, including wrist fatigue and fingernail delamination (Mousavi, et al. 7). The hand is just as important as the rest of the astronaut's body, and the efficiency of the mission and/or task can be affected by a hand injury. If there is any good place to start for improving the EVAs for long-distance missions, it is the suit's gloves.

Next Phase of Component

A way to reduce fatigue of the hand and wrist would be to integrate a user-controlled robotic skeleton into the glove. It would consist of pads that cover the user's fingertips inside the glove and are controlled the same way motorized prosthetics are controlled. The skeleton would rest either within the glove or on the outside, and the user would be able to control the skeleton by flexing their hand. To minimize the risk of fingernail delamination, the next step will be based off the hypothesis that the delamination is due to 1) a transition of the air in the glove's bladder from a high-pressure state to a low-pressure state, and 2) the positioning of the bladder inside the glove. To work around this, the glove would need a way to minimize movement of the materials and a way to reduce the air shift in the bladder.

Bridging the Gap

There are a couple of concerns that would need to be addressed for a robotic skeleton to function. The primary issue is joint mobility in extreme temperatures, where the temperature is either so cold that it locks up the moving joints in the robotic skeleton, or it is hot enough to potentially fuse the joints together. It would be reasonable to put the skeleton between layers of the glove and integrate a temperature regulating system. Another concern is delay time between the signal from the finger pads and the reaction of the skeleton. The skeleton could be designed to have movement with the astronaut's hand, so the hand would not be stuck in a single position while waiting for the skeleton to react, though with present technology and resources it is possible to reduce the reaction time to a fraction of a second.

The change in the glove's air pressure comes from the idea of the water tube toys from the 1990s. When undisturbed, the water remains evenly distributed throughout the shape containing it (with an exception at the edge of the cylindrical shape, where the plastic overlaps itself), but when the toy is squished, the water will move away from whatever is squishing it. This concept can be applied to the bladder inside the EVA gloves, except the thing "squishing" the bladder is the hand on the inside. When the astronaut is using their hands inside the gloves, they could be applying more pressure to the bladder, which would shift the air inside toward the wrist—which can be described as the part of an expanded hand with the smallest cross-sectional area—which is also the part of the hand that would exert less pressure on the bladder inside the glove. Since gas molecules will distribute themselves uniformly in a given space, the air that is pressurizing the fingers would shift slightly in the direction of the wrist. This process could be shifting the fabrics in the glove toward the wrist as well, which would force the fingers into the tips of the glove.

To overcome the change in pressure, the proposed change would be to modify the bladder in the gloves such that it is more difficult for air to move away from the fingers[2]. One option to solve this is to create a "unidirectional" bladder for the upper part of the hand (that is, the top of the palm and the fingers), so air can go in for pressurization but cannot go back out until a valve is released. This would effectively turn the bladder into two sub-parts within the glove. The second proposed solution is to lengthen the parts of the bladder material that extend

[2] This is assuming that the bladder is a glove-like shape inside the EVA, since the information found on glove design for this report did not clarify the exact shape of this layer inside the glove.

over the fingers. By extending the finger length by no greater than 1 centimeter past the palm-end of the finger, it would prevent the fabric from shifting toward the wrist, as well as provide a small amount of slack in the glove's fingers to minimize the amount of pressure being put on the astronaut's fingers.

Regarding the movement of fabric inside the glove, a simple solution could be to put a weak "spring" inside the glove that prevents the fabric from shifting toward the wrist. It would attach to or near the wrist bearing on the glove, and it would be made of a material that can behave like a spring in extreme environments. By putting a compressed spring near the wrist, it would push the material outward toward the fingers. A concern with this is that it may compromise the flexibility at the wrist, so an important specification in the spring design would be both material properties and attachment location in the glove.

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