



The *Bio-Suit System*: A Synopsis

The *Bio-Suit System* is designed to revolutionize human space exploration by providing enhanced astronaut extravehicular activity (EVA) locomotion and performance based on the concepts of a 'second skin' capability and of biomechanically and cybernetically augmented human performance capacity. The novel *Bio-Suit* concept provides an overall exploration *System* realized through symbiotic relationships between a suite of advanced technologies, creative design, human modeling and analysis, and new mission operations techniques. By working at the intersection of engineering, design, medicine and operations, new emergent capabilities and interrelationships could expand NASA's future mission possibilities, potentially allowing new directions for future NASA missions. In many respects, the *Bio-Suit System* mimics Nature (biomimetics). For example, a second skin is envisioned, capable of augmenting our biological skin by providing mechanical counter-pressure. Perhaps the 'epidermis' of such a second skin will be a 'spray-on', organic, biodegradable layer offering protection in extremely dusty planetary environments. Incorporated into the second skin will be electrically actuated artificial muscle fibers to enhance human strength and stamina. Locomotion and performance are further enhanced by implementing biomimetic locomotion algorithms to actuate performance-enhancing hardware. Wearable technologies will be embedded throughout the *Bio-Suit System* to place the explorer in an *information-rich* environment enabling real-time mission planning, prediction, and visualization. Human-in-the-loop modeling algorithms will be developed to calculate metabolic exploration costs and to plan and dynamically update optimal astronaut traverses that account for changing mission requirements. The *Bio-Suit System* addresses the feasibility of further augmenting human capabilities by coupling human and robotic abilities into a hybrid of the two, to the point where the explorer is hardly aware of the boundary between innate human performance and robotic activities. The proposed *Bio-Suit System* contributes to four NASA Institute for Advanced Concepts (NIAC) areas: human space flight, life sciences, information systems and software, and biology. The *Bio-Suit System* concept is relevant to NASA's strategic plan and stated visionary challenges in the Human Exploration and Development of Space (HEDS), Aerospace Technology, and Space Science enterprises. Additionally, the *Bio-Suit System* is essential for NASA to realize its technology road map development for journeys to L1, Moon/Mars, Near-Earth Objects, and eventually for the 'go anywhere' capability envisaged by the NASA Exploration Team.





Objectives of the *Bio-Suit System Study*

The primary goal of the Phase II *Bio-Suit System* effort is to provide a sound basis for NASA to consider the concept for future missions (NIAC, 2002), and our ultimate study goal is to produce a *Bio-Suit System* concept for human survival and enhanced performance in extreme, hostile environments. The main objectives of the proposed effort are to study the major feasibility issues, perform necessary research, and design a revolutionary concept for human exploration missions, namely, the *Bio-Suit System*, which is envisioned as a locomotion enhancing, life support system for astronaut extravehicular activity (EVA) based on the concept of providing mechanical counter-pressure (MCP). The *Bio-Suit System* concept is in stark contrast to the incremental space suit design approach and improvements witnessed over the history of human spaceflight in both the NASA and Russian programs, including the International Space Station. Our Phase I study concentrated on the conceptual exploration of numerous technologies and designs that could potentially be utilized in a *Bio-Suit System*. Phase II continues our illustrative design process by updating the suite of advanced technologies, modeling and testing the most promising *Bio-Suit System* candidates, and developing new mission operations techniques. Detailed objectives for the *Bio-Suit System* study include providing: 1) a novel design concept through symbiotic relationships in the areas of biomimetics, wearable and advanced technologies, innovative design, human modeling and analysis, and mission operations and 2) a synergistic multidisciplinary approach combining expertise from the fields of engineering, design, medicine, and space operations to assess the major feasibility issues associated with performance, key technology issues, cost and implementation, and development cycle of the proposed *Bio-Suit System*. Imagine astronauts on Mars utilizing the *Bio-Suit System* for their search to find the definitive proof of life, which requires them to repel cliffs, perform geology and real-time data analysis in extreme environments where Olympus Mons and Valles Marineris dwarf Mount Everest and Grand Canyon terrains, all the time working in extreme temperatures and storm conditions.

Motivation for the *Bio-Suit System* Concept

LOCOMOTION AND MOBILITY: Locomotion is a top priority for exploring terrestrial environments and performing useful geology work. Since the Apollo era only a few space suit concepts have been designed to provide locomotion, and all current NASA designs as well as the Apollo suits do not enable the human explorer, but rather hinder their performance. In an environment such as Mars, astronauts will need the ability to traverse loose terrain, steep grades, and possibly scale, if not repel, down cliff sides. These activities place new requirements on advanced suits in the areas of mobility and dexterity, which can only be attained through implementing designs that facilitate natural locomotion and minimize energetic expenditures. Due to the activities mentioned above as well as the evaluation of samples and the maintenance of equipment, manual dexterity is also a very high priority.





Motivation for the *Bio-Suit System Concept* (continued)

STRATEGY - WHY MCP? As suggested by Annis and Webb [1971], Clapp [1983] and others, mechanical counterpressure (MCP) suits have the possibility of greatly improving astronaut performance. The first MCP design, namely, the Space Activity Suit (SAS) [Annis and Webb, 1971], was a very creative idea before its time. The SAS used seven layers of highly elastic material in order to squeeze the wearer while a bubble helmet and chest bladder provided adequate breathing pressure [Annis and Webb, 1971]. While the SAS initiated the MCP concept and demonstrated advantages of mobility, low energy costs, and a simplified life support system, the difficulty in donning/doffing the SAS was the largest limitation. NASA did not pursue MCP suit development. A few additional MCP investigations such as those by Clapp [1983], Korona [2002], Tourbier et al. [2001], and Waldie et al. [2002] have advanced the state of the art of MCP glove design. These studies have investigated elastic materials or low-modulus MCP. The work of Tanaka et al. [2003] investigated important physiological issues such as blood flow and fluid distribution as well as pressure distribution. Tanaka and colleagues provide important evidence that MCP can be realized with no adverse physiological effects.

Given the performance characteristics of our biological skin, it seems reasonable to envision a second skin suit capable of augmenting our biological skin to the point where it can withstand the absence of a pressurized environment. If designed properly, Webb showed that a MCP suit could expose regions of skin no larger than 1 mm² to vacuum. There are two major advantages suggested by this result. First, this result suggests the improved safety of a MCP suit design. Especially on planetary surfaces where the astronaut will be exposed to highly abrasive environments and activities, tears become an issue of increasing concern. In a gas-pressurized suit, a small tear not only means the loss of pressure, but also the loss of breathable oxygen. In an MCP suit, however, this would not be the case. Webb's result suggests that should a small hole appear in a MCP suit, the user would be unharmed. There would be no loss of breathable oxygen, and the skin would not suffer any damage. Should the hole be larger than 1 mm², the wearer would still have sufficient time to return to a pressurized environment due to the fact that the effects of the reduced pressure would be highly localized. The second advantage suggested by Webb's result is that of thermal cooling. In a MCP suit, normal thermal cooling, including evaporation of sweat, is enabled by using air-permeable fabric.

The Bio-Suit initiative at MIT returns to the concept of MCP, leveraging new technologies in modeling and materials to envision future possibilities for the use of MCP in locomotive extravehicular activity suits. Design concepts are conceived to allow the explorer the same ease of donning as experienced with clothes. Conceptually this is achieved by creating a suit that shrinks around the wearer once it is donned. The wearer slips into the MCP garment and then the suit slowly shrinks to provide adequate body-surface pressure. The current strategy is to design in such a way that donning/doffing and pressure production are decoupled. Donning/doffing should be as easy as putting on clothes and pressure production should occur after the donning process is complete. One design solution utilizes inextensible materials to produce a 'second skin' suit that is a viable option for overcoming the challenges of planetary surface exploration that require high mobility, minimal mass, and quick don/doff time.

The following Image Gallery highlights the Phase I Bio-Suit design concepts produced in collaboration with Trotti and Associates, Inc. and drawn by Cam Brensinger. Enjoy!

