QUANTUM KNOTS DO YOUR SHOELACES HOLD THE SECRETS OF THE UNIVERSE?

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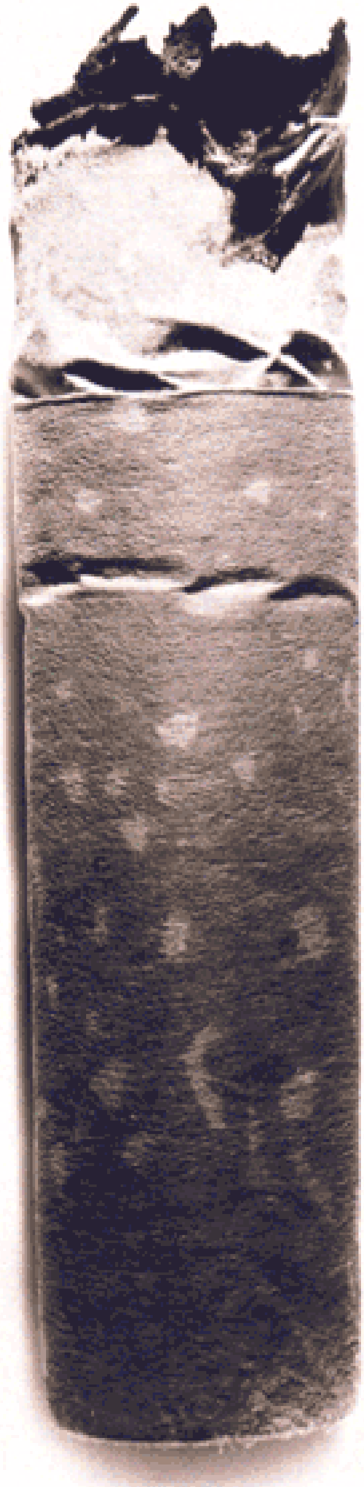

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POWER DRESSING

Slip on an exo and even the weediest become unstoppable. Paul Marks discovers how to leap tall buildings at a single bound

IT has got to be the most outlandish military project the Pentagon has ever dreamed up. In just four years, and with $50 million, they plan to create a wearable, self-propelled robotic suit that responds to—and amplifies—your every movement. Strap themselves in and troops will be able to run faster, jump higher, leap further, and drape themselves in awesome amounts of armour and high-calibre weaponry. It will turn your average GI into a heavyweight fighting machine with superhuman powers—a kind of Tank Girl meets the Six-Million Dollar Man.

Despite the military slant, researchers on the project say it's far more than simply toys for the boys. They predict major civilian spin-offs for workers in construction, mining and heavy industries. Exoskeletons, the proper name for these mechanical suits, could help firefighters cut victims from wrecked buildings or vehicles far faster than they can right now, and give disabled people new-found mobility—perhaps even put a motorised spring in their step.

But if the machine isn't going to grind to a halt at the first drop of rain, or shoot out of control like a runaway bulldozer, researchers need to develop a host of new technologies to satisfy their needs. They will have to design a strong but figure-hugging frame of metal or composite materials with joints that move in three dimensions. Triggered by motion sensors attached to arms and feet, small servomotors will allow the exoskeleton to respond to your every move (see Diagram, p 35). "This isn't a kit we're putting together," says Stephen Jacobsen of Sarcos, the Salt Lake City firm managing much of the project for the Pentagon's Defense Advanced Research Projects Agency. "We're like a baby in the forest on this, starting at the very beginning."

Which is why DARPA project manager Ephrahim Garcia, an expert in smart materials hailing from Vanderbilt University in Tennessee, is casting his net wide. Garcia has been kept very busy harnessing the skills of a disparate bunch of US universities and high-tech companies to make the exo happen.

They face a rough ride. The history of powered exoskeletons is an unhappy one. The idea was first tried in New York state in 1968, when the American electronics giant General Electric in Schenectady, with aeronautical engineers at Cornell University in Ithaca, began developing a metal monster of an exoskeleton called Hardiman. Picture Sigourney Weaver's exoskeleton from *Aliens*, except with bridge girders, and you get the idea. GE got as far as demonstrating one arm of the beast, which made lifting 700 kilograms feel like 20 kilos. "Hardiman was an interesting system, way ahead of its time," says Garcia. "But it was a massive machine that would have required a small room load of generators and hydraulic pumps to make it function." It probably couldn't have worked in the field autonomously.

In 1988, researchers at Los Alamos National Laboratory in New Mexico designed what they dubbed a Powered Exoskeletal Suit for the Infantryman, or PITMAN—inspired by Robert Heinlein's 1959 sci-fi tale *Starship Troopers*. But PITMAN remained on the drawing board, crippled—like other early ideas—by the lack of a power source to drive its joints.

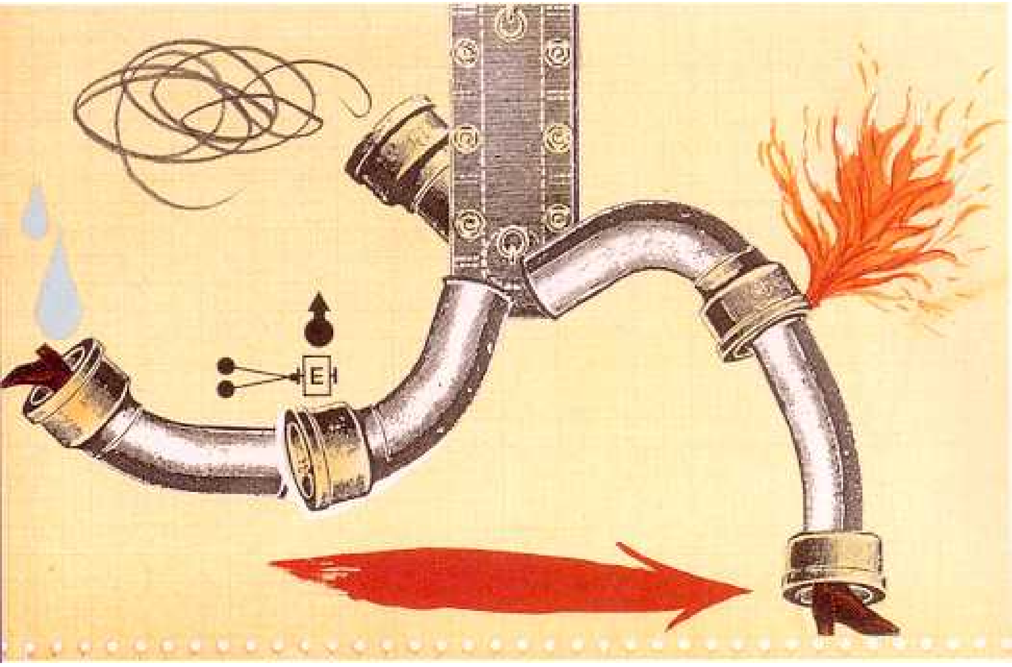
Garcia and his bosses at the defence department now believe that technology has moved on sufficiently to make the concept a reality. In particular, new lightweight composite materials and advances in micro-electromechanical engineering mean that it's now possible to build small engines that are far more fuel efficient than older designs. "The time has come when we can fuel inject, or control the fuel burn, in microscopic quantities," says Garcia.

Initially, the developers at DARPA are aiming for an exoskeleton that lets troops jog along effortlessly at 13 kilometres per hour carrying a 70-kilogram load for 12 hours at a stretch. Its superstrong framework, they believe, will support the weight of extra firepower and armour, plus the skeleton's own weight—another 20 kilograms at least. That way, the theory runs, troops will conserve their own energy, and boost their staying power on the battlefield.

But as researchers have discovered in the past, the cornerstone of any exoskeleton is an efficient, light and reliable source of power. Without that, there's no exo. "The long pole in the tent is definitely the energy storage—that's the big question right now," says Robert Martinage, an analyst at Washington DC based think tank the Center for Strategic and Budgetary Assessments.

So what sort of power do you actually need to improve upon a person's walking speed and lifting power? "A human walking

Sara Fanelli



about requires about 100 watts," says Garcia, "so we need hundreds of watts at the minimum, but probably 1 or 2 kilowatts."

That power requirement—equivalent to trying to power one or two bars of an electric fire from a portable power pack—makes batteries a non-starter. You may be able to demonstrate an exoskeleton with batteries, says Garcia, but you'll never be able to build anything of any use. Researchers at Sarcos have calculated that an all-electric exoskeleton with batteries and motors would weigh an absurd 1800 kilograms.

Petrol power

After toying with a variety of fuels, Garcia's team believe old-fashioned hydrocarbons win hands down. Rather than using one large engine, the researchers think it might be better to dot small combustion engines around the exoskeleton. The problem will be persuading these small motors to provide precisely controlled amounts of power to move the exoskeleton's limbs.

Garcia's researchers are pursuing one promising idea—merging the fuel combustor and the limb actuator into one device. You might be able to do this with state-of-the-art microelectromechanical gadgets. Made from smart materials such as shape memory alloys, these tiny devices can be used to throttle minuscule volumes of fuel into a combustor, says Garcia.

To get a cross between a working power source and an actuator, Garcia's high-tech contractors are racing each other to come up with the best design. In one variant, researchers at engineering company Arthur D. Little in Cambridge, Massachusetts, are working on a "power piston" for the exo which captures the combustion energy in a spring so it can be released slowly and smoothly.

> 'SHACKLE YOUR BOOTS IN AND YOU CAN TROT AROUND HAPPILY. TURN THE POWER OFF AND YOU FALL OVER'

Their system uses a spark to combust a hydrocarbon fuel, driving a piston down a chamber. By squeezing a hydraulic fluid, the piston stores its energy in a powerful spring held in a neighbouring chamber. The idea is that when required, the spring uncoils, transferring its energy back to the hydraulic fluid which, via a series of valves, provides seamless movement for the exo.

Roberto Pellizzari, until recently manager of the project at ADL, says that tests are due to start soon on a prototype power piston the size of a cola can. Ultimately, the aim is to have the exoskeleton run on JP-8, the military's all-purpose fuel which can burn in anything from a camp stove to a jet fighter.

Garcia also has Quoin, a firm in Ridgecrest, California, exploring other approaches to powering the exo. This company—which is also developing parts for the proposed US ballistic missile defence system—not only plans to generate exoskeleton motion with a novel miniature turbine, but also hopes to develop an electricity supply for the copious electronic sensing, imaging and communications systems that a battle-ready suit would need.

Quoin's generator uses dual pistons that are connected to a reciprocating rod which moves back and forth. The rod is surrounded by a metal coil and as the rod moves, a small magnet on it induces an alternating current in the coil. This could power sensors or other electronics mounted on the suit.

Beyond the motors and energy source, the next problem is the pesky human body. Where, for example, do you put the actuators to best support the human gait? And how can you design the suit to be adjustable for people of different heights and weights?

No one knows all the answers yet. But Boston Dynamics, spin-off from MIT's Leg Lab, is trying to find the answers with predictive modelling and computer visualisation. They're simulating combined exoskeleton and human limb motion so that when they build a prototype, the motors can drive it in smooth, seamless motion.

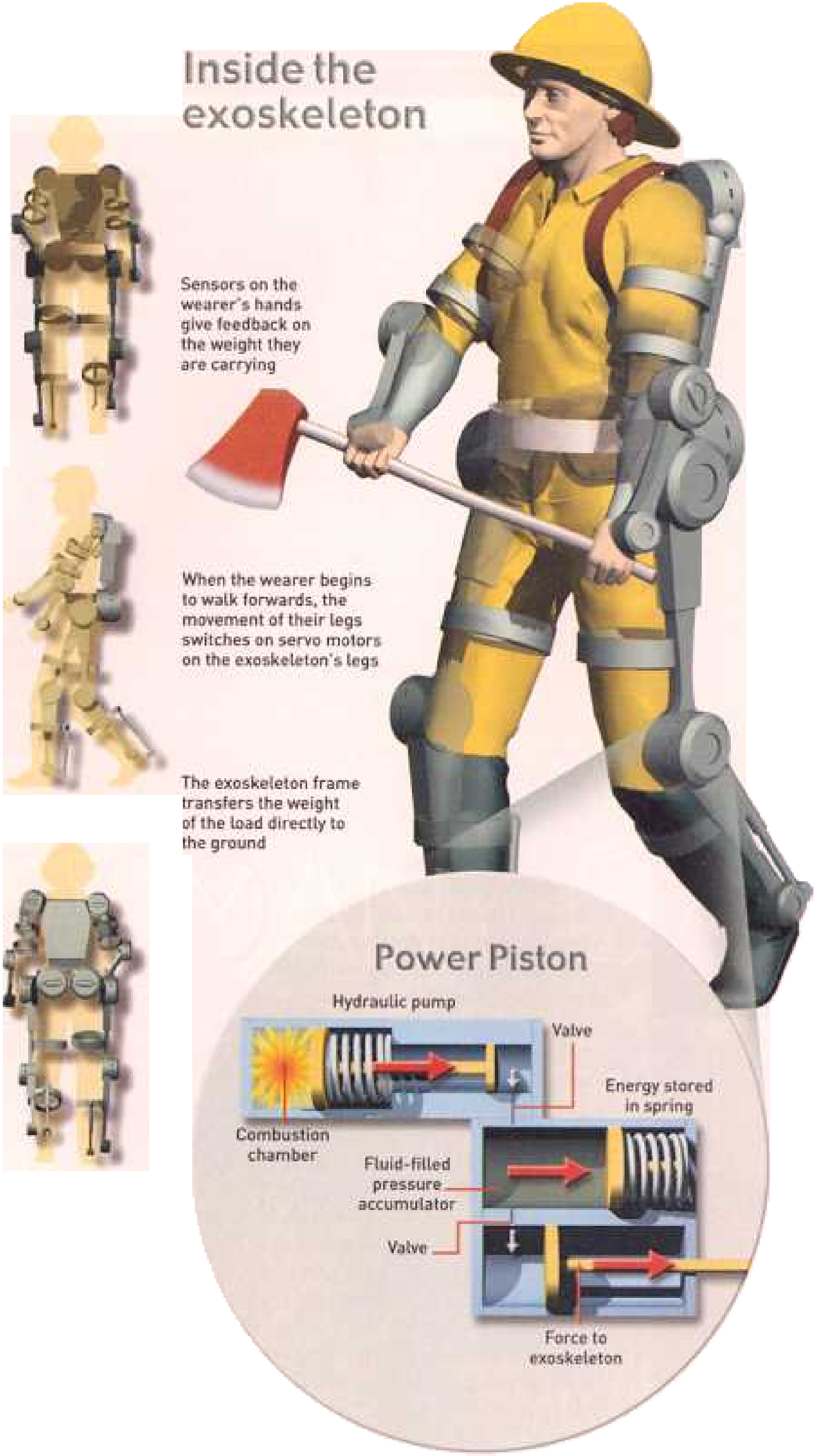
Meanwhile, mechanical engineer William Durfee and his team at the University of Minnesota in Minneapolis are developing what's called the exo's "soft tissue interfaces"—the bits that attach the person to the machine. Unlike leg braces, for example, which attach via clamps or bone screws, the exo will have to be strapped or zipped on, with fittings that somehow minimise the loading on skin and muscle.

They're aiming for the coupling arrangement to be "like a well-fitting shoe", says Durfee. But as they move, wearers of the system will only feel it gently touching them, as it will be set up to "walk like you walk, in synchrony", says Jacobsen.

Doing some of the legwork, quite literally, is Homi Kazerooni. He's a veteran of many walking robot projects at the Human Engineering Lab he runs at the University of California at Berkeley.

Kazerooni's team became involved because they've already built LEE—a lower extremity enhancer. It's basically a pair of powered, wearable legs for an exoskeleton. Unfortunately, the lack of a decent power source is all too obvious. LEE is driven by a noisy, heavy, exhaust-guffing chainsaw engine the wearer totes around in a bulky backpack. Shackle your boots into LEE's feet and you can trot around fairly happily—as long as the engine is running. Switch the power off and you just fall over.

Garcia expects a lot more than this crude technology for his $50 million. "I want to distance the exoskeleton project from that [LEE] rig. It has a limited cyclical walking motion that doesn't sense your motion and try to help you," he says. But it's early days, and the Berkeley team are confident they will be able to create more complex legs that squat, bend, swing from side to side, twist, walk and run. At the same time, other



researchers at Sarcos and at Oak Ridge National Labs in Tennessee are developing the suit's top half. And to support the weight of whatever weapon or rescue equipment the wearer is toting, the suit will need the mechanical equivalent of hands—in this case, probably some kind of metal grippers.

With a complete exoskeleton frame and the motors to drive it, the only thing you need now is the sensing system that lets you tell the exoskeleton when to lift an arm or jump a ditch. This is going to come from a novel touch-based, "haptic" control system that will sense what the exo-wearer wants to do and move accordingly.

Each limb of the exoskeleton will be equipped with an array of motion sensors that are in contact with the wearer's body. Once they detect slight movement in an arm or leg, for instance, the sensors will signal the haptic control system to switch on motors that move the exoskeleton's arm or leg to match. This will have to be done seamlessly, without hindering any activity. These haptics will also have to feed back an authentic lifting sensation to the user so they don't apply too much force and damage whatever they're lifting—or the exoskeleton itself.

Simple haptic control systems are already in place in the car manufacturing industry. On the production line, workers use hand-held controllers to manipulate items such as windscreens with a robotic arm. These controllers even give the users some mechanical feedback—letting them know how much force they're applying to help them manoeuvre the objects into place. But how they're going to adapt such simple systems for a much more complex exoskeleton is unclear. And even if it were, DARPA has applied a minor league news blackout on new exo developments. "We tend to get burnt if we promise too much in advance," says DARPA spokesperson Jan Walker. The researchers are optimistic, however. "This is the first time we've ever had a coordinated team effort," says Garcia.

They plan to have a prototype working by around 2004. If it works as they hope, the suit could eventually be capable of working for 18 hours and carrying a 140-kilogram load, says Jacobsen. "Exoskeletons could help people out in all sorts of emergency arenas," predicts Louis Piscitelle, a researcher at the US Army's Soldier Systems Center in Natick, Massachusetts. In a nuclear accident, for example, an exoskeleton could carry a huge weight of lead shielding, giving the engineer who dons it more time to tackle dangerous spills without exposing themselves to a fatal dose of radiation. It could even be given a degree of autonomy—so that should its wearer be injured, the suit could simply stroll to the nearest first aid post.

Yet the machines themselves aren't risk-free. Heading into a burning building or onto a battlefield strapped inside an exoskeleton loaded with highly flammable fuel is going to take some guts. "If the fuel is alcohol-based, it will easily burn," says Keijiro Yamamoto of Kanagawa University in Japan, who is developing a compressed-air powered exoskeleton (*New Scientist*, 28 July, p 22). And since you'll be locked into the suit, major malfunctions could easily be fatal. In fact GE's Hardiman was never turned on "for fear of what it might have done to the poor guy inside", says Garcia.

Climbing into one of these mean machines is sure to convert you from a wimp to an invincible giant. But just remember: stay away from naked flames, weak bridges and large magnets. And if your nose begins to itch, whatever you do, don't scratch it. You may never see it again. □