SBIR/STTR
Small Business Innovation Research / Small Business Technology Transfer

NASA SBIR 2019 Phase I Solicitation

H4.04 Exploration Pressure Garment System (xPGS) for deep space and surface missions

Lead Center: JSC

Participating Center(s): JSC

Technology Area: TA6 Human Health, Life Support and Habitation Systems

Surface Space Suit BootÂ

This subtopic is searching for concepts and technologies to be incorporated into future prototypes of a space suit bootÂ for a space suit that will walk on a planetary surface. Â Figure 1 (seeÂ https://www.nasa.gov/suitupÂ â€™EVA Boot SBIR Figuresâ€™)Â communicates the rough terrain that astronauts will encounter and will be expected to traverse. Â

The Phase I effort may focus on a particular challenge of the design in order to mature that concept or technology to progress to a Phase II effort. Â Test data and detailed design or 3-D models are acceptable results from Phase I. Â The Phase I final report also must indicate how the Phase I effort allows for successful implementation in the Phase II effort. Expected TRL is from 2 to 5.

The expectation for the Phase II effort is that a functional boot prototype will be created, tested at pressurized conditions, and delivered. Â As stated above, the results from Phase I are expected to provide confidence that the technology or design can be carried into a Phase II resulting in a boot prototype delivery. Â A functional boot prototype from Phase II would need to meet the following requirements:

- Carry pressure load of suit pressurized to 8 psi:
    - Indicates that a load path must be incorporated into the design and proven to carry the pressure load
    - Indicates that the entire structure can be pressurized to 16 psi without failing
- Provide mobility at the ankle:
    - No less than 40Â° of flexion (toes toward shin; 0Â° position to be used as the reference is foot flat on the floor with the leg 90Â° to the foot), and 20Â° extension (pointed toes)
- Provide boot sole flexibility when pressurized equivalent to that of an Air Force jump boot, sturdy hiking boot, or work boot:
    - This requirement has not yet been quantified, but subjectively the boot sole must function in a similar manner to these soles.
- Indicate ability to meet boot cycle life:
    - The vendor shallÂ not be required to test the boot to the anticipated cycle life of 800,000 steps, unless that is the primary requirement being addressed by the proposal.
    - All Phase II bootÂ designs delivered shall be delivered with test and/or analysis data that provides evidence/rationale for being able to meet theÂ cycle life requirement over a reasonable

development effort (1-3 years). Â

- Provide information to assure the design will function in an environment with surface temperatures of the Lunar Surface: -180 to 210Â° FÂ
- While surface boots will need to operate in a dust environment, dust mitigation methods are currently being developed under separate efforts and is not the focus of this topic. Â However, a discussion of why the design/technology/materials are expected to perform in a dust environment shallÂ be expected in the proposal.Â

Space suit walking boot continues to be a challenge. Integrating the high performance of hiking boots into a pressurized garment creates challenges of its own and are beyond those of a typical boot. While all hiking boots need to provide good fit and to be durable for thousands to hundreds of thousands of walking steps over rough terrain, meeting these requirements for a boot that is inflated to 8 pounds per square inch of pressure introduces new aspects to the challenge. Each of these challenges that can be addressed are described below:

Boot-to-foot integration

The boot is integral with the knee of the pressure garment in order to close the air retention layer function for the leg,Â the diameter of the ankle opening is matched to that of the knee which creates a challenge for good fit at the ankle. Additionally, the integration of the boot to knee of the suit means that the boot is donned when it is connected to the leg. Therefore, these two drivers make donning a space suit boot similar to stepping into galoshes. However, when walking, the foot must be well integrated with the boot in order to avoid injury to the foot and maintain walking stability and control. Mitigating slipping of the heel in the boot has been the focus of several efforts.Â Below is a brief summary of boot-to-foot integration concepts that have been investigated previously:

- Boot indexing concepts:
    - Straps:
        - Strap over the arch of the foot has been helpful:
            - See Figure 2Â (seeÂ https://www.nasa.gov/suitupÂ 'EVA Boot SBIR Figures')
        - Thickness, location, and tenacity of closure method are all critical design factors
    - Magnets:
        - Did not work well:
            - Attached to Liquid Cooling Garment (= Footed longjohns worn under the suit) bootie
        - Slippage; magnets not powerful enough resulted in heel lift:
            - Comfort can also be an issue due to a hard object under the heel
        - Could be worth looking at again with an overboot conceptÂ and/or electromagnets
    - Heel clip (overboot):
        - Developed for the AX-5 prototype space suit, however test data has not been located, if it exists:
            - See Figure 3Â (seeÂ https://www.nasa.gov/suitupÂ 'EVA Boot SBIR Figures')
        - Could be worth looking at again
    - Air bladders:
        - Reebok Pumps-style â€“ Implementation of repeated attempts has been problematic:

                - Location of bladders
                - Shape of bladders
                - Pressurization system complexity and reliability
                - Achieving acceptable pressure

    - Boa lacing:

        - Z-2 added heel lace in addition to dorsum lace, which was helpful, but did not completely resolve heel slippage issue:

            - See Figure 4Â (seeÂ https://www.nasa.gov/suitupÂ 'EVA Boot SBIR Figures')

    - Other ideas:

        - Vacuum pack forming to grab ankle using ambient vacuum
        - Power Strap (ski boots)

Boot design concepts that, in addition to performing its function of pressure retention/providing pressure to the foot, also allows for ease of don/doff and provides excellent and comfortable foot-to-boot integration are sought.

Boot material durability

Looking forward to long-duration exploration missions, the materials of the boot will be exposed to rough terrain over hundreds of thousands of walking cycles. Boot sole and boot upper materials are being sought for durability and flexibility in the rough environment and extreme temperatures of the space environment. Â In addition to being durable, the boot sole material also needs to serve as a functional boot sole when incorporated in a pressure garment, which means that the sole cannot allow the pressurization to modify its shape. Â For example, past materials that have been investigated have allowed the boot sole to become convex or rocker-shaped indicating that the boot sole material was too flexible. Similarly, boot sole materials that are too stiff so as not to allow natural gait have also been rejected. Â

The Phase I effort proposals shall be expected to address one or more aspects of these challenges in an innovative way.

This project could enable sustained Lunar surface EVAs as part of a human lunar program. More focused development beyond SBIR could come through Space Technology Mission Directorate (STMD).

References

- Ross, Amy, Joseph Kosmo, Nikolay Moiseyev, Anatoly Stoklitsky. "Comparative Space Suit Boot Test." 32nd ICES. SAE. July 2002, San Antonio, TX: SAE, 2002.
- Ross, Amy, Richard Rhodes, Shane McFarland. â€œNASAâ€™s Advanced Extra-vehicular Activity2 Space Suit Pressure Garment 2018 Status and Development Plan.â€Â Â 48th International Conference on Environmental Systems (ICES).Â Â July 2018, Albuquerque, New Mexico: ICES-2018-273.
- Ross, Amy, Richard Rhodes, David Graziosi, Bobby Jones, Ryan Lee, Bazle Haque, John W. Gillespie, Jr. â€œZ-2 Prototype Space Suit Development.â€ 44th ICES. July 2014, Tucson, AZ: NTRS JSC-CN-31290.
- Ross, Amy. â€˜Z-1 Prototype Space Suit Testing Summary.â€ 43rd International Conference on Environmental Systems (ICES). American Institute of Aeronautics and Astronautics (AIAA). July 2013, Vail, CO: AIAA, 2013: NTRS JSC-CN-28415.