**Exoskeletons Applications**

**The Ability to Run Faster, Carry More Gear and Leap Tall Buildings**

**Skeleton Warriors**

Source: Beyond 2000  
http://www.beyond2000.com/news/Dec\_00/story\_926.html

The United States wants its own starship troopers. As part of a project that's been quietly ticking away for months now, the Department of Defense has decided it needs to grant superhuman powers to its soldiers; providing them with the ability run faster, carry more gear and leap tall buildings. It plans to do this with powered combat armor exoskeletons, and the first contract in the project was awarded this week.

Buried way down in a mundane Pentagon announcement of successful service tenders was an eight line statement revealing that a Californian company was being paid several million dollars to develop and test a strap-on propeller system, enabling individual warriors to fly.

Want to know more?

Bug hunt

In Robert Heinlen's classic book Starship Troopers, his protagonist is a serving member of Earth's Mobile Infantry. Standard equipment for these troops is the 'power suit', a combat-specific ensemble that enhances its wearer's physical abilities with hydraulics and servo motors, granting Herculean strength and the ability to jump hundreds of meters in a single bound.

To military planners, Heinlen's invention now seems like a pretty good idea. Scientists at the Defense Advanced Research Projects Agency (DARPA) have been looking at the concept as part of a project called "Exoskeletons for Human Performance Augmentation".

DARPA's stated objectives are "to develop devices and machines that will increase the speed, strength, and endurance of soldiers in combat environments....(leading) to self-powered, controllable, wearable exoskeletal devices and/or machines."

What the agency is looking for is equipment that will:

\* Extend the mission payload and/or range of the soldier.   
\* Increase the "lethality" and "survivability" of ground troops for short range and special operations.   
\* Enhance mobility and load carrying capacity to allow soldiers to carry more ballistic protection and heavy weaponry.   
\* Augment human strength.   
\* Increase human speed and endurance.   
\* Allow troops to "leap extraordinary heights and/or distances."

The undeclared point of all this enhancement is to turn even a single soldier into a super-potent angel of death. He will be able to employ heavy weapons systems that are currently impossible for a human to even carry, let alone fire from the hip. He will pack more ballistic protection and carry more ammunition and supplies. The Pentagon figures these improvements will be effective in all combat environments, but especially in urban terrain.

As with any powered system, the most critical issue facing combat exoskeletons is energy storage and actuation. Maximizing energy output versus bulk is the key equation, and power sources will have to be man-portable. Currently, researchers are exploring the use of highly-efficient chemical fuels for the mechanical actuation of the suits (as opposed to other energy storage media, like batteries or compressed air). At the current state of the art, this seems the best way to provide an exoskeleton with a "militarily significant" range and duration.

Super fly

The first private contractor to be awarded a noteworthy slice of the exoskeleton budget is Millennium Jet Incorporated, which is the commercial front of a syndicate trying to develop a one-man flying machine called the SoloTrek Exoskeletor Flying Vehicle (XFV). The gasoline-powered SoloTrek has featured in the futurist media for some time now, and it's developers claim that when finished, it should be capable of hovering for 3 hours and travel laterally at speeds of up to 130 km/h. The strap-on helicopter has been displayed at various engineering, aviation and military exhibitions but is yet to make a flight, prompting cynics to put it in the same basket as flying rocket cars and teleportation.

Millennium Jet aren't listening to the doubters though. Under the contract, the Department of Defense has given the company $5 million and three years to complete development and testing of the SoloTrek. Wind tunnel trials are currently underway at NASA's Ames Research Center, one of the development partners.

Since sustained flight is the most difficult objective to achieve, SoloTrek will be a benchmark for exoskeleton proponents .If it can indeed get off the ground, the idea of non-flying power suits will appear well within grasp. Certainly it would seem that existing levels of bio-mechanics, force feedback and control processing are sufficient to begin the march of the Robo-warrior.

**Exoskeleton Performance**

**New Exoskeleton to Clothe Soldiers**

**$50 Million Project Intended to Increase Soldiers' Strength, Performance**  
by John J. Lumpkin

Source: Albuquerque Journal

The Pentagon is researching a powered exoskeleton that would make soldiers stronger, faster, able to carry heavier weapons and "leap extraordinary heights," according to military documents and officials.

The Defense Advanced Research Projects Agency or DARPA, the Pentagon's research arm, is spending $50 million on "Exoskeletons for Human Performance Augmentation."

Sandia National Laboratories is working on a segment of the project, with a small group of scientists in its Intelligent Systems and Robotics Center developing several technologies, officials acknowledged.

"The idea would be some kind of exoskeleton that would allow a soldier to have increased strength, increased endurance, increased speed," said Jan Walker, a DARPA spokeswoman in Arlington, Va.

The soldier would wear it as an outer skin, rather than operate it, and its functions would optimally become an extension of the soldier's natural movements.

"A guy in combat doesn't need to figure out which button to push," Walker said.

She emphasized the program is in the earliest of stages, with scientists and engineers figuring out what advances are needed to make it work. Tests could be as much as a decade away.

The developers' first task, according to Walker: build a compact, wearable and quiet power generator that would provide the juice for all the other devices on the exoskeleton. It would have to provide power for between four and 24 hours of continuous use.

"We're not sure what kind of fuel to use or how to store the fuel," Walker said.

With greater strength and endurance, the soldier could wear more armor and carry heavier weapons and more ammunition, she said.

DARPA, in documents displayed on its Web site, announced last year it was seeking devices that do one or more of the following:

-- "Assist pack-loaded locomotion"  
-- "Prolong locomotive endurance"  
-- "Increase locomotive speed"  
-- "Augment human strength"  
-- "Leap extraordinary heights and/or distances"

The suits could also be equipped with computers and communications gear that would give soldiers real-time intelligence about their comrades and targets; military documents say.

Such devices have long been the stuff of science fiction, most notably in Robert Heinlein's 1959 novel "Starship Troopers." The story is about the infantry of the far future, with soldiers wearing mobile combat armor to fight alien bugs.

In the 1986 movie "Aliens," Sigourney Weaver fends off the alien hive queen wearing a machine that looks like a cross between an exoskeleton and a forklift. And a whole genre of Japanese animation is devoted to these things.

Walker said the work is going on at various labs around the country. Sandia officials confirmed this week that theirs is one of them, but they declined to give many details.

Lab spokesman John German provided a written statement from project officials. "Sandia is proposing and assessing various solutions for improving speed, strength, endurance and payload," the statement said.

German said project officials declined to provide more information because they have not obtained patents on their work.

German said the lab has received $310,000 from DARPA to work on the project since 1999.

Last month, the Defense Department awarded Millennium Jet Inc. of Sunnyvale, Calif., $1 million under the program "for the development and testing of a one-man vertical takeoff and landing flying exoskeleton."

**Exoskeleton Robotics**

**The Pentagon is Trying to Develop Robotic "Muscle-Suits"**

**Muscle Power Dressing for Super Troopers**  
by Adam Sherwin

Source: The Times  
http://www.thetimes.co.uk/article/0,,2-89040,00.html

February 22, 2001

A GIANT leap for mankind may have begun with one small flip of a robotic fish. The fish is the first robot to be powered by real muscles and American military chiefs believe that the same technology could be harnessed to enable soldiers to leap tall buildings.

The Pentagon is trying to develop robotic "muscle-suits" to give more power to a soldier's natural movements. Like Steve Austin, the bionic man played by Lee Majors in the 1970s television series The Six Million Dollar Man, anyone wearing such a suit would be "better, stronger, faster".

In research funded by the military, scientists at the Massachusetts Institute of Technology built a robot fish that swam using live muscle tissue taken from a frog.

The leader of the research, Hugh Herr, has a special interest in the project. An attack of frostbite cost him both his legs below the knee, and he believes that his work could lead to improvements in artificial limbs.

The robotic fish worked by using a microprocessor that sent electric signals to frog muscles on either side, making them contract, New Scientist magazine reports. Tendons on the muscles were sewn to the nose and tail and the robotic fish wiggled and swam in response to the signals. The muscles took their energy from a glucose solution in which the fish swam.

The next step is to create another prototype that contains its own nourishing glucose. Bigger muscles would need an artificial circulatory system to pump the glucose to them.

The Pentagon is spending $50 million (£34.7 million) on developing the muscle-suits in which real muscles would activate the robotic components.

A spokesman for the Pentagon's Defense Advanced Research Projects Agency said: "The idea would be some kind of exoskeleton that would allow a soldier to have increased strength, increased endurance, increased speed."

The soldier would wear it as an outer skin, rather than operate it, and its functions would optimally become an extension of the soldier's natural movements. The suits, fully equipped with computers and communications gear, would run on a compact power generator that would provide 24 hours of continuous use.

Agency documents claim that the suits will "augment human strength" and allow soldiers to "leap extraordinary heights and distances". The Pentagon plans appear to be influenced by the mobile combat suits used to fight alien bugs in the 1997 film Starship Troopers.

Civilians could also feel the benefits. Artificial limbs tend to be stiffer than real ones and cannot adapt to different surfaces. Prototype limbs currently contain noisy joint motors. Dr Herr said: "If all our muscles were motors, we wouldn't hear ourselves talking."

His next step is to improve the prototype robot by giving it a small stomach to contain the nourishing glucose. Bigger muscles would need an artificial circulatory system to pump the glucose to them.

As long ago as 1786, Luigi Galvani discovered that electricity made a dissected frog's leg twitch. But until now, nobody has tried to apply the concept to power a machine. Dr Herr's original robot has now expired, since its muscles would keep only for a few hours.

Another American team is reported to have succeeded in growing artificial muscle cultures that live for several months. Bob Dennis, from the University of Michigan, and his colleague Paul Kosnick, have persuaded human muscle fibers to grow in the laboratory by stimulating them electrically. It is the first time that human muscle has been grown artificially.

The pair believe that the technique might make some animal tests redundant because chemicals could be tested on muscle cultures. Although the muscles survive three to five months, compared with only a few hours for natural muscle removed from the body, they are only a tenth as strong as the real thing. Yoseph Bar-Cohen, who heads Nasa's advanced actuators laboratory in Pasadena, California, admitted: "There are issues of robustness with these artificial muscles. They oxidize easily."

Bob Dennis, a colleague of Dr Herr, was skeptical. He said: "Why would anyone want to build artificial muscle? Real muscle can adapt to its environment, it can heal itself and it can self-regulate."

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**Exoskeletons for Humans**

**DARPA is Soliciting Innovative Research Proposals on Exoskeletons**

**Exoskeletons for Human Performance Augmentation**  
POC: Dr. Ephrahim Garcia - baa00-34@darpa.mil  
DARPA/DSO (EHPA), BAA00-34  
Fax: 703-696-3999

Source: DARPA  
http://www.darpa.mil/dso/solicitations/00/Baa00-34/cbd.htm

June 30, 2000

Due to the possibility of transcription errors, the official CBD announcement takes precedence over this transcription in any disagreement between the two. The transcription is provided for your convenience only.

PROGRAM OBJECTIVE AND DESCRIPTION

The Defense Advanced Research Projects Agency (DARPA) is soliciting innovative research proposals on Exoskeletons for Human Performance Augmentation (EHPA). The overall goal of this program is to develop devices and machines that will increase the speed, strength, and endurance of soldiers in combat environments. Projects will lead to self-powered, controllable, wearable exoskeletal devices and/or machines. The technological challenges that must be addressed are energy sources, power by generation, haptic interfaces, control algorithm development, as well as integration of actuation systems and all previously mentioned subsystems into a machine with an anthropomorphic architecture. Highly efficient actuators must be developed that can utilize a high density, man-wearable energy source in both a safe and quiet manner. The power provided to the EPHA system must support the exoskeleton for a duration of military significance, initially estimated to be 4-24 hours. Control approaches must be devised that enable direct and seamless interaction between human and machine. Finally, these devices and machines will be demonstrated in order to evaluate their utility to various military operations.

EHPA will enable new capabilities for ground forces. Inclusion of exoskeleton technology into land based operations will extend the mission payload and/or mission range of the soldier. Exoskeletons will also increase the lethality and survivability of ground troops for short range and special operations. The enhanced mobility and load carrying capability provided by the exoskeleton will allow soldiers to carry more ballistic protection and heavy weaponry. To meet the challenges set forth, DARPA is soliciting devices and machines that accomplish one or more of the following: 1) assist pack-loaded locomotion, 2) prolong locomotive endurance, 3) increase locomotive speed, 4) augment human strength, and 5) leap extraordinary heights and/or distances. These machines should be anthropomorphic and capable of bearing distributed loads, such as that generated by extensive armor protection, as well as typical pack loads. Other concepts for EHPA will also be considered in this solicitation.

Methods of transforming high-energy dense power sources to actuation power for these machines should be developed. Energy sources must be integrated with compact, man-wearable power generators and, possibly, new types of actuators that would allow long endurance missions. Concepts and designs that fail to address the full integration of energy sources, power converters and actuators into a complete exoskeleton system are generally not of interest. However, development of enabling technologies of extraordinary promise may be considered for support but are best melded into a larger effort of realizing a complete system.

WHITE PAPERS

All white paper submissions will be evaluated for responsiveness to the stated goals and objectives of this BAA. Those best meeting the criteria of this BAA will be asked to submit a full proposal. Proposers must submit an original and seven (7) copies of the white paper to DARPA/DSO, ATTN: BAA00-34, 3701 North Fairfax Drive, Arlington, VA 22203-1714 on or before 4:00 PM ET, April 21, 2000. White papers submitted by email or fax will be disregarded. White papers must meet the objective and format guidelines as described in the Proposer Information Pamphlet (PIP) in order to be considered. White papers are limited to seven (7) 1.5-spaced pages including cover sheet and should contain: 1) concepts for addressing the technical goals of EHPA; 2) program plan with technical milestones for developing components and critical subsystems; 3) integration approach and expected performance for an EHPA device or machine for DoD applications; 4) projected impact of developments on DoD applications; 5) proposed funding level for the effort; and 6) descriptions of experience and expertise of the performer(s) and sub-contractors. Appendices will be NOT considered in the evaluation of white papers. DARPA will acknowledge receipt of white papers within ten (10) business days and assign a control number that should be used in all further correspondence. Recommendations for full proposal submission will be made within approximately thirty (30) days of the submission deadline. All full proposals will be evaluated regardless of the disposition of the white paper.

FULL PROPOSALS

The proposed effort should be in two phases with an additional option at the end of the second phase, for a total not to exceed 60 months. The Phase I and Phase II periods will be conducted for up to 42 months and consist of an initial base effort that demonstrates proof-of-concept for key technologies, followed by an effort to complete the development of the individual projects. In addition to this 42-month period, a Phase II Option may be included that will proceed for an additional 18-month period to achieve end of program requirements as outlined in the PIP. The technical portion of the proposal is restricted to 40 pages (including figures). A suggested outline for full proposal follows:

1) an executive summary describing the concept(s), impetus, approach, and target application;

2) introduction with a statement of the perceived technical challenges and the concepts to be exploited to satisfy the requirements of the PIP;

(3) detailed technical discussion of the implementation of the proposed concept, technical risks, a set of metrics, and programmed milestones for evaluating progress;

(4) the overall management plan and a list of participating organizations, their relevant expertise, and tasks to be performed by each team member;

(5) a detailed Statement of Work with technical milestones and deliverables, including performance metrics and programmatic decision points;

(6) a summary cost and implementation schedule; and

(7) a plan for transitioning and commercializing the technology to industry and/or Government applications. References, resumes, or other supporting documentation may be included as appendices to the main body of the proposal, but will be included in the 40-page limit. A detailed cost and implementation schedule should also be included in a separate cost proposal. Further details are available in the PIP.

The total amount of funding available for this BAA is approximately $50M; it is anticipated that there will be multiple awards. The most important part of the full proposal will be the technical concepts proposed for the successful production of a human performance enhancing exoskeleton machine or device. The goal of the program is the development and demonstration of novel, self-powered exoskeleton machines that can be implemented to augment the performance and extend the mission capability of the ground combatant. The end products of this solicitation will be deliverable hardware demonstrating the approach achieved toward meeting the goals and objectives listed in the PIP. Proposals that are considered less than satisfactory in terms of Scientific and Technical Merit will not be evaluated further. Proposers must submit an original and nine (9) copies of the full proposal to DARPA/DSO, 3701 North Fairfax Drive, Arlington, VA 22203-1714 (Attn.: BAA00-34) on or before 4:00 PM, ET, June 30, 2000. Proposals must meet the objective and format guidelines as described in the PIP to be considered.

Proposal identified for funding may result in a contract, grant cooperative agreement, or other transaction, depending upon the nature of the work proposed, the required degree of interaction between parties, and other factors. If warranted, portions of resulting awards may be segregated into pre-priced options.

TEAMING ARRANGEMENTS

Teaming is encouraged to ensure that advances in technology can be rapidly integrated into useable military devices. To assist the teaming process an interactive web site has been established at URL: www.sainc.com/DARPA/EHPA. Individual researchers and organizations with specific, relevant expertise and/or capabilities may provide non-proprietary descriptions of their capabilities and interests. The web site will remain active from the date of issuance of this BAA until proposals are due. More information on teaming can be found in the PIP.

PROPOSAL EVALUATION

Proposals will be evaluated according to the following criteria in decreasing order of importance: (1) scientific and technological merit of the proposed program; (2) impact of the successful development on defense systems; (3) ability of the proposer(s) to achieve goals and execute project management plan (4) cost realism. All proposals will be reviewed by Government officials only. Input on technical aspects of the proposals may be solicited by DARPA from non-Government consultants and/or experts who are bound by appropriate non-disclosure requirements. Non-Government technical consultants will not have access to proposals that are labeled by the offerors as "GOVERNMENT ONLY." Restrictive notices notwithstanding, proposals may be handled, for administrative purposes only, by a support contractor. This contractor is bound by appropriate non-disclosure requirements. The Government reserves the right to select for award all, some, or none of the proposals received. Cost sharing is encouraged, but not required. All responsible sources capable of satisfying the Government's needs may submit a proposal that shall be considered by DARPA.

GENERAL INFORMATION

Proposers must obtain the pamphlet entitled "BAA00-34, Exoskeleton for Human Performance Enhancement (EHPA) Proposer Information Pamphlet (PIP)," which provides detailed information on program objectives, areas of interest, the submission, evaluation, and funding processes, proposal formats, and other program information. This pamphlet may be requested from the World Wide Web (WWW), fax, electronic mail (e-mail), or mail requests through the administrative contact information given below. This announcement and the PIP may be retrieved via the WWW at URL: /dso/ in the solicitation area.

Proposals not meeting the format described in the pamphlet may not be reviewed. All administrative correspondence and questions on this solicitation, including requests for information on how to submit a proposal to this BAA, should be directed to DARPA/DSO, BAA00-34, fax: (703) 696-3999, electronic mail (e-mail): BAA00-34@darpa.mil, or mail: DARPA/DSO, ATTN: BAA00-34, 3701 North Fairfax Drive, Arlington, VA 22203-1714 (e-mail or fax is preferred). DARPA intends to use electronic mail and fax for correspondence regarding BAA00-34. Proposals submitted by fax or e-mail will be disregarded. DARPA encourages use of the WWW for retrieving the PIP and any other related information that may subsequently be provided. This notice, in conjunction with the BAA00-34 PIP, constitutes the total BAA. No additional information is available, nor will a formal RFP or other solicitation regarding this announcement be issued. Requests for the same will be disregarded. Minority Institutions and Historically Black Colleges and Universities are encouraged to submit proposals and join others in submitting proposals. However, due to the technical nature of the hardware demonstration, no portion of this BAA will be set aside specifically for these entities.

**Exoskeletons for Solders**

**Is this the Shape of GIs to Come?**

**The Military Gets Mightier**  
by Mark Ward

Source: BBC News Online  
http://news.bbc.co.uk/hi/english/sci/tech/newsid\_1112000/1112411.stm

January 12, 2001

The US military is planning to turn soldiers into supermen by fitting them with powered exoskeletons.

The research arm of the US military is spending $50m to develop new technologies that will improve the speed, strength and endurance of soldiers.

The research program is aiming to give soldiers better protection against enemy fire, the ability to tote bigger guns, run faster, communicate better and help them avoid friendly fire.

The first trials of the technology are expected within the decade.

Power play

This month, the US Defense Advanced Research Projects Agency (DARPA) is expected to sign contracts to kick off the project to develop powered exoskeletons for its ground troops. The contract signings follow a year of meetings and assessments run by DARPA to find the most promising technologies.

So far, DARPA, the main research and development organization for the US Department of Defense, has not said which ideas it favors, but it has set out the broad goals of the program which calls for technologies that can help troops:

\* carry heavier packs;   
\* march faster over longer distances;   
\* lift heavier objects and use larger weapons;   
\* leap extraordinary heights and/or distances.

Dr Ephrahim Garcia, coordinator of the exoskeleton project, said its demands were "formidable" and much of the initial research was speculative to prove concepts rather than develop finished products.

"The controls, the power requirements, the human interface to the machine are all things that we do not know if we can do yet," he said. "There is a huge challenge here."

He added that the exoskeletons must be something that troops can wear and use without thinking rather than something they have to operate.

Suited up

The powered suits will help soldiers carry and use larger weapons and to take heavier loads into battle. Currently, soldiers carry a pack that is no more than a third of their body weight and usually take far less into combat.

Field trials have shown that troops typically dump anything too bulky or heavy to carry for long distances.

The exoskeletons will also have to be almost silent to operate and use fuel very efficiently. And soldiers must be able to use them for at least 24 hours before needing to refuel.

Early work sponsored by DARPA has used pneumatic muscles or deformable magnets to power artificial limbs or suits that soldiers could wear. Trials of a Spring walker system helped its developers travel at speeds in excess of 24 km/h (15 mph).

Stuck in the mud

The exoskeletons are expected to include a sensor web that expands a soldier's field of vision, passes on information about battlefield conditions, using GPS or thermal cameras, helps to co-ordinate groups of other soldiers and lessens the chance of being hit by friendly fire.

Conducting fabrics could be used to swap data between sensors, and wireless networks could pass information between squads or soldiers.

The suits could also act as body armor or have physiological monitoring systems that let officers know the health of the troops under their command.

Field trials of mock-ups of future systems on soldiers running a cross-country course revealed the limitations of some approaches.

Visors on helmets that could double as screens got in the way of rifle sights or made the headgear bulky and unstable. Other sensors or power packs distributed around the body of a soldier got in the way when combatants were crawling and made it harder for them to hide.