ABSTRACT:

Mechanical counter-pressure (MCP) spacesuits allow astronauts more degrees of freedom compared to traditional suits currently being used. MCP spacesuits have an increased performance and flexibility which allows for more complex experiments and spacewalks, that can be performed successfully in future human exploration missions.

The reality of donning a full suit fulfilling the potential of the best prototypes made so far is hindered by many key technologies that are waiting for a full understanding, and therefore, the full ability to manufacture new materials with new properties. Shape memory alloy (SMA) actuators when working in series or parallel with typical, passive fabrics which are smart textiles comprised both of sensors and actuators. An actuator is a mechanical device that takes energy, in Team 12's case electrical simulation and converts it into thermomechanical motion. Shape-memory alloy (SMA) actuators use electromechanically active materials and modeling methods for their control. Team 12's proposal relates to SMA actuators that are capable of miniaturization to achieve a quick response. SMAs are not the most efficient actuators because they lose some of the input energy to heat (because they are heated resistively). Reducing power consumption is achievable by lowering the hysteresis effect, which is the energy lost during each cycle of heating and cooling, which is highly dependent on the material system and the crystallography of the transformation. The goal for this proposal focuses on defining an approach to better understand and model a linear model of hysteresis in SMA actuators. Team 12 believes they can achieve this goal of modeling which leads to a lower power consumption rate needed to activate and keep the composite fabric material in a desired state for a specific period of time.

TECHNOLOGY MERIT AND WORK PLAN:

A phenomenological model based on the theory of hysteresis operator, referred to as MKP hysteresis model,[1] has high accuracy (+\- 1C, +\- 0.5mm) modeling the non-linearities of the hysteresis in SMAs and allows for control schemes to be considered when studying hysteresis behaviour in nitinol SMA actuators. Using this model, we will be able to define ranges in temperature and displacement for a more linear hysteresis behaviour on SMAs used for MCP spacesuits, potentially reducing the power needed to activate the passive fabric. Finding the ranges where SMA hysteresis is linear will help to establish key factors that impact the low power consumption. The strain-temperature hysteresis is present in all systems incorporating SMA actuators and is a key consideration for their control.

SMA's are power hungry and prone to hysteresis. Hysteresis is a non linear behavior poorly understood in SMAs. This particular hysteresis behaviour is a byproduct of phase transitions inside the SMA due to the internal friction generated by the movement of the austenite-martensite interface and by the creation of structural defects within the alloy (austenite is a solid solution of carbon and other constituents in a form referred to as gamma iron and martensite is formed when the austenite is cooled at a high rate, leaving no time for the carbon atoms to diffuse and resulting in a very hard constituent). The best approach to attempt to lower the hysteresis in SMA used for spacesuit manufacturing is to find the linearity conditions where the system using SMA is stable. At this time, the knowledge about linearity in SMAs is very limited, and not enough research with focus on spacesuits has been done yet.

Currently, SMA actuators can be used to produce the desired requirements for a successful MCP spacesuit: Controllable active counter-pressure up to 34.3 kPa, exceeding the requirement for EVA life support (29.6 kPa). Prototypes which incorporated fabrics with linear properties closely matched analytic model predictions (4.1%/ 2 10.5% error in passive/active pressure predictions); pressure non-uniformities were observed due to friction and the rigid SMA cartridge structure[2]

The current state of the art in power consumption of Shape Memory Alloys (NiTi) is 27 W of power to reach 29kPa (⅓ g) for 9 seconds for a strain of 3.81 cm. Team 12 milestones come in two folds. First, understanding hysteresis envelopes with major and minor loops where the linear behaviour of SMA conduces and enables lower power consumption (Fig. 1). The temperatures needed for the shape memory effects must be reduced and provide for longer times of the desired effect of displacement in the used fabric. Secondly, after having a better understanding of the martensite-austenite loop.

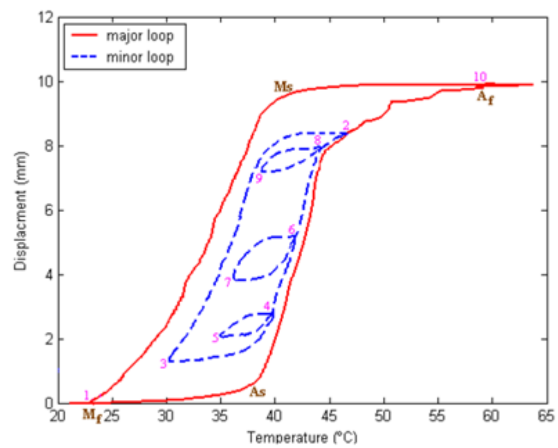

Fig. 1. A typical hysteresis curve of an SMA actuator by the example of a NiTi tension spring

1

Figure 1.

Currently, the known voltage - force displacement behaviour of SMAs is that an immediate rise in pressure after the voltage step input, equalizing to a steady state value, followed by a decay once power is removed. [2]

The steady state pressure value depends on, and therefore can be controlled by, the magnitude of power applied to the system. This power dependency is captured analytically through the SMA shear modulus term, which varies depending on the relative austenite - martensite ratio in the material. These alloys have intrinsic characteristics that make the control and manipulation of SMAs for spacesuit manufacturing a very complex task. The identified technical challenges are:

- Isolating the components of the Shape Memory Alloys responsible for hysteresis so we can clearly see what may be responsible for this behavior and study the different effects that changing factors such as temperature can have on it.

-Precisely quantifying how much of hysteresis comes from the process of manufacturing Shape Memory Alloys, the actual chemical make-up of the Shape Memory Alloys, or both.

Because this study is designed to better understand what causes hysteresis and the ways in which we can manipulate it, if any, to create reliable Shape Memory Alloys for spacesuits, the risk of implementation is negligible. These types of experiments have been performed before (for modeling and testing purposes) and no risks have been mentioned in the resulting papers.

There are successful prototypes of spacesuits that are promising in different areas: Mechanical counter pressure by a soft robotic layer [3], and mechanical counter pressure by SMA actuators [4]. Most attempts to come up with a functional full body spacesuit are challenged by other important underlying technologies, which are not well developed yet. Addressing these technologies by studying and understanding basic behaviour, will lead us to be able to manipulate and use known materials such as NiTi actuators in a more efficient way. After the team's search for papers on the topic of SMA and low hysteresis, the lack of research on hysteresis focused on spacesuit applications became clear. Based on the team's Subject Matter Expert's (SME) recommendation to study hysteresis behaviour in SMA as a way to reduce power consumption, we determined that we could bring the understanding on how to control and manipulate the factors involved in the hysteresis behavior to obtain a linear response. Particularly, to improve the use of SMAs for spacesuits. Reducing the power applied to obtain the needed displacement, without risking an astronaut with high temperatures can be attainable with this kind of knowledge about hysteresis.

POTENTIAL FOR MATURITY AND ALIGNMENT TO AGENCY AND NATIONAL NEEDS

SMA as actuators are very promising due to their very desirable properties: good reliability, high energy density, design simplicity, compactness in configuration, and quiet operation [1]. Our study will bring new information and further advanced development for SMAs requiring a new technology report. As they are practical to use, fields like Mechatronics and medical instrumentation are using them more. Particularly, in the spacesuit business, SMAs are the choice for every successful prototype [5]. The proceedings of this study will impact many other areas where SMAs are used: Aerospace (flight control surfaces, landing gear movement nose wheel steering, air brakes, powered doors/hatches), Automotive (braking, tappets, active suspension, active engine mounts, airbag deployment), Industrial equipment (lifting, automation), Developing Technologies (active control of structures, vibration suppression, active materials, surgical equipment, robotics, space structured deployment) and many others [6].

By studying hysteresis, we will have a better understanding of how to make SMA actuators more reliable, consume considerably less power and thus be safer for both commercial and non-commercial use. This study has a very high degree of value because NASA, for example, will be able to use this research to manufacture SMA actuators that surpass the design specifications for the ideal space suit. Team 12's proposal meets NASA's Strategic Objective 3.1 by not only adding more research for advanced materials but also research for enabling effective and safe human operations in space environments. In addition our study will be able to meet NASA'S Strategic Objective 4.1, engaging in partnership strategies, because the shape memory alloy can be used to build any equipment that needs to be flexible yet sturdy such as belts and flight control surfaces.

The application for SMA actuators stretch beyond usage in space and in fact can be found in things like golf clubs, helicopter blades and even inside arteries and veins for reinforcement. However, we can expand their applications even further with this study to increase the SMA actuators' reliability, stability, and to address processing, testing and qualification needed for large-scale application.

PROJECT MANAGEMENT APPROACH

Approach for Team 12: Qualitative Research

Team 12's management approach is one based on qualitative research. Instead of forming or conceiving a beforehand defined hypothesis, Team 12 will use a qualitative approach aimed at constructing a theoretical framework. With data analysis gathered during testing and research, Team 12 will be able to explain results in a coherent manner to better understand the hysteresis phenomena in SMA actuators. The methodology to be used is called Grounded Theory. It is "generating a theory from data means that most hypotheses and concepts not only come from the data, but are systematically worked out in relation to the data during the course of the research." (Glaser and Strauss, 1967). Team 12's research will be characterized by a spiral structure, in which each phase of our research is based on the previous stages so we're able to elaborate on the framework we construct. We essentially will operate as an on-going dialog between Team 12, research field, and mentors familiar with shape memory actuators. Team 12 would be able to utilize and improve our understanding of the latter. This approach, which intertwines the development of a theory together with the research process itself, it's therefore especially suitable for Team 12s investigation of hysteresis in SMAs actuators for MCP spacesuit design application.

Team 12's schedule spans just over 1 year using four phase cycles. The phase cycles are Research, Acquire, Experiment, and Implementation/ component testing. Each phase of Team 12's schedule can last several weeks to months. If the team fails to complete a phase in the allotted time, extension can be made. Team 12s project goal is to understand linear hysteresis modeling to lower power consumption in SMA actuators for spacesuit applications.

Project Schedule and Milestones (sub header)

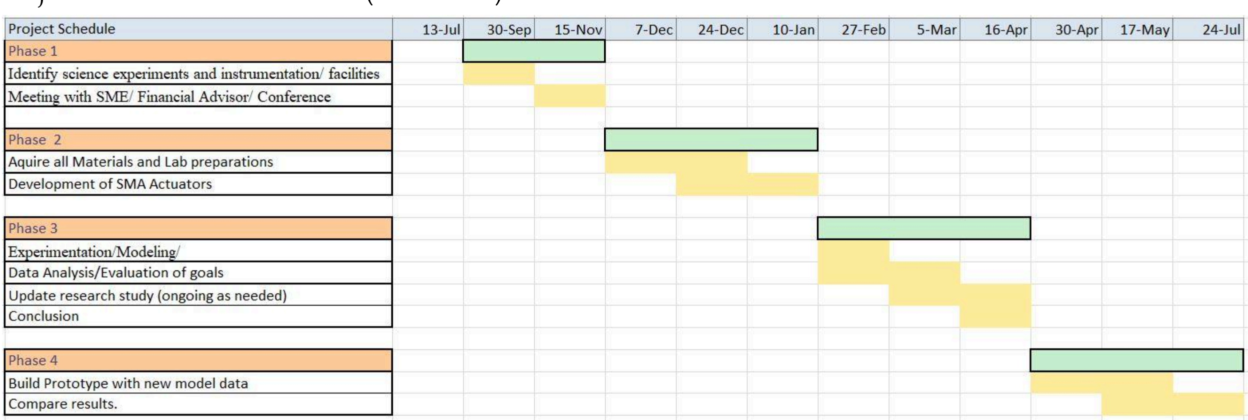

Figure 2.

Project Elements

Phase 1. Identify science experiments and instrumentation/ facilities/Identify and confirm scientists, SME, PI for the successful completion of research study.

Phase 2. Acquire all Materials and complete lab preparations.
Phase 3. Experimentation/Modeling/ Data Analysis/Evaluation of goals/ Provide necessary changes/updates to research study (ongoing as needed)/Conclusions
Phase 4. Prototype building with new model data from findings.

Roles for Teammates	Team Member	Brief Description for after Project
Principal Investigator	George Sardokie	Lead the research efforts setting goals and direction for the team.
Lead Analyst	Stephanie Buglione	Assist PI in accomplishing scientific goals and objectives. Helps run and set up modeling for data analysts team.
Project Manager	Alejandro Rincon	Plan and provides a timeline for the completion of the project on budget and on time. Assures that any risk for the project not to deliver will be addressed and mitigated.
Co-Project Manager	Celsa Canedo / Isra Ahmed	Assist Project Manager with the successful completion of goals and objectives as defined in the Schedule and Budget.
Budget & Scheduling	Stephanie Buglione	Provides a detailed list of tasks and costs for the success of the project. Works closely with PM to address and mitigate and risk or unforeseen situation that may result in delays or not delivering the desired results.
Supplies and Facilities	George Sardokie	Secures labs and tools, and provides ways and means to fulfill the successful completion of all required experiments. Makes sure all supplies are in stock and comply with the requirements of scientific objectives.
Admin	Celsa Canedo	Takes minutes of Team meetings, facilitate communication among the team. Assures that all reading materials, research content, is available and relevant to the project. Point of Communication with Subject Matter Expert.

Resources and Budget

George and Stephanie, PI and Lead Research Analyst, received the Students for the Exploration and Development of Space (SEDS) Scholarship to attend the Newspace Conference in Seattle, WA from July 16 - July 18, 2019. Scholarship covers conference fees and lodging from July 14 - July 19. They will be using this time to network the idea with private industry as well as NASA and other government agencies to produce funding for the next round of research.

Cost category	Rate	Total	Out of Pocket
Conference Registration (Scholarship)[1]	$1,399/person	$2,798	-

Airfare-George[2]	$254	$254	$254
Airfare-Stephanie[3]	$378	$378	$378
Ground Transportation[4]	$15/person	$30	$30
Meals -Breakfast and lunch included with conference fees	$15/person/day	$180	$180
Hotel (Scholarship)[5]	$304/person/night	$3,040	-
Total	-	$6,680	$842

Table I: Newspace Conference Budget (Award not used for this)

Table II shows how money would be spent on research for this proposal.

Table II budget shows how the money from the award will be used for further research on hysteresis. The rest of the $10,000 dollars will be used for further applications and the cost of visiting NASA Glenn or attending a different conference such as American Geophysical Union.

Table II: References for Budget of Research Project

3D Printer Cartridge Filament	How much does 3D filament cost? Amazon.com
Neoprene	Alibaba.com
NiTi Nitinol SMA Muscle Wire Shape Memory Allow	Nextmetal.com

1.) About NewSpace. (n.d.). Retrieved from https://spacefrontier.org/newspace2019/
2.) Alaska Airlines and United Airlines
3.) United Airlines and Spirit Airlines
4.) Plan a Trip. (n.d.). Retrieved from http://tripplanner.kingcounty.gov/
5.) Grand Hyatt Hotel

TEAMING AND WORKFORCE DEVELOPMENT:

Team Identification and Experience:

George Sarkodie
Role: *Principal Investigator*
Applicable Experience: George Sarkodie's background is Biomedical/Electrical engineering, He works in a Smart Polymer for Biomedical Applications research lab at UNT. Using shape memory polymers capable of softening and changing its shape so that the medical devices can adapt to the shape and surface topology of it surroundings. Securing electrodes in place to enable continuous recordings of motor and sensory neurons.
Celsa Canedo,

Role: Co-Project Manager
Applicable Experience: Mechanical Engineering student, with experience in Research on Dendritic Growth in half cell Zn electrodeposition on Cu hard substrate, and Data Analysis. Currently working on preparing a Database to use Anaconda Environment using Python to analyze big sets of data. Also some experience with Solid Edge and coding in Java.

Alejandro Rincón
Role: Co-Project Manager
Applicable Experience: Alejandro has a background in Aerospace Engineering. He is a build lead for the Longhorn Rocketry Association's Certification Group (University of Texas at Austin) and teaches younger students about high power rocketry construction and material makeup. He knows SolidWorks 3D CAD Design Software and can code in C++ and Matlab.

Stephanie Buglione
Role: Lead Research Analyst
Applicable Experience: Stephanie's background is in stable isotope Geochemistry. Started her own independent research at the beginning of 2018 in Condensation of Atmospheric Water Vapor on cold surfaces. Presented at the American Geophysical Union Fall 2018 Meeting. Knowledge of ArcGIS, CAD, R Studio, Matlab, X-Ray Diffraction, X-Ray Fluorescence, Triple Liquid Water Off-Axis Integrated Cavity Output Spectroscopy, Van de Graffe Particle Accelerator at WMU co-author with associated research.

Isra Ahmed
Role: VP Operations
Isra has a BS in Computer Science with a mathematics background and experience in technical writing, software development, finance and database management. Familiar with C++, Java, R Studio, and Python.

Subject Matter Expert: Dr. Alan Lai was a postdoctoral researcher at MIT until 2019. Now he has moved from academia to industry. He kindly accepted Team 12's invitation to be a SME through his friendship with Dr. Zachary Cordero at MSNE Rice University. He assisted the writing of this proposal as a guest and will not defer fees for his involvement.
Education:
2007 BEng, Metals and Materials Engineering, McGill University
2010 MEng, Resource Engineering, TUDelft
2016 PhD, Materials Science and Engineering, Massachusetts Institute of Technology
Research Interests: Shape memory alloys

Team Facilities (subheader)

Two universities have demonstrated possible interest for providing facilities for the Linear Shape Memory Alloy Actuator research. After proposal progresses, additional funding is acquired, and Team 12 conducts further networking, a permanent hub for research will be discussed and established.

The University of North Texas, Denton, TX
X Lab: Processing & Characterization of Structural Metallic Materials
Available Instruments and Processes: Optical microscopy, SEM, TEM, neutron diffraction, synchrotron X-ray diffraction and imaging, DSC, FIB, nanoindentation, and 3D atom probe

The University of Texas at Austin, Austin, TX
The Center for Mechanics of Solids, Structures and Materials
Available Instruments and Processes: In-plane biaxial shear/compression machine, Uniaxial testing machines, computerized data acquisition systems

APPENDIX ELEMENTS: (large Header)

Quad Chart: (subheader)

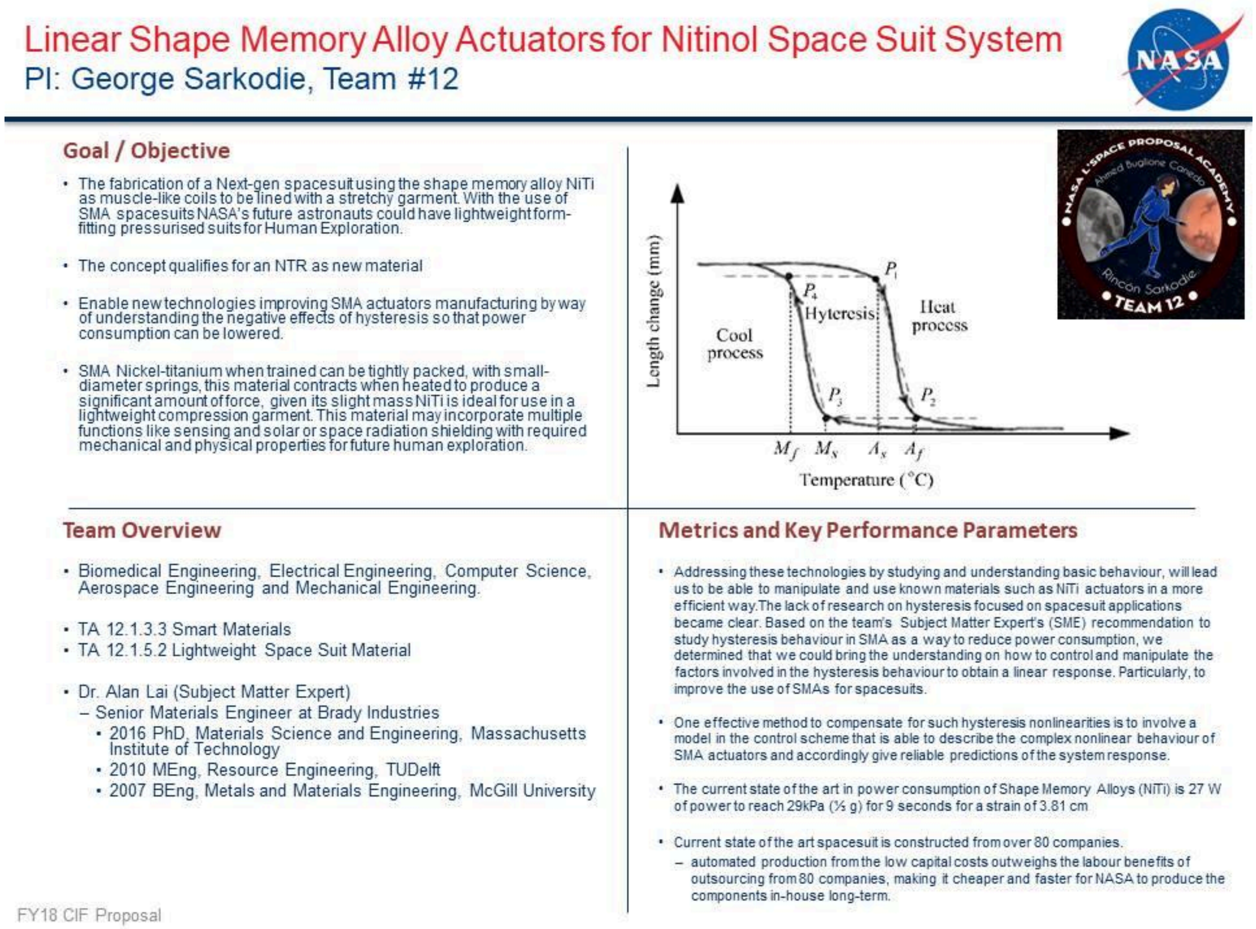

Figure 1.

References

(1) Hysteresis behaviour and modeling of SMA actuators, Hongyan Luo, Yanjian Liao, Eric Abel, Zhigang Wang and Xia Liu, Chongqing University P.R. China, University of Dundee, UK

(2) Morphing Compression Garments for Space Medicine and ExtraVehicular Activity Using Active Materials , Bradley T. Holshuh, Dava J. Newman

(3) New SmartSuit Promises a Better Fit for Astronauts, Jan McHarg, Texas A&M University College of Engineering.

(4) Skin-Wrapping SpaceSuits, Jennifer Chu MIT News Office September 18, 2014
(5) Mechanical Counter-Pressure Space Suit Design Using Active Materials, Bradley Thomas Holshuh.
(6) The Selection of Mechanical Actuators based on Performance Indices, J.E Huber , N.A Fleck and M.F Ashby
(7) NASA Strategic Plans 2018, National Aeronautics and Space Administration.

Logo Illustrator:

Cinthia A. Rincón
Studio Art BFA, Louisiana Tech University
Cinthiarincon@gmail.com

NTR Report

Team 12s NTR Report was submitted July 13th. e-NTR Number is 15599076 titled “Linear Shape Memory Alloy Actuators for Nitinol Spacesuit System.

National Aeronautics and Space Administration

Disclosure of Invention and New Technology (Including Software)

Form Approved O.M.B. NO. 2700-0009

DATE

CONTRACTOR CASE NO.

NASA CASE NO. (OFFICIAL USE ONLY)

This is an important legal document. Carefully complete and forward to the Patent Representative (NASA in-house innovation) or New Technology Representative (contractor/grantee innovation) at NASA. Use of this report form by contractor/grantee is optional; however, an alternative format must at a minimum contain the information required herein. NASA in-house disclosures should be read, understood and signed by a technically competent witness in the witness signature block at the end of this form. In completing each section, use whatever detail deemed appropriate for a "full and complete disclosure." Contractors/Grantees please refer to the New Technology or Patent Rights – Retention by the Contractor clauses. When necessary, attach additional documentation to provide a full, detailed description.

1. DESCRIPTIVE TITLE

Linear Shape Memory Alloy Actuators for Nitinol Spacesuit System

2. INNOVATOR(S) *(For each innovator provide: Name, Title, Work Address, Work Phone Number, and Work E-mail Address. If multiple innovators, number each to match Box 5.)*

George Sarkodie, Principal Investigator,
UNT College of Engineering
Department of Biomedical Engineering
3940 N. Elm Street Ste. B131
Denton, TX 76207-7102

3. INNOVATOR'S EMPLOYER WHEN INNOVATION WAS MADE *(For each innovator provide: Name, Division and Address of Employer, Organizational Code/Mail Code, and Contract/Grant Number if applicable. If multiple innovators, number each to match Box 5.)*

Arizona State University,
L' Space Academy
Tempe, AZ, 85281

4. PLACE OF PERFORMANCE *(Address(es) where innovation made)*

Department of Biomedical Engineering
UNT College of Engineering
3940 N. Elm Street Ste. B131
Denton, TX 76207-7102

5. EMPLOYER STATUS *(choose one for each innovator)*

Innovator #1: CU
Innovator #2:
Innovator #3:
Innovator #4:

GE = Government
CU = College or University
NP = Non-Profit Organization
SB = Small Business Firm
LE = Large Entity

6. ORIGIN *(Check all that apply and provide all applicable numbers. If multiple Contracts/Grants, etc., list Contract/Grant Numbers in Box 3 with applicable employer information.)*

- ☐ NASA In-house Org. Mail Code — WBS
- ☐ Grant/Cooperative Agreement No. — WBS
- ☐ Prime Contract No. — WBS
  - Task No. Report No.
- ☐ Subcontractor; Subcontract Tier — WBS
- ☐ Joint Effort *(contractor, subcontractor and/or grantee contribution(s), and NASA in-house contribution)*
- ☐ Multiple Effort *(multiple contractor, subcontractor and/or grantee contributions, no NASA in-house contribution)*
- ☒ Other (e.g., Space Act Agreement, MOA) No. — WBS

7. NASA CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE *(COTR)*

8. CONTRACTOR/GRANTEE NEW TECHNOLOGY REPRESENTATIVE *(POC)*

NASA FORM 1679 Nov 2012 PREVIOUS EDITION IS OBSOLETE.

Page 1 of 5

9. BRIEF ABSTRACT *(A general description of the innovation which describes its capabilities, but does not reveal details that would enable duplication or imitation of the innovation.)*

Mechanical counter-pressure (MCP) spacesuits allow astronauts more degrees of freedom compared to traditional suits currently being used. MCP spacesuits have an increased performance and flexibility which allows for more complex experiments and spacewalks, that can be performed successfully in future human exploration missions.

The reality of donning a full suit fulfilling the potential of the best prototypes made so far is hindered by many key technologies that are waiting for a full understanding, and therefore, the full ability to manufacture new materials with new properties. Shape memory alloy (SMA) actuators when working in series or parallel with typical, passive fabrics which are smart textiles comprised both of sensors and actuators. An actuator is a mechanical device that takes energy, in this case electrical simulation and converts it into thermostatically motion. Shape-memory alloy (SMA) actuators use electromagnetically active materials and modeling methods for their control. Sarkodie's proposal relates to SMA actuators that are capable of miniaturization to achieve a quick response. SMAs are not the most efficient actuators because they lose some of the input energy to heat (because they are heated resistively). Reducing power consumption is achievable by lowering the hysteresis effect, which is the energy lost during each cycle of heating and cooling, which is highly dependent on the material system and the crystallography of the transformation. The goal for this proposal focuses on defining an approach to better understand and model a linear model of hysteresis in SMA actuators. Sarkodie's believes he can achieve this goal of modeling which leads to a lower power consumption rate needed to activate and keep the composite fabric material in a desired state for a specific period of time.

SECTION I – DESCRIPTION OF THE PROBLEM OR OBJECTIVE THAT MOTIVATED THE INNOVATION'S DEVELOPMENT *(Enter as appropriate: A. – General description of problem/objective; B. – Key or unique problem characteristics; C. – Prior art, i.e., prior techniques, methods, materials, or devices performing function of the innovation, or previous means for performing function of software; and D. – Disadvantages or limitation of prior art.)*

A phenomenological model based on the theory of hysteresis operator, referred to as MKP hysteresis model,(1) has high accuracy (+\- 1C, +\- 0.5mm) modeling the non-linearities of the hysteresis in SMAs and allows for control schemes to be considered when studying hysteresis behaviour in nitinol SMA actuators. Using this model, we will be able to define ranges in temperature and displacement for a more linear hysteresis behaviour on SMAs used for MCP spacesuits, potentially reducing the power needed to activate the passive fabric. Finding the ranges where SMA hysteresis is linear will help to establish key factors that impact the low power consumption. The strain-temperature hysteresis is present in all systems incorporating SMA actuators and is a key consideration for their control.

SMA's are power hungry and prone to hysteresis. Hysteresis is a non linear behavior poorly understood in SMAs. This particular hysteresis behaviour is a byproduct of phase transitions inside the SMA due to the internal friction generated by the movement of the austenite-martensite interface and by the creation of structural defects within the alloy (austenite is a solid solution of carbon and other constituents in a form referred to as gamma iron and martensite is formed when the austenite is cooled at a high rate, leaving no time for the carbon atoms to diffuse and resulting in a very hard constituent). The best approach to attempt to lower the hysteresis in SMA used for spacesuit manufacturing is to find the linearity conditions where the system using SMA is stable. At this time, the knowledge about linearity in SMAs is very limited, and not enough research with focus on spacesuits has been done yet.

Currently, SMA actuators can be used to produce the desired requirements for a successful MCP spacesuit: Controllable active counter-pressure up to 34.3 kPa, exceeding the requirement for EVA life support (29.6 kPa). Prototypes which incorporated fabrics with linear properties closely matched analytic model predictions (4.1%/ 2 10.5% error in passive/active pressure predictions); pressure non-uniformities were observed due to friction and the rigid SMA cartridge structure.(2)

The current state of the art in power consumption of Shape Memory Alloys (NiTi) is 27 W of power to reach 29kPa (⅓ g) for 9 seconds for a strain of 3.81 cm.

SECTION II – TECHNICALLY COMPLETE AND EASILY UNDERSTANDABLE DESCRIPTION OF INNOVATION DEVELOPED TO SOLVE THE PROBLEM OR MEET THE OBJECTIVE *(Enter as appropriate; existing reports, if available, may form a part of the disclosure, and reference thereto can be made to complete this description: A. – Purpose and description of innovation/software; B. – Identification of component parts or steps, and explanation of mode of operation of innovation/software preferably referring to drawings, sketches, photographs, graphs, flow charts, and/or parts or ingredient lists illustrating the components; C. – Functional operation; D. – Alternate embodiments of the innovation/software; E. – Supportive theory; F. – Engineering specifications; G. – Peripheral equipment; and H. – Maintenance, reliability, safety factors.)*

Sarkdie's proposal looks for hysteresis envelopes with major and minor loops where the linear behaviour of SMA conduces and enables lower power consumption. The temperatures needed for the shape memory effects must be reduced and provide for longer times of the desired effect of displacement in the used fabric.

Currently, the known voltage - force displacement behaviour of SMAs is that an immediate rise in pressure after the voltage step input, equalizing to a steady state value, followed by a decay once power is removed. (2)

The steady state pressure value depends on, and therefore can be controlled by, the magnitude of power applied to the system. This power dependency is captured analytically through the SMA shear modulus term, which varies depending on the relative austenite - martensite ratio in the material. These alloys have intrinsic characteristics that make the control and manipulation of SMAs for spacesuit manufacturing a very complex task. The identified technical challenges are:

- Isolating the components of the Shape Memory Alloys responsible for hysteresis so we can clearly see what may be responsible for this behavior and study the different effects that changing factors such as temperature can have on it.

-Precisely quantifying how much of hysteresis comes from the process of manufacturing Shape Memory Alloys, the actual chemical make-up of the Shape Memory Alloys, or both.

SECTION III – UNIQUE OR NOVEL FEATURES OF THE INNOVATION AND THE RESULTS OR BENEFITS OF ITS APPLICATION *(Enter as appropriate: A. – Novel or unique features; B. – Advantages of innovation/software; C. – Development or new conceptual problems; D. – Test data and source of error; E. – Analysis of capabilities; and F. – For software, any re-use or re-engineering of existing code, use of shareware, or use of code owned by a non-federal entity.)*

There are successful prototypes of spacesuits that are promising in different areas: Mechanical counterpressure by a soft robotic layer, and mechanical counter pressure by SMA actuators. Most attempts to come up with a functional full body spacesuit are challenged by other important underlying technologies, which are not well developed yet. Addressing these technologies by studying and understanding basic behaviour, will lead us to be able to manipulate and use known materials such as NiTi actuators in a more efficient way. After the team's search for papers on the topic of SMA and low hysteresis, the lack of research on hysteresis focused on spacesuit applications became clear. Based on the team's Subject Matter Expert's (SME) recommendation to study hysteresis behaviour in SMA as a way to reduce power consumption, we determined that we could bring the understanding on how to control and manipulate the factors involved in the hysteresis behavior to obtain a linear response. Particularly, to improve the use of SMAs for spacesuits. Reducing the power applied to obtain the needed displacement, without risking an astronaut with high temperatures can be attainable with this kind of knowledge about hysteresis.

SECTION IV – SPECULATION REGARDING POTENTIAL COMMERCIAL APPLICATIONS AND POINTS OF CONTACT *(Including names of companies producing or using similar products.)*

Aerospace Indrustry, Medical Indrustry, blue Origin

10. ADDITIONAL DOCUMENTATION *(Include copies or list below any pertinent documentation which aids in the understanding or application of the innovation (e.g., articles, contractor reports, engineering specs, assembly/manufacturing drawings, parts or ingredients list, operating manuals, test data, assembly/manufacturing procedures, etc.).)*

TITLE	PAGE	DATE

11. DEGREE OF TECHNOLOGY SIGNIFICANCE *(Which best expresses the degree of technological significance of this innovation?)*

☒ Modification to Existing Technology ☒ Substantial Advancement in the Art ☐ Major Breakthrough

12. STATE OF DEVELOPMENT

☐ Concept Only ☒ Design ☒ Prototype ☒ Modification ☐ Production Model ☐ Used in Current Work

13. PATENT STATUS (Prior patent on/or related to this innovation.)

☐ Application Filed Application No. ____ Application Date ____

☐ Patent Issued Patent No. ____ Issue Date ____

14. INDICATE THE DATE OR THE APPROXIMATE TIME PERIOD WHICH THIS INNOVATION WAS DEVELOPED *(i.e., conceived, constructed, tested, etc.)*

06/2019

15. PREVIOUS OR CONTEMPLATED PUBLICATION OR PUBLIC DISCLOSURE INCLUDING DATES *(Provide as applicable: A. – Type of publication or disclosure, e.g., report, conference or seminar, oral presentation; B. – Disclosure by NASA or Contractor/Grantee; and C. – Title, volume no., page no., and date of publication.)*

N/A

16. QUESTIONS FOR SOFTWARE ONLY

(a) Using non-NASA employees to beta-test the program? ☐YES ☐NO If Yes, done under a beta-test agreement? ☐YES ☐NO

(b) Modification of this program continued by civil servant and/or contractual agreement? ☐YES ☐NO

(c) Copyright registered? ☐YES ☐NO ☐UNKNOWN If Yes, then by whom? ____

(d) Has the latest version been distributed outside of NASA or contractor? ☐YES ☐NO ☐ UNKNOWN

If Yes, date of first disclosure: ____

(e) Were prior versions distributed outside of NASA or Contractor? ☐YES ☐NO If Yes, supply NASA or contractor contract: ____

(f) Contains or based on code not owned by U.S. Government or its contractors? ☐YES ☐NO ☐ UNKNOWN

If Yes, name of code and code's owner: ____

Has a license for use been obtained? ☐YES ☐NO ☐ UNKNOWN

17. DEVELOPMENT HISTORY

STAGE OF DEVELOPMENT	DATE (MM/YYYY)	LOCATION	IDENTIFY SUPPORTING WITNESSES (NASA in-house only)
a. First disclosure to others	06/2019	Houston, TX	
b. First sketch, drawing, logic chart or code	05/2019	Houston, TX	
c. First written description	07/2019	Houston, TX	
d. Completion of first model of full size device *(invention)* or beta version *(software)*			
e. First successful operational test *(invention)* or alpha version *(software)*			

f. Contribution of innovators *(if jointly developed, provide the contribution of each innovator)*

N/A

g. Indicate any past, present, or contemplated government use of the innovation

A present use of shape memeory alloy (SMA) actuators is the SAW project which intends to obtain a wide spectrum of aerodynamic benefits in flight by folding wings through the use of SMAs. This material is built into to an actuator on the aircraft, This is the vital role of SMAs actuators in moving parts on the airplane, There ability to fold the outer portion of an aircraft's wings in flight without the strain of a heavy hydraulic system. Systems with SMAs they can reduce total weight by up to 80 percent less than traditional systems.

18. SIGNATURES OF INNOVATOR(S), WITNESS(ES), AND NASA APPROVAL

TYPED NAME AND SIGNATURE *(Innovator #1)*	DATE	TYPED NAME AND SIGNATURE *(Innovator #2)*	DATE
George Sarkodie	6/6/2019		
TYPED NAME AND SIGNATURE *(Innovator #3)*	DATE	TYPED NAME AND SIGNATURE *(Innovator #4)*	DATE
TYPED NAME AND SIGNATURE *(Witness #1)*	DATE	TYPED NAME AND SIGNATURE *(Witness #2)*	DATE
NASA APPROVED — TYPED NAME		SIGNATURE	DATE