SOUE News

Issue 9 Summer 2010

Society of Oxford University Engineers

Welcome to the ninth issue of SOUE News

Our feature articles in this issue include: Tim Woolmer on the "YASA" electric motor, an Oxford invention designed for propelling cars, which by some very clever engineering achieves a massive weight reduction compared with conventional motors; Denis Gross on hydrogen fuel cells as used in boats and vehicles; and Debbie Clifford on the fascination of meteorology.

We have also the Jenkin Lecture of last September, by Simon Watts on "Airborne Surveillance Radar" and the amazing things that can now be done with it; and the Lubbock Lecture of this May, by David MacKay, entitled "Sustainable Energy — without the hot air". These are very different topics. Both were very well received.

And there are obituaries of two SOUE members who died recently: John Coates, who gave the 2005 Jenkin Lecture on the trireme reconstruction of the 1980s, and the Duke of Hamilton.

The Society, or to be more precise, Lynsey Thomas with the Committee's encouragement, has set up an SOUE group on the computer network LinkedIn. We already have about 140 members, and our President, Martyn Hurst, has written a short note on the back cover encouraging as many as possible of you to join. As he says, the more who do, the more useful will it be.

This year's Jenkin Lecture, on 25 September, will be by Peter Raynes, on flat liquid crystal displays (for TVs, computers etc.), in the development of which Peter was much involved.

In This Issue

Head of Department's Report 2009–2010

Guy Houlsby

This has been my first full year as Head of Department. Although I have been in the Department a long time, the most interesting aspect of my new role has been to see the breadth of activities that are undertaken here.

Students' Achievements

The "Complete University Guide" 2011 published by the *Independent* rates Oxford as the best place in the UK to study general engineering, and this accolade is certainly borne out by the achievements of some of our students. There are too many to mention them all here, but some examples include James Dolan and Philip Sibson, second year undergraduates who both won RAEng "Engineering Leadership Advanced Awards". Sheeja Jagadevan, a second year DPhil student won a Schlumberger "Faculty for the Future Fellowship" to support her research. Susannah Fleming won a prize at the 2009 British Science Festival for a poster on her research on measuring children's breathing rates.

Research, Entrepreneurship, Culture and more

The diversity of activity in the Department seems to know no bounds, and one of the real pleasures of the Head of Department's job is to see a little more of the numerous things going on in it. The following almost random selection will give you just a glimpse of the sense of excitement in the Department.

This has been a good year for entrepreneurs. Last autumn Oxford Yasa Motors was formed, a spin-out from Malcolm McCulloch's work on novel electric motors for vehicles. Two of our graduate students, James Philbin and Mark Cummins set up "PlinkArt", which became the first company in the UK to be acquired by Google. Recently OxEmS was established — a company developing tagging technology for underground infrastructure, arising from a collaboration between Harvey Burd in civil engineering and David Edwards and Chris Stevens in the communications group.

Professor Yiannis Ventikos and Mr Bob Scott provided technical support for the "Ghost Forest" project. This involves a travelling art installation consisting of the massive roots of tropical trees. They were brought from Ghana for display in Trafalgar Square, before moving on to Copenhagen for the conference on Climate Change. They can now be seen outside the University Natural History Museum in Oxford (opposite Keble), where they will remain for the next year, and are already attracting much attention.

The Department has enjoyed considerable success in winning new research funds this year, with our Institute for Biomedical Engineering being particularly successful. This year has seen its establishment of the new Centre for Doctoral Training, as well as the start of substantial research grants supported by the Wellcome Trust, EPSRC and others. Dr Richard Willden, RCUK Academic Fellow in Marine Renewable Energy is leading a major project in the Department on wave and tidal power, sponsored by the Energy Technologies Institute.

One of the year's highlights was the Lubbock Lecture, delivered by Professor David MacKay FRS on "Sustainable Energy — without the hot air". A highly thought-provoking lecture was delivered to a packed Lecture Room 1, relayed to an equally packed Lecture Room 2 and also simultaneously broadcast on the web. During the past term we also hosted an intriguing Astor Lecture, delivered by Professor Robert Cohen from MIT on "Omniphobic Surfaces".

Dr Paul Newman has been awarded an EPSRC Leadership Fellowship, which will give him a wonderful opportunity to develop his work on autonomous vehicles over the next five years. He will also soon be taking delivery of the "Wildcat" test vehicle, crammed with computers and instrumentation. I am reassured by Paul that when it is being driven around Oxfordshire it will have a human driver!

Academic Staff News

September 2009 saw the retirement of Professor Rodney Eatock Taylor, who had been

Head of Department from 1999 to 2004, as well as Professor of Mechanical Engineering since 1989. He continues an active interest in research in the Department as well as having a visiting post at the National University of Singapore. In October 2009 we welcomed four new members of staff: Professor David Limebeer joined us from Imperial College as Professor of Control Engineering, Dr Heiko Schiffter and Dr Gari Clifford joined us as University Lecturers in the Institute of Biomedical Engineering, and Dr Budimir Rosic came from Cambridge as a University Lecturer in Turbomachinery and tutorial fellow at St Anne's.

During this year Dr Antonis Papachristodoulou, currently a Departmental lecturer, has been appointed to a University Lecturership in Control Engineering, and a Tutorial Fellowship as Worcester College.

Professor Martin Williams has been Senior Proctor during part of the last year. He will continue his involvement in the governance of the University at a senior level, as he has recently been elected to Council, giving the Department a useful voice in those quarters.

Buildings

Many readers are familiar with the turbomachinery laboratories in the old power station at Osney. The move to the nearby "Axis Point" building, to be renamed the "Southwell Building" is now almost complete, and we are looking forward to opening the new laboratories in September. In these financially stringent times we have been able to make little progress with our plans to rejuvenate the Thom Building, but I hope we shall be able to do something to improve its appearance and function within the next few years.

Please do keep in touch with the Department, as we very much value our links both with past members of the Department, and with our many friends in academia, industry and elsewhere.

July 2010

Nigel Perry FREng, and the Centre for Process Innovation

SOUE News congratulates Nigel Perry on his recent election as Fellow of the Royal Academy of Engineering. Nigel read Engineering Science at Jesus, 1976–9, and was one of the Founder members of SOUE in 1988. He was also on our Committee in its early years. His background has been in the chemical industry of the North-East, and for some years now he has been running and promoting the Centre for Process Innovation at Wilton. The Centre's objective is to take new ideas in chemical and biochemical processing that are still too immature for private industry to invest in, and put in the research, development and assessment that they need before they can "stand on their own feet". It is modelled to some extent on the numerous Fraunhofer Institutes in Germany, which have similar aims. The Centre receives funds from central government, from the EU and regional development agencies, and employs around 100 people. One independent assessment of it thinks it has secured or created some 3500 jobs in the North-East, and brought in £400m of inward investment.

Nigel's election to FREng was for his leadership of the centre, and its record of innovation and the generation of spin-out companies.

The 22nd Jenkin Lecture, 26 September 2009: Airborne Surveillance Radar

Simon Watts (Thales UK)

Introduction

Long range surveillance in all weathers is an essential requirement for the armed services, whether in times of peace or conflict. Airborne radar is one of the principal sensors able to provide such a capability.

This article is a summary of the topics covered in the 22nd Jenkin Lecture. It presents an overview of some airborne surveillance radar applications, starting with a brief introduction to the concept of radar and the early history of airborne surveillance radar, from before WWII. The early war-time radars evolved into radars such as the Searchwater family of radars, in service with the UK Royal Air Force and Royal Navy. The latest generation of airborne surveillance radars for battlefield surveillance are now being deployed on Unmanned Air Vehicles (UAVs), such as the Viper radar being developed by Thales for the British Army's Watchkeeper system. The operational use of these radars and the information that can be derived from them are briefly described here. The article finishes with a look at some technology trends for future systems.

Radar Basics

Radar is an electromagnetic sensor for the detection and location of reflecting objects. Figure 1 shows radar operation in simple terms. The radar radiates electromagnetic energy, usually in the form of a short pulse, into space from a directive antenna. The radar pulse propagates at the speed of light through space until it encounters a reflecting object, known as a target. The energy reflected by the target propagates back towards the radar, where it is intercepted by the radar antenna (now switched from transmit to receive). A radar receiver processes the intercepted energy to indicate the presence of the target. The range to the target is estimated from the time taken for the pulse of energy to propagate from the radar to the target and back. The radar antenna usually operates over a narrow angular beam and the bearing of the target is estimated from the pointing direction of the antenna at the instant that the target is detected.

Surveillance radars may emit a continuous stream of pulses (typically of the order of thousands of pulses a second, each having a

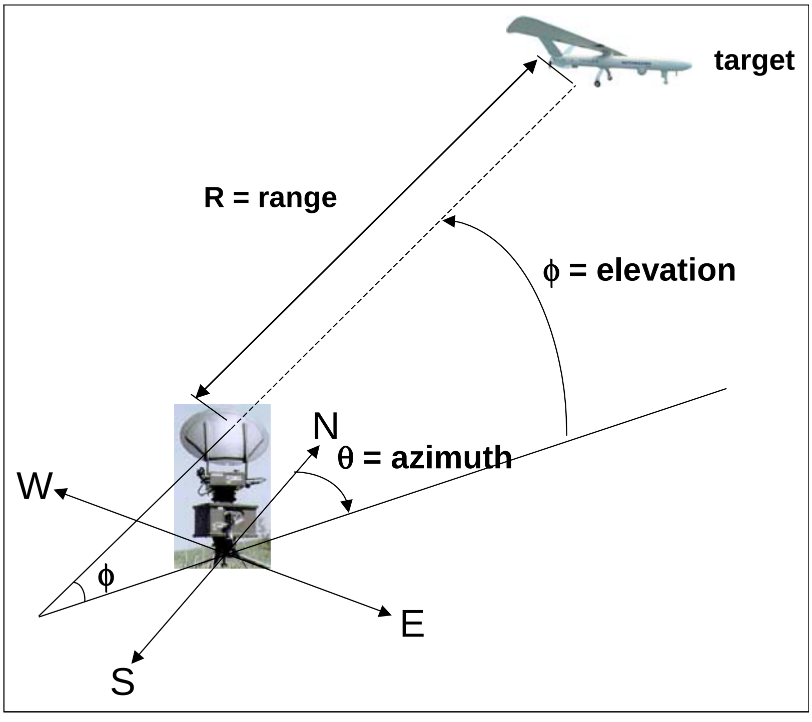


Figure 1: Radar operation

length of the order of a few microseconds) and scan the antenna beam in azimuth and elevation to achieve coverage in range and bearing. The radar returns from a target contain a considerable amount of information: not only the range to a target, but its radial velocity (imparting a Doppler shift to the radar carrier frequency) and, often, its shape. A modern radar uses very considerable computing power to process the returns from targets to provide detection, tracking, classification and, indeed, imaging of targets.

History

In August 1937 an RAF Avro Anson flew with the RDF2 equipment — what was to become known as radar. This was the world's first airborne surveillance radar. Figure 2 is a picture by Anthony Cowland commissioned by THORN EMI to commemorate the 50th anniversary of the death of Alan Blumlein (see below). This radar operated at a frequency of 200 MHz (VHF) and it detected ships at a range of eight miles on that first flight. At that time, the UK company EMI was developing the first electronically scanned television system and RDF2 used an EMI television receiver, operating at 60 MHz, as its intermediate frequency (IF) amplifier.

Figure 2: "The Big Echo" painting by Anthony Cowland illustrating the first airborne radar flight in 1937

EMI was not initially involved in radar but at the start of the war it took the technology developed for television and applied it to radar. Alan Blumlein had been a lead engineer in the development of television and then took over the radar work at EMI, until his death in a flying accident (testing the H2S radar) in 1942 (http://www.rafcaa.org.uk/goodrich.html). EMI had undertaken the engineering development of the H2S radar earlier that year, using the newly invented magnetron transmitter. The magnetron allowed high transmitter power to be developed at microwave frequencies (typically 1–10 GHz), providing better angular resolution from an aircraft antenna and improved immunity from jamming, compared to the existing VHF radars.

H2S was originally developed as a bomb-aiming radar, fitted to aircraft in RAF Bomber Command. Indeed, H2S Mk9 was still in service with the RAF in 1982, fitted to the Vulcan bombers that attacked Port Stanley in the Falklands War. H2S Mk1 operated at a frequency of 3 GHz and subsequent variants worked at 10 GHz, still the frequency band of many modern airborne surveillance radars. In 1942, radar was becoming an important weapon for hunting German U-boats in the North Atlantic. The ASV (Anti Surface Vessel) Mk2 radar, operating at 200 MHz was being deployed but was becoming vulnerable to jamming by the enemy. H2S Mk1 was fitted as ASV Mk3 in Wellingtom aircraft of RAF Coastal Command. The introduction of these centimetric radars was a major contribution to the winning of the battle of the Atlantic.

After the war, during the 1950s, EMI developed the ASV 21 maritime surveillance radar fitted to RAF Shackleton, Canadian Argus and Indian Constellation aircraft. In the early 1970s it was fitted to the new Nimrod MR1 aircraft, developed from the Comet airliner.

Nimrod

Coming more up to date, the RAF Nimrod MR2 aircraft entered service in 1980 and was recently retired from service in March 2010. This had the Searchwater radar, manufactured by EMI Electronics (now Thales). These Nimrod maritime patrol aircraft have been a vital element of our defence capability. The RAF originally had 20 Nimrod MR2 in service and

(Continued on page 6)

The 22nd Jenkin Lecture, 26 September 2009: Airborne Surveillance Radar cont.

(Continued from page 5)

this had reduced to 11 by the end of their service life with some of the fleet being used in the development of the Nimrod MRA4 (described below). They were used for submarine hunting (ASW), maritime surveillance (ASuW, previously ASV) and search and rescue. The aircraft had an endurance of 10 to 12 hours and a range of about 3800 miles. They operated at up to 40,000 ft for long range surveillance or at 500 ft or below for ASW operation. The aircraft were packed with electronics, including ESM, FLIR, MAD, sonobuoys, cameras, DAS, communications equipment and weapons, including Harpoon, Sting Ray torpedoes, Sidewinder air-to-air missiles and bombs.

Figure 3 shows a number of submarine masts, including a communications mast, a search periscope, an ESM mast and an attack periscope. These traditionally have been the main target for the radar and what drove its design. The smallest mast is the attack periscope, which may only be exposed about a metre above the sea surface. The radar must be able to detect such a mast after a brief exposure of only a few seconds in a high sea state and a range of tens of miles.

Figure 3: Submarine masts

The Searchwater radar was in its day one of the world's highest performing maritime surveillance radars. It had many advanced features, including pulse compression, pulse-to-pulse frequency agility, digital signal processing and computer control. The display was a colour raster-scanned CRT and operator control was achieved through the use of hard buttons, a roller ball and alpha-numeric keypad entry. The operator had considerable ability to reconfigure the radar according to the task and prevailing conditions.

In the late 1990s Thales won the contract to design and manufacture the next generation of maritime surveillance radar, Searchwater 2000, for the new Nimrod MRA4. It provides similar modes to the original Searchwater radar, with several new modes, including coherent air-to-air detection and radar imaging modes, known as synthetic aperture radar (see discussion below). The new radars include fully software-defined signal and data processing, providing an adaptive multifunction radar system with rapid mode switching and radar reconfiguration.

The new Nimrods are being manufactured by rebuilding the MR2 aircraft, with new wings, new engines and completely new avionics, including the new radar. A prototype aircraft is shown in Figure 4.

The new Rolls-Royce engines will give it a range of 6000 miles, compared to about 3800 miles for the MR2. Unfortunately this aircraft is still not in service and is many years late. The originally planned in-service date was 2003 for 23 aircraft and now only nine aircraft are due to enter service in 2012.

Synthetic Aperture Radar (SAR)

Modern airborne surveillance radars, such as the Searchwater 2000 and the I-Master UAV radar discussed later, include a radar imaging capability, called Synthetic Aperture Radar (SAR). Figure 5 is an example of a high resolution SAR image of fields, roads, buildings and an airfield. Notice the different textures and detail that can be observed.

Figure 4: Nimrod MRA4 prototype

A radar antenna with an aperture (width) D will have a beamwidth given by λ/D radians, where λ is the wavelength of the electromagnetic signal. A typical airborne microwave radar antenna may have a beamwidth of about 2°, achieved with an antenna aperture of about 1 m when operating at a frequency of 10 GHz. At long ranges the spatial resolution of such a radar may therefore be very poor. A beam of 2° is subtended by a cross-range dimension of about 3 km at a range of 100 km, and this means that the radar cannot resolve in angle objects spaced closer than about 3 km at that range. However, a realistic military requirement may be to resolve individual vehicles spaced only a few metres apart.

The range resolution of the radar is determined by its pulse bandwidth and a range resolution of the order of, say, 1 m is relatively easy to achieve (radars with range resolutions of the order of 10 cm are now practical). A com–parable azimuth resolution at 100 km range would require a real aperture of about 3 km at an operating frequency of 10 GHz, which is clearly not realistic for an airborne platform.

(Continued on page 8)

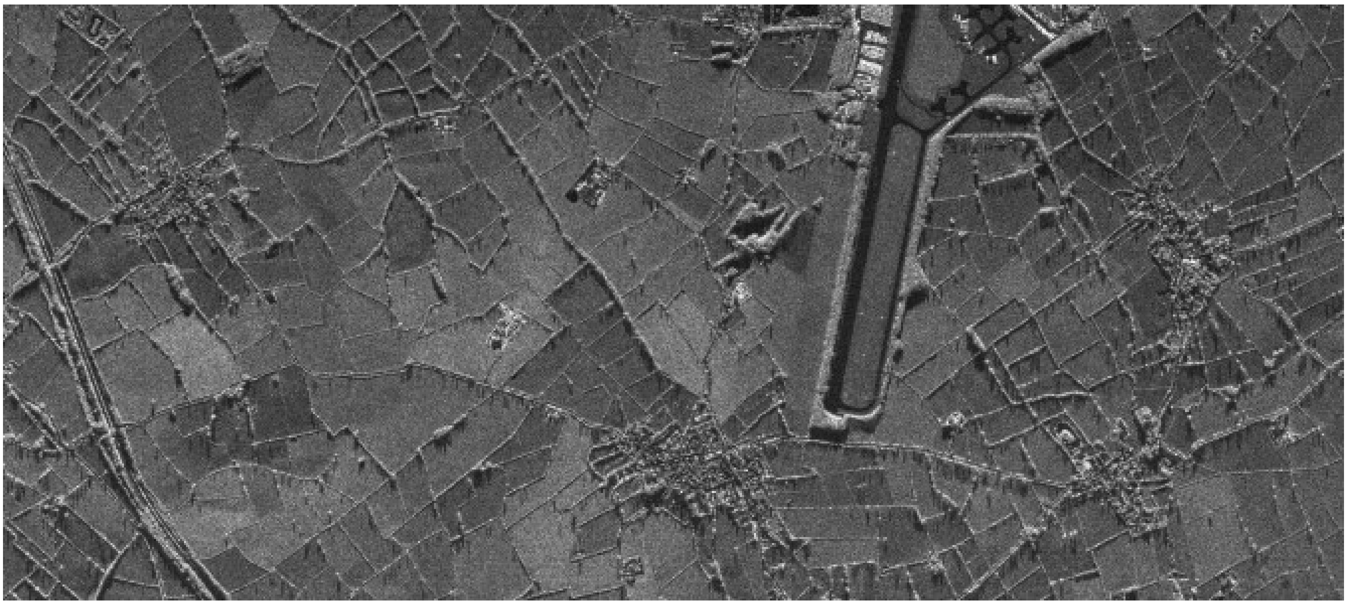


Figure 5: Synthetic Aperture Radar image of airfield runway and fields

The 22nd Jenkin Lecture, 26 September 2009: Airborne Surveillance Radar cont.

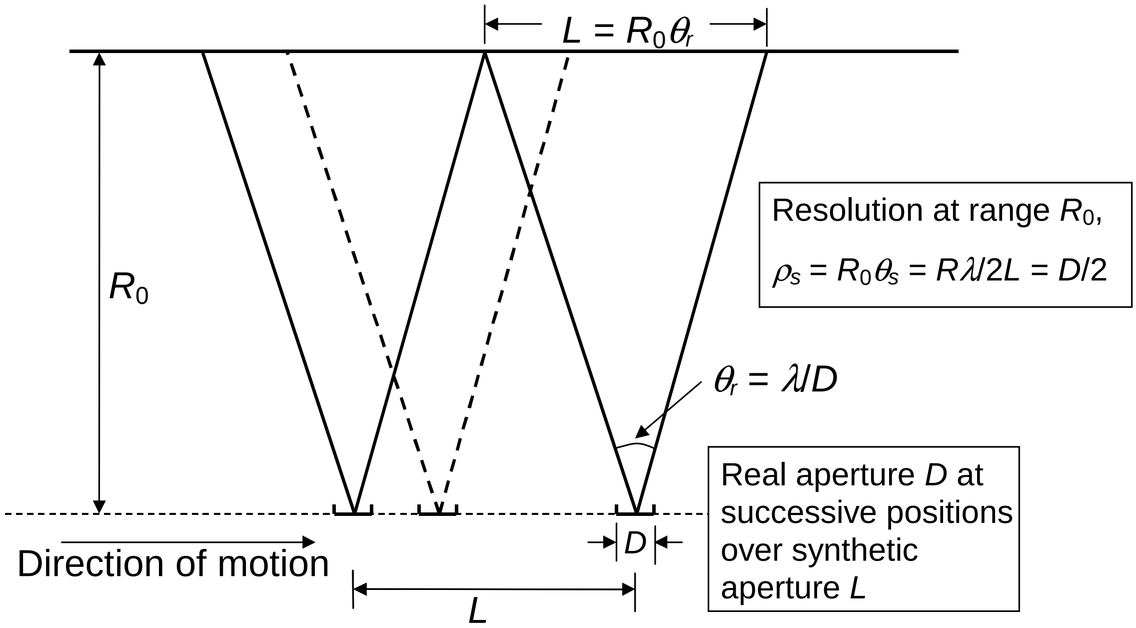


Figure 6: Synthetic Aperture Radar

(Continued from page 7)

By using a coherent radar (a radar that can measure the phase as well as the amplitude of the signals reflected from a target) it is possible to achieve considerably improved azimuth resolution by utilising the Doppler or phase content of the returns from successive radar pulses transmitted as the aircraft flies along a straight track. The radar records the returns to synthesise the signal that would have been achieved from a larger aperture lying along the aircraft track. This is the basis for synthetic aperture radar. The improved angular resolution of a target can be considered as being achieved by the translation or rotation of the target relative to the radar, similar to optical holography.

Figure 6 explains the basic principle of side-looking swath SAR imaging mode. A real aperture D has a real beamwidth θ_r that illuminates a cross-range extent of $L \approx R_0\theta_r$ at a range R_0 ($R_0 >> L$). By flying along a distance L and recording returns at intervals of $\lambda/2$ we can synthesise a phased array aperture of length L. Such an aperture would have a beamwidth given by $\lambda/2L$ (a factor 2 has appeared because the beam is formed by a two-way transmission of the radar pulses) and a range resolution ρ_s which equals, after substitution in the formulas, $D/2$ — a remarkable result that says we can achieve a cross-range resolution of half the real aperture, independent of range.

A radar operating in this mode can create a continuous map along its flight path, as shown for example in Figure 5. By steering the antenna to illuminate a fixed patch on the ground we can achieve synthetic apertures greater than L in the example here. This is known as spotlight SAR, and resolutions of down to less than 10 cm have been achieved in this way with microwave radars. Figure 7 shows an example of a spotlight SAR image, of the same scene as Figure 5, but imaged from a different direction. In this image, the runway shows up as black, with little signal reflected back towards the radar. Notice also the shadows cast by the trees and hedges in the fields.

Airborne Early Warning (AEW) Radar

In the 1970s the Royal Navy had large aircraft carriers with "organic" AEW (i.e. available on board) provided by Fairey Gannet aircraft. With the arrival of the "through-deck cruisers", flying helicopters and vertical take-off and landing (VTOL) Harrier aircraft, but no fixed-wing AEW aircraft, it was assumed that AEW cover would be provided by the RAF Shackletons or their

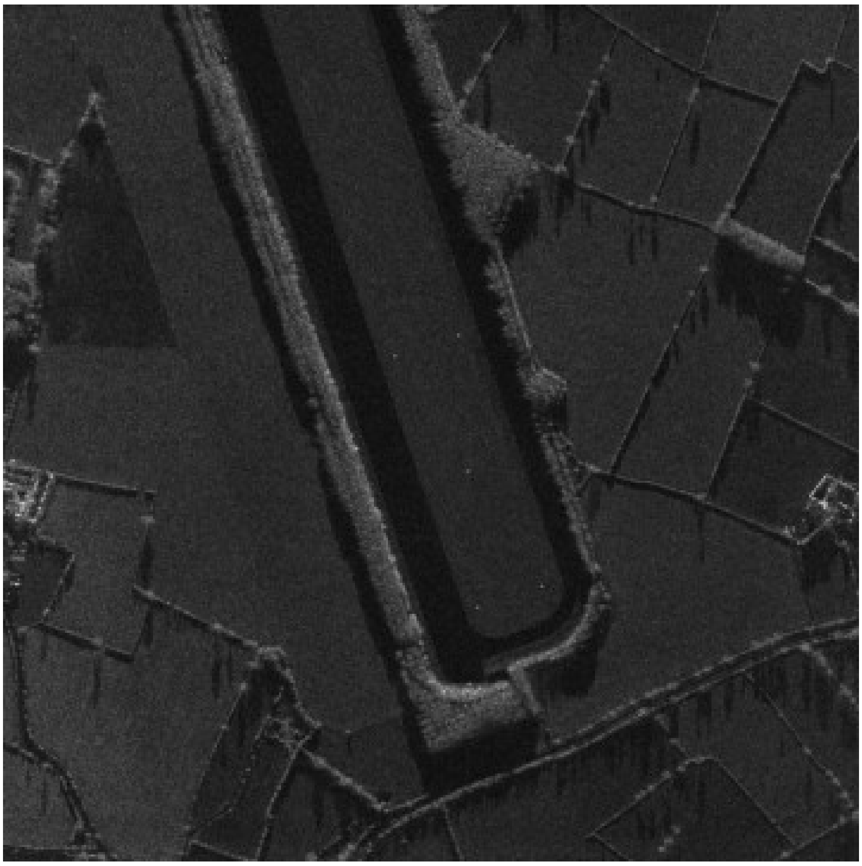


Figure 7: Spotlight SAR image of airport runway (see Figure 5)

successors, the E3-D AWACS, operating from land bases. By contrast, the large USA aircraft carriers have continuous organic AEW cover provided by their Hawkeye AEW aircraft.

Then in the Falklands War of 1982, the Royal Navy sailed to the South Atlantic where no AEW cover was available. This led to the early loss due to air attack of HMS Sheffield and subsequently a number of the RN ships, highlighting an urgent need for organic AEW.

In response to this urgent operational requirement, over a period of 11 weeks THORN EMI developed two prototype AEW platforms installed in Sea King helicopters, using modified Searchwater radars and a completely new antenna assembly and aircraft installation. These were embarked for the Falklands and arrived just as the war ended. The radars were very successful and RN 849 Squadron, which had previously flown the Gannet AEW aircraft, was reformed with the AEW Sea King Mk2 helicopters.

This radar and all the mission system avionics have now been completely replaced by Thales, in the Sea King Mk7 Airborne Surveillance and Control (ASaC) aircraft, shown in Figure 8 (overleaf).

The radar antenna and scanner is housed to the side of the aircraft in the "dustbin" assembly, which swings upwards towards the rear of the aircraft for landing. The pulse Doppler radar provides a full "look-down" capability to detect air targets over land and sea.

Unmanned Air Vehicle (UAV) radar

The use of unmanned air vehicles is becoming increasingly important in modern warfare. These platforms can provide wide area surveillance over long time periods, sending imagery and radar detections down to the forces on the ground. For example, the Watchkeeper tactical UAV (TUAV) system is about to enter service with the British Army. This system has been designed by Thales to meet the customer's statement of need:

(Continued on page 10)

The 22nd Jenkin Lecture, 26 September 2009: Airborne Surveillance Radar cont.

Figure 8: Sea King Mk7 ASaC

(Continued from page 9)

> WATCHKEEPER is required to provide accurate, timely and high quality imagery and Image Intelligence (IMINT), collected, collated, exploited and disseminated to satisfy land manoeuvre commanders' critical information and intelligence requirements within the context of Joint operations throughout a range of environments and across the spectrum of conflict.

The TUAV for Watchkeeper is shown in Figure 9.

Figure 9: Watchkeeper tactical UAV

The main sensors on the Watchkeeper platform are a radar and an electro-optic and infra-red (EO/IR) imaging system, in the two pods below the fuselage. Imagery and data collected by the sensor are relayed to a ground control station using a microwave data link. Whilst EO/IR sensors are widely used in many applications, radar is the only sensor that can provide all-weather, day and night, operational capability at long ranges. The radar has two main modes of operation, synthetic aperture radar (SAR) imaging and ground moving target indication (GMTI).

SAR Change Detection

SAR images, such as those in Figures 5 and 7, can show stationary vehicles and buildings, as well as cultural details, with spatial resolutions of less than a meter. An important application is the detection of changes between images of the same scene, taken at different times. Some changes can be detected in this way from optical images but this can be difficult, as the time of day and weather can significantly affect the images. Also the statistics of optical image amplitude and colour are not significantly affected by subtle changes. With a radar, the illumination of the scene can be repeated very accurately from successive flights of an air platform. Large changes to a scene, such as the movement of parked vehicles, may be detected by comparing the intensity of individual pixels (resolved picture elements) in accurately aligned images. However, if the phases as well as the amplitudes of the returns are compared, much more subtle changes can be detected. By comparing the phase of the signals, changes due to relative position movements of fractions of the radar wavelength (typically, therefore, fractions of 3 cm) can be detected. Such small changes would not be evidenced by any discernible change in image intensity.

GMTI

As well as the ability to image a stationary scene, and look for long-term changes in it, another important military requirement is the detection and localisation of moving targets. The GMTI radar mode provides the ability to detect slow moving targets over a large area and report their position in geographic map coordinates. Individual targets may also be tracked.

Future Developments

The technology of airborne radar continues to evolve. The advanced radar results discussed here require very precise radar instrumentation and considerable computing power for the signal and data processing. The large airborne radars discussed here (such as the Searchwater radar variants in the Sea King Mk7 and Nimrod MRA4) use travelling wave tubes (TWT) to generate their high power transmitted pulses. Increasingly now radars are being developed with solid state transmitters, using a technology known as Active Electronically Scanned Arrays (AESA). Now, instead of a single large TWT transmitter, the power is generated by a large number of small solid-state transmit/receive modules, distributed over the antenna aperture. The modules also act as the radar receiver, with the focused antenna beam being formed and steered electronically. This technology brings significant advantages from the ability to steer the beam very rapidly and also to adapt the beamshape, for example to steer nulls in the pattern in the direction of a jammer. In the area of signal processing, much research continues into the development of robust, high performance SAR and GMTI systems, with particular emphasis on classification and identification of targets, as well as detection and tracking in difficult environments. Perhaps the greatest challenge for radar designers in the future will be to achieve the very high performance discussed here with radars that are lightweight, small size and, above all, low cost.

Professor Simon Watts

Simon Watts graduated from the University of Oxford in 1971 (Engineering Science, St John's), obtained an MSc from the University of Birmingham in 1972 and a PhD from the CNAA in 1987. He is currently deputy Scientific Director of Thales UK, Defence Mission Systems, and is also a Visiting Professor in the department of Electronic and Electrical Engineering at University College London. He joined Thales (then EMI Electronics) in 1967 and since then has worked on a wide range of radar and EW projects. He is author and co-author of over 45 journal and conference papers, a book on sea clutter and several patents. He was chairman of the international radar conference RADAR-97. He was appointed MBE in 1996 for services to the UK defence industry and is a Fellow of the Royal Academy of Engineering, Fellow of the IET and Fellow of the IEEE.

Early Warning Systems via Machine Learning: from Jet Engines to Hospital Patients

A 2009 Jenkin Day talk by David Clifton

David's subject was the development of statistical algorithms which would look at the output of "sensors" attached to some machine or person, and try to deduce from their outputs collectively whether their host was behaving abnormally and therefore needing maintenance attention. He conceded that the computer was unlikely to be better than an expert human observer. But the permanent presence of a human expert is expensive, and the computer can be used to assist experts by guiding their attention to significant events. The problem was to attempt to represent human expertise "in a box".

His original objects of study had been aircraft engines, e.g. in the Eurofighter, Airbus 380 or the still-to-fly Boeing 787. A jet engine might have 20 sensors on it. A human presented with a simultaneous display of all these would have some difficulty interpreting them, and the quantities of data obtained from the sensors can be substantial. One flight might generate 500 Mbytes. A single test run of a racing car might generate ten times that. Even the data generated by hospital patients becomes substantial when whole wards are monitored for long periods. Thus automated methods are required.

It was useful to distinguish between model-based and data-based approaches. Oxford is active in generating computer models of biomedical systems, based on modelling single system components using *a priori* knowledge. A data-based system, on the other hand, provides only a moderate understanding of the system itself, but models the behaviour of a whole set of sensor outputs. Primitive systems that look only at a single sensor can usually do little more than set thresholds, and sound an alarm if they are exceeded. The result tends to be so many false alarms that the alarms are ignored, or just turned off. One can do much better by looking at multiple sensors simultaneously, but some automatic learning is then necessary, specific to the system in question, to deduce what combinations are normal, and which are dangerously abnormal. Complete failures tend to be rare in modern complex systems. So the behaviour of the system in "normal" conditions is modelled, and then events that are statistically "abnormal", compared with that model, are used to generate alerts. There is also the problem of reducing multiple variables down to two or three so that they can be displayed graphically on a screen to a mere human!

David quoted various examples of the application of this method. One was of a jet engine which had somehow acquired a loose nut rolling around inside it. Its vibration spectra could have predicted its eventual failure well before it actually happened. The change was very subtle, and only detectable using statistical methods, rather than conventional alerts. A medical application, in which alarms were based not on individual sensors, of temperature, pulse rate, blood pressure etc., but on a learnt combination of them all, resulted not only in a great drop in false alarms, but in reducing from 50 to zero the number of cardiac arrests over an 18-month period during clinical trials.

The audience responded to the talk with a lively questioning session.

Geotechnical Engineering for Offshore Pipelines

A 2009 Jenkin Day talk by Byron Byrne

Byron's subject was the flexible steel pipelines for oil and gas that are used to connect offshore installations to each other, to well-heads on the sea-bed, and to the shore. There are many hundreds of kilometres of these, for instance in the Pluto gas field off NW Australia, with which Byron was familiar, and in many other parts of the world.

The problem of interest was the tendency of these pipelines to buckle. When they are laid they are full of sea-water, and hence cold. In use, their contents may be quite hot, so they expand. This leads to two alternative forms of buckling:

> "upheaval buckling", if they have been buried (we were shown a photograph of this happening to a pipe in Abu Dhabi);

and

> "lateral buckling", if they have simply been laid on the sea-bed.

Lateral buckling can push the surrounding soil or sand into piled-up banks or "berms". This can constrain further movement, thus leading to excessive stresses in the pipe, hence possible fracture. It can be prevented by laying the pipe on cross-wise "sleepers", along which they can easily slide.

But there is a strong case for burying the pipe, especially in a site where it could be damaged by ships' anchors or fishing gear. In a soft or sandy bed this can be done with a trenching machine (an expensive item, e.g. $10m), which fluidises the sand with water jets, thus allowing the water-filled pipe to sink into it. The sand then settles back above the pipe, and, it is hoped, holds it down. But when the pipe is filled with gas it is much lighter, so any expansion will tend to lift it up. They had been conducting model experiments to measure how much force is necessary to lift a pipe out of its sand-filled trench. The force is quite high initially, but falls off, much as one would expect, as the pipe rises towards the surface. But if the sand gets fluidised it gets lighter, and the holding-down force is much reduced. There is some evidence that vibration in the pipe, e.g. from a travelling "pig" sent down to clean it, can initiate fluidisation, and hence cause "upheaval buckling".

If upheaval occurs, or is thought likely, one solution is to lay heavy rocks on top of the trench. But this may just transfer the upheaval to some other point, and we were shown pictures of where this had happened. One can end up having to lay rocks along the whole length — rather expensive!

Byron's group were also studying what happens in the pipelaying operation at the crucial point where the pipe coming down from the barge enters the trench.

The 36th Maurice Lubbock Memorial Lecture, 13 May 2010: Sustainable Energy — without the hot air

Lecture by Professor David JC MacKay FRS

A video of this lecture can be seen on the Department's website:

http://www.eng.ox.ac.uk/events/movies/lubbock2010.html

David MacKay is Chief Scientific Advisor to the Department of Energy and Climate Change. He saw his mission, in this lecture as in his book of the same title[1], to help us visualise how we might live without fossil fuels. These are not "sustainable", on three grounds:

- they are a finite resource;
- they generate climate-changing amounts of carbon dioxide;
- from this country's point of view, they lack security of supply.

His emphasis was on the need to do calculations (and back-of-the-envelope ones would often do) on the feasibility of various solutions. So he started with the story of a lunch with some Shell people, where the question was raised: "If we wanted to power all the vehicles on a given road with bio-fuels, how wide a road-side strip would be needed to grow the crops?" Some plausible assumptions about the traffic led to the conclusion that a continuous 8 km wide strip alongside each traffic lane would be needed. Which seemed to cast some doubt on this solution!

The amount of CO_2 in the atmosphere over past centuries can be measured from ice cores. When plotted, it is seen to have been constant from about 1100 AD to the late 18th century, when it started to rise at an accelerating rate. The start of the rise might be approximated to James Watt's patenting of his condensing steam engine in 1769 and the start of the industrial revolution. Current emissions amount to 5–6 tonnes of CO_2 per year per person on the planet. Ultimately we would like to reduce this to zero, but an intermediate target could be 1–2 tonnes/year/person by 2050. But of course it varies from country to country. In the UK the current figure is about 11, in the USA and Canada about 24, so getting down to 1 or 2 is going to be a major challenge. In the Congo and Bangladesh it is a mere 1 tonne/year/person right now.

[1] The book may be read on-line, or downloaded in PDF form for free, at http://www.withouthotair.com/

Too many quantitative comparisons between different forms of energy generation and consumption are framed to score points in arguments, and made incomprehensible to the layman by being expressed in millions, billions or trillions. Most people can't tell the difference! The speaker suggested that energy rates (power) be expressed in terms of kWh/person/day. 1 kWh/day is of course about 40 W, the consumption of a small light bulb. The chemical energy content of the food we eat is about 3 kWh/day, 1 litre of petrol contains about 10 kWh. The manufacture of an aluminium or plastic drink container needs about 0.6 kWh. Someone who flies to Los Angeles and back uses about 10,000 kWh in the process; if you do it once a year that is an average of 26 kWh/day. A typical American or British home uses about 80 kWh/day. An average European car uses about 80 kWh over 100 km. On the other hand, the mobile phone charger left on when not charging the phone, which we are always being urged to unplug, uses about 0.5 W, or 0.01 kWh in a day, about as much as a car uses in one second!

The average rate of energy consumption in Britain is about 125 kWh/person/day, of which about a third goes on transport, a third on electricity, and a third on heating. 1 kWh/day is about the physical work capacity of one human, so think of it as employing 125 servants.

In assessing the merits of various forms of renewable energy, it is useful to ask how many watts we can get per square metre of land utilised. MacKay displayed a graph showing the various countries of the world, with energy consumption per day per person plotted against people/km². The product of the two scales is power needed per unit area. The world-wide mean is about 0.1 W/m². The USA needs 0.3 W/m², but the UK with its much higher population density of 250/km² needs 1.25 W/m².

Wind farms can produce about 2.5 W/m², implying that to get all this country's energy that way means using half of all our land area. Could technical progress improve this? Not much, since although large windmills produce more power, and might do so more cheaply, they have to be spaced further apart, because they shield each other if spaced too closely. Larger ones are taller, and this does help a bit. If every 700 people had one 2 MW wind turbine between them, it would supply their *present* demand for *electricity*, and occupy an area about half the size of Wales.

Bio-fuel crops can produce about 0.5 W/m² (more in the tropics), so planting them over the whole of the Earth's land surface could produce five times the Earth's present energy needs. There would be some land left for growing food!

Photovoltaic solar panels are approaching their theoretical efficiency limit, about 31%, and can produce about 5 W/m². With a large installation, bigger than a house, one might get 150 kWh/day. By putting them in sunny deserts and using mirrors to concentrate the sun's rays, one ought ideally to be able to get a daily average of 250 W/m², but practical installations have been getting more like 20 W/m².

As for tidal power, one long-established French station in La Rance estuary generates 2.7 W/m² of tidal basin area. The Severn estuary has been suggested frequently as ideal for this purpose. And the North Sea is a vast tidal basin. If "underwater windmills" were deployed there in suitable high-current regions, they might generate 8 W/m².

Hydroelectricity typically produces (in the UK) 0.24 W/m² of catchment area, but obviously it depends critically on both rainfall and the vertical fall available.

The conclusion of all this is that, to be effective, renewables need to be country-sized. But before we install any of them, we have to consult neighbours, local authorities etc., and the "not-in-my-backyard" reaction can be very strong. If they insist, for example, that wind farms are not erected:

a) within 2 km of any dwelling, since it upsets the inhabitants;
b) in tranquil open spaces, because it spoils their amenity;
c) in any part of the sea where they might interfere with shipping, recreation, radar reception etc.,

then there is practically nowhere left.

So perhaps we could get our renewable power from other countries. Libya perhaps? Or vast photovoltaic arrays in Spain, with 50 GW transmission lines across Europe to get it to Surrey?

An alternative is to just reduce our energy consumption. This might be done by reducing our population, or radically changing our life-styles, but neither is likely to get popular assent.

So what are the alternatives if we are to drastically cut our CO_2 emissions?

a) clean coal (i.e. burying the CO_2);
b) nuclear power;
c) renewables elsewhere if we don't want them in our own backyard.

Let us look in turn at the main energy consumers:

Transport

The dissipation of energy here comes from:

- the swirling air left behind the vehicle (size- and speed-dependent);
- the kinetic energy created when accelerating, and then dissipated when decelerating;

(Continued on page 16)

The 36th Maurice Lubbock Memorial Lecture, 13 May 2010: Sustainable Energy — without the hot air cont.

(Continued from page 15)

- rolling resistance, i.e. the deformation of the road surface and the tyres;
- the poor efficiency of the engine, which wastes about 75% of the chemical energy in the fuel.

So to reduce the energy requirement, the vehicle should be of small frontal area, low weight, travel slowly at a constant speed, and have an efficient power source. This seems to lead us to a *bicycle*, which uses[2] around 1 kWh/person per 100 km, as opposed to 80 for a typical car. Public transport can manage about 6 kWh/p/100 km. The Cambridge "Eco-car" can do 1.3 (at 15 mile/hour), similar to a bicycle, but is hardly an acceptable vehicle for the general user.

One way to get a substantial improvement is to replace the internal combustion engine with electric motors, which can be around 85% efficient. This converts the 80 kWh/p/100 km to about 21 (measured at the charging socket). The "Tesla" electric car can manage 15, some others can do 6, and an electric scooter can do 3! Hybrid cars, in which the petrol engine is there just to get you home if the battery goes flat, manage about 25 kWh/100 km. If the electricity to charge the battery comes from a 30–40% efficient power station, then most of the advantage is lost. But it doesn't have to be. Wind turbines?

Heating

A modern gas-fired condensing boiler is about 90% efficient. To reduce heat consumption, turn the thermostat down 5° (could save 50%) and insulate the house (25%). To do better still, stick insulating panels on the *outside* of the house, as is done in Germany.

But the boiler's 90% efficiency is at turning the high-grade chemical energy of the gas into heat, a very low-grade form of energy. If we use a heat pump to extract heat from the ground or atmosphere, and feed it at a higher temperature into the house, our effective efficiency can rise to 300 or 400%. This figure is known as the "coefficient of performance" of the heat pump. Heat pumps are used routinely in other countries.

One way to reduce your energy consumption is to read your meters regularly, and act on your observations. In this way, the speaker managed to reduce his own gas consumption from 40 to 13 kWh/day, and electricity from 4 to 2. To get the latter result he just switched off all the items which previously had been left permanently on "standby".

Electricity

If we are going to electrify most transport, and get our heating from electrically-driven heat pumps, and maintain something like our present life-style, we are going to have to treble our electricity generation. This probably needs a diversified solution. One possibility, not necessarily the one the speaker would himself recommend, might be:

16 kWh/p/day from nuclear power (perhaps as a stop-gap);

16 kWh/p/day from clean coal (ditto);

16 kWh/p/day from other people's renew-ables;

8 kWh/p/day from wind power.

This scheme[3] would also need greatly expanded pumped storage for the better matching of supply and demand.

Conclusion

Getting off fossil fuels is not going to be easy. But it might be fun, for the engineers at least!

[2] Chemical energy from the fuel or food, not mechanical energy at the wheels, i.e. allowing for "engine" efficiency.

[3] The total of 56 kWh/p/day comes to 140 GW for a population of 60 million.

From Engineering into Meteorology

Debbie Clifford

Debbie (née Putt, Jesus, 1999–2003) has moved from engineering into meteorology, and wrote this article to convey her enthusiasm for her new-found field of work.

Last week I found myself sat around a table with some BBC producers, exploring the extraordinary and beautiful images taken of planet Earth by satellites. They want to use these images in a television programme, and I am part of a group of scientists working with satellite data who are enthusiastically showing off what our instruments can do. At the start of the meeting we introduced ourselves, and my potted history began with my undergraduate degree in engineering from Oxford.

So how did I get here? When I left Oxford in 2003, I knew I wanted to be an engineer. I'd always wanted to be an engineer. Fate, however, had other ideas, and I rapidly became disillusioned with the "real world"; although it was a lovely company, I realised that this flavour of engineering consultancy was not something I could spend the rest of my days doing. I hastened back to academia with the idea of training in environmental science, to become an environmental engineer, aspects of which we had only briefly considered at Oxford but which interested me much more.

Here I discovered what every academic knows, which is that research is creative, stimulating and (sometimes) satisfying, and certainly a lot more fun than a real job! So I signed up for a PhD with an inspiring and enthusiastic hydrology professor, and here it was that my career properly began. My research explored how we can observe global snow cover from space, and I realised that "Earth Observation", as the field is known, combined my interest in the environment with a long-held fascination with space and technology. Maybe this story actually started a much longer time ago, with a primary school project on space aged seven… I certainly got a childlike thrill at being able to spend two weeks working at NASA's Goddard Space Flight Centre in Washington DC, and have proudly kept my security badge!

I am now a post-doctoral researcher, working in the Meteorology department at Reading University, funded by the National Centre for Earth Observation (NCEO). I am developing an idealised model of atmospheric convection, complete with clouds and rainfall processes, for simulating novel radar measurements and learning how to use them more effectively in weather forecasts, a process known as "data assimilation". Unexpectedly, with this project I have used more of my engineering degree than at any time since finals — solving PDEs, optimisation, radar theory, computational fluid dynamics — HLT is still in pride of place on my shelf! I really can't think of a better degree to have prepared me for my current job.

There is so much more out there in academia that is open to engineering graduates than straightforward engineering research, if that doesn't appeal. I really enjoyed my fourth year project modelling freak waves with Paul Taylor, but I wasn't ready for a PhD then. A "year in" helped me discover where my skills and interests really lay, and allowed me to approach a PhD project with greater maturity and commitment.

I also have the freedom in my job to explore my wider interests, such as public outreach and working with the media. I am a recently signed-up STEMnet Ambassador, encouraging young people to explore science-technology-engineering-maths ("STEM") careers, and am part of a team developing an outreach strategy for NCEO as a whole. Last year I also spent three months working for the Royal Commission on Environmental Pollution in London, as part of a secondment scheme to give PhD students experience of the policymaking process.

In seven years my expectations for my career have changed completely. Right now, I have no idea where I will be in seven years' time. Whether scientist, policymaker, project manager, teacher, or anything else, what I do know is that I will always be an engineer at heart!

The YASA Electric Motor — an Oxford Invention

Tim Woolmer

Oxford YASA Motors is a recent spin-out company from Oxford University. The company was founded in September 2009 to commercialise the Yokeless And Segmented Armature (YASA) motor, which has been shown to have an outstanding torque to weight ratio. The company has already achieved £200k of sales and has a strong order book.

In April 2005 I began my DPhil at the Oxford Engineering department and was presented with a daunting task: to design, build and test the electrical power train of the world's first hydrogen sports car. My DPhil (supervised by Dr Malcolm McCulloch) began with a search for high torque lightweight motors available off-the-shelf. Unfortunately, it quickly became clear that there was a problem: the motors were too heavy. Instead of meeting the budgeted 20 kg/motor, they typically weighed 50–120 kg, presenting a major problem since four were required. To make matters worse, it was shown during the LIghtweight Fuel Efficient Car (LIFECar) project that overweight subsystems had a compounding impact on the weight and efficiency of the vehicle (for example, a heavy motor require a larger fuel cell, more ultra-capacitors and a heavier chassis…) The challenge had been set: produce a new motor 2.5 times lighter than any existing off-the-shelf technology.

After a focused literature survey it become clear that axial-flux machines (the flux moves "axially" rather than radially through the machine) offered the potential for a high torque density; however, the machines weren't available off-the-shelf in 2005 due to manufacturing difficulties. The key advantage of the axial flux (or "pancake") machine can best be described by comparing its shape to that of a disc brake: large in diameter and axially very short. In comparison, a radial flux (or conventional) motor could be compared to a drum brake, which typically has a lower braking torque density. Despite the potential for weight reduction it was the manufacturing of the axial flux technology that had meant it had limited commercial success. The motor could not be made by stacking laminations (as in a conventional machine), but rather required the lamination to be wound in a spiral and then spark eroded. The axial flux machine suffered from a number of additional problems including poor cooling capability (key to high torque density), difficulties in controlling the axial airgaps and a complex winding.

Despite the challenges I began researching the axial flux motor in combination with new materials in the hope of finding a novel solution to these problems. It was in September 2005 when the breakthrough came: by segmenting the axial flux motor in discrete "pole-pieces" the motor could be manufactured easily using Soft Magnetic Composite (SMC) parts. SMC comes in a powdered form and can be pressed at low cost into a wide variety of 3-D shapes. This removed the need for the complex laminations, overcoming the major manufacturing challenge of the axial flux machine. It also dramatically simplified the winding and ultimately transformed the cooling capability of the machine. Some of these advantages are described in Figure 1.

My research suggested that this motor would achieve a torque density of 15 Nm/kg — up by 50% on the best available motors at the time. It also estimated that the cooling capability of the machine could be doubled, potentially further increasing the torque density. However, the motor was still too heavy to drive the LIFECar wheels directly so a bespoke gearbox was designed and integrated into the motor. The overall package weighed 20.0 kg — meeting project weight budget.

The technical advantages of the YASA motor were so significant that a commercial proposition was put forward by ISIS Innovation (the technology transfer company owned by Oxford University). This led to the creation of Oxford YASA Motors Ltd, with £1.5m being invested in the company in September 2009. Further development of the motor (including four patent applications which are currently pending) has led to the company's first product, which boasts a torque density of 28 Nm/kg (a 23 kg motor producing 650 Nm). The motor's torque density is now sufficiently high that a gearbox is no longer required, which makes the overall driveline simpler and more efficient, yet still lower in weight. Further improvements of the YASA motor mean that the company's second product (due to be ready in early 2011) will produce a stunning 1000 Nm in a 25 kg package — a torque density of 40 Nm/kg. This is typically 3–8 times higher than the best motors currently available off-the-shelf.

Although Oxford YASA Motors is a relatively young company, it now employs 10 people and the company will achieve sales of £1–2m in its first year and estimates a further £1.5m of sales in 2011. A number of demonstrator vehicles can be seen using the motors, such as the Delta E4 Cope or the Westfield iRacer (http://www.oxfordyasamotors.com/drifting-electric-car). The company also won a £1.9m project (http://www.yamog.co.uk/), funded by the Technology Strategy Board, which aims to achieve a price point of £1000/motor (10,000 off volume). Although Oxford YASA Motors is currently focused on automotive applications, it is expected that the motor would perform equally well in a range of applications, such as aerospace, renewables or the industrial markets where weight reduction, efficiency and cost benefits could also be achieved.

Electric motors have been around for over 100 years yet the success of the YASA motor is a pleasant reminder that innovation is always possible where creativity and academic freedom are encouraged. Dr McCulloch — who is now on his third spinout company — should be applauded for this.

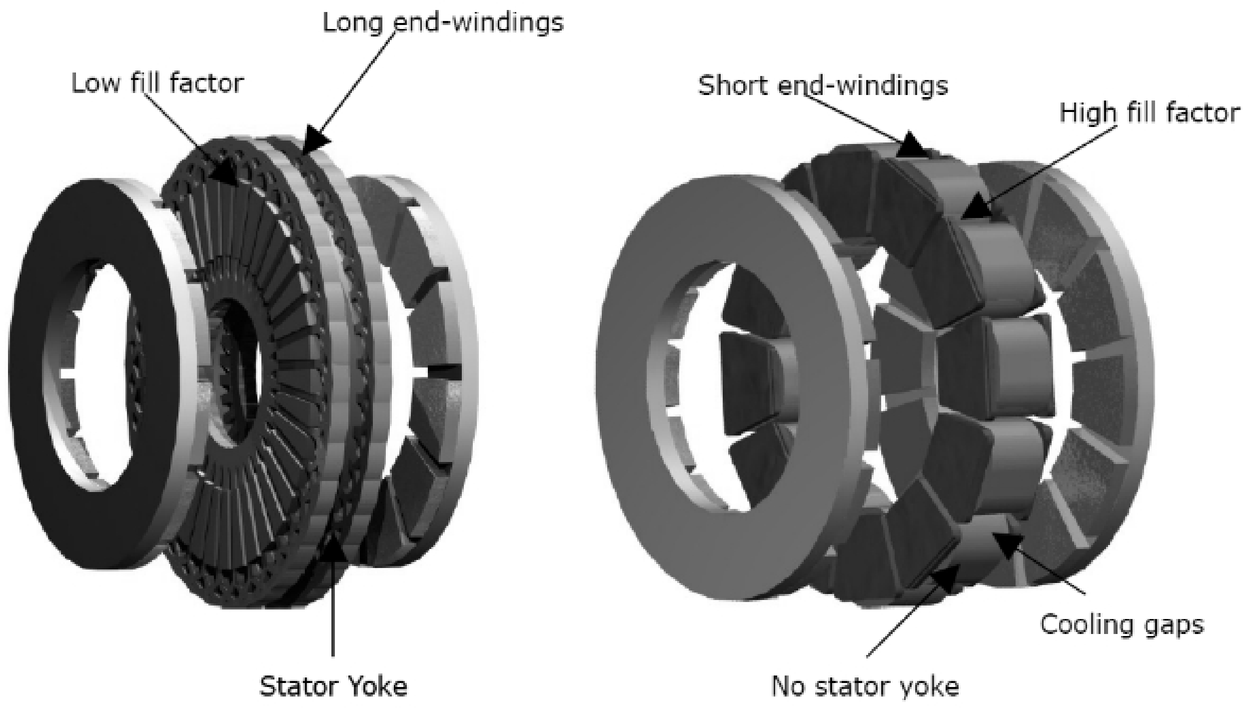


Figure 1: Left – typical axial flux machine; right – YASA machine[1]

[1] For those whose knowledge of electric motors may be a little rusty, the YASA motor is a "brushless dc motor", i.e. has its windings on the stator, with the currents switched electronically instead of by a commutator. The magnetic field is set up by permanent magnets on the rotor.

Hydrogen Power Takes to Water

Denis Gross

Hydrogen has for some time been proposed as an alternative energy source to carbon-rich fossil fuels, and there are "Hydrogen Highways" being planned and under discussion in several parts of the world including North America and Europe. In terms of propulsion, the automotive industry has looked at hydrogen for internal combustion engines (ICEs), and for use in fuel cells. Although BMW built a trial fleet of hydrogen ICE cars — the Hydrogen 7 — it too is now focussing on fuel cells. Mazda developed the Premacy Hydrogen RE Hybrid in 2007 as a bi-fuel version of the Mazda5, in which the two-rotor Wankel engine operates with hydrogen or petrol. Mercedes Benz, on the other hand, has developed its own fuel cell technology and the F-Cell has been introduced into the B-Class. Mercedes Benz has been working with fuel cells since 1994, and since 2003 has been running extensive testing of fuel cells in cars, vans, and service buses. Ford has looked at both technologies. Japanese and Asian auto companies have also been highly active in looking beyond the hydrocarbon era. Honda has been running its FCX fuel cell demonstrator cars on US roads for a number of years, and Nissan employs its own fuel cell technology in its X-TRAIL FCV. Generally speaking, a number of mainstream automobile manufacturers including Fiat have exhibited prototype fuel cell vehicles. All these vehicles are limited in number and require significant cost reductions before they can be commercialised.

A great attraction of fuel cells is their relatively high efficiency — currently 60% compared to 22% for petrol or 45% for diesel internal combustion engines. Coupling fuel cells to electric motors, which are more than 90% efficient, converts the chemical energy of hydrogen to mechanical work without heat as an intermediary.

Both hydrogen-fuelled and fuel cell vehicles emit only water at the exhaust, and thus they are able to meet future stringent automotive emission requirements. Thus programmes have been undertaken worldwide to test hydrogen-propelled buses, scooters, bikes and logistics vehicles as well as cars. Fuel cells are also used to propel boats and aircraft (mainly unmanned ones).

The majority of hydrogen generated today is obtained by reforming natural gas using electricity generated from hydrocarbon fuel, and using this hydrogen for "green" propulsion still generates a significant carbon footprint. The electrolysis of water to generate hydrogen similarly has an unwelcome carbon footprint, although utilising electricity generated from renewable sources to generate hydrogen for use in fuel cells and other applications, while relatively inefficient in a "well-to-wheels" calculation, would act as a store for intermittent energy (wind, solar, marine) that might otherwise be dumped if the grid could not take it.

Distributed hydrogen generation by small and medium sized electrolysers would address the lack of a hydrogen infrastructure, and could extend the use of fuel cells in off-grid applications including auxiliary power and recreation.

Hydrogen storage technology is improving, although current capabilities are best suited to return-to-base fleet delivery vehicles, such as logistics fleets, or, on a smaller scale, for fuel-cell bicycles. Storage solutions currently being pursued are high pressure tanks, cryogenic liquid hydrogen and the use of metal hydride storage systems. One reported problem with liquid hydrogen is the significant loss rate of the fuel in transportation. Most fuel cell and hydrogen ICE vehicles now utilise high pressure storage of hydrogen that allows for rapid dispensing and increased vehicle range.

Fuel cells have been around for a long time, and while scientists have been familiar with the principles of fuel cells since the nineteenth century, they first gained prominence in the manned spaceflight programmes of the 1960s. One type, alkaline fuel cells, famously provided electricity and drinking water for the Apollo astronauts, for example. Of the range of fuel cell types developed, the proton exchange membrane, also called polymer electrolyte membrane (PEM), type has been prominent in the "hydrogen economy", and there are many examples under development in the automotive and transport sectors.

In a PEM, hydrogen is channelled to the anode on one side of the fuel cell, and oxygen from the air to the cathode on the other side. A catalyst at the anode (usually platinum) splits the hydrogen into electrons and hydrogen ions, which pass through the membrane to the cathode. The electrons cannot pass through the membrane and thus travel around the external circuitry as an electric current. The hydrogen ions, when they reach the cathode, combine with the oxygen to form water, which exits the fuel cell. As each fuel cell generates a low voltage, stacks are assembled from a number of cells.

The fuel cell industry has been characterised to date by its hand-built, and hence costly, products, but there is a growing focus on volume manufacturing which is expected to produce dramatic reductions in the cost per kilowatt of a fuel cell.

How the land-based transportation sector will exploit the new technologies (battery-based electric vehicle (EV) technology, hydrogen ICE and fuel cells) remains to be seen. Meanwhile, fuel cells are beginning to find a growing application on the water.

In submarine propulsion, for example, the non-nuclear German Type 212 class U-Boat, developed by Howaldtswerke-Deutsche Werft AG (HDW) for the German Navy and the Italian Marina Militare, uses both diesel propulsion and an air-independent[1] propulsion (AIP) system based on Siemens 120 kW PEM hydrogen fuel cells. Elsewhere, in Hamburg the Zemship is an excursion ship that began operating on the Alster Lake in the summer of 2008. This is a pilot project, and is due to run for two years as a demonstration that ships powered by full cells offer the ideal solution for ecologically sensitive inland waterways.

While the Zemship is a 100-passenger vessel, smaller electric boats for leisure, powered by hydrogen fuel cells, have appeared on Lake Traunsee, Austria, and elsewhere. In Austria the group of companies Fronius, Bitter and Frauscher has developed what they claim to be the first fuel cell ready for serial production to power a boat. This is a 4 kW fuel cell that currently powers the "Future Project Hydrogen" boat for use on lakes.

On smaller boats, in particular sailing craft, fuel cells are finding use as a replacement for diesel generator sets as auxiliary power units. They also stand to gain as battery replacements for electric leisure boats in use on American and central European lakes.

European lakes are beginning to ban and/or introduce restrictions on the use of hydrocarbon-powered boats on their waters in an effort to reduce pollution. Consequently, Europe has seen the rise in popularity of fast electric power boats for use on lakes and inland waters. As more lakes, marinas, ports and seaside towns are likely to impose tougher restrictions on engine exhaust and similar pollution, the electric power boat could become a common feature in yachting and boating.

Similarly, there is a movement in the US for electric-only lakes. There is a growing number of lakes that ban the use of spark ignition engines in order to reduce noise and emissions.

These boats are primarily powered by batteries, and while doing sterling service, batteries have a number of limitations that are opening the door for fuel cells to replace these batteries, particularly with the availability of hydrogen stored in metal hydride canisters. The main advantage of these hydrogen fuel cell boats compared with conventional battery-powered electric boats is the fact that no time has to be spent charging the batteries. For conventional electric boats, 6–8 hours of charging gives just 4–6 hours of use. The hydrogen-powered electric boat requires just the time that it takes to change the fuel cartridge, only about five minutes.

(Continued on page 22)

[1] In the U212, hydrogen and oxygen are stored in tanks located between the pressure hull and the outer hull.

Hydrogen Power Takes to Water cont.

(Continued from page 21)

An approach emerging as highly appropriate for the recreational boating market is the hybrid battery/fuel cell system, in which the motor is driven by the battery which in turn is recharged by a hydrogen fuel cell. The hybrid system has the following advantages:

- Improved battery life (the fuel cell maintains the charge at above 80%, both at sea and on land)
- Greater duration in use (the fuel cell and hydrogen in metal hydride tanks extend battery life)
- Better performance (electric motors are more efficient than combustion engines for torque and power).

Such a hybrid system is being used on the HIDRO tender, a hydrogen powered tender developed jointly by Acta Energy and Callegari, shown below.

These are still early days for the commercial use of fuel cells in transportation, but the cost and technology barriers to quiet, emission-free travel on land and on water are falling.

Finals and Prelims Prizes Awarded 2010

The Examiners recommended the following awards in respect of Final Honour Schools in 2010:

Engineering Science Part 2

Maurice Lubbock Prize for best performance:

Zeng Wang, St John's

Edgell Sheppee Prize for excellent performance:

Benjamin Kirollos, University

Head of Department's Prizes for excellent performance in examinations:

Si Ying Wang, St Hilda's; Paul King, Magdalen; Richard Mason, St Catherine's

ICE Prize for best performance in Civil Engineering:

Meng Wan, St Anne's

IMechE nomination to the Frederic Barnes Waldron Prize:

Anton Hunt, Christ Church

IMechE Best Student Certificate

Richard Gowland, Christ Church

IET Prize for outstanding academic achievement, and Oxford Instruments Prize:

James Nutton, Lincoln

IET Manufacturing Engineering Prize:

Christopher Neale, Exeter

IChemE Prize, and Lonza Biologics Prize for the best final-year performance in chemical engineering:

Haani Paienjton Jr, St Catherine's

Jacobs Prize for the best project in Civil Engineering:

Benjamin Harland, New College

IMechE Prize for the best project in mechanical engineering:

Benjamin Kirollos, University

IMechE Certificate for an outstanding project in mechanical engineering:

Stephen Liu, Somerville

Motz Prize for best project in electrical engineering:

James Nutton, Lincoln

Ronald Victor Janson Prize for best project in electronic communications:

Rikki Gorman, Oriel

Rohde & Schwarz Prize for best project in high-frequency test and measurement

Haani Paienjton Jr, St Catherine's

BP Prize for best project in chemical engineering

David Hanbury, St John's

The Worshipful Company of Scientific Instrument Makers Project Prize:

Edward Jackson, Magdalen

HMGCC Project Prize in Information Engineering:

Toby Miller, Keble

Cornhill Prize for an outstanding project in biomedical engineering:

Junaid Mohammad, Lady Margaret Hall

Engineering Economics and Management, Part 2

Maurice Lubbock Prize for best performance:

Maximillian Leeb, Keble

Edgell Sheppee Prize for best performance in an engineering project:

Luise Birgelen, St Hilda's

Pilkington Prize for best performance in a management project

Maximillian Leeb, Keble

Engineering and Computer Science, Part 2

Maurice Lubbock Prize for best performance:

Arvinda Atukorala, Balliol

Engineering Science, EEM and ECS Part 1

Edgell Sheppee Prize for laboratory or drawing office work:

Kirsty McNaught, Lady Margaret Hall

Gibbs Prize for best Part 1 project, jointly to:

Benjamin Anderson, Christ Church; Mark Baker, St Edmund Hall; Matthew Betney, Lady Margaret Hall; Peter Daunton, Wadham

BP Prize for best Part 1 chemical engineering project, jointly to:

Samuel Fishwick, Keble; Jack Gilbert, Balliol; James Hopkins, Christ Church; Federica Nocera, University; Keong Yuan Yeoh, Somerville

The Moderators recommended the following awards in respect of the Preliminary Examination

Crown Packaging UK plc Prize for best performance:

Jian Min Sim, St Edmund Hall

Shell Prizes for outstanding performance:

Patrick Thill, New College and jointly to Maurus Wuethrich, Pembroke; Eliot Clark, Wadham

Project Exhibition 2010

David Witt

This is the tenth year in which the Society has organised an exhibition of fourth-year projects in Trinity Term. Over that period we have had 169 entries, of which 109 won prizes. If we list them by colleges, St John's comes out in the lead with 11 prizewinners, closely followed by Lincoln with nine. The contest is judged by a group of former undergraduates, four of them usually, from about 5–15 years back, now engineers in the "real world", who seem to enjoy coming back to do this. This year they were:

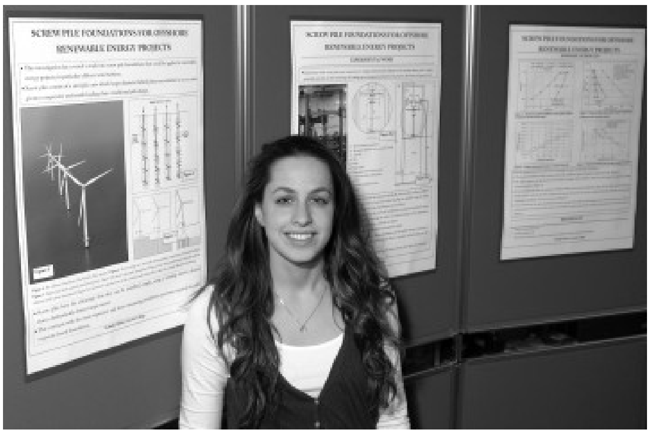
Gareth Jones, Balliol 1995–9, now with Strainstall

Manish Pindoria, Pembroke 2001–5, now with Sony Broadcast and Professional

Jonathan Rhodes-James, Brasenose 1991–5, now with Arup

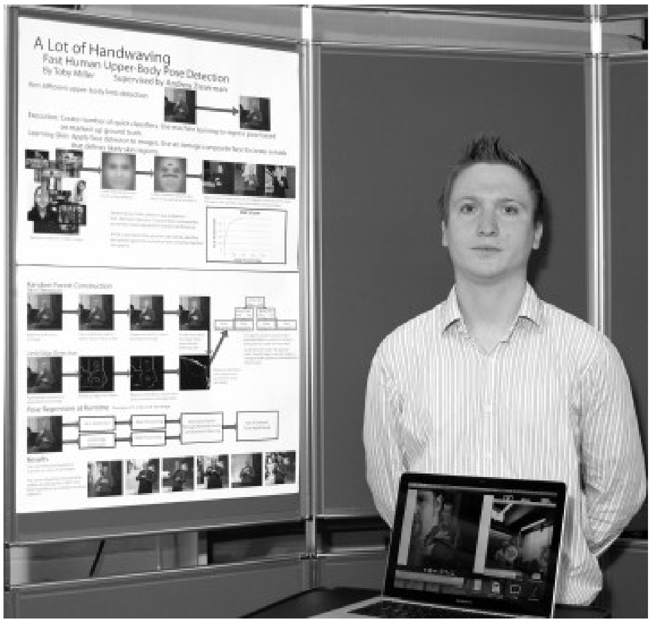
Lynsey Thomas, Balliol 1995–9, now a telecommunications consultant

The prize money this year amounted to £2500 in total, sponsored by Atkins and GlaxoSmithKline (well-established regulars) and Sony BPRL (a new one this year). We are very grateful both to the firms for the sponsorship and to the alumni working for them through whose initiative the sponsorship is generated.



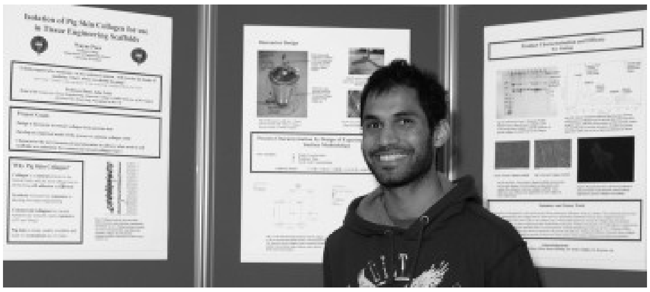
The £500 Atkins Prize for an exhibit in the civil/structural field went to Nathalie Hakim of Lincoln (above), describing a study of a new way of fixing off-shore windmills to the sea-bed.

The large horizontal force on a windmill means that a foundation pile on the windward side can be in tension, and therefore apt to lift. Nathalie's model used 25 mm diameter piles with 100 mm diameter helically-shaped flanges which "screwed" into the soil when rotated about their axes. They therefore carried tensile force more as a screw does than a nail. Tests on dry sand 900 mm deep showed results much as expected, except that the torque needed to screw the pile in did not increase with depth as much as predicted. What difference does it make if the sand is wet? And the writer wondered if further inspiration might be got from that type of Rawlplug used to fasten bathroom cupboards to plasterboard walls!

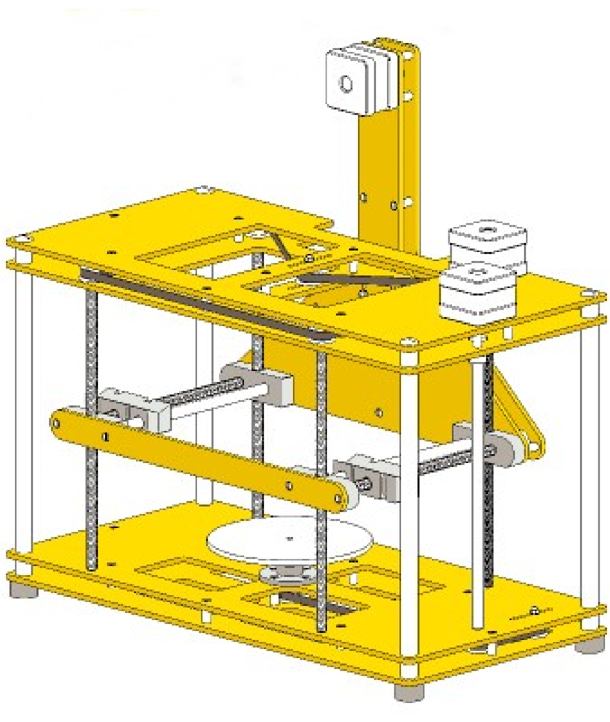


The £300 Sony Prize, for an exhibit relating to image, video or audio processing, was awarded to Toby Miller of Keble (above), for "A lot of handwaving — fast human upper-body pose detection". This used existing software to find a face, and then looked for other areas of the same skin colour, and assumed they were hands.

The judges awarded £400 prizes both for the best "poster-only" exhibit and for the best one involving hardware. Both were awarded to exhibits in the bio-engineering field. The former went to Wayne Paes of Wadham (opposite top)



for "Isolation of pig skin collagen for use in tissue scaffolds". Collagen is a natural protein in humans, and is used in regenerative medicine to promote cell adhesion and growth. It has, surprisingly, been extracted from rat tails, but pig skin is a cheap and readily obtainable alternative, with some technical advantages. The project was concerned with scaling up to bio-reactor size an extraction process already tried in a beaker, using pepsin and lactic acid. The variation of yield was plotted as a function of pepsin level and residence time.



The "best hardware" prize went to Chris Wilkinson of Lincoln for a 3-D ultrasound tomography scanner (above). The transmission of ultrasound through the specimen had to be plotted as the transducers were moved horizontally past it, and repeated for different azimuthal orientations of the specimen. Computer analysis of this data could map a cross-section of a horizontal slice, and the sequence would then be repeated at different heights. So the transducers had to be movable both horizontally and vertically, and the specimen rotated in azimuth. This was done with stepper motors and belt drives driving a multplicity of lead screws. All the moving parts (except the motors) had to operate under water and contain no metal. We did not see it in operation, but the design seemed very elegant.

Five further prizes were awarded, making nine in total, out of the eighteen who entered, to:

Ian Horn, Christ Church, for "A high resolution micro-indentation device for testing the stiffness of biological tissue";

Nennia Orji, St John's, for "Can we detect a stroke before it occurs?";

Peter Charlton, Hertford, for "Demonstrating elastic stability theory";

Ben Harland, New College, for "Solitary wave interactions in the open ocean";

Ben Kirollos, University, for "How do you solve a problem like cooling a jet engine?"

The nine other entrants offered exhibits on a wide variety of topics, ranging from "rainwater harvesting for disaster relief", through "the dynamics of bell towers", to "the dynamics of shaken-baby syndrome". This last was one of the eight exhibits in total that related to some aspect of bio-engineering, an area of rapidly growing popularity in the Department.

Obituaries

John F Coates, Queen's 1940–3

John Coates was one of two distinguished naval architects who graduated from the Engineering Department in the 1940s, the other being Ewan Corlett (obituary in SOUE News 2005). Both men were at Queen's, in successive years.

Coates was at Oxford in the first three years of World War II, and was one of just five people graduating in Engineering Science in 1942. The Examiners gave them all Seconds! He joined the Royal Corps of Naval Constructors, and saw sea service in 1944–5. Thereafter he was employed in various duties in ship design, structural research and repair. He was awarded an OBE in 1955, at the unusually young age of 33, for work on the development of inflatable life-rafts and lifejackets, including, it has been said, testing the latter himself by jumping off the sides of ships.

From 1957 he led work on the design of the County class of guided-missile-carrying destroyers, the first such vessels built by the Royal Navy. These were large vessels for destroyers, 6800 tons at full load, with combined steam and gas turbine propulsion. They carried the Sea Slug guided missile, itself very large too, primarily for use against aircraft. Later versions carried the French-designed Exocet. Eight of the class were built in total, of which two, HMS Fife and Antrim, suffered damage in the Falklands war of 1982.

He retired in 1979, as Deputy Director of Ship Design, but subsequently pursued his interest in applying naval architecture to historical ship research. He wrote papers on the strength of wooden ships, hypothetical reconstructions, and on recovered remains such as the Mary Rose and the Ferriby boat. From about 1983 he was greatly involved in the design of the reconstructed Greek trireme. The instigation of this was a lengthy controversy in the correspondence columns of The Times of 1975 about whether, and how, the trireme could have had the performance historically attributed to it (e.g. a row of 130 nautical miles in a "long day").

A typical trireme was known to have had 170 oarsmen, but how they, and their oars, were arranged, had been the subject of much dispute. The "tri...", or "three" clearly had some significance here, but was it three men to each oar, or three men on each seat pulling separate oars, or three rows of oarsmen separated vertically? The objection to this last arrangement had always been that the oars would have had to be of different lengths, so it would have been impossible to pull them in synchronism. But JS Morrison, a classics don at Cambridge, had suggested that if the upper row had their thole-pins set on outriggers, while the lower ones were in the skin of the hull, then all the oars *could* have the same length (as indeed they were known to be from ancient shipyard inventories). Coates and David Moss built a full-scale replica of one "unit", (three oarsmen at different levels) and showed that they could row in synchronism. A "Trireme Trust" was formed to raise funds and work towards building a complete replica trireme with the oarsmen so arranged. Coates took over responsibility for its design, including all the details of how it could be constructed, out of wood, in a historically believable way. Long planks were held each to its neighbour by hundreds of tenons to resist shear, and the hull was pre-stressed longitudinally by a tensioned rope fastened between the ends. *"The Athenian Trireme"* by Morrison and Coates gives a full account of all this.

The trireme was built in Greece, at the expense of the Greek Navy, christened *"Olympias"*, and tested in the Mediterranean with volunteer crews (including at least one SOUE member) in 1987 and subsequent years (right). In 1997 she could be seen being rowed up the Thames in London. The trials showed that the reconstruction was successful in the main, though open to improvement in detail. In particular the longitudinal spacing of the oarsmen needed to be increased, so that they could generate more power without being constrained by the ship's structure. This was not only because people are bigger now than they were in Greece of the fifth century BC, but also because the spacing had been based on a

The reconstructed trireme *"Olympias"*

written source that said it was "two cubits". It turned out that cubits had been variously defined, and they probably used the wrong conversion factor!

John Coates gave the Jenkin Lecture on the trireme reconstruction in 2005. He died on 10 July this year, aged 88.

The Duke of Hamilton

The Marquess of Clydesdale, as he was then, read Engineering Science at Balliol in the late 1950s. He had learnt to fly before he came up, and joined the University Air Squadron. After graduation he joined the Royal Air Force, following his father who had had a distinguished career in it, for example being one of the pilots of the expedition that flew over Everest for the first time, in Westland biplanes in 1933. The son flew Canberras in Malaya during the 1960s emergency there, and as a recreation drove racing cars in Singapore. In 1967 he was invalided out of the RAF, but continued to fly and motor-race. He was involved in the development of Scottish Aviation's Bulldog aircraft, as test-pilot, and also of an amphibious vehicle, the Supercat.

On the death of his father in 1973, he became the 15th Duke of Hamilton, inheriting as well as the title more properties than he could make proper use of. Three of them he managed to get sold and adapted for contemporary use. One office that came with the Dukedom was Hereditary Keeper of the Palace of Holyrood House in Edinburgh, which acquired fresh significance when Scotland got its own Parliament again. In politics, he described himself as a cross-bencher in the House of Lords, with interests in energy, defence and transport. Another long-standing interest was animal welfare, which he shared with his third wife Kay, who survives him. He died on 5 June this year, aged 71.

SOUE Network

As you may be aware, we have recently set up an SOUE Network through LinkedIn. This provides an excellent way for SOUE members to stay in touch. A trawl through the network shows the wide range of activities which alumni are engaged in throughout the world.

With this range of knowledge and experience, it can be a useful source of career advice to younger members. It can also help those in more senior positions seeking information outside their particular field.

Details of how to join are available on the SOUE website and it only takes a few moments. I would encourage you to join — the larger the network becomes the more valuable it is to its members.

Martyn Hurst

President SOUE

SOUE News

Produced by David Witt (Magdalen 1959) and Simon Turner (Lincoln 1984)
Printed by Holywell Press

Society of Oxford University Engineers
Department of Engineering Science
University of Oxford
Parks Road
Oxford
OX1 3PJ

E-mail: soue@soue.org.uk

Visit our website:

www.soue.org.uk