Feedwater Supply Assembly Design

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ABSTRACT

A call for improvements in space exploration technology is being made in light of the U.S. government pushing NASA to return to the Moon in 2024. As part of this effort, various elements of the existing space suit are being improved, including the relocation and redesign of the feedwater supply assembly (FSA). The function of the FSA in the portable life support system (PLSS) is to supply additional water to the thermal control subsystem as the water is gradually being expelled into vacuum by the suit water membrane evaporator (SWME). The primary focuses of this study include: prototype analysis and selection, compatible material literature review, and bubble detachment literature review. Three prototypes were analyzed in a proof-of-concept test to identify which FSA design would produce the most repeatable volume measurements. It was determined that the implementation of flex sensors to relate the curvature of the FSA bladder to volume remaining in the bladder was the best option based on the repeatability of volume measurements in each test iteration. It was found that perfluoroelastomer (FFKM), fluoroelastomer (FKM), polytetrafluoroethylene (PTFE), and fluorinated ethylene propylene (FEP) were all potential materials to make the FSA from because they were compatible with water and iodine and they would leach minimal contaminants into the water.

BACKGROUND

Collins Aerospace has a rich history in the space systems industry. It first began in 1962 when NASA awarded Collins a contract to build the first portable life support system (PLSS) for their Apollo program. The purpose of a PLSS is to provide a closed-loop environment in which the astronaut can survive when exposed to hostile conditions during an extravehicular activity (EVA). The existing PLSS must be redesigned, as the existing EMUs are deteriorating and difficult to reproduce on a larger scale. Focusing on the specific parts of the PLSS that will be modified, the feedwater supply assembly (FSA) is a component that will be improved for the next-generation suit.

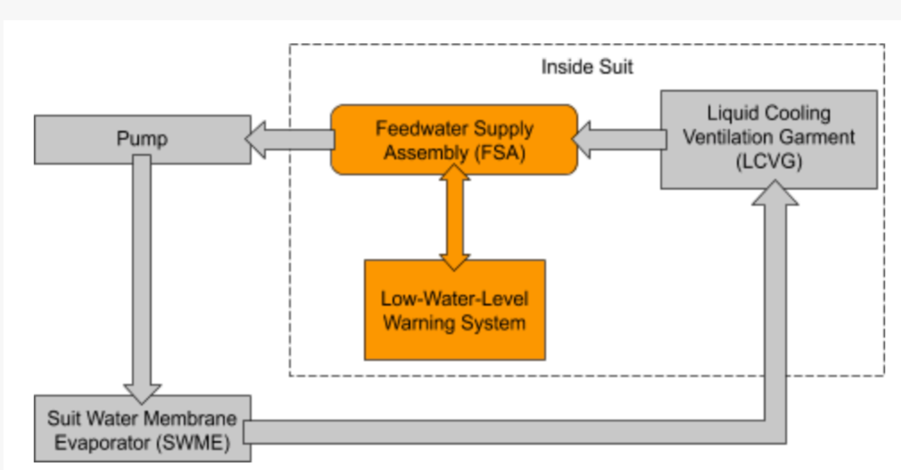

Figure 1: *Flow chart of thermal control loop, including the FSA and the low-water-level detection system.*

The FSA is a reservoir that provides supplementary water to the thermal control subsystem of the PLSS. The thermal control subsystem is responsible for providing the astronaut with temperature control so that he or she will not overheat. The component of the thermal control subsystem that provides cooling is the suit water membrane evaporator (SWME), which evaporates some of the thermal control loop water supply into the vacuum environment. The chilled water from the SWME is then pumped through the liquid cooling ventilation garment (LCVG) which is a bodysuit the astronaut wears with small capillary tubes sewn into the material that passes cold water over the astronaut's body. After the water leaves the LCVG, it returns back to the FSA where the cycle repeats.

PROJECT DESCRIPTION

The objective of this project was to redesign, fabricate, test and analyze a feedwater supply assembly and low-water-level detecting system. The metrics for the FSA project, outlined by Collins Aerospace, are as follows:

- FSA must be no more than 1.8 in. deep and 12 in. wide.
- FSA must hold 4.5 lbs. of water.
- FSA must have a low-water-level detector that is triggered when 30 minutes of water remains in the system.
- FSA material must be compatible with water and iodine.
- FSA material must not leach contaminants into the cooling loop.
- Minimize water stagnation areas to reduce air pockets. Bubbles must be eliminated in less than 10 minutes of when they are formed.
- FSA must be compatible with a cooling loop flow rate of 200 lb/hr.
- FSA must be filled via the suit cooling loop and must take less than one hour to fill.

PROOF-OF-CONCEPT TESTS

After a comprehensive design phase, three FSA prototypes were brought forth: the flexible compression, rigid compression, and auxiliary supply designs. The preferred design would report the narrowest spread of voltage readings, given a particular volume, referred to in this project as repeatability. To determine the FSA's efficacy in microgravity, each design was tested four times in six different orientations.

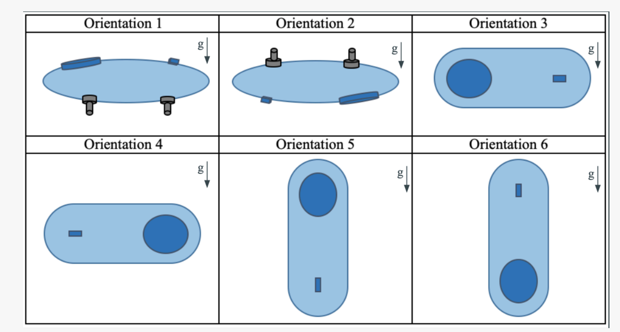

Figure 2: *Table of FSA positions and their according number assignments.*

The rigid compression design (Figure 3, left) involved the FSA bladder restrained between two wooden restraints. A total of four flex sensors were used to measure the distance between the restraints as volume decreased. The sensors were used as variable resistors in the setup, meaning that, as the bag lost volume, the sensors flexed more, and their resistance would increase, causing the voltage to accordingly increase. The flexible compression design (Figure 3, right) involved the FSA held to a single wooden restraint by the use of three elastics. On the top of each elastic was a flex sensor, held in place by electrical tape. As volume decreased in this design, the flex sensors would flatten out, causing a proportional decrease in voltage.

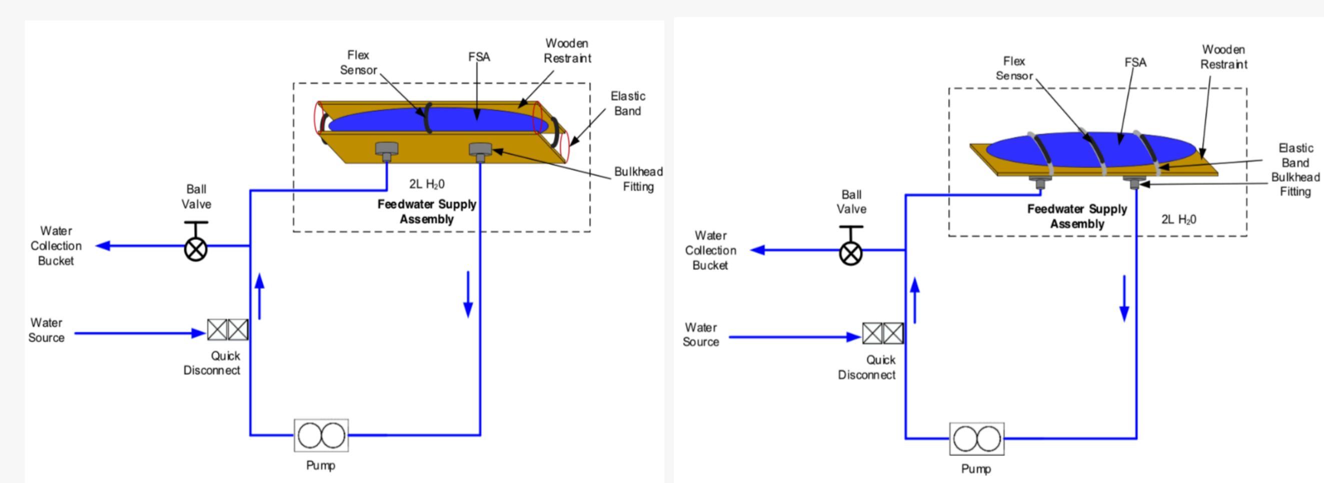

Figure 3: *Proof-of-concept schematics for the rigid compression design (left) and flexible compression design (right).*

It was discovered early on that the auxiliary compression design was not viable. A 0.5 psid, normally-closed check valve was between the auxiliary bag and main flow loop. The presence of this valve caused an over-pressurization of the auxiliary bag, which led to holes forming in the bag after a few tests. In addition, this design did not yield constant volume measurements, as a pressure drop would only occur when the main FSA emptied.

DATA ANALYSIS

What was evident in the compiled results from the flexible and rigid compression tests was the grouping of orientations (Figure 4, left). For the rigid compression design, when the water was not evenly distributed the voltage-to-volume ratio was lower (Figure 4, left). For example, orientation 6 of the rigid compression design registered an average of 3.125V when the volume was at 0.5L. For orientation 2 a voltage of 3.125 would indicate a volume of 1.4L (Figure 4, left). This would possibly result in a false warning signal.

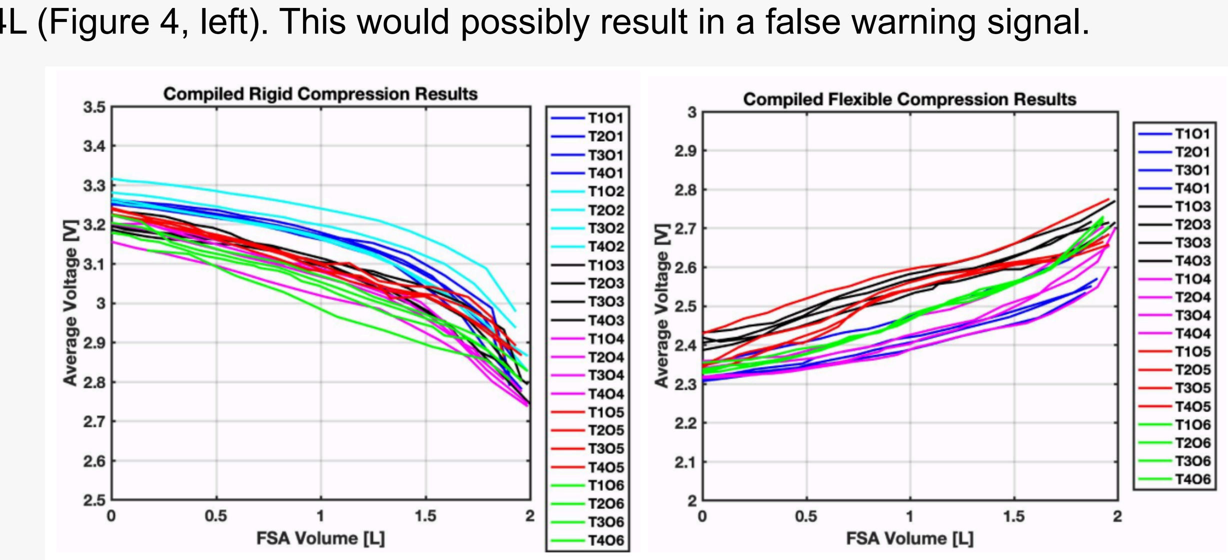

Figure 4: Compiled results for the rigid compression (left) and flexible compression (right) tests.

For the flexible compression design, the findings were flipped. The voltage-to-volume ratio was higher for orientations 3-6, where the water was not evenly distributed throughout the bag (Figure 4, right). The only exception to this finding was with orientation 4, where it had a very similar voltage-to-volume ratio to orientation 1. More testing and robust recording instruments may help to shed light on the reason this discrepancy occurs in the future.

RESULTS

Using the original data points for each test in Figure 4, it was necessary to approximate what the voltage would be at each volume reading because data was collected every 30 seconds, meaning that not every test will have a recorded voltage when its volume was at (or near) 0.75L. To compensate for this, spline curves were fit to each test to interpolate the voltage values at each 0.25L. The average of all tests' voltages were taken at each 0.25L, which is represented in Figure 5 by a circular data point. The height of the error bars at each point was dictated by the respective standard deviation (Figure 5).

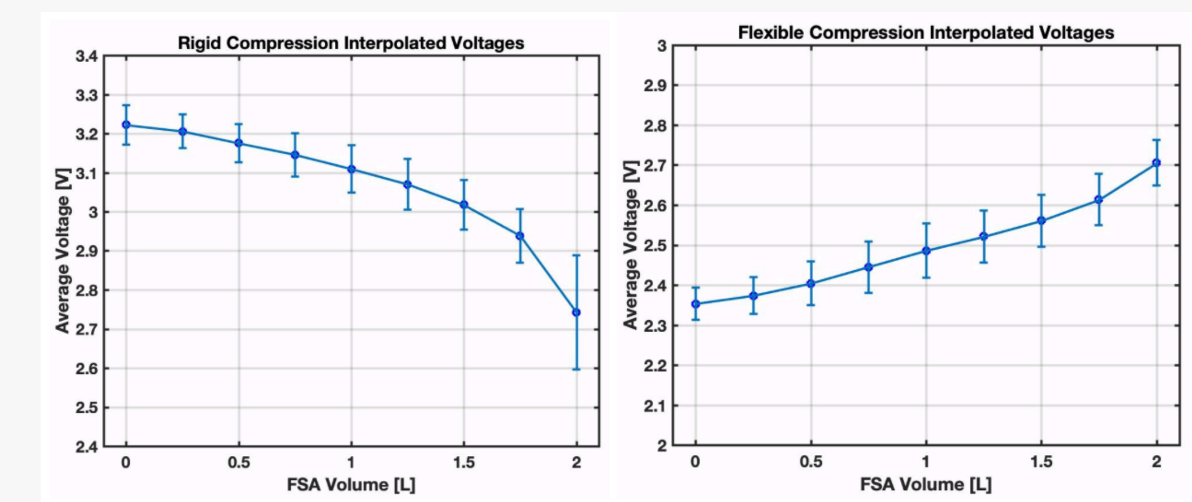

Figure 5: *Averages of each test's voltage, given a particular volume, for the rigid compression (left) and flexible compression (right) designs.*

Per the initial goal of this study, the most important metric to come out of the data analysis was to determine which test was most repeatable. To assign a "repeatability score" to each test, the average of the standard deviations in Figure 5 was taken. The repeatability score of the rigid compression was 0.0669 L and the score of the flexible compression design was 0.0582 L. Therefore, the design that yielded the most similar voltages at each volume measurement was the flexible compression design because it had the lowest repeatability score.

CONCLUSION

The design that is being proposed for development into further iterations is the flexible compression design. Not only did this design have the lowest repeatability score, but it also had the most ideal geometry. Since the system must fit in the small of the back of the astronaut, it must be as flexible and small as possible. This system was constructed entirely out of COTS parts, making it ideal to construct on a mass-production scale in the future. In addition, the use of COTS parts instead of custom parts made it less expensive to construct, something well-suited for the project budget. The flexible compression design also had a reduced risk of failure because its functioning did not rely on the use of any mechanical moving parts, such as a check valve.

FUTURE IMPROVEMENTS

For future iterations, it is suggested that a custom bag be made out of either FFKM, FKM, PTFE, or FEP. These materials are compatible with water and iodine and all, except for FFKM, have been shown to not leach contaminants. Literature was not readily available regarding the leaching of FFKM. The bag should be constructed in a football shape with a cylindrical body and tapered ends. Furthermore, additional flex sensors should be applied over the FSA bag. This is advantageous since using the voltages from a greater number of flex sensors will be more representative of the entire bag compared to the proof-of-concept testing performed which only utilized three flex sensors over the middle section of the bag. The addition of flex sensors will provide a more uniform compression across the length of the bag so that folding will not occur in the bag. It will also add redundancy, which will provide more security against whole system failure if, for any reason, one of the sensors fails. In future iterations of the flexible compression FSA design, a more rigid restraint should be used in place of the wooden board implemented in the current iteration. The wooden board used was prone to bending which may not be consistent from trial-to-trial and would skew voltage readings from the sensors between trials. A possible solution to this problem may be to use the space suit interior walls as the rigid, or semi-rigid, constraint.

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