

# Exoskeletons for warriors of the future

Dr Carlo Kopp

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Berkeley Bionics / Lockheed-Martin HULK exoskeleton.

THE concept of a powered exoskeleton or augmentation system to provide a soldier with strength, endurance and speed well beyond what the human body can provide has had an enthusiastic following over many decades. Less well known is that recent developments in robotics are producing the first designs that have actual potential for implementation.

In medieval times, knights or Samurai warriors clad in chain mail and armour conveyed superior warfighting capabilities, and this style was popular with period armies in the West and the Far East. Modern exoskeletons, however, derive more of their popularity from more recent ideas, articulated in the Mobile Infantry powered armoured suits of Robert Heinlein’s ‘Starship Troopers’ novel published in late 1959, or the subsequent Iron Man powered suit imagined by Stan Lee and first published in Marvel Comics in 1963. Both themes have become the subject of very successful recent cinema franchises by Verhoeven and Favreau, in which special effects have been used extensively to create an illusion of reality. The popular appeal of military robotics technology also gained much from the successful, long running Terminator franchise launched in 1984.

The original Heinlein and Lee ideas emerged after the Korean War, in which heavy losses in infantry were sustained by Western conscript armies. The prospect of being drafted and sent into conflict was very real for young men of this period, and the idea of a powered armour suit invulnerable to infantry weapons was understandably apt to be popular. The infantry-intensive COIN campaigns of the past decade have reinvigorated interest recently.

Fifty years ago robotics technology was in its infancy and a powered exoskeleton or suit was science fiction. In 2011, the basic technology has evolved to the point at which real products are now becoming technically feasible, although with significant limitations compared to sci-fi concepts. But will the future belong to a real Mobile Infantry, clad in servo driven rocket propelled armour suits

providing superhuman strength and speed, and bristling with advanced sensors and weapons?

## CONTEMPORARY EXOSKELETON TECHNOLOGY

Numerous technological obstacles need to be crossed before this technology can be deployed spanning the full gamut of control systems, motion and force sensors, actuators, and especially power supplies. Evolution in robotics has brought important advances across many of these areas but the problem of providing a durable high density lightweight power supply remains to be solved.

The first genuine attempt at a powered exoskeleton was by General Electric during the 1960s, as part of the Hardiman (Human Augmentation Research and Development Investigation/MANipulator), intended for heavy industrial applications. Immature technology resulted in an expensive failure. The concept did however reappear in science-fiction, implemented as the powered loader exoskeleton in James Cameron’s 1986 classic, ‘Aliens’. A parallel soldier exoskeleton research effort by Los Alamos National Laboratory, under the US Army sponsored Project Pitman, also failed to produce viable results.

A number of promising developmental projects currently active leverage advances in robotic actuator, sensor and control system technology, and exploit Moore’s Law driven growth in computing performance per dollar. The ability to precisely control motion and force in complex servo-mechanical systems of this kind requires a lot of fast computation. For comparison, aircraft digital flight controls recompute the aircraft kinematic and control models 50 to 100 times every second.

An exoskeleton would be very similar, but with processing required for a considerably larger number of control actuators and sensors. Reliability, given the injury risks to wearers and bystanders, dictates multiply redundant controls, inevitably resulting in triplex or quadruplex designs.

One of the most interesting developmental projects currently underway is the long running LIFESUIT project, launched two decades ago by Monty Reed, a former US Army ranger who suffered a debilitating spinal injury during a failed parachute jump (<http://theyshallwalk.org/>). His agenda is to provide a device which enables paraplegics to walk – inspired by reading Heinlein’s novel. The LIFESUIT project has evolved through a series of prototypes, now up to LS#15. While not designed for a military application, this project has the potential for improving the quality of life for many victims of spinal injuries. Spinal injuries and maimed limbs remain one of the most frequent injuries suffered in infantry combat, and have been an unfortunate feature of recent IED-centric COIN campaigns.

Another project is the New Zealand-based Rex Bionics Robotic Exoskeleton or REX. This project is commercial, and aims to replace wheelchairs used by paraplegics. The REX is controlled by a hand-operated joystick and is a relatively simple product compared to military exoskeletons.

A third notable project is the Hybrid Assistive Limb 5 (HAL5) being developed by Tsukuba University in Japan, commercialised by Cyberdyne Inc, a Japanese startup company named after the manufacturer of the Terminator robots in the Cameron movie (<http://www.cyberdyne.jp/english/index.html>). The important advance in the HAL5 is the use of bio-electric sensors to detect nerve impulses to muscles, removing the need for an external control interface. The HAL5’s internal processing and control system uses inputs from motion and force sensors to provide feedback against the bio-electric sensor command inputs. The 23 kg exoskeleton will operate for 2.6 hours continuously on a single battery charge, and is intended for the elderly, infirm or disabled.

Honda’s Fundamental Technology Research Center in 2008 revealed its ‘Experimental Walking Assist Device’, a lightweight exoskeleton design 2.8 – 6.5

kg, powered for up to two hours by a 22.2 Volt Lithium Ion battery, and using brushless DC motors for actuation. The technology is derived from Honda’s ASIMO ‘humanoid’ robot project.

The Defense Advanced Research Projects Agency (DARPA) is currently funding the Massachusetts Institute of Technology project to develop an exoskeleton for military and medical applications. The prototype weighs ~12 kilograms, is powered by a 48 Volt battery, includes a damping mechanism for knee loads and elastic components to store energy in the exoskeleton hip and ankles. The lead researcher, Associate Professor Hugh Kerr, who was disabled in a mountain climbing accident, is aiming to develop a neural interface to enable this technology to be adapted for prosthetic use. A report in the Scientific American journal indicated that trials with the prototype allowed wearers to carry much heavier loads while walking, but the exertion required was still greater than walking with no load at all.

A parallel project run by Berkeley Bionics and the University of California, more recently commercialised by Lockheed-Martin, is focused on two designs: the ExoHiker for long cross country marches, and the ExoClimber for assisted climbing of steep slopes with heavy payloads, a major issue for military operations in mountainous terrain. Berkeley’s prototype ExoHiker allowed a 65 kilometre walk at 4 km/h speed using a single 0.45 kilogram Lithium polymer battery. The prototype ExoClimber permitted a 185 metre ascent with a 70 kg payload, with the energy stored in the same battery type.

Lockheed-Martin have licenced this technology and are marketing it to military users as the Human Universal Load Carrier or ‘HULC’. The stated aims of the HULC are “mobility and endurance enhancement” with a 70 kilogram payload and with an additional “Lift Assist Device” the stated intent is “performance enhancement for sustainment capabilities,” which is essentially logistics. In late June, 2011 the prototype ruggedised military HULC entered testing at the US Army Natick Soldier Systems Center in Massachusetts. The HULC permits its wearer to “run, walk, kneel, crawl, and even go into low squats”.

Protonex was recently engaged by Lockheed-Martin to develop and supply fuel cell based power supplies for the HULC, for extended duration operation in excess of 72 hours, and powering of soldier payloads. Protonex are best known as a developer and supplier of proton exchange membrane (PEM) and solid oxide fuel cell (SOFC) technology. Protonex PEM cells can be fuelled with methanol, chemical hydride hydrogen generators, or gaseous hydrogen, while the SOFC cells claimed to be in development can be fuelled with propane, kerosene, gasoline, diesel, JP8, biodiesel, bioethanol, butanol and other alcohols, biogas, and “future lignocellulosic-based biofuels made from non-food organic feedstocks”.

An anecdotal observation is that SF units using an SOFC fuel cell have the option of stealing farmers’ moonshine to power their equipment, if the exoskeleton fuel supply runs out.

The principal competitor to the HULC is the Raytheon XOS 2, based on the Sarcos XOS design developed in a DARPA funded exoskeleton project, initiated in 2000. Raytheon and Sarcos have disclosed little technical detail on their designs and technology employed.

What has been disclosed is that the XOS 2 uses high pressure hydraulic actuators to provide strength and agility, and hard hydraulic tubing for distribution. Unlike the HULC, which is primarily a lower torso assist device, the XOS 2 provides powered arms and a back support structure, making it a full exoskeleton design. The XOS 2 is due to power demands currently tethered, and intended for logistics applications.

In September 2010, Dr Fraser Smith of the Raytheon/Sarcos development team stated that Lithium batteries were rejected due to their potential to explode or burn if hit by hostile fire, with the project focusing its effort on highly energy efficient hydraulics powered by an internal combustion engine. He also pointed out the important dichotomy between operational needs in exoskeletons, as logistical applications required brute force and endurance, while combat applications required light weight, high agility and untethered operation from a battery or other power supply.



Left to right:

New Zealand developed Rex-Exoskeleton for paraplegics.

Japanese Cyberdyne Inc HAL5 exoskeleton for disabled patients.

DARPA funded MIT exoskeleton prototype.



*Clockwise from far left:*

*Raytheon/Sarcos XOS 2 exoskeleton used to break boards in a strength demonstration.*

*Raytheon/Sarcos XOS 2 exoskeleton used to make pushups easy.*

*Raytheon/Sarcos XOS 2 exoskeleton used to play soccer in an agility demonstration.*



Smith predicted the operational use of tethered 'logistical' exoskeletons in a half decade, and untethered 'combat' exoskeletons in about a decade, the latter subject to evolution in power supply technology.

In summary, contemporary technology is approaching the level of maturity where operational use will begin over the coming decade, and the technology base is already stratifying into three distinct categories of exoskeleton, for medical, logistical and combat applications.

## MILITARY UTILITY OF EXOSKELETON TECHNOLOGY

Powered exoskeletons clearly will provide valuable capabilities in military operations, but it is yet to be determined whether these will be in logistical or combat applications.

An exoskeleton built for a logistical application can be employed to increase the productivity of personnel manually handling materiel, and reduce the frequency of back injuries that can significantly deplete personnel strength and incur long term liabilities if a disability develops.

While in many civilian applications specialised loading and handling equipment can be easily deployed, this is much less frequently the case for military forces who must often improvise and both handle and store materiel under conditions no commercial operator would ever contemplate. The more remote the deployment and less developed the infrastructure, the more reliant military forces become upon the manual handling of stores. Combat damage to infrastructure, a feature of most combat, especially combat between developed nations, exacerbates the problem.

In this environment, both tethered and untethered exoskeletons have very high utility. Unimpeded resupply of munitions, fuel, food and other stores has been a feature of successful high intensity combat operations, and failures in resupply often

led to catastrophic failures in combat. Perhaps one of the best examples is the disastrous German Kursk offensive, when manoeuvre forces outran their logistical supply tail. High intensity combat over recent decades has seen repeatedly the sensitivity of operational effectiveness upon the unrestricted resupply of materiel.

Augmentation of existing logistical units with powered exoskeletons provides 'headroom' in capability, especially in dealing with surge demands characteristic of highly fluid manoeuvre operations. No less importantly, powered exoskeletons extend the capability into forward operating environments, which have traditionally presented a challenge for high tempo logistical operations.

The technology may have less obvious applications: one is flight line handling of munitions and heavier aircraft components during flightline maintenance. Another is damage control in warships, where the additional strength of an exoskeleton could prove most useful.

It is likely that once military exoskeletons developed for logistical applications mature, commercial operators will adopt them, and with increasing volumes in production, they will become very affordable over time, and the technology will evolve rapidly.

The future of combat exoskeletons is less easily divined, as the demands upon such designs are much more challenging.

A combat exoskeleton must be untethered, presenting major challenges with power supply technology and fuel load; it must be agile, this presenting major challenges in weight and actuator technology bulk and vulnerability;

It must be resistant to combat damage, be it spill and shrapnel, or bullet hits; it must be robust enough to operate in a very hostile environment, exposed to fresh and salt water, mud, dust, sand, and subjected to rough treatment and often poor in-field maintenance; and it must not significantly increase the infrared, acoustic or radar signature of the user, so as not to permit early acquisition and engagement.

These problems are not easily solved, but are eventually solvable if research is properly funded and properly focused and planned.

What combat exoskeletons offer is at a minimum 'superhuman' endurance and ability to manoeuvre on foot in complex terrain, with larger than traditional payloads of supplies and ammunition. They also become an 'enabler' for heavier infantry weapons, infeasible in the past due to ammunition or propellant weights, weapon weight, or weapon recoil.

The outer envelope of technology encompassing armoured suits with integrated weapons is some distance away, and will only become a reality once the more basic exoskeleton matures in operational use. Science-fiction fans may have to wait some time yet!



*LM HULC exoskeleton.*



*LM HULC with logistical 'Lift Assist Device' fitted.*