# DEFENCE SCIENCE

VOLUME 1 ISSUE 1 MAR 2010 | ISSN 1837-8404 and ISSN 1838-0093 (Online)

AUSTRALIA

Flexible solar panels for frontline power

Blast debris x-rays to develop better armour

Reducing risk of missile strike

Whale watching with a difference

Australian Government
Department of Defence
Defence Science and Technology Organisation

The Defence Science and Technology Organisation (DSTO) is part of the Department of Defence and provides scientific advice and support to the Australian Defence Organisation. DSTO is headed by the Chief Defence Scientist, Professor Robert Clark, and employs about 2300 staff, including some 1300 researchers and engineers. It is one of the two largest research and development organisations in Australia.

Defence Science Australian is published quarterly by DSTO Defence Science Communications. 

**Managing Editor:** Jimmy Hafesjee
e-mail: jimmy.hafesjee@dsto.defence.gov.au

**Editor:** Tony Cox
e-mail: dsaeditor@dsto.defence.gov.au

**Design and illustration:** Maria Lucarelli

**Media enquiries:** Phil Mayne
Phone: 61 2 6128 6384
e-mail: media@dsto.defence.gov.au

**Mailing list enquiries:**
e-mail: dsaeditor@dsto.defence.gov.au

**More information is available about DSTO on its web site at: www.dsto.defence.gov.au**

ISSN 1837-8404

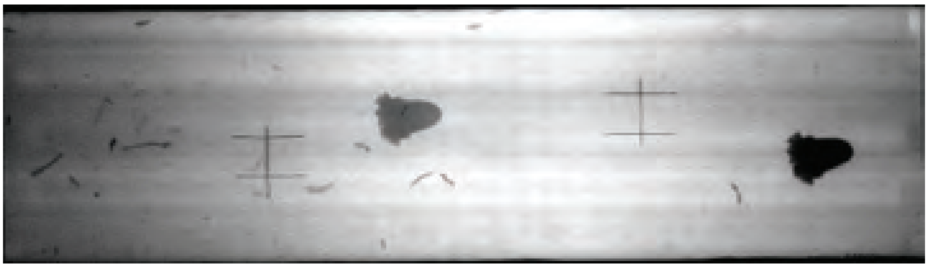
# Contents



*Cover image: Flexible photovoltaic cell developed by Australian National University being investigated for use in portable frontline power supplies.*

# X-ray views of blast debris to develop better armour

The development of armour for the Australian Defence Force (ADF) by DSTO is being assisted by the capture of Flash X-ray radiographs of weapons firings.



In 2008, Defence asked DSTO to study the effectiveness of add-on vehicle armour to protect personnel and vehicles against weapons such as Improvised Explosive Devices (IEDs) commonly used in operational arenas.

To develop better armour, the impact of high-velocity particles striking armour test plates from IEDs or other weapons has to be investigated photographically to establish which particles hit the armour, and what effects they have on the armour.

"However, when high velocity particles hit armour they produce a lot of debris, fire and smoke," says DSTO researcher Dr Jeremy Anderson.

"The use of Flash X-ray imaging allows us to look inside the debris cloud to see the state of particles before they hit the armour, and also what happens to them afterwards.

"This work helps develop understandings for the creation of effective new armour designs."

### Imaging fast moving objects

The Flash X-ray imaging process captures images in just 30 nanoseconds – 30 billionths of a second – meaning that sharp images can be taken of objects travelling at kilometres per second.

The apparatus involves two X-ray emission tubes aligned side by side, so that they project images onto the same radiograph.

By measuring the distance between images of a particle on the radiograph, and knowing the time between exposures, the particle's velocity can be calculated.

Crucial to the capability is triggering software that instigates the X-ray capture process at just the right times.

The software was developed by Dr Anderson while on a Defence Science Fellowship with the US Army Research Laboratory.

### Another vital study ingredient: space

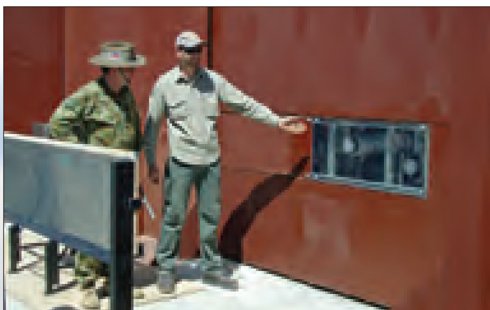
Flash X-ray imaging has been available to DSTO researchers in laboratory settings for many years, but its current use to study IEDs has required the establishment of a purpose-built stand-alone facility located well away from any human workplace or habitation.

For these safety reasons, DSTO constructed a field-based Flash X-ray facility in the wide-open spaces of the Proof and Experimental Establishment near Port Wakefield, South Australia.

Construction and testing were completed over the last twelve months following a request from the Counter Improvised Explosive Device Task Force in order to provide rapid support for Army and the wider ADF.

During this work, the researchers arrived at many innovative solutions for overcoming explosive and radiation hazards involved in the conduct of studies. The system is believed to be the only one of its kind in the southern hemisphere, and one of only several in the world.

In addition to studies currently being conducted on add-on vehicle armour, the facility will be used to test and evaluate next-generation armour for vehicles, body armour for personnel, and for the study of threats posed by newly emerging weapons that may be used against the ADF.



*Above: Flash X-ray images of a copper disk deformed by explosion, with two images captured in the same photo milliseconds apart.*
*Right and below: DSTO's Flash X-ray facility.*

# Peering inside aircraft alloys to see corrosion at work

DSTO researchers have been using X-ray tomography to study the process of corrosion attack within aluminium alloys, so that prevention and management practices can be improved.

Alloys of aluminium, made with zinc, magnesium and copper, are given thermo-mechanical treatment during manufacture to optimise mechanical properties – such as the ability to resist deformation when stressed – with resultant grain structures that readily corrode.

Corrosion can take the form of surface decay called 'pitting' and sub-surface decay known as 'intergranular' corrosion. The latter has a major effect on the fatigue life of aircraft structures, and so, is of particular concern to Australian Defence Force (ADF) aircraft fleet operators.

To better understand the cause and propagation of atmospheric intergranular corrosion, DSTO embarked on an experimental program involving two aluminium alloys, AA2024 and AA7050, which are both commonly used in aircraft components.

The work was assisted with funding from the Defence Materials Technology Centre.

### Getting to know a covert enemy

A problem for such studies is that intergranular corrosion has been difficult to identify and quantify since it occurs internally.

"Previous study methods involved the painstaking work of cutting sections through a test sample to reveal what has happened beneath the surface," explains DSTO researcher Maria Salagaras.

"This approach required time-consuming destructive analysis of the sample, and even then, the results obtained didn't fully describe the extent of the attack, being limited to what can be seen by dissection."

Greatly improving on this situation, X-ray micro-computed tomography can now be used to reveal the hidden activity of corrosion.

The three-dimensional digital images this technology produces not only portray the extent of corrosion more readily and more precisely, but also enable studies to be done on corrosion volumes and morphology.

### The experimental process

Samples were first fashioned into 2 mm diameter pins so that X-ray tomography images taken of corrosion outcomes could be gained at maximum resolution.

The end grain surface of the metal was selected for exposure to corrosion attack, being the most susceptible to intergranular corrosion. A 0.002 millilitre droplet of salt solution at 3.5% concentration was placed on this surface to initiate the intergranular corrosion process, simulating the effect of naturally occurring salt contaminants under high-humidity conditions.

All the pins were then placed into a 97% relative humidity environment.

To study the effects of time, samples were removed from the 97% relative humidity environment after elapsed periods of 4, 8, 24, 48, 96 and 168 hours.

To study the effect of differing relative humidity levels, after four hours initial exposure to 97% relative humidity, groups of specimens were then removed and placed in environments with either 45%, 66% or 82% relative humidity for a further 164 hours.

After all the samples had undergone their requisite environmental exposure, they were cleaned and dried for X-ray tomography examination.

### The outcomes observed

The specimens were exposed to polychromatic X-ray illumination for 50 seconds per projection, producing images with resolutions as high as one micrometre.

A set of 720 exposures was captured for each pin, with the specimen being rotated in intervals of 0.25 degrees through a total of 180 degrees. This process took more than eleven hours per specimen to complete.

Each set of two-dimensional x-ray images was then combined to produce three-dimensional images using mathematical algorithms and imaging software.

The post-imaging processing also involved the application of a software filter to improve image quality by reducing signal noise.

This filter, developed by researchers at La Trobe University, was designed to enable retention of fine image detail while leaving important information, such as the geometry, distances, shape and distribution of the corrosion, unaltered.

### What the research found

Not all specimens exposed to the corrosive elements developed intergranular corrosion growth. It is not known why this was the case, but the researchers suspect that defects in the oxide film on the alloy surface may be implicated in cases where corrosion did develop.

When corrosion occurred, its depth increased with time and with increased level of relative humidity. The effect high humidity had was two-fold; equilibrium salt concentrations were lower, resulting in greater uptake of oxygen that drove the corrosion process, and there was less evaporation resulting in higher moisture coverage on the surface, making corrosion more prevalent.

For alloy AA2024, the depth of corrosion attack appeared to reach a limit after 96 hours exposure to 97% relative humidity, after which, corrosion grew laterally. With alloy AA7050, however, the depth of attack grew to the end of the test. Test times longer than 168 hours are therefore required to determine if a limiting depth exists for this alloy.

The researchers theorise that this difference in corrosion behaviour for the two alloys may be due to differences in the composition of the alloys at grain boundaries, giving rise to slightly different electrochemical conditions under which corrosion proceeds.

Increased exposures in length of time and level of relative humidity were also seen to cause an increase in corrosion volume for both alloys. Both exhibited similar volume growths with a large increase observed in the interval from 96 to 168 hours at 97% relative humidity.

Corrosion growth was found to occur fastest away from the surface initially exposed to corrosion for both alloys. This propensity is thought to be influenced by the metal grain structure, with higher growth rates occurring in directions where the grain structure allowed for a less tortuous corrosion path.

## Setting future directions for the work

In the course of the study, the researchers found that a specimen of one alloy showed less depth of corrosion attack at 168 hours compared to another exposed for just 96 hours. Similarly, some samples did not succumb to corrosion at all, even in conditions of high humidity and after a long period of exposure.

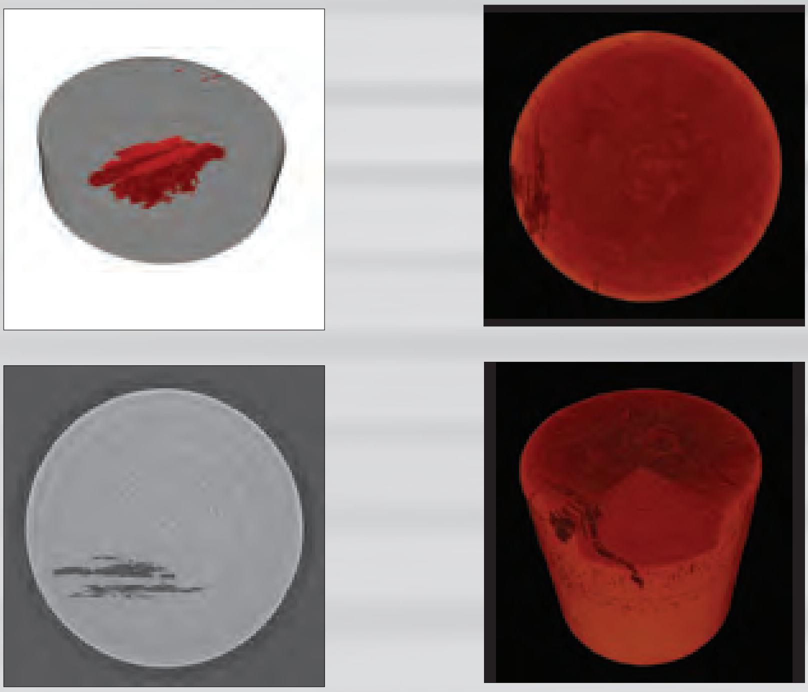
These findings suggest the need to study atmospheric intergranular corrosion growth by observing a single sample continuously throughout the corrosion process rather than by observing several samples exposed for different durations and under different humidity conditions.

This would also provide accurate information about when corrosion commences, which cannot be determined using a multiple-specimen post-exposure observation approach.

Real-time corrosion studies are not possible using standard X-ray sources due to the time taken to gain images. However, the much brighter X-ray illumination generated by a synchrotron, enabling images to be gathered much more quickly, makes *in situ* type corrosion studies feasible.

The DSTO researchers plan to extend their work in this direction using synchrotron facilities in the near future.

The recent work has been written up in a paper titled *The use of X-ray tomography in the study of intergranular corrosion on aircraft aluminium alloys,* co-authored by Steven Knight, Maria Salagaras, Alison Wythe, Benedicta Arhatari (La Trobe University) and Tony Trueman.



*Opposite page: DSTO researcher Maria Salagaras preparing test specimen for X-ray tomography examination.*

*Above: Alloy test specimen being subjected to corrosion growth conditions.*

*Above right: 2-D and 3-D imagery obtained of intergranular corrosion.*

*Right: DSTO researchers studying an intergranular corrosion image.*

# Knowing about local ways to improve mission outcomes

The development of research methods that better inform overseas deployed commanders about local cultural practices is proving very beneficial, and has also unearthed some incidental surprises along the way.

DSTO has for several years been assisting Australian Defence Force (ADF) commanders in the field with analysis of operational problems through the use of deployed Operations Analysis teams and the provision of 'reachback' access to research personnel and resources in Australia.

While operations analysis has been highly effective in solving problems that are quantifiable – queries of the 'how much' and 'how long' kind – its use for advising on task force strategies that involve social and community matters has been less successful.

The challenges in this latter regard arise from the fact that a community in an operational area may contain a mix of political, tribal and religious groups, and may also have cultural practices and understandings very different to those of the task force personnel.

These challenges are particularly problematic in unconventional conflicts, such as stabilisation or counter-insurgency operations, where long-term objectives are not clear and there are less tangible indicators of success.

"If the approach and principles of researchers are not correct in the way they conduct themselves, how they empower civilians, and in the techniques used to elicit information, then task force operations mounted on the basis of this information may be ineffective, or worse," explains DSTO researcher Alison Hickman.

Meanwhile, commanders are increasingly seeing a need for positive engagement with locals for mission success, and thus, are increasingly looking to operations analysts for assistance.

### Improved approach to community dealings

In recent years, Hickman has worked in a field called Community Operations Research (COR) to develop a methodology for gaining a better appreciation of local community workings.

Previous methods for doing so were largely adaptations of traditional mathematical and statistical operations analysis techniques, which are not well suited to understanding the complexities of human behaviour.

Hickman's approach, drawing from multi-disciplinary sources including sociology, political science, operations research, cognitive psychology and development practice, defines the principles and techniques for effective community engagement as well as ways to conduct rigorous research on the needs, perceptions and aspirations of target communities.

"At a strategic and operational level, achieving a better understanding of the complexities of human behaviour in a given community reveals trigger points for destabilisation, leverage points for influencing perceptions and insight into the population's concepts of positive change and their vision for the future," she says.

"The use of this approach overall makes commanders better able to decide on the right type of engagement, priorities and time required for projects, as well as appropriate measures of effectiveness for post-operations analysis.

"At a tactical level, COR training will equip soldiers to optimise their interactions with locals and better understand the value of what they are observing on foot patrols, and to avoid misinterpreting what they see through their own preconceptions."

### COR in action

The ADF is already successfully employing some community engagement techniques on an *ad hoc* individual basis in current counter-insurgency and stabilisation operations, such as the Mentoring and Reconstruction Task Force activities in Afghanistan.

One such success story coming out of Afghanistan is of ADF soldiers encouraging the use of local skills and resources for operation of a bakery. As a result of this initiative, and in conjunction with ADF efforts to make the area stable and secure, locals have resumed using the village markets and some also have been earning an income from the bakery.

*Main photo: DSTO Community Operations Research analyst Alison Hickman on deployment in East Timor.*

*Photo montage: DSTO Operations Analysts and ADF personnel deployed in East Timor, Solomon Islands and the Middle East.*

Meanwhile, a curious example of how well-intentioned efforts to assist a community can go awry was witnessed by Hickman in East Timor some years ago.

A consignment of soft toys sent to a village by a church group ended up adorning the approach to the village lashed to trees or as severed heads atop stakes, with some toys also being strapped to the front of vehicles as mascots – this outcome arising because the toy donors were not aware that these children do not play with soft toys.

## Training for analyst deployment

The research to date has delivered a Defence-tailored methodology — a set of ten Practitioner Principles —to enhance reflective practice.

This training package was delivered to the 2009 Operations Analysis course, and has been verified in the context of fly-away team research experience in East Timor in July last year.

# Solar energy for soldier mobility

With frontline soldiers becoming ever more reliant on electronic aids, the issue of battery power is as crucial as firepower for mission effectiveness, and technology to capture the sun's energy will soon provide vital support.

As part of the Australian Defence Force (ADF) soldier modernisation program, infantry soldiers are being equipped with a number of electronic devices to enhance their close combat tactical awareness, lethality and survivability.

Establishing a power supply for these devices that keeps them operational throughout missions is therefore essential to the success of this initiative.

Currently, soldiers are dependant on battery power provided by a wide range of conventional battery types. Each has different endurance and reliability levels, and each rechargeable type requires its own kit, compounding the bulk and weight needing to be carried. According to recent studies done on battery usage, 20 kg of spent lithium batteries are typically discarded by a single soldier during a five-week deployment, and up to 88 AA-cell primary batteries may be consumed on a five-day mission.

While battery technology research has delivered considerable improvements on this situation, the goal of a small, lightweight power storage system, capable of sustaining all electronic equipment for as long as the soldier can stay in the field, is seen to be still a long way off.

This being so, attention has turned towards ways of harvesting ambient energy using devices such as vibration transducers, thermoelectric converters, radio frequency collectors and photovoltaic cells. Of these, the solar option is currently seen to be the most viable and the most likely to provide a field power generation capability soonest.

*ANU researchers undertaking microscopic examination of an elongate photovoltaic cell (right).*

### Investigating the solar option

Work on developing person-portable solar power generation technology for use by the ADF is being undertaken by DSTO through a Capability and Technology Demonstrator (CTD) Program project with the Australian National University (ANU).

"A photovoltaic cell developed by ANU, referred to as monocrystalline elongate cells, is seen to hold the most promise for creating a system that meets ADF requirements," explains DSTO researcher Dr Vinod Puri.

Traditionally, silicon cells are made from slices cut from silicon ingots, forming a rigid brittle wafer about 150 mm in diameter and 0.2 mm thick. Under sunlight, each cell produces 0.5 volts, with output current proportional to cell area.

Elongate cells are thin silicon strips, typically 50 to 100 mm long, 2 to 3 mm wide, and only about 50 microns (thousands of a mm) thick – similar to the thickness of a sheet of paper or a human hair.

One form of elongate cell, called 'planks', is made using chemical etching and laser cutting techniques to divide a wafer of 10 to 20 microns thickness into hundreds of 2 mm-wide strips. Being fabricated at present in small numbers in ANU's laboratory, they are seen to perform well in terms of energy conversion efficiency as well as flexibility.

A similar type of elongate cell, called 'sliver cells', is formed by finely slicing through wafers of 2 mm thickness with a laser to produce thousands of strips just tens of microns thin, using the cut edge as the solar collection surface. This form of cell was also developed at the ANU, and is currently being commercialised by Australian company, Origin Energy.

These modes of production ensure that much greater user is made of a given volume of silicon – an expensive material due to the extremely high purity levels required – thus reducing the cost of producing solar panels, the original goal of ANU's work.

## Outshining its photovoltaic rivals

A further key attribute of ANU's approach is the use of monocrystalline silicon, considered the 'gold standard' material of choice for photovoltaic systems. This form of silicon offers high and reliable performance, with proven efficiency in converting sunlight into electricity of greater than 20% over the course of 20 to 30 year panel lifetimes.

It also delivers better performance than 'thin-film' cells of non-silicon material, which are currently finding use in flexible panels.

Made by depositing a layer of photovoltaic material onto a substrate surface of polymer or metal, thin-film cells perform less well at converting sunlight into electrical energy, and are less durable. For some applications, however, these downsides are offset by lower costs of production and the flexible lightweight nature of panels that can be made this way.

For frontline military use where minimising the weight and bulk of gear carried is the overriding consideration, monocrystalline silicon elongate cell technology stands out as a preferred option because of its capability to generate the most amount of power per kilogram of system weight.

## A system good for bright sun and shadowy places

The ANU CTD is investigating the possibility of using efficient elongate silicon solar cells to obtain power-to-weight ratios of greater than 150 watts per kilogram (W/kg) – a performance level more than five times that of currently available systems, and about three times that of state-of-the-art thin-film systems.

The reason such a high target has been set is that, unlike domestic and industrial uses of the technology where panels can be fixed in place to maximise sunlight capture, soldiers on a mission may not be able to avoid shading due to the need for concealment, and sunny days might not occur during the mission anyway.

Hence, a frontline military-use system must be capable of generating power under full light as well as in the low-light conditions of clouded skies and shade.

Also, unlike domestic and industrial uses, a frontline military-use system must comprise a much smaller area for portability purposes, meaning that high conversion efficiency is of great importance.

The ANU CTD is developing modules capable of generating battery charging voltage levels from a very small unit area – about one square centimetre. The overall system is made from many unit areas wired in parallel. This setup enables the system to continue supplying charge to the batteries under conditions of partial shade, unlike conventional panels whose outputs drop to nearly zero when just one or two cells fall into shade.

## A roll-up mobile power source

Being thin, elongate cells are not only very lightweight but also very flexible, to the degree that they can literally be wrapped around a finger. Initial work by ANU has shown high tolerance of these cells to flexing, unaffected by flexing to a curvature radius of just two to three centimetres even after 100,000 cycles.

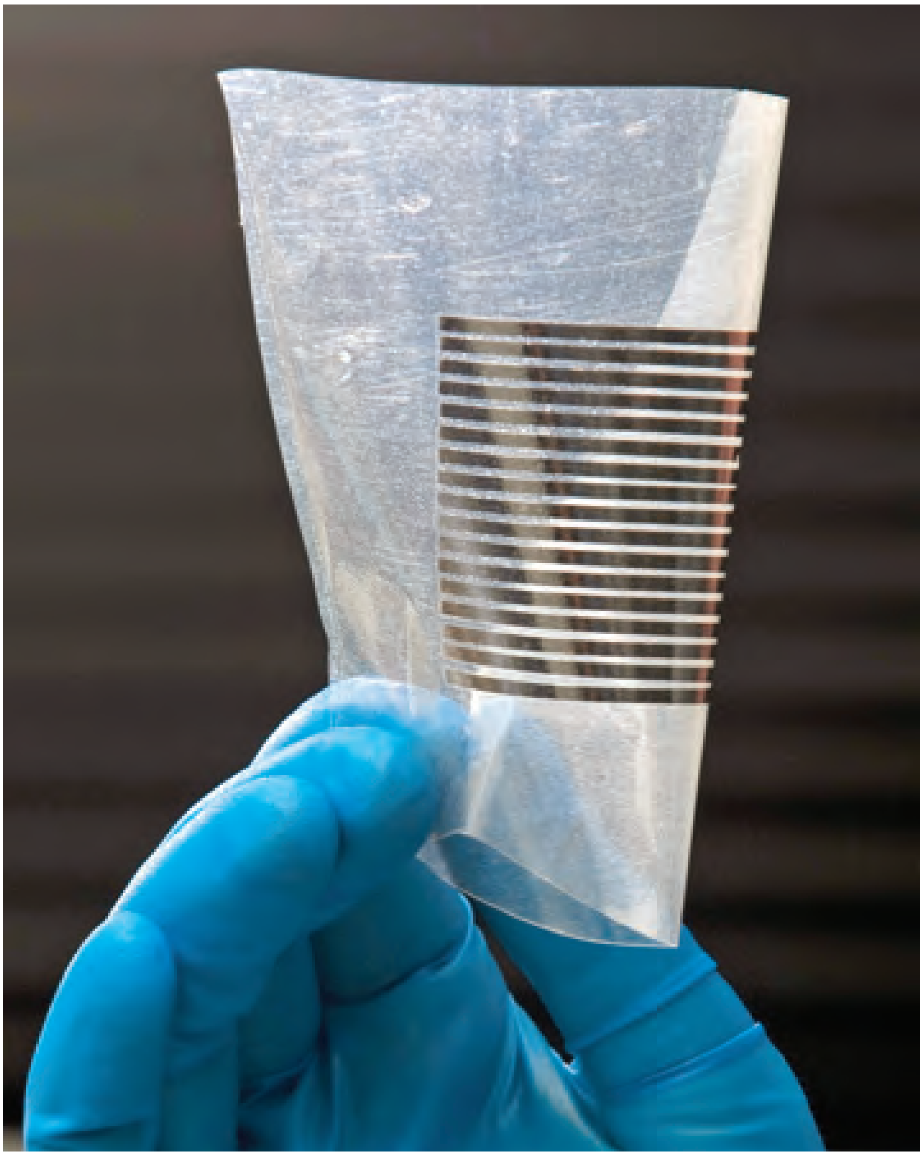
The university is developing a manufacturing process for fabricating micro modules of elongate cells using flexible transparent protective packaging. These modules are expected to have a bending radius of five centimetres, possibly less.

Because most of the weight of an elongate micro module is its transparent protective packaging, and the cells are highly efficient, very high power-to-weight ratios of hundreds of watts per kilogram are possible.

Even higher power-to-weight ratios are potentially achievable for short-term applications – above one kilowatt per kilogram – through the use of thinner, albeit less robust, packaging. This option is made possible by the fact that silicon is a durable material, and can survive outdoors for long periods with minimal protective packaging.

"A kilowatt-rated module for short-term use could feasibly be packed within the volume of a wine cask," says Puri.

The researchers anticipate that this form of technology could be available to the ADF within two to five years' time.



*Flexible photovoltaic module being developed by ANU.*

# Reducing the risk of missile strike

DSTO is applying engineering solutions that passively reduce the infrared (IR) signatures of aircraft by masking heat emissions.

All aircraft are vulnerable to a degree to attack from heat-seeking IR-guided missiles, but helicopters are particularly at risk due to their low operating heights and speeds plus the large amounts of heat radiation emitted by some types.

Of particular concern is the threat posed by shoulder-launched IR-guided missiles that have proliferated in regions such as the Middle East and Afghanistan where Australian Defence Force (ADF) personnel are serving.

Measures that lessen the IR signature of an aircraft can significantly increase its survivability by reducing the capability of an IR-guided missile to achieve lock-on, and if lock-on is established, they enhance the effectiveness of the defences that the aircraft can deploy to divert the incoming missile.

DSTO's measures to reduce ADF aircraft IR signatures take a variety of forms, including the use of suppression systems added to the aircraft structure to mask engine heat emissions.

One ADF platform receiving this kind of attention is the CH-47D Chinook Army transport helicopter, which is seen to be very susceptible to IR-guided missiles due to the nature of its flight envelope and deployment in regions where it might be fired upon by such missiles.

## Chinook IR suppression program

As part of a broader program for enhancing aircraft survivability, the Defence Materiel Organisation (DMO) funded the design and development of a scale model CH-47D rig to test infrared suppression concepts for the helicopter.

The rig was produced by GKN Aerospace, which has supplied scale models of other ADF aircraft to DSTO for component testing. The Chinook model was installed in DSTO's IR Suppression Test Facility in 2006.

At around the same time, DSTO embarked on a project with GKN under the Capability and Technology Demonstrator Program (CTD) to develop a prototype IR suppression scheme for the Chinook.

The CTD project consists of four phases: design and manufacture of one-fifth scale models of IR suppression concepts for testing at the DSTO IR Suppression Test Facility; design and manufacture of full-scale prototype units based on the selected concept; testing of the prototype at a suitable engine test facility and then installation and ground testing on a CH-47D; and finally, flight testing of the prototype on a CH-47D to assess IR suppression effectiveness in an airborne environment.

The program is currently well into the third phase.

## Preliminary DSTO activities

DSTO's initial role in the CTD was to produce conceptual designs of IR suppression systems for the Chinook according to specifications detailed in the CTD brief.

DSTO researcher Shane Favaloro explains, "These specifications called for designs that significantly reduce the contributions from the engines to the overall IR signature of the Chinook, that remain within certain weight constraints, and that do not impose any major losses in engine performance."

Two designs were developed for IR suppression schemes and evaluated via computer modelling with the use of fluid dynamics and IR radiation codes.

Based on this modelling, both designs were found to largely meet the above specifications, with some differences in performance between the two concepts noted.

GKN then undertook to design and manufacture one-fifth scale models of the two suppression concepts.

## Two IR suppression concepts

Both concepts involve modifications to the engine exhaust system by removing the existing tailpipe and replacing it with a purpose-built duct.

In both cases, they use air from the environs entrained by the exhaust gases to cool engine hot spots as well as to cool the exhaust gases, and also in both cases, the designs are intended to prevent direct line-of-sight viewing of the hotter parts of the engine and exhaust system.

In one of the designs, this is achieved by entraining a film of cool air through an outer casing over engine hot spots before mixing with the exhaust gases. The device then directs the combined cooling air and exhaust gases up and away at an angle.

In the other design, a similar cooling effect is achieved using cool air entrained through louvre structures surrounding a centre body structure that conceals the engine hot spots.

## Scale model concept testing

Experimental testing of the emitted radiation from both scale model suppression concepts, undertaken at DSTO's IR Suppression Test Facility, is now complete.

The test conditions simulated included the flight modes of hovering and maximum forward speed, with measurements of emission levels taken for these using an IR camera.

For both concepts, emission levels were found to be almost an order of magnitude lower in tail-on and upward-viewing directions when compared with those from the original tailpipe, and major reductions in radiation were also evident in other viewing directions.

Both concepts were therefore seen to substantially reduce the lock-on range for IR-guided missiles and enhance the effectiveness of existing countermeasures.

However, the first design concept was shown to perform marginally better than the second in terms of suppressing IR emissions detectable from tail-on and side viewing aspects.

Additionally, some drawbacks were identified with the second concept. Strong reflections of radiation from the plume and centre body were seen on the inner surfaces of the louvres, and the exposed parts of the centre body were not cooled as much as anticipated. Overcoming these shortcomings was seen to present difficulties in the short term.

Consequently, the first concept was selected for full-scale prototype development.

## Progressing the work at full size

Following concept selection, GKN undertook to finalise the design of the first concept for a full-scale prototype CH-47D IR suppressor.

The prototype was then built by GKN, and instrumentation for testing was subsequently installed at DSTO. In mid 2009, this was shipped to the United States for engine performance testing. Final testing of selected suppressor components was successfully completed in late 2009.

Two prototype IR suppressors – one for each engine on a CH-47D – are currently being manufactured and assembled in Melbourne.

The remainder of Phase 3 and Phase 4 of the CTD program will be completed back in Australia when an aircraft is available for ground and flight testing.

*Opposite page and above: Full-scale prototype of Chinook anti-missile countermeasure undergoing testing at DSTO Melbourne.*

# Major research effort delivers air power enhancement

Work undertaken by DSTO on deployment of the Joint Air-to-Surface Stand-off Missile (JASSM) from F/A-18 aircraft will help provide Defence with an important new capability, saving millions of dollars in the process.

DSTO's work was carried out in association with the Aerospace Operational Support Group (AOSG) in support of the Defence Materiel Organisation's Procurement Project AIR 5418.

The attainment of airworthiness certification for carriage and launch of JASSM from the RAAF's Hornets is a worldwide 'first' for F/A-18A/B aircraft. This is a strategically important capability for Australia.

DSTO's contribution to Project AIR 5418 began in 2003, with subject matter experts in a range of fields involved in a tender evaluation for the acquisition of a Follow-On Stand-Off Weapon that would enable ADF aircraft to launch a precision strike far from the reach of enemy fire.

Risk reduction engineering techniques were used to evaluate three competing candidate missile systems (including Lockheed Martin's AGM-158 JASSM) to determine whether they could be carried and released from RAAF Hornet F/A-18s and also Orion AP-3Cs, later dropped from consideration.

After JASSM's selection, DSTO then investigated issues arising from its integration into the F/A-18A/B weapons systems as well as how to test and effectively deploy it.

### Issues of carriage and launch

JASSM is a large, turbojet powered, non-axi-symmetric, long-range air-to-surface cruise missile that flies after launch using extendable folded wings and flight control fins.

"The size, shape and manner of launch posed a number of challenges for successful deployment with the F/A-18A/B platform," says DSTO researcher Andrew Snowden.

In order to study the airflow effects entailed by arming Hornets with this weapon, testing was carried out in DSTO's transonic wind tunnel using a sub-scale model of the missile, alone and in close proximity to a sub-scale model of the aircraft.

Computational fluid dynamic modelling was used similarly to study the airflow behaviour of an F/A-18A carrying a JASSM weapon with selected combinations of other wing-mounted deployable weapons.

This work and the wind tunnel testing were seen to be crucial to the success of AIR 5418.

In another line of inquiry, the DSTO researchers used a software flight dynamic model to investigate how the aircraft would behave in flight with JASSM mounted.

*Above: Computational fluid dynamic modelling graphic of airflows over F/A-18 carrying JASSM.*

Adapting an existing flight dynamic model of the F/A-18A/B for this purpose, the work set out to establish whether the aircraft's handling characteristics for particular asymmetric configurations and flight conditions would be adversely affected by carriage of the missile.

### Vibration testing

DSTO team members undertook vibration testing of JASSM mounted on an F/A-18 aircraft, conducted with the aircraft on the ground and in the air. Excessive vibration can damage sensitive components in the missile, impairing its operation.

During the ground vibration testing, electromagnetic shaker systems were used to vibrate both the aircraft and the missile, attached to an outboard wing pylon, and the effect on JASSM was measured using accelerometers. The purpose of testing was to quantify the vibration characteristics of both the F/A-18 and JASSM for a range of carriage configurations, as well as providing support for flight test analyses.

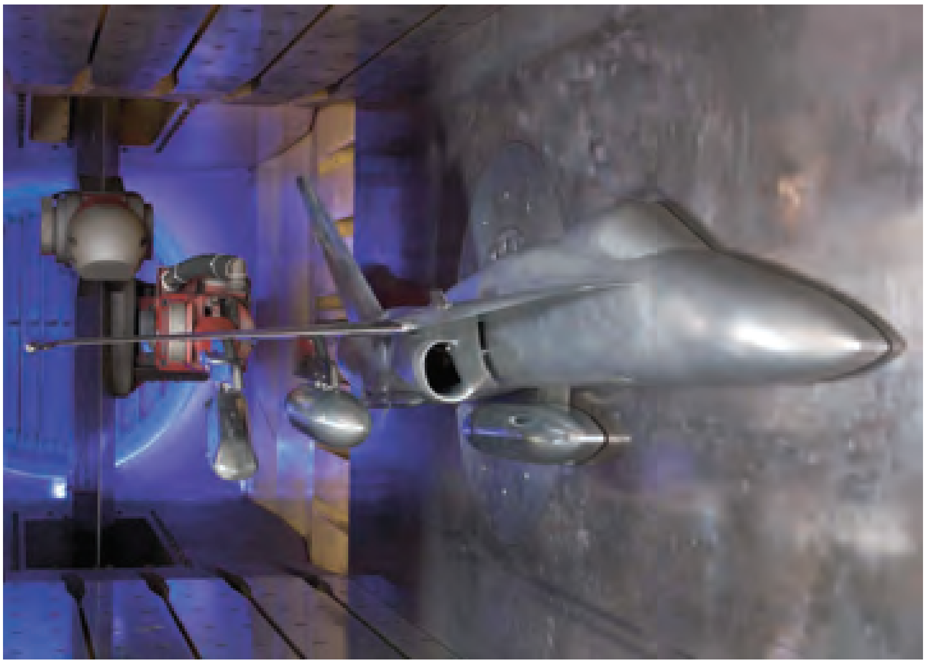
This analysis was undertaken on noise and vibration data acquired during flight tests, obtained using an instrumented version of JASSM carried on an outboard wing pylon of the F/A-18.

The aim here was to determine JASSM component vibration levels for carriage on the F/A-18 and compare these to levels encountered during its initial certification. This was done to determine a flight envelope – the safe limits of flight speed and manoeuvrability – that would not expose JASSM to more vibration damage than experienced in previous certification testing.

### Flutter testing

The term 'flutter' refers to large-scale oscillatory motion in aircraft structures such as wings, ailerons and body panels caused by the action of aerodynamic forces on flexible structures.

In severe cases, flutter can occur very rapidly, giving rise to large wing deflections that may cause the destruction of these and other structures, possibly leading to loss of the aircraft.



DSTO carried out computer modelling and analysis of flutter for the purposes of predicting the safe operating envelope for F/A-18s when armed with JASSM.

Following the completion of this work, flight testing was conducted to establish in actuality the safe operating envelope for such flight. The airborne study was undertaken in a carefully planned series of test flights that incrementally expanded the operating envelope.

DSTO was an active participant in this high-risk flight testing, thereby ensuring that the greatest possible operating envelope was obtained safely.

## Aerodynamic load analysis

Further analysis was required to investigate the additional stress placed on the F/A-18 airframe when carrying JASSM due to loads caused by aerodynamics and aircraft manoeuvring.

Ordinarily, load analysis is conducted by collecting data in the course of flight trials.

The DSTO and AOSG engineers, instead, undertook to arrive at load findings through analysis of existing F/A-18 aerodynamic load data along with wind tunnel data analysis and computational fluid dynamics modelling.

Through this work, they managed to successfully establish that flight testing was unnecessary, delivering savings to the project of several million dollars.

“The analysis was pivotal in establishing the operational limitations for carriage and deployment of JASSM from RAAF F/A-18A aircraft,” explains Snowden.

## JASSM launch process

The flight trajectory of JASSM after release from the aircraft was studied using the DSTO release evaluation suite (DSTOres).

The DSTO and AOSG researchers also studied aerodynamic data sets provided by Lockheed Martin, and afterwards developed a tool of high predictive accuracy to model the process of JASSM separating from the F/A-18A/B.

From this analysis came recommendations on timelines for the opening of JASSM’s fins after launch, a critical component of the AOSG program.

## The journey to impact point

Another DSTO study investigated the endpoint of JASSM’s flight, using a DSTO-developed computer-based analytical system called The Range Safety Template Tool (RSTT).

This form of study is required for safety reasons before real-world operational test and evaluation (OT&E) firings can take place on an Australian test range.

“RSTT is a world-first application that delivers accurate predictions of ground impact point using statistical methods and mathematical modelling of a weapon’s trajectory, taking into account likely equipment and system failure criteria,” explains DSTO researcher Kevin Robinson.

A further area of DSTO’s work involved that of designing the OT&E target site. Of relevance here are the forms of guidance used on JASSM, these being a GPS-aided inertial navigation system for midcourse flight, and an imaging infrared seeker and a general pattern match-autonomous target recognition system for target detection and strike.

“Ensuring a successful target strike therefore requires a high level of pre-mission planning that includes not just the target but also its surrounds,” says Robinson. “Correspondingly, to ensure that a test firing produces useful weapon performance findings, the test target and environs must be operationally realistic.”

Other considerations to be factored into OT&E target site design are the weapon attack profile, site signatures, target robustness and vulnerabilities, and environmental conditions.

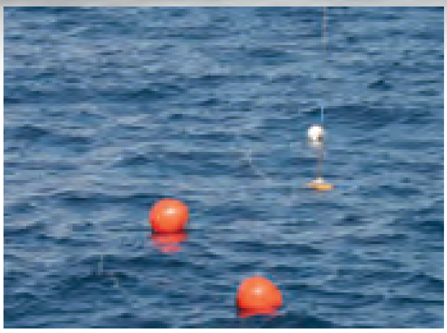
DSTO has also been providing advice on deployment matters such as mission planning and capability analysis.

Through involvement in the JASSM program, the organisation has acquired valuable new expertise and technological capabilities, better equipping it to undertake studies on the acquisition and deployment of other weapons.

*Top: Wind tunnel testing on F/A-18 carrying JASSM.*
*Above: JASSM mounted on F/A-18 for ground vibration testing.*

# On a whale hunt to save the wildlife

A study coordinated by DSTO on a type of marine mammal called 'beaked whales' has helped minimise the risk of harm to them arising from military exercises conducted in Australia's northern seas.



Beaked whales comprise several species of dolphin-like toothed whales, some of which are found in Australian waters. These are generally little known to researchers because of where and how they live.

"They are elusive hard-to-study creatures, being deep-water feeders in the seas beyond continental shelf drop-offs," explains DSTO researcher Mark Savage.

"The depths they can dive to are among the deepest for any marine mammal at nearly two kilometres, and they can stay under water for as long as an hour and a half. Like many other whales and dolphins, they use sonar sensing to locate their prey."

While much is yet to be learned about these marine mammals, one thing that is known is their sensitivity to human-generated sonar emissions.

In light of that knowledge, preparations for the biennial 2009 US-Australian Combined Task Force 'Talisman Sabre' exercise in the Coral Sea included a project to establish whether there were beaked whales in the area, and if so, what mitigation measures to apply.

## Searching in a wide blue ocean

DSTO was tasked by Navy to carry out a study on the number and distribution of beaked whales in the proposed exercise area, 200 nautical miles off Gladstone at the edge of the Australian continental shelf.

The work, funded by Navy Headquarters, Defence Support Group and Headquarters Joint Operations Command, was conducted from onboard HMAS *Labuan*, a Heavy Landing Craft vessel. The study team involved scientists from the University of Sydney, University of Queensland, Macquarie University and Curtin University of Technology as well as DSTO.

Two combined acoustic and visual surveys were undertaken over periods of three weeks in 2008 and 2009.

The acoustic survey involved the use of hydrophones to listen in on beaked whale sonar emissions. The devices included a towed hydrophone array and two free-drifting acoustic logger systems, suspended to depths of 400 metres.

From the acoustic data collected, researchers were able to identify the presence of beaked whales by the very distinctive sonar 'click' sounds they make while hunting.

The use of click sounds to identify individual beaked whales – these sounds being much higher pitched than humans can hear – was facilitated by computer software analysis of recorded signals.

## Findings drawn on an elusive subject

The visual survey results included 75 group sightings of marine mammals, numbering 526 individuals in total, of which, twelve individuals were beaked whales.

Meanwhile, some 500 hours of digital recordings were collected during the surveys. Many beaked whale click sounds were detected in areas around the sloping sides of coral islands and reefs in the area, suggesting a significantly greater number of individuals than were seen.

The work overall established that the waters around one particular location, Cato Island, was a favoured habitat. This study was the first time in Australian waters that visual and acoustic detection methods had been used together to determine beaked whale distributions, and that confirmed beaked whale vocalisations had been recorded.

According to CMDR Steve Cole, Navy's Environment Manager, "The trial results, obtained using new and very specialist equipment, greatly assisted us to tailor our environmental management practices and minimise the impact of exercises on the beaked whales."

*Top of page: Beaked whale. Photo provided courtesy of David Donnelly.*
*Above left: Free-drifting acoustic logger system deployed.*
*Above: DSTO research team member conducting visual survey for beaked whales.*

# Briefs

## Measuring propeller turns and torque to manage bio-fouling drag

DSTO is undertaking research on bio-fouling for Navy to improve the speed and fuel-efficiency performance of its vessels.

Bio-fouling is a major problem for fleet operators, particularly in tropical waters, because it can greatly increase the amount of drag a vessel experiences. Another problem it poses is that of translocation of invasive pest species between ports and operational areas.

The DSTO work involves fitting torque meters to the propeller shafts of an Armidale-class vessel to measure torsion strain and rotational speed. These measures thereby serve to indicate the level of bio-fouling buildup.

The work will be used to determine optimal intervals at which hull cleaning should be undertaken, and is expected to deliver substantial fuel savings for Navy.

## Assisting Army to learn more effectively from experience

The Australian Army is seeking to become a Learning Organisation (LO) as part of its Adaptive Army initiative to better equip itself for operations in today's highly complex environment.

In support of this LO development process, DSTO has embarked on a longitudinal research program that will establish ways of monitoring and improving Army's learning capabilities at the individual, collective and organisational levels. The research program will run until 2012.

A key part of the research involves the conduct of a questionnaire. Pre-testing of the questionnaire, adapted to measure learning in Army, was carried out at Puckapunyal last October and a pilot test with 3 Brigade in Townsville was run in November.

The questionnaire is now being launched Australia-wide, with responses being sought from all Army personnel in a wide range of locations.

Data produced by the current work will be used to generate LO profiles for a variety of formations and Army overall. These will benchmark progress already made by Army towards becoming a genuine LO, and establish a baseline for comparisons within and between Army and other organisations.

The findings will also serve to identify areas that create and maintain supportive learning environments as well as areas requiring improvement, with DSTO to make recommendations for effectively inculcating LO principles and practices.

## Better imaging capability for underwater explosion studies

DSTO has recently upgraded its facilities for research into the effects of underwater explosions on surface and underwater vessels.

This work, involving test detonations in a disused quarry along with computer simulations, is undertaken to support assessments of both the vulnerability of Navy vessels and the lethality of Navy weapons. The explosive tests are performed to explore the physics of underwater explosive damage, and to validate computer simulations.

In the course of a test explosion event, high-speed footage plus transducer measurements of acceleration, pressure and strain are recorded to investigate the complex events that unfold.

*DSTO's underwater explosion test facility.*

Explosion processes of interest include generation of the underwater shock wave and pulsating gas bubble, the transmission of shock and pressure waves through the water and their interaction with structures, the dynamics of the gas bubble, and responses exhibited by the target structure.

Following installation of a new camera with much improved spatial resolution and frame rates up to 60,000 per second – twenty times faster than before –critical short duration aspects of the explosion event can now be imaged. This represents a major advance in DSTO's ability to study such events.

Technology upgrades undertaken concurrently for data management and transfer operations have also delivered substantial speed and efficiency gains, further contributing to the establishment of more insightful, reliable and cost-effective study methods.

# Calendar

**1 - 2 Apr 2010** **Workshop on the Theory of Belief Functions**

*A workshop dedicated to the confrontation of ideas, reporting of recent achievements and presentation of the wide range of applications of this theory.*

Brest, France
**http://www.ensieta.fr/belief2010/**

**17 May 2010** **TTCP Defence Human Systems Symposium 2010**

*A symposium addressing Human Systems with a particular focus on Work Analysis, Teams and Anthropometrics.*

Australian Maritime Museum, Darling Harbour, Sydney
**http://www.dsto.defence.gov.au/events/5984/**

**24 - 27 May 2010** **OCEANS'10 IEEE Sydney Conference and Exhibition**

*An international event showcasing advances in marine science and engineering.*

Sydney Convention and Exhibition Centre, Darling Harbour, Sydney
**http://www.oceans10ieeesydney.org/**

**23 - 27 Aug 2010** **The 20th International Congress on Acoustics**

*An opportunity for acousticians around the world to meet and discuss recent advances in their fields of interest.*

Sydney Convention and Exhibition Centre, Darling Harbour, Sydney
**http://www.ica2010sydney.org/Home.htm**

**8 - 13 Nov 2010** **Multi Autonomous Ground-robotic International Challenge (MAGIC 2010)**

*Staging of grand challenge event. Jointly sponsored by Australian and US Defence to attract innovative proposals for development of next-generation fully autonomous ground vehicle systems for military and civilian emergency situations.*

South Australia, Australia
**http://www.dsto.defence.gov.au/MAGIC2010/**

**15 - 19 Nov 2010** **Land Warfare Conference 2010**

*A major event for users, providers, academics, designers and manufacturers to share new and visionary ideas on Land Systems.*

Brisbane Convention and Exhibition Centre, Brisbane
**http://www.dsto.defence.gov.au/lwc2010/**