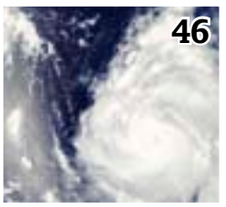
science | innovation | technology

www.science.mod.uk ▢ Issue 5 ▢ Winter 2009

Defence Codex

December 2009

The Journal for Defence Engineering & Science



Fighting fit

DMRC Headley Court support and rehabilitation

MINISTRY OF DEFENCE

[dstl]

[dstl]

Dstl's science and technology makes a difference to UK Armed Forces on the front line

The Defence Science and Technology Laboratory is part of the Ministry of Defence

Find out more about Dstl's work:
T +44 (0)1980 658091
E dstlcustomercommunications@dstl.gov.uk
www.dstl.gov.uk

Editorial

Our first priority is to support operations and the men and women who risk their lives in Afghanistan and elsewhere.

This applies as much to the science and technology community as it does to other areas of the defence effort.

As usual we have been out and meeting the people who may not hit the headlines, but play an important role in the defence effort. We have been talking to the medics who save lives on the battlefield, the scientists who work on the cutting edge of defence, and academics and military personnel who influence future generations through education and training.

Lt Gen Graham talks openly about the important role of the Defence Academy and how he is shaping the organisation in order to help prepare personnel from across defence for current and future challenges. We also visit Welbeck College where a talented future generation prepare for a science, engineering and technology career in the Armed Forces or Civil Service.

The courage and determination of those who have been injured in service is matched by the commitment and skills of the teams that care for them at DMRC, Headley Court. We were privileged to meet some of the patients and talk to the military and civilian staff who travel with them through their recovery. Science and technology has an important role to play in rehabilitation and developments in prosthetics have made it possible for many servicemen and women to return to active duty. But there is more that can be done here and a recent Centre for Defence Enterprise (CDE) call has resulted in some interesting proposals for developments in this area.

MBDA invited us to Stevenage to look at their work and discuss how they have adapted to become more responsive to present day demands for agility and closer collaboration with partners. These principles have allowed systems such as the anti-armour weapon BRIMSTONE to undergo rapid development and undertake new vital roles in Afghanistan.

Finally I am delighted to welcome Dr Mike Steeden who has taken on the role of Journal Editor. As Technical Director of Defence Science Technology Laboratory (Dstl) and current President of the Royal Aeronautical Society he has a wealth of experience in defence science and engineering and along with his colleagues will develop this section of Codex in future issues.

Gavin Copeland
Editor

Cover Photo – Sergeant Colin Hamilton

Codex – Award of Excellence
Communicators in Business (CiB) 2008–2009 Awards

Contents

Codex

Codex is the Latin word for the first Roman books that replaced scrolls and were collections of the key learning of the day. In the modern age, Codec is a shortened version of compression/decompression, the algorithms used to efficiently store and transmit large quantities of digital information.

Published by science | innovation | technology, Ministry of Defence, Zone 1-K MOD Main Building, Whitehall, London SW1A 2HB

Editor
Gavin Copeland
Defence Technology & Innovation Centre, Hackett Building, Defence Academy, Ministry of Defence, Shrivenham, Wiltshire SN6 8JU

Assistant Editor
Wendy Jacob
0113 399 4126
codex.editorial@cds.co.uk

Advertising Manager
Paul Meersman
0113 399 4020
codex.advertising@cds.co.uk

Subscriptions
www.science.mod.uk/codex/subscribe.aspx

General Enquiries
science-codex@mod.uk

[dstl]

Journals Enquiries
01980 658090
codex.journal@dstl.gov.uk

Distribution
Current policy is that Codex will be distributed at all main MOD sites and free of charge to UK and BFPO addresses, subject to availability.

Printed on Era Silk – made using 50% recycled waste and fully certified by the Forest Stewardship Council.

Online magazine

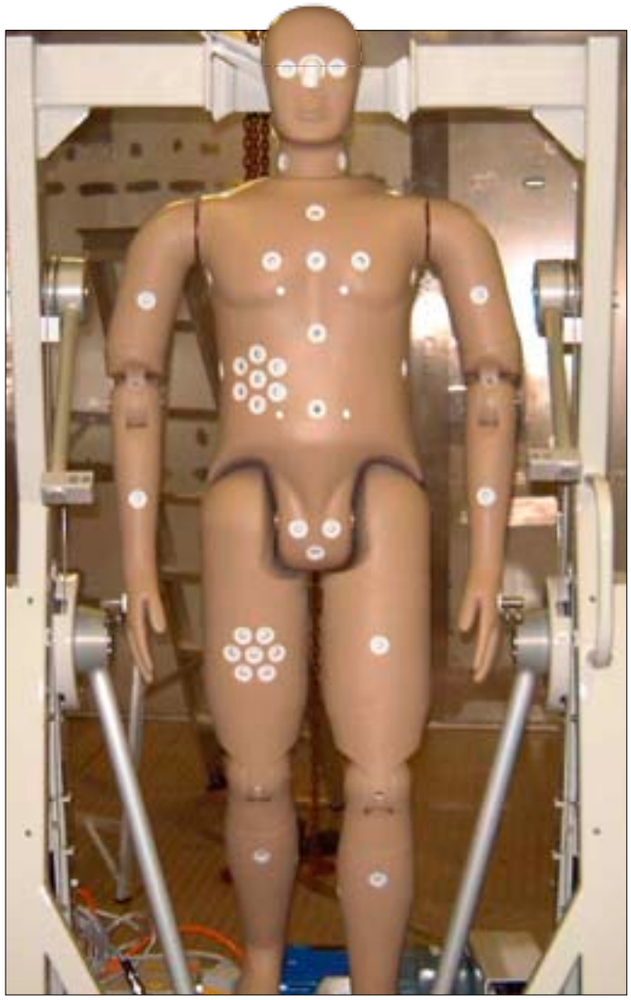
- **www.science.mod.uk/codex**

Designed and produced by CDS – WP423590

CDS
www.cds.co.uk

Protection testing measures up

Defence Science and Technology Laboratory (Dstl) demonstrated a new, real-time method of measuring chemical warfare agent penetration beneath a clothing system using Ion-Mobility Spectrometry (IMS).



Real-time, in-suit monitoring of protective clothing systems provide concentration-time profiles and enable the protective performance of a clothing system to be quantified as a function of time. From this data, it is possible to determine when physiologically critical exposure dosages occur and provide detailed information on suit performance. The current sampling technique uses Passive Adsorbent Dosimeters (PADs) and dosimeter tubes, to determine the mass that has been adsorbed.

Successful trials have now been carried out using IMS in the form of a Lightweight Chemical Detector (LCD) as a real-time monitor for the measurement of the blister agent sulphur mustard beneath an experimental suit system.

This is believed to be the first demonstration of a concentration-time profile of a live chemical warfare agent measured beneath a clothing system. In addition to greatly improving full-system test procedures using Dstl's 'Porton Man' animated mannequin, this research could lead to improved toxicological assessments and provide a far more detailed evaluation of military and civilian protective clothing systems.

- www.dstl.gov.uk

Surgeon General calls for assistance

The Surgeon General, Lt Gen Lillywhite attended a recent seminar at the Centre for Defence Enterprise (CDE) to support a call for proposals in the area of Battlefield Medical Technology.

Lt Gen Lillywhite described the challenges of working in the battlefield and outlined areas where developments could impact on survival rates and quality of care. These include: quality of survival, battlefield analgesia and medical force protection.

The oversubscribed event gave participants from industry and academia the opportunity to meet military personnel and gain from their first-hand experience of working on the front line. Lt Gen Lillywhite welcomed proposals from anyone who has an idea that would contribute to the combat casualty care programme or wider public health issues but stressed: "Proposals must be practical and effective and they need to take into account the environment."

The call is being developed by CDE, Surgeon General, Assistant Chief of Defence, Staff Health, Royal Centre for Defence Medicine and the Medical Logistics division.

- www.science.mod.uk

PACSCAT demonstrator takes to the water

The Partial Air Cushion Supported CATamaran (PACSCAT) Innovative Solution Demonstrator Craft (ISDC) has entered the water for the first time and will now undergo rigorous sea trials.

The craft, which is designed to off-load front line vehicles and troops from Royal Navy amphibious ships to the beach, is being developed in response to MOD's requirement to launch rapid and effective amphibious operations from over the horizon.

QinetiQ are managing the sea trials that will test the full scale demonstrator vessel. They have already conducted 1/15th scale model tests in their testing tanks at Haslar and a one third scale manned model has already shown enhanced performance over current in-service capability during manned model trials.

- www.griffonhoverwork.com
- www.qinetiq.com

Gray report published

An independent review led by Bernard Gray, recently published a report on MOD's equipment procurement process.

The report identified a number of areas where the acquisition process could be improved, including the need to bring equipment plans into line with likely available resources and the need to improve equipment programme planning, management and delivery.

Minister for Strategic Defence Acquisition Reform, Lord Drayson, believes that the report supports MOD's determination to ensure that the right equipment is delivered in the most efficient way: "We accept most of his recommendations and are getting on with implementing them alongside broader work to develop a future strategy for defence acquisition, which will ensure we deliver as effectively as possible the equipment the Armed Forces need."

Gray will work with the MOD to develop an overall Strategy for Acquisition Reform which will be published in the New Year.

In Brief

Anglo French agreement

UK and France this year signed up to a four year Technical Agreement on Low-Frequency Active Sonar (LFAS) covering Wideband and Multistatic ASW technology. The agreement includes three experiments to demonstrate operational benefits to each nation's navy.

By 2012 the Anglo-French project will develop and test at sea different combinations of Wideband and Multistatic technology and processing. The trials and post-trial analysis will assess their contribution to submarine detection and false alarm rate and lead to recommendations on the features to incorporate into each nation's LFAS systems. The project will also demonstrate the benefits of moving towards a NATO-wide interoperable LFAS network.

Research over the past 20 years has demonstrated that multiple sonars, working cooperatively in the same area, can enhance the detection and tracking of slow-moving submarines. The greater emphasis on cooperative war-fighting in recent years, coupled with the proliferation of LFAS capability, presents the opportunity for in-service Multistatic Active operations.

Astute technology on test

The Astute nuclear powered submarine recently entered the sea in her first trial heading from BAE shipyard at Barrow-in-Furness to her home port of Faslane on the Clyde in Scotland.

Astute is equipped with the latest stealth technology, a world beating sonar system and armed with 38 torpedos and missiles. Advanced nuclear technology means she can circumnavigate the globe without refuelling.

Full acceptance by the RN is expected next year.

- www.mod.uk
- www.baesystems.com

Water, water… but not everywhere!

Safe drinking water is vital to troops working in temperatures in excess of 50°C in Afghanistan and other hot climates. Advances in drinking systems that decontaminate water are currently being trialled by British troops for use on operations.

BW Technologies' Pure Hydration Expedition Field Pump System draws water from a contaminated source, purifies it by removing bacteria, waterborne pathogens, sediment and heavy metals, and pumps it back, decontaminated, into the service issue Camelback.

Lifesaver Systems' Lifesaver bottle uses a manual pump to filter dirty water through a membrane. This is then instantly decontaminated to remove bacteria, viruses, fungi and waterborne pathogens.

Over 4,000 filters are being trialled with members of 19 Mechanised Brigade currently serving in Afghanistan. The trials, which test the effectiveness of the filters, their ease of use and durability under harsh battle conditions, are expected to be completed this year.

- www.bwtechnologies.com
- www.lifesaversystems.com

SET awards 2008

MOD Chief Scientific Adviser (CSA), Professor Mark Welland this summer presented awards to the winners of the Atomic Weapons Establishment (AWE) Science Engineering & Technology (SET) Awards 2008 which recognises the achievements and hard work of individuals in this area.

Clive Marsh Award: Dr David Johnson for his contribution across all areas.

JC (Charlie) Martin Awards: Mike Hutchinson for his paper 'The escape of blast from fragmenting munitions casings'. And Alan Mears for his report 'Further analysis of KRAKATAU region 1'.

Chief Scientific Adviser, Ministry of Defence Award: Chris Marsh for his invention of an ingenious stronglink concept based on explicitly driven code events in a dual maze arrangement to discriminate the unique signal.

John Challens Medal: John Maw in recognition for his sustained, high quality and valued contribution to the work of AWE.

- www.awe.co.uk

Flying forces on the front line

If AESIR has its way, a three tonne robot flying saucer will soon be hovering over the battlefields.

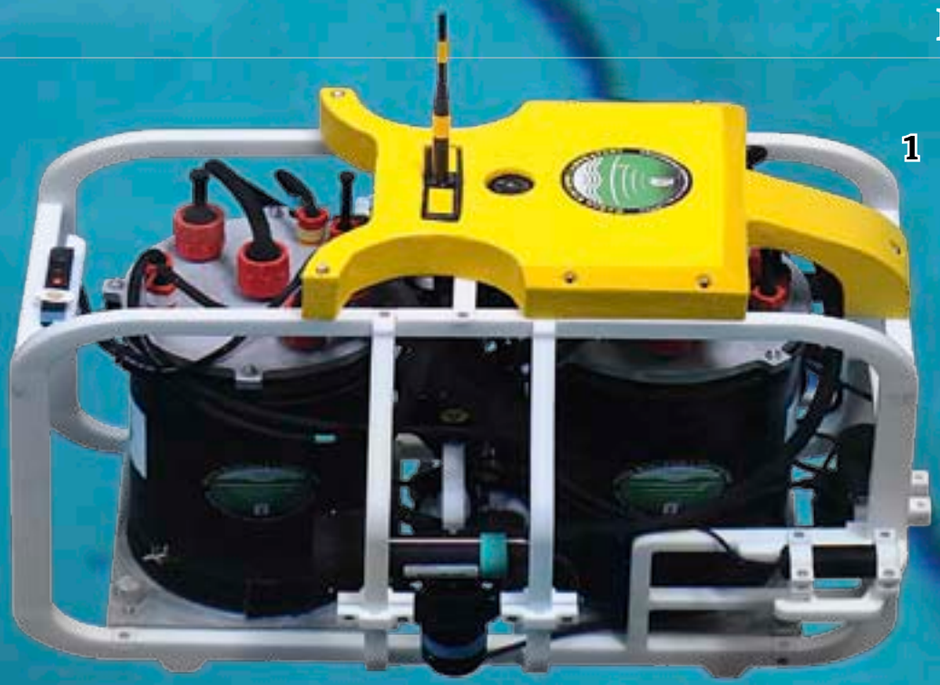
AESIR has developed a family of Vertical Take Off and Landing (VTOL) Unmanned Airborne Vehicles (UAV) designed to operate in both urban and rural environments. These provide a platform suitable for a variety of uses including surveillance and cargo lift.

The craft utilise the Coanda effect to generate lift with inherent stability making it suitable as a surveillance platform. The design has no external rotating parts and can survive low speed impact with the ground, buildings and other fixed objects.

The range includes Hoder, a heavy lift craft which can carry a one tonne payload and is primarily intended for cargo transport and the resupply of front line forces, replacing the need for piloted helicopters or ground convoys. Though early in the stages of development it is expected that it will be multi-engine. In addition to logistic support it can be used in a variety of roles where persistence is of greater importance than payload.

- www.aesir.com

Nessie floats to the top – again!



In another outstanding performance, Nessie outshone seven competing teams to win the annual Student Autonomous Underwater Challenge – Europe (SAUC-E) and the £3,000 prize money sponsored by BAE Systems.

Photo 1 and 2 – Nessie in action
Photo 3 – Haslar Ocean Basin
Photo 4 – Heriot-Watt team

Heriot-Watt University's robot, 'Nessie', performed consistently throughout the two days of competition, performing a series of underwater tasks, including passing through gates without touching frames, parking inside a box and following a moving target. This year's event was held at QinetiQ's Ocean Basin in Haslar, Gosport, Europe's largest freshwater tank.

The competition is supported by UK and French MODs and open to student-led teams. It is designed to challenge a new generation of engineers to build a vehicle and perform realistic missions underwater. Dstl Judge Ben Evans was impressed with Nessie's abilities and the team's hard work: "The robot did nearly all the challenges and carried out far more of the underwater course than the others. Nessie has had a long period of development and some of the problems from previous years have now been overcome."

French team ENSIETA (Ecole Nationale Supérieure des Ingénieurs des Etudes et Techniques d'Armement) from Brest, Brittany, came second, with German team Avalon from the University of Bremen, third.

- www.dstl.gov.uk

Haslar

The Ocean Basin at Haslar is the largest freshwater tank in Europe and is used to test the design and manoeuvrability of scale models of submarines and ships in different sea conditions. The tank is 120 x 60m and 5.5m deep, with a rotating arm with a maximum radius of 27.5m and speed of 0.6 rad/s.

The five element wavemaker can make regular and irregular waves. The flow field which includes the velocities, waves and pressure around a ship has been studied on model scale for over a century.

A facility sharing agreement has been negotiated with France for the UK to use the GTH cavitation tunnel at Val de Reuil, and for France to use the Ocean Basin at Haslar for submarine hydrodynamic and manoeuvring testing. Both nations have committed themselves with a Statement of Intent, signed at the UK-France summit in March 2008, to work towards signing a long-term legal agreement by 2009.

- www.qinetiq.com

Capability Visions – speedy innovation

Science and Technology Capability Visions (CVs) were launched in February 2009 with the aim of encouraging innovators and industry to work with MOD to develop revolutionary ideas and address five long-term defence challenges.

- **Reducing the Burden on the Dismounted Soldier**
- **Future Protected Vehicle**
- **Reducing Operational Dependency on Fossil Fuels**
- **Novel Air Concept**
- **Electronics Defeat.**

As part of the Defence Technology Plan (DTP) the CVs have successfully stimulated new activity in the wider R&D community and challenged existing and new suppliers to apply their science and technology in new and innovative ways.

Over 50 contracts have now been placed with a wide range of organisations across industry and academia. Around 35 of the contracts are a direct result of a series of Centre for Defence Enterprise (CDE) calls which were supported by briefing events which included background information, networking opportunities and meetings with defence and military personnel.

Working alongside MOD's mainstream research programme, CVs add to the drive for the best innovation to deliver a major step change in key military capabilities.

- www.science.mod.uk

Novel Air Concept

This Capability Vision will consider new concepts and demonstrate technologies for unmanned air vehicles (UAVs) and unmanned combat air vehicles (UCAVs) in order to provide a more cost-effective means to achieve the effects currently provided by manned aircraft and cruise missiles. The concepts will have to be capable of operating within an urban landscape, up to 1,000km inside defended airspace.

Future Protected Vehicle

This aims to deliver within four years a demonstrator with the capability, agility and logistic footprint of a lightweight vehicle, combined with the effectiveness and survivability associated with a heavyweight force.

The CDE call has resulted in four contracts with other proposals under consideration. BAES/MIRA and Innov8 (Thales, Fraser Nash, Supacat, Prodrive, QinetiQ, MillBrook, Lotus) are also conducting concept studies in this area. The best technologies will then be chosen and integrated into a demonstrator for further development in conjunction with users and DE&S.

Reducing Operational Dependency on Fossil Fuels

MOD currently has an annual fuel bill of around £1 billion. Armed Forces depend on a secure source of fossil fuels; for tankers that supply power to bases in Afghanistan; flying troops and supplies between the UK and Afghanistan; and for the Royal Navy patrolling the ocean's trouble spots.

This CV is investigating the impact of and the opportunity to exploit alternative energy sources and technologies that are under development across the military and, more importantly, the civilian markets.

Nine contracts have been placed covering areas including: Formula One KERS energy systems, robust solar technology; portable wind generators and other power technologies. MOD will also be working with the Research Councils and the Technology Strategy Board on issues such as 'green shipping' and Hydrogen fuels. Biofuels, the impact of using simulators for training and ways of extracting power from waste are also being considered.

A further CDE call is being considered for 2010 with the aim of bringing together some of the best technologies. This will examine how Forward Operating Bases (FOBs) can drastically reduce or eliminate their dependence on diesel fuel.

Reducing the Burden on the Dismounted Soldier

This is a two year £10 million programme which aims to identify ways to reduce the physical and logistical burden on the dismounted soldier to improve agility, endurance and tactical effectiveness. The main tasks are:

- **Lightweight Personal Protection**
- **Weapon system**
- **Energy Efficient Soldier**
- **Assisted Carriage**
- **Soldier System Architect.**

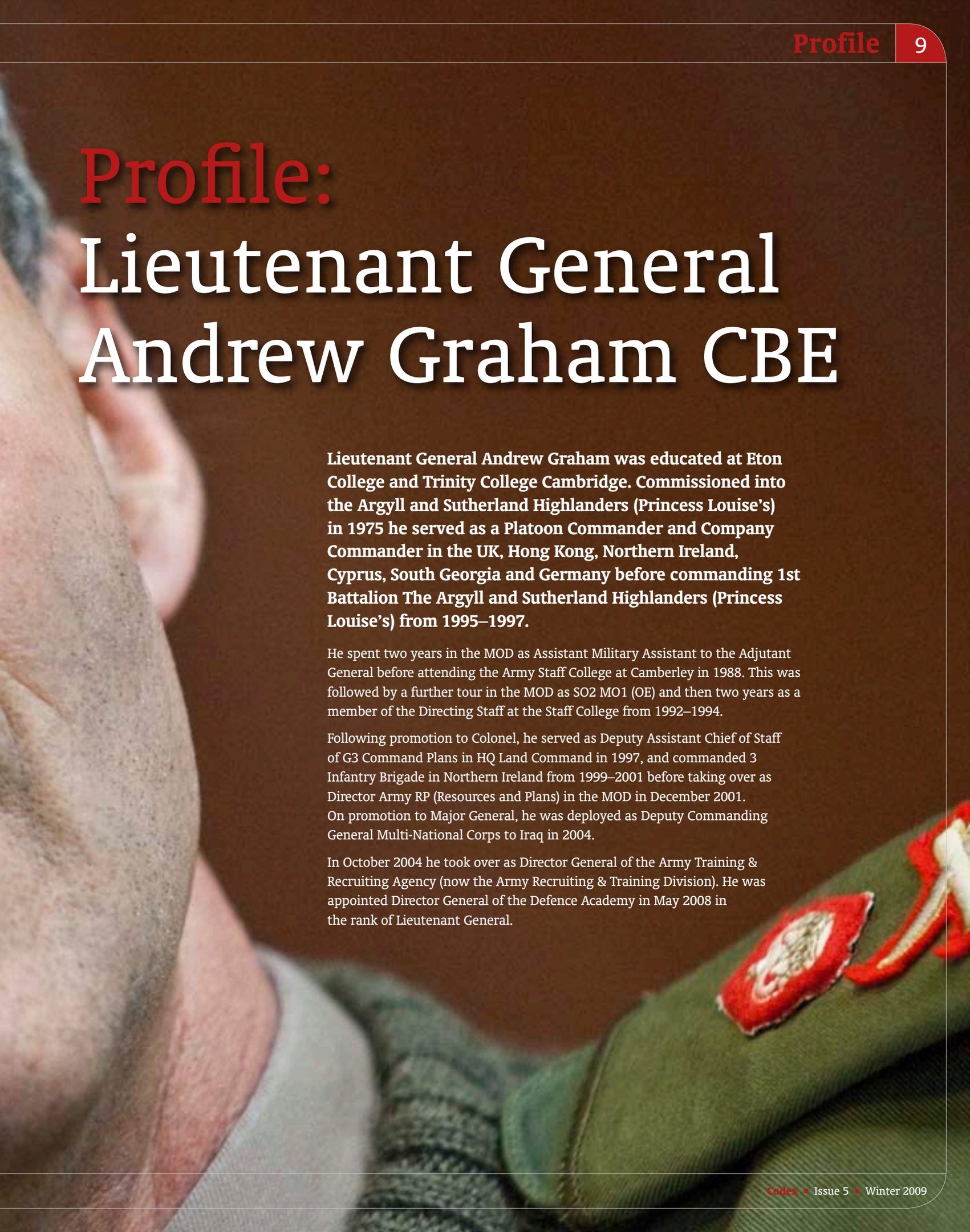
Over 30 contracts have now been placed with the majority coming through CDE calls. These include looking at new materials or designs for ammunition and armour; high efficiency batteries and novel power sources (including micro turbines and energy scavenging); as well as technologies for automated unmanned 'mules' that can follow and support soldiers, carrying some of their burden.

The soldier system architect will bring these technologies together during the two year programme. It will then be possible to assess whether the ambitious weight saving target has been achieved. Work to date has already identified a possible 25 percent reduction in overall weight, with work continuing to find more savings.

Electronics Defeat

Understanding how sophisticated electronic systems and information technology can be attacked, and the protective measures which can be adopted is vital to the future of UK defence. This CV is looking at developing a deeper understanding of the threats to systems and how these can be minimised, improving system protection and vulnerability.

Profile: Lieutenant General Andrew Graham CBE



Lieutenant General Andrew Graham was educated at Eton College and Trinity College Cambridge. Commissioned into the Argyll and Sutherland Highlanders (Princess Louise's) in 1975 he served as a Platoon Commander and Company Commander in the UK, Hong Kong, Northern Ireland, Cyprus, South Georgia and Germany before commanding 1st Battalion The Argyll and Sutherland Highlanders (Princess Louise's) from 1995–1997.

He spent two years in the MOD as Assistant Military Assistant to the Adjutant General before attending the Army Staff College at Camberley in 1988. This was followed by a further tour in the MOD as SO2 MO1 (OE) and then two years as a member of the Directing Staff at the Staff College from 1992–1994.

Following promotion to Colonel, he served as Deputy Assistant Chief of Staff of G3 Command Plans in HQ Land Command in 1997, and commanded 3 Infantry Brigade in Northern Ireland from 1999–2001 before taking over as Director Army RP (Resources and Plans) in the MOD in December 2001. On promotion to Major General, he was deployed as Deputy Commanding General Multi-National Corps to Iraq in 2004.

In October 2004 he took over as Director General of the Army Training & Recruiting Agency (now the Army Recruiting & Training Division). He was appointed Director General of the Defence Academy in May 2008 in the rank of Lieutenant General.

Graduation day is a time for congratulations and celebrations but at the Defence Academy College of Management and Technology (DA-CMT) the atmosphere is also serious befitting a military establishment committed to preparing students for present and future conflicts and the complexities of the 21st century world. Over 140 students are receiving their degrees from Field Marshal The Lord Vincent, Chancellor of Cranfield University at this year's ceremony held in the spacious Defence Capability Centre at the DA's main site at Shrivenham, Wiltshire – the military hardware and national flags providing a visible reminder that this is education with a purpose. Defence Academy, Director General, Lieutenant General Andrew Graham has invited Codex Assistant Editor, *Wendy Jacob* to spend the day at the Academy and discuss his plans for the future.

With graduates from 25 countries and representatives from the Armed Forces, MOD, industry and academia this year's DA-CMT graduation ceremony reflected the diversity of the College and the vast range of courses that it offers. Back in the ordered tranquillity of his office, Lt Gen Graham has time to reflect on the proceedings and the relevance of the ceremony: "Today is a vindication of the power of linking a world-renowned academic provider Cranfield University, the College of Management and Technology, and military and civilian experience. It demonstrates one of the unique characteristics of the Defence Academy which combines deep academic knowledge and understanding of subjects to the skills, experience and training of military practitioners to produce an outcome that is relevant, properly grounded and that has impact."

The day not only celebrated the achievements of the new graduates, but also brought together leading figures in defence, including Lieutenant General Sir Edmund Burton who received an Honorary Degree in recognition of his contribution to Cranfield University.

Sir Edmund's speech stressed the importance of technical knowledge in

"With a few notable exceptions, those who make 21st century policy, plan and set the budgets have insufficient knowledge of technology."

Lieutenant General Sir Edmund Burton

1

combat and the need for education and training in this area for the military and the Civil Service. With over 38 years' service and as a previous Commandant of the Royal Military College of Science, Shrivenham, and Military Attaché in the British Embassy, Washington DC, he has a particular interest in the professional development of leaders and is uniquely qualified to speak on the role of technology in defence education: "Our young service men and women are familiar with the strengths and weaknesses of the equipment that they use on operations and they are entitled to expect their commanders to have an appropriate level of knowledge, both of current and emerging threats and capabilities. My observation is that, with a few notable exceptions, those who make 21st century policy, plan and set the budgets, have insufficient knowledge of technology and information and of their potential to transform the business of government and defence.

"But all is not lost, for the College has continued to demonstrate what can be achieved, delivering technical knowledge and understanding to generalists and specialists, through this innovative partnership, in a very tough budgetary environment."

Although Lt Gen Graham is the first to admit that he is not a 'technical' man, he supports Sir Edmund's stand but is keen to stress that technology is just one aspect of military capability: "With technology, there is always the demand to do everything quickly, but tactics and procedures are needed when you are fighting an enemy that isn't linear and doesn't really exist except on the days that they come together and plant bombs. This is very tricky…"

For Lt Gen Graham, providing training, education and learning that is usable and relevant is his focus, as well as a commitment to meeting the requirements of what he calls 'the demanders' – primarily the Army, Navy and RAF: "The Services have stringent demands for through career command and staff training. As an example, every Direct Entry Army Major comes through our hands, as well as every Squadron Leader in the Royal Air Force and about half the direct entry Lieutenant Commanders in the Navy. I suspect this demand will grow so that every middle ranking officer will come through us at some stage for the intermediate level of command and staff training, preparing them for their 'field officer/subunit' stage of command and their SO2/SO1 staff posts."

Photo 1 (opposite) – Lieutenant General Sir Edmund Burton
Photo 2 – The Graduation ceremony in the Defence Capability Centre

This means understanding that the three Services have different aspirations and cultures but also that they need to understand one another's capabilities and limitations if they are to integrate, synchronise, network and work effectively together.

Lt Gen Graham explains that education and training must continue to evolve and it is important to decide not only what to offer, but how the knowledge will be used. "We should be committed to providing what is really needed, to identify where gaps exist and to develop training and education solutions, which may be formal courses, to meet specific needs. For example, there may be limited technology teaching at Sandhurst but a considerable number of Army officers will be required to gain sufficient technological understanding to take their place and be effective in defence equipment; hence the Battlefield Technology Course has been developed, and the numbers look set to increase in the next two years. We are increasingly discovering opportunities to fill gaps, provide what is needed as well as what is useful, and bring the Academy alive.

"We should also stop saying that this is a 'post graduate' institution. We are a training and education establishment that provides higher level learning for people in Defence. Public Sector Agreement 30 espouses cross-Government working and there are clear opportunities in what we already do to develop shared training and education activities with other government ministries."

He stresses that training and education underpinned by doctrine dedicated to meet clearly articulated requirements are 'force multipliers': "It is essential for defence that they are recognised and supported as such and not treated as bit part activities, optional extras or merely desirable. We need effective, confident, motivated people with the skills to do their particular jobs, the understanding to take decisions and make the plans to support those decisions, the leadership and management skills to inspire, motivate, develop their people, the resilience to anticipate and withstand future knocks and for little input we can provide all this."

His vision for the Academy is clear and he is determined to convince those that may not share his views that they are at risk of underestimating its importance: "Training and education are fundamental to any organisation that wants to operate at the peak of its powers; I am certain that we, and the entire Defence training and education effort, are essential in strategic terms, in providing sufficient, capable, motivated people and preparing them for the complexity of future operations."

He is keen that more people recognise the relevance of the Academy's work and appreciate that the value that the courses provide are 'direct and tangible'. "We produce people who are going to jobs on the front line and in direct support of the front line. And importantly, we also do our bit to sustain the spiritual side of service and the moral component of fighting power. Developing people who 'know what right looks like' and who feel at ease with themselves is a very important aspect of our work through the Armed Forces Chaplaincy Centre alongside the prime responsibility to the providing churches of training chaplains of the three Services for their ministry."

Photo 3 – Lt Gen Graham talks to Lt Col Andy Stevens in the Ammunition Hall at the defence Capability Centre

“We are a training and education establishment that provides higher level learning for people in defence.”

Photo 4 – (L to R) Maj (Retd) Mark Winston-Davis, Ltd Col (Retd) Wilf Hyde-Smith, Lt Gen Graham, Brigadier Robbie Scott-Bowden and Lt Col Andy Stevens

Along with Lt Gen Graham's military experience it is apparent that he is strongly influenced by the people he has worked with, not only in the Armed Forces, but throughout MOD and other government departments. He explains that operational capability depends on a number of 'links' in a long chain – from scientists and engineers through to those working in validation and procurement – who all contribute to the success (or failure) of operations. "We are a people organisation but not a J1 function. We are not just providing education for the sake of it but building skills, knowledge and understanding to make people more confident and motivated which benefits any organisation that is interested in improving its performance and retaining good people."

If leadership and commitment to duty are genetic traits, then Lt Gen Graham had a head start…The son of Sir John Graham, Bt, GCMG, formerly UK Permanent Representative to NATO and Ambassador to Iran and Iraq, and the grandson of Lt Col Sir Reginald Graham who was awarded the Victoria Cross in WW1, he was educated like his forefathers at Eton and is viewed by present colleagues as an energetic leader who has the charisma and determination to take the Academy forward, securing its future in the vanguard of defence education and training.

Although Lt Gen Graham is likely to shrug off any compliments and see this as just part of his role, for those who have watched or been part of his first year, there is enthusiastic support for his 'hands on' approach and his ability to quickly assimilate what needs to be done and distil this into a workable plan for the future. Lt Gen Graham also returns the praise and support that he is receiving: "One of the key things about the Defence Academy is that it is a relatively small organisation with relatively few people, many of them contractors, but they are good people, determined, imaginative, and committed to 'the cause'."

It is hard to deflect Lt Gen Graham from his campaign to promote the Academy and its importance conceptually to Defence as a whole, and other areas within Defence. For him, education and training are more than just an interlude, or a start to duty or employment. "It is", he explains, "about developing qualities, knowledge, understanding and skills throughout a career; and all this gives professional competence leading to confidence and confidence leading to the ability to innovate. It is essential that the Academy is seen as a key part of military capability. We provide focused learning – learning that supports capable people and provides a blend of training, education and experience which encourages motivation, gives accreditation and sharpens credentials for promotion. This can mean enhanced opportunities for the individual leading to increased retention levels for the employer as well as improved performance for both of them. By developing people they will, quite simply, be more useful and feel more fulfilled; this has to be invaluable to the Armed Forces and the Civil Service."

And what about future plans for the Academy? Lt Gen Graham explains the options and what he describes as the 'snowball effect': "With a snowball, you can do two things – hold it in your hand and watch it melt, which means that we will melt into a solid core of large, long-term contracts, or you can, metaphorically, roll it downhill and watch it grow in bulk and mass. You can then start to shape it, mould it, harden it and

> "It is essential that the Academy is seen as a key part of military capability."

turn it into something that really suits your long-term purposes." The snowball is the current 'core' of the Academy which he now believes is starting to become more of an entity. "The MOD," he explains, "has only five sub-brands – Royal Navy, Army, Royal Air Force, DE&S and, I am delighted to say, the Defence Academy. Within the Academy brand we recognise that each component college has a crucial part to play in its own area of expertise and acts as a beacon for particular subsets of the Defence population. Each must be recognised as excellent in its field, but in a complex, joined up, multinational world it is important that we act, and are seen as acting, in a united fashion and have a coherent approach to training, education, research and learning and how these can be delivered in the future." Aptly for one with a heritage in the port industry, he compares this to LVMH – the holding company for brands such as Moet & Chandon, Hennessey and Louis Vuitton – each brand unique and of high repute in a particular market area but LVMH being the share that is traded in the market.

And if anyone is in doubt, Lt Gen Graham sees the Defence Academy as pivotal to the future plan for effective Defence: "The value of training and education to Defence is different than for any other profession. The opportunity to sustain knowledge simply by 'doing' is not guaranteed, notwithstanding the tempo of current operations; without training and education we lose the ability to develop and support new competences, new proficiencies, new skills and to evolve. I'm passionate about the value of education to an organisation that wishes to keep its edge and I am clear where the Academy must contribute to developing and retaining the professional competence of the Civil and Armed Services in a complex world against a background of diminishing resources."

A first step into defence

MINISTRY OF DEFENCE

- Internet-based application process
- Speedy assessment of proposals
- Seminars and workshops

CDE is the gateway into MOD for anyone with a good idea in defence science and technology. It offers a fast, effective route into the UK defence market and access to the Armed Forces, MOD and other government departments, creating opportunities to develop and exploit innovation and new technology.

centre for defence enterprise

science | innovation | technology

www.science.mod.uk/enterprise
E: science-enterprise@mod.uk
T: 01235 438 445

The College of Management and Technology (CMT) is the largest of the three main colleges of the Defence Academy providing high quality education, training and advice in technology, management and leadership, together with relevant aspects of security and resilience to students in defence and the wider security area. CMT Director, Jonathan Lyle tells Codex about their work and its value to defence capability.

Top of the class

Lyle enthuses about the variety and number of courses they offer, ranging from one hour skills modules in areas such as equality and diversity required by anyone employed by the MOD, to two day or one week courses, right through to the deep-end of academia with Masters Degrees and cutting edge defence research.

Another area where he is keen to point out their interest is in their nuclear department which is based at HMS Sultan in Gosport, Hampshire. This provides education and training for service and civilian personnel working in the Naval Nuclear Propulsion Programme (NNPP) and training in radiation protection for all MOD service personnel. "We are the defence educators in nuclear propulsion and support the RN and civilian workforce in sustaining the nuclear submarines programmes," explains Lyle.

The breadth, depth and number of courses on offer are a response to the demands of their defence students and are enabled by their long-term (now in its 25th year) relationship with Cranfield University, a key academic provider to the Academy. Lyle explains that Cranfield are unique as the university only educates students at postgraduate level providing them with professional development which will either enhance an existing career, or help them move on to a new one…

"Most courses here are a joint effort between the military and Cranfield with the Defence Capability Centre, Shrivenham as home," Lyle continues. "Courses are offered to all forces, MOD, Civil Service and an increasing number of foreign students, all of which add to the diversity of the college. Overall, because of the history of Shrivenham there are more Army students in core courses which reflects their long tradition

The Defence Academy (UK)

The Defence Academy is the UK's Defence higher educational establishment responsible for post-graduate education and the majority of command, staff, leadership, defence management, acquisition, and technology training for members of the UK Armed Forces and MOD Civil Servants. It is also MOD's primary link with UK universities and international military educational institutions.

Royal College of Defence Studies (RCDS)
The RCDS is based in London and focuses on military strategy, preparing future leaders from the UK and overseas for senior responsibility. The College aims to develop analytical powers and improve knowledge and understanding of defence and international security.

Joint Services Command and Staff College (JSCSC)
The JSCSC at Shrivenham, delivers Command and Staff education and training, developing students from the UK and overseas for military command and supporting operations. Courses aim to develop students' understanding of contemporary global operations and the business environment, training them to make decisions and resolve complex issues.

Defence Academy – College of Management and Technology (DA-CMT)
Working closely with its academic partners, DA-CMT delivers education, training and research in all aspects of Defence business, acquisition, technology, nuclear, leadership and management. With over 700 courses and electronic learning packages, it is managed from its Headquarters in Shrivenham.

It also has a number of Regional Training Centres and runs Welbeck Defence Sixth Form College and the Defence Technical Undergraduate Scheme.

Armed Forces Chaplaincy Centre (AFCC)
The AFCC develops, promotes and provides spiritual, moral and pastoral training and education to the Armed Forces, including the Chaplaincy Branches of the three Services. Based at Amport House, Hampshire, it offers a unique atmosphere where people of any rank or background can work, engage, learn and relax together.

- www.da.mod.uk

> "It is very sobering to hear that people we have trained have tragically been killed or injured dealing with IEDs in theatre."

of sending people here, but the other Services are adjusting."“Most courses here are a joint effort between the military and Cranfield with the Defence Capability Centre, Shrivenham as home," Lyle continues." Courses are offered to all forces, MOD, Civil Service and an increasing number of foreign students, all of which add to the diversity of the college. Overall, because of the history of Shrivenham there are more Army students in core courses which reflects their long tradition of sending people here, but the other Services are adjusting."

One intake that Lyle is confident will go on to secure the future of engineers into the Armed Forces is from Welbeck College which has provided the Army with many of its future Technical Officers for over fifty years.

In 2005 MOD invested in a brand new purpose-built Defence Sixth Form College for Welbeck at Woodhouse near Loughborough, Leicestershire. The college is one of the UK's top sixth form colleges and has developed an outstanding academic reputation.

For Lyle this means that after AS and A levels from Welbeck, completion of a technical university degree and with continued military support throughout, they will have the engineers of the future: "We already have around 650 at the end of their training who have the requisite technical education and military background, including leadership qualities and levels of fitness to go on for successful careers in the Army, Royal Navy, RAF and Civil Service. This, I believe, is a wise and strategic investment in our future."

Lyle is aware that the education and training that the DA provides goes beyond the classroom and the laboratories of the campus and has a real and tangible impact on current operations: "This is a vital part of what

Photo 1 – Beckett House, residential training facility at Defence Academy, Shrivenham
Photo 2 – Jonathan Lyle © Simon MaLaughlin
Photo 3 – Aerial view of the South part of the Defence Academy site at Shrivenham

we do and is visible in courses such as the Ammunition Technical Officers Course. So, it is very sobering to hear that people we have trained have tragically been killed or injured dealing with IEDs in theatre."

But, he is keen that the Defence Academy should also be known for the whole range of courses they offer: "Our skills training and education are not just for operations but the whole business of the MOD. We support our military and civilian colleagues in all aspects of their work – including Head Office, Abbey Wood and beyond."

The relationship with Cranfield means the DA benefits from their strong research pedigree and Lyle is committed to this area of their work: "It is not possible to be a good educator and trainer without equipping people with the skills they need to be credible, as well as encouraging and supporting cutting-edge research." This, he says also has other benefits such as the grants and external revenues that it attracts. "We also fund some relevant research in defence and we are always keen to look at proposals that will underpin the future challenges faced by MOD."

An example of how courses have evolved and can be tailored to the defence industry's current needs is in the relationship which the Defence Academy & Cranfield have with the Weapons Company MBDA. Lyle is excited by the possibilities of working with industry and the benefits it gives to all parties. "It gives MBDA access to Cranfield research and expertise and gives us access to materials and an insight into their technology and innovation. I would like to exploit this more and I think there will be further opportunities to help the MBDA workforce work more closely with MOD, giving skills and opportunities to both parties."

This he believes reflects the principles of partnering outlined in the Defence Industrial Strategy which states MOD's commitment to encouraging closer working relationships with Industry. Lyle is encouraged by the feedback he has had so far and believes this will develop in the future: "These courses help understanding by bringing people together for short periods and teaching them from the same toolkit. This means that they will be better able to work together in the future and creates mutual understanding."

3

"Courses are offered to all forces, MOD, Civil Service and an increasing number of foreign students, all of which add to the diversity of the college."

Photo 4 and 5 – Sandhust Officer cadets visit the Defence Academy to take a close look at an Apache helicopter and find out more about battlefield technology
© Simon McLaughlin
Photo 6 – Lt Col (Retd) John Starling and the arms display

Asked why the DA should be first choice for both students and employers, Lyle is quick to respond; "We have a vision that people working in defence should see the DA as the first place to come to improve their skills, and that they should keep coming back at every stage of their career. We would like to be seen as the Alma Mater for defence. Many of the building blocks are now in place and the continuing challenge is to help the 300,000 military and civilian workers in defence understand the breadth of what we offer and how we are adapting to current and future needs."

Summarising the aims of the DA, Lyle stresses the need to be agile and offer good value for money within current resource constraints: "We must continue to demonstrate that we can react and fulfil the requirements of all our customers and sponsors. I am committed to doing this and doing it well…"

> "We have a vision that people working in defence should see the DA as the first place to come to improve their skills…"

Unique collection of arms

An exceptional collection of weapons are housed in two large rooms cocooned amongst the offices and corridors of the Defence Academy. Here, Head of Armoury, Lieutenant Colonel (retired), John Starling oversees an expanding display of around 1,000 small arms which have been collected and housed at the Defence Academy since 1945.

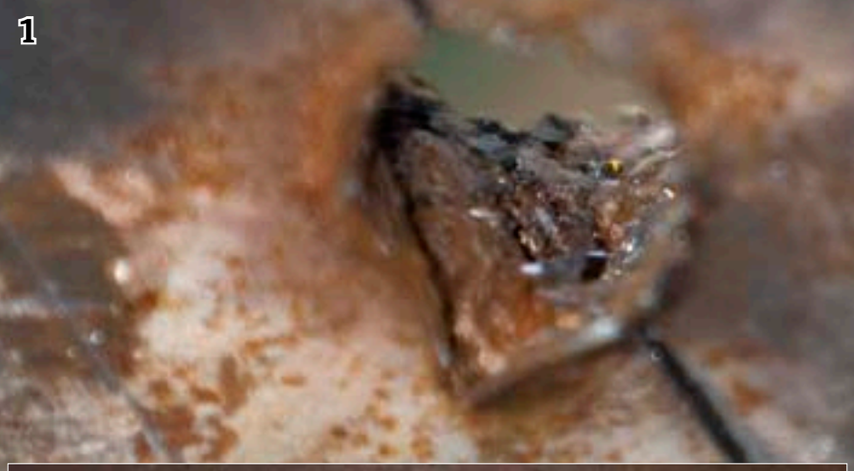
The display includes weapons from many countries including Russia, France, Sweden, USA and Germany. Starling is pragmatic when asked his opinion on what makes an effective weapon: "Ours are the best for reliability and range but there is always a trade off – the game is to match your requirements with what is available. There is no perfect solution."

Starling offers a fascinating insight into innovation on the battlefield and explains the major developments – from the muzzle loader used in the Brown Bess at Waterloo (which was the same weight as weapons used in current operations) to the breach loaded Snider of the 1870s through to the introduction of the brass cartridge case in the 1880s.

Asked to name the 'best' rifle ever manufactured he does not hesitate: "The Enfield, from WW1 – extremely accurate and still in use. It is still in use today!"

Leaders in defence research

1



2

3

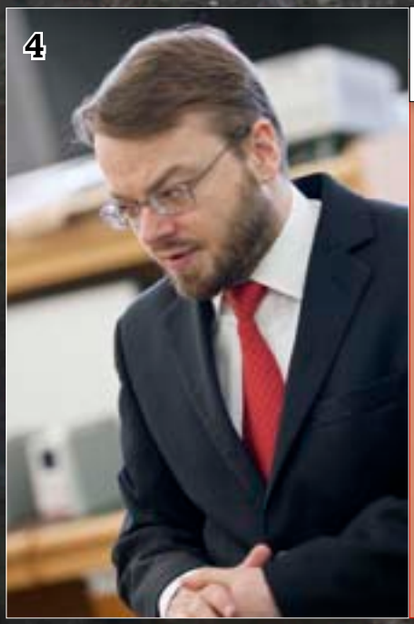
Dynamic Response Group

Dr Paul Hazell researches and lectures on the dynamic behaviour of materials. The group is studying shock wave loading, including the impact on composites, shock propagation in complex laminates, shock behaviour of biological materials, shock-to-detonation characteristics of high explosives and impact and penetration of lightweight armour solutions.

The Group currently uses several single-stage gas-guns to carry out their research and houses flash X-ray to interrogate in-material penetration events and high speed photographic systems.

Photo 1 and 2 – Steel target plates with hole from Shaped Charge Attack
Photo 3 – Dr Paul Hazell
Photo 4 – Professor Rafal Zbikowski
Photo 5 – The flapping wing demonstrator
Photo 6 – Dr Ivor Morrow
Photo 7 – Alex Mikhalev
Photo 8 – Marc Kirby
Photo 9 – Mark Carpenter and the Planetary Mixer
Photo 10 – Explosives Press

4



Autonomous Systems Group

By studying the structure of insects with 'flapping' wings, the team have developed a working model for studying the dynamics of flight for application in future Micro Air Vehicles.

Professor Rafal Zbikowski and his team have constructed flapping wing demonstrators to aid understanding of the flow characteristics of structure and movement through Particle Image Velocimetry (PIV) and force measurements. These have led to advances in understanding of this flight regime both in terms of aerodynamics and structures.

5


6


7

Communications and Wireless Networks Group

The Group provides a focus for the teaching and research activities of the Department of Informatics and Sensors (DoIS) focusing on commercial and military communication systems and wireless networks. Research is predominantly in the development of broadband radio systems for the provision of civilian and military radio services and data links.

Laboratory facilities include a fully-equipped microwave lab with a large anechoic chamber and a networks simulation lab.

Dr Ivor Morrow is pioneering research into adaptive antenna systems and is responsible for two recent patents.

Alex Mikhalev is working on maximising the utilisation of the Electromagnetic spectrum in communications.


9


8

Centre for Forensic Computing

Forensic computing is a dynamic area of criminal investigation, with new tools, techniques and methods becoming available to both the investigator and the investigated. The Centre for Forensic Computing was opened in 2003 and provides short and postgraduate courses, as well as research on behalf of UK law enforcement agencies.

Deputy Head, Marc Kirby has over 20 years of experience in the police and explains that the centre is the first of its kind in the UK and is the result of demand from law enforcement agencies and the military to provide education, research and consultancy on forensic computing topics. “Our customers come from the military police, government departments and other organisations. We are often asked to do work that they cannot do themselves and have a secure site and access to facilities here that complement our work.


10

Explosives Formulation Facility

The formulations facility is a remote processing plant for the production of explosive composition. Process operations are monitored from an isolated control room via CCTV.

Studies are currently looking at developing explosive compositions with reduced vulnerability that are able to maintain performance levels.

Preparing for success

Welbeck DSFC educates students from all backgrounds to achieve their ambition to become an Officer in the Armed Services or the Civil Service.

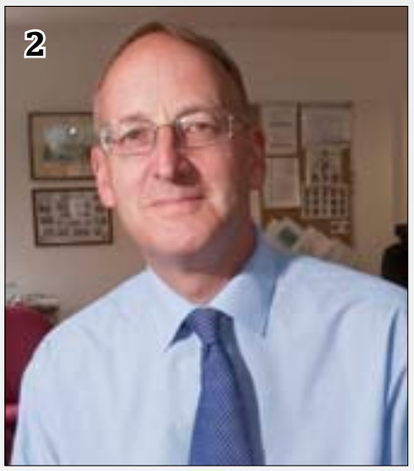


Photo 1 – Welbeck DSFC
Photo 2 – Tony Halliwell
Photo 3 – State-of-the-art facilities

DSFC Vision Statement

This vision is echoed in the ambitions of the students who come to Welbeck from numerous different backgrounds but with common aims – to enter the Armed Forces, prove themselves and have a secure future.

Student blogs (www.dsfc.ac.uk/blogs) confirm their ambitions with students such as Rosemary Smith writing that for her "it was the best route to become an engineer in the civil service". This is echoed by Robert Sharp who says: "I wanted to secure my place within the Armed Forces and Welbeck was the ideal way of doing so providing world class facilities, excellent IT equipment, and a clear path to the future."

There is no doubt that the facilities are impressive, with on-site, en-suite accommodation, and the latest equipment. But it is the 'ethos' that makes the college outstanding and the enthusiasm of the students, staff and their military sponsors makes Welbeck a very special place.

Principal, Tony Halliwell has been at the college for ten years and was heavily involved in the transition from an Army Sixth Form College to the new college. With a background in both the independent and state sector of education he is well qualified to lead and motivate the 300 students, 32 full-time teachers and 4 military staff currently at the college.

He emphasises that the role of Welbeck is to provide technical and engineering officers and the curriculum is targeted in this direction. "We offer a unique tailor-made package for potential engineers from sixth form through to university and on to commissioning as an Officer. Our aim is to ensure that all of our students make a reasoned, valued decision as to which AS/A2 subjects they intend to take in order for them to progress through their training and become an Officer in the Royal Navy, Army, Royal Air Force, or enter the MOD Civil Service."

He explains that the college prepares students in three phases. "Firstly, they come here to study via intensive A level courses primarily in Maths and Science with an additional focus in subjects such as Design Technology and Electronics.

"Secondly, they go on to read for a degree at university via the Defence Technical Undergraduate Scheme (DTUS). Thirdly, after graduation, they move onto Officer Training with the Armed Services or Initial Professional Development Training with the MOD Defence Engineering and Science Group (DESG) Graduate Scheme."

Academic study is combined with the leadership training programme and fitness training regime which Halliwell explains is a crucial part of their education: "They mature academically, hone their leadership and fitness skills and gain real confidence in their ability to progress forwards towards being a highly trained and capable young officer."

Students can read for a degree at Newcastle, Southampton, Aston, Northumbria, Birmingham or Loughborough University. Places are also available at Oxford or Cambridge for students achieving high A-level grades. All DTUS students are also required to join a Military Support Unit which are staffed by members of the Armed Services who mentor and follow undergraduate's progress through university.

> "We offer a unique tailor-made package for potential engineers."

Opportunities after graduation are varied and demanding and with the Army this could mean leading troops in a front line situation, supervising a combat engineering mission or working in civil engineering. The Navy offers opportunities in weapons, marine or air engineering and in the RAF engineers play a crucial role in keeping aircraft flying and investigating technical problems. DESG offers broad career prospects including work in specialised areas such as nuclear and routes into research and development, with graduates working at the forefront of technology, managing projects worth millions of pounds.

And Halliwell is proud of their reputation with over 50% of the officers in the Royal Electrical and Mechanical Engineers (REME) former Welbexian students and the RN and RAF currently aiming to recruit at least 50% of their engineer officers through Welbeck. But Halliwell is keen that his students understand the relevance of their studies, saying: "It is vital that in a technological driven world front line troops have well qualified, trained engineers to back them up in operational theatre, giving them the support and assurance they need to deliver their respective missions."

- www.welbeck.mod.uk

Routes to excellence

Welbeck Defence Sixth Form College (DSFC)
The DSFC is operated under a 30 year PFI contract, run by Minerva Education and Training Ltd (METL). Its first full year of operation was the 2005–2006 academic year. Tuition is free but a contribution towards maintenance is required from parents based on their residual income.

Defence Technical Officer Engineer Entry Scheme (DTOEES)
DTOEES was set up to recruit technical graduates to serve as officers in the Armed Forces and Civil Service. Candidates sign an undertaking with one of the services before they are accepted into Welbeck.

After A levels students read for an engineering, technical, business or logistics degree at one of the Defence Technical Undergraduate Scheme (DTUS) partner universities. They receive technical bursaries which are conditional upon academic success and training at their support unit.

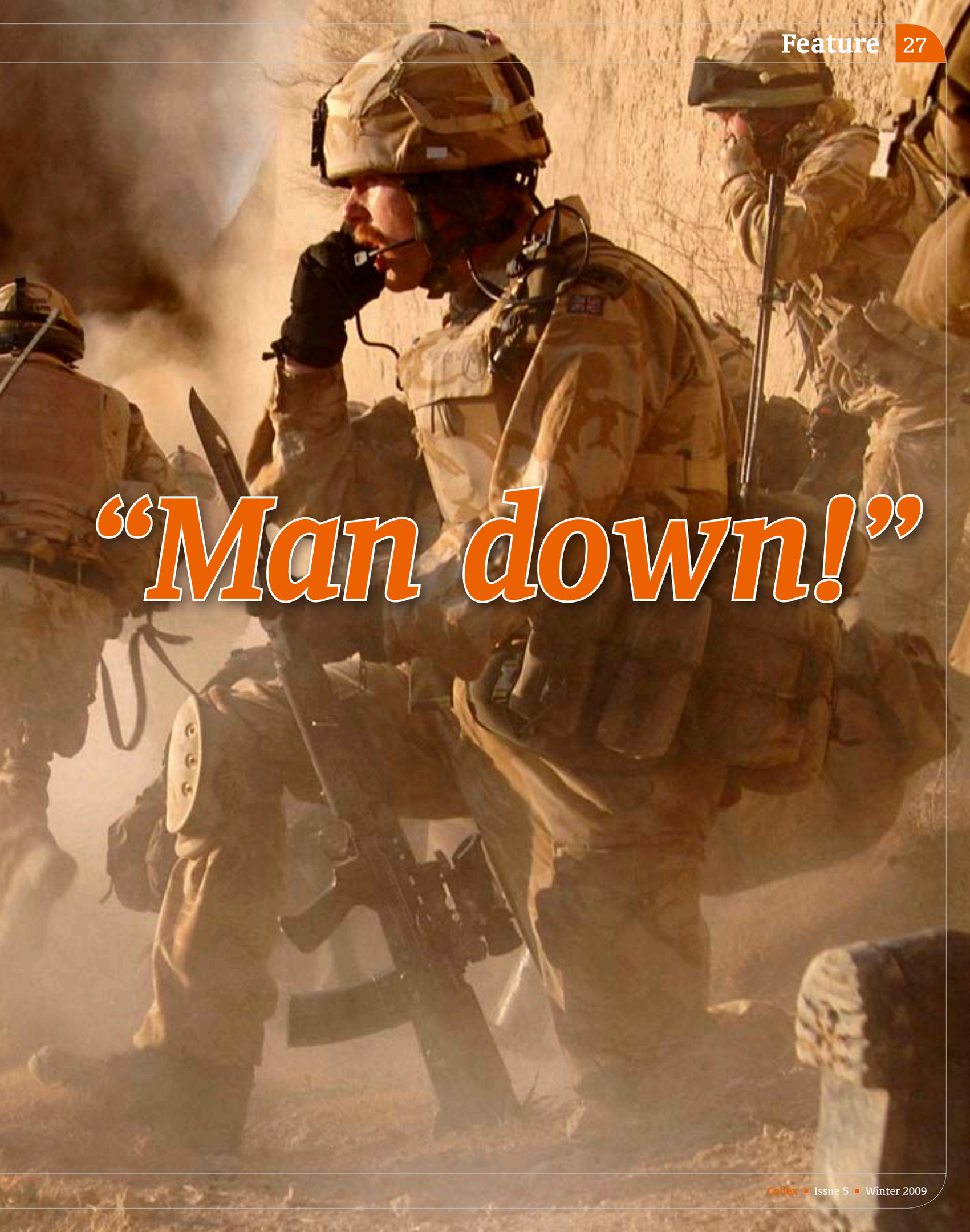
Defence Technical Undergraduate Scheme (DTUS)
DTUS has four support units: Thunderer Squadron (Southampton), Trojan Squadron (Newcastle and Northumbria), Typhoon Squadron (Loughborough) and Taurus Squadron (Aston and Birmingham).

Support Unit Commanding Officers hold visiting lecture status within the engineering faculty or school of each university and also sit on the various university academic boards.

After their degree, students move on to officer training at Brittania Royal Navy College Dartmouth, the Royal Military Academy Sandhurst, the Royal Air Force College at Cranwell or the Civil Service Defence Engineering and Science Group.

- www.desg.mod.uk

In 2008, the Defence Medical Rehabilitation Centre (DMRC) saw 103 new patients – 50% blast injuries – 40 of them amputees…



“Man down!”

1

Small steps forward on the road to recovery

The air is fresh and the sun is rising over the English countryside. Leaving the busy main road that skirts round the nearby towns and villages, it is a tranquil drive along a winding tree-lined road towards the Defence Medical Rehabilitation Centre (DMRC) at Headley Court, Surrey. But this is no easy path to convalescence and those that approach the Edwardian building with its 85 acres of grounds will experience the dedication, skill and commitment of the multi-disciplined teams that will guide them through their rehabilitation. Codex Assistant Editor, *Wendy Jacob* visited the centre to find out more about their work.

Car bombs, machine gunfire and Improvised Explosive Devices (IEDs) rip through human flesh and tear away limbs. Glass, rusty nails, sand and grit savage and penetrate the mind and body – shattering bone, invading tissue and creating devastating physical and emotional damage. Success in saving patients that previously would have died on the battlefield has led to an increase in loss of limbs and internal system damage. In a recent statement Surgeon General, Lieutenant General Louis Lillywhite, recognised the role that medical science plays in addressing current challenges in rehabilitation and that there is now a greater need to focus on longer term care of wounded personnel: "Success in saving patients that previously would have died has resulted in the survival of individuals with complex injuries. We know that these will have needs that will be very different from those from previous conflicts."


2

DMRC at Headley Court is receiving an influx of patients from recent operations in Afghanistan and is expanding staff and facilities so that each patient will continue to receive the very best in quality and quantity of care that will maximise their chances of returning to service, or minimise disability on

Headley Court

The Defence Medical Rehabilitation Centre (DMRC) Headley Court is the principal centre for medical rehabilitation of injured and ill military personnel. It primarily focuses on musculoskeletal, neurological and complex trauma injuries.

Headley Court is supported by an additional 15 Regional Rehabilitation Units (RRUs) located across the UK and Germany which have the facilities to treat less complex cases in geographic proximity to the workplaces of ill and injured personnel.

Following DMRC admission and assessment procedures, patients at the centre are grouped by pathology/injury and undertake intensive 3–4 week in-patient programmes within these groups. Each patient receives individualised care from a multi-disciplinary team through a combination of individual and group sessions.

- www.mod.uk

Photo 1 – DMRC, Headley Court ©Allan House
Photo 2 – Lt Col Rhodri Phillip
Photo 3 – Lance Corporal Tom Neathway and team support
Photo 4 – Adjusting a prosthesis

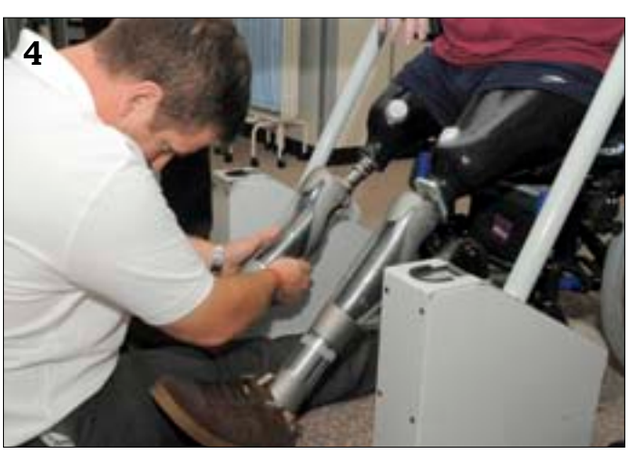
Wounded

For the first time, MOD allowed television cameras to follow the recovery and rehabilitation of severely injured soldiers returning from Afghanistan. The programme, which was shown in September followed the rehabilitation of Lance Corporal Tom Neathway and other subjects in the BBC One documentary 'Wounded'.

- www.bbc.co.uk

discharge. Although advances in body protection and trauma care are saving lives, an increasing number of British troops survive with injuries that require dedicated rehabilitation programmes. All military personnel who are injured on combat operations pass through Headley Court to be assessed and however slight or serious, their injuries will be given a programme aimed at maximising their recovery.

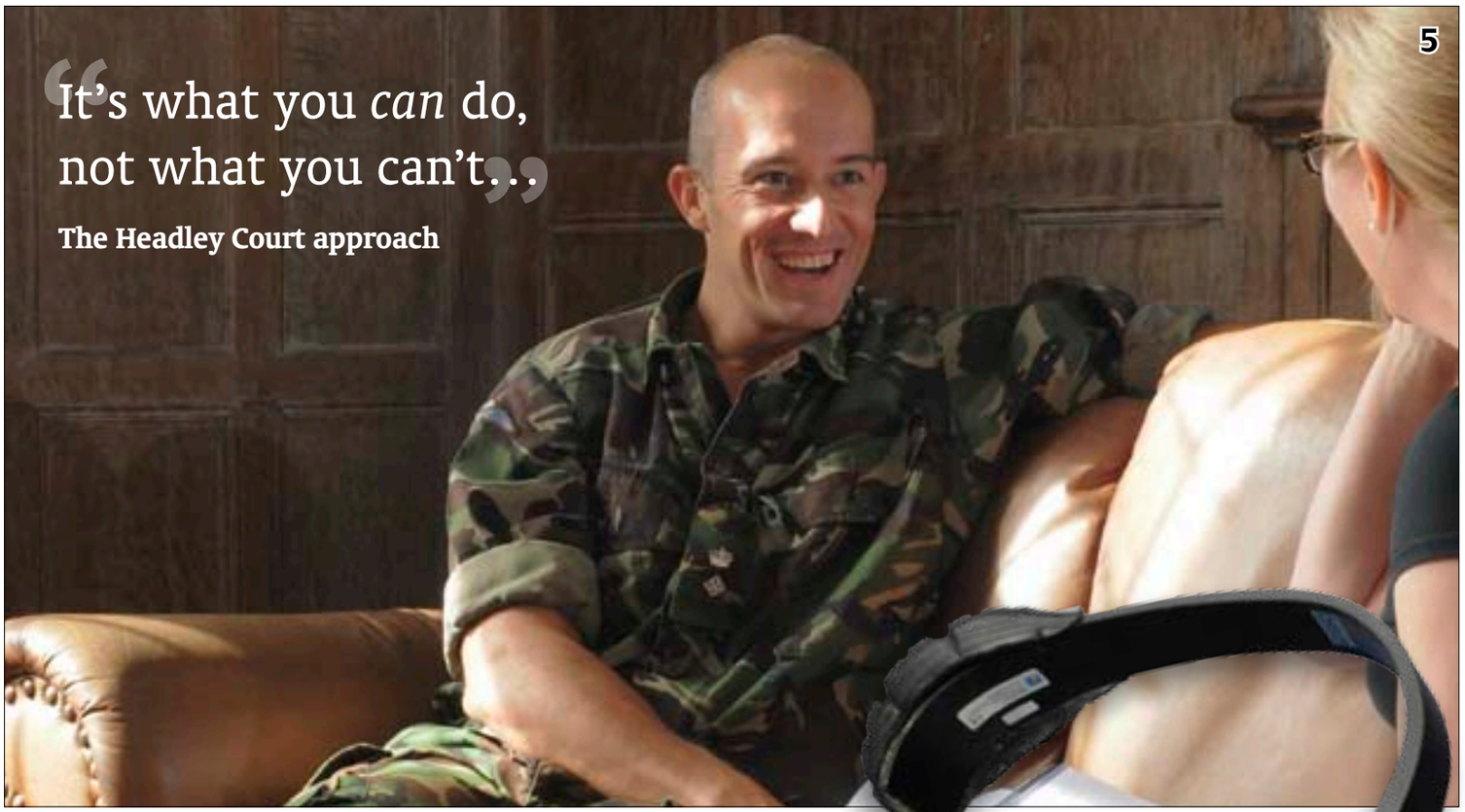
Lt Col Rhodri Phillip, a Consultant in Rheumatology and Rehabilitation Medicine has been at Headley Court for the last year and explains that as the number of trauma cases has increased, they have changed their practice to accommodate their needs: "In the past, the majority of patients came from road traffic accidents or training injuries. Over the last four years there has been an increase in casualties from IEDs and gun shot wounds. In 2006 we created a Complex Trauma Team which improved management in this area by creating dedicated teams rather than the traditional musculoskeletal groups."



One of the most life changing injuries is loss of limb and in current and recent conflicts there has been an increase in multiple amputations and other traumatic, complex injuries. Phillip explains that the same principles of care apply, but there has been a difference in the scale of injuries that they are receiving: "The nature of IED injuries is such that patients often have multiple injuries which can include brain injuries, loss of sight or hearing, as well as loss of limbs."

Phillip says that although amputations are often the most visible signs of injury, there are other injuries that are equally devastating and require long-term rehabilitation: "Protective armour can reduce the need for amputation but we are getting more smashed feet as a result of blast contacting with the vehicle's metal base. This transfers force through the feet and ankles causing compression fractures. We have head injuries from being thrown in the air, multiple digit loss, and recently we have seen an increase in eye and facial injuries. Some of the hardest cases are from feet and ankles and those who require elective amputations at a later date."

The courage and determination of the patient is matched by the commitment and skills of the multi-disciplinary team that deliver the rehabilitation programme. Using a bio-psychosocial model of rehabilitation that combines physical training, mental health, occupational therapy and social work, they work with the patient to maximise their physical ability and psychological health with the unified aim – getting patients back to their units and a normal life. This has led to an urgent requirement for improved prosthetics and Phillip is keen to emphasise the importance of developments in this area: "Achieving a good fit can be a



“It’s what you *can* do, not what you can’t...”

The Headley Court approach

Photo 5 – Lt Col Rhodri Phillip and Codex Assistant Editor Wendy Jacob

Photo 6 – Lower leg prothesis with running foot

Photo 7 – A brief rest during rehabilitation

problem as stumps may be irregular with skin and muscle wounds. The surgeon tries to maintain as much limb length as possible without compromising the patient. They try to keep as much healthy tissue as they can, but in a blast injury fabric and dirt are forced into tissues which will come out with time.”

Technical improvements in prosthetics, dedicated rehabilitation programmes, psychological support, as well as individual aspirations influence long-term outcome and an increasing number of personnel are returning to their units ready and willing to carry on the fight. Historically, around 95% of patients have returned to military duty but recently this has fallen to 85–90% due to the number of serious injuries [figures from NHS/Defence Medicine 23.3.09].

Military amputees are usually fit, young and prior to injury, used to participating in physically demanding professional and recreational activities. Phillip says that this can be a problem for patients who may feel that they are not progressing fast enough. He puts this down to the young and fit being naturally competitive and admits it is sometimes difficult to temper their expectations: “Maintaining motivation and morale when things aren’t going quite so well is a challenge. One of the drawbacks of being motivated is that when things aren’t going so well, it can be a bigger knock-back than for someone with lesser expectations.”

The use of lower limb prosthetics places heavy demands on the body and research shows that walking with a lower limb prosthesis uses 125% more energy than walking with uninjured legs. The energy demands increase with higher

Alter G takes the strain

The anti-gravity technology behind the G-Trainer™ was originally developed at NASA, and uses air pressure to help patients walk, run and enjoy the benefits of movement again.

Physical activity has a direct impact on the mind as well as the body and the G-Trainer reduces body weight to as low as 20% with 1% reductions allowing for progressive return to weight bearing.

Patients are able to maintain a normal gait and stride length with speeds that can be adjusted up to 18 mph in forward motion, 10 mph in reverse and with an incline up to 15%.

- www.alter-g.com

New Army Recovery Centre for Scotland

The Army Recovery Centre, a dedicated 12-bed wing of the £8.6m Erskine Edinburgh Home, is the result of a partnership between the Army, veterans charity Erskine and Help for Heroes (H4H), who together are providing accommodation and support for soldiers wounded or injured on duty.

This is the first purpose-built Army Recovery Centre to be launched in the UK. Continuous evaluation of this pathfinder scheme will show the way to deliver similar services wherever the need is identified, with planning already underway towards a second pathfinder facility in Colchester.

- www.erskine.org.uk

6

amputations so physical fitness and motivation are essential for progress. Another area where this patient group differs from other amputee populations is in reports of phantom limb pain. Military amputees rarely suffer from this which may be down to a number of factors including the youth and fitness of the patient, aggressive use of neuropathic pain modulators and intensive rehabilitation programmes including early mobilisation.

The desire to be up and walking may be delayed by nerve injuries leading to loss of function and pain. These may require direct repair, grafting or waiting for the nerves to repair themselves which can take up to two years. Complications include scarring, tethering of tissue from operations and plastic surgery which can also delay the fitting of prosthetics.

Despite the challenges, developments in prosthetic legs mean that it is now possible for an amputee to walk with a near normal gait and stride. Even a double amputee can adapt and learn to walk, and run again (South African Oscar Leonard Carl Pistorius, known as the 'Blade Runner' – the fastest man on no legs' is a double amputee using artificial limbs that are contoured to bend like a human ankle).

7

Lighter prosthetics, made from carbon graphite, titanium, silicon and different types of gel, as well as improved methods of attachment using suction or vacuum, instead of buckles and straps not only improve mobility and function, but are more comfortable. The development of prosthetics that have been designed specifically for different uses – from everyday, wearing in the shower and the numerous different sports that amputees participate in – means that it is not unusual for an amputee to have a 'wardrobe' of five or more 'limbs'. The cost of these can be considerable and as Phillip will confirm, the military user will test these to the limit.

Phillip believes that science and technology could make a greater contribution to the rehabilitation and quality of life of his patients and he has recently been involved in an MOD Centre for Defence Enterprise (CDE) initiative seeking proposals and expressions of interest in the areas of prosthetics and rehabilitation. CDE is working jointly with Headley Court to stimulate interest and seek innovative ideas that will insure that injured personnel benefit from current and future research and developments in these areas.

Although Headley Court already has a research programme looking at many aspects of patient care, they are turning to industry and academia to add to their expertise. Broadly, the research requirements fall into two areas: Physiology and Repair Processes and Functional Restoration and Retraining. Phillip has been impressed by the interest he has received and proposals are currently being assessed:
"The call is now closed and we have had over 30 high quality proposals and decided to develop seven of these".

This commitment to innovation is echoed by Lieutenant General Lillywhite: "I believe that the care of injured soldiers receive in this conflict [Afghanistan] is significantly better than they've received in previous conflicts. But we continue to seek even better outcomes for our service personnel."

Multi-disciplined teams work closely with patients

Civilian Clinical Specialist and Physiotherapist, Kate Sherman has been at Headley Court for seven years and has seen a change in the injuries and needs of patients: “Generally blast injuries are creating harder demands on rehabilitation programmes due to their complexity. At Headley Court we can meet these challenges and provide the different environments that help patients progress.”

The future

Today, myroelectric arms can use muscles to move motorised hands, elbows or shoulder joints.

Scientists are moving toward transplanting nerves into prosthetics to allow patients to use the same neurological pathways they had used to manipulate natural limbs.

Photo 8 – Kate Sherman
Photo 9 – Ian Jones
Photo 10 – Computer technology enables accurate measurement
Photos 11 and 12 – A 3D model is produced on site
Photos 13 to 15 – Blatchfords produce prosthetics at Headley Court

Sherman believes that determination and motivation are strong influences in the speed of rehabilitation and pays tribute to the patients who she says are ‘hard to hold back’. “This is a very special environment with a positive atmosphere and patients set their own challenges and what they want to achieve – and they do achieve.”

She also pays tribute to the multidisciplinary teams that work with patients – from the physios and the prosthetists through to the occupational therapists who visit patients’ homes to advise on adaptations and aids that may be required. “We have very supportive teams here and work together with the patients who motivate each other and on occasions, are sometimes hard to stop getting into mischief,” jokes Sherman.

Fast track prosthetic service

Since 2006, prosthetic services have been contracted out by the Armed Forces to a private company, Blatchfords. Headley Court has its own limb-fitting service which provides state-of-the-art fitting and manufacture of prosthetic devices which means that prescription and adjustment can be done during the patient’s stay.

Blatchfords Prosthetist, Ian Jones is based at Headley Court and believes that the service they offer patients has considerable benefits: “We are able to interface with patients throughout their stay and spend plenty of time with them. With digital imaging techniques and everything we need on site we can see patients as soon as they are admitted and then have them back the following week for a fitting.”

- www.blatchford.co.uk

11

On-site fitting and manufacture set the pace of rehabilitation


14


15

Battle Back to sport and fitness

Major Martin Colclough runs Battle Back at DRMC Headley Court. From his small office high in the historic building, he is organising sporting opportunities and training which would challenge the fittest. He talks about his adventurous approach to rehabilitation.

Photo 1 – Major Martin Colclough
Photo 2 – Headley Court are currently building a new frame for throwing sports
Photo 3 – Diving prosthesis made at Headley Court
Photo 4 – The thrill of taking to the air
Photo 5 – Adapted water skiing

A sporting fanatic, Colclough has a personal passion for sport and learning and enthuses about the value of his role: "Sport is a great way to have fun and get together. Our guys are competitive, risk-taking animals and sport is a way back to being active and discovering new opportunities."

Battle Back was launched last year as a tri-service initiative to provide opportunities for seriously-injured personnel to experience the physical and confidence-boosting benefits of a range of activities. The brainchild of Lieutenant Colonel Fred Hargreaves, it is proving a great success as it helps patients readapt to their previous activities or introduce them to new challenges.

Colclough explains that as long as an activity is not contraindicated by their rehabilitation programme, there are no restrictions to what is available: "When someone is ready, they can take part in a number of activities – from evening and weekend opportunities to others of longer duration – that will fit in with and underpin their rehabilitation.

"There is no limit to what is on offer, from trekking and climbing to cycling and sailing. By integrating in existing able-bodied programmes and with the Para Olympic sporting movement, they are able to provide well-established coaching systems and join in existing programmes. "We use military resources and 'up skill' participants to create an inclusive environment which helps raise disability awareness and is beneficial to all involved."

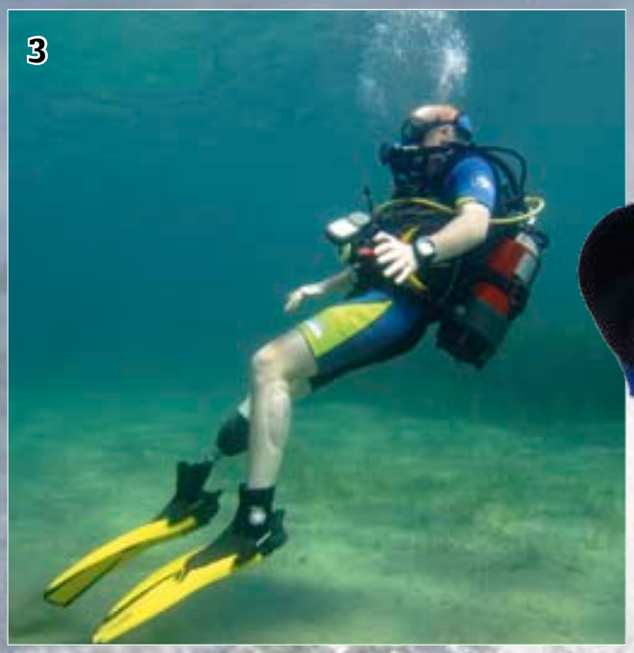
The courage and determination of the participants is matched by the ingenuity of the prosthetists and technicians who adapt and create limbs and other equipment. Golf carts have been adapted to tilt patients with spinal injuries into position, coaching techniques developed for playing with one arm and prosthetic limbs created for numerous different sports.

As one of two full-time officers at Headley Court, Colclough stresses that the responsibility for rehabilitation lies with the medical staff, physios and clinicians but Battle Back can complement their work by increasing confidence and self-esteem. "They experience the same pleasure, thrills and discomfort that we all do and this can lead to a return to an active lifestyle that will benefit their rehabilitation. Their sporting life may be changed, but it is not over…"

Battle Back is a single point of contact for wounded personnel seeking sports and adventure opportunities. It is also for instructors or prospective event organisers looking for policy guidance, clinical or relevant Service charity contacts and general advice on setting up adventurous or sporting activity for post-trauma Service personnel.

- www.battleback.mod.uk

"Their sporting life may be changed, but it is not over..."



Mirror box for phantom pain

The mirror box 'tricks' the mind into believing that an amputated limb is moving by mirroring the existing limb. The patient places a limb into one side of the box and the stump of the amputated limb into the other. The mirror sees a reflection of the healthy limb where the missing limb would have been and receives artificial visual feedback that this is moving.

Invented by Vilayanur S. Ramachandran it is used to treat phantom limb pain by giving visual feedback that convinces the patient that they can still move the phantom limb.

The art of recovery

Sergeant Colin Hamilton lost his right leg above the knee and suffered serious burns from an electric shock whilst trying to save a comrade who later died, in Kosovo in 2001. Since then he has fought hard to become fighting fit and continues to push himself to the limit.

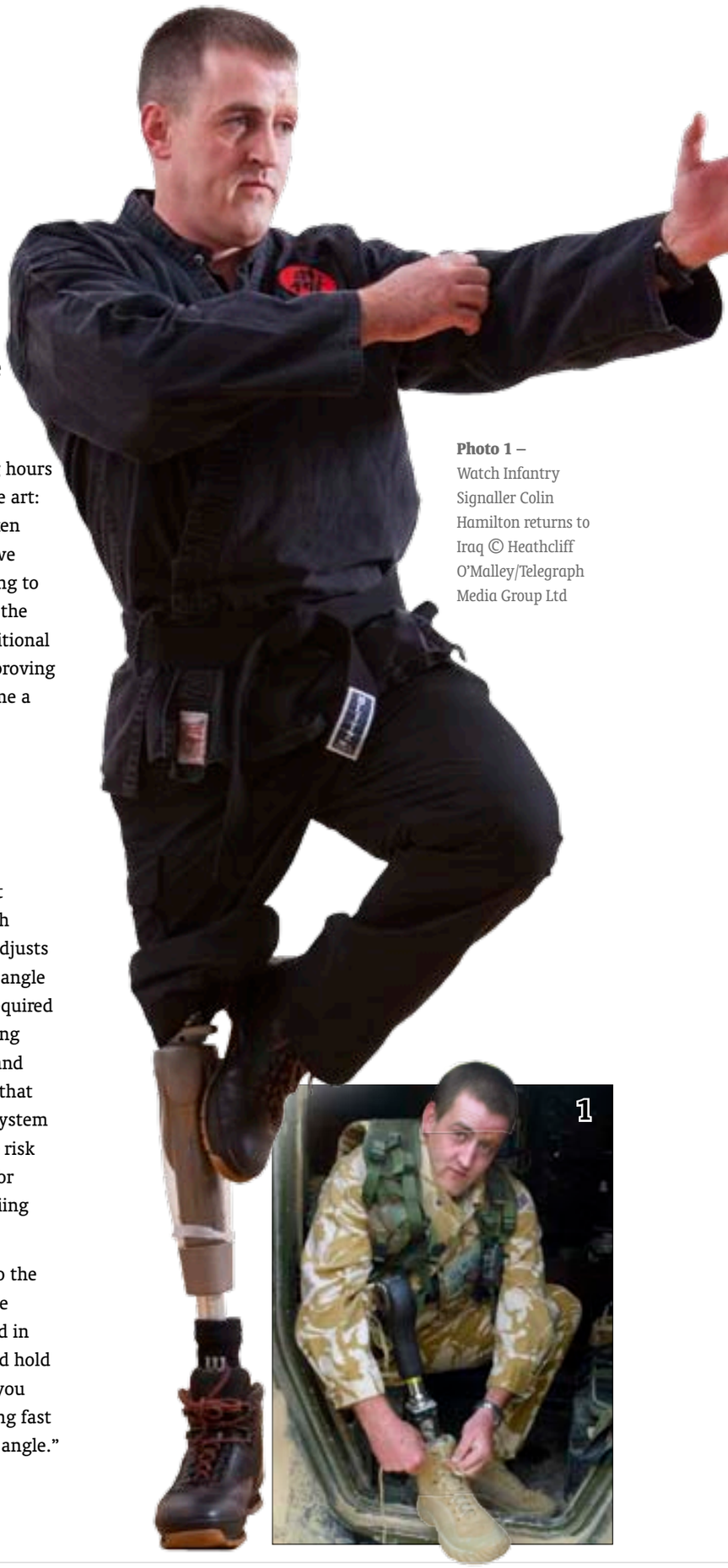


Photo 1 – Watch Infantry Signaller Colin Hamilton returns to Iraq © Heathcliff O'Malley/Telegraph Media Group Ltd

Sgt Hamilton's first prosthetic leg was fitted by the Selly Oak Limb Centre, Birmingham and after rehabilitation he returned to Iraq in the spring of 2003. Subsequently, he was fitted with a further high activity leg by the Birmingham Amputee Rehabilitation Centre. This, along with a dedicated rehabilitation programme at DMRC, Headley Court and his determination to prove that he could return to active duty, challenged him to achieve the second fastest time of six minutes 50 seconds for an 800m run by a military amputee.

Hamilton remembers that during this time he had very few problems and despite the conditions – on one occasion he wore his prosthetic leg continuously for almost three days – he played a key role at Camp Dogwood in Iraq as a Signaller in the Battalion Operations Room.

Now back in the UK, based at the Unit Welfare Office, Inverness, Hamilton continues to take on new challenges. Recently fitted with the revolutionary C-Leg® (which he claims he "hardly notices") he is a martial arts student in the Bujinkan Scotland and competes with the fittest.

He has a black belt and is a 1st dan in Ninutsu, a martial art that is highly demanding for even the very fittest. His teacher, Jock Brocas from the Shinsin Shingan in Inverness praises Hamilton's commitment and skill and explains how the C-Leg has stood up to the long hours of training and the demands of the art: "He has been a member of the Hiken Dojo for a considerable time and we have used varied methods of testing to ensure that his leg will withstand the rigors of training in Japanese traditional warrior arts. His current C-Leg is proving the most successful and has become a natural extension for him.

"Colin uses the leg, not only as a support system but also as a very effective weapon to re-educate egotistical students!"

The C-Leg which has an intelligent knee joint always recognises which walking phase the user is in and adjusts accordingly in real time. The knee angle sensor supplies the information required for the dynamic control of the swing phase, depending on step length and frequency of the user. This means that in any situation or condition the system automatically adapts reducing the risk of falling. It can also be adjusted for activities such as cross-country skiing and cycling using a second mode.

Hamilton has tested his new leg to the limits and is enthusiastic about the improved stability and balance and in his own words: "It will 'kick in' and hold you up and is always there when you need it... The old leg wasn't reacting fast enough and this one reacts at any angle."

A leap in technology

The C-Leg® was a stride forward when it was first introduced by Otto Bock healthcare in 1999. It uses computers that control resistance in the knees to adjust to the terrain. The microprocessor that controls the C-Leg receives feedback from multiple sensors 50 times a second, allowing the knee to anticipate the next move and make adjustments in real time.

Upper body prosthetics are more complex as the human hand requires multiple movements from the shoulder, elbow and wrist to determine movement and grip. Current prosthetic arms use muscle movement for power and are limited in what they can do.

With prosthetic arms, better function means increased weight and many patients choose split hook attachments for their functional ability despite the availability of myoelectrical systems which use EMG signals from contracted muscles to control the prosthesis.

For the military patient, who may be required to carry up to 45kg in theatre, durability and robustness are important considerations.

- www.ottobock.co.uk

"It will 'kick in' and hold you up and is always there when you need it..."

MBDA targets future challenges

With locations in France, Italy, Germany and USA as well as the UK, MBDA operates in all the major world markets, designing and producing missile systems for the UK Armed Forces and their multinational customer base. Codex Editor, *Gavin Copeland* visited their largest site in the UK at Stevenage to look at some of the technology and discuss their contribution to UK defence.

1

Photo 1 – Mark Slater
Photo 2 – System Integration using high performance HWIL flight table
Photo 3 – Early integration of the Fire Shadow munition fuselage at the inert build facility

With an annual turnover of €2.7 billion in 2008 MBDA has operations in Britain, France, Germany, and Italy. Formed in 2001 by the merger of the missile system businesses of Aérospatiale-Matra Missiles (of EADS), Finmeccanica and Matra BAE Dynamics, the company employs over 10,000 people throughout Europe. Their multinational teams work on major European defence programmes integrating French, Italian, German and UK defence capability into a single company. MBDA has a unified management and operating structure which is supported by its three major shareholders – EADS, BAE Systems and Finmeccanica.

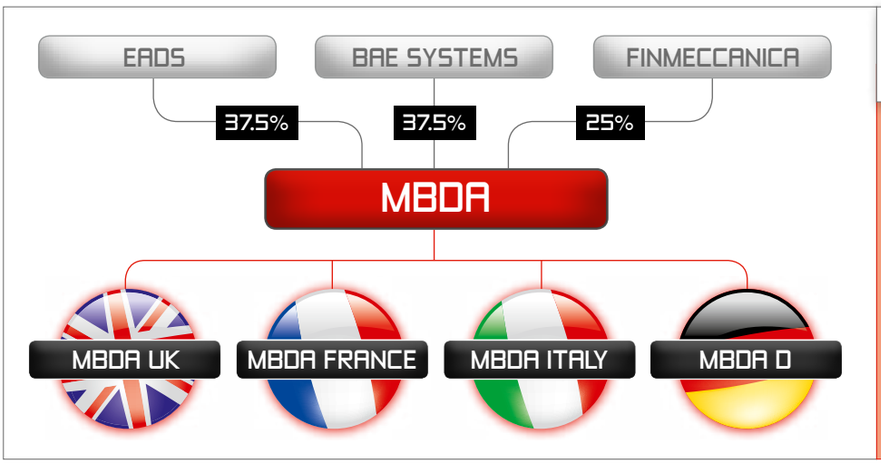
MBDA Future Systems Director, Mark Slater is responsible for all Future Systems work across Europe and is keen to stress that the company is not just a 'provider' of missiles: "The broader capability that we provide to military capabilities is not always understood. We provide missiles to Armed Forces in the UK and across the world, but we also operate in the battlespace providing weapon systems such as PAAMS in the Type 45 destroyer which includes the radars, the command control system as well as the launcher and the missiles themselves."

This capability is evidence of the broad base of skills that MBDA has – not only in equipment and facilities – but also in their 10,000 strong workforce. "Broadly speaking, our company is engineering-based with 4,000 in mainstream engineering and another 3,000 in production which uses mainly engineering-related skills. Many of our support staff also come from engineering before moving into other roles," explains Slater. "But there is also a disadvantage in this and we have to compensate for the natural tendencies of engineers to come up with a particular engineering direction by injecting sufficient creativity and innovation into our work…"

The challenge and responsibility of MBDA's work is destined to keep them all on their toes and Slater believes that their role is ultimately to deliver their expertise to the military commanders that are their customers. And understanding the customers' needs dominates Slater's thinking: "My team are responsible for

MBDA
MISSILE SYSTEMS

> "The broader capability that we provide to military capabilities is not always understood."



MBDA – a global company

MBDA was created in December 2001, after the merger of the main missile producers in France, Italy and Great Britain. The restructuring of the industry in Europe was completed with the acquisition of the German subsidiary EADS/LFK in March 2006.

identifying the responses and future needs of our customers and this means working closely with MOD – as close as we can get.

"My team needs to interact directly with the customer and we try to create the right networks that allow us to understand their requirements. For example, in major programmes it is essential that we know what the Army needs in the battlespace of the future, so that we can respond with different concepts. But I hope and believe that in the future we can be more influential by helping to recognise those needs and working more in partnership."

MBDA works closely with MOD through science | innovation | technology (SIT) and Slater is excited by MBDA's recent involvement in developing the first Centre for Defence Technology (CDT) for Complex Weapons (CW). Along with the other MOD and industry stakeholders, led by QinetiQ, the CDT will offer an efficient and coordinated approach to all phases of R&T and provide technology planning for Team CW. The vision is to "Deliver battle-winning technology solutions for Complex Weapons in a timely manner that are mutually beneficial to MOD and industry".

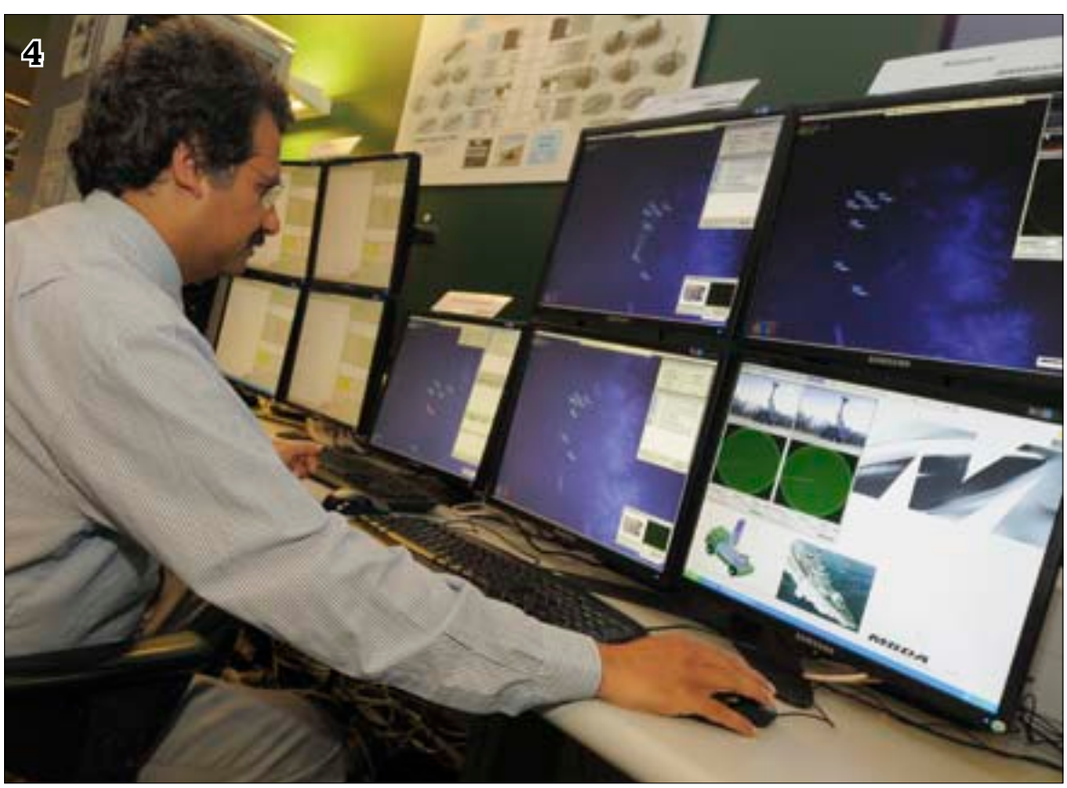
MBDA is also responding to two Capability Visions (CVs), the MOD initiative to encourage innovative solutions to specific challenges that may go on to provide future capability. They are already working on the Novel Air Concept CV which is looking at Unmanned Air Vehicles (UAVs) and Unmanned Combat Air Vehicles (UCAVs).

They have formed a team which includes GKN, Selex and QinetiQ. The next phase (if they are successful) will take them into a three-year demonstrator programme but Slater explains that MBDA have already initiated their own programme. "We are using our own funding in the consortium and have already started the demonstrator programme as we think we have something really good to show off!"

MBDA have also been involved in the Electronics Defeat CV which aims to provide a detailed understanding of how sophisticated electronic systems and information technology can be attacked and the protective measures which can be adopted, which is vital to the future of UK defence.

These challenges are adding to the impetus to develop different ways of doing business and Slater explains that MBDA embrace the new opportunities that come with this. "Since 2005, we have been on a huge transformational road which came from our need to change. We made a proposal to UK MOD for a different way of working, which in 2006 was recognised by Lord Drayson as part of the Defence Industrial Strategy leading to the announcement in July 2006 that initiated Team CW."

Photo 4 – Running a generated scenario using Synthetic Environments (SE) visualisation
Photo 5 – CAMM missile test hardware on display



"It is essential that we know what the Army needs in the battlespace of the future..."

In July 2008 MOD launched the Assessment Phase (AP) of Team CW which heralded a new era in purchasing missiles and guided weapons. In line with the Defence Industrial Strategy, the launch of the AP marked the start of a process giving MOD access to a streamlined industrial base as well as offering Team CW industrial partners a better understanding of the MOD's future programmes and equipment needs in the sector.

Aimed at retaining key skills and technologies in missile development and protecting future operational sovereignty, the programme brought together MBDA UK, QinetiQ, Roxel (Rocket Motors UK) and Thales UK in a £74 million first year Assessment Phase which initiated six new weapon projects. The value of the AP as a whole is some £250 million.

The six projects that were selected to test the new approach were:

- Indirect Fire Precision Attack Loitering Munition (MBDA-led with the Fire Shadow weapon)
- 100kg weapon family to meet first the requirement for a Future Air to Surface Guided Weapon (Heavy) (MBDA)
- light weapon family to meet the Future Air to Surface Guided Weapon (Light) requirement (Thales UK)
- 50kg weapon family to meet the Selected Precision Effects at Range (SPEAR) requirement (MBDA) for an air-to-ground missile for attack helicopters and fast jets
- the Common Anti-air Modular Missile (CAMM) family to meet the requirement for a Future Local Area Air Defence System for T23 Frigate and the Future Surface Combatant (MBDA)
- a Capability Enhancement Programme for Storm Shadow (MBDA).

Team CW has led to new energy and commitment between partners and Slater believes that this is strongly evident across a broad range of stakeholders: "One of the things that has happened is that there is a new focus within the procurement areas of MOD and this has meant that we work together in partnership and are better able to talk about problems and find ways of solving issues. We have a level of openness that I would suggest has never been seen before in this industry and we are able to be flexible in the ways we do business together. The level of trust that is growing through the communities is something new and it is now a very healthy environment to work in. This includes the way we are all dealing with the current financial changes where we are looking at the options that are available to us."

The partnership between MBDA and MOD is, he believes, fundamental to the success of new and ongoing projects. Pragmatic about current requirements to solve problems through collaboration and deliver capability at a good price and within tight timescales he accepts that there are lessons to be learnt: "In the past, we have seen cost overruns and overspends but we can now take full responsibility for these things. In products like Storm Shadow, we have proven our ability to do that and with Meteor, the missile development has stayed on track since the beginning of the programme despite bringing six nations together."

MBDA UK Executive Group Director, Steve Wadey highlights the change Team CW has made to the way all participants work together: "What makes the Team CW approach different, is that it is managed as a whole, linked through common route maps, shared architectures, subsystems and platform integration solutions, as well as common manufacturing systems and in-service support solutions," explains Wadey.

Another area of cooperation is in defence equipment research, where MBDA have been in partnership with a coordinated


5

Complex weapons

Complex weapons are strategic and tactical weapons that rely upon guidance systems to achieve precision effects. This area covers a broad range of technologies reflecting the increasing diversity and use of sophisticated 'smart' missiles, shells and warheads in all environments and operations.

Tactical complex weapons fall largely into five categories: Air-to-Air; Air Defence; Air to Surface; Anti-Ship/Submarine (including Torpedoes); and Surface to Surface.

General Munitions are 'simple' systems needing minimal maintenance and based on generic engineering and technology, primarily energetics (the delivery of a lot of energy, usually through a combination of weight and very high speed, or an explosion).

Fire Shadow sets the pace for rapid development

In April 2008, Team CW Loitering Munition (LM) successfully fired its Fire Shadow Loitering Munition, completing a rapid development demonstrator programme lasting just 15 months.

Design work began on the new weapon system in January 2007, with the aim of finding a solution to the UK's requirement for a low cost, all-weather, 24 hour capability to carry out precision attacks against surface targets which may be time sensitive and difficult to engage.

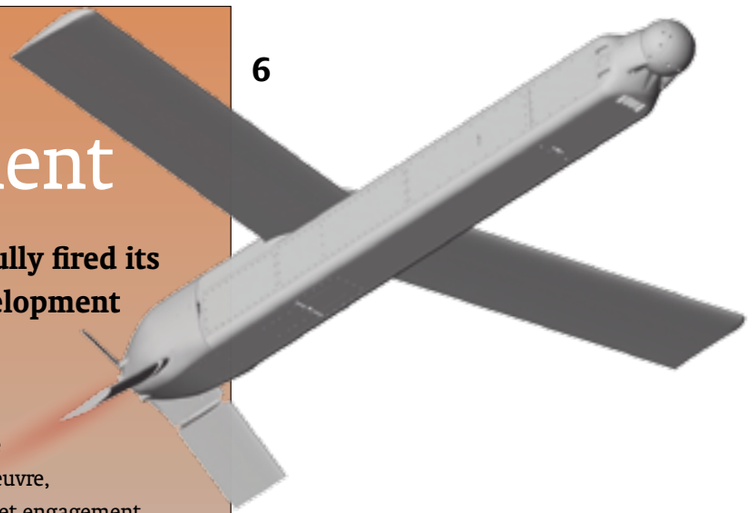
With MBDA at its head, Team LM comprises Roxel (UK Rocket Motors) Limited, Thales Air Defence Limited, Thales Missile Electronics Limited, Thales UK Limited, QinetiQ Limited, Meggitt Defence Systems Limited, Ultra Electronics Limited, Marshall SDG Limited, Blue Bear Systems Research Limited, Lockheed Martin UK INSYS Limited, Cranfield University, SELEX Systems Integration Limited, Cranfield Aerospace Limited, SELEX Sensors & Airborne Systems Limited, E2V Technologies PLC and subsidiaries and CDL Systems Limited.

Firing took place at the QinetiQ-managed UK MOD Aberporth trials range in West Wales and demonstrated launch, separation, flight and terminal manoeuvre of the design which incorporates a forward swept wing. Following the boosted launch and separation, the munition climbed to altitude and flew a pre-planned flight path. The munition then executed a terminal dive incorporating a high-g manoeuvre, representing a simulated target engagement.

Throughout the flight trial, on-board video imagery and position data was transmitted from the munition via a datalink which was received and displayed in the ground station of the range.

The flight represents a key milestone towards the radically reduced delivery timescale of a new weapon system that will meet the UK's requirement for an affordable weapon with an operating range of more than 100km and a high degree of terminal precision combined with its Man-In-The-Loop (MITL) operation. It will be targeted by ISTAR assets such as Watchkeeper and will be compatible with other battlefield systems. The munition will loiter in the target area for around ten hours and will be particularly effective in complex and urban environments.

6



"What makes the Team CW approach different, is that it is managed as a whole."

Steve Wadey,
MBDA UK Executive Group Director

8

7

team – including large businesses, SMEs and academia in the Innovation and Technology Partnership on Materials and Components for Missiles (MCM ITP). This is being performed under a Technical Arrangement between MOD and the French Delegation pour l'Armement (DGA) aimed at coordinating and optimising missile research.

Strategic guidance, technical assurance and governance are provided by government representatives and MOD SIT is represented by Defence Technology and Innovation Centre (DTIC) and Defence Science Technical Laboratory (Dstl) with Detection de l'Expertise et des Essais (DET) representing DGA.

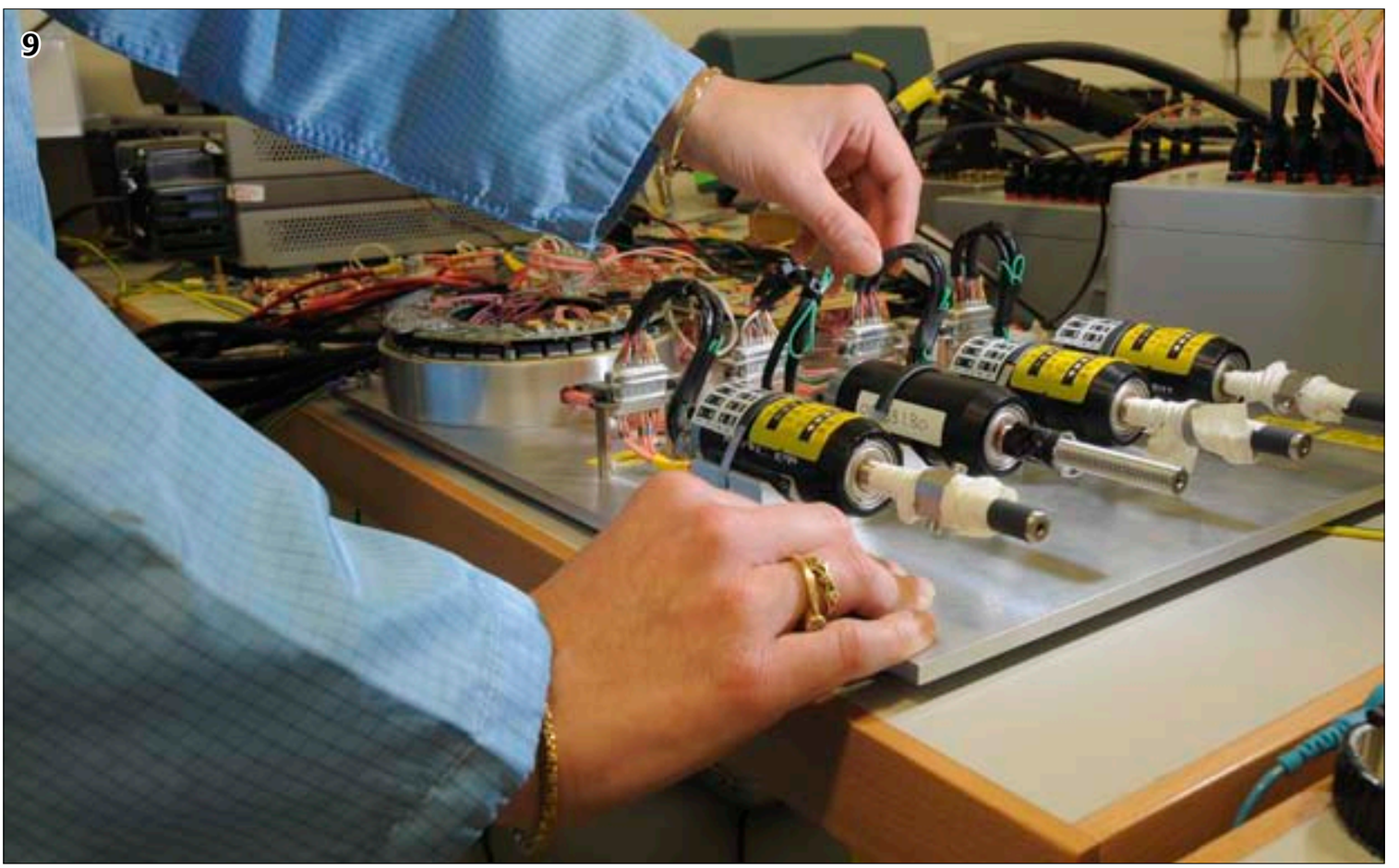
The sharing of research themes encourages development of new and emerging technologies and Wadey believes that this will lead to the next generation of cooperative missile programmes: "The designation of MBDA as leader of a research programme as sensitive as MCM IPT is an additional recognition of our work and the benefits of cooperative programmes like Storm Shadow/SCALP, PAAMS/Aster and Meteor."

Slater points out that even before these initiatives, MBDA had recognised that they needed to change the way they do business and deliver capability: "I think that the main things that we have put in place need to stay, in particular the modular family of weapons, but that doesn't mean that we don't need to be innovative any more – you need to be more innovative to deliver this in a cost-effective way. That takes a lot of innovation!"

This will also, he believes, mean that they will need to encourage all stakeholders to buy into this new challenge. The emphasis is on responding to operational requirements and getting it to the front line – quickly. "There is also another benefit to doing things quicker," he claims. "Traditionally, it could take 20 years from idea to introduction into service and we need to change those timescales – it is also cheaper when you do things faster. We now ask ourselves if we can move from a blank piece of paper to being in service in less than four years."

The drive to be leaner, more agile and cooperate with stakeholders is driving innovation in MBDA. Slater is convinced that this is the right way to move forward to meet customer's needs and provide cutting-edge capability at an affordable price within demanding timescales: "There is now a far greater understanding of all the different areas and this is

Photo 6 – Computer generated image of LM
Photo 7 – Graphic of operational application
Photo 8 – Test firing of PAAMS/Sea Viper from Longbow trial platform
Photo 9 and 10 – Prototype Fire Shadow actuation electronics and motors and integration 'flat bench' rig with prototype representations of the munition subsystems



producing new opportunities. We now look at capability and ask what else can be done with it? For example, if we are developing a launcher system for a particular weapon, we consider what else we might launch it from and this creates a new type of thinking…"

For Slater, with 25 years in the business, there is a recognisable change in the way MOD is doing business and he is convinced that Team CW will provide MOD with the capability it wants, at an affordable price: "I think we are on a good path and that we should stay with it. There are some really good ingredients in Team CW that are already delivering and will deliver a lot more in the future. You have to keep moving on to keep improving…"

- www.mbda-systems.com

11

Storm Shadow/SCALP
Conventionally-armed stand-off air-to-ground long range missile

Storm Shadow/SCALP is a long-range air-launched and conventionally-armed missile which entered full service in 2004 and is one of the most advanced weapons of its kind in the world.

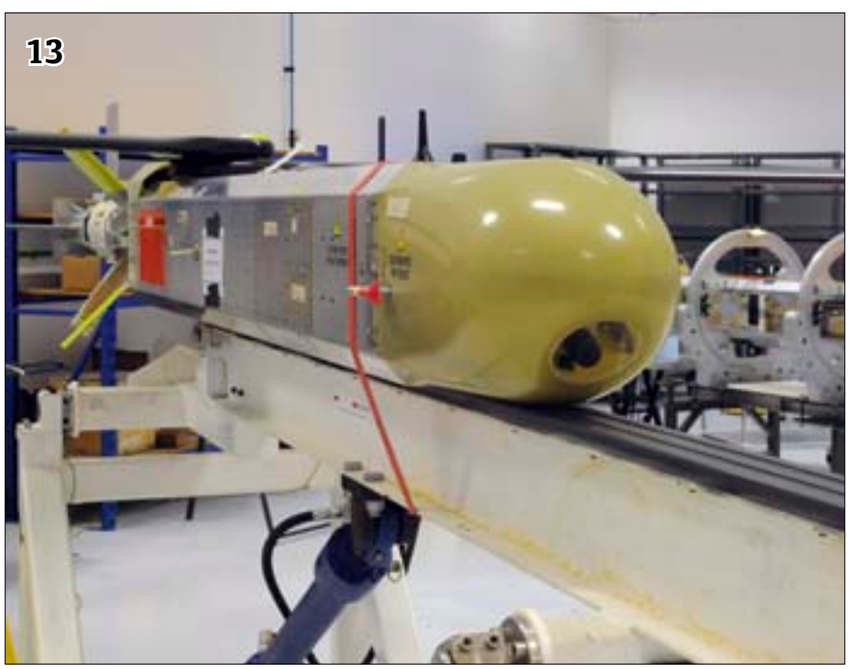
The missile is equipped with a powerful warhead and is designed to attack hardened targets and infrastructure, such as buried and protected command centres. Mission data, including target details, is loaded into the weapon's main computer prior to aircraft departure. After missile release, the wings deploy and the weapon navigates its way to the target at low level. During this time the navigation system is continuously updated through information supplied by its navigation sensors which include a Global Positioning System (GPS). The multi input system provides excellent navigational precision and high resistance to countermeasures.

On final approach to the target the missile climbs and uses an advanced infrared seeker to match the target area with stored imagery. This process is repeated as the missile dives onto the target, using higher-resolution imagery, to ensure maximum accuracy.

Storm Shadow was combat proven during Operation TELIC and is in service with the RAF on the Tornado GR4 and the French Air Force on the Mirage 2000D. It will also equip Rafale, Mirage 2000-5 MKII, and Eurofighter Typhoon.

- Range: In excess of 250km
- Missile weight: Approx 1300kg
- Missile length: 5.10m

12



13

14

15

> "The seeker concept has been developed through MOD and company research funding."

BRIMSTONE® Advanced anti-armour weapon

BRIMSTONE Air-to-Ground Precision Attack weapon is the RAF's principal anti-armour weapon, with the new Dual Mode variant ideally suited to current demands for Close Air Support (CAS) and Counter Insurgency (COIN) roles.

Dual Mode BRIMSTONE (DMB) recently entered service with the RAF as part of a 2007 Urgent Operational Requirement (UOR). It was successfully deployed supporting Operation TELIC and was fired during Operation HERRICK.

MOD and industry have worked together using innovative rapid development techniques to deliver cost-effective capability enhancement, adapted to the Armed Forces' operational demands. DMB makes maximum re-use of existing missiles and only requires a modification to the existing seeker and revised software.

The seeker concept has been developed through MOD and MBDA funding and is based on the existing BRIMSTONE millimetric wave radar seeker, with the addition of a sensitive Semi Active Laser (SAL) capability and the ability to operate in single mode or a dual SAL and RF guidance mode. The guidance mode can be selected at the cockpit, enabling the missile to engage with precision with all types of target.

The existing small, multi-effect tandem charged charge/blast warhead has been demonstrated to minimise collateral damage and enables engagement of targets in environments where there is high collateral risk. The combination of precision, MITL target discrimination and extremely localised effects provides improved capability for the RAF.

DMB is in-service on the Tornado GR4/4A and nearing completion for integration on the Harrier GR7 and GR9A aircraft. It is also a candidate for integration on the Eurofighter Typhoon and F-35 JCA aircraft.

- Missile weight: 50kg
- Missile length: 1.8m
- Missile diameter: 0.18m

Photo 11 – SCALP on the Mirage 2000D © Alexandre Paringaux
Photo 12 – Visual/ Interactive Hardware integration using Synthetic Environments (SE)
Photo 13 – Fire Shadow Demonstrator Trials proving munition on unelevated launch rail
Photo 14 – Theoretical maximum flight configuration for GR4
Photo 15 – BRIMSTONE installed on Tornado

Battling

Background – RAF Chinook Helicopter re-supplies 42 Commando Royal Marines at Patrol Base Delhi in the Afghan district of Garmsir. © Crown Copyright/POA(Phot) Sean Clee

the elements

By providing weather services to support the Armed Forces, both in the UK and abroad, the Met Office helps improve the safety of troops. Services to defence include advising on weather risks on the ground, such as heat stress, through to predictions of dust that impact aircraft on take-off and landing. Codex travelled in a south westerly direction to visit their Exeter headquarters and find out more about their work in defence.

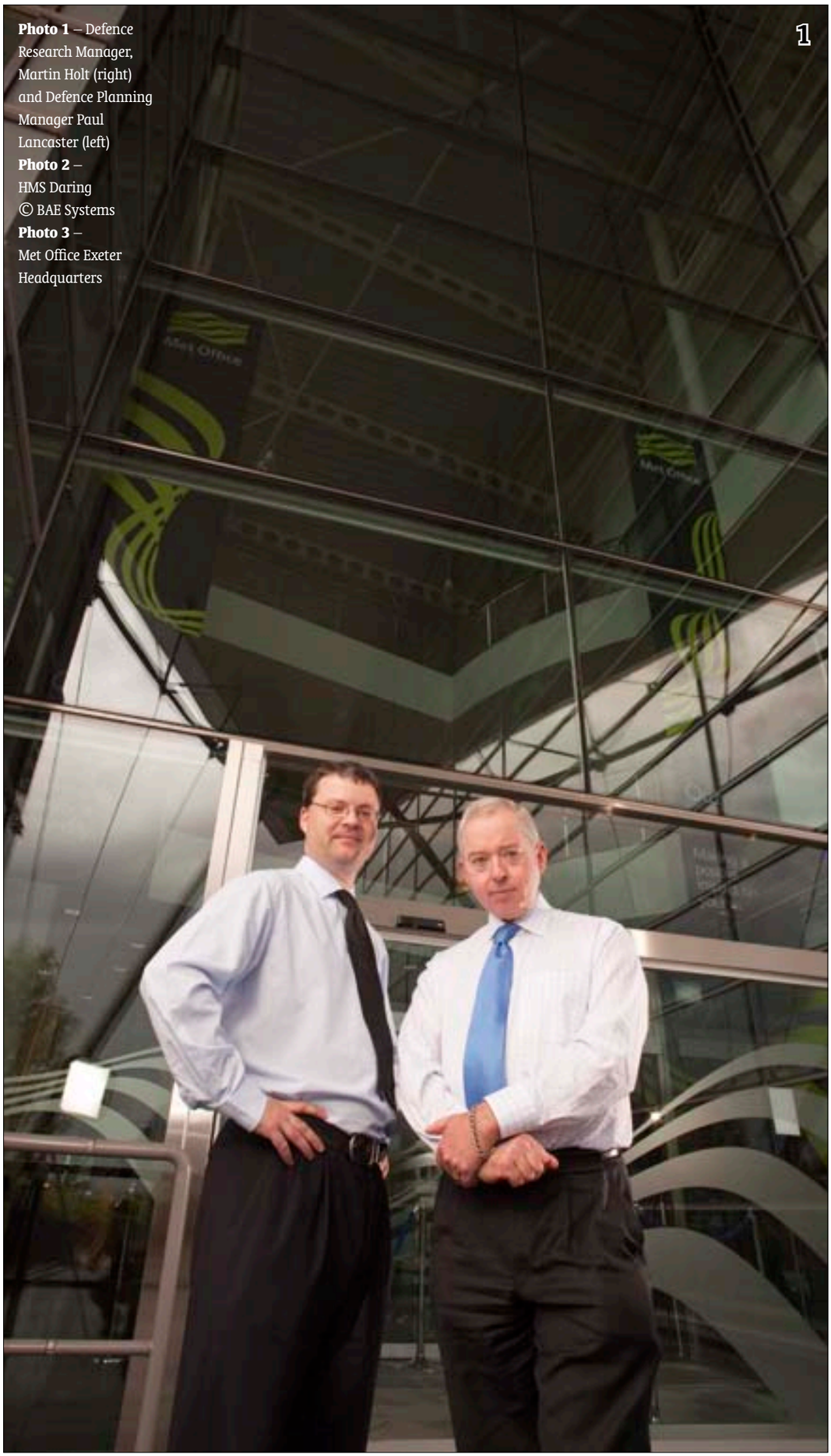


Photo 1 – Defence Research Manager, Martin Holt (right) and Defence Planning Manager Paul Lancaster (left)
Photo 2 – HMS Daring © BAE Systems
Photo 3 – Met Office Exeter Headquarters

A trading fund of the MOD, the Met Office advises military decision makers on the impact of climate and environmental factors and provides a range of tools and systems to support military operations. Their research into future climate change helps plan future equipment capability and an understanding of how future conflicts may develop.

The Met Office Operations Centre in Exeter and its partner forecasting site in Aberdeen, form the operational heart of the UK's national weather service, delivering forecasts to customers across the world. As well as providing first-class forecasting, the Met Office leads the world in climate change prediction and is at the forefront of climate change consultancy, employing its world-renowned climate research from the Exeter-based Met Office Hadley Centre.

Observations underpin the forecasting of atmospheric conditions and data is collected around the world throughout the atmosphere to 2,000 metres below sea level. These are made into complex simulations on a supercomputer which along with modelling predicts how the atmosphere will change over time.

The main sources of observations are from weather satellites, balloon profiles, surface and marine data and aircraft observations. The Met Office is responsible for maintaining the observation network over the United Kingdom and contributes to the funding of weather satellites and buoys. Observations which are made 24 hours a day, all across the globe, are passed to the world's major weather forecasting centres.

'Assimilation' is the process of ingesting raw observational data into a numerical representation of the atmosphere in the forecast model. Even tiny changes in the atmospheric conditions can lead to drastically different weather patterns after only a short time, so it is vital that the current state of the atmosphere is represented as accurately as possible. This process is highly mathematical and today it takes the supercomputer longer to accurately estimate the current atmospheric state than it does to actually make the forecast…

Each day, the Met Office receives and uses around half a million observations of temperature, pressure, wind speed and direction, humidity and many other properties to provide the starting conditions for their weather forecast model.

Met Office Hadley Centre

The Met Office Hadley Centre (MOHC) was opened in 1990 and is the leading climate research centre in the UK and worldwide. They produce guidance on the science of climate change and have played a key part in the IPCC Assessment Reports for over 20 years.

MOHC studies the global climate and uses atmospheric models to provide an understanding of the physical, chemical and biological processes and to build representative computer models that simulate changes in global and regional temperatures. This enables scientists to predict changes over the next 100 years and attribute recent climatic changes to specific factors.

- www.metoffice.gov.uk/climatechange

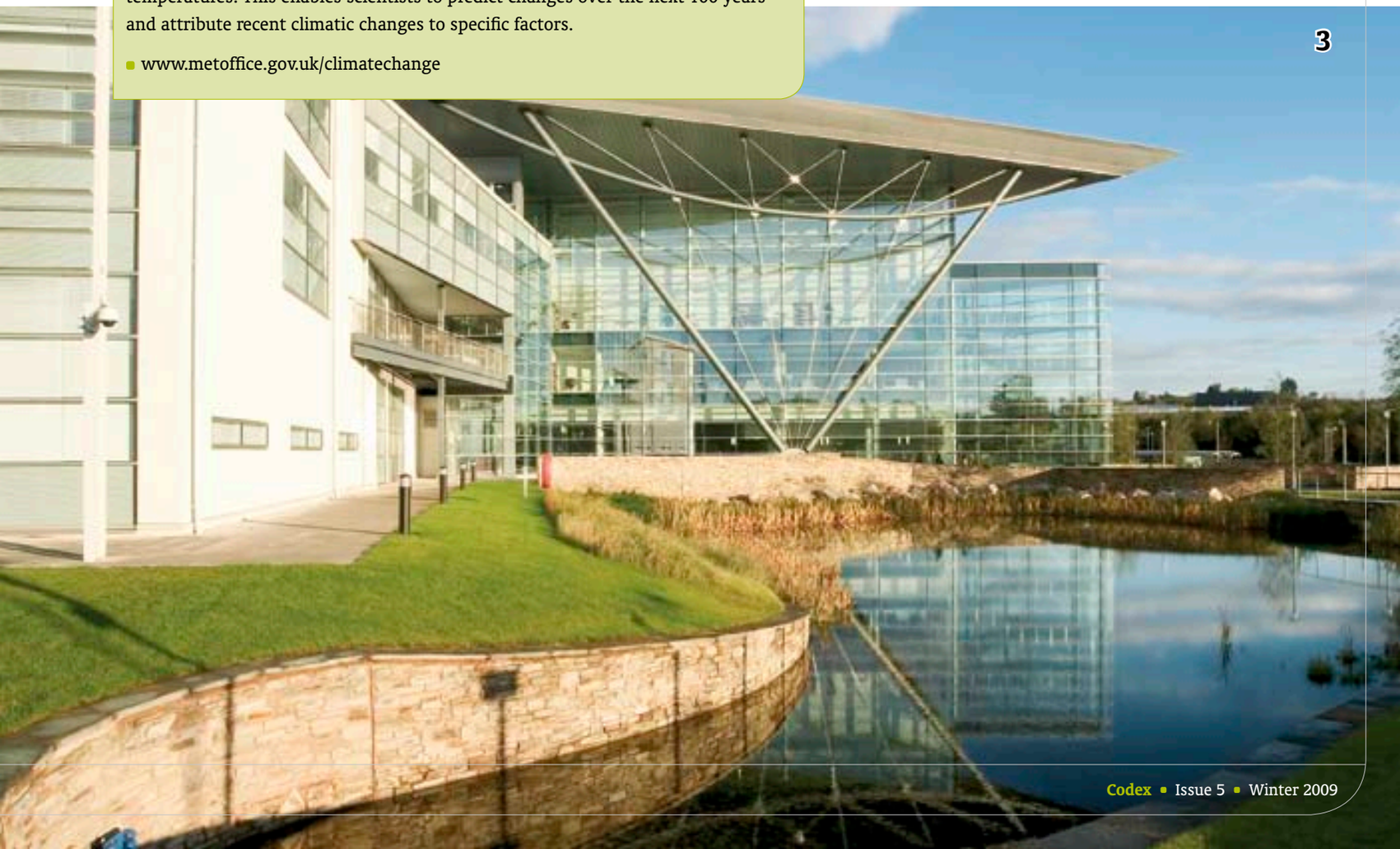
2

Met Office in Type 45 testing

HMS Daring sailed in UK waters this autumn to test her Infrared (IR) signature ensuring correct identification and protection of this major asset.

During the trial, thermal sensors and the Neon Marine Target Model (MTM) weather platform were deployed on board Daring, with Dstl sensor and countermeasure thermal imagers positioned ashore. The data that was gathered from the trial will benefit Dstl in their work with signature identification and classification of vessels and the Met Office with development of their electro-optic sensor performance tool Neon.

The Type 45 destroyer is scheduled to enter service with the Royal Navy in 2010 and will combine state-of-the-art power and propulsion systems, world class weapon systems and modern accommodation for its crew.



3

MOD Climate Change Strategy

Climate Change Vision

'Effective delivery of Defence capability that is robust to climate change and does not substantially contribute to its causes.'

The 2007 Intergovernmental Panel on Climate Change (IPCC) report confirmed the impact that climate change will have on defence and preserving peace and stability in the changing world. It is now internationally accepted that climate change is a reality and a factor that will have to be addressed for many decades to come.

The Met Office is a key player in the field of climate change research, helping MOD develop knowledge and supporting the work of the IPCC, other government 'think tanks' and the UN Security Council.

The strategy sets out MOD's aims and the processes they will adapt in Defence planning to identify the risks to global security presented by the complex geopolitical interactions resulting from a changing climate and the means by which they will address and reduce carbon emissions.

The Defence Technology Plan (DTP) states MOD's research strategy relevant to climate change and Capability Visions (CVs) seeks scientific, technological and economic solutions in areas such as reducing dependency on fossil fuels.

Climate Change Strategy

- www.mod.uk

Defence technology Plan

- www.science.mod.uk

Computer power

In 2008, they signed a contract for a new supercomputer with IBM which is capable of 125 trillion calculations per second and will be the second most powerful computer in the UK and in the top 20 worldwide. The five-year contract includes a mid-life upgrade and by 2011 the computer will be 30 times more powerful than the previous supercomputer.

Strategic support

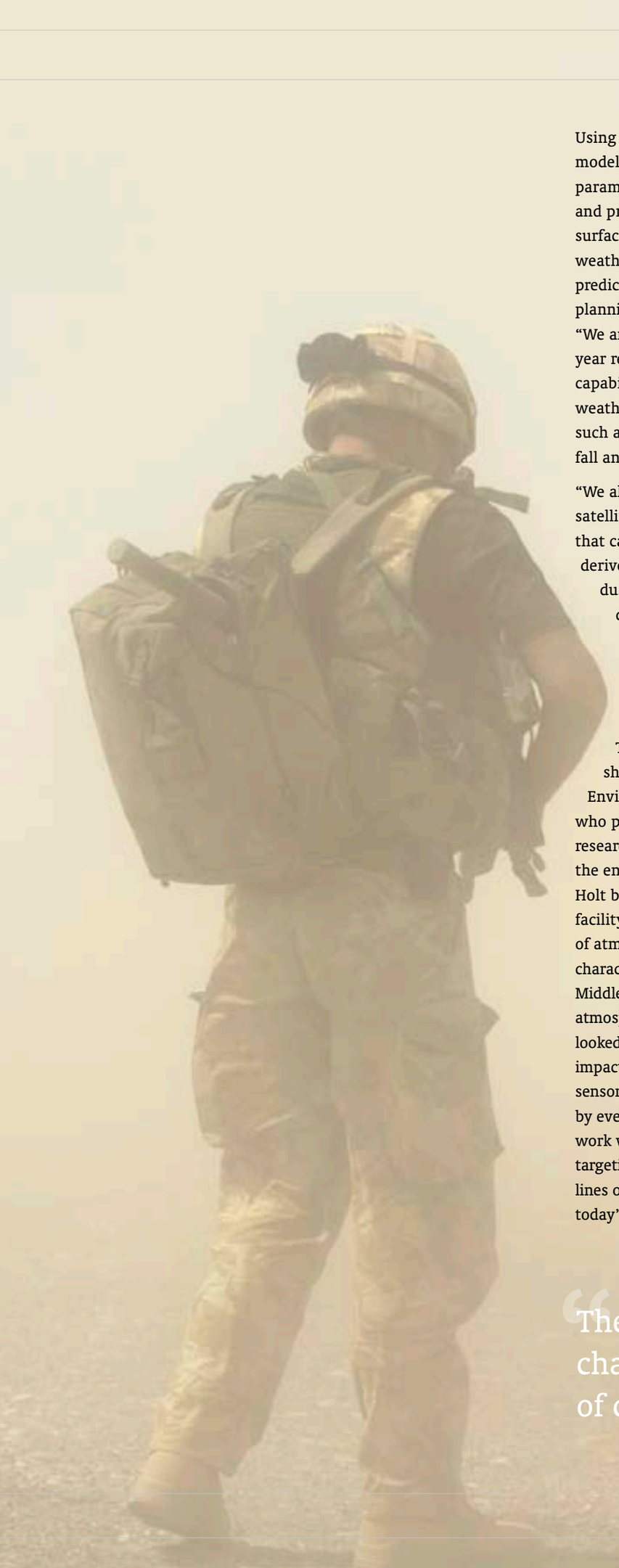
With current and recent operations taking place in hot environments, there is increased recognition of the need to adapt existing equipment to operate more effectively and to develop future equipment with a specification that will meet future environmental demands. There is also the expectation that UK Armed Forces will be called on to respond to humanitarian disasters around the world.

As well as their support for current operations, the Met Office advises on the likely impact of climate change around the world. This is increasingly relevant to strategic planning in defence which needs to look at every aspect, from operations, to procurement and future engagement.

Mission support

Met Office Defence Research Manager, Martin Holt makes sure that their work fits in the with Defence Technology Plan (DTP) to meet MOD requirements. From his base in Exeter, he describes how their work covers air, sea and land, with additional support for each of the Services. Holt is also keen to highlight the work of colleagues who work on the front line, supporting operations in Afghanistan: "The Mobile Met Unit are currently at Camp Bastion and Kandahar and undertake a key role in advising our forces on the potential environment impacts on their operations."

The Met Office has a range of mission support tools and delivery systems that look at the specific application of science for defence and where this can have an impact on missions. Dust forecasting is one example.



Using numerical weather prediction models, which represent the physical parameters such as wind, temperature and pressure as well as knowledge of surface soil type, moisture levels and weather predictions, they are able to predict amounts of dust and assist in planning operations. Holt explains: "We are in the final year of a three year research programme developing capabilities to forecast dust using weather modelling and information such as the size of grains of sand, rain fall and evaporations.

"We also have scientists looking at satellite applications and measurements that can be taken from space which can derive measures of dust and create a dust index. This can show how much dust will stay near the surface and how much will be lifted. This is a very exciting part of our research with a direct effect on operations."

The Met Office also have part share in an aircraft with the Natural Environment Research Council (NERC) who provide comprehensive airborne research capability for the benefit of the environmental science community. Holt believes that this is a key research facility for the UK, taking measurements of atmosphere, aerosol and chemical characteristics. It was deployed over the Middle East earlier this year looking at atmospheric dust. Holt explains: "It also looked at infrared imaging and how dust impacts on ground operations. Infrared sensors and thermal contrast are affected by everything in the atmosphere. This work will help target acquisition and targeting. This is integrated with several lines of research and is very relevant to today's operations."

Target detection

Another application developed by the Met Office is Neon. Neon is used to assess the environmental impact on electro-optic sensor performance and when cross referenced with other information improves targeting decisions. Knowing when or where sensors will be able to detect a target is critical in planning and executing successful missions. At what distance will the sensors on an Apache helicopter be able to identify a ground-based missile battery from the surrounding area? Will this put people and assets at risk by placing them in range for possible counter-strikes? These complex mission decisions are helped by Neon.

The electro-optic sensor performance Tactical Decision Aid (TDA) Neon predicts the effect of the environment on the ability to identify targets. The latest version provides a range of features including estimates of target acquisition range and a Marine Target Model.

Planned enhancements in the next version include the use of dust and cloud predictions in the Radiative Transfer Model (RTM), improvements in the modelling of the background land surfaces and a greater range of targets.

It has recently been deployed for training with Apache squadrons and has also been developed for use by the Joint Strike Fighter (JSF) aircraft. Holt believes this will give additional support to squadrons using Neon either ashore or on a carrier: "We are also looking at weather impact on JSF and if this will affect the aircraft and how our forecasts can advise pilots on targeting decisions using thermal imaging," he adds.

"The Met Office leads the world in climate change prediction and is at the forefront of climate change consultancy."

There will be clear skies ahead…

Mobile Met Unit support and advice for operations

Photo 4 – Satellite dish
Photo 5 – Zoe Philcox talks about her front line experiences
Photo 6 – Geostationary satellites issue infrared pictures 24 hours a day

For Met Office Defence Research Account Manager, Zoe Philcox supporting operations is more than just forecasting the weather. With seven deployments behind her, she is back at base in Exeter to talk about her experiences and how their work can make a real difference on the front line.

Weather and other environmental factors can have a critical impact on the success of operations and Met Office advisers travel to battle zones to offer support and advice to military decision makers. "As well as being trained meteorologists, we also understand the impact weather and the environment have on military operations. We communicate this advice in a way that enables timely and accurate decisions to be made that can provide our forces with a battle winning edge," explains Philcox.

But this is just part of their work. As part of the Met Office's Mobile Met Unit (MMU) they are deployed at bases in the UK and overseas (from Cyprus to the Falklands) and in operational theatres, working alongside deployed UK and allied forces. The MMU is a sponsored reserve unit of the RAF which can call on around 70 men and women who have undergone military as well as meteorological training.

Philcox has been with the Met Office for nearly eight years and spent six months back in the classroom and a further five months training at RAF Linton on Ouse, North Yorkshire, before being sent on her first mission to Kuwait in 2003. Since then she has deployed four times to Basra, once to Bosnia and last year, her final deployment to Kandahar province in Afghanistan.

Advisers have access to the most up-to-date weather information, whenever and wherever they need it, including outputs from high-resolution forecasting models, which can be set up wherever UK armed forces are conducting operations.

"Our main customer is usually RAF and we could be supporting helicopters, fast jets and transport planes operating from the base where we are located. We also forecast for army units moving around on the ground, some naval squadrons, the Special Forces, RAF and anyone else who can benefit from our support… We also provide a 'weather watch' which is passed to air traffic control to give warnings of bad weather, helping them to prepare for strong winds, thunderstorms and other challenges. We deploy with a portable weather station which measures wind speed, pressure, temperature, cloud base etc. and computers with satellite links to the Met Office which sends out numerical weather prediction model data similar to that in the UK, but with slightly less data and frequency."

Philcox works with anyone who can benefit from the information and support she can give, from senior executives to helicopter pilots who request information before a sortie. Face to face contact, she believes, gives the military extra confidence and by developing an understanding of the issues that are important to them, she is able to offer the appropriate support. "We make a real effort to find out what issues are important to them and give them plenty of warning of any potential weather problems, such as cross winds.

"This is really important as we are the experts on the weather and their operations are dependent on the conditions. The more we understand their needs and requirements, the more support we can give, as well as expert advice…"

But being on operations is not for everyone, and Philcox was very aware that she was in a war zone in Iraq where the base was under frequent rocket attack and they would need to take cover: "Generally, we would feel secure as we were working at the base, but this is part of the work and why we are there."

Now back in Exeter, Philcox can reflect on her experiences and use these to help with her current work as a Defence Research Account Manager. Asked to sum up her work on operations, she does not hesitate: "The camaraderie of working alongside the military gives you insight into the challenges they face and how we can provide valuable support. And yes, I would do it all again!

"The more we understand their needs and requirements, the more support we can give."

5

Night eyes

Improving the effectiveness of a range of night vision devices has enabled the military to carry out an increasing number of activities under the cover of darkness, including covert missions and identifying targets from helicopters.

Carrying out missions at night-time can provide a battle winning edge to the Armed Forces on operations.

Met Office Night Illumination Model (MONIM) provides information on the levels of available light so that night-time missions can be planned more effectively.

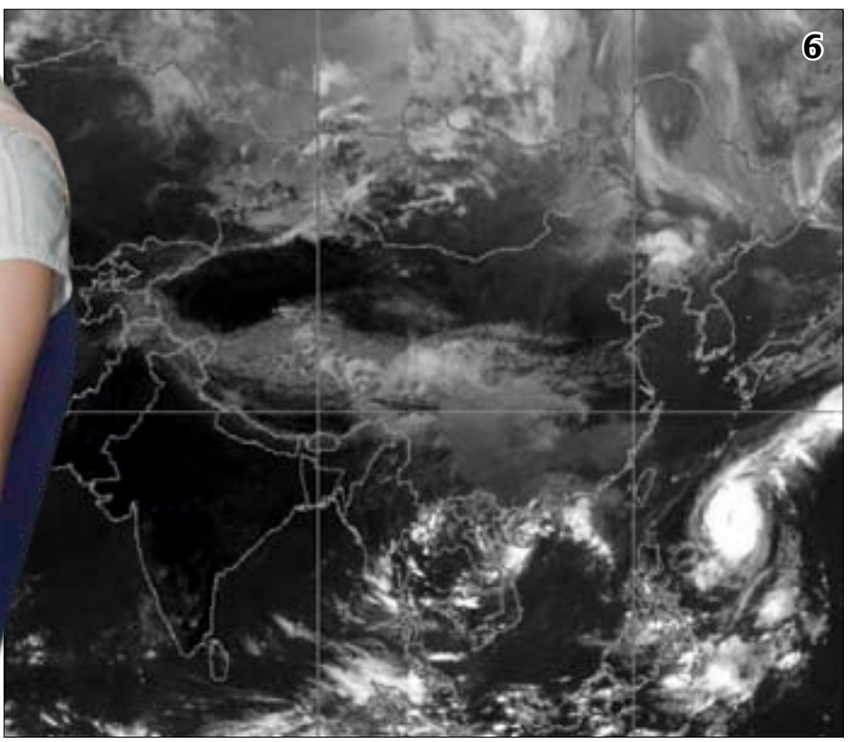
Night vision devices work by amplifying available ambient light which can be generated from a number of sources including sunlight (at twilight), moonlight, starlight, airglow and cultural light. The level of available light is also affected by cloud cover. MONIM accounts for the transmission of these sources of light through the atmosphere to provide a predicted level of light throughout the night-time. This means that missions can be planned to take best advantage of conditions and it also provides tables of lunar and solar ephemeris data, such as rise/set and twilight times.

Holt believes that science and research play an important role in defence: "Ideas are continually evolving and building on more recent technology developments means we can bring forward a much greater level of capability."

Weather warning

A critical part of the Met Office's service to defence is making sure its information and support tools can get into the hands of military decision makers as and when they are needed. This is achieved by using a specially developed data server, the Joint Environmental Dynamic Data Server (JEDDS) which can be deployed onto restricted and secret military networks, providing detailed information from tools such as Neon.

The Met Office also provides forecasts to the MOD for test ranges and helps with test development for Unmanned Air Vehicles (UAVs). They provided forecasts for last year's Grand Challenge, which despite its August finale, was a victim to the English summer [*it rained and was extremely cold! Ed*]. Holt sees this as a good example of how weather impacts on defence, and as he says: "it can often be left as an afterthought…"



6

Library and archives

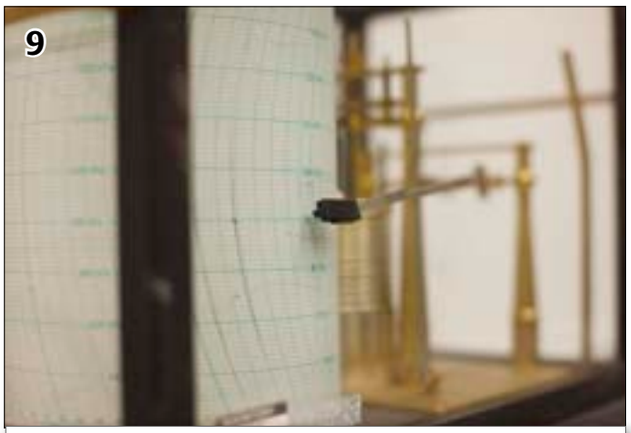
The library collection covers meteorology, climatology and related sciences including a comprehensive selection of books and scientific papers from general interest to academic texts.

One of the most fascinating collections is a complete set of the Daily Weather Summaries detailing the weather for every day from 1 July 1869 to the present. Weekly, monthly and annual summaries are also available.

This and the display of historic instruments, including the original Beaufort Scale, illustrates the science and commitment to detail behind today's weather reports. They also hold registers of meteorological observations and autographic records for approximately 1,000 sites, dating back to the mid-nineteenth century, covering temperature, wind, rainfall, solar radiation, snow and sunshine.

Their marine weather logbooks hold worldwide records from merchant and Royal Navy ships, including those from historic voyages such as of the HMS Prince of Wales when she attacked the Bismarck in WW2.

Photo 7 and 8 – Inside the library
Photo 9 – A 1941 Barograph which records pressure



History

The Met Office is an MOD agency with connections going back to 1854 when naval sea captain, Robert FitzRoy was chosen to head up a new, experimental government department within the Board of Trade. As hydrographer and meteorologist he instituted a system of storm warnings, based on synoptic information that remained in use for over a century. FitzRoy initiated the exchange of meteorological data, notably with the French, and published the first regular daily weather report on September 3, 1860.

In 1944, forecasters advised General Eisenhower of a 36-hour 'weather window' for the D-Day landings. "Probably the only day during the month of June on which the operations could have been launched", President Truman later declared.

In 1984 they were awarded World Area Forecasting Centre status for aviation, one of only two globally to provide forecasts for flying at high altitude.

In 1991, a Cray Y-MP supercomputer became the first to be used by the Met Office. Capable of one billion calculations per second, it is able to process a single numerical model (merging ocean and atmosphere) to be used for climate and weather prediction. The latest IBM supercomputer is hundreds of times more powerful than the first, able to do more than 100 trillion calculations per second.

Journal

Issue 5 ▢ Winter 2009

The efficient harnessing of science and technology (S&T) to benefit defence and security is extremely and increasingly important. Codex Journals communicate right across the UK defence and security community, from those working in the vanguard of scientific discovery, through to those who depend on S&T on the front line.

Codex Journals provide a valuable resource for communicating challenges, updating progress and helping support the successful exploitation of new ideas. Dstl will continue to ensure that published papers are widely accessible and technically authoritative. To this end, we undertake rigorous peer review, drawing on the expertise of the Defence Science Advisory Council.

As editor, I look forward to receiving journal papers, suggestions and feedback and hope that you find the following papers stimulating and instructive.

Dr Mike Steeden
Journal Editor
Dstl Technical Director
President of the Royal Aeronautical Society
codex.journal@dstl.gov.uk

Contents

For full details of requirements and how to submit a journal visit: www.science.mod.uk/codex

[dstl]

The SARTOM Project: Tomography and Polarimetry for Enhanced Target Detection for Foliage Penetrating Airborne SAR

The SARTOM project has assessed the value of a range of advanced research techniques to the subject of foliage penetrating radar for the detection and classification of military targets; in particular this has focused on synthetic-aperture radar (SAR) tomography and polarimetry. In this paper we present a summary of our results.

By
Nick Walker
eOsphere Limited
www.eOsphere.co.uk
Email: nick.walker@eosphere.co.uk

Ralf Horn and Matteo Nannini
German Aerospace Center (DLR)

Armando Marino and Iain Woodhouse
University of Edinburgh

This paper was presented at the Electro Magnetic Remote Sensing (EMRS) Defence Technology Centre (DTC) conference, Edinburgh, July 2009. Please see www.emrsdtc.com for further information.

Introduction

The SARTOM project has addressed a key area of defence interest, namely the detection and identification of targets hidden in foliage. The project has provided a rich source of data obtained from a series of flight trials that were conducted in September 2006 at a test site near Munich, Germany. This multi-frequency (X-, C- and L-Band) and fully polarimetric data set has been examined with the use of advanced processing techniques designed to extract the maximum amount of information contained in the data: namely SAR tomography and the analysis of multi-polarimetric scattering characteristics of the foliage and target signatures.

The SARTOM project was able to provide the first demonstration of target detection under foliage using tomography (Figure 1). It also combined tomography with polarimetry to highlight the different scattering mechanisms between the targets and the foliage overhead and in the background.

An important aspect of the study has been to address the practicality of the tomographic technique for real applications. This has focused on the need to ensure that the technique works without the need for corner reflectors to calibrate the phase in the data and to establish the minimum number of passes required to generate a tomogram.

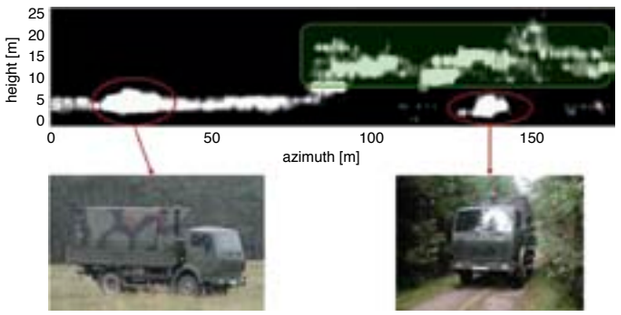
In supporting work, a new polarimetric target detection algorithm has been developed, which, according to our results, outperforms existing algorithms. This is especially the case for small point targets (such as vehicles) which is why this is of particular interest for defence applications (Section 0). Another important factor is that as well as detecting targets amongst background clutter, the algorithm offers the possibility for target classification.

SAR tomography & polarimetry

SAR tomography [1] is an imaging technique that allows a vertical resolution to be resolved through the construction of a synthetic aperture (tomographic aperture) in the direction perpendicular to the flight path. Hence, separation of multiple phase centres within a resolution cell becomes possible, leading to a 3-dimensional representation of the scene.

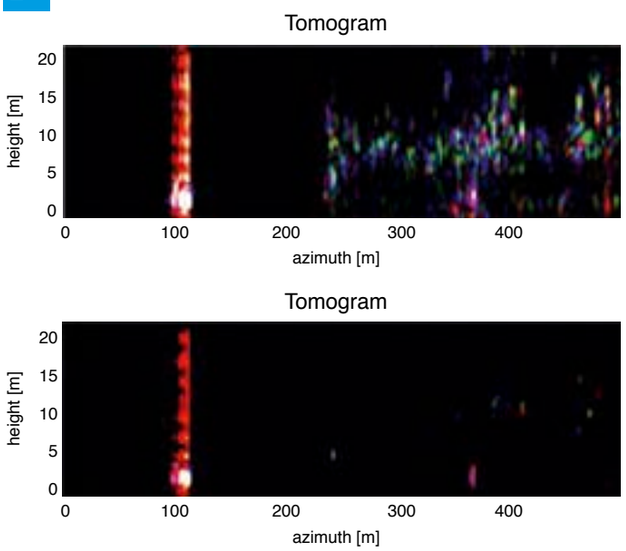
By analysing the polarimetry of a backscattered signal it is possible to derive information concerning the main scattering mechanisms related to a target and consequently to characterise it through its signature. In particular, by carrying out a change of basis from the lexicographic (measured by the radar) to the “Pauli basis”, it is possible to obtain a three element vector (monostatic case) that detects for: odd-bounce (Pauli1), even-bounce (Pauli2), and volumetric contributions (Pauli3).

1



SAR tomography allows a 3-dimensional picture of a scattering volume to be constructed in contrast to the usual 2-dimensional SAR image. The image shows two military trucks; one situated in a forest and the other in a field. The tomogram is clearly able to identify the truck despite the foliage which can be seen above it.

2



Colour coded polarimetric tomogram in the Pauli basis of the hidden truck by means of the TDB algorithm. R=Pauli2, G=Pauli3, B=Pauli1. In the top image the dynamic range of the image values has been set to provide a reliable representation of the canopy through the Pauli3 contribution. The target outside the forest is represented by the red spot on the left (double bounce) and the target hidden beneath the vegetation is identified by the purple spot. In the bottom image the scaling of the dynamic range has been adjusted so that the hidden target is emphasised (at the azimuth position of ~370m).

In Figure 2 the results obtained on the SARTOM data using time domain beam-forming (TDB) [2] are shown. This is a coherent processing method that, due to its linearity, allows the combination of all the polarimetric information to be combined in one single colour-coded tomogram.

Incoherent methods like the Capon beam-former [3] have also been investigated.

It can be seen in Figure 2 that the backscattered power of Pauli3 in correspondence to the target has no significant amplitude when compared with the Pauli1 and Pauli2 components. The truck is represented by the yellow spot located under the canopy that corresponds precisely to the combination of Pauli1 and Pauli3 components. It is interesting to observe that different polarizations detect different parts of the truck (e.g. Pauli1 is more sensitive to the rear part of it, while Pauli2 is more sensitive to the front of it).

Tomography: practicality issues

The tomography results demonstrate that the technique can provide information that is very useful for the detection of targets under foliage; however, the extra price to be paid for this information is considerable, in terms of the number of flight passes to be made over the target and the extra processing required. Two topics have been examined to investigate these practicality issues: (i) Ensuring that it is possible to complete the phase calibration part of the processing without needing to make use of corner reflectors present in the scene; (ii) Examining the effect of reducing the number of passes on the quality of the derived tomogram.

Phase calibration: Figure 3 shows two tomograms where one has been produced using the absolute phase calibration achieved using a corner reflector that was present in the field. The other image shows the tomogram produced using a relative phase calibration made without the corner reflector. It can be seen that the quality of the second tomogram has not suffered appreciably with respect to the former, indicating that this stage of the tomographic processing can be achieved without the need for special equipment to be placed in the field prior to the data acquisition.

The number of passes: A study has been conducted examining the quality of a tomogram as the number of passes used in its construction is reduced. From the SARTOM trials, 22 passes were available for use to construct a tomogram, such as that shown in Figure 1. Clearly it would not be feasible in an operational situation to make this many passes.

The study was conducted using the Capon and the MUSIC algorithmic approaches and is described in more detail in [4].

Figure 4 provides a demonstration of the tomogram that was derived using the MUSIC algorithm using only six passes. We hope to pursue this issue further with the aim of establishing the limit on the number of passes, and possibly examining whether different flight-pass geometries can assist in reducing the number of passes needed to construct a tomogram that meets our target detection requirements.

Enhanced target detection & classification using SAR polarimetry

A target detection algorithm has been developed that exploits a particular aspect of the polarimetric target response which is characterised by a concept known as the polarimetric fork. The detector is not based on a statistical technique, but rather by a physical approach based on sensitivity of the polarimetric complex coherence to changes in polarisation.

Work to-date comparing the new algorithm with previous algorithms has considered PolInSAR techniques (an example of which is that due to Cloude *et al* [5]), target decomposition theorems (Freeman-Durden [6] and Entropy/alpha/beta [7]) and the polarimetric whitening filter (PWF) due to Novak [8].

The detector is based on the fact that a man-made target can be uniquely characterised by its polarimetric signature, which can be completely encapsulated by the polarisation fork (PF). The PF is composed by a unique set of polarisations related to the physical material. In particular, this unique set of polarisations is often defined by those specific polarisations that when transmitted have a maximum or minimum return.

It is well known that transmitting and receiving on only one polarisation (and not the whole set of optimum polarisations) can lead to misclassification of the target since two completely different targets can have exactly the same response for a single polarisation (e.g. different targets can be confused with each other). However, this is not the case for the whole set of optimum polarisations. Fortunately, the optimum polarisations can be reconstructed in post processing starting from the classical fully polarimetric acquisition. By basing the algorithm on the PF the detection is assured to be unique (since the PF is uniquely linked to the single target for a specific viewing geometry).

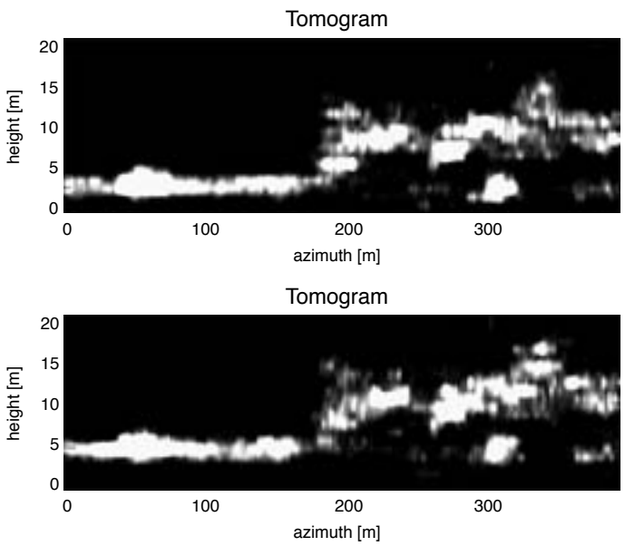
The algorithm has demonstrated better detection rates to other techniques, including the PWF, which is considered to be optimal in some respects (see Figure 7 and Figure 8). The improved performance is particularly evident for targets hidden under foliage, and in other noisy clutter environments, such as in ploughed fields, where we have been able to achieve a large reduction in the false alarm and missed detection rates.

Conclusion

The SARTOM project has provided a highly valuable dataset upon which a range of novel techniques have been applied for the purpose of target detection for targets covered by foliage.

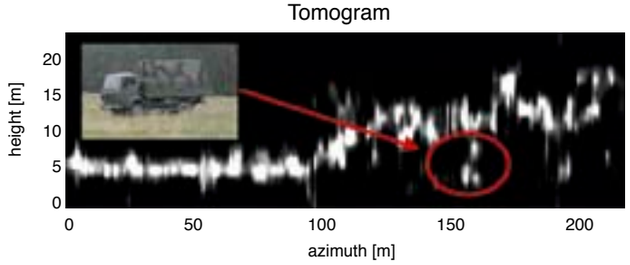
Results obtained by means of polarimetric SAR tomography have been presented. The 3D polarimetric analysis completed with the TDB algorithm led to consistent and reliable results

3



The top image shows the tomogram produced using the absolute phase calibration achieved using a corner reflector. The bottom image shows the tomogram produced using the relative phase calibration made without the corner reflector.

4



Pseudo-power of the MUSIC algorithm with N=6 tracks. The robustness of the algorithm allows the detection with this reduced constellation.

5

Original SAR image, in Pauli RGB format, geo-located with the two detection images below. In this section of data 3 corner reflectors were hidden under the forest canopy.

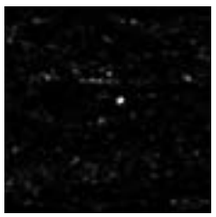
6

One of the 70cm corner reflectors placed under the forest canopy.

7

The Marino detector correctly identifies all three corner reflectors (in blue) at their correct locations. The "red" detected point represents the double bounce from tree trunks in a small clearing. Similar results were obtained for different military targets hidden under the foliage, and when measured in comparison to other algorithms.

8



The polarimetric whitening filter to be compared with the Marino detection algorithm in Figure 7.

that can be exploited to define a signature of the hidden target for target detection purpose.

A study has been conducted seeking to make tomography as practical as possible and attempting to establish the number of passes necessary to produce a useful tomogram.

A new polarimetric target detection algorithm has been developed which only requires the data to be acquired from one pass. Results indicate that this algorithm has a number of features that make it attractive for the detection of targets underneath foliage, or for relatively small targets in a high clutter background. This is due to the fact that the algorithm's formalism allows for the characterisation of the target to be established, making target classification possible, and because the algorithm makes use of the target's polarimetric scattering properties rather than the scattering strength of the target.

Acknowledgements

The work reported in this paper was funded by the Electromagnetic Remote Sensing (EMRS) Defence Technology Centre, established by the UK MOD and run by a consortium of SELEX Galileo, Thales UK and Roke Manor Research.

References

1. Reigber and A. Moreira, *'First Demonstration of Airborne SAR Tomography using multibaseline L-Band Data, IEEE Trans. on Geosc. and Remote Sensing'*, Vol. 38, no.5, pp.2142–2152, 2000.

2. M. Nannini and R. Scheiber, A Time Domain Beamforming Algorithm for SAR Tomography, Proc. EUSAR conf., Dresden, 16–18 May, 2006. A. G. Thomas, M. C. Berg, *'Medium PRF set selection: an approach through combinatorics'*, IEE Proc.-Radar, Sonar Navig., Vol. 141, No. 6, December 1994, pp.307–311.

3. F. Lombardini and A. Reigber, *'Adaptative spectral estimation for multibaseline SAR Tomography with airborne L-band data'*, in Proc. IGARSS, Toulouse, France, 2003.

4. M. Nannini, R. Scheiber and A. Moreira *'Estimation of the minimum number of tracks for SAR tomography'*, IEEE Transaction on Geoscience and Remote Sensing, February 2009.

5. S. R. Cloude, D. G. Corr and M. L. Williams, *'Target detection beneath foliage using polarimetric synthetic aperture radar interferometry'*. Waves Random Media 14 (2004) S393–S414.

6. A. Freeman and S. L. Durden, *'A Three-Component Scattering Model for Polarimetric SAR Data'*, IEEE Transaction on Geosciences and Remote Sensing, vol. 36, pp.963–973, 1998.

7. J. Lee, M. R. Grunes, T. L. Ainsworth, L. J. Du, D. L. Schuler, and S. R. Cloude, *'Unsupervised Classification Using Polarimetric Decomposition and the Complex Wishart Classifier'*, IEEE Transaction on Geosciences and Remote Sensing, vol. 37, pp.2249–2258, 1999.

8. L. M. Novak, M. C. Burl and M. W. Irving, *'Optimal Polarimetric Processing for Enhanced Target Detection'*, IEEE Trans. Aerospace and Electronic Systems, vol. 20, pp.234–244, 1993.

Trusted Reasoning Engine for Autonomous Systems with an Interactive Demonstrator

We present a mathematical formalism for an explainable decision-making system and illustrate its applications in the context of a simple urban search scenario.

By
Jens Kröske, Kevin O'Holleran and Hannu Rajaniemi
ThinkTank Maths Limited
www.thinktankmaths.com
Email: a.mathis@thinktankmaths.com

This paper was presented at the Electro Magnetic Remote Sensing (EMRS) Defence Technology Centre (DTC) conference, Edinburgh, July 2009. Please see www.emrsdtc.com for further information.

Introduction

A key mission management issue in tasks involving autonomous systems is *human-machine trust*. Human operators can be required to supervise and collaborate with machines that often react to their environment in unexpected ways. To accept and trust autonomous systems, human operators need to be able to understand their reasoning process and the factors that precipitate certain actions. The machine needs to be able to communicate the reasoning behind its actions in an unambiguous manner that is also accessible to non-technical personnel – in other words, to *explain itself*.

While there has been some previous work on explainable artificial intelligence (AI), most of it has focused on static expert systems [1] or rule-based agent frameworks [2]. There has been relatively little work on explainable reasoning systems that operate in dynamic environments involving uncertainty.

The aim of the current project is to set a firm mathematical foundation for explainable decision-making systems and eventually produce an implementation of such a system, tailored to a particular scenario (e.g. urban search) – along with an interactive demonstrator allowing users to interact with autonomous systems that attempt to explain their actions.

At the time of writing, the project is approaching the end of its first six-month phase and has so far focused on exploring decision-making and explanation in the context of a simplified toy model.

Explanation philosophy

Theory of explanations and explainability is a subject usually studied by philosophers and psychologists rather than mathematicians or computer scientists. However, explainable decision-making requires us to capture some elements of an explanation formally – something that can be informed by a given philosophical approach to explanation [3]. It is therefore worth clarifying precisely what we mean by an explanation.

For the purposes of this project, we consider an explanation to be *a transfer of knowledge between agents which allows one agent to understand a belief held by, or an action performed by, the other* [4].

It is not necessary, and indeed not common, that agents in an explanation process have the same *knowledge base* (KB). With the same KB, an explanation can be seen as a trivial transfer of facts and observations. However, with different KBs an explanation process involves a transformation between the two bases. In the case of a human user interacting with an autonomous system it is the latter situation which arises.

It is also worth considering when a user would *require* an explanation from the autonomous system. According to Schank [5] there are four different needs that require an explanation: *external, respond, empathise* and *remedy failure*. Their respective types of explanation are: *explain away, canned, analogical* and *additive*.

- *Explain away:* an explanation given to a question whose domain is of little relevance to the explainer. This type of explanation aims to satisfy the question without care of whether the explanation is correct. An example of such explanations are those given on the street by the general public to roaming TV reporters asking arbitrary questions such as; "why do you think the credit crunch happened?"

- *Canned:* canned explanations are those which come from a standard library of explanations already used and deemed correct for certain questions. These are simply retrieved when required.
- *Analogical:* these explanations attempt to connect different domains by drawing similarities between parts of the domains.
- *Additive:* when an observation conflicts with a model of the world, then that observation requires explanation. These are additive in the sense that they add to the model, changing it in some way. This is the most powerful type of explanation and can be subdivided into:
  - predictive: explains a failed prediction
  - intent: explains the intent of another agent
  - pattern: explains past sequences of events.

The need for an explanation and corresponding explanation type are shown schematically in Figure 1. The need for an explanation can arise from any part of an environment or actions of individuals in those environments. In the context of our scenario (the simplified urban search model discussed below), it is worth discussing the explanations that deal with *intent* with more detail.

A generic model for an agent's intent consists of belief, goal, plan and action, defined as follows:

- Fundamental beliefs: The beliefs and facts that an agent possesses
- Goal(s): The goals that an agent may have. Possibly only one active at a given moment
- Plan: The 'high level' action that the agent will perform to achieve the current goal(s)
- Action: The atomic action performed at a given moment

Formal definition of an explanation

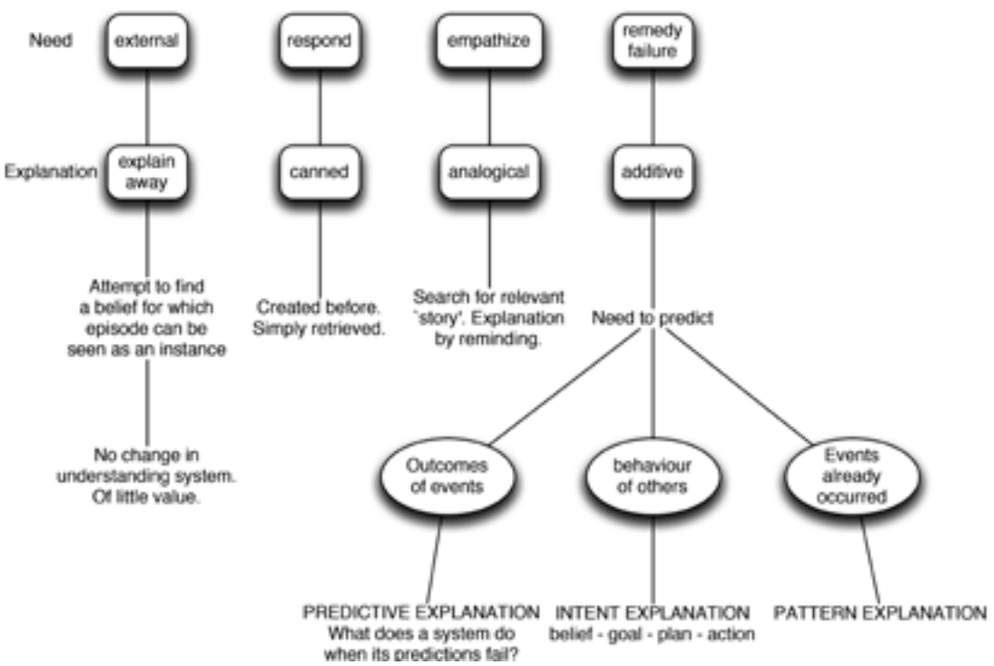
We define a generic decision-making system as follows:

Definition 1: A decision making system is a mapping

$$\delta : FB \longrightarrow A$$

where FB are the fundamental beliefs that an agent has about the world that he operates in and A is a finite set of actions available to the agent.

1



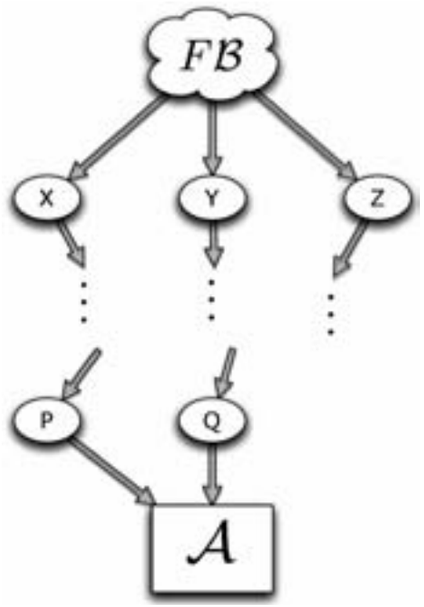
A graph showing how need for an explanation relates to the explanation type [5].

We assume that the agent makes this decision through numerical operations (e.g. through computing the optimal solution to a partially observable Markov Decision Process [6]) that is too complex to report back in detail. Hence an explanation system should *simplify and abstract* this process.

As the fundamental belief space FB is usually extremely large for realistic worlds, we will contract it into 'pots' (subsets of the belief space that in some sense capture the essential features of the world) as shown in Figure 2. Essentially, we can then *approximate* the decision-making system with a network consisting of various operations represented by arrows and factors and situations represented by symbols. The specific form of the operators, factors and situations depend on the model. The key idea is that the user can *understand the agent's action/plan by knowing the situation and the relevant factors*[1]. An explanation system can therefore report on the factors that led to the situation and the situation itself.

This is the process that we attempt to model formally in the following.

2



Contracting fundamental belief space FB into pots.

[1] To justify this informally, communicating the situation is often sufficient explanation for an action for a human being – escaping from a burning house does not require a detailed explanation of facts!

Definition 2: An explanation through situations for a decision making system δ is given by a tuple (com, F, class, S), where F is a set of factors,

$$\text{com} : FB \longrightarrow F$$

is a compression map, $S = \{S_1, \ldots, S_n\}$ is a set of situations and

$$\text{class} : F \longrightarrow S$$

is a classification.

The set of factors F will have significantly less free parameters than the set FB of fundamental beliefs. Moreover, the parameters in F are chosen in such a way that it is easy to represent an element $f \in F$ by linguistic descriptions.

This formalism also allows us to measure the quality of an explanation quantitatively, i.e. how well it allows us to reconstruct the reasoning behind the agent's behaviour.

Definition 3: The quality of an explanation is determined by how commutative the following diagram is.

$$\begin{array}{ccc} FB & \xrightarrow{\delta} & A \\ \text{com} \downarrow & & \uparrow \text{inv} \\ F & \xrightarrow{\text{class}} & S \end{array}$$

Here

$$\text{inv} : S \xrightarrow{l} FB \xrightarrow{\delta} A$$

is the inversion mapping that turns a situation first into a typical fundamental belief and then into an action. We have implemented a simple explanation system that is able to extract relevant factors and situations and to generate corresponding explanations for a given decision-making system and scenario, described in more detail below.

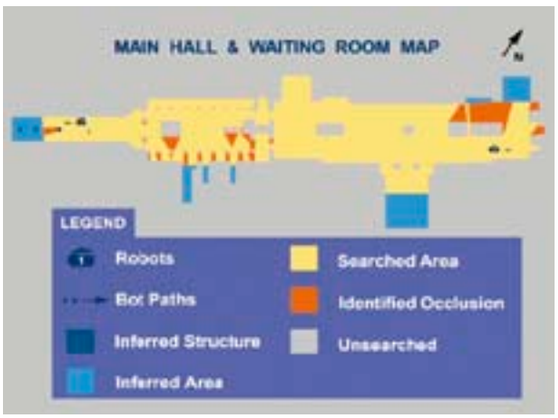
Example: an urban search scenario

A simplified urban search scenario

The scenario we have primarily focused on is a variant of the urban search scenario: an agent is given a map of a building and is asked to explore this building with the goal of locating a hostile who moves around the map. A typical map can be seen in Figure 3, which is a screenshot of the interior search vignette

animation provided to ThinkTank Maths (TTM) by the Systems Engineering for Autonomous Systems Defence Technology Centre (SEAS DTC) Office.

3



Interior search animation screenshot.

The basic ingredient to model this scenario is a graph whose nodes correspond to spatial position that the agent and the hostile can occupy. A link between two nodes indicates that the agent and the hostile can move from one node to another node in one turn. Moreover, the initial graph is a rectangular grid in which nodes (and corresponding edges) have been deleted (corresponding to obstacles).

In addition to the agent, the environment contains several other players. Each player can either be hostile or civilian: one of the agent's goals is to obtain evidence to determine which player is which (using observations and Bayesian inference). In case the player is hostile, the goal of the agent is to observe him and avoid being on the same node. In case the player is civilian, the goal is to protect the civilian and guide him out of the graph (to an exit node). Moreover, the agent runs on a battery that he has to recharge after a certain number of steps. In order to do this, he has to return to the exit node.

The actual decision-making system of the agent consists of a hybrid system involving a partially observable Markov decision process and a Markov game [7].

Situations

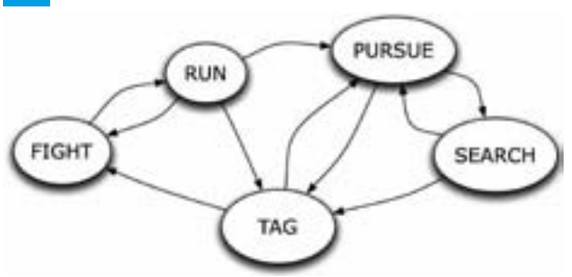
At any given point in time, the agent is in a situation with each player, depending on the player type. If the player is assumed to be hostile, we have the following situations:

- Search: The agent is uncertain about the position of the hostile and searches the area.
- Pursue: The agent is not certain about the position of the hostile but has a rough idea of where on the graph he might be. He pursues the nodes which have a high probability of being occupied by the hostile.
- Observe: The agent can observe the hostile from a distance.
- Fight: The agent knows that the hostile is close to him and has to deal with the threat.
- Run: The agent knows that he is close to the hostile, but has turned his back to him to escape from this dangerous situation.

If the player is assumed to be civilian the following situations are identified:

- Protect: The agent is close to the civilian and stays in his immediate vicinity.
- Search: The agent is uncertain about the position of the civilian and searches the area.
- Seek: The agent has some idea of where the civilian is and hence decides to walk towards her.
- Tag: The agent has spotted the civilian and will go straight towards her.

4



The situation network for the agent/hostile pair.

By recording the situation for each move, we can also learn the transition probabilities between the situations. For example, we learn that the most likely transition from *fight* is *run*. This can be shown in Figure 4 that shows the agent hostile situations as nodes with a directed link between them if the transition probability is above a certain threshold. This information can be used to generate explanations for the most likely transitions. For example, if the agent is in *search* mode for some time and then suddenly goes into *tag* mode, the warning 'I spotted the hostile' is printed. It indicates that the mode of operation has changed and that the agent may now be pursuing a new goal

with a new plan. This warning is created automatically, reporting back which relevant factors have changed.

The explanation system in the urban search scenario

The explanation system we have implemented for the toy scenario allows the user at each time step to:

- Find out which player (or players) the agent is dealing with.
- Get the situation(s) that the agent is in with the relevant player(s).
- See the plan that the agent would carry out given no further observations.
- See the goal that he is pursuing with his plan in conjunction with the specific rewards that he is currently getting.
- See a map that shows the belief over possible positions of the player he is dealing with.
- Read all or just the relevant factors that imply the current situation.
- See his confidence in his action.
- See what evidence he has to arrive at this probability about the player mode.

The system automatically reports which relevant factors have changed if the situation that the agent is in with a specific player has changed. Just by looking at this constant stream it is possible to understand what the agent is doing and why. A screenshot can be seen in Figure 5.

In Table 1 we have summarised the explanations that are generated for each situation and the corresponding plan the agent pursues in this situation.

A typical summary of relevant factors is given by:

- battery power okay
- player location is approximately known
- player is likely to be hostile
- player is close
- player is behind me.

for the situation *run*. If the situation changes from *run* to *pursue*, then the only relevant factor that has changed is: *player is in front of me*.

Conclusions

In the urban search scenario, explanation through situations seems to produce useful results. It is possible to understand what is happening just by watching the stream of updated relevant facts. When a more detailed explanation is required the various features of our explanation system provide useful information that allows the user to understand exactly what situation the agent is in, why this is the case and what the agent is going to do.

In future work, we intend to explore other scenarios and underlying decision-making systems to assess the robustness of our formal explanation framework. Provided this work is successful, the toy model and the explanation system will be extended to a more feature-rich interactive demonstrator illustrating the possibilities and utility of explainable decision-making in a more realistic environment.

Acknowledgements

The work reported in this paper was funded by the Systems Engineering for Autonomous Systems (SEAS) Defence Technology Centre established by the UK MOD.

References

1. G. Yap, A. Tan and H. Pang, *'Explaining inferences in Bayesian networks'*. Applied Intelligence.

2. Lane, van Lent, D. Gomboc, S. Solomon and M. Rosenberg, *'Building explainable artificial intelligence systems'*. Proceedings of the National Conference on Artificial..., Jan 2006.

3. W. Wallach, *'Moral Machines: Teaching Robots Right from Wrong'*. Oxford University Press, USA, 2008.

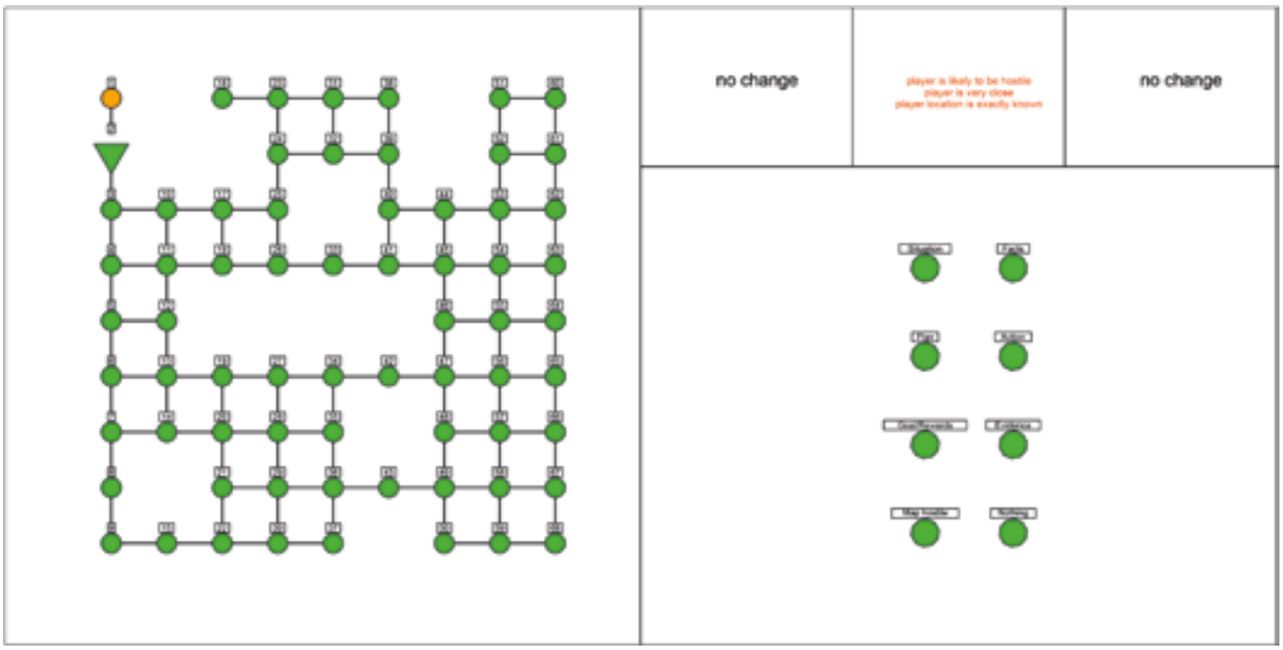
4. S. Bromberger, *'On what we know we don't know: Explanation, theory, linguistics, and how questions shape them'*. University of Chicago Press, Jan 1992.

5. Roger C. Schank, *'Explanation patterns: Understanding mechanically and creatively'*. Lawrence Erlbaum Associates, Inc., Jan 1986.

6. K. Murphy, *'A survey of POMDP solution techniques'*.

7. M. Littman, *'Markov games as a framework for multi-agent reinforcement learning'*. Proceedings of the Eleventh International Conference on..., Jan 1994.

5



A screenshot of the game. The graph and the agent (represented by a triangle) are shown on the left. The explanation interface is on the right. The boxes on top right show the agent's knowledge about various other players in the model. The buttons allow the user to drill down on various explanation elements.

Table 1

Situation	Plan
I am low on battery.	I am going to charge up my battery.
I am fighting with a hostile.	I am trying not to get stood on by the hostile while observing it.
I have located a civilian exactly.	I am going to the civilian.
I cannot determine whether the player is hostile.	I will get more information or go back to the base.
I have located a hostile exactly.	I will continue to observe the hostile.
A civilian is very close to me.	I will continue to stay close to the civilian.
I am pursuing a hostile.	I am going to an area where I am likely to observe him from.
I am in danger.	I am running clear of the danger to observe the hostile from a node which is further away from his position.
I am searching for a civilian.	I am going to a node where the civilian is likely to be.
I am searching for a hostile.	I am going to a node from which I can observe areas where the hostile is likely to be.
I am seeking a civilian.	I am going to an area where I am likely to find the civilian.

Situation descriptions and corresponding plans.

Autonomic Middleware and Resilient Information Systems

We describe work generated within a data and information fusion defence technology centre (DIF DTC) cluster project called 'Hyperion' [1]. The objective is to create an adaptive agent-based architecture capable of significantly enhancing the functionality and resilience of network-centric information fusion and Command and Control (C2) processes. The system supports the requirements of future Network Enabled Capability (NEC) operations, namely, intelligent and real-time reconfiguration of information and communication technology (ICT) services to meet bandwidth, hardware and human constraints.

This article focuses on the middleware component called 'Nexus', developed at BT, which provides resilient peer-to-peer messaging infrastructure and a knowledge support application 'Cyclone', which is used to categorise unstructured or semi-structured information from heterogeneous services, either hosted in the Nexus environment or from external sources.

By
Alex Healing, Hakan Duman and Robert Ghanea-Hercock
Centre for Information & Security Systems Research (CISSR), BT Innovate
Email: alex.healing@bt.com | hakan.duman@bt.com | robert.ghanea-hercock@bt.com

Introduction

The problem facing both the security and defence communities is the volume, complexity and timeliness of information. In particular the ability to locate and access the right information at the right time is crucial to achieving real-time responsiveness and situational awareness. The Nexus system is a Peer-to-Peer (P2P) agent-based middleware that creates a fully distributed and highly resilient Service Oriented Architecture (SOA). The combination of a structured P2P overlay network and autonomous service discovery delivers a powerful capability to support network-centric command and control; reducing the need for staff dedicated to data transfer and training costs for end users, as well as being able to offer a new degree of accuracy and timeliness for information provision.

This paper outlines the overall architecture of the Nexus system and its application in a defence situational awareness scenario. A detailed review of the publish/subscribe methodology which allows users to define and subscribe to topics of interest is presented with particular focus on the proactive nature of Nexus for information and service delivery. More specifically we explain how the system derives useful clusters of information on the network autonomously and learns from users' behaviour how best to categorise services. This work combines elements of human factors research for information visualisation with an underlying resilient information architecture, focused on making the infrastructure intelligent, such that the system acts as an effective broker between users and information on the network.

Methodology

The Nexus middleware is based on three key paradigms: Service-Oriented Architecture (SOA) [2], Peer-to-Peer Computing, and Autonomous Agents; all of which have been identified as key components of future NEC network architectures [3, 4, 5].

The SOA approach acts to connect distributed sources and users of information, dealing with the integration of legacy systems and reducing complexity by wrapping and abstracting resources as uniform services. Most implementations of SOA, however, are to a large extent pre-engineered and centralised in their infrastructural implementation. Core services for enabling

an SOA, such as discovery, are typically controlled by a single centralised entity, which not only results in a rigid solution but also a highly vulnerable one in domains where attack is likely.

In the design of Nexus, we have sought to decentralise the SOA enabling infrastructure, allowing service discovery, for example, to be performed without reliance on a central registry so as to remove any potential single point of failure. The research challenge when decentralising such a large-scale system is effective management in a distributed context. We employ Autonomic Computing [6] to help manage the complexity and design a system of collaborative software agents embedded within the Nexus middleware which perform service discovery and semantic selection tasks [7]. Using the peer-to-peer overlay as a substrate, these agents learn about the changing supply of information services on the network as well as users' requirements, and adapt to suit.

Architecture

The Nexus middleware is intended for deployment on any number of distributed platforms and, as it is implemented in the Sun Java programming language, it is not dependent on the operating system environment. An instance (peer) of the middleware is deployed on each machine in the network and, assuming there is physical connectivity, the peers automatically configure to form an overlay network. Figure 1 shows the layered architecture of a single Nexus peer.

Phase I of the Nexus project was focused primarily on the lower two levels in Figure 1. It was established at this early stage that the challenge to be tackled was how to make a completely decentralised model of discovery effective in the large-scale distributed and dynamic environment that NEC mandates. The aim has always been to create a resilient yet highly useful medium for a user of the system, in order to drive information fusion.

Phase II has seen the focus of research move to the top two levels where there are far more possibilities to give the system an understanding of semantics and thus engineer autonomic behaviour [6, 7]. A reliable, standards-based approach to offering a discovery and messaging substrate has been developed, based on the work conducted in Phase I, which is used by the higher-level autonomic components. An example is the use of a collaborative multi-agent system to collectively model which network services are best suited for particular users [7]. In this case, the agents form part of the Service layer of Nexus but rely on the Messaging layer to disseminate quality-of-service information between one another, and that in turn relies on peers having discovered each other in the first place. The autonomic components form the majority of the novel research undertaken and several patents have been filed in the areas of decentralised security, multi-agent systems, and the semantic web.

It should be noted that although the higher levels are dependent on the functionality of the lower levels, they are at the same time agnostic to how exactly the lower levels have been implemented. For example, in the current implementation of the Nexus middleware we adopt a fully decentralised approach at the discovery layer, but this could be replaced with a centralised approach without affecting the layers above. The rest of this section describes each of the four layers in more detail.

1

The Nexus Peer Architecture.

Discovery layer

The discovery layer's prime function is peer discovery, such that a platform on the network can determine the presence of other platforms. Each Nexus peer broadcasts its presence on a shared channel which allows peers to collate the endpoints to all other peers. This so-called *worldview* of the peers forms the basis of the peer-to-peer overlay network and is maintained such that new peers are discovered automatically and those leaving the network are removed from the worldview. The presence

information is minimal in size enabling the approach to scale well and, unlike many alternative peer-to-peer discovery techniques, allows for a complete view of the network.

Messaging layer

As the underlying peers may be highly dynamic in their availabilities, when designing Nexus, rather than focusing on direct messaging between peers, we allow abstraction to *topics* of message by implementing a publish-subscribe methodology. We use a decentralised implementation of the Java Message Service (JMS) specification to manage the message routing. Typically, message-oriented middleware and indeed most enterprise uses of JMS rely on a centralised message broker. In the version we employ, each peer in the overlay network has the ability to act as a broker. This ensures that there is no single point of routing failure, if there is a failure it is localised and potential bottlenecks are avoided.

Each message in Nexus is published on either one or many topics. The topics form a hierarchy where sub-topics of existing topics can be defined. When a user wishes to receive messages they subscribe to either one or more topics and will then asynchronously receive the messages published to the topics until they choose to unsubscribe. The challenge is how the topics should best be defined, such that they are tailored for the collective of users and the NEC requirements, i.e. allowing access to the right information 'at the right place, at the right time – and not too much'. It is this challenge which has been the focus of research and is elaborated on in the rest of the paper.

Service layer

The service layer builds upon the messaging layer by using it to disseminate information about the platforms in the network, the services that they host, the structure of information in the network, as well as the service content itself. This layer represents the core of the SOA approach and allows for all Nexus peers to be able to *host* services. Services in the context of Nexus are typically information sources where the default mode of interaction is *pull*, however, services with a more complex interaction could also be incorporated, for example computational services that offer some processing capability. Fundamentally, though, any service has some description which needs to be disseminated to all interested parties on the network, such that they can discover its presence and interrogate it for further information.

The foundation of the service layer is the format of the messages sent between Nexus peers. There are three different Nexus message types: Host Advertisements, Service Advertisements, and Topic Advertisements. These advertisement type messages are typically used for notifying subscribing peers of the presence and description of other Nexus Peer's logical hosts (e.g. where the platform running the Nexus peer is located), their hosted services (information sources being published from the platform) and the current map of topics (subscription channels which are currently being published to).

Achieving effective service discovery without a centralised registry of some form is a non-trivial problem. Much the same way as peer discovery is achieved at the bottom layer of Nexus, the logical descriptions of platforms and their services are kept track of by each peer having their own 'view' of the 'world'. This equates to each peer having their own registry which they populate from the advertisement messages that they receive. Keeping this view of the other entities in the network up-to-date requires a significant amount of traffic and thus the point of partitioning the message space into topics is reiterated. Such partitioning of the message space depends on knowledge about the information providers and the actual information content, such that similar relevant information sources can be clustered and published on specific shared topics.

When deciding on a suitable framework for the metadata of the services within Nexus, which is used to describe both the information provider and to some extent the information content, the following concerns were identified as being important:

- Expressive: there should be sufficient coverage of the functional attributes of the information provider and the information itself.
- Lightweight: due to the challenges imposed by adopting a purely decentralised environment and a potentially bandwidth-restricted NEC environment, the metadata must be as lightweight as possible, such that the resultant advertisement message sizes remain small.
- Extensible: due to the dynamic nature of a service's description and the frequency of update for different parts (e.g. the location of a mobile service altering more frequently than the service's overall capability), it is occasionally important to send updates for only those parts of the description that have changed.

- Human *and* Machine readable: the initial process of mark-up of a service need be human-friendly enough that it doesn't require a huge amount of effort. Complementing the notion of empowering the fringes of the network that the P2P approach introduces, it may be realistic to allow the service consumer the authority to alter the mark-up of services. Making sure that the metadata is machine-readable is clearly necessary for any autonomic system to then act upon it, e.g. fusing and orchestrating services on behalf of a user.

Given these constraints a description schema based on eXtensible Markup Language (XML) was developed. This is a relatively primitive technology compared to more recent attempts at metadata languages such as the Resource Description Framework (RDF), or Web Ontology Language (OWL) [7], however these more advanced formats introduce additional complexity due to their verbosity and machine-oriented focus. Such standards employed in typical Semantic Web [8] efforts, in particular ontological languages such as OWL, also mandate a high level of pre-engineering. Instead, by remaining simple, the format chosen for Nexus is lightweight whilst flexible and is capable of scaling to both the network complexity and time constraints of the intended deployment environment.

We have sought to define a description schema which, although based on XML, does not solely consist of structured and explicit terms – for example RDF statements consist of well-defined triples. The motivation being that the construction of well-defined and structured concepts is a costly process and difficult to adapt. Naturally, without having some elements of the metadata structured in advance makes processing upon the elements unrealistic; and indeed attributes such as location, for example, have been made explicit in our schema to achieve inference on certain aspects. The focus of our research, however, has been to investigate the degree to which an unstructured portion of the metadata may be useful with regard to both human and autonomic interaction with the description. Of particular interest is whether it is possible to effectively use both structured and unstructured metadata in conjunction, such that an explicit goal-based capability as well as flexibility is achieved from each of the approaches respectively.

Our approach is aligned with the trends on the Web over the past few years whereby the vision of the Semantic Web is not yet a reality and despite numerous standards being drafted, none have experienced widespread adoption. The growing trend of lightweight 'tagging' for marking up resources has instead become popular and forms the basis of searching and indexing within most large modern websites regarded as constituting what is now widely known as Web 2.0. Nexus thus allows service providers, or indeed service consumers, to manipulate the mark-up of the services by changing the set of tags describing them. The tags themselves act as a rough categorisation and the approach of collaborative tagging is often called *folksonomy* – a combination of folk and taxonomy.

A 'Categories' field in the Nexus service advertisement message is used as a more concrete notion of categorisation than tags and may only be manipulated by an authorised administrator of the information network, whereas the policy for changing tags may be laxer. Typically in information systems, the structure of the categories is pre-defined, usually by means of an ontology, however, Nexus assumes no such prior knowledge or agreement. Instead, it uses a mixed-initiative process to categorise services based on their informal sets of tags supplied by the collective of users.

We are not proposing that such a lightweight methodology is the answer to the problem of resource description in its entirety; however it may be short-sighted to assume that an approach of pre-engineering an ontology of resources, for example, is a complete solution for all cases [9]. Making such a description framework based on folksonomies scale to large, complex systems by 'distilling' them, from an informal set of tags to a concrete taxonomy, is a challenge that we have addressed with our research into the *Cyclone* application later in this article.

Presentation layer

The purpose of the presentation layer of Nexus is to interface with the user and as such be information-centric, abstracting away from much of the lower functionality. It is in this layer that the autonomic capability of Nexus is being primarily developed, however, the user is retained in the loop rather than letting the system-based automated reasoning function purely alone. Instead, we have designed a system that can accept feedback from users and learn; hence adapting so as to improve its automated behaviour.

The typical approach to fulfilling an information requirement of a user is to formalise both the goal and match that with a

formalised and elaborate service descriptor. For the reasons discussed in previous sections, Nexus has neither a very elaborate nor formalised service descriptor. Nevertheless, if the system is able to reason about how similar other services are to each other then it could, for example, offer similar information to that which a user is already browsing. Failed or degraded services can be substituted with relevant alternatives using the same logic.

Rather than assuming that similarities as a result of analysing the service metadata are absolute, we have developed a tool called *Cyclone*, which incorporates automated clustering algorithms. It involves the user and learns from their actions so as to autonomically categorise services. Once categorised, services are advertised in publish-subscribe topics matching the name of each of their categories, allowing users to subscribe to all sources of a particular category of information. The Cyclone system is described in detail in the following section.

'Cyclone' categorisation

The Cyclone application, developed alongside Nexus, is used to formally categorise the services that have metadata based on sets of unstructured tags. This allows information providers to supply merely a lightweight, tag-based description of their services, and an authorised system administrator, for example, to organise the information network, updating those informal service descriptions and form an emergent taxonomy. This is particularly important when the service descriptions are highly dynamic and thus mandate a fluid taxonomy, as well as those which have been derived automatically by a keyword extraction algorithm.

The on-the-fly nature of categorisation by the Cyclone system makes it possible to incorporate and structure information created internal to operations, e.g. intelligence created in theatre in a military scenario; as well as external information, e.g. from open sources on the Web. For both cases only a limited amount of metadata is necessary, but rather than relying on this metadata alone to advertise and discover the information, Cyclone allows this to be refined into more formal and usable categories. Figure 2 illustrates this at a conceptual level; where a 'tag-cloud' on the left-hand side, the most common visualisation of tagged information systems on the Web, which can be useful for some systems to gain an overview but typically does not scale sufficiently, is contrasted with a formal tree of categories where each one contains a set of the information sources available and relationships between the categories can be defined.

A screenshot of the Cyclone application is shown in Figure 3 and demonstrates the juxtaposition of information services from the Nexus middleware system, as well as incorporating feeds from the Internet. Information sources are displayed in the centre panel and visual clustering illustrates how similar they are derived to be. Before any user interaction, this similarity analysis is based solely on the metadata supplied, but as a user creates categories and assigns the data to them, the system adapts its clustering to reflect the changes.

We have sought to automate the process of categorisation based on service metadata by employing well-known unsupervised clustering techniques but in order to keep the user in the loop as much as possible, an important requirement for our system at design-time was that the output from this clustering be presented at all times to the user. This is achieved by translating the similarity values, derived from cosine similarity analysis, into forces between each of the data nodes and representing them as a force-directed graph. The resultant graph with edges removed is what makes up the majority of the centre panel of the application.

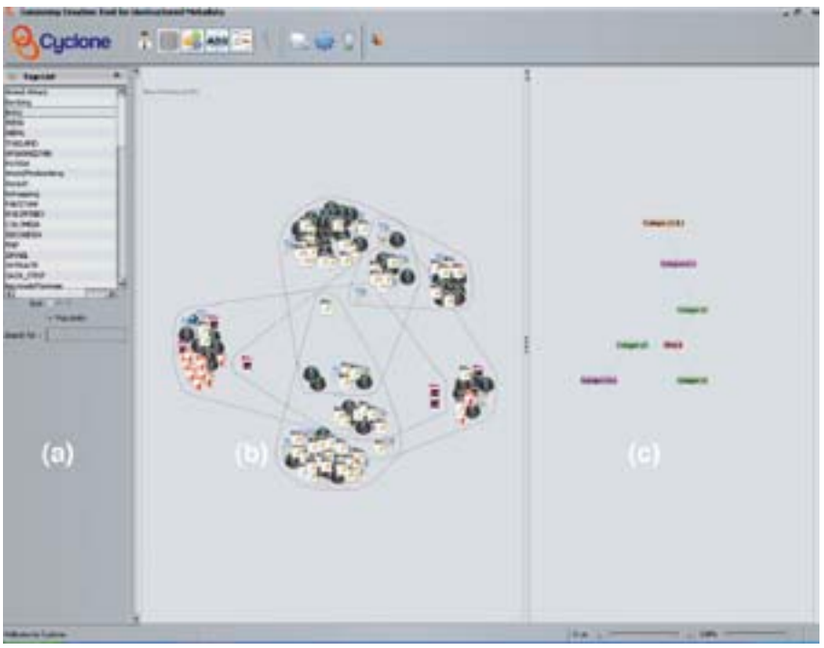
In order to enhance the user-centric nature of the system, the unsupervised clustering algorithm is augmented with supervised learning based on a neural network, which adapts the forces to improve the clustering accuracy as users interact with the system. The result is that over time the system adapts such that its automated behaviour is increasingly accurate at categorising data, becoming personalised for a particular user or group of users. Given this knowledge, Cyclone can then autonomously assign new information to categories.

The Cyclone system was demonstrated at the Coalition Warrior Interoperability Demonstrator (CWID) UK 2008 where information feeds from other demonstrator partners were aggregated and categorised. For further technical information on the Cyclone system we refer the reader to the following papers: [10, 11].

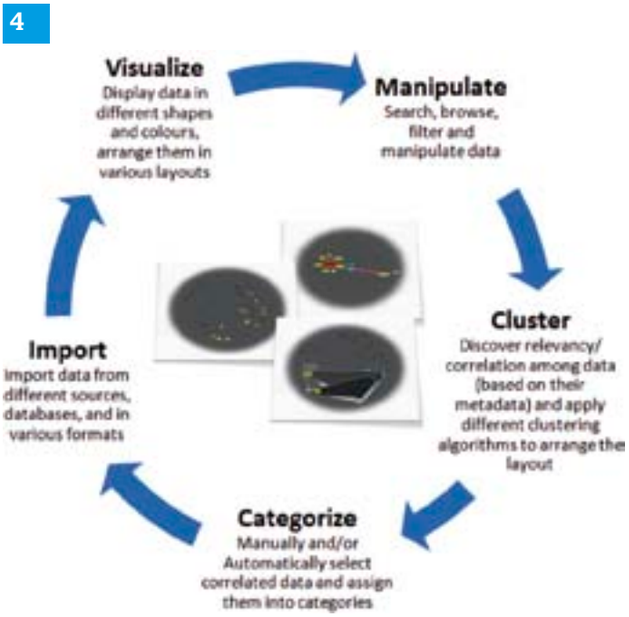
2

The overall concept of Cyclone is to allow for an improvement to the descriptive vocabulary of folksonomies in Web 2.0 systems and improve upon the commonly used Tag Cloud interaction (left-hand side) by creating a more formal Taxonomy (right-hand side).

3



Cyclone Graphical User Interface: (a) List of tags for all services discovered by Nexus, (b) Clustering Panel showing similarity between services as fuzzy clusters (grouped icons), (c) Taxonomy Panel showing the hierarchical structure of categories which may be either predefined or constructed by users as a result of the interaction with the Clustering Panel.



The iterative process of interaction with the Cyclone system.

Conclusion

The aim of Nexus and Cyclone is to make the supporting technology 'invisible' to the end user. The value is to reduce the cognitive workload of the user and to make dynamic service provision as seamless as possible, without detracting from the users' local knowledge or forcing constrained solutions on them. The philosophy is 'just enough AI' to help bridge disparate systems and services together, but not so much that the solution becomes part of the problem; as is so often the case in large-scale ICT systems.

The resulting value to the NEC process is reduced manpower to support ICT systems, and reduced training requirements to operate large-scale C2 NEC systems. The value to the field commander is a true 'plug-and-go' ICT capability.

References

1. R. Ghanea-Hercock, E. Gelenbe, N. R. Jennings, O. Smith, D. N. Allsopp, A. Healing, H. Duman, S. Sparks, N. C. Karunatillake, and P. Vytelingum, *'Hyperion Next-Generation Battlespace Information Services'*, The Computer Journal, 2007.

2. M. N. Huhns and M. P. Singh, *'Service-Oriented Computing: Key Concepts and Principles'*, IEEE Internet Computing, vol. 9, no. 1, pp.75–81, 2005.

3. A. Alston, *'Network Enabled Capability – The Concept'*, Journal of Defence Science 8(3), 108–116, 2003.

4. S. Manoski, *'Eliminating the Middleman, Peer to Peer technology for Command and Control'*, http://www.mitre.org/news/the_edge/summer_02/manoski.html

5. R. Prouty, K. Kalbus, and L. Lee, *'Peer-to-Peer Discovery: A key to enabling robust interoperable C2 architectures, C4ISR/C2 Architectures'*, The Tenth International Command and Control Research and Technology Symposium Virginia, 2005.

6. J. O. Kephart and D. M. Chess, *'The Vision of Autonomic Computing'*, IEEE Computer, 36(1):41–50, 2003.

7. S. A. McIlraith, T. C. Son, and H. Zeng, *'Semantic Web Services'*, Intelligent Systems, Special Issue on the Semantic Web. 16(2):46–53, March/April, 2001.

8. T. Berners-Lee, J. Hendler, and O. Lassila, *'The Semantic Web'*, Scientific American, May 2001, pp.28–37.

9. C. Shirky, *'Ontology is Overrated: Categories, Links and Tags'*, 2005, http://www.shirky.com/writings/ontology_overrated.html

10. H. Duman, A. Healing, and R. Ghanea-Hercock, *'An Intelligent Agent Approach for Visual Information Structure Generation'*, 2009 IEEE Symposium on Intelligent Agents, April, 2009.

11. H. Duman, A. Healing, and R. Ghanea-Hercock, *'Adaptive Visual Clustering for Mixed-Initiative Information Structuring'*, to appear HCI International 2009 Conference, July, 2009.

Advances in Inter-Vehicle Communications Systems and Potential Military Applications

By
Richard Gunstone
Information Management Department, Dstl, Porton Down, Salisbury, Wilts, SP4 0JQ.
Email: regunstone@dstl.gov.uk

Introduction

This article gives an overview of Vehicular Ad Hoc Networks (VANETs), starting with a brief discussion of the larger Mobile Ad Hoc Network (MANET) concept followed by a description of VANETs and their characteristics. Its purpose is to provide an insight into potential military applications of VANET technology.

MANETs and VANETs provide an exciting prospect for ad hoc military communications in areas with little or no usable infrastructure. For instance, in peacekeeping or responses to humanitarian disasters such as a major flood, their Commercial-Off-The-Shelf (COTS) technologies make them an attractive tool for first responders, be they military or civilian.

Background

The traditional distributed system was first introduced approximately 20 years ago using fixed infrastructure [1]. Since then nomadic distributed systems have gone on to combine wireless edges with a fixed core infrastructure, where the load is primarily carried on the fixed infrastructure [1]. In this regime, the periphery of the communications system is composed of wireless devices potentially using a combination of Bluetooth, 802.11/WiFi, and similar technologies; these in turn connect to a fixed central infrastructure, composed predominantly of dedicated physical wire links of various types, potentially with a small proportion of point-to-point wireless technologies (e.g. microwave).

Ad hoc networks such as VANETs, on the other hand, consist of mobile hosts connecting through variable quality links in a dynamic way, with no fixed infrastructure. They require ad hoc routing protocols and present challenging scalability issues [1]. The requirement for effective, scalable routing in such networks is a key research problem and is intertwined with the underlying message delivery requirements.

MANETs

Before introducing the VANET in detail, it is worthwhile examining the more generic form in many respects, which is the MANET.

The MANET is a dynamic communications network in which nodes are self-configurable and asynchronously interact without using fixed infrastructures or centralized administration [2]. MANET nodes are normally wireless devices, possibly incorporating simple or relatively powerful computational processing. MANETs can be formed using many existing communications technologies, and they have recently become popular network architectures for analysing social interactions using Bluetooth and mobile phones. In addition to mobile phones, many other types of devices can be used as nodes in a MANET, for instance PC laptops. MANETs can adapt rapidly to changes in their environment and are therefore a key interest for military applications, as they offer a means to build communications topologies that can adapt to changing mission requirements. MANETs form a focus area for the UK/US basic research International Technology Alliance (ITA) in Network and Information Sciences [3].

VANETs

The VANET can be regarded as one of the most significant applications of MANETs [4]. A VANET is a specialisation of a MANET, in which nodes are realized as vehicles and roadside infrastructure, albeit with VANET-specific characteristics. Inter-vehicle communication, such as that provided by VANETs, is regarded as a primary application of MANETs [5]. A VANET node could be a troop transport vehicle with built-in processing and dashboard mounted information displays[1].

[1] Body Area Networks (BANs; not considered further) might be present on personnel forming their own ad hoc MANET, using the VANET as a back-haul communications network.

1

A graphical depiction of a VANET. The unloading vehicle blocks a route and the surrounding vehicles can adopt alternate routes to avoid disruption. Image © Car 2 Car Communications Consortium (used with permission).

Figure 1 gives a graphical representation of a VANET: the unloading vehicle signals to nearby vehicles (in yellow) that a route is obstructed (in red), allowing vehicles to change their navigation to unrestricted routes (in green). This example shows one of the best aspects of VANETs, in that communications can quickly be distributed to nearby nodes without human intervention, allowing seamless changes to navigation for instance.

VANETs do not suffer resource limitations inherent in MANETs, such as data storage, processing or electrical power, due to the underlying platforms used, which provide stable and plentiful power supplies and do not stipulate man-portability as a requirement [2]. VANETs are also ideal for receiving geographical positioning information, e.g. from the Global Positioning System (GPS), which can also provide a network-wide, common, time synchronization source [2][2]. As a consequence, VANETs are much more powerful in what they can achieve, but are specific to the vehicles they are mounted upon.

Governmental VANET support

Understandably, VANETs have significant industrial and governmental support, as their potential safety and congestion-management applications in the consumer automotive world are profound. It is widely thought that future civilian vehicles will be able to communicate autonomously amongst themselves, exchanging data on upcoming traffic accidents, congestion, and other transport-related phenomena, and advising or even acting automatically in response. These aspirations have been translated into significant momentum: in the US for instance, a 75MHz part of the Dedicated Short Range Communication (DSRC) [6, 7] spectrum at 5.9GHz was quickly allocated for Vehicle-to-Vehicle (V2V) communications in VANETs by the United States Federal Communications Commission (FCC) [7]. Similar initiatives are currently being examined in Europe and the UK.

Both MANETs and VANETs present challenging research problems and the technologies they borrow from other communications architectures do not necessarily translate across in a straightforward way. Significant amounts of research have been carried out on the fundamental problems in VANETs, particularly the Physical Layer (PHY) and Medium Access Control (MAC) layer of the communications model. MANETs make heavy use of shared transmission channels, which means they must ensure they do not interfere with transmissions from other users of the spectrum. The protocols required for this, MAC protocols, are currently an area of active research, particularly ones that ensure efficiency and throughput [2]. As VANETs operate in a spatial context (i.e. topographically), the routing of data becomes more complicated, and again this is an active research area. Innovations are possible in the way topographic information is used in the routing policies; however this is very much dependent on effective mobility modelling[3].

VANET properties

Broadly, nodes in a VANET (known as On Board Units or OBUs [8]) exhibit the properties of MANET nodes. However, specific VANET characteristics include high node mobility and fast topological transformations, mainly due to high velocities [2, 5]. They can also exhibit limited temporal and functional network redundancy, in addition to frequent fragmentation or partitioning of the network topology [4, 9]. For example, vehicles may change formation as part of a convoy; some vehicles may break away from the convoy, and others may join the convoy during a journey. To complicate matters even further, and in the process introduce a recursive aspect, the VANET itself can modify its own topology, for instance through the way drivers respond to messages sent out by the VANET.

[2] For a video of a VANET in action see http://www.car-2-car.org/index.php?id=124.

[3] Mobility modelling is concerned with the effective simulation or characterisation of the spatial movement of VANET nodes, and is essential if, for example, simulations of VANETs are to have any accuracy.

A VANET also involves occasional communication to roadside fixed infrastructure (known as Roadside Units or RSUs [8]). In civilian applications, roadside communication may be to a roadside network carrying accident or traffic black spot alerts. In military applications, this might be to receive Command and Control (C2) instructions, to send update maintenance and health-status data from vehicle management systems (such as remaining fuel level), or to download mapping data [8].

The main differentiators between VANETs and MANETs are [7]:

- a particular mobility model – when a vehicle is travelling on a highway its mobility pattern must conform to the topology of the road. In contrast, MANET topologies may exhibit much less conformism.
- high speed – the moving speed of the vehicle may be up to 60mph or 130km/h. The relative speeds of vehicles may be higher than this, especially when moving in opposite directions (termed here 'incidence') or in an overtaking manoeuvre. In contrast, MANETs, for instance pedestrian implementations, may exhibit much lower velocities and are less prone to severe forms of incidence.

In the main, civilian applications of VANETs are focused on active safety, that is, the set of hardware and software tools needed to prevent accidents through anticipatory or preventative actions, such as Car-to-Car (C2C) warning systems at junctions [2]. Some aspects of VANETs are very demanding, for instance the time available for communication between OBUs and RSUs, the latter of which may be accessed by multiple OBUs, can be as small as 18 seconds at a speed of 120km/h [8]. Communications between OBUs are likely to be even more demanding if vehicles are travelling in opposing directions and at high speed. However despite these limitations, useful amounts information can be exchanged within the limits available.

Medium Access Control (MAC) is used throughout communications systems to govern what can access a shared communications medium at any given time. In Ethernet computer networks, this is typically a copper wire, and in wireless systems, the medium is part of the radio spectrum. MAC protocol development is a recognized priority in VANET theory, where improvements must capitalise on the benefits provided by VANETs such as the greater availability of power and time synchronization while minimizing the deleterious effects of fast topology changes and medium access delay (which is critical for safety applications) [2]. As a result, the MAC protocols developed in these applications become very different to those used in other communications systems, for instance fixed-wire Ethernet.

The ubiquitous Institute of Electrical and Electronics Engineers (IEEE®) 802.11 standard is widely employed in the design of VANETs, and its MAC protocol designs are therefore of critical importance to the efficacy of VANET technology [2]. Standardisation activities have been undertaken in recent years. For instance, the IEEE is currently working on an 802.11 extension known as Wireless Access in Vehicular Environments (WAVE) – also known as 802.11p. This is being driven by developments in the active safety for transportation arena, with ambitious targets such as a 500ms VANET broadcast of an accident from one vehicle to surrounding vehicles within a 500m range [2]. Indications are that 802.11p will offer substantial advances in vehicular connectivity, with speeds up to $54Mbs^{-1}$ on some parts of the spectrum [2][4].

VANETs provide a useful cross-cutting, thematic inspiration for military research and indeed, they have formed a focus for the Dstl contribution to the UK/US Network and Information Sciences ITA in Technical Areas 1 (Network Theory) and 2 (Security across a System of Systems). They are interesting prospects for ad hoc communications in areas with little or no usable infrastructure, such as in peacekeeping missions or responses to humanitarian disasters. Their COTS technologies make them highly desirable for military applications. In particular, they offer the ability to reuse existing, tried and tested technologies from the civil sector at lower cost, providing greater reliability and portability than a bespoke solution while at the same time using the latest electronics manufacturing processes. Optionally they also use parts of the civilian spectrum, which may be an appropriate option in times of congested military spectrum or when interacting with Non-Governmental Organisations (NGOs).

However, as with other COTS ICT, security and vulnerability remain issues that can limit applications. Securing reliable communications, particularly in the portion of the civilian

[4] The development of vehicular technologies is currently a high priority, driven in part by the demand for connectivity at the vehicle level, for instance the provision of broadband access inside cars. It is unclear however what technology will be used, or whether a combination of technologies may emerge, for instance EDGE or 3G for Internet-centric communications and a less elaborate but higher-performance technology for inter-vehicle VANETs.

spectrum normally assigned to civilian ad hoc networks, may be difficult in urban areas where the spectrum could be highly congested. In addition, the ad hoc nature of VANETs precludes any detailed spectrum-management planning, potentially exacerbating the problem and raising the potential for communication outages due to interference. Tracking of VANET vehicles is also a potential risk based on their broadcast communications.

Wireless security vulnerabilities are well known in consumer markets. Security in such systems, particularly those based on 802.11, has only recently begun to reach maturity, with corresponding impact on any military adoption of such technologies. Ad hoc networks in particular also require innovative secure routing schemes; for instance ones that do not allow an intermediate node to decode the full message for a destination other than itself.

How a VANET can operate in the absence of a Public Key Infrastructure (PKI) Certificate Authority (CA), to which it can ascribe trust to validate cryptographic keys, will become a difficult problem to remediate. One potential avenue is to make cryptographic keys expire automatically; however this must be balanced against constraining connectivity unnecessarily. Further, in the event a cipher key is compromised, the requirement to change keys within the communications channel becomes imperative; however if parts of the VANET are fragmented, the adoption of new cryptographic keys becomes an awkward co-ordination problem.

Complicating matters, a strong cipher in continuous operation may not be realistic all of the time; in some operational circumstances it may be desirable to remove barriers to interoperability, particularly if information must be exchanged with NGOs or coalition forces, creating further security considerations.

Applications

For the military, VANETs offer a means of rapidly establishing an ad hoc communications infrastructure for relatively little effort[5], such as in peacekeeping or search and rescue following natural disasters. They may also provide another communications route from the field to the analyst or decision-maker for information that does not attract both time-criticality and delivery guarantees. When VANETs are used as a communications infrastructure, information can hop between nodes in the network, from OBU to RBU and vice versa, as it attempts to find a path back to the destination or a suitable communications back-haul (for example SKYNET).

The civil application of VANETs to broadcasting accident events may also find ready military applications. For example in signalling where an improvised explosive device has been detected, a VANET may be able to respond much faster than human perception and verbal radio messages. Such approaches might be used to convey important information to a military convoy or may find uses by being integrated with automated protection measures.

Conclusions

We have discussed the relevance of MANETs and VANETs for ad hoc communications in areas with little or no usable infrastructure. They find potential applications in peacekeeping or responses to humanitarian disasters. We have also highlighted their COTS technologies, which makes them an attractive tool for first-responders, be they military or civilian. We have given an overview of MANETs and VANETs, the governmental support for VANETs, and the distinguishing characteristics of VANETs. We have also touched upon developments for 802.11p.

Much work has still to be done in the area of VANETs; research currently underway is promising and will provide the foundation for the widespread adoption of VANETs in both civilian and military applications.

[5] Compared to the design, procurement and implementation of a bespoke military VANET architecture, designed from first-principles.

References

1. G. Chen and D. Kotz, *'A Survey of context-aware mobile computing research'*, Technical Report, Dept. of Computer Science, Dartmouth College, 2000.

2. H. Menouar and F. Filali, '*A survey and qualitative analysis of MAC protocols for vehicular ad hoc networks'*, IEEE Wireless Communications, October 2006.

3. R. E. Gunstone, *'Vehicular Ad hoc Networks'*, Distillation, Issue 13, June 2009.

4. Z. Wang and C. Chigan, *'Countermeasure Uncooperative Behaviors with Dynamic Trust-Token in VANETs'*, in the proceedings of ICC 2007.

5. T. Leinmuller, E. Schoch, and F. Kargl, *'Position verification approaches for vehicular ad hoc networks'*, IEEE Wireless Communications, October 2006.

6. J. Zu and S. Roy, *'MAC for Dedicated Short Range Communications in Intelligent Transport System'*, IEEE Communication Magazine, December 2003.

7. C-C. Hung, H. Chan and E. H-K. Wu, *'Mobility Pattern Aware Routing for Heterogeneous Vehicular Networks'*, in the proceedings of WCNC 2008.

8. Y. Zang, L. Stibor, B. Walke, H-J. Reumerman and A. Barroso, *'Towards Broadband Vehicular Ad Hoc Networks – The Vehicular Mesh Network (VMESH) MAC Protocol'*, in the Proceedings of IEEE WCNC 2007.

9. J. Blum, A. Eskandarian and L. Hoffman, *'Challenges of Intervehicle Ad Hoc Networks'*, IEEE Transportation Systems, vol. 5, pp.347–351, Dec. 2004.

Developing a System Using the MOD Architecture Framework – a Case Study

Systems Engineering can be regarded as the process of defining a system's boundaries and performance requirements, of partitioning the system into appropriate sub-systems for ease of implementation and of integrating them after manufacture into a working entity that fully meets the specified performance.

"Developers of government systems face the same challenges as product developers in the commercial world – increased capability at reduced costs in rapidly decreasing time periods."[1]

This article presents a Model-Based Systems Engineering (MBSE) case study where the MOD Architecture Framework (MODAF) has been successfully applied to baseline a new equipment to support UK ground forces. Within four months the work provided an Invitation to Tender (ITT) to allow early teaming with industry.

By
Gary Davis and Keith Washington
Security Sciences Department, Dstl, Fort Halstead, Sevenoaks, Kent , TN14 7BP.
Email: gsdavis@dstl.gov.uk | kwashington@dstl.gov.uk

Background

In recent times the demands placed on the suppliers to UK's Land Forces have increased substantially. UK's Land Forces' requirements have evolved significantly since moving from historic theatres of operation in Europe and homeland UK. Traditionally, military equipment has been developed as a standalone capability with limited compatibility and integration with other deployed equipments. Predominantly mission driven, equipments today have largely evolved as fragmented solutions to specific needs, with diverse logistic requirements in today's environment [2]. Many equipments are now considered essential "green army" components, so a new approach is required to provide a capability for wider operational use that (as a minimum):

- supports theatres world-wide
- minimises user overheads
- is modular, scalable and readily upgraded
- accommodates technology insertion and integration of Commercial-Off-The-Shelf (COTS) elements
- is interoperable with other UK and Allies' equipments
- fulfils the needs of each Defence Line of Development (DLOD).

Introduction

The development of complex systems requires the rigorous application of systems-engineering techniques in order to fully define and then implement a workable solution that fulfils the users' requirement and which can be delivered on time and to budget. These techniques help manage this complexity and allow a holistic approach to be taken from the initial concept through to its implementation and, eventually, its disposal.

One such technique is enterprise modelling. Enterprise modelling captures the many aspects, or views, that can be taken of an organisation, its people, its processes and the systems and data that support that organisation, and establishes a basis from which to apply Model-Based Systems Engineering (MBSE) in the synthesis of the product. For the UK defence domain it is the MOD Architecture Framework (MODAF) that defines the framework within which the MOD can state its enterprise-level requirements and organise its people, processes and systems to meet those requirements. It also facilitates the planning of future procurements so that capability levels can be maintained or enhanced by presenting the information required to make planning decisions in a simple, easily understood format.

This article presents a MBSE case study where MODAF has been successfully applied to baseline a new generation of protection equipment for ground forces. The work has been carried out at Dstl Fort Halstead by the Systems and Integration Team during 2007/08.

The programme

Initially championed by the Department's Chief Technologist, the Security Sciences Department at Dstl Fort Halstead commenced the Concepts and Architectures study [3] to address the question "Given a fresh start, what capability should we be aiming to provide in five to ten years time to enable UK Land Forces to carry out military tasks safely?"

The Systems Engineering study applied an adaptation of the 6σ (Six Sigma) interpretation of the Taguchi Viewpoint analysis to identify:

- bounding functional requirements
- non-bounding constraints [2].

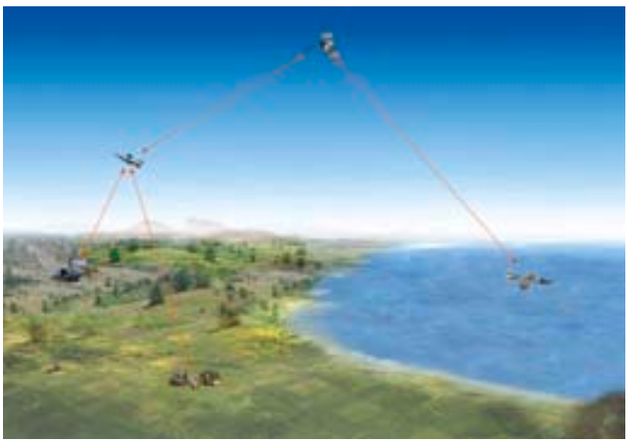
6σ is a management strategy that seeks to identify and remove the causes of errors in business processes [4]. Taguchi Viewpoint analysis allows the collation of a set of requirements from every aspect of the system, providing a requirements baseline to which all future developments can be traced. It became apparent that the presentation of these aspects of the system would significantly benefit from the use of a coherent, cohesive, holistic model. The evolution of the resultant architecture model was subsequently championed by the (then) newly formed MOD Counter Terrorism Science and Technology Centre (CTS&TC).

Model Based Systems Engineering (MBSE)

MBSE is a recent initiative, sponsored by the International Council on Systems Engineering (INCOSE) [1] as an enabler for capability-based architecting for today's System-of-Systems and Family-of-Systems acquisitions [5].

In the United States (US), MBSE is applied during project development using the Department of Defense Architecture Framework (DODAF) whilst in the UK it is MODAF that is used with an aim to deliver needed insight into the requirements and analysis phase of a military project.

1

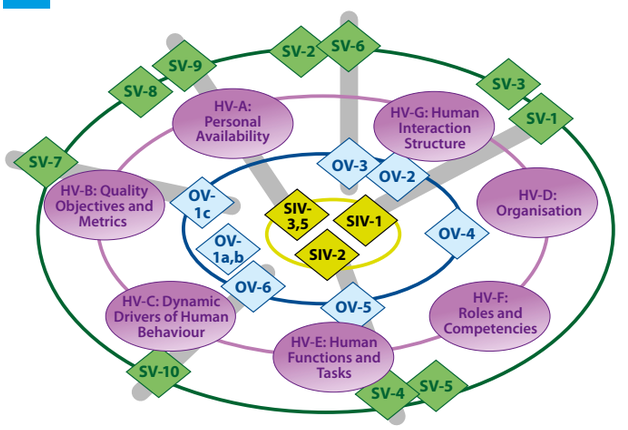


An example MODAF Operational View (OV-1a).

2

MODAF version 1.1.

3



Human Factors (HF) views.

The MOD Architecture Framework (MODAF) model

MODAF provides semantic rigour for defining an architecture via meta-model "Views" that allow the expression of:

- the 'why' – the strategy
- what the solution is required to do – the operational need
- how it is going to be constructed – the technical system aspects
- when is it to be done – the programmatics.

The views provided by MODAF are:

- Strategic Views (StV) – to assist with capability planning
- Operational Views (OV) (Figure 1) – to describe the conduct of operations and present user requirements
- System Views (SV) – to present the system requirement or solution
- Technical Views (TV) – to present applicable standards used, or to be used in the architecture
- Acquisition Views (AcV) – programmatic details of the architectural elements
- All Views (AV) – Overview and summary information.

The new architecture requirement was modelled in version 1.1 of MODAF (Figure 2), but with the introduction of version 1.2, MODAF now has Service Views to facilitate the development of service-oriented architectures.

Another advance since the development of this new architecture is the release of the Views for Human Factors. Although not currently part of the core set of MODAF Views these incorporate Human Factors analysis into the overall architecture to ensure that it is considered at an early stage. Via liaison with the Dstl Human Factors experts, these views are to be incorporated into the new Land Forces' equipment description in later revisions of the architecture (Figure 3).

The Strategic Views for the new capability were presented using terms from existing doctrine so as to be familiar to both the military and industry. However, without an endorsed set of capabilities – the capability taxonomy – there is a risk that each architecture that incorporates Strategic Views will use a different source reference or make up its own, creating confusion and causing an additional overhead where architectures are linked together or merged. It is possible that the terms used for the new system Strategic Views may also not be accepted as recognised capabilities for this reason.

The Operational Views showed that taking an abstract, high-level view successfully stripped away the unnecessary complexity that can clutter the presentation of the core requirement. The maintenance and support requirements were also modelled in the Operational Views, an aspect that is often overlooked.

As the programme was still in the concept stage, the System and Technical Views were used to represent the user requirement and example configurations that may satisfy the operational requirement shown in the Operational Views. They depicted potential deployments and showed which existing systems could be used as a system-of-systems to provide the required information management and communications.

The Acquisition Views are easily understood Gantt-style diagrams that give an immediate indication of programme interactions and potential scheduling problems. For the new system, the platforms that were going out of service were quickly identified so that their replacement could be identified and informed of the new requirement. It also highlighted that some platforms would be scheduled for the fitting of legacy equipment at a time when the later system should be considered as the correct fit.

The complete set of MODAF views [6] selected for the new capability comprises:

- All Views AV-1 & AV-2
- Strategic Views StV-1, 4 & 6
- Operational Views OV-1a, 1b, 2,3, 4, 5, 6a, 6b
- System Views SV-1, 3 , 4[7], 5, 6, 7 , 9, 10a, 10b
- Technical View TV-1
- Acquisition View AcV-2.

Results

This project has demonstrated that the MBSE approach using MODAF:

- enhances communications across multiple teams
- provides a basis to manage critical risks and resolve issues (including those associated with emergent behaviour,

budget and resources) as they arise. As each user need is traceable to a stakeholder, any future issues can be resolved by consultation with the owners of the relevant requirements
- enables effective management of the interfaces (including strategic reallocation of capability). Early consideration of the Human Factors aspects of the system ensures that required involvement of any user does not compromise the system's effectiveness in service
- ensures consistency from the initial phases of system definition whilst supporting change impact analysis and technology insertion.

For the Land Forces' equipment programme in Dstl's Security Sciences Department, MODAF has thus established a basis for the expression of the user requirement and system documentation in a way that facilitates their capture in more traditional textual tools such as DOORS™ (Dynamic Object Orientated Requirements System – a proprietary requirements management tool) [8].

Advantages gained

Distinct advantages have been gained from the MBSE approach using MODAF:

1. A cohesive and holistic representation of the needs of all stakeholders is provided, that allows the architecture to be presented from many aspects.

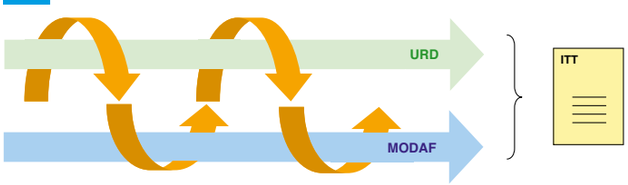
2. It is a truly top-down set of views allowing a clear definition of the key customer needs to be identified quite readily. The analysis is devoid of any preconceptions of what a solution might be, so unnecessary implementation constraints on the system's key requirements are avoided.

3. The system concept was defined very efficiently in a short time (the modelling commenced in April 2008 and resulted in an ITT for Industrial involvement in June 2008) because:
   - having evolved from a stakeholder analysis, as the implementation progresses every requirement is traceable back to its source
   - the process benefited from the clarity of thought derived from 1 above
   - it was possible to evolve the model, the Concept of Operations and User Requirement Document (URD) concurrently (Figure 4) so that they remained consistent with the:
     - functional requirements
     - non-functional requirements (system constraints)
     - compliance with all appropriate standards.

4. This approach provides a common (graphical) engineering language that was shown to be understood by:
   - sponsors
   - users
   - industrial partners
   - supporters
   - reviewers.

5. The MBSE Views of the model are not isolated representations (as alternative design/requirement diagrams would be) – the tool in which the model resides provides for direct, bi-directional translation into:
   - requirements documentation systems such as DOORS™
   - tools providing mass analysis
   - tools providing thermal analysis
   - tools for representing behavioural or functional characteristics
   - logistic analysis packages
   - statistically based manufacturing packages such as the six sigma Minitab™.

4



Process illustration. URD – User Requirement Document, ITT – Invitation to Tender.

Future work

The scheduled in-service date for the new equipment is 2014, at which time a functional capability is planned for brigade operation. In preparation, the project is already following the CADMID/T (Concept / Architecture / Design / Manufacture / In-Service / Decommission / Terminate) project life-cycle specified in the MOD Acquisition Operational Framework (AOF) [9].

With increasing support from industrial partners:

1. The MODAF model will be developed to support the required Initial Gate and Main Gate acquisition milestones.
   The only outstanding view required to meet this objective is the SV-2c which requires a clearer definition of the system communications. This will be achieved later when the architecture definition has been established.

2. The System Requirement Document that builds upon the user requirements, architecture and framework will be produced and published in DOORS™ by mid 2010.

3. In concert with the system's System Requirement Document, the system Interface Control Document, sub-system design requirements and interface requirements will be developed to establish a baseline against which:
   - concept demonstrators can be produced
   - equipment procurement specifications can be developed
   - test, evaluation and integration planning can be carried out.

4. The full CADMID/T life-cycle can be evoked efficiently and effectively so that:
   - the logistic supply and support services can be in place to effect a smooth transition into service
   - effective and efficient performance can be provided during service
   - an uneventful withdrawal from service can be achieved when the time comes.

This programme, having successfully applied MBSE to define the baseline for this new generation of system, continues to explore innovations in MBSE such as the latest concepts in the MODAF Human Factors Views. These Views were first presented at the INCOSE international conference in Utrecht in June 2008 and will be evaluated as part of the model produced for this new system.

The authors of this article presented this work at the INCOSE spring conference in March 2009 where it stimulated much interest.

Conclusions

This article describes the innovative MBSE work of the Systems and Integration Team at Dstl Fort Halstead and itemises the advantages of the MODAF modelling developed for one new capability.

The model has established a firm foundation for effective, efficient, timely achievement of the required project milestones to forecast with minimum risk.

This new system will significantly enhance the inventory of programmes already supported by Dstl out of the Systems and Integration Team. As a full procurement programme (unlike many that have been procured as Urgent Operational Requirements) this programme will follow the full CADMID/T cycle as defined in the MOD AOF which the Dstl workforce is ideally placed to support in partnership with industry.

So far, indications are that the achievements are very encouraging:

- Accolades have already been received from the sponsors [10] who have requested support of this approach for other programmes
- Industrial suppliers have acknowledged the clarity of the user requirements
- The programme continues to act as a platform for evaluation of the newly specified Human Factors Views.

The Systems and Integration Team members look forward to pursuing the progress of the MODAF model into representations for evaluation of the various future phases of the programme.

References

1. http://www.INCOSE.co.uk accessed 24 September 2008.

2. Dstl Internal symposium poster [DSTL/PS26230], 2007.

3. Concepts and Architectures study report, v2.0 [DSTL/24637], 30 April 2007.

4. http://en.wikepedia.org/wiki/Six_Sigma accessed 9 October 2008.

5. http://www.INCOSE.org accessed 04 September 2008 (call for MBSE papers).

6. http://www.modaf.org.uk accessed 25 September 2008.

7. MODAF model SV-4 view [DSTL/TR29955].

8. http://www.telelogic.com accessed 25 September 2008.

9. http://www.aof.mod.uk accessed 5 September 2008.

10. Dstl Project feedback form 115, v1.0, J D MacMillan, 24 April 2008.

Millimetre-Wave Soldier-to-Soldier Communications for Covert Battlefield Operations

Mobile ad hoc networking of dismounted combat personnel is expected to play an important role in the future of network-centric operations. High-speed, short-range, soldier-to-soldier wireless communications will be required to relay information on situational awareness, tactical instructions and covert surveillance-related data during special-operations reconnaissance and other missions. This article presents some of the work commissioned by the UK MOD to assess the feasibility of using 60GHz millimetre-wave smart antenna technology to provide covert communications, capable of meeting these stringent networking needs. Recent advances in radio frequency front-end technology, alongside physical layer transmission schemes that could be employed in millimetre-wave soldier-mounted radio, are discussed. The introduction of covert communications between soldiers will require the development of a bespoke directive medium access layer. A number of adjustments to the Institute of Electrical and Electronics Engineers (IEEE) 802.11 distribution coordination function that will enable directional communications are suggested. The successful implementation of future smart antenna technologies and the direction of arrival-based protocols will be highly dependent on a thorough knowledge of transmission channel characteristics prior to deployment. A novel approach to simulating dynamic soldier-to-soldier signal propagation using state-of-the-art animation-based technology developed for computer-game design is described, and important channel metrics such as root mean square angle and delay spread for a team of four networked infantry soldiers over a range of indoor and outdoor environments is reported.

By
Simon Cotton and William Scanlon
School of Electronics, Electrical Engineering and Computer Science, The Queen's University of Belfast, Belfast, Northern Ireland, BT9 5BN.
Email: simon.cotton@qub.ac.uk | w.scanlon@qub.ac.uk

Bhopinder Madahar
Information Management Department, Dstl, Porton Down, Salisbury, Wiltshire, SP4 0JQ.
Email: bkmadahar@dstl.gov.uk

Introduction

The infantry soldier of tomorrow promises to be one of the most technologically advanced that modern warfare has ever seen. Around the world, various research programmes are currently being conducted, such as the US Future Force Warrior (FFW) and the UK Future Infantry Soldier Technology (FIST), with the aim of creating fully integrated combat systems. Alongside vast improvements in protective and weaponry sub-systems, another major aspect of this technology will be the ability to provide information superiority at the operational edge of military networks by equipping the dismounted soldier with advanced visual, voice and data communications. Helmet-mounted visors, capable of displaying maps and real-time video from other squad members, ranges of physiological sensors monitoring heart rate, core body temperature and mobility, arrays of biochemical sensors detecting noxious gasses as well as a range of night-vision and heat-sensing cameras will all become standard issue. These devices will improve situational awareness, not only for the host, but also for co-located military personnel who will exchange information using mobile ad hoc wireless networks (MANETs).

The integration of body-worn wireless systems into the dismounted combat soldier platform will present a unique set of challenges to scientists and engineers alike. Wireless devices will be expected to operate in a range of environments, much more diverse than those encountered in civilian applications, yet still maintain an ultra-high level of performance in terms of reliability and efficiency. From a material perspective, these wireless devices must be compact, lightweight, unobtrusive to soldier movements and ideally mounted conformal to the body surface. As soldiers may go for days between the opportunities for battery recharge or replacement, power saving will be concurrent throughout all layers of the protocol stack. Physical layer (PHY) technologies must be resilient to jamming, able to operate in marginal conditions while using the minimal amount of energy conserving hardware. The medium access control (MAC) layer must also be designed to act in a power-saving, bandwidth-efficient manner while maintaining an excellent quality of service (QoS). Wireless security will be critical to maintaining a tactical edge as message interception and decryption could lead to compromise of the mission. When combined with covert communications – by covert we mean that signal transmissions remain hidden from the enemy – we have the prospect of achieving secure and robust wireless MANETs while maintaining the "element of surprise". These are formidable challenges, but may be surmountable using both recent developments in millimetre-wave (mm-wave) transceiver technology [1], and the 5–7GHz of contiguous bandwidth currently being made available throughout the world in the 60GHz mm-wave band [2].

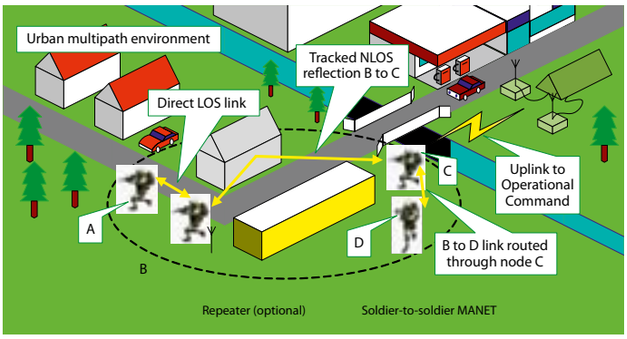
In this article we present some of the work undertaken in conjunction with the UK MOD to investigate the feasibility of using mm-wave body-worn antenna arrays to provide covert mobile ad hoc wireless networking for dismounted combat personnel. The objective of this article is twofold. Firstly, we begin by introducing the concept of a soldier-to-soldier MANET and briefly discuss some of the competing air interface technologies that could be used to provide high-speed wireless networking for dismounted combat personnel. We then discuss some of the potential issues at the PHY and MAC layers in relation to the implementation of stealthy, high data-rate, mm-wave soldier-to-soldier communications. One of the key challenges that remain for military hardware and network designers is the simulation of the wireless transmission channel. A good approximation of channel characteristics is fundamental to testing the performance of newly designed protocols, and understanding the required operating margins for front-end radio design. Therefore, the second section of this article takes a novel approach to the simulation of the wireless transmission channel by exploiting state-of-the-art animation-based technology developed for computer-game design, to accurately encapsulate the dynamics and mobility of soldier movement in the simulation of signal propagation within soldier-to-soldier MANETs.

Soldier-to-soldier MANET concept

The concept of a short-range soldier-to-soldier MANET is illustrated in Figure 1. In this example, a small team of co-located infantry troops are wirelessly networked to facilitate high-speed communications within a cluttered urban warfare environment. As the combat team progress through the environment their communications requirements will be extremely varied, with needs ranging from short message text (e.g. "spoken" by the receiving terminal or displayed on a helmet-mounted visor) and peer-to-peer voice (avoiding the need for shouting or hand movements), through to real-time streaming video. What is fundamental however, and a key discrimination between soldier-to-soldier MANETs and other MANETs, is that the communications are secure and resilient, with a low probability of detection and low probability of

intercept, that is, inherently stealthy. This is especially true for special operations forces where knowledge by enemy forces of increased activity in any region of the radio spectrum may lead to discovery, capture of transmitted data and/or interference with it. Such intelligence of, or inference of intent from, communications may compromise operations, for example, by revealing the movements of the forces or by loss of the element of surprise.

1



Soldier-to-soldier mobile ad hoc network (MANET) concept.

Short-range covert air interface technologies

To achieve optimal network-centric operations, tactical information must be effectively distributed among soldiers while maintaining a low probability of detection and intercept. Ultra-wideband (UWB) is an air interface technology that could supply sufficient bandwidth to meet the high data rate requirements of future body-worn military communications systems. UWB radios operate by employing very short duration signal pulses that result in large transmission bandwidths. The US Federal Communications Commission (FCC) defines a UWB device as any device where the fractional bandwidth is in excess of 0.2 of the arithmetic centre frequency or greater than 500MHz, whichever is less [3]. The FCC have granted permission for unlicensed UWB devices to operate in the 3.1–10.6GHz frequency range with the spectral density emission limit set at -41.3dBm/MHz to reduce interference with other co-located wireless systems operating within the same spectrum space. The stringent transmit power limitations placed on UWB devices have been chosen so that they minimize the risk of interference to authorized radio services by operating close to the noise floor. This is a feature that many in the military community will find attractive as it introduces a lower probability of detection compared to conventional wireless systems. UWB could provide the dismounted soldier with a maximum data rate of 100Mbps [2] for transmitter-receiver separations less than 10m and as much as 480Mbps at very small separation distances (typically less than a few metres). Improvements to operating distance and channel capacity could be realized by raising the spectral density emission limit, however such a move could prove unpopular as it will lead to increased interference with licensed radio users and remove the stealth mode of operation, leading to easier detection by the enemy.

Compared to UWB, 60GHz mm-wave communications will operate in currently under-utilized spectrum space and will provide high data rates of up to several gigabits per second for short-range applications [2]. Operating ad hoc network communications for dismounted combat personnel at 60GHz will offer a number of distinct advantages compared to the other competing lower-frequency technologies. Factors which would generally be considered to hinder traditional radio communications can be exploited to provide the desirable signal-propagation characteristics required for short-range military communications. These include: increased covertness, high-frequency reuse and reduced risk of interference which may be attributed to higher path loss, increased atmospheric oxygen (O_2) absorption and narrow antenna beam width. Another important feature of mm-wave frequencies is the small size of product that may be achieved. Ultra-low form factor transceiver design will become reality due to the extremely short wavelength (λ 5mm), that will also facilitate the construction of wearable smart antenna arrays capable of electrically steering highly focused beams of electromagnetic energy in chosen directions. To realize the objective of directional mm-wave communications, there are still a number of hurdles at the PHY and MAC layers, which need to be overcome as discussed below.

Millimetre-wave soldier-to-soldier communications: PHY-layer challenges

Channel characteristics

It is widely recognized that the successful development of hardware and wireless-networking protocols is highly dependent on a thorough knowledge of transmission channel characteristics relative to deployment. Much of the current research involving mm-wave short-range communications has been carried out considering a range of indoor environments for stationary transmitter and receiver scenarios [4]. Here statistical descriptors of the channel, such as path loss

exponent and mean root mean square (rms) delay spread, are found to be heavily influenced by antenna configuration and the local surroundings. While these studies are useful for the development of indoor wireless networks, any attempt to apply this channel information to the design of mm-wave soldier-to-soldier networks would be inappropriate, especially considering issues such as the scattering of signals from both users and pedestrians, and the inherently dynamic and highly mobile nature of military operations.

At present, very little is known about the characteristics of signal propagation between wearable wireless devices forming a human body-to-body network (BBN). Recent narrowband studies at 2.45GHz [5] have shown that signal propagation is dependent upon the user's physical characteristics, including mobility, and may be modelled using κ–μ fading statistics [6]. The effect of human-body shadowing on mm-wave wireless links has received some coverage in the literature. In [7] it is reported that human-body shadowing can cause attenuations of greater than 20dB on indoor 60GHz device-to-device links. Field trials performed for this study to investigate human-body shadowing events on indoor point-to-point links have found similar results (attenuations of 20–25dB), with greatest shadowing events found to occur when the human body moved in the direct vicinity of a 60GHz node, blocking line of sight (LOS).

Transmission schemes

There are a number of different transmission schemes that could be adopted for soldier-to-soldier communications. These include the single carrier (SC) and orthogonal frequency-division multiplexing (OFDM) schemes which are currently being investigated by IEEE 802.15 TG3c [8]. OFDM is well known for its ability to mitigate against frequency selective fading due to multipath, by turning the transmission channel into a series of suitably modulated (e.g. quadrature amplitude modulation) orthogonal sub-carriers. This has the effect of greatly reducing the complexity of transceiver design through the use of inverse fast Fourier transform (IFFT) and FFT signal-processing stages for signal transmission and reception respectively, and negates the need for intricate wideband equalizers. While OFDM may be resilient to multipath effects, it is prone to a high peak-to-average power ratio (PAPR), phase noise and carrier offset. High PAPR will be a particular problem for soldier-mounted radios, as it will cause non-linear distortion and low-power efficiency in the power amplifier [2] directly impacting on battery life. The complexity of time-domain channel equalization in wideband SC systems is regarded as its main drawback for use in high data-rate mobile radio channels. However, this challenge can be overcome through the use of frequency domain equalization (FDE). Single carrier systems with FDE (SC-FDE) typically use transmission blocks with a cyclic prefix to prevent interblock interference. Signal recovery at the receiver is then performed through FFT processing with equalization followed by an IFFT stage. SC-FDE will then deliver performance similar to OFDM, with essentially the same overall complexity [9], but because SC modulation uses a single carrier it has the added advantages of lower PAPR and less sensitivity to both phase noise and carrier offset [10].

Radio frequency front-end technology

The choice of 60GHz radio frequency (RF) front-end technology for soldier-mounted radio will introduce a trade-off between performance and cost. Traditionally group III–IV semiconductor technologies such as gallium arsenide and indium phosphide have been used for mm-wave radios. While they offer superior noise characteristics and high gain at mm-wave frequencies, they also suffer from a high cost per unit, poor integration and low power efficiency. Complementary metal-oxide semiconductor (CMOS) technology on the other hand will offer lower-cost mass production, improved integration and increased power efficiency. However CMOS front-end circuits will also have to address issues in power amplifier output, local oscillator phase noise and low-noise amplifier design as discussed in [10]. As a compromise, more recent advances in silicon germanium (SiGe) technology have now made it possible to build miniaturized, low-cost mm-wave radio devices, such as the 60GHz, 0.13μm, SiGe BiCMOS double-conversion superhetrodyne receiver and transmitter chipset recently developed by IBM [1]. Here, data rates of up to 630Mbps have already been demonstrated for this chipset over a 10m indoor LOS link using folded-dipole antennas for both transmitter and receiver modules. Based on link budget calculations made in [1], the authors also state that increasing the receiver gain by 12dBi (e.g. using smart antenna technology) could increase the range by a factor of four assuming free space propagation. Undoubtedly, even greater operating distances may be attained by sacrificing bandwidth and data rates or improving overall system gain. It is clear that multi-gigabit short-range mm-wave devices will be readily available in the short-term.

Millimeter-wave soldier-to-soldier communications: MAC-layer challenges

Directional MAC

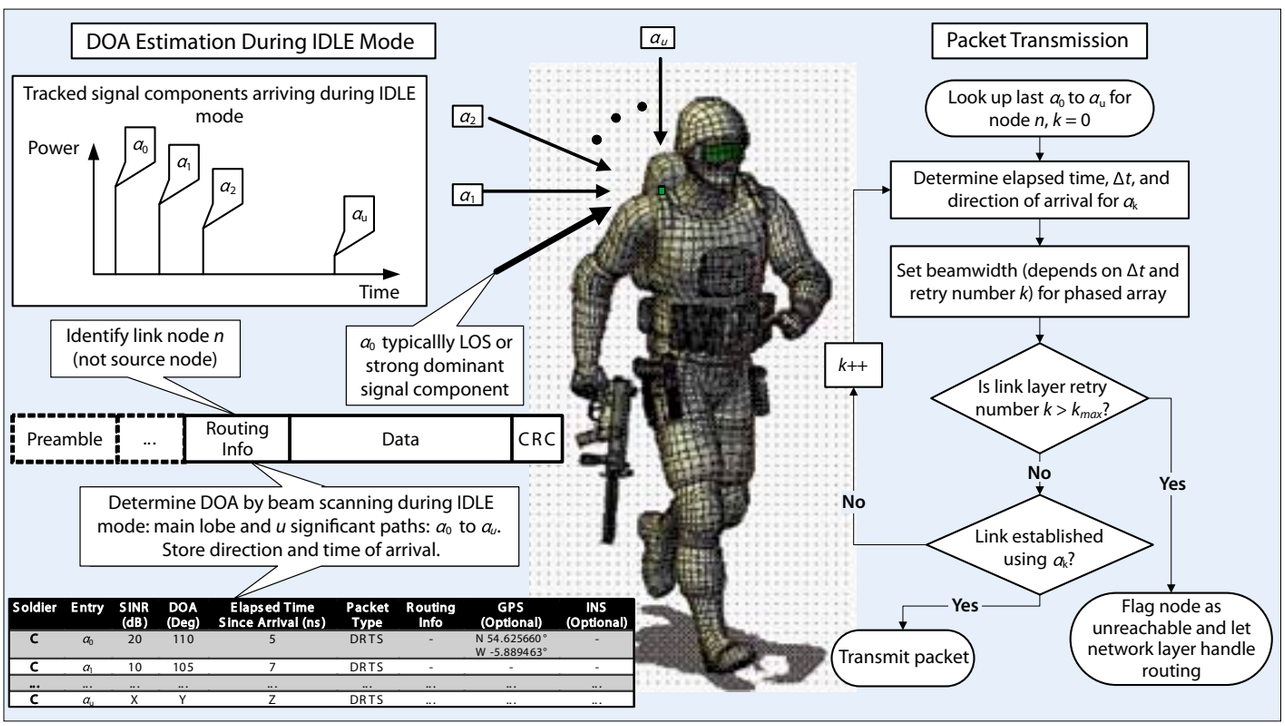
The successful introduction of covert 60GHz soldier-to-soldier communications will require the development of a robust and efficient, bespoke directional MAC (DMAC), which will be underpinned by future developments in beam-forming hardware, driven by the widespread adoption of standards such as IEEE 802.15.3c and IEEE 802.11-very high throughput (VHT) into the wireless consumer market. At 60GHz, it is possible to construct a cylindrical antenna array with 32 elements placed half-wavelength apart, all within a radius of 13mm. This will permit the development of compact, wearable smart antenna technology that uses adaptive beam forming to dynamically adjust the array pattern by altering the amplitude and phase of a feed network. Highly directive, narrow-beamwidth, interpersonal communications coupled with a 60GHz operating frequency will help counteract eavesdropping, improve resilience to jamming and provide a lower probability of detection by enemy forces. However, it will introduce a number of key design challenges at the MAC layer.

Many of the DMACs currently proposed in the literature are directional variations of the single-channel carrier-sense multiple access/collision avoidance (CSMA/CA) approach [11, 12]. One of the most widely used and well-understood CSMA/CA-based protocols is IEEE 802.11. The adaptation of the current IEEE 802.11 MAC for use in directional military systems will require a number of non-trivial adjustments, most notably to the distribution coordination function (DCF). Virtual carrier sensing (VCS), which is performed by listening to a directional request to send (DRTS) and directional clear to send (DCTS) exchanges in the local vicinity, should be performed directionally. Nodes that detect a DRTS or DCTS control packet will update a table of directional network allocation vectors (DNAVs) [11]. When the channel is sensed idle, the DNAV will be used to determine whether to defer transmission in a particular direction.

For a node to perform directive VCS (DVCS) and transmit its RTS directionally, it must know, or have a good estimate of, the location of its intended receiver. This is probably the single biggest challenge facing directional protocols, but one in which military wireless systems designers may be well placed to resolve. RTS direction could be obtained from an internal positioning table that is compiled using time and direction of arrival (DOA) of signal components. In [11], it is suggested that nodes should listen for ongoing transmissions omni-directionally while in idle mode and during random back-off intervals in contention periods, providing the opportunity to collect time and DOA information as illustrated in Figure 2. Directional information could also be retrieved during packet reception, using proactive training beacons [12] and from routing information obtained from relayed packets. Digital navigation aids that are often utilized by the military such as global positioning system (GPS), e.g. soldier's digital assistant, and inertial navigation systems may also be used to provide useful information on node locations by appending readouts to the data payload of control packets. However, these methods of DOA estimation may not be as effective in indoor environments or when the direct LOS link is obstructed.

To illustrate the operation of a directive MAC layer in a soldier-to-soldier MANET, we return to the scenario depicted in Figure 1 and assume that the soldiers are equipped with radios which make use of mm-wave adaptive beam forming technology, based on a directional derivative of the IEEE 802.11 MAC. As an example, consider single-hop communications between soldiers B and C, and assume that the team has been tracking each other's movements, e.g. using proactive beaconing, and hence, have good estimates of their relative locations or DOAs of significant multipath components. If soldier C wishes to initiate communications with soldier B, he must transmit a DRTS using the last known "good" directional entry for soldier B in his internal positioning table. All nodes that receive the DRTS transmission (e.g. soldiers A and B who are in idle states) then update their DNAV and internal positioning tables with the incoming signal's DOA and adjust the elapsed time of arrival information. This will include tracking and storing all major multipath components as well as the most significant path as shown in Figure 2. If soldier B's DNAV table permits transmission in the return direction, the node uses the stored information to beamform in the direction of soldier C and attempts to send a DCTS for a predefined period before timing out. Meanwhile, soldier C also beamforms in the direction of soldier B waiting for the DCTS. If the DCTS is successfully received, soldier C initiates the directional transmission of data. Throughout this process, all nodes that can hear the exchange, continuously update their positioning tables. In the case of soldiers B and C, this will provide the maximum opportunity of re-establishing the link should it unexpectedly go into outage, before abandoning transmission

2



Direction of arrival (DOA) estimation and packet transmission in a mm-wave soldier-to-soldier mobile ad hoc network (MANET). Soldier model (height 1.83m) generated using Poser 7 animation software.

and handing the problem to the network layer for routing as outlined in the "packet transmission" flowchart in Figure 2. This is a relatively simple overview of how directional communications could work in soldier-to-soldier MANETs. However, DMACs will be particularly susceptible to many of the common issues associated with wireless networking such as the hidden node problem, deafness, and gain asymmetry. Clearly, these are issues that also need to be carefully considered and warrant further research.

Adaptive power control

Another facility that would further enhance the stealth mode of wireless operation is judicious adaptive power control. Here, radio transmit power is adjusted on a packet-by-packet basis to the minimum level required for operation with a given capacity and error probability. These schemes are often desirable in mobile wireless systems for the purposes of reducing interference and prolonging battery life. In [13] a simple method of implementing power control within the RTS/CTS framework is proposed. This technique could be readily adapted for use in directional systems by including the beamforming gain within the link power control budget. The directive RTS is always transmitted with a predetermined power (e.g. maximum power, P_{TX}, measured in decibels) and the beamforming gain (B_{TX}) used to transmit the DRTS stored in memory. Upon successful DRTS reception, the receiver calculates the difference between the instantaneous received power and its received power threshold, and adds this to its future intended beamforming gain (B_{RX}) to calculate the power difference, denoted P_d. This value is then added to the data payload and transmitted with the DCTS. When the sender node begins transmitting data, it does so using the predetermined power and previous beamforming gain, less the difference (i.e. $P_{TX} + B_{TX} - P_d$). An optional safety margin (P_s), which takes into account fading and node mobility, may also be added to the adjusted output power level chosen by the sender (i.e. $P_{TX} + B_{TX} + P_s - P_d$). Including adaptive power control in future soldier-to-soldier MANETs will not only aid with reducing interference and battery longevity, it will also improve the covert nature of communications.

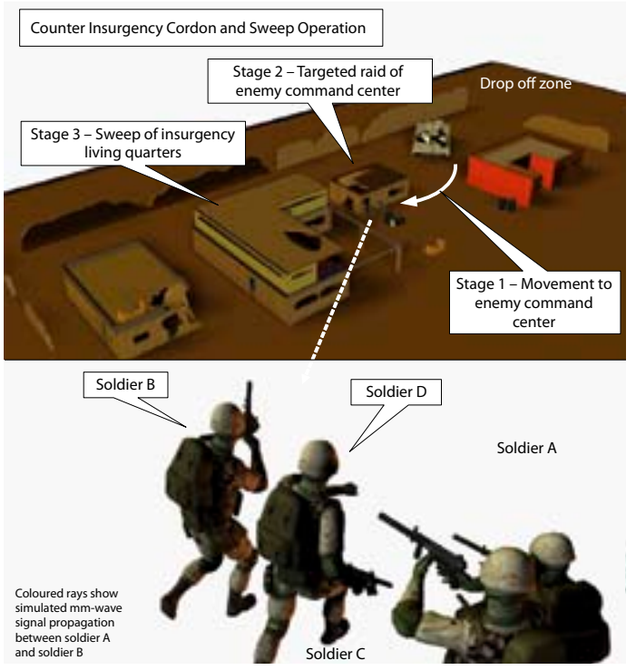
Simulating soldier-to-soldier signal propagation

A range of electromagnetic solver tools are available for simulating signal propagation in wireless channels. Of these, the finite-difference time-domain (FDTD) and ray-launching methods are of particular interest. FDTD modelling works by solving Maxwell's equations in the time domain. The FDTD method becomes computationally intractable over large distances at mm-wave frequencies due to the high simulation grid resolution required to achieve an accurate result. Another approach, which is based upon geometrical optics (GO) and the uniform theory of diffraction (UTD), is ray launching. In ray launching, the transmit antenna launches N rays over a selected spatial angle. The ray-launching algorithm then tracks each of the rays until it illuminates the area of interest or until the power of the ray falls below a pre-selected threshold level. Because ray launching is based on GO, as the frequency of the carrier increases, the approximation of ray launching to signal propagation improves. A particular strength of using ray-launching simulation methods to make channel predictions is that they allow infinite resolution of transmitted and received signal contributions in both time and space. This feature will make them inherently suitable for generating transmission channel information to be used in conjunction with network simulators (e.g. OPNET, NS2), allowing time/direction of arrival-based protocols to be rigorously tested. To illustrate the use of ray launching in the simulation of signal propagation in soldier-to-soldier MANETs, we now describe the steps taken to simulate the mm-wave transmission channel between a team of four dismounted combat personnel performing a hypothetical counter-insurgency cordon and sweep operation (this is the fictitious operation depicted in Figure 3).

Dynamic human body and environmental model generation

A particular problem with achieving realistic transmission channel predictions in scenarios that involve the human body is the encapsulation of movement. One possible solution to this problem is the use of animation software to generate the required dynamics. These programmes typically allow the straightforward manipulation of user-created, 3D polymesh human figures with the ability to export the animation sequence to a native file format readily interpreted by computer aided design (CAD) software (e.g. drawing exchange format). Figure 2 shows an example snapshot of the soldier model used in this study generated using the walk designer feature of the Poser 7[1] animation software. The lifelike model of the US infantry soldier includes the improved outer tactical vest (IOTV) and lightweight helmet, backpack, pouches and weaponry. Also shown in Figure 2 is a single 60GHz wireless node positioned on the right shoulder which, for simulation purposes, was fitted with a vertically polarised (when soldier is standing upright) dipole antenna, chosen because of its favourable omni-directional radiation characteristics in the azimuth. The computer-generated environmental model created for this study was designed using the AutoCAD software package from Autodesk®[2]. It was based upon a small compound as encountered by coalition troops in the Middle East as shown in Figure 3.

3



Upper image: illustration of all three stages of the cordon and sweep-operation simulation within a 2,258m² Middle-Eastern enclosure. Lower image: expanded picture of simulated mm-wave signal propagation between soldiers A and B as the team prepares to raid the enemy command centre.

A simulated counter-insurgency cordon and sweep operation

In this section, we present a selection of simulation results from the hypothetical military operation shown in Figure 3. The simulations followed three distinct stages of a cordon and sweep-type operation, and modelled bi-directional signal propagation between a squad of four US infantry troops.

[1] http://mysmithmicro,com/win/poser/index.html
[2] http://usa.autodesk.com

Simulator operation and settings

The dynamic soldier-to-soldier transmission channel simulations used a full 3D ray-launching algorithm[3] that was set to calculate all reflections, penetrations and diffractions. A library of purposely written executables were responsible for the amalgamation of the animation sequence and CAD environment model, assignment of dielectric properties to material layers, transmit power and other related channel-simulation properties as well as controlling the automation of the ray-launching algorithm. Proprietary software also tracked the changes in antenna orientation caused by soldier movements in 3D vector space. The soldiers were given movements and speeds relative to their role within the operation. The animations were performed at a rate of 50 frames per second, which for the purposes of ray-launching simulation, is analogous to 50 samples of the mm-wave channel per second. The 60GHz wireless nodes were set to transmit at a power level of +20dBm.

Simulation description

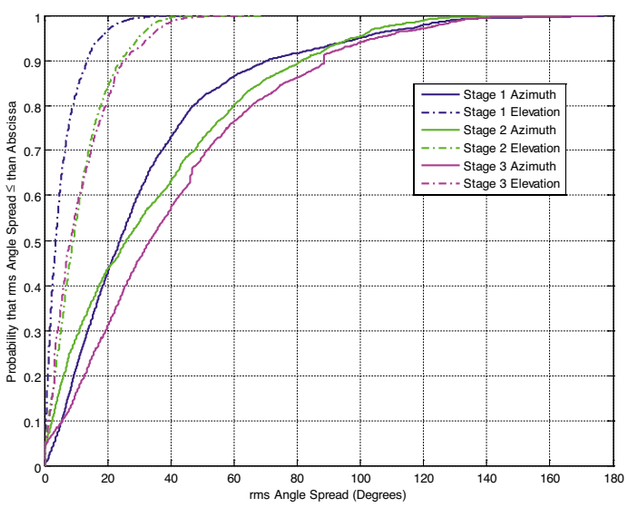
The overall simulation scenario was designed to encompass a wide range of channel types: indoor, outdoor and indoor to outdoor. Stage 1 involved movement of the team from a "drop-off zone" beside the Abrams M1 tank (Figure 3), to the entrance of an enemy command centre and analysed outdoor soldier-to-soldier signal propagation. This stage took approximately 5s to complete. Stage 2, duration 4.5s, investigated both indoor and outdoor-to-indoor signal propagation as three of the team swept the building, while the remaining soldier maintained guard at the entrance. Finally, stage 3 lasted for 5.2s and studied the movement of the team within a large multi-room building structure.

Direction of arrival (DOA)

In this study, we are particularly interested in the DOA of significant signal components and more importantly their angular distribution in space. This knowledge will be crucial for proving the covert aspect of communications at mm-wave frequencies and the usefulness of beamforming in future soldier-to-soldier MANETs. The key question here is: "Is the distribution of DOA suitably constricted to provide a stealth mode of operation and warrant the use of beamforming arrays but not too narrow as to limit the system's ability to overcome channel impairments?" The azimuth (or elevation) rms angle spread of the channel impulse response is a measure of the angular dispersiveness of the channel [14]. A transmission channel in which major signal components arrive from significantly different spatial orientations is characterized by a large rms angle spread and vice versa.

The azimuth and elevation rms angle spreads were calculated at each simulation time step (animation frame) for individual soldier-to-soldier links. Figure 4 summarises these results by presenting the cumulative distribution functions (CDFs) of rms angle spread over all the simulations (all three stages), and for all bidirectional links. For stage 1, the azimuth rms angle spread had a 90% probability of being less than 90°. The corresponding figure for the elevation rms angle spread was lower at 20°, an observation most likely to have been caused by the fact that each of the soldiers were of the same height and were vertically upright for the duration of stage 1. Most importantly, these results provide solid evidence of the directional characteristics of the outdoor transmission channel, and the potential for beamforming arrays to provide a good degree of covertness.

4



Cumulative distribution functions (CDFs) of root mean square (rms) angle spread over the three stages of simulation for all bidirectional links.

For stage 2, rms angle spread for both azimuth and elevation planes were increased compared to stage 1 (Figure 4). The increase in rms angle spread, especially elevation, within indoor environments was to be expected, and may be explained by the larger number of multipath components caused by the close proximity of scattering and reflecting objects such as

[3] Algorithm formed part of RPS software package available: http://www.actix.com/radioplan_rps/

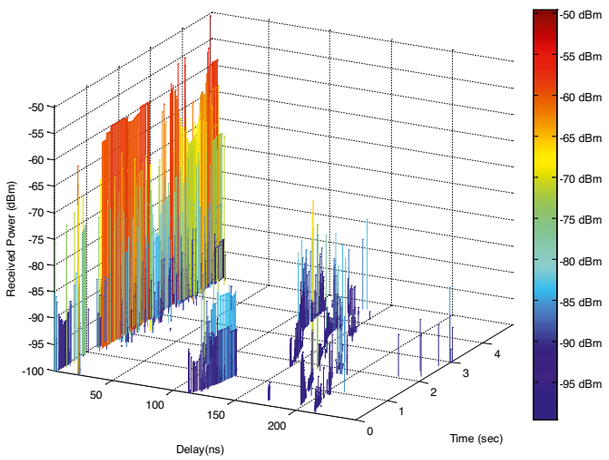
walls, ceilings and furniture. In stage 3 of the operation, the rms angle spread also increased compared to stage 1. The results from stages 2 and 3 show quite clearly that rms angle spread increases as the soldiers move from a mostly uncluttered LOS outdoor communications scenario to often obstructed indoor communications one. The rich multipath conditions observed within indoor environments at 60GHz should generate enough signal components with sufficient angular separation to sustain short-range soldier-to-soldier communications should the main signal path become unexpectedly shadowed or blocked. It is worth noting that while larger rms angle spread within indoor environments may appear detrimental to the proposed stealth mode of operation, mm-wave propagation characteristics will mean that supporting structures should inhibit signal propagation beyond the perimeter boundaries.

Rms delay spread

When high data-rate wireless systems operate under dispersive channel conditions, they can be subject to intersymbol interference (ISI), which may significantly degrade their performance. The rms delay spread is considered as one of the most important parameters for defining the time extent of a time-dispersive radio channel [15] and assessing the potential impact of ISI. When the modulation symbol time is of the order of the rms delay spread, the wireless link is generally considered to be at risk from ISI. Therefore, rms delay spread provides important information for ISI mitigation techniques such as equalizer design. In this work, we calculate the rms delay spread from the discrete time power delay profile (PDP), obtained from the complex channel impulse response, acquired at each individual simulation time step. Figure 5 shows an example PDP for the wireless link from soldier A to soldier B during stage 1. It can be seen quite clearly that the vast majority of the energy is contained within the direct path, which typically arrives within 25ns. Figure 5 also shows the existence of occasionally significant multipath components which arrive between 100 and 150ns.

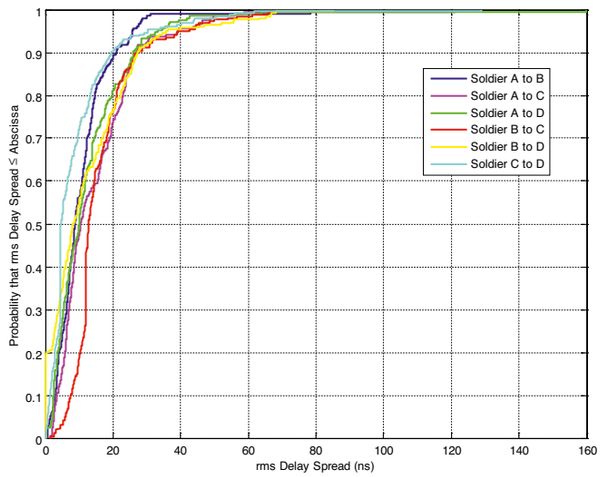
Table 1 provides a summary of the rms delay spread statistics for all bidirectional soldier-to-soldier links for all of the three stages. In stage 2, where the majority of soldier-to-soldier links were confined within the small dimensions of the enemy command centre, the median rms spread was much lower than stage 1 due to much shorter contributing path lengths. Interestingly, stage 3 had comparable median rms delay spread to stage 1 despite considering a different environmental scenario. The maximum rms delay spread for stage 3 was 160ns (Table 1) which, as Figure 6 indicates, is a relatively rare event. The similar shapes of the rms delay spread CDFs in Figure 6 also suggest that a similar type of wideband equalizer may be used for all wireless channels in this scenario. This trend was also repeated for stages 1 and 2, and this in turn means that the complexity of the design of mm-wave transceivers for soldier-centric communications design is reduced.

5



Power delay profiles (PDPs) for wireless link from soldier A to soldier B for the duration of stage 1.

6



Cumulative distribution functions (CDFs) of all root mean square (rms) delay spreads calculated for each bidirectional link over the duration of stage 3.

Table 1

Stage	Median rms delay spread (ns)	Inter-quartile range of rms delay spread (ns)	Max rms delay spread (ns)	Min rms delay spread (ns)
1	9.1	17.9	162.5	~0.0
2	5.3	6.5	96.1	~0.0
3	10.1	12.4	160.0	~0.0

Summary statistics for rms delay spread over all three stages.

Conclusions

Covert high-speed wireless networks are now a functional requirement of modern infantry and special operations warfare. In this article, we have discussed a wide range of issues associated with the application of directive mm-wave systems to meet future soldier-centric networking needs. The concept of a soldier-to-soldier MANET has been introduced, and used as an example of a military scenario that could benefit from a stealth mode of operation. To realize covert ad hoc networking, considerable challenges relating to hardware, directive protocols and power control must be addressed. OFDM and SC-FDE transmission schemes coupled with recent advances in SiGe technology look promising for providing high-bandwidth, mm-wave soldier-mounted radio. The short electromagnetic wavelength at 60GHz will allow the construction of compact adaptive beamforming arrays. A directive MAC layer will be required and expected to provide seamless connectivity, as well as effective management of resources including power control. To this end, possible strategies for creating a directive MAC layer based upon the IEEE 802.11 MAC have been described.

A fundamental understanding of the soldier-to-soldier transmission channel will be necessary to rigorously test future protocols and hardware. With the aim of gaining greater insight into signal propagation within soldier-to-soldier transmission channels, we have combined computer-generated dynamic human body models and a commercial ray-launching engine to perform channel prediction. It is worth noting that this platform has the ability to simulate dynamic military scenarios beyond soldier-to-soldier signal propagation such as soldier-to-vehicle, including unmanned aerial vehicles (UAVs) and UAV-to-UAV, and is applicable in the frequency range 300MHz to 300GHz. Simulations performed for this study were based around three distinct stages of a military cordon and sweep-type operation. For outdoor operations, it was observed that signal DOA was adequately constricted to provide a good degree of covertness. When the team moved indoors, the signal DOA was observed to increase, although the favourable propagation characteristics at mm-wave frequencies mean that signal propagation is likely to be contained within the structure. Delay dispersion was also dependent upon local surroundings with the greatest rms delay spreads observed outdoors and within large building structures.

Acknowledgements

This work was supported by the UK MOD through the 'Competition of Ideas' programme, under project reference RT/COM/5/001.

References

1. S. K. Reynolds et al., *'A silicon 60GHz receiver and transmitter chipset for broadband communications'*, IEEE Journal of Solid-State Circuits, vol. 41, no. 12, pp.2820–2831, Dec. 2006.

2. C. Park and T. S. Rappaport, *'Short-range wireless communications for next-generation networks: UWB, 60GHz millimeter-wave WPAN, and ZigBee'*, IEEE Communications Magazine, pp.70–78, August 2007.

3. FCC, *'First Report and Order: Revision of Part 15 of the Commissions Rules Regarding Ultra-Wideband Transmission Systems'*, ET Docket 98–153, 2002.

4. H. Yang, P. F. M. Smulders, and M. H. A. J. Herben, *'Channel characteristics and transmission performance for various channel configurations at 60GHz'*, EURASIP Journal on Wireless Communications and Networking, vol. 2007, no. 1, pp.1–15, January 2007.

5. S. L. Cotton and W. G. Scanlon, *'Channel characterization for single and multiple antenna wearable systems used for indoor body to body communications'*, IEEE Trans. Antennas & Propagation, Special Issue on Antennas & Propagation for Body-Centric Wireless Communications, Vol. 57, 4, April 2009.

6. S. L. Cotton and W. G. Scanlon, *'Higher order statistics for the k–μ distribution'*, Electronics Letters, vol. 43, no. 22, pp.1215–1217, 2007.

7. S. Collonge, G. Zaharia, and G. E. Zein, *'Influence of the human activity on wide-band characteristics of the 60GHz indoor radio*

channel', IEEE Trans. Wireless Communications, vol. 3, no. 6, pp. 2396–2406, November 2004.

8. IEEE 802.15 WPAN Millimeter Wave Alternative PHY Task Group 3c (TG3c). Online: http://www.ieee802.org/15/pub/TG3c.html.

9. D. Falconer, S. L. Ariyavisitakul, A. Benyamin-Seeyar, and B. Eidson, *'Frequency domain equalization for single-carrier broadband wireless systems'*, IEEE Communications Mag., vol. 4, no. 40, pp.58–66, April 2002.

10. C. H. Doan, S. Emami, D. A. Sobel, A. M. Niknejad, and R. W. Brodersen, *'Design considerations for 60GHz CMOS radios'*, IEEE Communications Magazine, vol. 42, no. 12, pp.132–140, December 2004.

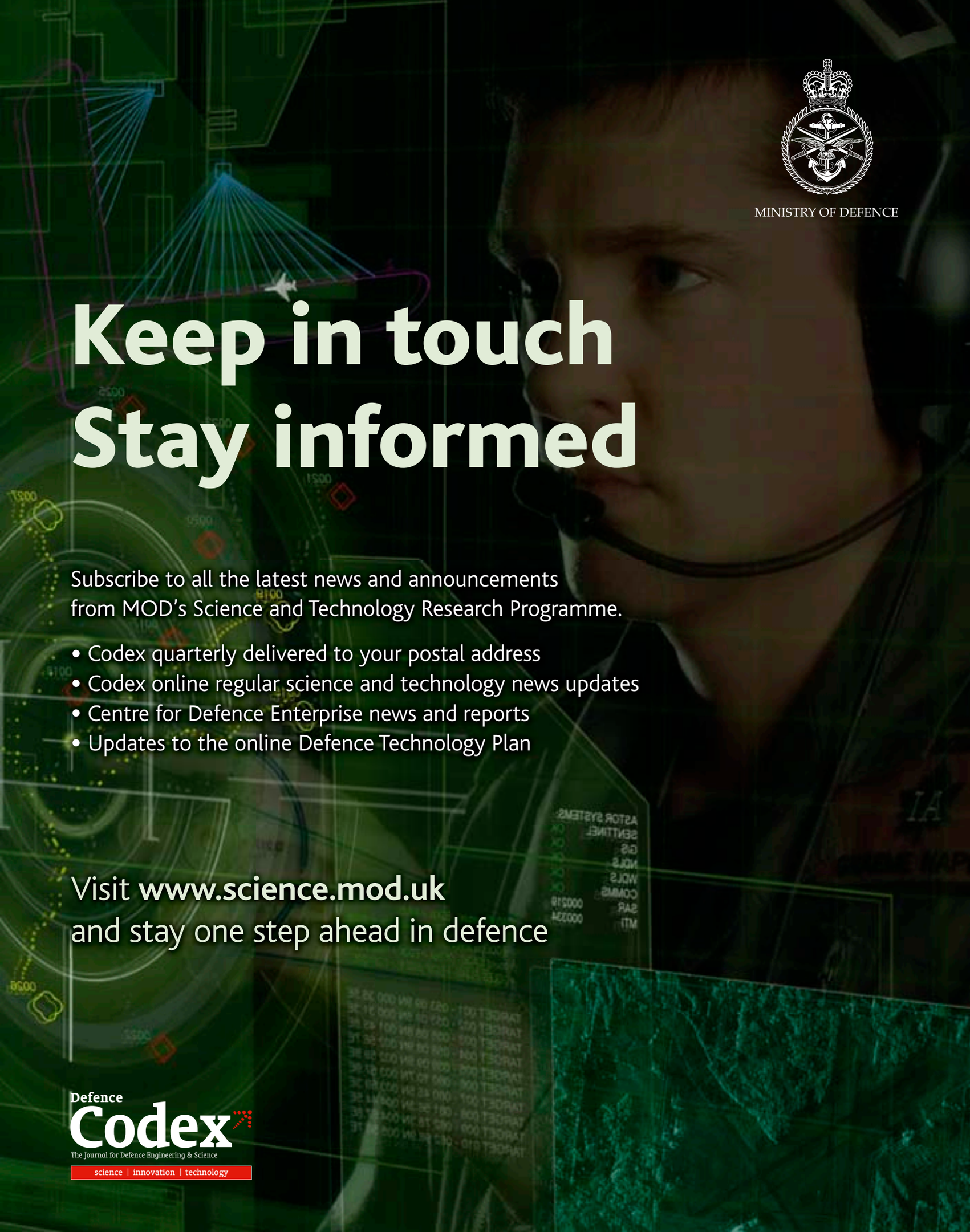
11. R. R. Choudhury, X. Yang, R. Ramanathan, and N. H. Vaidya, *'On designing MAC protocols for wireless networks using directional antennas'*, IEEE Trans. on Mobile Computing, vol. 5, no. 5, pp. 477–491, May 2006.

12. R. Ramanathan, J. Redi, C. Santivanez, D. Wiggins, and S. Polit, *'Ad hoc networking with directional antennas: a complete system solution'*, IEEE Jnl. Selected Areas in Communications, vol. 23, no. 3, pp.496–506, March 2005.

13. R. Ramanathan, *'On the performance of ad hoc networks with beamforming antennas'*, International Symposium on Mobile Ad hoc Networking & Computing, Long Beach, CA, USA, 2001, pp. 95–105.

14. J. C. Liberti and T. S. Rappaport, *'Smart antennas for wireless communications: IS-95 and third generation CDMA applications'*, Upper Saddle River, New Jersey: Prentice Hall PTR, 1999.

15. K. Witrisal, *'On estimating the rms delay spread from the frequency-domain level crossing rate'*, IEEE Communications Letters, vol. 5, no. 7, pp.287–289, July 2001.



MINISTRY OF DEFENCE

Keep in touch
Stay informed

Subscribe to all the latest news and announcements
from MOD's Science and Technology Research Programme.

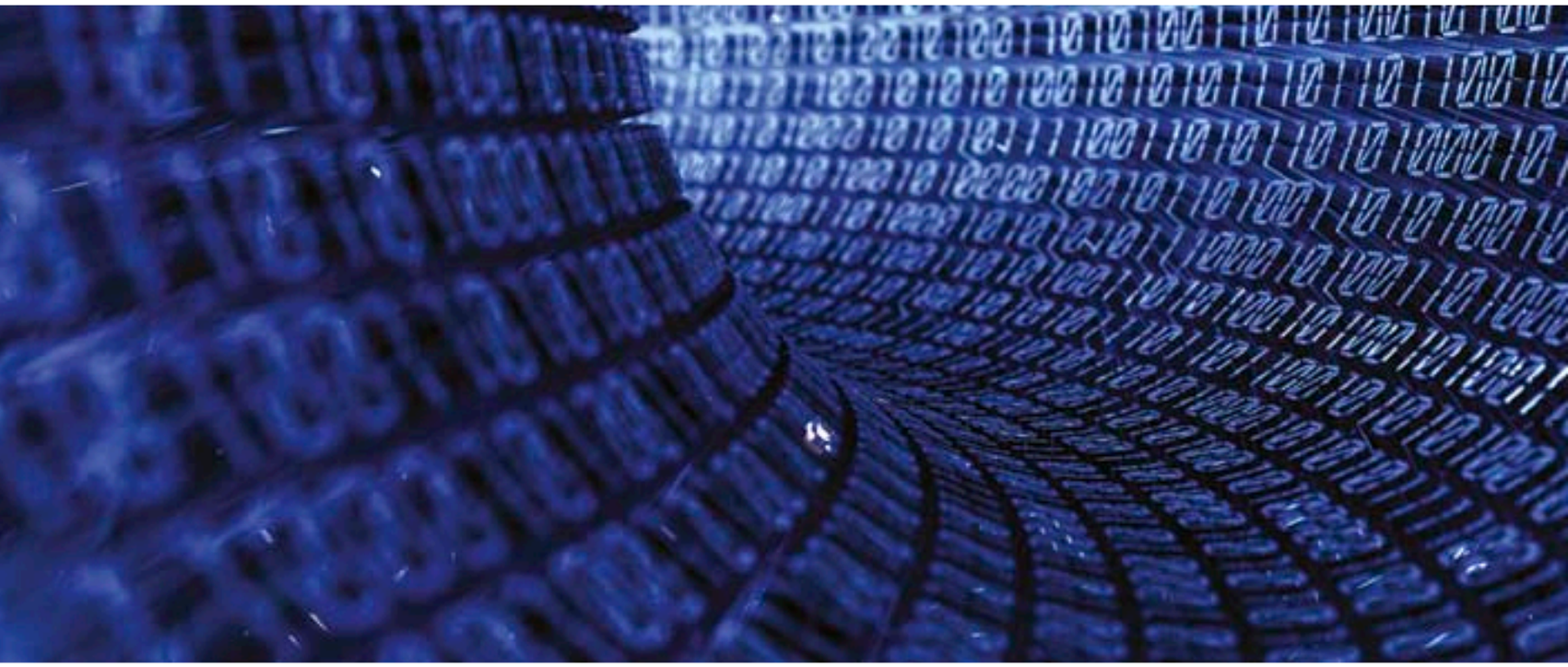
- Codex quarterly delivered to your postal address
- Codex online regular science and technology news updates
- Centre for Defence Enterprise news and reports
- Updates to the online Defence Technology Plan

Visit **www.science.mod.uk**
and stay one step ahead in defence

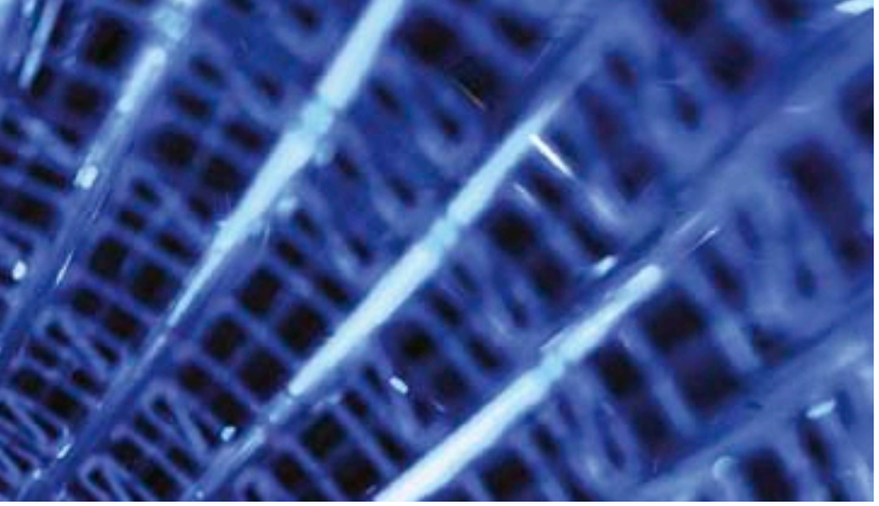
Defence
Codex
The Journal for Defence Engineering & Science
science | innovation | technology

ATHENA is the MOD's central library for storing scientific and technical reports. It provides a range of products and services which are available to organisations working in defence.

- Access information from past and present research programmes
- Share information more efficiently
- Find experts working in a particular field



science | innovation | technology



ATHENA Defence Research Abstracts

A monthly journal providing bibliographic information of new reports added to the DRD using the COSATI taxonomy.

ATHENA Defence Reporter

A quarterly unclassified bulletin providing bibliographic information on unclassified research reports recently added to the DRD.

Produced by MOD Defence Science and Technology Laboratory (Dstl) and Defence Technology and Innovation Centre (DTIC), Defence Reporter is part of a series of services aimed at helping the defence community access up to date information on developments in defence science and technology.

Example A

Collection system identifier
Title

R0001C6D0
Airframe Structural Integrity Research and Technology Strategy - Phase 2
Dstl Porton Down (GB) (2009)
Within this report, Phase 2 of the task raised by CASD-ASI to develop a Structural Integrity Research and Technology Strategy is described. Additionally, development of fatigue data management systems to support several in- service aircraft fleets and expansion of low-cost Operational Loads Measurement capability development tasks are detailed.

Publisher, year of publication
Abstract

To subscribe to the free service email your full name and address to: defencereporter@dstl.gov.uk

---

For more information, please contact:

athena@dstl.gov.uk

ATHENA is funded by MOD science | innovation | technology and managed by Dstl.

[dstl]

BiP SOLUTIONS EVENTS MANAGEMENT 25 YEARS 1984–2009 DELIVERING INNOVATIVE SOLUTIONS

de&s Suppliers Service

MINISTRY OF DEFENCE

UK Ministry of Defence

science | innovation | technology

Defence Research 2010

Annual Conference & Exhibition

23 & 24 March 2010 – Birmingham International Conference Centre

Defence Research 2010 is the only official event where the UK MOD will present the whole of its £450 million annual research investment to industry, academia and other suppliers, alongside key members of the MOD and the Armed Services.

WHY ATTEND

- Over 80 exhibitors including the MOD, academia, Prime Contractors and sub-contractors
- Information on the MOD's £450 million annual research programme
- 15 unique conference streams
- Develop business relations with key decision makers working across the MOD, including SIT, DTIC, DE&S, ECC (military customer), Dstl and the Centre for Defence Enterprise as well as suppliers from Prime and sub-contractors to SMEs, academia, research organisations and individuals
- Extensive networking opportunities with over 1500 delegates

REGISTER **FREE** NOW: **www.defenceresearch.co.uk**