SilSuit Generation 2

Mechanical Counter Pressure Space Suit Design For the Next Generation of Space Exploration

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[4] This project is export controlled and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR)

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Abstract

In the past, many organizations have attempted to construct a mechanical counter pressure (MCP) suit with varying degrees of success. While none have been capable of full operation to date, modern materials and techniques may be used to construct such a suit, as clearly demonstrated by a scale model constructed in the course of this research project.

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Introduction

Gas pressure suits have a long and proud history of bringing humans to the edge of the earth's atmosphere and beyond. The development started in the 1920's with the suits worn by airmen attempting to break altitude records. This research was performed by many nations, culminating in tests in the first half of the 1930's[5]. Current gas pressure suits, including the new suits by ILC Dover[6] and David Clark[7], can trace their lineage directly to these early attempts.

There are issues with gas pressure suits in terms of bulk, weight, and flexibility[8]. The future will bring more people living and working in space and performing more tasks, each more intricate than the last. The issues with the gas pressure suits will directly impact the ability to perform these tasks quickly, safely, and efficiently.

[5] Thomas, Kenneth, and Harold McMann. "Reaching Upward and Outward." In *US Spacesuits*, 6. 2nd ed. New York: Springer, 2011.
[6] ILC Dover. "Space." ILC Dover. September 11, 2013. Accessed October 16, 2014. http://www.ilcdover.com/space.
[7] David Clark Company. "Red Bull Stratos Team to Receive IAASS Safety Award." David Clark Company Worcester, MA. May 29, 2013. Accessed October 18, 2014. http://www.davidclarkcompany.com/aerospace/news.php?newsid=21.
[8] Jenkins, Dennis. "Partial Pressure Suits." In *Dressing for Altitude*, 175. Washington DC: NASA, 2012.

Figure 1. Z1 Space Suit Concept. Courtesy, National Aeronautics and Space Administration[9]

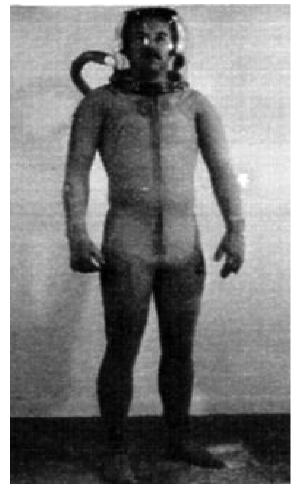

Figure 2. Early MCP suit concept. Courtesy, Webb and Associates[10]

Mechanical Counter Pressure (MCP) suits differ from gas pressure suits in that the body is compressed to equalize internal and external pressures by elastic or rigid (mechanical) constriction rather than the pressure of the gas contained within the suit envelope. While the design creates design challenges, it solves many more. These suits tend to be lighter, smaller, and largely immune to the ballooning issues which cause most of the mobility issues in gas pressure suits. MCP suits and components were being developed as early as 1959, though materials available at the time severely limited implementation, and many early efforts were often abandoned.[11]

[9] "Z-2 Spacesuit Design Vote." Z-2 Spacesuit Design Vote. January 1, 2012. Accessed November 18, 2014. http://jscfeatures.jsc.nasa.gov/z2/.
[10] Annis, James, and Paul Webb. Development of a Space Activity Suit. November 1, 1971. Accessed October 2, 2014. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720005428.pdf.
[11] Thomas, Kenneth, and Harold McMann. *US Spacesuits*, pp. 209-211. 2nd ed. New York: Springer, 2011.

New materials, advanced fabrics, and construction techniques commonly available today were unknown or uncommon in the 1960's and 70's when the majority of MCP suit research was performed, may be ideally suited to the task[12]. Ironically, many of these have been developed as a spin off of space suit development or from other elements within the aerospace industry.

These materials have largely become ubiquitous and inexpensive, enabling the continuation of MCP suit development. Thus, a reevaluation of these materials in the context of a next generation MCP space activity suit is in order. To that end DARPA and their subcontractor SpaceGAMBIT have approved research by Luna Desic and it's contractor Issyroo Farms in the technologies to build a standard method of evaluating an MCP suit arm performance through the anticipated mobility range, then constructing suit arm models of several designs to test them and thoroughly document the results.

[12] Reisch, Marc. "WHAT'S THAT STUFF? - SPANDEX." WHAT'S THAT STUFF? - SPANDEX. February 15, 1999. Accessed November 17, 2014. http://pubs.acs.org/cen/whatstuff/stuff/7707scitek4.html.

Materials and Methods

In order to properly evaluate a material for use in a MCP suit, they must be subjected to tests, some of which have not been clearly defined by prior work. In these cases, test conditions matching established mathematical models are created by controlled experiments with a test apparatus. In the event such a device model was used, construction details and test procedures and datasets are located in the appendices[13].

As a primary materials criteria, all components must meet the flammability guidelines as defined in NASA-STD-6001B[14]. While the tests defined within the specification were *generally* followed, some abbreviation and approximation[15] of the testing regimen was necessary as cost and time control measures. This adaptation was only justified during the materials selection phase, since the finished prototype must be tested fully by an approved and certified facility.

As a secondary criteria, the material must retain flexibility and compression (elasticity) throughout the anticipated operational temperature, pressure, and mobility range. There does not seem to be a defined testing procedure for this criteria, so our own test

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[13] Not all details and appendices are available in the public document due to export control restrictions pursuant to CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3)

[14] "Flammability, Offgassing, and Compatibility Requirements and Test Procedures." NASA Technical Standards Program. August 26, 2011. Accessed November 17, 2014. https://standards.nasa.gov/documents/detail/3314908.

[15] Some details of this test such as materials selection are not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR)

methods, protocols, and equipment were devised. While human testing could have been used at this stage, developing a test rig was deemed a superior option because of cost savings, data objectivity, and ethical considerations.

The test rig consists of a 1:4 scale model of a human arm (wrist to shoulder) constructed from an aluminum skeleton. The elbow and shoulder are supported by bearing journals and bump stops to limit joint deflection to that of a standard human range of motion. No effort was made to simulate lateral shoulder motion, as this would add complexity to the joint which translates to unnatural dimensions and motions at the test jig's scale. The extra cost was not as much of a factor as the integrity of the data. Construction details of the arm test jig may be found in Appendix C[16].

The arm has 16 fluid-filled vessels placed in strategic locations or zones to register any changes in direct pressure of cylinder stress. These are reconfigurable in order to facilitate testing under varying circumstances and simulating various levels of fitness (bulk) as well as simulating the interface between the extensible portions of the anatomy and the lines of non-extension[17].

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[16] Appendix C is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR)

[17] "The Use of Lines of Nonextension to Improve Mobility in Full-Pressure Suits." Defense Technical Information Center. November 1, 1964. Accessed November 18, 2014. http://www.dtic.mil/dtic/tr/fulltext/u2/610519.pdf.

Pressure sensors within each of these zones measured the vessels' internal pressure under various temperatures, ambient pressures, and arm positions. The arm assembly is covered with a compliant material which prevents accidental contact, stress, or damage to the fluid-filled vessels, sensors, or wiring. It should be noted that none of the materials used in the test jig arm were tested for LOX/GOX compatibility.

The arm was articulated by a low speed (6 RPM) motor with arm position sensed independently at the elbow. Arm cycle start and stop points were set with a limit switch which also acted as a cycle counter. This ensured consistent data within test datasets and simplified running multiple tests.

Data from the sensors was measured and recorded by the data acquisition system (DAQ) for later review. During each test run, an independent dataset was created. This file contains a row for each sequential reading. These rows bear a timestamp, arm position, and normalized measurement from the sensors in each of the 16 zones.

The original DAQ only delivered a test rate of 20Hz which yielded datasets with 200 rows per arm motion cycle. This resolution was deemed insufficient, as it represented a measurement for approximately every 1.5 degrees of elbow deflection, and small trends could be detected as an increase in statistical noise, but not resolved.

A new DAQ was installed which had the ability to take readings at a rate of 10,000Hz[18] yielding datasets with 100,000 rows per arm motion cycle or a measurement for every 0.0013 degrees of elbow motion. While this resolved the resolution issue and had the added benefit of introducing floating point may to the calibration and normalization routines, each arm cycle generated datasets of 40-50MB per arm motion cycle. For a typical test of 25 to 100 cycles, it was possible to generate datasets in excess of 3.6GB in size.

A small dedicated Linux server was installed in the lab to stream the dataset from the DAQ as it was created. This prevented the DAQ from being overwhelmed by the volume of the datasets since it was designed with only 4GB storage. This architecture allowed concurrent access to the dataset by both the DAQ and the workstations used for analysis. Datasets created by the DAQ were set as owned[19] by the DAQ and set as read only access to everyone else to preserve dataset integrity. The dataset on the server cannot be modified or deleted by users. Users must make a copy of the dataset for use and manipulation.

This server was set up as a local cloud[20] for the project and became the central repository for project code, documentation, and pictures on a dedicated hard disk.

[18] "AM335x Sitara™ Processors." Texas Instruments Literature, Data Sheets. 2014. Accessed October 30, 2014. http://www.ti.com/lit/ds/symlink/am3358.pdf.
[19] "Ubuntu Documentation." User Management. January 1, 2014. Accessed November 11, 2014. https://help.ubuntu.com/14.04/serverguide/user-management.html.
[20] "OwnCloud Administrators Manual." Introduction — 7.0 Documentation. January 1, 2014. Accessed October 30, 2014. http://doc.owncloud.org/server/7.0/admin_manual/.

Since the vast majority of data contained on the server is expected to be export controlled, the server was specifically blocked by the facility's firewall from any access to the internet as well as the wireless network to prevent casual access by guests and personnel who were not specifically cleared for access to this project.

Data was either accessed through workstations connected to the lab's isolated and secure ethernet network, or specific and reviewed (non-EC) data was moved by the organization's export compliance officer (ECO) to a workstation through the use of a freshly formatted USB flash drive to prevent an inadvertent leak of sensitive data or malware infection.

With these measures in place, we are satisfied with the quality and integrity of the data used in this study. Due to the size of the raw datasets, this information is available upon request by qualified organizations only and will be provided on DVD-R media at the cost of time, media, and shipping. It should be noted that this project has generated approximately 546GB of data to date and would require about 150 DVDs, each containing individual test runs. The summary and final report is available to qualified individuals and organizations at no cost[21].

[21] Not all details and appendices are available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR)

Results and Discussion

The prototypes of the actual MCP suit were also constructed as 4:1 scale prototypes. Performing trials on different materials qualified by the abbreviated flammability test, it was determined that a three-ply unquilted sandwich of [the selected elastic materials][22] provided the mechanical compression necessary for hard vacuum EVA, determined to be 5 PSI according to Figure 3.

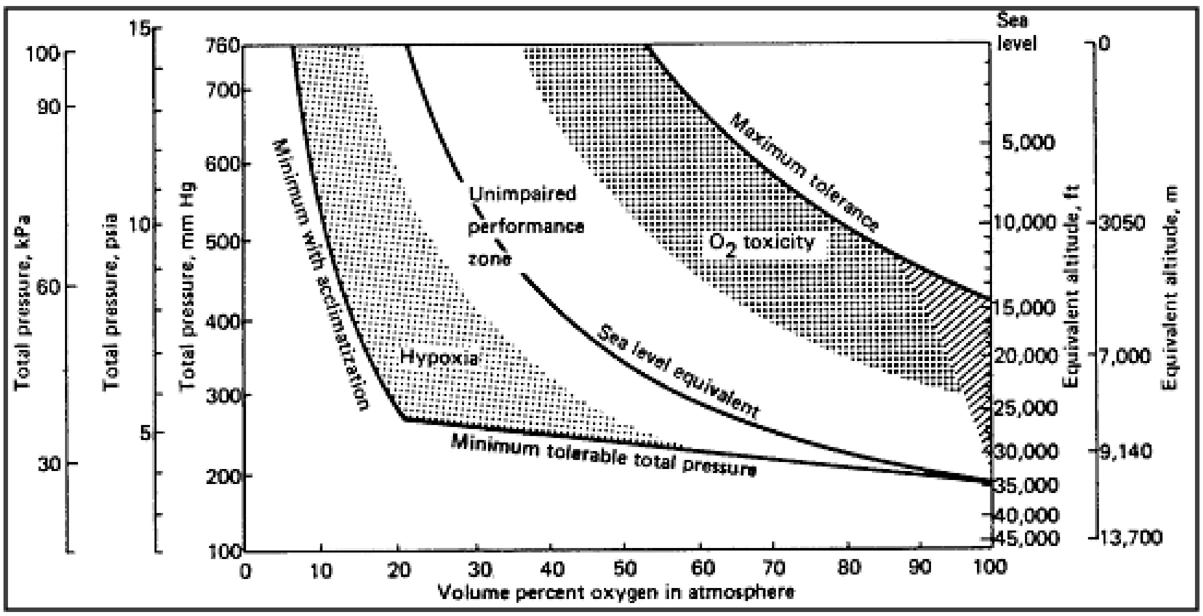

Figure 3. Relationship Between Percentage of Oxygen in Atmosphere of Space Vehicle and Total Pressure of that Atmosphere. Courtesy, National Aeronautics and Space Administration[23]

[22] The selected materials are not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).

[23] Jeeveraja, Antony. "NATURAL AND INDUCED ENVIRONMENTS." NATURAL AND INDUCED ENVIRONMENTS. May 7, 2008. Accessed November 13, 2014. http://msis.jsc.nasa.gov/sections/section05.htm#_5.1_ATMOSPHERE.

In order to accomplish a compressive force on an arbitrary thin wall cylinder, the hoop stress must be calculated with a form of the Young-Laplace equation:

$$\sigma_\theta = \frac{P \cdot r}{t}$$

where P is the pressure, r is the radius of the cylinder, and t is the wall thickness. solving for σ_θ, the pressure must be 5 PSI, the radius is 0.6 inches, and t is the wall thickness of 0.124 inches, the hoop stress is calculated to be σ_θ=24.2 lbs of force distributed across the 8 inches of the zipper.

A total of 24.2 pounds of force requires a stretch of 11% of the sandwich of [the selected elastic materials]. Given the circumference of 3.77 inches, this means that the measure of the arm circumference measured from centerline of the zipper teeth on either side of the closure is 3.355 inches, leaving a gap of 0.415 inches to pull together 3.025 pounds per inch. This is well within the capabilities of all but the most fragile commercially available zippers.

In a full scale suit, these numbers change only in scale. A 6 inch diameter forearm becomes $\sigma_\theta = \frac{5 \cdot 3}{0.124} = 121$ lbs. While this seems like a lot of hoop stress, it is distributed across the length of the closure of 11.25 inches 10.76 pounds per inch, pulling together 2.07 inches of gap, which is well within the capability of a commercially available medium to heavy duty zipper. To reiterate, no special equipment or techniques have been required to this point, and none are anticipated in the construction of a full sized MCP suit arm.

The prototype suit arms were constructed with [a selected non-elastic material][24] to prevent stretch in areas defined as lines of non-extension. While this was not strictly necessary on the prototype arm, this extra step give us valuable data on how the non-elastic sections interact with the elastic sections and closures as the arm moved through the arm motion cycle, and should be representative of the way a full size arm will react under similar conditions.

Multiple configurations of [the selected elastic material] were tested. Using the first DAQ, we got indications that the configuration was a success, but noticed that the system did not perform as expected[25], and thus the resulting file had poor resolution and repeatability in some cases. This lack of repeatability, once closely examined was not due to quality control issues as originally thought, but rather was an increase in statistical noise in some configurations of the sandwiched elastic materials. It became clear that something was happening at a rate much higher than the DAQ was capable of detecting.

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[24] The selected materials are not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).

[25] "Arduino - AnalogRead." Arduino - AnalogRead. Accessed October 18, 2014. http://arduino.cc/en/Reference/AnalogRead.

The new DAQ clearly identified the problem. In certain configurations of the elastic material sandwich, the weave of the material would bind momentarily between layers resulting is small and rapid spikes of pressure on the inside and outside of the arm as it moved through the range of motion. Through a process of trial and error, the proper configuration was discovered that minimized this effect. In the process, this optimization also reduced the internal friction, reducing wear, and thus the expected operational lifespan of the suit.

The result is that the final version of the prototype suit arm was able to maintain 5 PSI as reported by the DAQ +/- 0.08 PSI during a normal range of motion (90 degrees); fluctuations remain within a 1.6% margin. Research performed at the University of California, San Diego[26] clearly indicates that a healthy person can tolerate a negative pressure differential between the inside to outside of the body (decompression) in the dorsal region of the hand (a particularly sensitive area) of nearly 2 PSI with mild discomfort. Anecdotal evidence indicates that differential compression of 5PSI and beyond is not an issue for extended periods of time.

Since the variance or the prototype MCP suit arm has been demonstrated to remain within 0.08 PSI, or 1/25th of the comfort range within the normal range of motion with a mild rise in the compression as the elbow joint goes beyond 90 degrees, it is doubtful

[26] Tanaka, Kunihiko, Ryan Limberg, Paul Webb, Mike Reddig, Christine Jarvis, and Alan Hargens. "Mechanical Counter Pressure on the Arm Counteracts Adverse Effects of Hypobaric Exposures." NASA Technical Reports Server. August 1, 2003. Accessed August 7, 2014. http://ntrs.nasa.gov/search.jsp?R=20040087560

that a human subject would notice the slight variations in mechanical counter pressure experienced within the anticipated range of motion. Given this ability of the passive layer to adapt to the full range of anticipated motion, no active layer was constructed for the test arm as it was clearly not needed.

While it is unknown whether or not the full sized suit will require an active layer, it is the hope of the research team that an active layer is unneeded; that all motion may be accommodated with layers of [the selected materials] strategically placed, arranged, and quilted to other layers of the elastic and non-elastic materials. This would mean the final version MCP suit could be constructed without an active layer at all, and this simplicity would equate into higher reliability and lower cost.

Future work includes a properly executed flammability tests on the materials, which should be done without delay. Following this, tests should be performed on either a full size test jig or a live subject with the fully implemented suit implemented as a scaled up version of the 4:1 scale model prototype. Human joints and soft tissues require support in ways which cannot be adequately simulated by the methods used to date[27]. Continuation of the research must therefore involve the development of a full size, wearable, and functional prototype MCP suit.

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[27] Schmidt, Patricia. "An Investigation of Space Suit Mobility with Applications to EVA Operations." DSpace@MIT:. January 1, 2001. Accessed November 17, 2014. http://dspace.mit.edu/bitstream/handle/1721.1/8105/51284116.pdf?sequence=1.

A fully operational suit requires quite a bit of time and money to engineer the life support system alone. It should be noted that it is not strictly necessary to implement a full life support system or test the completed suit in a vacuum at first. Since the suit operates by mechanical counter pressure offsetting the pressure differential between ambient and the gases supplied to breathe, it would be a much easier and safer test to simply provide breathable compressed air at 5 PSI above ambient levels and wear the suit. Once this check passes and a life support system is developed, then and only then would it be time to test the suit in a vacuum chamber.

Once fully tested, the resulting suit should be tested along with other space suits of all designs in real-world conditions performing tasks both intricate and strenuous. The point is to push the limits of what the suit and the wearer can do in order to determine how designs may be improved and resolve any safety concerns in a controlled environment. Examples of the tasks to be performed in the suits include swimming unassisted, climbing a rugged mountain, repairing an electrical connector, and crossing a dune region.

Silsuit is designed to be a modular system with the MCP suit as the inner layer, similar to thermal undergarments worn when working in cold conditions. Additional garments are worn on top for both general and task specific uses. This creates increased flexibility and adaptability for the suit system since the wearer may choose from an array of task specific garments. An example of these garments include a thermal protection layer for working outside in a vacuum, protection garments to be worn while welding or performing other tasks which may damage the suit, or an overgarment to protect against windblown dust and penetrating regolith.

A side benefit of the modular design of SilSuit is that an ecosystem is created where overgarments for the suit may be produced by a wide variety of companies which might not be qualified or comfortable with the manufacture of a full space suit. This would provide economic benefit to a wider array of small businesses, increasing the economic health of their communities, as well as increasing public buy-in of space activities which they will see as their own.

Conclusion and Project Termination

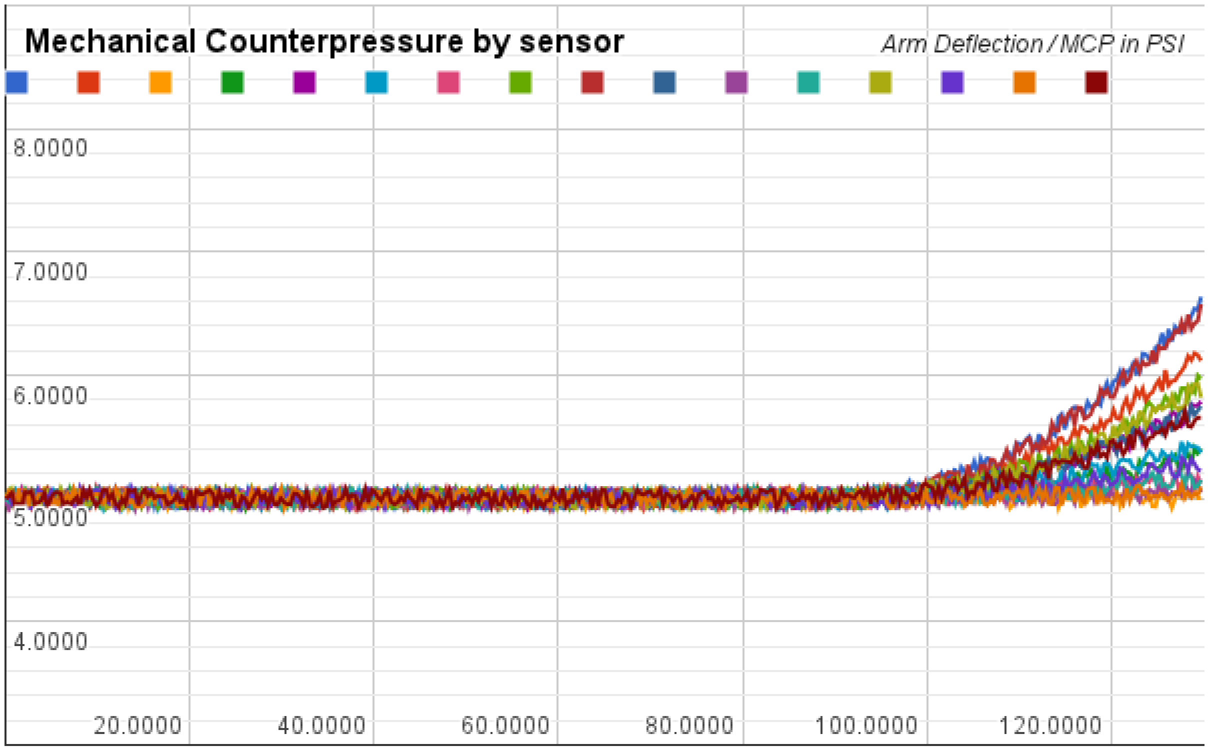
Research and data from previous mechanical counter pressure (MCP) suit development efforts from the last 50 years have been invaluable, and when combined with modern materials and methods yield striking results. The research outlined in this document has clearly shown that modern materials are capable of being made into a MCP space activity suit, and further development along these lines will continue to bear fruit.

Future plans relating to this research should include the construction of a full scale and complete MCP suit to fully test the materials and methods pioneered in this research activity. To that end, it is our recommendation that the third generation of SilSuit, a fully functional full size MCP space activity suit be fully funded in order to develop the next generation of protection garment with increased reliability, flexibility, and cost effectiveness over the existing array of gas pressure suits.

The results of this research are to be publically released in a export control compliant format and specifically sent to SpaceGAMBIT and Luna Desic. The full documentation, which will be export controlled pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR), is to be retained by Issyroo Farms LLC. for internal use, provided to DARPA personnel, and Ethan Chew, the primary researcher at Luna Desic who is a verified US person pursuant to Issyroo Farms export control regulations and a signatory of Issyroo Farms Technology Control Plan (TCP).

Upon completion of the project as indicated by SpaceGAMBIT and/or DARPA representatives, the project files, including all test data will be archived by removing the dedicated hard disk from the server, labeling it to indicate the nature and sensitivity of the contents, and placing it in Issyroo Farms' vault. It is our hope that this data will be useful as the development of a practical MCP suit continues.

Appendix A, Old DAQ test dataset and graph



Partial Sample Dataset from Previous DAQ (Arduino-based)

Position/Sensor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000
0.3516	4.9473	5.0340	5.0108	5.0778	5.0360	5.0682	4.9617	4.9486	4.9715	4.9565	5.0708	4.9895	4.9414	4.9832	5.0115	4.9695
0.7031	4.9802	4.9985	5.0602	5.0240	4.9975	4.9228	5.0509	5.0524	5.0191	4.9222	5.0759	5.0261	4.9872	4.9256	4.9865	4.9246
1.0547	5.0032	4.9375	5.0132	4.9515	4.9453	5.0347	4.9927	5.0151	5.0242	4.9550	4.9962	5.0302	4.9346	4.9697	5.0547	4.9659
1.4063	5.0615	4.9749	5.0032	4.9426	4.9383	4.9302	4.9897	4.9408	4.9875	4.9405	5.0259	5.0587	5.0305	5.0313	5.0064	5.0186
1.7578	4.9401	5.0734	4.9828	5.0667	5.0398	4.9440	5.0315	5.0705	5.0201	4.9294	4.9416	5.0366	4.9873	4.9714	5.0438	4.9819
2.1094	5.0621	4.9989	4.9696	5.0101	4.9659	4.9719	4.9672	4.9698	5.0518	4.9266	4.9585	4.9580	5.0656	5.0154	5.0071	5.0449
2.4609	4.9867	4.9522	4.9392	5.0639	4.9427	5.0302	4.9560	5.0595	4.9415	5.0701	5.0492	5.0259	4.9659	5.0694	4.9420	4.9761
2.8125	5.0793	5.0079	4.9440	4.9264	4.9974	4.9937	4.9350	4.9515	4.9613	5.0613	5.0126	5.0291	4.9387	5.0721	5.0057	4.9964
3.1641	4.9719	4.9299	5.0729	4.9413	4.9217	4.9417	4.9800	4.9648	4.9329	4.9639	5.0214	5.0019	5.0312	5.0235	4.9845	5.0187
3.5156	5.0661	4.9725	4.9315	5.0151	4.9918	4.9377	4.9550	4.9620	5.0524	5.0523	4.9442	5.0142	4.9516	5.0650	4.9922	5.0637
3.8672	4.9572	4.9298	5.0772	4.9371	4.9795	4.9207	4.9257	4.9265	5.0018	4.9436	4.9479	5.0029	5.0037	4.9202	4.9537	5.0336
4.2188	4.9993	4.9678	5.0631	5.0302	4.9912	5.0574	5.0129	5.0265	4.9789	4.9420	4.9388	5.0051	4.9298	5.0563	5.0159	5.0519
4.5703	5.0516	4.9460	4.9979	4.9942	4.9627	5.0043	4.9341	5.0499	5.0573	4.9305	4.9521	4.9547	4.9723	4.9719	4.9978	4.9938
4.9219	5.0728	4.9552	5.0685	5.0331	5.0482	5.0657	4.9520	4.9537	5.0634	4.9347	5.0562	5.0367	5.0089	4.9234	4.9832	4.9667
5.2734	5.0492	5.0085	4.9980	4.9207	4.9260	4.9630	4.9350	5.0044	5.0657	4.9970	5.0428	5.0251	4.9733	4.9834	4.9357	4.9328
5.6250	4.9827	4.9750	4.9419	4.9219	4.9629	4.9520	5.0326	4.9852	5.0688	5.0232	5.0794	5.0451	5.0091	4.9344	4.9850	5.0488
5.9766	4.9374	5.0353	5.0496	4.9480	5.0044	4.9928	5.0532	5.0524	4.9699	5.0649	5.0336	5.0363	5.0022	5.0660	4.9993	4.9286
6.3281	5.0503	4.9289	4.9364	4.9404	4.9326	4.9902	5.0713	5.0123	5.0451	5.0216	4.9879	5.0137	4.9217	4.9317	4.9446	5.0225

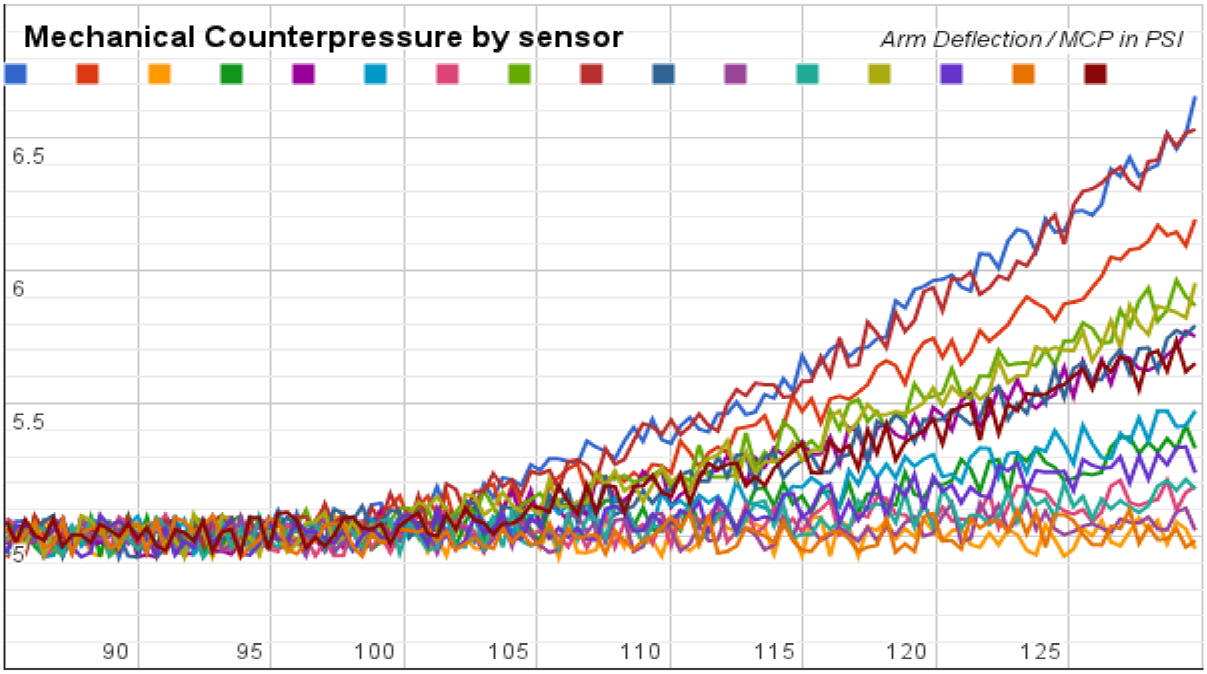
Partial Sample Dataset from Previous DAQ (Arduino-based), cont'd.

Position/ Sensor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
41.4844	5.0443	5.0641	4.9894	4.9708	5.0727	4.9585	5.0261	5.0487	5.0046	5.0313	4.9251	5.0190	5.0510	4.9602	5.0759	4.9464
41.8359	5.0290	5.0641	5.0321	4.9831	5.0613	4.9487	4.9451	5.0791	4.9852	5.0021	4.9566	5.0551	4.9702	5.0362	4.9595	4.9589
42.1875	4.9752	5.0647	4.9734	4.9729	4.9741	4.9985	5.0797	4.9531	5.0233	5.0566	4.9656	5.0706	4.9961	4.9615	4.9811	5.0315
42.5391	5.0072	5.0678	5.0787	5.0188	5.0241	5.0185	5.0363	5.0168	4.9988	4.9553	4.9316	4.9251	4.9395	4.9730	4.9317	4.9590
42.8906	5.0572	5.0648	4.9865	5.0075	4.9246	4.9356	4.9936	4.9960	5.0585	5.0551	4.9574	5.0674	5.0601	5.0077	5.0317	4.9485
43.2422	5.0610	4.9407	5.0284	5.0427	5.0096	5.0566	5.0048	5.0185	4.9336	5.0632	4.9900	4.9450	4.9841	4.9221	5.0734	4.9464
43.5938	5.0302	4.9409	5.0333	4.9823	5.0437	5.0756	4.9976	5.0391	4.9935	4.9864	5.0322	4.9283	5.0373	5.0346	4.9679	4.9995
43.9453	5.0137	4.9771	5.0182	5.0631	4.9994	4.9913	5.0384	5.0574	4.9301	5.0764	4.9920	4.9482	5.0512	5.0172	5.0589	4.9534
44.2969	5.0621	4.9260	4.9218	4.9346	4.9442	5.0377	4.9332	4.9685	5.0734	4.9218	5.0477	5.0610	4.9868	5.0695	4.9607	4.9414
44.6484	4.9299	4.9282	5.0095	5.0104	4.9749	5.0722	4.9597	4.9548	5.0164	4.9813	4.9356	5.0620	4.9656	5.0678	4.9311	4.9578
45.0000	4.9464	4.9455	5.0760	4.9598	5.0158	4.9880	4.9252	4.9337	5.0115	5.0743	4.9779	5.0031	5.0777	4.9829	5.0338	5.0760
45.3516	5.0561	5.0656	5.0432	4.9458	4.9569	4.9229	5.0648	4.9546	5.0556	5.0594	4.9650	4.9750	5.0379	4.9443	4.9967	4.9746
45.7031	4.9908	4.9731	4.9473	4.9408	5.0434	4.9562	4.9316	5.0670	4.9646	4.9940	5.0284	4.9484	5.0213	4.9403	5.0778	4.9209
46.0547	4.9795	4.9457	4.9346	4.9264	4.9410	4.9713	5.0726	5.0108	4.9348	5.0065	4.9692	4.9382	5.0223	4.9734	5.0494	4.9423
46.4063	5.0759	5.0413	5.0656	4.9772	4.9867	4.9997	5.0444	4.9827	4.9859	4.9668	4.9645	5.0775	4.9290	4.9231	5.0093	4.9822
46.7578	5.0579	5.0020	4.9346	5.0452	5.0620	4.9332	5.0021	4.9534	4.9866	4.9425	4.9938	5.0683	5.0653	4.9228	4.9603	5.0659
47.1094	5.0399	4.9702	5.0511	5.0229	5.0023	4.9914	5.0406	5.0191	5.0676	5.0133	4.9829	5.0502	4.9226	5.0479	5.0351	4.9916
47.4609	4.9506	5.0417	5.0351	5.0530	5.0176	5.0320	5.0028	5.0321	4.9621	4.9575	5.0546	5.0688	4.9945	5.0080	5.0600	4.9928
47.8125	5.0564	4.9394	4.9245	5.0182	4.9861	4.9865	4.9710	5.0484	5.0480	4.9477	4.9979	4.9916	5.0547	4.9871	4.9232	5.0544
48.1641	4.9813	5.0793	5.0308	4.9695	5.0487	4.9323	4.9481	4.9726	4.9998	5.0221	4.9593	5.0282	4.9436	5.0479	4.9521	5.0470

Note near linear relationship with minimal anomalous compression or expansion.

Position /Sensor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
60.1172	4.9814	5.0505	5.0168	5.0073	4.9402	5.0531	5.0179	5.0694	5.0657	4.9474	4.9258	5.0077	5.0590	5.0075	5.0081	5.0278
60.4688	4.9711	4.9964	4.9615	5.0451	4.9297	4.9268	5.0577	4.9211	5.0157	5.0607	5.0599	5.0496	4.9928	5.0575	4.9373	5.0503
60.8203	4.9807	4.9469	5.0122	5.0020	5.0393	5.0664	4.9705	4.9447	5.0468	4.9248	4.9858	5.0242	5.0108	5.0498	5.0284	5.0425
61.1719	5.0358	5.0725	4.9403	5.0462	5.0501	4.9764	5.0761	4.9965	5.0586	5.0025	4.9881	4.9408	5.0127	4.9845	4.9991	5.0756
61.5234	5.0418	4.9990	5.0533	4.9326	4.9310	4.9905	5.0236	5.0733	4.9294	5.0670	4.9863	5.0010	4.9418	5.0693	5.0180	4.9627
61.8750	5.0564	4.9229	4.9848	4.9461	4.9887	4.9775	5.0680	5.0260	4.9675	4.9844	4.9889	4.9555	5.0635	4.9642	5.0712	5.0734
62.2266	5.0729	4.9844	4.9709	4.9661	4.9366	5.0447	5.0453	4.9621	4.9618	4.9238	5.0263	5.0381	4.9488	4.9634	4.9332	5.0778
62.5781	4.9599	5.0585	4.9207	4.9388	5.0454	5.0659	4.9841	4.9640	4.9245	4.9634	5.0022	5.0636	5.0086	5.0623	4.9422	4.9466
62.9297	4.9796	4.9337	4.9902	4.9741	4.9721	5.0549	4.9424	4.9412	5.0758	4.9375	5.0480	4.9799	4.9246	4.9311	4.9297	4.9685
63.2813	5.0234	4.9528	4.9806	5.0616	5.0457	4.9398	4.9202	5.0502	5.0512	5.0780	4.9828	5.0444	4.9725	4.9936	4.9324	5.0443
63.6328	5.0292	5.0484	4.9821	4.9709	5.0136	5.0702	4.9388	5.0622	4.9523	4.9868	4.9888	5.0596	4.9255	5.0202	5.0401	5.0514
63.9844	4.9847	5.0753	4.9356	4.9779	5.0327	4.9741	5.0004	4.9579	4.9600	5.0789	4.9268	5.0776	4.9419	5.0677	4.9672	4.9510
64.3359	4.9299	4.9762	5.0029	5.0751	4.9323	5.0390	4.9729	5.0467	5.0288	4.9392	5.0785	5.0323	5.0430	4.9773	4.9380	5.0039
64.6875	5.0333	5.0729	5.0673	5.0446	5.0798	4.9275	5.0683	5.0326	5.0754	4.9626	5.0216	5.0106	4.9896	5.0749	5.0397	4.9975
65.0391	4.9822	5.0008	5.0168	4.9723	4.9432	5.0276	5.0601	4.9628	4.9580	5.0289	4.9404	4.9236	5.0341	5.0002	4.9240	4.9230
65.3906	5.0516	5.0768	4.9650	5.0709	4.9356	4.9997	5.0465	4.9715	5.0188	4.9911	4.9418	5.0692	5.0268	5.0219	5.0761	4.9236
65.7422	4.9705	5.0303	5.0253	5.0019	4.9304	4.9712	4.9731	5.0414	5.0433	5.0733	4.9516	5.0678	5.0191	4.9612	4.9310	4.9328
66.0938	5.0629	4.9598	4.9881	4.9610	5.0163	5.0776	5.0549	5.0192	4.9507	4.9464	5.0353	4.9472	4.9972	5.0747	4.9229	4.9633
66.4453	4.9572	5.0443	5.0386	5.0639	4.9246	5.0521	4.9515	5.0207	5.0652	5.0463	5.0560	4.9252	5.0422	5.0264	4.9968	4.9435
66.7969	5.0685	4.9637	5.0202	4.9970	4.9289	5.0405	4.9869	5.0780	5.0264	5.0157	5.0196	5.0723	5.0457	4.9893	4.9767	4.9226

Beyond 90 degrees of deflection the material begins to move beyond the linear response region.



Position /Sensor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
88.2422	4.9846	5.0136	4.9399	5.0113	5.0459	4.9357	4.9426	5.0243	4.9595	5.0626	4.9527	5.0057	4.9954	5.0063	4.9956	5.0324
88.5938	5.0259	5.0211	5.0065	5.0043	4.9401	4.9843	5.0554	4.9548	4.9455	5.0746	5.0414	4.9761	5.0426	5.0057	4.9835	4.9547
88.9453	5.0065	4.9958	4.9339	5.0464	5.0531	4.9333	4.9433	4.9548	4.9673	4.9715	5.0740	5.0013	5.0709	4.9710	4.9514	5.0239
89.2969	4.9453	4.9962	5.0640	4.9813	4.9761	4.9201	4.9366	4.9804	4.9938	4.9567	5.0675	5.0209	5.0021	5.0256	5.0791	4.9386
89.6484	5.0624	4.9480	4.9594	5.0136	4.9625	4.9207	5.0183	5.0508	4.9717	5.0162	5.0796	4.9325	4.9356	5.0000	4.9899	5.0694
90.0000	5.0396	4.9431	5.0163	4.9557	4.9436	5.0005	4.9927	4.9771	5.0019	4.9638	4.9879	4.9894	5.0672	5.0400	4.9437	4.9340
90.3516	4.9588	5.0657	5.0267	5.0627	5.0398	4.9822	4.9417	5.0402	5.0395	5.0295	4.9553	4.9374	5.0075	4.9414	4.9369	5.0015
90.7031	5.0689	5.0057	5.0055	4.9386	4.9439	4.9916	5.0237	4.9769	5.0424	4.9204	4.9295	5.0336	5.0729	5.0500	5.0406	4.9482
91.0547	5.0758	4.9715	5.0036	5.0554	4.9869	5.0305	4.9428	5.0058	4.9766	4.9864	4.9586	4.9318	5.0736	5.0671	4.9903	5.0675
91.4063	4.9442	5.0607	4.9628	4.9835	5.0454	4.9335	5.0282	4.9335	5.0679	5.0766	4.9350	4.9696	5.0021	5.0760	4.9479	5.0603
91.7578	4.9404	5.0014	5.0674	4.9732	5.0410	5.0276	4.9437	4.9746	5.0470	4.9652	5.0655	5.0795	4.9393	5.0650	4.9922	4.9327
92.1094	5.0088	4.9572	5.0299	4.9804	4.9874	5.0359	4.9732	5.0412	4.9738	4.9379	5.0510	4.9481	5.0556	5.0614	5.0473	4.9804
92.4609	5.0404	4.9872	5.0389	5.0805	5.0663	5.0504	5.0597	5.0651	5.0653	4.9907	5.0531	5.0194	5.0589	4.9831	5.0608	5.0495
92.8125	5.0488	5.0039	4.9423	5.0275	4.9503	5.0391	5.0000	4.9259	5.0763	4.9340	4.9560	4.9506	5.0571	5.0037	4.9464	5.0137
93.1641	4.9610	5.0450	4.9914	4.9358	5.0248	4.9294	5.0046	5.0594	4.9708	5.0362	5.0119	5.0456	5.0633	4.9311	4.9290	5.0384
93.5156	4.9418	5.0767	4.9516	5.0384	5.0357	5.0687	4.9757	5.0683	5.0672	5.0283	4.9449	4.9693	5.0314	5.0229	4.9870	5.0798
93.8672	5.0041	4.9731	5.0318	5.0014	5.0361	5.0420	4.9710	4.9758	4.9419	4.9903	5.0653	4.9803	4.9750	5.0598	4.9307	4.9666
94.2188	4.9823	4.9897	4.9678	5.0397	4.9886	4.9638	4.9929	5.0796	5.0932	5.0171	4.9275	5.0815	4.9649	5.0405	4.9554	5.0665
94.5703	5.0554	5.0051	5.0691	5.0407	4.9683	5.0603	4.9748	5.0228	5.0719	4.9510	4.9568	4.9428	4.9870	4.9776	4.9911	5.0728
94.9219	5.0426	5.0448	4.9210	5.0642	4.9964	5.0854	4.9942	4.9455	5.0110	5.0237	4.9986	5.0612	4.9860	5.0267	4.9651	5.0286

Note that the compression levels remain within tolerance through the anticipated elbow mobility range of 130 degrees of deflection.

Position/ Sensor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
123.3984	6.0808	5.8350	4.9871	5.2433	5.5384	5.2579	5.1208	5.7314	6.0338	5.5966	5.1031	5.1471	5.6192	5.1361	5.0226	5.4653
123.7500	6.2152	5.8255	4.9870	5.2773	5.4633	5.2300	5.1796	5.6929	6.1538	5.5438	5.1196	5.0882	5.5693	5.1976	5.1040	5.4417
124.1016	6.1787	5.9475	5.0025	5.2669	5.4796	5.3360	5.0692	5.6892	6.0558	5.4913	5.0143	5.0807	5.5976	5.2428	5.0605	5.4914
124.4531	6.2555	5.9207	5.0338	5.2960	5.6278	5.2990	5.1191	5.6778	6.1299	5.4889	5.1290	5.1240	5.7474	5.2824	5.0094	5.4855
124.8047	6.1886	5.8881	5.0655	5.1910	5.6371	5.3476	5.1820	5.7261	6.2239	5.5235	5.1109	5.1129	5.7574	5.2043	5.0767	5.5159
125.1563	6.1867	5.8846	5.0015	5.3414	5.5925	5.3143	5.0575	5.6998	6.2583	5.5932	4.9945	5.2093	5.6455	5.2955	5.0747	5.5478
125.5078	6.2891	6.0091	4.9504	5.2091	5.5802	5.4066	5.0815	5.6800	6.2659	5.5901	5.1105	5.1703	5.7088	5.2950	4.9808	5.5288
125.8594	6.2363	5.9388	4.9337	5.2499	5.5714	5.2822	5.1270	5.7634	6.2577	5.6544	4.9845	5.1516	5.7449	5.3018	5.0190	5.5750
126.2109	6.2396	6.0386	4.9701	5.2954	5.6629	5.3856	5.1531	5.8399	6.2682	5.5417	5.0732	5.0965	5.7396	5.1841	5.0359	5.5139
126.5625	6.2980	6.0190	4.9313	5.2352	5.6291	5.3161	5.1481	5.8200	6.3508	5.6256	5.0645	5.1718	5.8072	5.2543	5.0392	5.6440
126.9141	6.3970	6.0418	5.0444	5.3019	5.6162	5.4397	5.2080	5.8245	6.3070	5.6055	5.0221	5.1559	5.7383	5.2382	5.0967	5.5297
127.2656	6.3369	6.0211	4.9712	5.3578	5.5920	5.3737	5.2147	5.9130	6.3428	5.6575	5.0491	5.1020	5.8289	5.1839	5.0118	5.6828
127.6172	6.3918	6.0185	5.0779	5.3078	5.6142	5.3578	5.1207	5.8037	6.4001	5.6191	5.0939	5.1810	5.8506	5.2226	4.9638	5.6195
127.9688	6.5122	6.0888	5.0614	5.2939	5.6865	5.3873	5.0766	5.8978	6.3999	5.6744	5.1389	5.1242	5.8663	5.2828	5.0452	5.6032
128.3203	6.5435	6.1477	5.0011	5.3256	5.7220	5.4076	5.2211	5.8805	6.4532	5.7299	5.1515	5.2239	5.8306	5.2353	4.9848	5.6899
128.6719	6.5127	6.1794	4.9389	5.3883	5.7153	5.4439	5.1715	5.8556	6.4631	5.7109	5.0640	5.2093	5.8726	5.2346	5.0735	5.6589
129.0234	6.4796	6.1019	5.0235	5.2847	5.7875	5.4575	5.1917	5.9444	6.5115	5.7779	5.0179	5.1681	5.7885	5.2798	5.0737	5.6226
129.3750	6.5334	6.1328	4.9824	5.2728	5.7406	5.3718	5.1416	5.8721	6.4578	5.6517	5.1263	5.1628	5.9304	5.2200	4.9676	5.7430
129.7266	6.6227	6.1379	4.9585	5.3388	5.7593	5.3968	5.1996	6.0184	6.6005	5.7724	5.0875	5.1484	5.9634	5.3176	5.0016	5.6442

Appendix B, Abbreviated Flammability Test

As a primary materials criteria, all MCP suit components must meet the flammability guidelines as defined in NASA-STD-6001B[28]. While the tests defined within the specification were *generally* followed, some abbreviation and approximation of the testing regimen was necessary as cost and time control measures. This adaptation was only justified during the materials selection phase, since the finished prototype must be fully tested by an approved and certified facility.

It should be noted that this test is far more rigorous than the actual environment SilSuit will see. A pure oxygen environment of 5 PSI is the maximum the suit is expected to see, but without a vacuum chamber to drop the pressure of the purged and filled test chamber to 5 PSI of pure O2, the best that can be performed would be a simple ambient atmosphere test (which was run as a baseline). Instead, the test used pure O2 at an ambient pressure of around 12 PSI since the test lab is at around 7000 feet ASL.

The test was performed in a lab with a fire suppression system, a fume hood with polycarbonate scatter shield, stainless steel sink, and a heat resistant ceramic work surface.

[28] "Flammability, Offgassing, and Compatibility Requirements and Test Procedures." NASA Technical Standards Program. August 26, 2011. Accessed November 17, 2014. https://standards.nasa.gov/documents/detail/3314908.

A pyrex graduated cylinder which had sufficient vertical height to facilitate the test was selected for use as a test chamber.

A loose coil of standard copy machine paper fashioned from a strip ½" wide and 11" long and tamped gently to the bottom of the test chamber. Each test required one of these to test burning debris transfer, so each material tested required 5 of these coils to be fashioned.

A O2 safe gas line was placed in the test chamber with the exit aperture at the bottom of the cylinder in close proximity to the paper coil. To ensure gas flow, the end was cut in a V which would allow gas to exit the sides of the gas line at the bottom of the chamber.

The gas line is attached to a small O2 bottle through a ¼ turn ball valve. During use, the O2 bottle's flow valve is kept to a low flow rate (about ½ turn from fully closed).

A loose plug was fashioned from a ½ inch length of PTFE rod to hold the material under test vertically in the chamber while also holding electrodes to be positioned on either side of the material near the bottom. This plug allowed gas flow, secured the gas line, and suspended the material 1 inch from the paper coil. No attempt was made to make this plug gas tight, as this could yield a dangerous pressure build up during combustion.

A high voltage power supply is connected to the electrodes. Set to 18,000 VDC at 20 uA, it is switched on for a one second period.

A small votive candle was placed near the base of the test cylinder on a length of scrap 18ga steel sheeting (3 by 14 inches) so that it could be moved to a safe location while maintaining a safe distance from the flame and paraffin fuel. The purpose of the candle is to determine if GOX is overflowing the test chamber, which indicates a 100% GOX environment within the chamber since the oxygen has displaced the other gasses.

Materials under test were cut in strips ¾ by 8 inches long. 5 such samples are required for each material tested.

<u>Test Procedure:</u>

1. Double check safety measures including the gas valve position (off), gas shutoff valve (off), and location of fire suppression equipment.
2. Attach a sheet of the test material to the clip making sure the lower end of the fabric is between the electrodes.
3. Place the paper coil in the bottom of the test chamber taking care not to crush the material.
4. Lower the gas line to the bottom of the test chamber taking care not to crush the paper coil.

5. Place the PTFE plug on top of the test cylinder. The end of the fabric must be between the electrodes, and the end of the fabric ½ inch above the paper coil.
6. Secure the gas line to the PTFE plug to prevent motion during gas discharge or combustion.
7. Light the votive candle and place it on the steel sheet near the test chamber. Position the steel sheet in such a way that it can be used to move the candle.
8. Slowly open the ¼ turn gas valve, then open the O2 flow valve ½ turn. Observe the votive candle to changes in burn rate.
9. When the votive candle flares, use the steel sheet to relocate the candle to the sink next to the vent hood.
10. Close the vent hood scatter shield and ventilation.
11. Turn on the high voltage power supply for a period of one second. The material is expected to catch fire.
12. Allow any combustion to continue until it self extinguishes, noting the type of burn, amount of material burned, and the condition of the paper coil.
13. Enter the data in the appropriate spreadsheet cell. If there was anything noteworthy, make note of this in the notes section.
14. Allow the test apparatus to cool completely and disassemble. Inspect all components for damage. Wash and dry the test chamber to remove residue.
15. Repeat this test 5 times for each material. Ignition of the paper coil or lack of self extinguishment of a single test constitutes a failure of the material under test.

Test results:

Identification of specific materials is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR). Each material sample will be identified by its elastic characteristic and letter designation, eg. Non-elastic B.

Material	Baseline	Flam. test	Burning debris	Notes:
Non-elastic A	PASS	FAIL	FAIL	Material violently burst into flames, immediately igniting the paper.
Non-elastic B	PASS	PASS	PASS	Burned traveling upward approximately 2 inches before self extinguishing.
Non-elastic C	PASS	PASS	FAIL	Burning material dripped on the paper igniting it immediately.
Elastic A	PASS	PASS	PASS	Burned upward 1 inch before self extinguishing, but fraying rendered the material useless.
Elastic B	PASS	FAIL	FAIL	Burning material dripped on the paper igniting it immediately.
Elastic C	PASS	FAIL	PASS	Material completely burned, but did not ignite the paper.
Elastic D	PASS	PASS	PASS	Burned traveling upward approximately 2 inches before self extinguishing.

Due to the clear results, non-elastic material B and elastic material D were selected for the project by default. It should be noted that this test should be revisited and performed properly according to NASA STD 6001B rather than this simplified and abbreviated test which likely more stringent in most cases, but may be non-representative of actual conditions.

Appendix C, Test Structure Construction Details

This data is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).

Appendix D, Test Article Construction Details

This data is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).

Appendix E, New DAQ Test Dataset and Graph

This data is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).

Appendix F, Future Development Plan (preliminary)

This data is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).

Appendix G, Future Development Budget (preliminary)

This data is not available in the public document due to export controls and subject to restrictions pursuant to USC title 15 part 774 aka. the Commerce Control List (CCL), bearing ECCN 9A505.f, and formerly under CFR 121 Category X paragraphs (a)(4), (d), (e), (f)(2), and (f)(3), aka. the International Traffic in Arms Regulation (ITAR).