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Situation awareness with SPAM

Harnessing energy from waste

DSTO research support for RAAF's Hercules C-130J

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, and employs about 2500 staff, including some 1300 researchers and engineers. It is one of the two largest research and development organisations in Australia.

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Cover image: RAAF C-130J Hercules dispensing flare reserves carried for infrared- guided missile defence as a standard onboard fire safety measure prior to landing at RAAF Base Amberley.

New technique for assessing situation awareness

DSTO is using a technique called Situation Present Assessment Method (SPAM) to examine the impact of new submarine operator-system interface technologies on situation awareness.

Previous ways of studying situation awareness have involved asking the operator questions after the completion of a task, or interrupting the task at various stages to ask questions.

Both these approaches have drawbacks.

Concerning the former, asking an operator about the performance of a task afterwards may result in minimal levels of recall even though the person could well have had very good situation awareness during the exercise.

"The situation is very much like that of driving home after work," explains DSTO researcher Kate Ponton. "While we manage to arrive home safely each time, having had really good situation awareness throughout, we may have little recollection later of the individual moments of the journey."

Similarly, the latter approach of interrupting a mission exercise to ask an operator questions reduces the realism of the exercise, impinging on study outcomes in that way.

SPAM solution

The innovation the SPAM approach offers is a way to ask questions during an exercise without requiring the exercise to be paused. This maintains exercise realism and overcomes the issue of potentially limited operator recall that would arise with post-exercise questioning.

SPAM situation awareness studies can be carried out on just one operator or possibly several during a given exercise. Applying the technique involves firstly asking participants if they are ready for a question to ensure no workload problems bear on their abilities to respond. The questions asked are typical of those that Command would put to operators, enhancing the realistic feel of the exercise.

Since good situation awareness requires a good grasp of current happenings as well as those expected to happen, the questioning is designed to probe situation awareness for both present and future time frames.

A question on future situation awareness, for example, that might be asked of a submarine commander is, 'How many vessels do you expect will be within ten thousand yards of your boat in five minutes from now?'

The responses from operators are later checked for correctness against exercise data about what actually happened, thereby enabling measures of operator situation awareness to be derived.

Simulation exercise results

To test the usefulness of SPAM in a simulated submarine environment, a study was conducted at DSTO Stirling involving teams of tactical operators led by a Watch Leader.

The teams completed two scenarios, one considered a baseline scenario, and one with greater uncertainty levels involving a number of abrupt and fade-in fade-out vessel contacts.

"The results showed that SPAM is sensitive to picking up differences between current and future situation awareness," says Ponton.

"The uncertainty built into the second scenario led to an increase in workload with fewer correct responses being given to SPAM questions. As well, questions about current situation awareness took longer to answer.

"These findings show that SPAM has promise as a tool for measuring situation awareness."

Studies to assist future Navy

DSTO in collaboration with the University of Western Australia is investigating several human performance measures, including the SPAM technique, to assist human-systems integration research being done for the development of future Navy platforms.

This work, led by Dr Sam Huf, takes a 'big picture' look at all the human factors issues involved in submarine operations, not just particular technology aspects.

The research is providing good measures for assessing control room and combat system design concepts, and, potentially, performance in operator and command training.

Above: DSTO researcher Kate Ponton conducting Situation Present Awareness Method survey during simulated submarine operations exercise.

Herculean research effort for a key Defence aircraft

The RAAF's Hercules C-130J aircraft provides the Australian Defence Force (ADF) with a medium to long-range transport capability, and DSTO research carried out over the past decade has helped keep this workhorse flying effectively and safely.

The C-130J, introduced to service with the RAAF in 1999, can carry a payload of 18 tonnes over a range of 5,000 kilometres. It is flown by a minimum crew of just three – two pilots and a loadmaster – with flight deck avionics that feature state-of-the-art 'head up' computer-operated displays and controls.

The ADF's fleet of 12 is operated by 37 Squadron from RAAF Base Richmond near Sydney. The tasks they can undertake include troop transport, special forces insertion, force parachute drops, air drops of vehicles, equipment and supplies, search and rescue operations, aero-medical evacuation and disaster relief.

DSTO has played a vital support role to the ADF in maintaining and enhancing C-130J capabilities through research work done in a range of areas – from vibration control to survivability against guided missile attack and structural integrity.

Airframe structural integrity

One aspect of work in this area involves measuring and modelling stress loads typically experienced by the aircraft.

In-flight stress data are gathered by strain gauges attached to critical parts of the airframe. This information then provides the basis for computer simulations that can be used to investigate the effects of different workloads and flight conditions on the structural response.

Another related aspect involves conducting fatigue tests on the aircraft structure to ascertain the locations where cracking will occur and when these cracks will become a safety issue.

Fatigue testing involves subjecting an airframe structure, such as a wing or fuselage, to the stresses typically experienced in flight by mounting the structure in a rig and exposing it to representative forces through the use of actuator devices. During testing, the structure is periodically inspected to establish when and where damage onset occurs, thus providing a measure of flying hours that would produce the same effect.

The findings from this work enable accurate determinations to be made about how long an aircraft can safely fly before maintenance and repairs need to be undertaken.

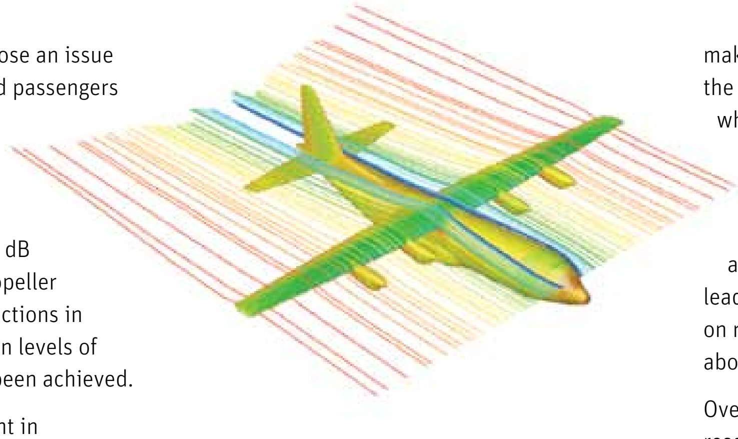
Noise and vibration analysis

In support of a rapid acquisition project, a concern that required study was the impact on the aircraft of dispensing flares as a countermeasure to infrared-guided missile attack. To determine this impact, the structural strength and vibration characteristics of the C-130J airframe had to be taken into account.

DSTO accordingly undertook vibration testing of a C-130J in a hangar. Prior to testing, the C 130J's flare dispensing system was integrated into the aircraft. The ground vibration test program, successfully completed at short notice, provided results used by the RAAF Aerospace Operational Support Group to establish suitable firing intervals for various countermeasures from the aircraft's multiple dispenser locations. These results helped enable the deployment of 37 Squadron overseas in fulfilment of ADF operational requirements.

In another study, airframe vibration was measured during flight trials to quantify the vibration levels and spectrums present throughout the cargo bay and on palletised cargo. Of particular concern was the vibration environment exposure of vibration-sensitive cargo, such as explosive ordnance. Differences in the vibration environment from the RAAF's previous model of Hercules, the C-130H, were quantified and vibration qualification spectra for C-130J transport were defined.

Above left: Fatigue testing setup for C-130J airframe.
Above centre: Airframe vibration testing apparatus in C-130J cargo hold.
Above right: C-130J propeller balancing work in progress.



Noise and vibration also pose an issue for the comfort of crew and passengers on board the C-130J, with noise levels generated by the engines reaching rock-concert proportions of 115 dB or more. By optimising propeller synchrophase angles, reductions in average noise and vibration levels of approximately 8 dB have been achieved.

Another major development in this area is a propeller balancing technique that makes use of data on vibrations gathered during flight.

This new approach eliminates the need to fit and remove additional ground support equipment and ground running of the engines, and can be completed between flights during aircraft turnaround times. Estimated savings for Defence over the aircraft's lifetime are in excess of $2 million per aircraft due to fewer maintenance hours required and fuel savings from the eliminated engine ground runs. A further gain is that of increased aircraft availability.

DSTO's software is now considered by other C-130J fleet operators to be an invaluable aid, and will soon be in use under licence in the UK, Italy, Denmark, Canada and Norway.

Combating corrosion

The aluminium alloys used to construct aircraft offer exceptional resilience to stress through heat-treatments applied during manufacture. Some of these treatments, however, can make these alloys very susceptible to corrosion when in contact with moisture.

DSTO has assisted in implementing two key approaches to managing this problem.

One involves the process of Retrogression and Re-ageing, a heat-treatment technique applied to the aluminium alloy using an oven that alters the alloy's crystalline structure to make it more corrosion resistant. DSTO is currently working with the ADF and the Defence Materiel Organisation to certify the technology for use on C-130J aluminium alloy 7075-T6 components.

The other key approach is a technique called Corrosion Reliability Centred Maintenance.

This involves firstly detecting the precursors to corrosion, which may include loose or missing rivets, damage to protective coatings in the form of blistering, peeling and cracking, and water stains or discolouration. Pro-active measures can then be taken to prevent corrosion occurring, thereby avoiding expensive and time-consuming replacement or repair.

Infrared signature measurement

Measuring and modelling C-130J infrared radiation emissions is crucial to assessing the aircraft's vulnerability to detection by infrared-guided weapons and surveillance systems.

DSTO has produced a detailed computer model that predicts infrared emissions for the C-130J arising under particular operational conditions.

To arrive at this capability, measurements were firstly made of the infrared emissions emanating from different parts of the aircraft – propellers, engines and skin – using infrared cameras. The state of various parameters influencing emission levels was also measured. Upon entering all this data into a computer model, simulation studies of emission outcomes for different flight conditions could be conducted by simply altering input parameter levels.

This work has helped establish ways of modifying C-130J operational use that limit its vulnerability to infrared threats. It has also served to optimise the electronic warfare self-protection capability of the aircraft.

Human factors

Following the decision by Defence to acquire the C-130J in December 1995, a critical issue to be determined was whether missions previously conducted by a crew of five, as used on the RAAF's C-130H model aircraft, could now be successfully handled by a crew of just three.

The model upgrade delivered by Hercules' maker, Lockheed Martin, involved removing the positions of navigator and flight engineer while introducing advanced computer-based flight deck avionics with significant levels of automation.

At the time that the RAAF's C-130J aircraft were acquired, Australia was a lead customer, and thus had to rely heavily on research done in-country for answers about such human factors questions.

Over the past decade, DSTO has provided research support on a range of crew performance issues including workload capabilities, situation awareness, and the use of night vision goggles for a range of tactical missions including unlit, unsealed airfield landings.

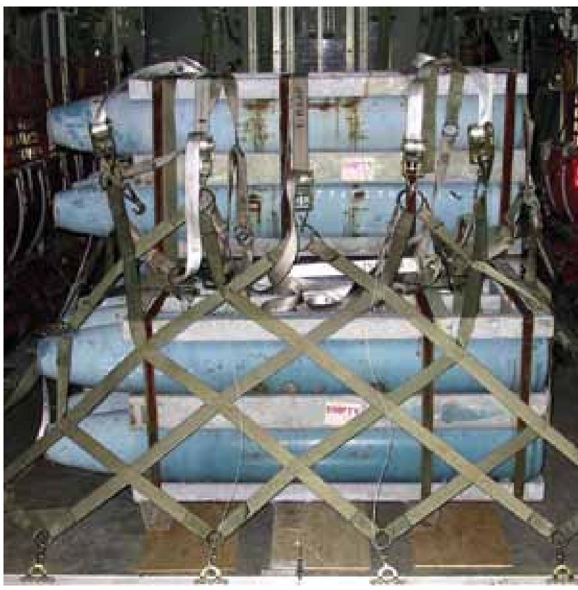
Maintaining low visibility with paint

After several years of service, the original paint scheme of the C-130J aircraft had faded, increasing its visibility and susceptibility to detection by night vision equipment.

In responding to these concerns, DSTO developed an improved paint scheme that uses counter-shading – a form of camouflage where the aircraft is darker on the top. This makes the aircraft blend into its background environment when viewed from either above or below.

Not only does the paint scheme offer low visibility to the ground observer, it is also effective against night vision equipment and lessens the aircraft's susceptibility to infrared threats.

DSTO's support overall for C-130J operations is expected to continue as far as 2030. Ω



Top: 3D graphic display of computational fluid dynamics modelling of stresses experienced by C-130J airframe in flight.
Above right: Measurements being taken of C-130J airframe vibration levels and spectrums impacting on palletised cargo.

Studying snorting pressures on submarine diesel engines

When a diesel-powered submarine runs its engines while operating at periscope depth, exhaust backpressure levels can greatly impact on engine performance.

Diesel engines have been the primary source of mechanical power for submarines ever since the advent of these boats, and continue in common use today. Modern diesel electric submarines use the diesel engine to generate electricity, which is stored in banks of batteries that power electric motors for both surface and deep running.

Operating the diesel engine requires the submarine to be at or near the surface so that oxygen for combustion can be obtained from air. To facilitate stealth, an air inlet snorkel is used, enabling the boat to remain submerged at periscope depth – a mode of operation known as 'snorting'.

***Main photo:** HMAS* **Dechaineux** *crew member inspecting the boat's diesel engine.*

***Above right:** Dr Peter Hield with DSTO's research diesel engine at HMAS* **Cerberus.**

The consequences of snorting on engine operations, compared to those of surface running, are that exhaust pressures are much higher since the engine exhaust gases have to escape through several metres of water. With water being far denser than air, it takes much more effort to displace, meaning the engine must work harder, which in turn has various impacts on engine efficiency and reliability.

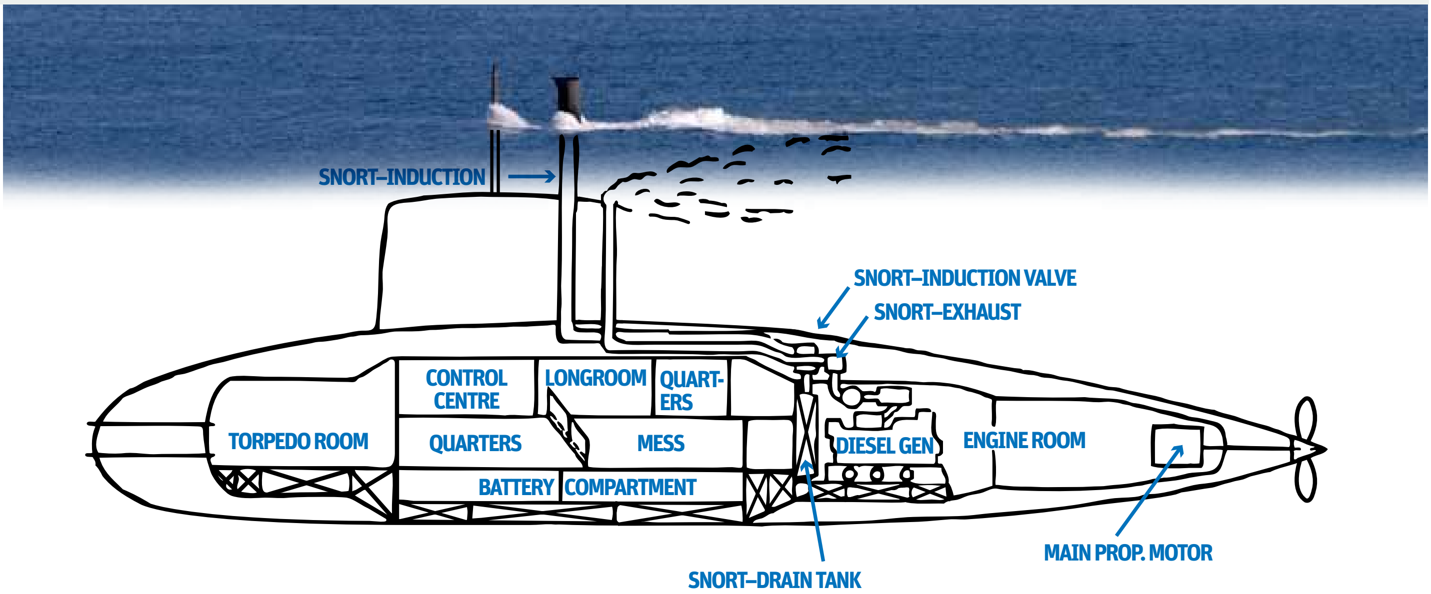
Moreover, the depth of water the boat passes under varies according to the wave heights and intervals of the wave field involved, with exhaust backpressure varying in a cyclical manner in association with both wave amplitude and periodicity. When backpressure increases, greater fuel flow rates are required to deliver the power needed to maintain constant engine speed, and the engine overall is put under increasing stress. One manifestation of this is higher temperatures.

Although snorkels and the practice of snorting first appeared in use as far back as the 1930s, little research has been done so far on the associated problems. Against this background, DSTO recently undertook investigations to arrive at a better understanding of the problems and thus establish how engine performance can be improved.

Turbocharged diesel engine research

The work examined the effect of increased backpressure on an 11-litre straight-six turbocharged diesel submarine engine operated in snorting mode. The engine was assumed to be turning a generator with a constant torque load of 1,000 Newton metres running at a constant 1,800 revolutions per minute.

To carry out this study, an engine modelling tool called *Ricardo Wave* software was applied.



"*Ricardo Wave* provides a powerful tool for investigating the behaviour of engines under varying backpressure conditions," explains DSTO researcher Dr Peter Hield.

"The software also has the capability to model engine control systems, allowing the development of control strategies to mitigate the effects of the varying backpressure."

The study firstly considered the effect of steady-state backpressure conditions as would arise with a constant depth of water above the engine exhaust. Baseline backpressure levels were assumed to be 1.45 bars (1.45 times atmospheric pressure at sea level), which are considered typical for submarine operations.

Later, the added complication of cyclically varying backpressure conditions was examined, thus taking into consideration the effects brought to bear by various wave heights and periods. While actual waves have steeper peaks than troughs – a wave shape known as trochoidal – these are difficult to manipulate mathematically, and so, waves were assumed to be sinusoidal.

Outcomes

The study arrived at a number of findings, the overarching one being that variations in backpressure cause large effects on engine output, with the scale of effects dependent on the initial state of engine operations plus the amplitude and period of backpressure variations experienced.

This outcome was found to be mostly due to the effects of varying backpressure levels on turbocharger performance, with high backpressure levels leading to restricted engine air supply.

While engine responses to changes in backpressure were virtually linear for wave heights of three metres at ten-second intervals (equivalent to conditions of Sea State 3), the response became increasingly non-linear as the wave heights increased further.

Varying the period of the waves had similar effects, if less extreme. Reducing the period caused an increase in amplitude of the fluctuations in most engine parameters, but below the period of four seconds, fuel fluctuation amplitude was reduced, presumably due to the finite response speed of the engine's governor. At the other extreme, increases in wave periods reduced fuel flow amplitude – up to a duration of twelve seconds, beyond which, no further effect on amplitude was seen.

Part of the work involved studying lags in the system, with attention given to the operations of the engine's speed governor that maintains constant speed by adjusting fuel flow. Since a lag inevitably occurs between changes in conditions and engine response, fluctuations in engine speed over and under the required speed arise in response to changes in backpressure before a stable point of operation is reached again.

Heat effects

Meanwhile, exhaust gas temperatures were found to rise significantly with increasing backpressure due to the increased power required to overcome the additional exhaust pumping work and the reduced airflow. In addition, backpressure fluctuations can cause large exhaust temperature fluctuations, which further increase the maximum temperature and also induce a thermal cycling effect.

"The increase in temperature, if left unchecked, may result in failure of pistons, cylinder heads and valves via phenomena such as torch erosion and thermal fatigue cracking. High local heat flows through the piston rings can lead to breakdown of the oil film, which causes fretting and increased wear of the pistons and cylinder walls. Thus, excessively high exhaust temperatures lead to a reduction in engine reliability," says Dr Hield.

Having established these findings using a modelling approach, Dr Hield and co-workers are developing an experimental program to validate the model and to investigate methods of improving the performance of turbocharged submarine diesel engines. Ω

***Above:** Photo shows HMAS* Dechaineux *running in snorting mode with the top of periscope and the snort inlet tube above the water's surface. Diagram shows schematically how the submarine operates its diesel engines when snorting.*

Supercharger versus turbocharger

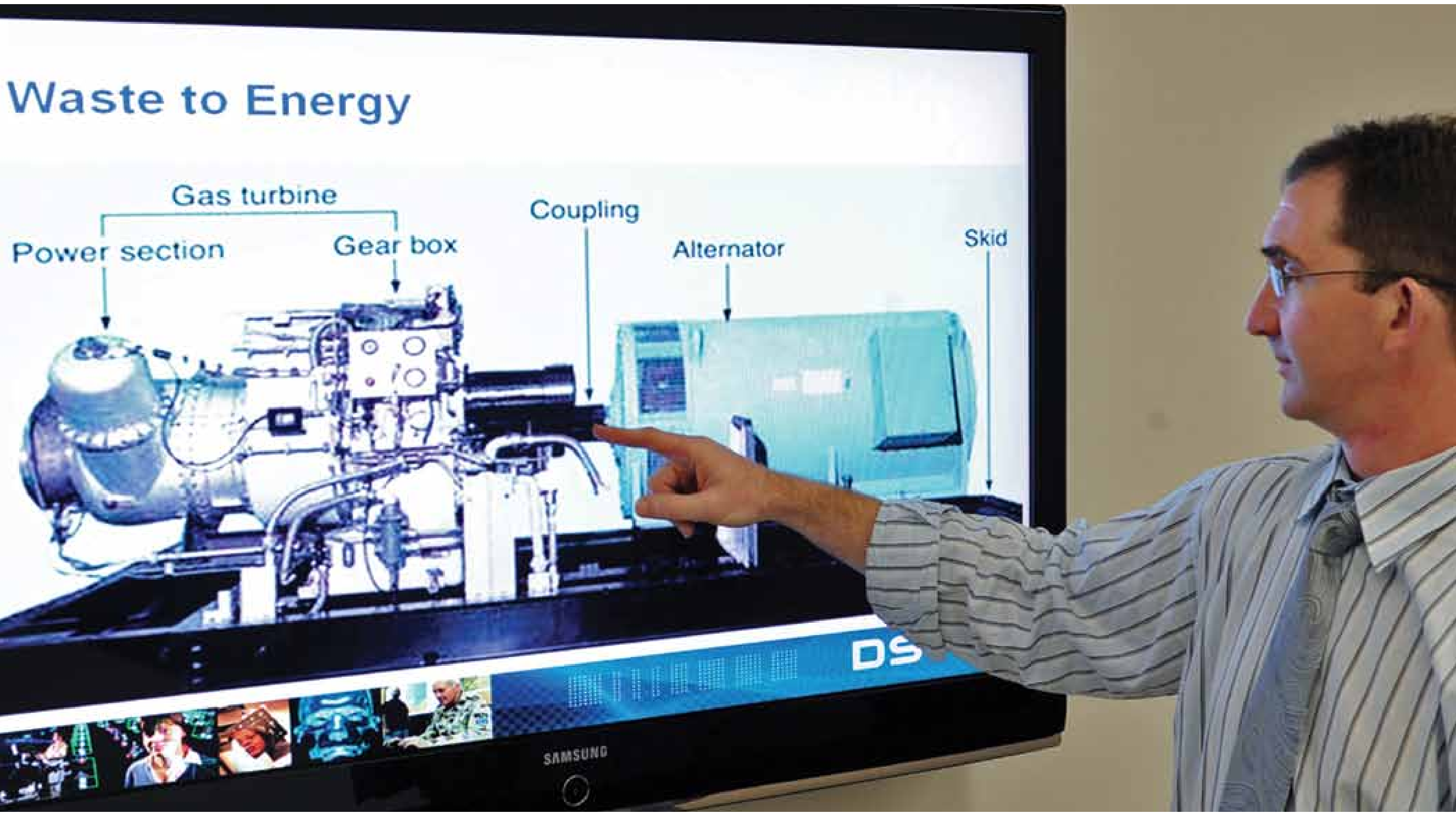
Diesel engines, like all forms of internal combustion engines, can be performance-enhanced by the use of air compressor technology in the form of supercharger or turbocharger devices.

These deliver much greater volumes of oxygen for combustion than available through normally aspirated carburetor systems. Each kind has its advantages and disadvantages.

Superchargers are less susceptible to inlet and backpressure variations, but draw the energy needed to compress air from the engine crankshaft, thus imposing an extra load on engine output.

With turbochargers, the compressor is powered by a turbine driven by exhaust gases, harnessing energy that would otherwise be wasted. A turbocharged engine therefore offers greater fuel efficiencies for a given power output, but at the same time, is much more susceptible to variations in performance due to the impact of pressure variations on turbocharger output. Ω

From waste disposal problem to energy source asset



DSTO and HRL Technology are developing a capability that uses the solid waste produced by deployed forces to power their electrical energy needs.

The issue of waste management for deployments is no small matter, with each force member generating about two to six kilograms of waste per person per day.

For an ADF battalion of 500, total waste generated is in the order of one to two tonnes per day, and at the Joint Task Force level, around 48 tonnes per day. This waste material consists largely of paper, cardboard, wood, plastics and food – all of which are readily combustible when dry.

Managing waste materials in such volumes, a significant logistics burden, has conventionally been handled by burial in landfill deposits or by burning in open pits.

Both methods result in environmental degradation, the latter being of particular concern on health grounds since uncontrolled burning releases large amounts of irritant smoke and associated pollutants. These emissions have recently been linked to cases of chronic illness experienced by US soldiers.

Fuel costs in the field

Another major concern for deployed operations is that of energy needs, with fuel required to run transport for operational and logistical purposes as well as to supply the base with electricity.

According to studies done by the US Department of Defense, about one third of all fuel delivered to forward bases is used in diesel powered electricity generators for base power supply.

The cost of delivering the various kinds of petroleum fuel required is considerable. One such cost is the toll on personnel wellbeing, with three casualties being sustained per hundred fuel convoys on average.

The other cost in material terms includes costs associated with transporting fuel over long distances via possibly several modes of conveyance – air, sea, land – throughout which, protection from attack is required. Costs per litre for delivered fuel, referred to as 'fully burdened costs', may therefore be many times that of retail rates.

Meanwhile, research has established that the energy embodied in a tonne of solid waste when burnt is equivalent to about 350 litres of diesel.

'Win-win' outcomes

An approach to waste management based on burning it in a purpose-built heat energy capture system offers a range of advantages over that of diesel fuel savings.

It also reduces the landfill impact on the environment, averts the risk posed to personnel from open pit incineration, and lowers the greenhouse gas impact of the deployment overall.

Concerning this last outcome, a salient factor here is that the organic materials in solid waste, such as wood, paper and food, biodegrade after burial and give off methane.

Although the volume of methane produced by buried solid waste is much less than the volume of CO^2 gas produced by burning it, the global warming impact of the methane released is of the same order of magnitude since it is a much more potent greenhouse gas.

One tonne of buried waste produces a volume of methane equivalent to the release of 0.85 tonnes of CO^2 gas. Burning the same tonne of waste would produce about one tonne of CO^2 gas. Hence, the global warming impact of burning the waste is only marginally greater than that of burying it.

If the heat produced during burning is harnessed for electricity generation, the emission of many tonnes of CO^2 gas otherwise occasioned by burning diesel fuel can be avoided. Thus, the greenhouse gas impact of the deployment will be markedly reduced.

As for impact in terms of volumes of waste going to landfill, burning the waste still leaves ash that needs disposal, but this amounts to only five to ten percent of the original volume of waste.

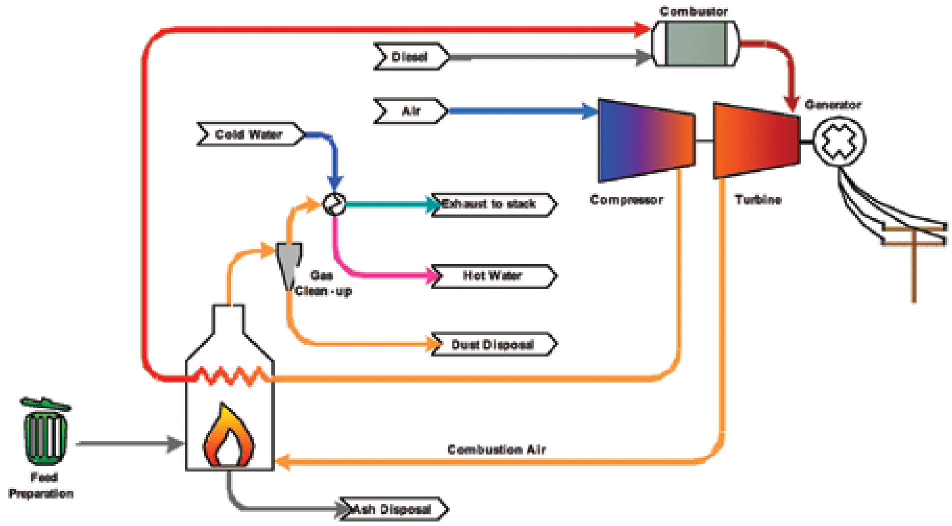
Building on this background state of knowledge, DSTO has launched a project to investigate the potential of energy in deployment waste to offset diesel fuel needs and to deliver associated benefits.

DSTO's proposed waste-to-energy system

The initial phase of the study investigated a number of emerging and mature technologies to appraise the qualities they offered.

"Sought-after features included the ability of a single technology to process a range of solid wastes, notably food, in volumes of one to five tonnes a day," says Dr Chris Hulston. "The technology was also required to be simple and robust for ease of maintenance in the field, need little water for operation, and be transportable in just one or two shipping containers for ease of deployment."

One option that met each of the project criteria involved the use of hot combustion gases to heat compressed air for subsequent expansion through a turbine, thereby avoiding the need for large amounts of water.



Such a system could be assembled using well-established commercially available technologies, including solid fuel combustion units, heat exchangers and gas compression and expansion turbines. Also available are technologies to control emissions of particulates and pollutants to the environments.

Operational options include the alternatives of diesel fuel only, waste only, or a combination of both depending on the availability of waste and the power needs of the site at a particular time. The diesel-only and combination fuel source options also give the unit the capability to provide electricity with very short start-up times and in situations where only small amounts of waste are available.

Another important design feature is the use of waste exhaust heat for fuel drying, including fuel in the form of wet food, and for producing hot water and steam for use by the deployment.

Modelling the energy solution

Initial process modelling of proposed system configurations has shown that for a deployment of 500 to 1,000 personnel, a 200 kW externally fired gas turbine would be optimal.

At this scale, the capacity for power generation per hour would be in the order of 80 kW to 110 kW running on burnt waste only, and around 200 kW when co-fired with diesel.

The waste heat could also produce around 150 litres of hot water per hour.

Waste-to-energy system performance at these levels would deliver fuel savings in the order of 50 litres of diesel per hour. On a per–annum basis, using fully burdened cost figures ranging from $2 to $10 per litre of diesel, cost savings for the ADF would be around one to five million dollars.

Compact and flexible field asset

Commenting on the advantages offered by DSTO's proposed system, Hulston says, "The beauty of the technology is that it's relatively small and deployable and requires little or no water.

"The system could also be used at military bases between deployments to generate power, thereby saving on fuel costs and lowering Defence greenhouse emissions as well as waste sent to landfill.

"We're hopeful that such a system would be suitable for use in disaster relief situations, such as the recent floods in Queensland, these being situations when many electrical assets are destroyed and large amounts of combustible waste or debris are available," he says.

A proposed technology development venture, titled In-theatre Power Generation from Waste, is currently under consideration by the Department of Defence's Capability and Technology Demonstrator Program. If successful, a prototype unit is expected to be ready for initial demonstration trials some time in 2013.

Opposite: Dr Chris Hulston with image of waste-to-energy technology setup.
Top: Schematic diagram of proposed waste-to-energy system.
Above: US Air Force servicewoman in Iraq disposing of deployment waste in open pit incinerator. (Photo: US Air Force.)

Sentinel stands guard against submarine threats

DSTO has developed a sophisticated, long endurance, acoustic surveillance system for monitoring maritime activity in coastal waters.

Sentinel is a passive underwater listening device that can be used in shallow coastal areas for the protection of harbours and forward deployed forces.

Designed and built by DSTO over the past three years, *Sentinel* features advanced acoustic signal processing that allows it to discern faint vessel signatures from background ocean noise.

"Individual *Sentinel* units are able to detect targets and provide a direction finding capability, and the use of multiple units in an area enhances the technology's ability to localise and track targets," explains DSTO engineer Matthew Steed.

Seafloor snoop par excellence

Each unit consists of three parts: a seabed component for acoustic signal processing and power control, a string of sensors attached to the seabed unit for collection of acoustic signals, and a float device cabled to the seabed unit to provide secure satellite and 3G radio communications with a shore base.

Sentinel can be deployed from almost any small work vessel in a matter of minutes. The seabed unit, with its acoustic sensors, is manually lowered by cable to the sea floor and the cable is detached. The unit then immediately begins to collect and process data.

All control and monitoring now occurs remotely, undertaken either from the work vessel or shore base.

When system retrieval is required, a recovery float and line are released from the seabed unit, and the equipment is hauled back to the surface using a small capstan winch on the workboat.

Intelligent and enduring

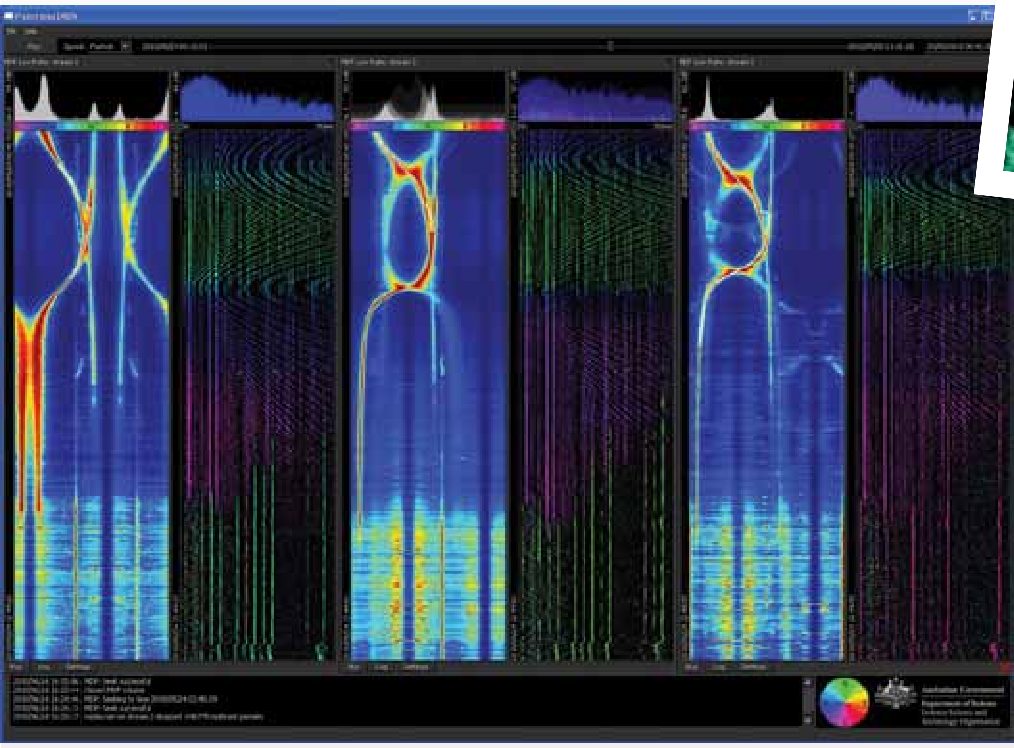
One goal for the designers was to make the units small and light for ease of handling during deployment, while remaining substantial enough to survive the rigours of the marine environment. At around 60 kilograms, *Sentinel* is only a tenth of the weight of previous DSTO-designed systems.

Another performance priority was the efficient use of power resources to enable long deployments with minimal battery size. *Sentinel* is capable of operating continuously for 300 hours, and through the use of a 'sleep' command, can remain deployed for periods of several months.

Smart signal processing maximises the performance of the acoustic sensors, and data compression reduces the amount of information that is transmitted to the shore facilities. The type of processed data sent can be tailored to suit the capacity of the communications link.

"We've designed flexibility into *Sentinel* in order to investigate different signal processing techniques," says Steed.

Above left: **Sentinel** ***system with hyrdophone array (left), seabed unit (centre) and surface float for communications to shore base (right).***
Above right: DSTO researcher deploying **Sentinel** ***unit during trials.***



Inadvertent test of *Sentinel's* durability

In the course of the Western Australian anti-submarine exercises, one of the deployed *Sentinel* seabed units experienced a power failure that prevented it from being brought to the surface using the built-in recovery system.

Recovery attempts using the surface float communication cable also proved unsuccessful. The cable snapped and the seabed unit ended up back on the seafloor 75 metres down.

Three months passed before it was retrieved with the aid of a remotely operated underwater vehicle. An inspection of the rescued unit found that no internal damage had been sustained despite its prolonged unscheduled stay on the seafloor.

The cause of the power failure was identified as a minor leak at one of the connector interfaces.

On trial at sea

Sentinel's performance has been tested at sea in order to inform Navy about ways of using this capability and to identify limitations of this type of deployed sensor.

Sea trials were initially undertaken off the South Australian coast where three units were deployed from a small fishing vessel and operated continuously for about 80 hours.

During this time, all units captured and processed acoustic signals from surface vessel traffic in the area. Data transmitted to a shore facility was then fused, enabling vessel tracks to be plotted.

The *Sentinel* technology went on trial again during an Anti-Submarine Warfare Exercise involving Navy and RAAF off the coast of Western Australia. In this case, three units were monitored from HMAS *Stirling* over a period of six days.

The trials overall demonstrated that two or more units, deployed a few kilometres apart, provide a capability to not only detect but also track submarines and surface vessels.

Capability enhancements to be investigated include improvements to target detection algorithms and the possible addition of active sonar processing functions.

Through the Department of Defence's Capability and Technology Demonstrator (CTD) Program, the DSTO developers of *Sentinel* are also working with Australian company, L3-Nautronix, to further develop this technology as part of the L3-Nautronix Autonomous Undersea Surveillance Network (AUSNET) CTD.

***Above left:** Graphic display of processed sonar data captured by three deployed* Sentinel *units.*
***Above right:** Shot taken from a remotely operated underwater vehicle during a mision to recover a* Sentinel *unit from the seafloor.*

Keeping aircraft in the air with adhesive repairs

A long-standing DSTO research program is clearing the way for more widespread use of adhesive bonded repair technology on aircraft, with the promise of greater cost savings and aircraft availability for Defence.

The technology involves bonding a patch of aluminium or fibre-reinforced composite with adhesive over a damaged aircraft structure. If performed correctly, these repairs can withstand stress loads of hundreds of kilograms per square centimetre.

A previously developed repair method involves attaching aluminium plates with bolts or rivets, which requires that holes be drilled in the parent structure for plate attachment. An undesirable side effect here is the creation of structural weak points that concentrate stress.

This repair technique, furthermore, delivers low reinforcing efficiency since load transfer occurs only at the fastener locations. Additional drawbacks are that any subsequent cracking under the patch is hard to detect, and corrosion can develop between the patch and the parent structure.

"With the adhesive bonded repair approach, no holes need be drilled," explains DSTO researcher Eudora Yeo. "The patch is attached instead via adhesive over the full surface of the repair, which results in reduced stress concentrations, reduced damage to the parent structure and reduced likelihood of corrosion under the patch."

Impressive track record

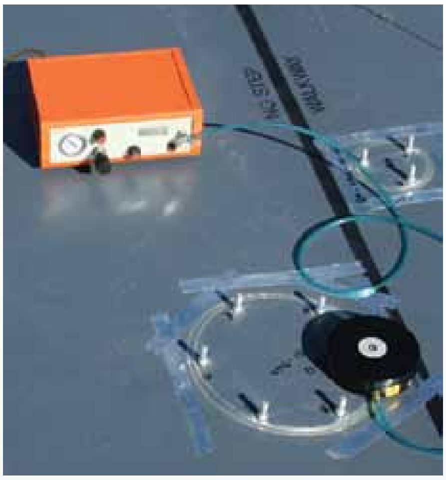
After more than 30 years of use and over 5,000 applications on Australian Defence Force (ADF) aircraft, adhesive bonded repair technology has been found to effectively lower maintenance costs and increase aircraft availability.

This experience has been gained almost entirely through applications on secondary and tertiary aircraft structures – those parts that will not endanger the aircraft's structural integrity if they fail. Only three times have such repairs been used to restore the strength of primary aircraft structures where structural integrity depended on the strength of the repair.

The reason why adhesive bonded repair technology has not been more widely used by the ADF for repair of primary aircraft structures – and the reluctance of civil aviation operators to use it at all – is due to the limited certification status it has been accorded by the government aviation authorities responsible for overseeing aircraft safety requirements.

The two main reasons for this are uncertainty regarding the lack of a scientifically validated non-destructive inspection (NDI) technique that can detect a reduction in bond strength, and uncertainty about the environmental durability of repairs when applied under non-factory conditions.

Above: DSTO researchers studying adhesive bonded repairs made to RAAF F-111 aircraft (now decommissioned) at RAAF Base Amberley.



The latter issue arises from the fact that repairs are often carried out on aircraft components *in situ*. Thus, the repair environment cannot be as easily controlled as that for in-factory manufacturing of secondary bonded structures. Factors of concern in this context include variations in temperature and humidity in the aircraft hangar and the ability to apply vacuum pressure and heat *in situ*.

A unique and brief window of opportunity to at least partially assess the uncertainties involved in the use of adhesive bonded repair technology arose with the retirement of RAAF's F-111 fleet in December last year. With each F-111 having been repaired in this way numerous times, the efficacy of these repairs could now be rigorously tested.

Retired F-111s serving Australia still

The F-111 Adhesive Bonded Repair Assessment Program (FABRAP) was formed by DSTO in 2010 at the request of the Directorate General Technical Airworthiness-ADF with the purpose of generating statistically valid data on the efficacy of NDI techniques and the environmental durability of adhesive bonds.

The main NDI method investigated was known as 'tap testing'. This form of testing requires a technician to tap all over a repair patch with a small metal hammer. The resultant sound reveals whether the patch is properly attached throughout or not, a clear ring indicating a sound bond, and a dull thud, a gap or 'disbond'.

Environmental durability was established by measuring the residual strength of the adhesive bonds in the repairs. This was done with an instrument called a pneumatic adhesion tensile test instrument (PATTI).

The PATTI test firstly involves the use of a hole saw to cut a circular groove through the repair patch and into the adhesive below, but not through the underlying parent metal. A circular test stub is then bonded onto this cutout portion of repair and connected to the PATTI tester, which applies load to the stub until the adhesive in the repair fails and the stub is pulled off.

The force required to do this gives a measure of the strength of the adhesive bond in the repair. A final step involves inspecting the failure surfaces to ascertain the quality of the adhesive bond.

FABRAP testing

Once approval for the DSTO team to access the aircraft had been received, the first phase of FABRAP took place in November 2010 at RAAF Base Amberley, with further inspections undertaken in May 2011 prior to aircraft disposal.

The DSTO researchers identified adhesive bonded repairs on eleven F-111 aircraft, with inspections of more than 300 repairs carried out and close to 900 PATTI tests conducted.

The research processes included tap testing, PATTI testing, removal of the patch to photograph the surface state underneath, storage of test stubs and repair patches for further analysis, and bonding of a temporary cover over the repair site.

While at RAAF Base Amberley, the researchers also removed 30 repaired components from F-111 aircraft to allow for more detailed investigations back at the DSTO laboratory in Melbourne.

A long and dusty paper trail

In addition to the *in situ* repair testing work, the researchers sought to locate service records for the aircraft whose repairs they had tested. The point of this was to enable an assessment of the environmental durability of the repairs.

The task of finding the relevant documentation turned out to be quite challenging, and once found, matching the actual repairs with paperwork was far from straightforward. So far, about 50% of the paperwork on repairs and more than 25% of service histories have been matched.

By studying the records, a range of factors to be considered during repair durability analysis were identified. These included the type of adhesive used, the bonding procedure and the environment, the number of flight hours sustained, age of the repair, temperatures of service exposure, and whether there may have been exposure to chemically aggressive compounds such as fuel or hydraulic fluid.

Further work

Additional testing is to be done in-laboratory at DSTO on adhesive bonded repairs made to F-111 components, with three such cases involving repairs carried out on primary flight structures using boron fibre composite patches.

Work is still under way on correlation of the PATTI test results with the properties of materials used in the repair design, and to quantify the effect of PATTI configuration variables on the test results.

When completed, this work is expected to significantly advance the case for the airworthiness certification of adhesively bonded repair technology for use on primary aircraft structures.

FABRAP is sponsored by the Directorate General Technical Airworthiness-ADF and supported by the Strike Reconnaissance Systems Project Office. On-the-ground assistance has been provided by Boeing Defence Australia, 6 Squadron NDI-Bonded Structures Technology Team and QinetiQ Aerostructures. RMIT University is contributing to post-test analysis.

Top: PATTI testing apparatus in use.

Below: Tap testing being conducted on adhesive bonded repair.

Flexible approach to future electronic warfare

A novel DSTO approach to delivering electronic warfare (EW) applications harnesses the reprogrammable potential of generic computing hardware to overcome problems of obsolescence, limits to expandability and system duplications.

Most EW systems developed along traditional lines use custom-made hardware tailored to the operations of just one particular EW application. Readying such a system for service typically involves many costly development cycles undertaken over lengthy periods, meaning that the technology may be out-of-date by the time of delivery.

Through a project called the Generic EW Core (GEWC), DSTO researchers are investigating a flexible, inexpensive and rapid way to bring 'high-end' EW applications into service.

"What we're aiming to achieve is analogous to the functionality provided by a personal computer – the creation of a generic computing framework where multiple applications can run on the same platform, and also where a new application can be added simply by loading software," says Dr Don Dissanayake.

The success of this approach is based on the use of commercially available hardware, thus eliminating the lengthy development cycles otherwise required while also providing a clear and cost-effective upgrade path for the system.

Adaptable advantage

Another major advantage the DSTO approach offers is its use of reconfigurable electronic circuits known as field programmable gate arrays (FPGAs). With these being quickly reprogrammable, the possibility arises that a system sent to perform one mission task could be adapted to perform another while still in the field.

For example, an unmanned aerial vehicle equipped with surveillance systems, having identified an enemy radar system, could be tasked to disable that radar through conversion of its surveillance equipment into an EW jammer.

The DSTO work has successfully integrated commercially available computing components with FPGA circuitry. This has given the system design what is termed open architecture functionality with well-defined interfaces.

Open architecture, in contrast to closed or proprietary architectures, is a type of computer system design that enables components to be readily added, upgraded or swapped, hence allowing a system to evolve with the new technology. A system with well-defined interfaces is one where the component parts are designed to allow for ready transfer of information between them to ensure the overall system functions well, and in turn supports the open architecture concept.

In the process of arriving at a working GEWC technology, solutions have had to be found for a number of challenging technical issues. Having done so, the team has now developed a GEWC-based proof-of-concept radar threat emulator. It has also successfully undertaken trials to demonstrate the usefulness of a GEWC-based reliable data capture application.

EW field set to burgeon

The DSTO researchers envisage that once their innovations become an established part of EW technology, EW domain experts will be able to concentrate on developing applications since they will have minimal work to do on hardware maintenance with a generic EW core in place.

"By implementing a well-defined GEWC interface, any outdated hardware can be upgraded without the need to recode 'high-end' computer program applications, and would not affect application-specific algorithms," explains Dr Dissanayake.

The next developmental step planned by the researchers is to further generalise the GEWC framework and expand the system to include more sophisticated electronic attack and electronic support functionality. They foresee that after this, the technology may also find application in several other areas of DSTO research and development.

This work has been undertaken as part of the Distributed Electronic Warfare Situational Awareness and Response program, a research and development program in collaboration with the US Department of Defense research agencies on future EW concepts, applications, systems and techniques.

Above: DSTO researchers examining signal readouts of Generic Electronic Warfare Core apparatus in development.

Briefs

New facility for protective clothing studies

To assist the development of protective clothing, DSTO recently opened a research facility designed to simulate environmental conditions that Defence personnel are likely to encounter.

The $4 million facility, capable of producing temperatures from -20°C to +50°C, will be used to assess the performance and functionality of existing uniforms, developmental materials, and new design options for use in a range of hazardous and toxic environments.

A key part of the test apparatus includes a full-size, articulated mannequin that replicates the movements personnel make when carrying out various operational tasks, such as running, bending and lifting. This capability enables testing to be carried out on protective clothing fabrics, closures and equipment as a whole, constituting a major advance over previous study methods where testing could only be carried out on swatches of fabric.

This work is expected to result in improved comfort and protection as well as better integration of other combat equipment for Australian Defence Force personnel.

The facility will also enable assessments to be made of the limits of human physiological performance in climatic extremes.

Wearable solar power technology for soldiers

A DSTO Capability and Technology Demonstrator (CTD) project with the Australian National University (ANU) has now delivered a demonstration version of a wearable solar power capability for the Australian Defence Force.

The extremely thin nature of the silicon sliver cells developed makes them both very light-weight and very flexible while producing high power yields per square centimetre. By encapsulating them in clear plastic-type material, they can be incorporated into personnel kit for power generation while on deployment.

An area of around 30 square centimetres connected to a rechargeable battery is considered sufficient to power a soldier's electronics communication and surveillance equipment and torch. Currently, deployed soldiers have to carry several kilograms of pre-charged disposable batteries of different kinds.

The solar panels have been developed to work in partial shade, after being fully immersed in water and in temperatures from -40°C to +65°C. They are constructed of durable materials to ensure a long life outdoors. Testing has established that the system performs well even under conditions of environmental extremes, with only minor falls in output.

The next phase of development will be to integrate wearable solar cells with the Flexible Integrated Energy Device, a vibration harvesting energy device developed by CSIRO, and the Smart Power Management System developed by Tectonica. These technologies are also being developed under the CTD program in collaboration with CSIRO, ANU and Tectonica.

Demonstration version of wearable solar panel technology being developed for Defence by the Australian National Unversity.

Mine countermeasures trial of underwater vehicle capabilities

DSTO recently undertook a trial of underwater vehicles off Cairns as the latest in a series conducted over the past five years to assist with the acquisition of deployable mine countermeasures systems for Navy.

The trial involved studying the performance of a Kongsberg Maritime HUGIN 1000 autonomous underwater vehicle fitted with a high-resolution synthetic aperture sonar called HiSAS 1030, and a remotely operated underwater mine disposal vehicle called MineSniper.

HUGIN provides a capability for very high-resolution mine hunting and bathymetric mapping, while the torpedo-shaped MineSniper is designed to approach and detonate mines with an explosive charge.

The trial was carried out in depths ranging from 10 to 350 metres, testing for system abilities to detect a range of mine shapes and other features of interest.

The purpose was to assess what level of survey detail could reasonably be expected from a deployable system when hunting for small objects like mines or when producing a bathymetric map. These findings will inform the drafting of request for tender requirements for such assets.

Calendar

31 Jan - 3 Feb 2012 **Pacific 2012 International Maritime Exposition**

The commercial maritime and naval defence showcase for the Asia Pacific.

Sydney Convention and Exhibition Centre
Sydney
http://www.pacific2012.com.au/content-exposition/index.html

31 Jan - 3 Feb 2012 **Royal Australian Navy Sea Power Conference 2012**

The seventh biennial RAN Sea Power Conference, to be held in association with Pacific 2012.

Sydney Convention and Exhibition Centre
Sydney
http://www.pacific2012.com.au/content-exposition/index.html

20 - 23 Feb 2012 **International Armoured Vehicles**

The largest and best-attended conference and exhibition internationally dedicated to the armoured vehicles community.

Farnborough Five
London, United Kingdom
http://www.internationalarmouredvehicles.com/Event.aspx?id=518778

21 - 22 Feb 2012 **9th Annual ADM Defence/Industry Congress**

Attracting senior officials from all areas of Defence and Defence industry, this is a critical forum for any organisation operating within the defence business sector.

Hyatt Hotel
Canberra
http://www.australiandefence.com.au/event/adm2012-9th-annual-adm-defence/industry-congress

23 - 24 May 2012 **Heli and UV Pacific**

A key event for the military and parapublic rotorcraft and the unmanned systems communities to network, discuss and demonstrate their products and experiences in the Australasian region.

Queensland RACV Royal Pines Resort
Gold Coast
http://www.shephardmedia.com/events/heli-uv-pacific-2012-69/

22 - 26 Oct 2012 **Land Warfare Conference**

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

Melbourne Convention Centre
Melbourne
http://www.dsto.defence.gov.au/lwc2012/