

## ***Society of Oxford University Engineers***

### **Welcome to the seventh issue of SQUE News**

This issue of the News is the longest ever (56 pages), since we have a very full report of the Department's Centenary celebrations, by Alistair Borthwick who master-minded the year's events. One of the big events was the publication of Alastair Howatson's history of engineering at Oxford, "*Mechanicks in the Universitie*", of which signed copies sold like hot cakes (or ice-cream cornets perhaps?) at the well-attended Garden Party in July. It is reviewed by Rod Smith on p.25.

The topics of our technical articles are mostly of major significance to the world we live in, e.g. water treatment, cancer therapy and tidal power, but we are allowed a little bit of fun too, in this case a robotic dog on which one of the editors worked a few years ago.

The Jenkin Lecture by Sir Vivian Ramsey and the Lubbock Lecture by Lord Browne are reported on, as is the other Jenkin Day lecture, by Martin Oldfield, on 38 years of gas-turbine research at Osney.

The Faculty has completed its revision of the course structure. The new course has public exams at the end of each year, including the second, which may set old-timers muttering, but the changes (the first of any significance since the introduction of the four-year MEng about 20 years ago), and the reasons for them, are summarised by Richard Stone on p.10.

That some of this issue of SQUE News is in colour is due to a generous (and anonymous) donation by a member towards printing expenses. He thought that perhaps others might follow his example in future years. If they do we shall of course be delighted and grateful!

Jenkin Day this year will be on Saturday 20 September, and the Jenkin Lecture will be given by Professor David Clarke, who is on the point of retirement. Details on an enclosed slip.

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## Head of Department's Report 2007–2008

Richard Darton

### Introduction

The past year has been the year of our centenary, 1908–2008. The celebrations are described elsewhere in this newsletter, and I am very grateful to Professor Al Borthwick who chaired the Centenary Committee and all those many members of the Department who contributed to the success of the programme. We really marked this milestone! The celebrations reminded us that there is a huge fund of goodwill amongst our alumni and our business contacts, and that we must make more effort to tell our friends what we are doing. Some highlights of our year are mentioned in this newsletter, though we do not say much about our "core business" — our teaching and research programmes in Engineering Science. Our research activities at least, written up for the Government's competitive Research Assessment Exercise, will be published around Christmas 2008, so those interested in the detail will get plenty of it, and be able to compare us with other places. Watch out for our ranking in the league tables.

### Awards

For the second year in a row an Oxford student has been selected as Best Civil Engineering Student of the Year at the national SET awards: in October 2007 Ross McAdam (KBL) was named the winner of the Balfour Beatty Award Trophy for his work on *Model testing of a novel design of a turbine to generate power from tidal flows*. Three of our students were also given Royal Academy of Engineering Leadership Advanced Awards: Sofia Akram (SHU), Toby Miller (KBL), Nneka Orji (KBL). At the 2007 Awards Ceremony of the Institution of Engineering and Technology in November 2007, Oxford students won a large number of awards, including a Belling Award for Engineering Excellence to Marco Diliberto (JES). Others were: Jubilee Scholarships — Samuel Adcock (SEH), Louise Ellis (HTF), Joshua McFarlane (STJ), Rebecca Threlfall (KBL); Engineering Degree Scholarships for Women —

Megan Duffy (WAD); IET Fuse Scholarships — Gary Gibb (STA), Alexander Johnson (SEH), Kevin Ling (EXT), Michael May (WOR), Edward McCaul (WAD), Tsun Wong (WAD).

Graduate scholarships were awarded by the IET to Mr Yangyang Zhang for *Intelligent Transmission Strategies for Future Communication Systems* and Mr Yi Liu. The Richard Way Memorial Prize for the best IC Engine thesis in 2006 was awarded by the Universities Internal Combustion Engine Group to Hongrui Ma for his thesis *Optical Diagnostics and Combustion Analysis in a Gasoline Direct Injection Engine*. Hongrui worked on a project funded by EPSRC, Jaguar and Shell, and now works for Shell at their Thornton Research Centre.

A team led by Departmental Lecturer Suby Bhattacharya, including three Oxford engineers (Joshua Macabuag — PBK, Louisa Man — STC, Peter Brice — SEH) won a top 2007 Mondialogo Engineering Award of € 20,000 following three days of presentation at Mumbai. These awards were set up by DaimlerChrysler and UNESCO to encourage engineering students in developing and developed countries to form international teams to create project proposals that address the United Nations Millennium Development Goals. Their winning project was *Extending the collapse time of non-engineered houses in the Himalayan Region during earthquakes*. This is a simple technique originally developed at the University of Tokyo with further work carried out at Oxford. It will be implemented in Nepal and India.

Professor Lionel Tarassenko received a Rolls-Royce High Value Patent Award for Technical Innovation, for his QUICK technology for monitoring engine health. Dr Harvey Burd was awarded a 2007 Leverhulme Trust/Royal Academy of Engineering Senior Research Fellowship to pursue a research programme in Ophthalmic Engineering. Professor Steve Roberts' ARGUS II project won the 2007 *Engineer* magazine award for the best University-Industry collaboration. This five-partner project is developing distributed and

reactive agent-based data and information fusion systems that are capable of adapting to their environment and making the best use of whatever information is available. It is a collaborative research programme under the Defence and Aerospace Research Programme initiative. Dr Constantin Coussios, whose research is in the area of Therapeutic Ultrasound, won an Institute of Acoustics 2007 Young Person's Award for Innovation in Acoustical Engineering.

While celebrating 100 years of the Department, it is appropriate to mention Sheila Widnall, who was awarded an Honorary Degree of Doctor of Science by the University of Oxford in June 2008. Sheila Widnall is a Professor of Aeronautics and Astronautics at MIT and was a former United States Secretary of the Air Force, and former Vice-President of the National Academy of Engineering. She is renowned for her work in fluid mechanics, in particular the so-called Widnall instability. We are delighted that an engineer has been honoured by the University during our centenary year. Other achievements of merit during the year include the election of Professor Sir Michael Brady to a Fellowship of the Academy of Medical Sciences, the elevation of Professor Richard Darton to President of the Institution of Chemical Engineers, the election of Professors Alison Noble and Tony Wilson to Fellowships of the Royal Academy of Engineering, and the admission of Professor Rodney Eatock Taylor to an Honorary Fellowship at University College London.

The University's own John Fell Fund made awards to: Dr Martin Booth for *Three-dimensional optical nano-fabrication*, Dr Chris Stevens for *Nano-structured electrodes for enhanced dye-sensitised solar cells* and Dr Hua Ye for *Development of in vitro three-dimensional tumour models – a feasibility study*.

It is very satisfactory to be able to report that an F1 team sponsored by Engineering Science has become national champion. In January 2008 the *F1 in Schools* National Finals took place as part of the Autosport exhibition at the NEC Birmingham. The "Hippos Strike Back"

team, based at St Gregory the Great School in Oxford won the award for being the top team in the 11–14 year category with their model racing car. Engineers in the making!

### Academic staff movements

In September 2007 Dr Janet Smart (previously Efstathiou) resigned to take up the post of Director of the BT Centre for Major Programme Management at the Saïd Business School. There were no retirements at that time, but during the year we lost Career Development Fellow Jinming Huang, and Departmental Lecturers Suby Bhattacharya and Alex Matthews. We wish all these well in their future careers.

### Buildings

The Institute of Biomedical Engineering, within the Old Road Medical Campus development at Headington, part of a £55 million building started in March 2006, was occupied in February 2008. It was officially opened by Sir William Castell, Chairman of the Wellcome Foundation, on 16 April 2008. The opening was a gala event, distinguished also by the first Oxford Medtronic Lecture, by Professor Shu Chien of the Whitaker Institute of Biomedical Engineering at the University of California, San Diego, who spoke on *Biomedical Engineering in the New Century*. When fully staffed, the Institute building will house around 145 people (staff and students). The project was completed on time and within budget, and we are delighted to have acquired such a fine building, designed by Ken Shuttleworth, one of the country's leading architects.

As announced last year, the University has approved our establishing a new engineering research laboratory in the Axis Point building on the Osney Mead industrial estate, so that we can vacate the Southwell building. This £4.3 million project is now in progress with preparatory work at Axis Point. The move of wind tunnels and other experimental rigs will begin shortly.

The Department has also acquired fine new space at the Begbroke Science Park, for water

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## Head of Department's Report 2007–2008 cont.

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research, high strain-rate mechanics, and electrical power systems for renewable energy. We are adopting the policy that projects that are space-demanding, and near-market, are appropriately located at the Park, which offers ease of business contact. Refurbishing the computer suite on Thom floor six was delayed from 2007 and is taking place now, so that students will be making use of a brand new computing facility from October 2008. They will also be able to make use of the newly refurbished, but creaking, lifts.

The University is also drawing up plans to renovate the whole science area — anyone with a billion pounds to spare should get in touch with the Vice-Chancellor! Rebuilding the iconic Thom building is part of this plan, but it is not clear if and when this might happen. Meanwhile, with its new Information Engineering Building (opened 2004) and the projects mentioned above, the Department is feeling relatively well-housed at the moment.

### Development and fund-raising

As part of our centenary celebrations, we launched an appeal for contributions to the Centenary fund, whose primary objective is the support of graduate students reading for higher degrees. You can even contribute to this on-line: a first for the department (see [http://www.giving.ox.ac.uk/academic\\_departments/mpls/engineering.html](http://www.giving.ox.ac.uk/academic_departments/mpls/engineering.html)). Some may find this type of appeal rather brash, but I am pleased to say that it is delivering funds, and these are really really valuable to the department, so a huge thank you to our benefactors.

Earlier in 2008 the University reviewed the Division of which Engineering Science is a member, and concluded that this department should grow significantly. We see plenty of opportunities to do so — Engineering is one of the key skills needed in providing wealth and welfare to the world. The challenge of how to bring about this growth is before us, and one that we will take on enthusiastically.

Oxford, July 2008

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## The 20th Jenkin Lecture, 15 September 2007: Law and Engineering: Resolution of Technology Disputes

*Sir Vivian Ramsey (Oriel 1969–72)*

### Introduction

After some introductory remarks, the speaker explained that he would be concentrating on the relationship between law and civil/structural engineering, since that was where his background lay, but the principles would apply in other engineering fields too. There were numerous myths about how the law operated, e.g. that it involved lengthy and expensive procedures of no benefit to engineering or indeed to anybody, but he hoped to show that they were indeed myths, at least where technical disputes were involved. This talk would explain the genesis of technology

disputes and how they can be resolved efficiently and effectively.

### Overview of dispute resolution

When a dispute arises, there needs to be a process for dealing with it, following defined rules and reaching a conclusion. There has to be information, and an approach to analysing it. One might make a comparison between the process of analysis in engineering design and that in law. In engineering, the design process uses data which by applying formulae and other experience arrives at a design of the item that will hopefully be built. In law, there is a background of experience in existing laws and judicial precedents and there is data in the

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form of the evidence relating to the case. Applying the experience of law to the evidence leads to a judgment, which will decide the matter and may be stored as a further precedent for future cases.

Why do engineering disputes cause so much difficulty? There can be an incompatibility between legal processes and the complexities of engineering disputes. Is a legal trial intended to lead to "justice", whatever that is, whatever the time and cost may be, or is it intended simply to lead to a cost-effective solution? A trial usually results in a winner and a loser. In the familiar TV reports of cases the winner often rejoices before the cameras that "he has got justice", while the loser complains of the injustice of the process. There is no obvious engineering analogy to the winner and loser.

Justice requires a fair trial, which means there has to be evidence which needs to be assessed in terms of proof. In civil cases the party must prove its case on the balance of probability whilst a higher standard is required in criminal cases where guilt has to be proved beyond reasonable doubt. The process must lead to an answer, but it must also be cost-effective. A balance is needed. A murder trial is a more serious matter than one involving a minor assault, and a dispute involving the construction of Wembley Stadium is likely to be more serious than a small claim involving a car accident. The legal process needs to be adaptable — hence the recent development of new ways of solving technology and engineering disputes.

### **Historical background: the Engineer, certification and arbitration**

There has always been a choice between private arbitrators and the public courts. Since the 18th century, the customary way for an individual or public body to employ a contractor was for him to engage an architect or engineer who would not only do the design but also supervise the construction, certify that the contractor had satisfactorily completed some portion of the work and authorise that he be paid for it. This person would also adjudicate when variations might be requested by either

side, perhaps by the employer who had changed his mind about what he wanted, or by the contractor because of constructional difficulties not originally foreseen. And someone needed to define what was acceptable quality in the work undertaken. So the Architect or Engineer came to hold a key position in the contract between employer and contractor.

The role of the Engineer and the effect of Engineer's certificates were considered in a number of cases. Ideally a person in the position of the Engineer (or the Architect in building contracts) should be independent. But, someone appointed or employed by the employer or owner could hardly be viewed as truly independent, particularly by the contractor! Contractors often sought to obtain payment by commencing proceedings in court but were met by a defence that the certificate of the Engineer or the Architect was required to obtain payment. Only if collusion, corruption or fraud was found could the Engineer be impeached and the certifying process avoided.

In the 1854 case of *Ranger v GWR*, there was a dispute between a contractor and the Great Western Railway. Payments to the contractor were to be made on the certificates of the GWR's Principal Engineer, in this case, the well known Isambard Kingdom Brunel. The contractor complained that the Engineer was not only an employee of the GWR, but also a substantial shareholder in it, with a vested interest in ensuring that the contractor should not receive any additional payment. The Court of Appeal agreed with the contractor, saying that Brunel was "acting as a judge in his own cause". But the House of Lords took the opposite view, that the Engineer was not intended to be impartial, so his shareholding was irrelevant, and the case was decided in favour of the GWR — the Engineer's certificates could not be disregarded.

In a case in 1911, *Hickman v Roberts*, the contractor wrote to the architect asking for an extra payment in what was meant to be a fixed-price contract. The architect was willing to approve the request, but his employer was not

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willing to make the payment. The architect therefore told the contractor that his hands were tied by his client's instructions, so he could not authorise the payment whatever his private views might be. The case eventually went to the House of Lords, which held that in the circumstances the contractor did not need a certificate from the architect, but was entitled to ask the Court to rule on the amount to be paid. Lord Atkinson said that the architect (Hobden by name) had been "led astray" by his desire to satisfy his employer, but that there was no suggestion of "collusion, corruption or fraud". This widened the scope to which a certificate could be impeached, in that if someone had "influenced" a certifier, then he could not be said to be independent and the contractor could recover without a certificate.

The role of the Architect was considered in the 1967 case of *Sutcliffe v Thakrah*. A judge acting in a private capacity proposed to build a house and employed architects to produce drawings and engage a contractor to build it. The judge became dissatisfied with the work and terminated the contract, but then discovered that, on the basis of the architect's over-certification, he had overpaid the contractor by £2000 and could not recover the sum from the contractor. Could he sue his architect for that sum? There was an argument that the certifier was acting in a quasi-judicial capacity and therefore was immune from suit in the same way as a judge or arbitrator is. In giving judgment, Lord Reid said that an architect had two different functions. In one capacity, as a designer, he had to follow his employer's instructions; but in the other, as certifier, he had to decide for himself. He said that it was therefore implicit that the architect was obliged to act with due care and skill, and in an unbiased manner. This opened the way for employers to sue their certifiers.

Another particular problem arose in relation to the court's powers to deal with certificates. Building and engineering contracts, particularly in the past, often tended to specify arbitration

by an independent arbitrator as the means by which disputes could be resolved. The arbitration clause frequently stated that the arbitrator had the power to "open up, review and revise" certificates. What then happened if the dispute went to court instead of the arbitration? In *Crouch v NRHA* the Court of Appeal held that the court did not have the same powers as arbitrators to decide disputes, so that certificates were binding in the courts and could not be opened up, reviewed or revised except in an arbitration. Thus, if there was no arbitration clause, the certificate was final, and the court could not interfere.

In a case from Northern Ireland, *Beaufort Developments v Gilbert Ash*, Lord Hoffman said that the certificate had a provisional validity, and determined matters if not challenged. If it were challenged then the court could determine the dispute. Also, he pointed out that the architect was the agent of the employer, a professional person, but not to be regarded as independent. He added a comment about the historical role of the architect and said that the question of conflict of interest had not been so well understood in past times as it was now.

A much more recent example of the role of the certifying Engineer was provided in *AMEC Civil Engineering v Secretary of State for Transport*. This case concerned the Thelwall Viaduct, which carries the M6 motorway over the Manchester Ship Canal. AMEC undertook the replacement of the roller bearings which supported the spans, and did so in 1996. In 2002 these bearings became defective under the weight of the traffic. But the law specifies a "limitation period" of six years from the completion of the work, within which any proceedings must be started. On 6 December 2002 the Highways Agency suddenly realised that this period would expire on the 23rd of that month. But the terms of Clause 66 of the ICE Contract forbade the appointment of an arbitrator until a dispute had arisen and been referred to the Engineer. The Arbitration could be commenced when a party was dissatisfied

with the decision of the Engineer or if the Engineer failed to give one for three months after being asked to do so.

Somewhat late, the Department sent a letter to AMEC alleging breach of contract and negligence, and made the same allegation against their consulting engineer, who had been appointed to act as the Engineer under the contract. AMEC replied that "they were in no position to comment" on the allegation because they did not have sufficient information. So did a dispute exist yet which could be referred to the Engineer? The Highways Agency did not inform the Engineer of the response from the contractor but asked the Engineer for a decision about the contractor's liability, and gave him only a few days in which to do it. After eight days, on 18 December, and without seeking any comment from AMEC, the Engineer pronounced that AMEC were at fault. This meant that they could refer the dispute to the arbitrator on 19 December, just four days before the "drop dead" limitation date came into effect.

AMEC complained that the engineer had been put under undue pressure to take a decision in eight days, the normal time allowed being three months; he had not enquired whether they had any defence; and that both contractor and engineer had been blamed for the same fault. The case came to the Court of Appeal, who took a pragmatic view, deciding that the engineer had acted fairly and that the arbitration was validly commenced. This case provides a recent example of the difficult position in which the Engineer can find himself in such cases.

### **The changing climate of cooperation and dispute resolution**

Such issues arising from disputes about the process of certification by the Engineer and the consequent arbitration or litigation of disputes meant that the resolution of technology disputes was often a long and complex process. But in the last 15 years there had been a remarkable change in how construction disputes were dealt with. The industry has changed and the report of Sir Michael Latham "Constructing the Team" has had a significant impact in this area.

The first change was in methods of procurement. In many current contracts, though still overall a minority, the functions of the Engineer have been replaced by three people: the project manager; the supervisor; and the adjudicator. What is more, contracting parties are encouraged to adopt cooperative rather than confrontational attitudes. Contracts now often include a preamble declaring that it is the intention of all parties to work together in a collaborative manner, sharing information openly and supplying feedback to each other and welcoming such feedback. There are statements that the parties will act in good faith and a spirit of mutual trust. This is quite a contrast to old-fashioned forms of contract. The speaker confessed that he was rather looking forward to a case where the purchaser was alleged to have "failed to welcome feedback offered in a spirit of mutual trust"!

### **The need for compensation: liability of engineers**

The rise of the "Limited Liability Partnership" is a sign of the times when parties seek compensation for losses. Now there are many disputes between engineers and clients. The tendency for modern projects is for them to involve a whole raft of different suppliers and participants. In that mass of participants, there have traditionally been defined contractual relationships but these are often far fewer than the number of relationships between parties involved in the project. In the past the Common Law has sought to fill the contractual gaps so as to provide routes for claims in negligence where one party has been affected by the negligence of the other party. This led to a situation in the 1980s when almost anyone could sue anyone, but following a number of House of Lords decisions, this phase has now passed. Rather, contractual relationships are being created by forms of warranty which are given by all conceivable parties involved in procuring, designing or constructing the project to those who fund, own or occupy the building or structure. Thus, whilst liability for negligence at Common Law has contracted somewhat, liabilities under warranties have increased.

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But how are courts, judges, juries, to decide whether someone has been negligent? If one asked a class of 150 students to design, say, a reinforced concrete beam, one would expect to get 150 different answers, which might, if arranged in order of merit, lie on something like a "bell curve", with most of them near the centre. Where on this curve would one put the threshold of negligence? Not presumably, close to the middle, but somewhere out to the side. How far out? Equally in terms of design the same question could be asked about an acceptable factor of safety. Is 2.5 acceptable? Or 2.0 or 1.05 or 0.99? Even the latter figure could be acceptable if the material were known to have considerable reserve capacity, or if a safety factor had already been applied to the expected loads or if the loading was unexpected and short term.

These matters are very difficult to decide. But we were invited to consider three different cases, to illustrate the complex issues that arise and the strict view that the courts have often taken where things have gone wrong.

### *Emley Moor Tower*

First, in the 1960s the television mast on Emley Moor, owned by the Independent Broadcasting Authority, collapsed one night in March. Enquiries established that the causes were vortex shedding and asymmetric ice loading. The designers had not allowed for this latter possibility in their calculations. Were they negligent? Unfortunately for them, they had given a paper about the mast to the Institution of Structural Engineers, in which they raised the possibility of windy conditions and ice loading, although they had observed ice to be shaken off the stays. The court judged that the designers had been negligent in failing properly to consider that condition.

### *Abbeystead*

The second case concerned a methane explosion in Abbeystead water pumping station,

full of visitors at the time, one of whom probably lit a cigarette thereby setting off the explosion. The methane was believed to have leaked from a natural reservoir into the water pipe, empty at the time, and hence into the station. The owners, designers and contractors were all sued and found liable, both in the lower courts and in the Court of Appeal. But one of the judges dissented. Lord Justice Bingham thought that the designers at least were not negligent. Engineers, he said, cannot be expected to be polymaths and prophets, and could not have been expected to foresee the cause of the accident.

### *Heathrow Tunnel Collapse*

Thirdly, there was the collapse of a tunnel being driven under Heathrow Airport. On a Health and Safety prosecution, the contractors Balfour Beatty did admit criminal liability, but the Austrian tunnelling consultant who had been advising them denied liability. The jury found him guilty of breaches of the legislation. It was accepted that the tunnelling method they recommended was safe if conducted under careful supervision, but they had failed to provide this.

So, how can the court decide? It has of course no expert knowledge itself, so must rely on expert witnesses to bring them up to a state of knowledge where they can take a decision. The law requires a professional man to exercise only the "ordinary" skill of his art, not that of the "highest expert". But the people called as expert witnesses are usually persons of distinction, and therefore likely to have rather more than "ordinary" skill. Whilst the experts have a duty to the court, their evidence almost always supports the case of the party that has instructed them.

The speaker suggested that in the first and second at least of the above cases, the court might have been expecting rather more than an "ordinary" standard of skill.



## **Current methods for solving disputes**

It can be seen that construction and technology disputes raise complex issues of practice and professional conduct. Just as practices in the industry have changed so in recent years have the methods of dispute resolution. The speaker described four that are now available:

### *Mediation*

A mediator is an independent person who tries to bring the parties together by informal negotiation. Many engineering disputes cases are now resolved in this way, since it provides an opportunity for both parties to work towards a cost-effective agreement. It is sometimes criticised as being in the nature of "horse-trading" and because the parties may be open to the exercise of unfair pressure. However, it allows parties to come to an agreed settlement on terms which they have negotiated and has proved to be very popular.

### *Adjudication*

The Latham Report introduced this concept and it was then given statutory effect by the Housing Grants Construction and Regeneration Act 1996. All Construction Contracts must include a provision for adjudication. In this process, one party may apply for an adjudicator to be appointed within seven days. When appointed, he has 28 or 42 days to make a decision, which is binding until a final determination by the courts in arbitration. It will be enforced by the courts in the meantime so that, for instance, a party will have to make payment even if that party intends to challenge the decision. It provides a quick, temporary solution which in most cases is accepted as resolving the disputes or leads to a settlement. It can apply to any dispute but is perhaps not suitable for a case like that of Emley Moor.

### *Dispute Review Board*

This is frequently used on large infrastructure projects. The board usually has three members, one nominated by each of the two disputing parties, and the third an independent chairman. It meets on a regular basis and provides decisions which may be binding or non-binding depending on the form of procedure

adopted. It allows for a group to become involved in the project and to give decisions based upon knowledge gained from that involvement.

### *The Technology and Construction Court*

If these or other procedures are not appropriate or cannot resolve the disputes then the courts provide a specialist facility for resolving those disputes. Although historically there were Official Referees who dealt with construction and technology cases, this court has recently been through a series of changes to establish a court where disputes can be resolved effectively and efficiently. The Technology and Construction Court or TCC, as it is known, is now seeing an increased workload and the introduction of permanent High Court judges as members of the court. The speaker had recently been appointed as judge-in-charge. The procedures in the TCC derive from the Civil Procedure Rules and now involve a necessary pre-action procedure. Once commenced, short cases can reach a hearing within 28 days and long cases reach trial within 12 to 18 months, with all the necessary steps being the subject of case management conferences between the parties and the TCC judge assigned to the case.

In addition, there are opportunities for Early Neutral Evaluation and a novel Court Settlement Process which is being piloted in London.

## **Conclusion**

In conclusion, Sir Vivian hoped he had demonstrated that, in view of these new developments, there were efficient and effective ways of resolving complex technology disputes and that the legal system was not the dinosaur that it was often portrayed to be.

## Changes to the Engineering Science Course

*Richard Stone, Chairman of Faculty Michaelmas 2005–2007*

The content of all the first and second year courses has been reviewed and revised, and the lectures organised so as to reduce any overlap. The third and fourth years have had a significant re-ordering of material. As new options have been introduced in the last decade or so, this has led to some Year Four material being common to more than one paper. Even within courses where the title has not changed there has been evolution, so it has been timely to review the course as a whole. The main burden for the review fell on Stephen Duncan who gallantly morphed from being a member of the Review Group to chairing it.

The most obvious change has been the introduction of second year exams. This follows the pattern of other sciences (e.g. Physics, Chemistry, Biological Sciences), and the changing examination patterns in schools — modularisation means that students are no longer used to preparing for exams over two years. Another significant change has been the sub-division of B and C papers (of Years Three and Four) from 32-lecture courses to 16-lecture ones, and the doubling of the number of B and C papers to be taken. In some cases, material in the B and C papers has been re-allocated, so that material which is needed by more than one C paper is taught in a B paper. The shorter lecture courses give students greater choice and flexibility in the way they assemble their final year courses.

The proposed changes in the structure of the current Engineering Science MEng course can be summarised:

- Prelims — no significant change, only a redistribution of material within the

existing framework. (Four written papers and laboratory work.)

- The current Part I comprises both core papers and the initial specialisation with exams at the end of Year Three. The revised course is to have:
  - ♦ Second year exams (Part Ia) that will cover four core papers (A1–A4) drawing from material previously taught in A1–A5 which had been taught 80% in Year Two and 20% in Year Three. The 'Transferable Skills' material taught in Year Two will be examined in Year Three. The written papers (four papers) would be taken in Week Three of Trinity Term.
  - ♦ Third year examinations (Part Ib) that will comprise six B papers (each half a unit of assessment), the Third Year Group Project (as now, with the weight of one unit) and Transferable Skills. Of the six B papers, one will be compulsory (B0 — based on material that has been displaced from the core), and the other five will be chosen from a list of 14.

The current Part II comprises both three C option papers and final year project (weighted as three units of assessment), and this weighting and content will be unchanged.

Transferable Skills is perhaps the area where there has been the greatest change in the core syllabus, and the strand with the least satisfactory name. Transferable Skills is being used as a term to describe all the lectures that are not in the engineering core. It includes Design, Dimensional Analysis, Risk & Safety, Ethics, Management, Computing and many other topics.

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We regret that the list of prizes awarded by the Examiners, which we have included in recent years, was not available at the time of publication.

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## Water, Water, Everywhere?

*Dr Nick Hankins, Director of the Oxford Centre for Sustainable Water Engineering*

The writer Mark Twain once wrote ironically that: "Whiskey is for drinking, water is for fighting". Perhaps there is more than a little truth in this statement. At the Institution of Chemical Engineers AGM in 2007, Sir David King — who at the time was the UK's chief scientific advisor — remarked that the continuing crisis in Darfur, Sudan had been triggered by a dispute over the supply of clean water.

But Darfur isn't the only water-borne crisis. In the Spanish city of Barcelona, water has currently had to be brought in by ship, as extended dry periods have left reservoirs dry. The south-eastern part of Australia, particularly the state of Victoria, is experiencing its worst drought in history. Meanwhile, the increasing use of crops for biofuels drives up demand for irrigation, and global population, along with potable water demand, is increasing rapidly.

Although some 70% of the earth's surface is covered in water, most of that is ocean. In fact, of all the world's water, only 3% is considered 'fresh', and of that quantity, 75% is trapped or locked away in ice caps or glaciers and hence unavailable. The majority of the remainder is stored as groundwater, too deep to be accessible, and only about 1% of fresh water is easily accessible as surface water. In short, aside from some very incremental and expensive gains in overall supply (e.g. through desalination), water remains one of the planet's most precious and finite natural resources.

During the past century, while the population of the world tripled, the use of water increased six-fold. Today, irrigation, industry and municipal use account respectively for 70%, 20% and 10% of total water withdrawals. The high environmental cost of this increased withdrawal is staggering — some rivers no longer reach the sea and many others are at risk (see Table 1). 50% of the world's wetlands have disappeared, 20% of freshwater fish are endangered or extinct, and many of the most important groundwater aquifers are being

extracted, with already deep water tables dropping by metres every year, and others already damaged permanently by sea-water ingress. In the Middle East and North Africa region, 85% of water is used for agriculture — much of it for crops that are more easily grown in other places and imported, and nearly 80% of all the water that falls is used. In stark contrast, other areas such as Latin America, the Caribbean and Sub-Saharan Africa use only about 2% of available water.

<i>River Basin</i>	<i>Corresponding Threat</i>
Salween — Nu	Infrastructure — Dams
Danube	Infrastructure — Navigation
La Plata	Infrastructure — Dams and Navigation
Rio Grande	Water Over-extraction
Rio Bravo	Water Over-extraction
Ganges	Water Over-extraction
Indus	Climate Change
Nile-Lake Victoria	Climate Change
Murray-Darling	Invasive Species
Mekong-Lancang	Over-fishing
Yangtze	Pollution

**Table 1: Summary of threatened rivers (source: WWF, the Environment Agency, the EU Observer)**

1.1 billion people in the world do not have access to clean drinking water, and 2.4 billion lack sanitation, when 80% of developing world diseases are water-borne. Demand for fresh water is increasing. With agriculture using 70% of supply, the World Commission on Water has projected a 60% increase in demand on the water supply to feed two billion more in the next 20 years, and one third of the world population may then be facing a serious water crisis. Compounding the relative scarcity of water is the steady deterioration in water quality in most developing countries. Even in the developed countries, with installed water distribution and purification infrastructures, maintenance of supply is a priority issue against a background of pressure to remediate

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## Water, Water, Everywhere? cont.

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and reduce pollution. The sustainable supply of potable water and the sustainable treatment of wastewater are thus among the major engineering challenges of the 21st century. Because of this, the response through investment and research is urgent and critical to solving the world's water dilemma.

Recently, the World Bank called for increased investments from private and public sources in order to enhance water security in developing countries. The Bank accounts for about 50% of external financing for water resources – a total of about \$3.3 billion a year (19% of all World Bank lending). Their investment portfolio includes water resources management for the environment, water supply and sanitation services, irrigation and hydropower, and the development of related infrastructure. Current investment in new infrastructure in developing and emerging economies is roughly \$80 billion per year, but this will have to more than double in the next 20–25 years, to around \$180 billion per year. Much of this increase will be for household sanitation, wastewater treatment, treatment of industrial effluents, irrigation and multipurpose schemes, and desalination.

What are the solutions to these challenges? The traditional view of water resource planning has been to predict future needs and develop corresponding infrastructure. In the 1970s, plans for massive reservoirs, big pipelines and river transfers were the best solutions of the day. But today, the environmental impact and energy consumption of such projects are no longer acceptable. Instead, sustainable development of water resources is required, involving technical, socio-economic, political, and institutional issues that underpin sustainable water use. Innovations by engineers and scientists lie at the heart of providing key intellectual and practical solutions to real-world problems of water treatment, supply and resource management. In the words of David King: '... chemical engineers are crucial'.

In June 2003, the Foresight Programme

published its report 'Future View' on Sustainable Water Management in the UK. Aimed at key stake-holders, it identified the key driving forces: new regulatory frameworks, the consequences of climate change, and demographic shifts. Sustainability of the UK water sector was a key priority, with emphasis on environmental protection, economic viability and future societal responsibility. The report highlighted innovation as a core-value. It recommended that technology-based innovation should be given significant financial impetus at the research level in new and modified water and wastewater treatment processes, with major energy reduction targets. It also encouraged the take-up of public-funded research in new technology.

Household demand here in the UK is expected to rise by more than 12% in the next 25 years. The current preferred solution is to build five new reservoirs, extend three, and construct two desalination plants to deliver an extra 900 megalitres per day. But water services providers must also look at options to reduce treatment costs, and make better use of existing resources. Options such as real-time control, rainwater harvesting at source, aquifer recharging, and wastewater reuse are cost-effective and sustainable alternatives; the government is now offering capital tax relief on associated equipment, such as membrane filtration. Accurate water metering and pressure monitoring will manage demand and pinpoint water leakage in the distribution network, and water efficient fixtures and appliances (with efficiency labelling) will defer future demand. Integrated pollution control will be better than end-of-pipe treatment for promoting a safer and cleaner environment. To implement this innovation, funding programmes such as the Sustainable Technologies Initiative and investment incentives such as the DTI's Green Technology Challenge will play key roles.

New challenges in the developed world, particularly in Western Europe, North America and Japan, will arise from increasingly stringent legislation on water quality and discharge



standards such as the EU Water Framework Directive (see Table 2), emerging environmental issues, and infrastructure improvement. In addition, high rates of growth in potable and wastewater treatment are anticipated in China, Central and Eastern Europe, the Commonwealth of Independent States (formerly USSR), South East Asia and Latin America. Drivers for the latter include long-term economic and industrial development, improvements in the quality of life, and environmental remediation. Future climate change will lead to world-wide droughts and stressed or interrupted supplies on the one hand, and storms and flooding on the other, so that both may eventually threaten economic production and growth. Again, sustainability unites these contradictory drivers. For example, rain harvesting and wastewater recycling cuts down on the use of expensive treated water, and eases pressure on ground water and reservoirs.

Under the direction of Dr Nick Hankins, a University Lecturer in Chemical Engineering in the Department of Engineering Science, a

- We are less wasteful with our water.
- The water we use is priced fairly.
- Those who pollute it are made to pay.
- To improve inland and coastal waters and protect them, especially from diffuse pollution in urban and rural areas, through better land management.
- That wastewater is properly treated before it is discharged rather than being dumped untreated or partially treated into lakes, rivers.
- To create a wiser, sustainable use of water as a natural resource.
- To create better habitats for wildlife that lives in and around water.
- To create a better quality of life for everyone.

**Table 2: Objectives of the EU Water Framework Directive (source: EU)**

research centre for sustainable water engineering is being developed at Oxford (Figure 1). Its activity focuses on water treatment and supply, and will initially encompass three main areas: potable water treatment and desalination, wastewater treatment and reuse, and industrial process water treatment. A major award of £100,000 from the John Fell Fund main awards scheme in 2007 has provided pump-priming resources for equipping a 100 m<sup>2</sup> analytical facility at the Begbroke Science Park. This in turn has allowed the execution of feasibility studies in the three main areas, enabling the preparation of research grant applications. The centre will also play an important part in a major consortium to be established between Singapore, Peking and Oxford universities in environmental resources engineering, by leveraging further resources from the Economic Development Board of Singapore. Past, present and future possible research activities in the three areas are described below.



**Figure 1: Oxford Centre for Sustainable Water Engineering**

### Potable water treatment

#### *Automatic coagulant dosage and monitoring of floc settling*

Natural organic matter (NOM) is an increasing source of contamination in drinking water supplies. It is derived from soil humus and terrestrial plants, recent years showing an upward trend in the NOM content of raw water derived from both upland and lowland sources<sup>[1]</sup>. Traditional 'clarification' treatments based on trivalent, positively-charged cationic

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## Water, Water, Everywhere? cont.

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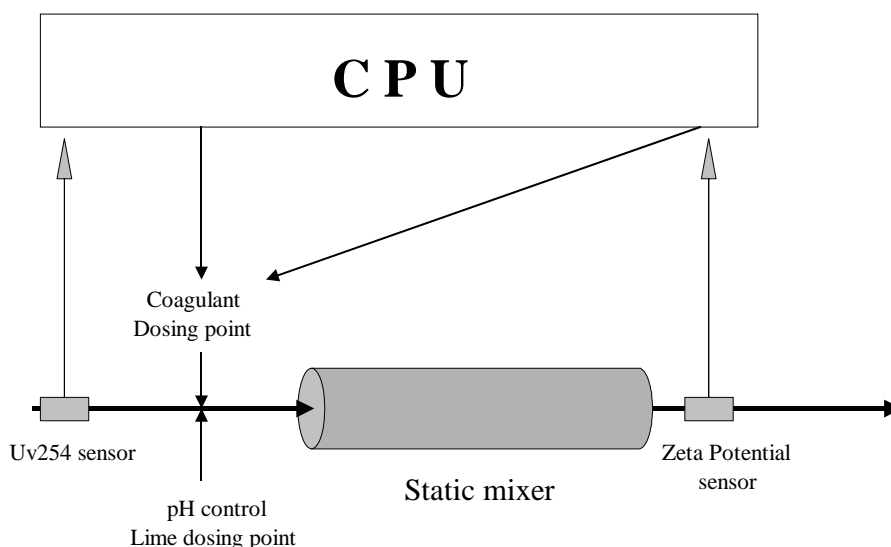
**Figure 2: Solids contact unit for water clarification**

coagulants such as aluminium chloride, which cause the negatively charged NOM molecules to aggregate in flocs and settle out (Figure 2), have been relatively successful in the past, but operational problems are now arising and particularly during periods of elevated organic levels during warmer, drier weather. This has an economic impact; the traditional solution has been an increased and excessive safety margin in coagulant dosage. It also has an impact on water quality, with a potential increase in the production of toxic disinfection by-products and a deterioration in taste, odour and appearance. Sustainable improvements in NOM removal strategy are called for, in order to

reduce costs and improve removal. On-going work aims to control coagulant costs through real-time NOM monitoring, automatic dosage control, and monitoring of settling. 'Zeta potential', a measure of the negative charge on the NOM, is a highly promising variable for monitoring. A closed-loop dosing process is being developed for use at pilot-plant scale ( $\approx 1 \text{ m}^3$  per day). This consists of a feed forward ultraviolet absorbance sensor to set initial dosage, and a feed-backward zeta sensor for optimisation (Figure 3). Preliminary results have been promising<sup>[1]</sup>, indicating that the combination is superior to the currently used manual control. In another project, sedimentation of the treated water is being analysed using an electrical impedance imaging system developed in the Centre to determine sedimentation rate, which is dependent on dosing and mixing: small aggregates sediment slowly, and lead to large pressure drops in downstream filtration beds.

### *Desalination by forward osmosis*

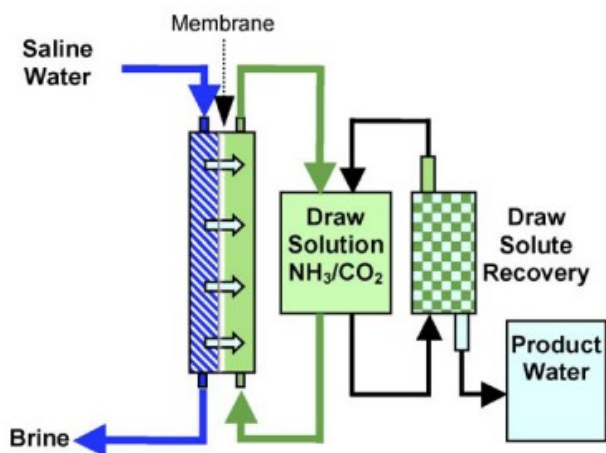
Osmosis is a naturally occurring, physical phenomenon which has been exploited by human beings since prehistoric times. Early cultures realised that salt could be used to desiccate and disinfect foods for preservation. Possible applications extend from water treatment and desalination, to food processing, power generation, and controlled drug release.



**Figure 3: Automated dosage control for potable water clarification**

Osmosis is defined as the net movement of water from a weaker, less concentrated solution across a selectively permeable membrane, with rejection of solute molecules or ions, to a stronger, more concentrated solution on the other side. For forward osmosis (FO), the explanation stops there. The more familiar reverse osmosis (RO) uses hydraulic pressure to oppose, and exceed, the osmotic pressure of an aqueous feed solution to produce purified water. But FO employs only the natural osmotic pressure gradient. Water molecules from the feed solution — brackish water or even sea water in unlimited supply — are transported naturally across the membrane by osmosis into a concentrated draw solution on the other side, containing a quite different solute.

As water is drawn from the feed-water across the membrane, the draw solution becomes diluted (Figure 4). In order for the process to be viable, it must be possible to extract the draw solute from it, easily and inexpensively, to leave potable water, and in such a way that the solute can be recycled or otherwise used.



**Figure 4: Forward osmosis process schematic**  
(source: Raphael Semiat and David Hassan: Energy Issues in Desalination Processes, First UK-Israeli Workshop and Research Event on the Application of Membrane Technology in Water Treatment and Desalination, St Hilda's College, Oxford, June 2008)

Potentially, FO is much more sustainable as a desalination process than RO. The osmotic driving forces in FO can be much greater than the hydraulic driving forces in RO, leading to higher fluxes and recoveries. The use of latent

thermodynamic energy and the lack of applied hydraulic pressure makes FO potentially much less energy intensive than RO, while minimising the discharge of brine concentrate. FO has a high rejection of a wide range of contaminants, and may have a lower membrane-fouling propensity.

Finding an effective draw solution is critical to achieving success in a large scale, continuously operated FO system and is the subject of on-going research. An ideal draw solute must have a high osmotic efficiency, high solubility and diffusivity, low toxicity, non-reactivity with the membrane and a low solution viscosity. And it will only be useful if the energy required to separate it is much less than would be required to extract the salt from the original feed solution. Furthermore, new membranes must be developed in both flat-sheet and hollow-fibre configuration, providing high water permeability, high solute rejection, reduced internal fouling, high chemical stability and mechanical strength<sup>[2]</sup>.

A small FO system has already been developed for personal, emergency use, in which sea water can be transformed into a high calorie fruit drink in which the draw solution is concentrated glucose. One such unit consists simply of an immersible bag requiring no electricity or hand pumping.

### Wastewater treatment

Wastewater streams contain all the components necessary for sustainability. One m<sup>3</sup> of domestic wastewater is normally produced by five to ten people per day and contains enough water for domestic reuse by a similar number of people. It also contains roughly 2 kWh of equivalent chemical energy, which covers the domestic power needs of one person for half a day in developed countries (and ten people for a day in developing countries!) and enough nutrients to fertilise 1 m<sup>2</sup> of agricultural production for a year. At a glance, it can be seen that recovery of these resources from wastewaters could have a dramatic global impact<sup>[3]</sup>.

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## Water, Water, Everywhere? cont.

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Yet current treatment plants actually consume additional energy to destroy the organic compounds and nutrients available, and much of the treated water is not even reused! Wastewater treatment processes currently represent 3–5% of the total electricity consumption in developed countries. The remaining energy and nutrients in the sludge are increasingly incinerated and buried in landfills, rather than being used as fertilisers! Clearly such practices are not sustainable.

We must change to an attitude in which we see wastewater treatment as an exercise in resource recovery. To reduce water resource demands, membrane processes are being investigated to recycle water for both non-potable and potable uses. One of the leaders in this field is the small nation of Israel, which recycles 60–65% of its wastewater. Promising water technology companies there may turn Israel into the water technology equivalent of Silicon Valley, with \$5 billion in exports by 2010.

Relatively simple and highly sustainable concepts are appropriate, applying Natural Biological Mineralisation Routes (NMBR) for wastewater treatment, and implementing Decentralised Sanitation and Resource Recovery and Reuse (DESAR). The former implies the use of a biological degradation sequence of organic residues under natural conditions involving anaerobic digestion followed by further aerobic processes as a post-treatment. The latter implies transport of wastewater is kept to an optimum level and that use is made of the extracted pollutants.

To recover energy from wastewater streams, a number of options are available and are increasingly the subject of research efforts. The reduction of energy and chemical inputs can be achieved by changing to an anaerobic biological treatment, or from long to short sludge-age aerobic processes and using biological rather than chemical phosphorus removal. Methane recovery is possible through anaerobic processes, particularly for high

strength wastewaters, using the methane to replace natural gas. Energy conversion efficiencies are potentially much higher than for bio-fuels, and might allow treatment plants to be more than energy self-sufficient.

Perhaps even more promisingly, microbial fuel-cells — combined bioreactors and fuel cells — are gaining major attention for direct electricity generation, and are suited to low concentration, low strength wastewaters at ambient temperatures. They generate electricity in one step, no gas treatment is necessary, and effluent quality is better than for anaerobic processes. Nevertheless, challenges remain in scale-up and the large capital costs — this technology has its real niche in places where electricity is very precious!

Finally, the chemical energy in wastewater may be converted to value added products, either by direct conversion of the organics into products, like biopolymers, or by using electrons from the organics to generate new products such as hydrogen, ethanol or 1,3 propanediol.

The contamination of freshwater systems with an increasing number of industrial and natural chemical compounds is a key environmental problem. Although they are present at low concentrations, such micro-contaminants raise significant toxicological problems. Such chemicals do not degrade (e.g. heavy metals) or only very slowly (e.g. DDT or polychlorinated biphenyls). Cost effective and appropriate remediation and water treatment technologies must be developed and refined. An example is the rising levels of endocrine (hormonal) disrupting compounds, such as oestrogen, discharged from sewage treatment works into the environment, an issue of increasing concern to the UK Environment Agency. This is not least because they have the potential to interfere with the normal reproduction and endocrine systems of aquatic organisms. We are currently investigating ways to increase oestrogen and other micro-contaminant removal efficiency by sewage treatment works above 90% by practical and cost-effective



improvements to existing plants.

### Industrial process water treatment

The process industries are under increasing pressure to reduce the discharge and contaminant level of aqueous effluents; rather, they must recycle water associated with internal streams, and recover from them valuable product intermediates. Conventional physico-chemical technologies for pollutant removal exist in water treatment; when the additional need to recycle the pollutant is considered, they face severe drawbacks, such as cost, energy usage and mineralisation. Amongst novel and promising methods to achieve this, methods based on surface-active agents (surfactants, often found in soaps and cleaning agents) have received strong attention in recent years: aggregates called micelles form in aqueous solutions and provide a versatile and powerful environment for the removal of dissolved pollutants.

A novel colloidal flocculation process known as Adsorptive Micellar Flocculation (AMF) has been investigated at the bench-scale<sup>[4]</sup>. When negative anionic surfactant ions form micelles in aqueous solution, strongly charged positive cations are then able to bind on to the surface of the micelles. The charge neutralised micelles are thus made to 'flocculate' or aggregate. Simultaneously, if the charged anion of a dissociated organic acid pollutant (a process end product or synthetic intermediate) such as the pesticide 2,4-D is present, it will associate locally and strongly with the highly positive charge of the bound multivalent cations. The anionic pollutant remains associated with the bound cations within flocculated micelles. Because of this association with the micelles, the anionic pollutant is effectively removed from the bulk aqueous solution upon flocculation. The resulting macroscopic 'flocs' retain the anionic pollutants within their structure. Since they have a rather open, porous structure, they are easy to filter off on to paper or cloth, while the purified bulk water can be drained off rapidly. The flocs can be dried, and pollutant then separated from surfactant and flocculant by solvent extraction; the surfactant and flocculant is recycled to the AMF process, and

the concentrated pollutant is either recycled to the process upstream or destroyed.

Previous laboratory-scale work has provided substantial insight into AMF in terms of removing a variety of industrial aqueous effluents, including organic acid pesticides such as 2,4-diphenoxy-acetic acid and synthesis intermediates (benzoic acid, phenol, phthalic acid). An investigation into the types of aqueous streams suitable as targets shows that AMF is particularly effective on solutions of organic acids and bases, especially those with a degree of aromaticity. These illustrate the great potential of AMF as a sustainable, industrial process stream treatment technique.

The process has the advantage of simplicity, efficiency, low cost and low volume. In order to further develop the application of this promising water treatment technique, pilot feasibility studies (Figure 5) are essential for establishing the scale-up from the bench-scale to a continuously-operated unit at commercial scale, focussing on flocculation time, floc settling, optimum agitation rate and reagent dosage. Residual concentrations in treated water indicate a surfactant removal efficiency of 95–98%, and pollutant removal/recycle reaches 78% in two stages of process operation. If reagent recycle is employed according to a previously developed strategy, the process may prove to be economically viable.

### ... and finally, some Holy Water

We all know bottled water is big, if not sustainable, business. But now Holy Drinking Water is being filtered and bottled in the San Joaquin valley, California, taking things to a divine level. Though it is normally associated with a church, Brian Germann of Linden decided to bottle it. He got the idea on 6 June 2006 – 6.6.6. He asked himself "what if you could drink holy water as a defence against evil?".

He found a company in Stockton willing to do the bottling, and took on some clergymen willing to perform the blessing. The warning to sinners printed on the label says: "If you are a

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## Water, Water, Everywhere? cont.

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sinner or evil in nature, this product may cause burning, intense heat and oral irritations".

Nick Hankins obtained an MA in Chemical Engineering from the University of Cambridge in 1985, and a PhD in Chemical Engineering from the Institute of Applied Surfactant Research, University of Oklahoma, in 1989. He held a Postdoctoral Fellowship at the Department of Physical Chemistry, University of Bristol UK, and a Visiting Scholarship at the Department of Chemical Engineering, Pennsylvania State University USA. He then worked in industry for a number of years: as a Project Leader with Shell International

Exploration and Production in Den Haag, the Netherlands, and as an Applications Engineer for Aspen Technology in Cambridge UK, developing, selling and supporting Aspen's simulation package for industrial adsorption processes. In 1999, he returned to academic life as a lecturer in chemical engineering at the University of Nottingham, UK. He transferred to the Department of Engineering Science at the University of Oxford in 2005. He is currently Director of the Oxford Centre for Sustainable Water Engineering, and Tutor for Engineering at Lady Margaret Hall.

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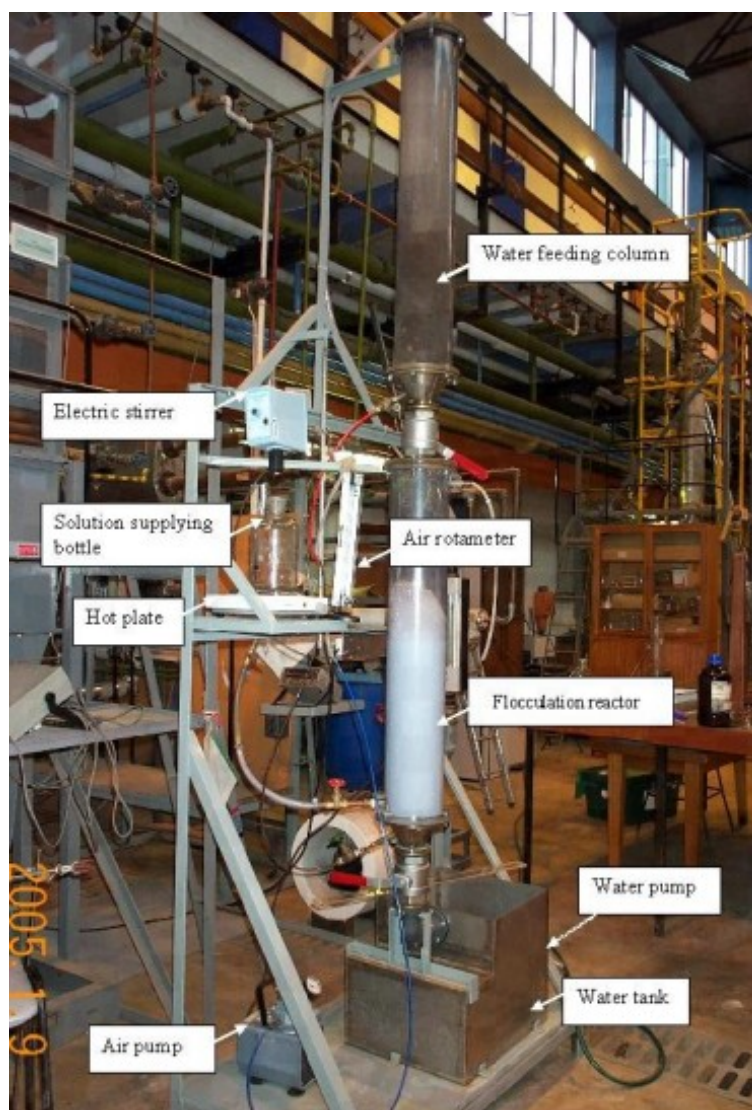


Figure 5: Pilot Plant for Adsorptive Micellar Flocculation

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## The Centenary Maurice Lubbock Memorial Lecture, 15 May 2008: On Being an Engineer

*Lord Browne, President of the Royal Academy of Engineering*

Lord Browne started by noting that Lord Avebury, representing the Lubbock Trustees at the meeting, was one of those rare individuals who had combined careers in engineering and politics. Too few engineers got involved in public life, but he hoped to show that in fact they had a unique set of views and perspectives that qualified them to make a greater contribution there than they actually did.

To illustrate this point he proposed to talk for about 20 minutes about a project he was involved in as Chief Executive of BP, the building of the BTC pipeline to take oil from the Caspian Sea to the shores of the Mediterranean. There would then be plenty of time for questions.

100 years ago, when the Department of Engineering Science was being founded, the Model T Ford was just being put into mass production. This started a transportation revolution that changed the world, giving billions of people access to personal transport, and bringing about the changes to working patterns, industry, roads, city layouts etc. that flowed from it. And it led to the growth of the oil industry, in which the speaker had spent most of his career. Engineers, he pointed out, don't just build things, they change the way we travel, live, communicate. So what should an engineer know, and be able to do, in order to handle these responsibilities? Clearly,

mathematics and the physical sciences to start with, but also how to solve real-world problems, engage with communities, politics, economics and environmental considerations. There was a need for *judgement*, and for *empathy*.

The BTC pipeline, whose story he was about to outline, runs from Baku, on the shores of the Caspian in Azerbaijan, via Tbilisi in Georgia to Ceyhan on the Mediterranean coast of Turkey (see Figure 1). Its success depended on the abilities of engineers to solve all sorts of political, economic and environmental problems. The Caspian oilfield had been known for a long time, and there were about 3000 wells there even by 1900. But there was a need for a more effective way of getting the oil out, partly to reduce the number of tankers going through the narrow Bosphorus with its vulnerable historic sites. The pipeline as built runs for more than 1000 miles, goes up to 3000 m above sea level in places, crosses 1500 rivers and roads, and cost \$4 billion to build. And it is buried along its whole length.

The route it takes is not the one that would have been chosen on the basis of mere physical geography, distance, gradients etc. A more direct route could have been found into Turkey through Armenia or Iran. But there has been hostility between Azerbaijan and Armenia for many decades, occasionally leading to military action. There was too much risk in taking the pipeline that way. And the situation between Iran and the USA ruled out that option

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## The Centenary Maurice Lubbock Memorial Lecture: On Being an Engineer cont.

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too. So it had to go through Georgia. The Georgian authorities, though somewhat uncertain of their own political stability, were in no doubt of their strong position vis-à-vis BP, and of course exacted their price. All three countries through which the pipeline passes changed their leadership at least once during the construction period, so there was a good deal of re-negotiating of agreements, which had to be expressed in different languages and drafted according to different sets of laws. The engineering management team, 500 of them in 17 different offices, had to display remarkable diplomacy, sensitivity and negotiating skills.

There were inevitable risks of environmental damage, primarily from leaks. The possibility of these occurring had to be minimised, and means set up for coping with them if they did. The pipeline is buried in a trapezoidal trench, which is filled with a granular material intended

to permit seismic movement, and designed to cope with a 1 in 10,000 year earthquake.

Although 750,000 people were affected in some way by the work, none was permanently displaced. 1000 landowners, owning between them 30,000 parcels of land in three countries, were disturbed only temporarily until the land covering was restored, and they were compensated. At the height of the work, 22,000 people were employed on it. 70–80% of them were local, and BP trained them for the purpose.

It is essential of course that engineers involved in such a project should recognise the limits of their own competence, and seek expert help when necessary, e.g. from wildlife specialists, human rights lawyers and archaeologists. There have to be trade-offs between conflicting interests, so it is inevitable that not everyone will go away completely happy.



Figure 1: The BTC pipeline



It was time, Lord Browne suggested, to redesign the package that defines the term "professional engineer". They need to be taught to understand business, politics, public policy, and to be prepared to tackle real-world problems. An education that balanced creativity and scientific rigour with the need for practical solutions would surely attract the most talented students.

Almost as an afterthought, Lord Browne pointed out that when the Model T Ford was being put into production, there was a need to find a suitable fuel for it, that could be made widely available. It could equally well have been either gasoline or ethanol. The choice fell on gasoline, partly because it was cheap, but also because the American "Prohibition" policy of the time restricted the production of ethanol. This was a highly significant choice, not only for greenhouse gases, but also because for many decades gasoline needed the addition of lead tetraethyl to improve engine performance, which inflicted substantial damage on human health until it was given up.

Finally he expressed the view that the greatest challenge now was preventing climate change,

where engineers could have a profound effect on the policies to be adopted. Engineers cannot predict the future, but they can certainly affect it.

The audience then presented the speaker with a long series of questions, the replies to some of which brought out further interesting facts. The questions included:

- What should be the energy mix of the future?
- What disciplines should be added to engineering education?
- What about the security of the pipeline against terrorist attacks?
- What were the alternatives to building the pipeline?
- Should there be more engineers in the Civil Service?
- What about bio-fuels?

The full lecture, and the ensuing question-and-answer session, can be seen on the Department's website: [www.eng.ox.ac.uk/events/centenary/videos.html](http://www.eng.ox.ac.uk/events/centenary/videos.html)

## Engineering a New Approach to the Treatment of Cancer

*Nick Hughes*

Cancer is one of the primary causes of death in the industrialised world. In the United Kingdom, one in four people will die of cancer, whilst one in three will be diagnosed with cancer at some point in their life. Whilst these figures make for grim reading, the arena of cancer research presents a wide range of challenges and opportunities for engineers. Engineers are set to play a key role in developing new approaches for the early detection of cancer, and for improving the treatment of cancer once it has been detected.

As a postdoctoral research fellow in biomedical engineering, I am working to advance the field of *personalised cancer therapy* (or more grandly — personalised medicine).

Personalised cancer therapy is an emerging field of research which offers the potential for a dramatic improvement in the treatment and management of many common forms of cancer. The aim of this field is to develop techniques to enable specific, individualised treatment options for cancer patients. Thus, for a particular patient with a given tumour, personalised therapy involves determining the specific course of treatment (from the different options available) which will be most beneficial for the individual patient.

My current research is focused on two clinical studies which aim to advance the state-of-the-art in personalised cancer therapy. The first study, which is currently underway at the Churchill Hospital in Oxford, is concerned with

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## Engineering a New Approach to the Treatment of Cancer cont.

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the use of combined chemotherapy and radiation therapy (so-called chemoradiotherapy) for patients suffering from rectal cancer. This type of treatment is commonly given to patients prior to surgical removal of the tumour. The hope is that the treatment will cause the tumour to shrink or "downsize", which in turn will improve the likelihood of a more successful surgical resection and ultimately the long-term prognosis for the patient.

In reality the situation is more complex. Approximately 10% of rectal cancer patients treated with pre-operative chemoradiotherapy show a complete response, such that there is no visible tumour present in the resected specimen. Unfortunately, since the treatment response can only be evaluated after surgery, these "complete responders" undergo an unnecessary and highly invasive surgical procedure. At the other end of the spectrum, there are a significant number of patients (approximately 30%) who show little or no response to the treatment. For some of these patients, their tumours do not change much during the course of the treatment (so-called stable disease). However for others their tumours continue to grow in spite of the treatment, such that by the time of the surgery the cancer may be considerably more advanced than at the time of the initial diagnosis. For this subset of patients it would clearly be more beneficial for them to proceed directly to surgery, rather than undergoing a futile period of chemotherapy and radiation therapy. The problem for clinicians is that they currently have no way of knowing which patients will respond and which will not. The challenge for engineers is to develop accurate and robust techniques for predicting patient response from the available clinical data.

In order to address this problem, the patients in the rectal cancer study will undergo two different types of imaging scans, both before and after treatment with chemoradiotherapy. The first type of scan is known as *dynamic contrast-enhanced magnetic resonance*

*imaging*, or DCE-MRI for short. With this type of imaging, the patient lies inside an MRI scanner and a small amount of a "contrast agent" is injected into the patient during the imaging procedure. The contrast agent is a specially designed paramagnetic molecule which is carried by the blood vessels throughout the body. The contrast agent arriving at the site of the tumour will leak into and back out of the "extravascular space" surrounding the tumour over a period of minutes. The resulting images, which are acquired at a temporal resolution of approximately ten seconds, can then be used to quantify the pattern of blood flow throughout the extent of the tumour. This can provide useful information regarding the aggressiveness of the given cancer, since more aggressive tumours typically develop a more advanced network of blood vessels.

The second type of imaging scan which the patients will undergo is known as *positron emission tomography*, or PET. With this approach, a radioactive probe or tracer is injected into the patient whilst they are lying inside a PET scanner. The counts due to decay of the radiolabelled tracer are then measured inside the scanner and this information is used

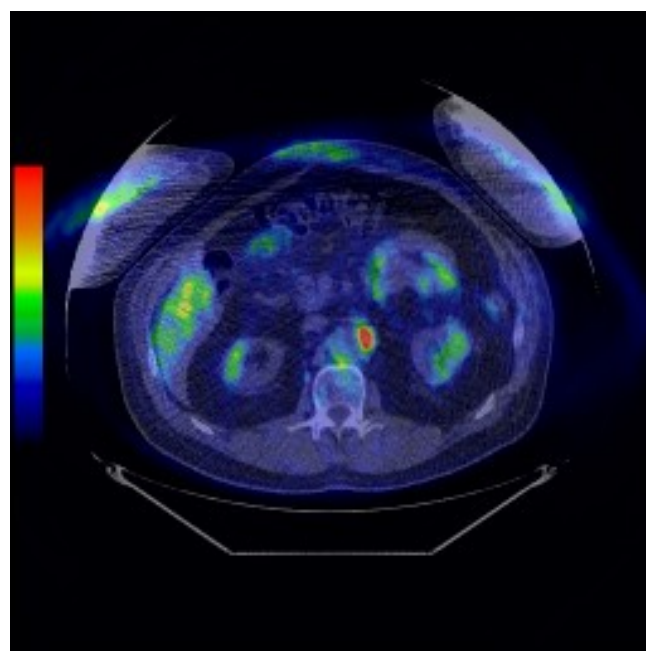


Figure 1: PET/CT image for a patient with cancer. The "hot spot" in the image indicates the location of the tumour

to reconstruct a series of three-dimensional images of the concentration and location(s) of the tracer through time. The key to PET imaging is that the tracer molecule is designed in such a way that it becomes trapped inside metabolically-active cancer cells, yet is only taken up in relatively small amounts by normal healthy cells. Thus PET images can be used to quantify the metabolic activity of a given tumour, which in turn provides crucial information for predicting how the tumour will respond to different kinds of treatments.

Given the DCE-MRI and PET scans for a particular patient, how do we then predict if the patient would benefit from pre-operative treatment with chemoradiotherapy, or whether it would be more beneficial for the patient to proceed directly to surgery? This is where techniques from the domain of information engineering can play a crucial role. Since modern imaging scans, such as those

described above, produce 4-D data (3-D space + time), mathematical models must be used to extract compact and physiologically meaningful descriptions of the data.

In the case of DCE-MRI, we can use a type of model known as a "pharmacokinetic model" to quantify the rate constants which relate to the flow of the contrast agent into and out of the tumour. Similar models can be used with PET scans to quantify the rate constants describing the uptake of the tracer within the tumour. The parameters extracted from different types of imaging scans can then be combined or "fused" to generate a *signature* for a given tumour. A collection of such tumour signatures (for a large number of different patients) can then form the input to a machine learning algorithm, which can be used to identify the particular patterns that relate to the different classes of treatment response (e.g. complete response,

(Continued on page 24)

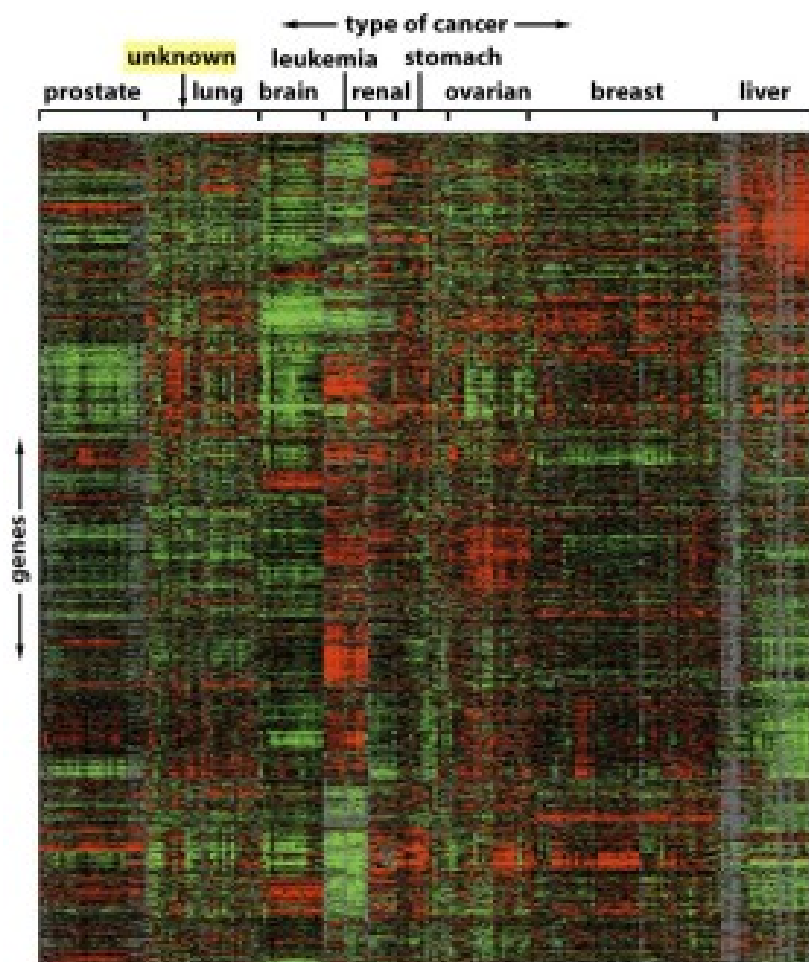


Figure 2: Surveying the expression levels of thousands of genes in different cancers using gene arrays. Higher-than-average levels of expression are indicated in red, whereas lower-than-average are in green

## Engineering a New Approach to the Treatment of Cancer cont.

(Continued from page 23)

stable disease, progressive disease).

A similar approach to that described above is being employed in a separate study (also taking place at the Churchill Hospital) focused on a new drug for the treatment of breast cancer. The drug, which is known as Avastin, is designed to disrupt the network of blood vessels which feed the tumour (commonly referred to as the "tumour vasculature"). However, the response of breast cancer patients to Avastin is quite varied, with only one in five patients typically exhibiting a significant response. Since modern anti-cancer drugs such as Avastin are expensive and generally only benefit a subset of patients, there is a great deal of interest in identifying the markers that will predict those patients who will respond best in order to personalise these expensive therapies (see Figure 2 overleaf).

To achieve this aim, we are using DCE-MRI scans to image the tumour vasculature before and after treatment with Avastin. The imaging data will then allow us to quantify the degree of vascular response to the drug for the different patients in the study. In addition, DNA microarrays or "gene arrays" are being used to examine the expression levels of thousands of genes within the tumours. Using this combined imaging and genomics approach, we hope to identify a gene expression signature that will enable clinicians to predict those patients whose tumours will be most responsive to Avastin. An additional benefit of this approach is that the particular set of genes which are predictive of response may also provide new insight into the biological mechanisms which differentiate responsive tumours from their non-responsive counterparts.

Although personalised approaches to cancer therapy such as those described above offer the potential for a substantial change in the way in which cancer patients are treated, a more dramatic change may come from the advent of early detection technologies<sup>1</sup>. A

significant research effort is currently underway to identify biomarkers — trace amounts of proteins produced by cancers — which can be detected reliably and robustly within small blood samples. By identifying multiple biomarkers for different tumour types, it should be possible to develop simple diagnostic tests which can be used to detect cancer at an early stage. Imaging, and in particular molecular imaging approaches such as PET scans, can then be used to identify the location of the nascent tumour within the body. Once the tumour has been localised, early-stage intervention procedures can be used to treat the cancer whilst it is still in its infancy.

The motivation for the early detection approach is simple: the chances of patient survival are significantly greater if cancer is diagnosed whilst still confined to the organ of origin and before it has had a chance to spread to other parts of the body. Conversely, survival rates tend to decrease dramatically as tumours enlarge and subsequently metastasise.

As with personalised cancer therapies, early detection strategies will require solutions to a number of key engineering challenges if they are to come to fruition. How can we build accurate and reliable models for predicting the presence of an early-stage cancer given (noisy) measurements of multiple biomarkers from blood samples? How can we accurately localise small early-stage tumours using medical imaging scanners with limited spatial resolution? And how can we improve the characterisation of a given tumour by fusing the multiple sources of information which are increasingly available (i.e. multi-modal imaging scans, protein biomarker measurements, and gene expression profiles)? These challenges and more will continue to keep engineers working on cancer busy for many years to come.

<sup>1</sup> More information on early cancer detection can be found at: <http://www.canaryfoundation.org/>



## Book Review: *Mechanicks in the Universitie*

*Mechanicks in the Universitie*

A History of Engineering Science at Oxford

Alastair Howatson, Department of Engineering Science, University of Oxford, 2008

182 pages, softback

*Review by Professor Roderick A Smith*

I matriculated in 1967. In 2005, I was delighted to be elected the Senior Visiting Research Fellow of my old college for the academic year. On the first day, I joined the Fellows for lunch, entering the Senior Common Room for the first time. Feeling very new and out of place, I introduced myself to my neighbour. "And what do you do?" "I am an engineer." "So you won't have anything interesting to say." Welcome to Oxford! I regret I did not think fast enough to make the response, "It depends to whom I am speaking."

Alastair Howatson has got many interesting things to say to all of us in his history of engineering at Oxford, but he makes the point that engineering's birth and development has been far from easy and, in some quarters at least, as I found out for myself, the work and achievements of the engineers is less than fully appreciated. This book stems from the Centenary of Engineering Science at Oxford; its launch at the Centenary Garden party in June was pre-dated by a lecture on the same topic in the Centenary series. I attended that lecture (as you can by following the link given at the end of this review), confident that it would be special because of my memories of Howatson's superb lectures to the undergraduate classes of the late sixties. I don't think I missed any of his scheduled lectures, whilst my average attendance overall was probably in the order of 20% at most. Given that he was lecturing on electrical engineering, a subject which I was passionately ambivalent about, you can judge the high regard I accorded to him. And the years had not changed his attractive mixture of authority and self-deprecation, humour and quality information. The lecture was outstanding; and so, of course, is the book.

The events prior to the establishment of engineering at Oxford are treated in some detail.

The roots are evidently deep, penetrating as far back as Richard of Wallingford (c.1292–1336) who built an astronomical clock and wrote on the theory of gears. In the 17th century, John Wallis studied the reciprocal frame, whilst even the least interested current undergraduate will be familiar, at least in a simplified form, with Hooke's eponymous law (1676), originally stated in a Latin anagram. The Victorian era in Oxford was largely concerned with modernising the University, a process to which Howatson devotes a complete chapter. Oxford's contributions to the great strides in engineering of this period were few: Froude, known for his non-dimensional fluid mechanics number, worked in many areas, including a study of the lateral forces generated on a curved railway track whilst working with Brunel on the Great Western Railway. Vernon-Harcourt became Professor of Civil Engineering at University College London and a leading figure in his profession.

My interlocutor in the conversation with which I introduced this piece was (you might have already guessed) a Classicist. It is ironic that the first engineering appointment in Oxford was that of a pass degree Classicist clergyman, the Revd Fredrick John Smith, as the Millard Lecturer in Experimental Mechanics and Engineering. The Millard Laboratory was established in 1886 in the Dolphin Yard of Trinity College, sandwiched in the tiny space between St. John's and Balliol, but accessed via a gate in St. Giles. In 1872 the Millard bequest of £8000 (approximately £4.5 million now) was the largest Trinity College had received since that of its founder. The bequest was to be used to benefit mathematical and general science, and through the enthusiasm of the schoolmaster President of Trinity, Revd John Percival, part of it was eventually used to fund an engineering laboratory. It is noted that despite the tiny size of the laboratory (140 m<sup>2</sup>), no space could be found to house it on University land because the science professors had marked out all available space for their own subjects! The notice advertising the opening of the laboratory promised theoretical instruction on "the principles on which the strength, arrangement and

*(Continued on page 26)*

## Book Review: *Mechanicks in the Universitie* cont.

*(Continued from page 25)*

proportion of machines are determined" and practical instruction on "the use of hand and machine tools, working in wood and iron, &c." Some details are given of an amusing incident in 1897 during which Smith's mechanical chronograph was used to convict two men of "furious" driving on the Banbury Road (actually 12 mph). The progress of technology is interesting. I was flashed by a speed camera at the same location in 2006. Tracing me and the levying of the fine of the offence (34 mph at 5 am on a Sunday morning) was made automatic by the use of the computer.

But the centenary we are celebrating arises from the appointment of Charles Frewen Jenkin to the Chair of Engineering Science in 1908. I will not spoil the story by summarising the difficulties which had to be overcome in the University to arrive at this happy outcome. Suffice to say that by this time engineering was well established at many of the younger Universities in the UK. Even Cambridge beat Oxford to it by 33 years: a canvas in the time scales of the ancient universities. The first graduate of the Department emerged in 1910. The name will be very familiar to railway buffs: that of Charles Edward Fairburn, later Chief Electrical and Mechanical Engineer of the LMS Railway. From this point on, the general story, but not perhaps the detail, will be more familiar to many readers. I will not attempt to even outline the story of expansion, growth and diversification which has attended the last century, but I assure you in the steady hands of Howatson it makes fascinating reading. However, several of the themes enlarged upon in the book are worth noting.

The development of the various buildings which now comprise the Department started with the occupation of the Keble Road triangle starting at the north end in 1914 and expanding in 1927 and 1936. The statue atop the northern gable of the Jenkin building forms an attractive cover picture for this history. Designed by Jenkin's sister-in-law, the boy on tortoise sculpture is supposed to represent youthful engineering subduing the earth and was for many years re-

garded as the Departmental icon. The number of students graduating up to the end of the Second World War was approximately ten per year. This number climbed steadily in the post war years, eventually necessitating the new Thom building, opened in 1963. This is the building I knew as an undergraduate and was then stung by the criticism of its external appearance from colleagues in other Departments. Well, even today it is somewhat of a geometric perturbation to the skyline, but artistic opinion is in the eye of the beholder, and the paternoster lifts were exciting and different! The approximately 50 per year graduating at the time of the Thom building had risen to about 90 at the time of the Holder building (1976) and further to 130 for the engineering and technology building in 1988. The completion of the Information Engineering Building in 2004 just about filled in the triangle and coincided with an output of about 150 graduates each year.

Howatson claims, with considerable justification, that over the years the Department has enjoyed good leadership. Certainly the status of the Department has risen as it has grown. The growth of its research output is another theme developed in the book as is the diversification of the courses on offer. Many well known names of graduates are mentioned in the course of the story, often eliciting a pleasant surprise, "I didn't know he was from Oxford." Another surprise is the current number of professors in the Department. As recently as 1984, there were just three. Currently there are nearly 40, about the same number as the other ranks: one hopes the leadership can deal with so many chiefs. This fact could perhaps have merited greater explanation, indeed more statistical data could have, with advantage, been included in the Appendices. It is not as though Howatson is unfamiliar with these kinds of details: meat and drink to an author of HLT!

I have not sought to seek out and nit-pick errors and indeed am ill qualified so to do. However, the availability of The Times Archive online enabled me to read a reference given as a footnote on page 15 to an article of 24 April

1871, to find that a foolish comment quoted in the text and ascribed to the Chancellor of the Exchequer was not actually made by him.

It would be quite wrong to end with these petty quibbles. This history is the product of considerable work, which has unearthed much previously unpublished material. The result is an extremely well written, beautifully produced and engrossing story of the first 100 years of the

Department of Engineering Science at Oxford University. The author deserves our warmest thanks and his book deserves to be read and enjoyed by the widest possible audience.

Dr Howatson's lecture in the Centenary series can be accessed through the link:

<http://www.eng.ox.ac.uk/events/centenary/movies/howatson2008.html>

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## Book Review: The Leaves We Write On

The Leaves We Write On

James Cropper: A history in paper-making

Mark Cropper

Ellergreen Press, 21 Kensington Park Road,  
London W11 2EU, 2004

ISBN 0 9549191 1 4

*Review by David Witt*

This book is the history of a family firm, founded in 1845 in the River Kent valley north of Kendal, on the fringe of the Lake District, and of how it has survived and grown in the face of foreign competition, wars, recessions and other challenges. It is not an engineering firm — they make paper — but its production relies on expensive machinery, so an appreciation of engineering has always been a key to their success. But I suspect many of our readers have an interest in industrial history and may find this story as fascinating as I did. To those involved in running family companies its lessons will be even more compelling.

How I came across the story is an interesting sub-plot of its own. In the course of looking into the family history of my maternal great-grandmother, I found that her youngest sister and brother became orphans when their father died in 1869, and for a time were in Liverpool workhouse. Then in the 1871 Census I found the sister, aged 15, with four other Liverpool girls, living in Burneside near Kendal, and working as an "envelope maker" at the local paper mill. An internet search showed that this firm was James Cropper Ltd, that it was still in existence and apparently thriving, and that the great-great-great-grandson of the founder had recently written this history of it.

The firm's founder, James Cropper, was the grandson of another James, a successful Quaker merchant of Liverpool. The Cropper-Benson partnership owned a fleet of ships, and traded with America, Russia and India in the first two decades of the 19th century, making a great deal of money. From about 1820 James senior retired from business to promote various good causes, in particular the anti-slavery movement (the British slave trade from Africa to America had been abolished in 1807, but it was not until 1834 that slaves were finally freed in the British Empire). His son John made successful investments in railways and continued the philanthropic tradition in Liverpool, but his grandson James junior was initially very uncertain as to how he was going to spend his life. But by the age of 17 he was deeply in love with his cousin Fanny Alison Wakefield, from a prominent Kendal family, and it seems to have been Wakefield influence that persuaded him to buy two paper mills in the Kent valley, one of which had originally been built as a cotton mill by a Wakefield. But a subsequent purchaser had re-equipped it as a paper mill, and sold both to the inexperienced 21-year old James for what turned out to be an excessively inflated price of £13,000 (a lot of money in 1845).

Still, he married his cousin and built a house in the village, determined to make a success of the enterprise. It did not break even until 1854, but the next 25 years were ones of growing output and respectable profits. He brought in commercial partners, leading to new customer contacts; he recruited talented staff and installed new machinery and power plant (both

*(Continued on page 28)*

## Book Review: The Leaves We Write On cont.

*(Continued from page 27)*

water power and steam). They made paper in many grades, including coloured paper, and started making envelopes, as we have seen, for which the newly established penny post was creating a big demand. Older readers will remember the little orange envelopes in which the Post Office used to deliver telegrams. Croppers got a lucrative contract to supply these. Production was largely mechanised and the girls just applied the finishing touches. In 1873 they were said to be making five tons a week of them. If this is correct it must represent something like two million envelopes a week, and some very nimble young fingers!

The growth of trade experienced by Croppers was typical of the prosperity of these years. It was largely triggered by the growth of the railways. Croppers in particular were lucky in having the Kendal to Windermere railway running right past their door. But from around 1880 to 1910, although production held up, profits did not. James Cropper gave up paper-making for politics at Westminster, and handed over the management to his son Charles. Though Charles was not quite the businessman his father was — fox-hunting was a major distraction — it was foreign competition that was the main problem. Other countries were rivalling the technical supremacy that had been Britain's earlier in the century, and only by lowering prices could sales be maintained. Many mills succumbed to imports and went out of business.

But raw material prices were falling too. Paper had formerly been made from rags. Jute and other fibres had been used too, but by the end of the century wood pulp was becoming the major source, and eased production by its more consistent properties.

In 1886 and again in 1903 Burneside mill suffered major fire damage, disrupting production for months, and in 1893 the mill chimney blew down, killing three young female employees. There were other industrial accidents too, some of them attributable to lack of proper supervision (by today's standards at least). But on the

whole the firm seems to have shown care for the welfare of its employees, even if it didn't pay them very much, and labour relations were usually harmonious. It must have helped that everyone lived in the same village.

The 20th century was, for Croppers as for industry in general, a succession of booms and slumps. The two World Wars and their immediate aftermaths were generally profitable, helped by import restrictions and price-fixing agreements (not illegal in the UK until 1956). The decades immediately following both wars were ones of extensive expansion and modernisation, assisted by the company policy of putting most of their profit into reserves rather than distributing it to their shareholders (i.e. the Directors themselves to a large extent).

The 15 years from 1967 were very different. Foreign competition, in the paper industry as in others, caused massive closures and unemployment. That Croppers managed to survive when so many others went under is remarkable. They drew their horns in, but managed to avoid any compulsory redundancies. The author attributes this to their modernisation programme of the 1950s, new automated production techniques, and their diversified range of products, more specialised and "up-market" than that of many other mills. "Reducing employment costs by designing jobs out of the business" was company policy, no doubt welcome even to the employees when many of these jobs were extremely unpleasant ones. The firm continued its modernisation programme through the 1980s, "investing at the bottom of the cycle rather than at the top, so that the capacity is there when the market moves up". This policy requires some courage, and either extensive reserves or a very accommodating bank manager! It also requires the company to be independent, and several proposals for amalgamation or takeover were rejected in order to preserve their autonomy.

Another contributor to survival which strikes this reviewer is the willingness of sons to follow their fathers into the business, and in many cases to learn the trade from the bottom on



doing so. Five successive generations of Cropers have been Chairman; that they were not lured by a "gentleman's education" to abandon "trade" is in marked contrast to what happened in many British firms.<sup>1</sup> Maybe it helped that the setting was rural and that the founder was in no sense a "self-made man".

I found the book a very good example of industrial history, well researched and comparable for a small firm to e.g. Scott on Vickers or Reader on ICI, larger books on much larger organisations. The author does not stint criticism of his forbears, or the firm's former practices, when appropriate. I thought a bit more on how paper is actually made would have been help-

<sup>1</sup> See e.g. Martin Wiener, "English Culture and the Decline of the Industrial Spirit 1850–1980", and for biting comment if not evidence, Kipling's poem "The Mary Gloster": "... Harrer an' Trinity College! I ought to ha' sent you to sea — But I stood you an' education, an' what have you done for me? ..."

ful. He describes the early hand-made process, but not how a modern machine does it. And what for instance, is a twin-wire machine?

The book has been published by Ellergreen Press, apparently a subsidiary of James Cropper plc, and seems not to have been widely publicised, which is a pity. The Bodleian's copy is in their stack, and there is none in the Said Business School's Library. But there is a lot to learn from it.

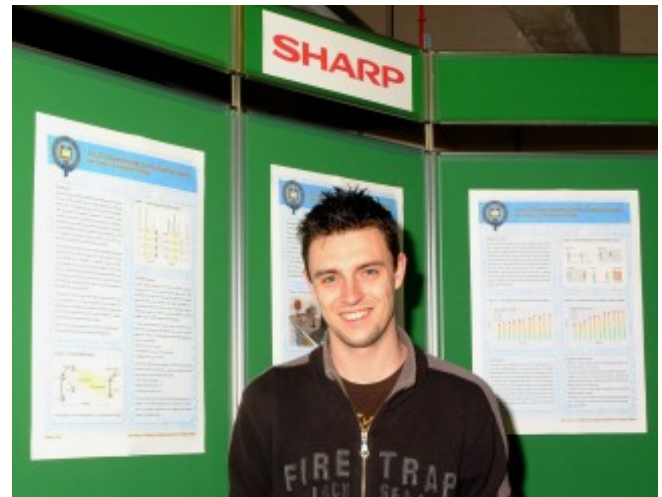
And Martha, the young envelope maker? Three months after her 21st birthday she married a young man from the village, and they moved out west to the then rapidly expanding steel and ship-building town of Barrow-in-Furness. She brought up eight children, apparently successfully, and lived to the age of 76, dying in Barrow in 1932. Maybe her descendants are there still.

## Project Exhibition 2008

*David Witt*

We again have to thank our sponsors, Sharp Laboratories of Europe, Atkins, Glaxo Smith Kline and QinetiQ, for contributing £3250 of prize money between them, which enabled us to offer some worthwhile prizes. SOUE supplied the organisation, and of course the contacts who persuaded the sponsors to give us the money! We had 15 entries, significantly less than the 29 and 24 of the previous two years, but still quite enough to keep the judges busy. Perhaps the fact that the exhibition was the day before the reports had to be in had something to do with it.

The £500 prize for an electronic exhibit went to Ben Jones of St Catherine's (right) for "An LED-based parallel communication system". By having several light beams in parallel the information capacity was greatly increased, and being line-of-sight made for a secure link. A direct descendant of the heliograph used by the British Army in the Boer War? Unfortunately (for the rest of us), he was not allowed to show it working, in case the light from the LEDs got into someone's eyes!



The £500 Atkins prize for a civil or structural engineering exhibit went to James Solly of Magdalen (overleaf) for a "Large-span expandable shelter", another of the series of remarkable folding structures we have been seeing exhibited in recent years. In fact it was a small model of a "large-span shelter", or it would never have got into Lecture Room 3 (or been built with his project budget), but it looked as if full-scale versions of it might have been useful in Burma or China this May.

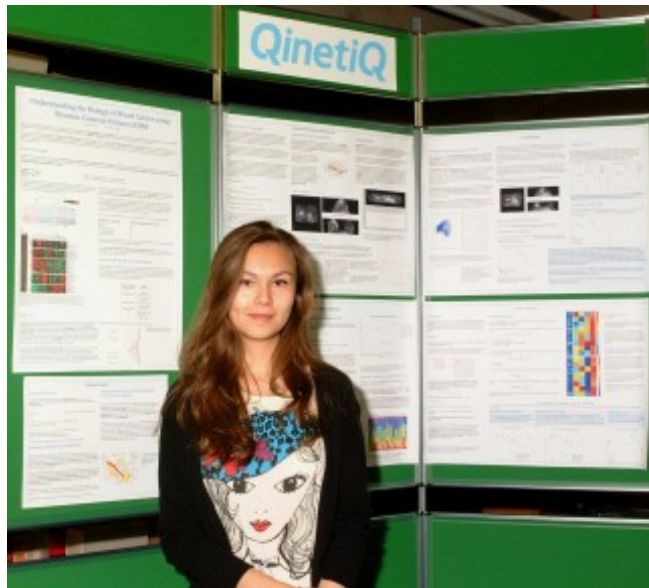
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## Project Exhibition 2008 cont.

(Continued from page 29)



The £400 QinetiQ prize for an "exhibit working towards an innovative solution of an important problem" went to Annika Wong of St Hugh's (below) for "Understanding the biology of breast cancer using dynamic contrast-enhanced MRI (magnetic-resonance imaging)".



Other prizes were awarded as follows:

£250 Poster Prize to Alan Carter, St Hugh's, for "Transporter bridges – an effective way to span a river?", a comparative technical study of two such bridges built about a century ago. He had calculated that the safety factor of one of them under the worst loading was not exactly generous!

£250 Hardware Prize to Matthew Cole, Brasenose, for "Stimulus and test equipment for a smart dust optical receiver". For those not in the know, "smart dust" is apparently a swarm of tiny sensors, ideally about 1 mm across, taking their power from the ambient light and sending back information about their environment.

£250 to David Marshall, New College, for "Full-bore imaging in a spark-ignition engine"

£250 to David Rowlinson, Hertford, for "Modelling the interaction of spectators during grandstand egress"

£250 to Kai Zhong, Wadham, for "Controlling the coagulation stage of water treatment using electrical impedance tomography"

£200 to Winston Churchill, St John's, for "Vision-based path detection for a mobile robot"

£200 to Daniela Footerman, Balliol, for "Cryopreservation of bovine mesenchymal stem cells"

£200 to Adrien Geiger, Somerville, for "Model predictive control of an inverted Furuta pendulum"

Choosing the prizewinners is no trivial task. This year's judges, to whom we are very grateful, were:

Alan Coombs, LMH 1999–2003, now with Cambridge Silicon Radio

Jac Cross, Trinity 1995–9, now with Arup

Hugh Griffiths, New College 1995–9, now with Griffiths

Alexandra Hatchman, Somerville 1993–7, now with Tescos

We have been running this exhibition annually for eight years now, in which time there have been 129 exhibits. There now remains ONE undergraduate college which has never yet produced an entry. But I won't shame them in print by saying which one!

## Tidal Turbines

Ross McAdam

Climate change has burst into public awareness over the past decade due to a plethora of scientific research, media coverage of severe weather events, and proponents such as Al Gore. Along with a growing number of modern engineering students, my main interest during my undergraduate degree at Oxford was the production of clean renewable energy and how to use it sustainably. While some would argue that there is no definitive proof that global warming is a man-made problem, I would say that the consequences of not acting are far more severe than if the sceptics are right.

In the summer of 2006 I got a stroke of luck while doing some vacation work for Dr Malcolm McCulloch on the electric motors for a Morgan hydrogen-powered sports car. With a little help I managed to persuade my fourth year project supervisor for the next year, Professor Guy Houlsby, to change my project and allow me to work on his idea for a new design of marine tidal turbine, the Transverse Horizontal Axis Water Turbine (THAWT).

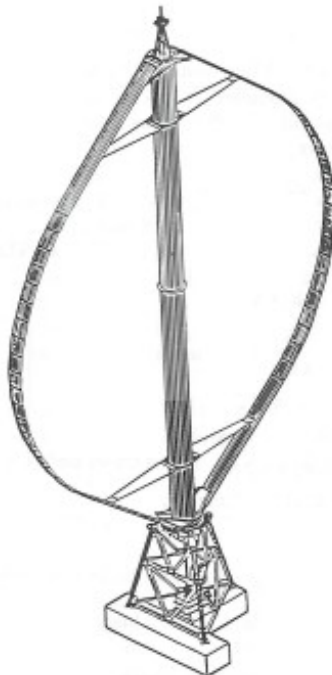


Figure 1: Early Darrieus wind turbine

THAWT is a conversion of the vertical axis Darrieus wind turbine to a horizontal axis for use in a water stream or channel.

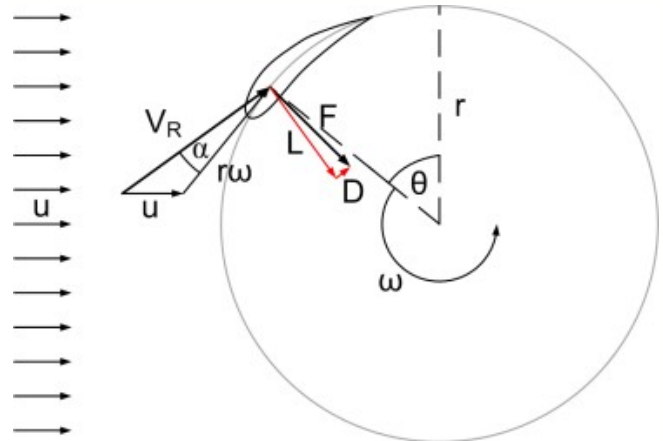


Figure 2: The basic flow mechanics of a Darrieus turbine

The basic Darrieus turbine design is made up of a number of hydrofoils, which rotate about an axis in an oncoming flow. The combination of the blade's instantaneous velocity and the oncoming flow velocity produces a resultant velocity ( $V_R$  in Figure 2), which acts at an angle of attack to the blade. This resultant velocity produces a perpendicular lift and a parallel drag. If the angle of attack is greater than the angle subtended by the lift to drag ratio then a positive torque and power will be produced. By using a symmetrical hydrofoil, positive torque can be produced when the angle of attack becomes negative, which means that the turbine rotates in the same direction with flow from either direction. All channels have a velocity profile with slower flow at the base and faster flow at the surface, which should favour one flow direction, but the experimental tests have shown that this has a relatively small effect on the turbine performance.

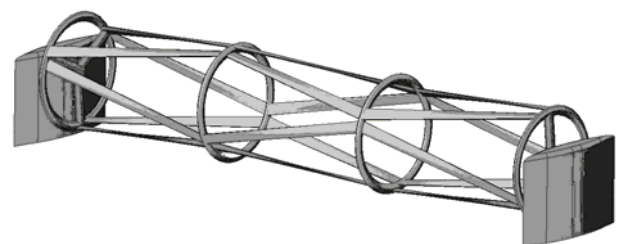


Figure 3: A vertical axis Darrieus wind turbine and an early concept truss variant of the Transverse Horizontal Axis Water Turbine

(Continued on page 32)



## Tidal Turbines cont.

*(Continued from page 31)*

The key feature that Professor Houlsby had conceived was to use the turbine blades as structural members in a truss-like configuration. This would theoretically allow several turbine units to be attached end to end and to benefit from an economy of scale, without compromising the stiffness of the structure.

The turbine had been studied the previous year by two fourth year project students under the supervision of the gas turbine expert, Professor Martin Oldfield. One of the students had managed to extract as mechanical power more than 59% of the kinetic energy in the upstream flow, which is known as the Lanchester-Betz limit and at the time was thought to be the most power that could be extracted from a fluid flow. Whilst it had previously been accepted that tidal turbines extract kinetic energy from fluid flows, Professors Oldfield and Houlsby managed to show that in reality both kinetic and gravitational potential energy are extracted — i.e. the water surface is lower downstream. This meant that in the slow tidal flows commonly found around the world, much more energy is available than was previously thought. Currently all of the turbines that we have tested have spanned the entire width of the flume. If the turbine were used in open water with flow passing around the sides of the device, the proportion of channel area occupied by the turbine would reduce so the height change across the device would decrease along with the proportion of the power extracted.

Continuing from the previous work done in the two fourth year projects of 2005, I designed, built and tested a series of 0.16 m diameter turbines in the third floor flume of the Thom building. The results showed that in some flow conditions the turbine could extract energy up to 3.6 times the kinetic energy in the upstream flow. A finite element model of the turbine was also created which showed that stresses in the truss turbine blades were as much as three times less than the conventional straight bladed design.

With a set of great results, the group applied for a patent for the device and moved towards spinning out a company based on the truss design, in partnership with ISIS Innovation, the University-owned company designed to help spin-outs. In the summer of 2007, as well as generating commercial interest, the academic team began to swell with four DPhil students, an affiliated RCUK fellow and the three senior academics.

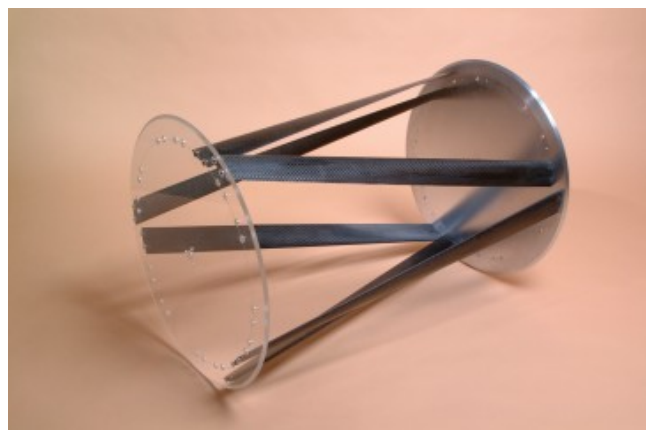


Figure 4: 0.5 m diameter turbine



Figure 5: Testing it at Newcastle University

Having started my DPhil in September 2007, I have continued to develop the design and successfully tested a series of 0.5 m diameter turbines in March 2008 in the combined wind, wave and current tank at Newcastle University. Of all the engineering experiences that I have had at Oxford, this was by far the most difficult



and the most valuable in terms of my education. I now understand what it takes to manage an entire project, from the design of the apparatus and testing process to the logistics of obtaining facility time and transporting people and equipment. One of my happiest moments, or perhaps one of my greatest reliefs, was watching the turbine fit perfectly into place in Newcastle having been designed over 200 miles away.

During the tests, the turbine was mounted in an aluminium frame which could be lifted in and out of the flume to allow different configurations of the turbine to be installed quickly. A Perspex endplate allowed videos to be taken of bubbles passing through the turbine to be analysed later using Particle Image Velocimetry. The power from the turbine was brought out of the water using a toothed belt, into a torque and speed sensor and finally into a motor-generator. At certain flow velocities the turbine self-starts but for the lower flow velocities, the motor is used to accelerate the turbine to an angular velocity where it can produce power. In these scale model tests the Reynolds number, a dimensionless value of scale and velocity, was relatively low so the torque produced by the

hydrofoils was not as high as anticipated on the full scale device. This can have a severe effect on the turbine performance of smaller-scale devices but can also be taken into account in the numerical modelling of the device.

Despite the low Reynolds number of the flow, the tests proved themselves invaluable as we exceeded the Lanchester-Betz limit with all of our designs, as well as discovering several ways in which the design could be further optimised. Simply watching the turbine operate allowed us to see features in the flow pattern which we had not realised would occur. After taking account of these in our numerical models we were able to increase the accuracy of our power prediction from roughly 60% to over 90%.

With encouraging results as well as a wealth of knowledge about the device, there has been a lot of interest in the project from investors and new research students. The workgroup is now performing consulting for other turbine developers, as well as helping to write standards for the design and application of marine tidal devices. Expect to hear a lot more about the THAWT in the very near future.

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## Keep it Cool! 38 Years of Gas-Turbine Research

*A lecture given by Martin Oldfield on Jenkin Day, 15 September 2007*

Martin started by saying that his task was to describe the work of about 200 people over 38 years, so he would not be able to go into very great detail. They had designed and built a whole series of innovative wind tunnels, mostly short-duration ones, and instrumentation for measuring heat transfer, mainly directed at the cooling of gas turbine blades, and had had a remarkable record of success, of significant benefit to the aircraft-engine industry.

To see why the topic was so important, we were invited to compare the 1938 Whittle single-shaft jet engine, uncooled and not very efficient, with a recent Rolls-Royce Trent three-shaft machine, which achieves a

thermodynamic efficiency of over 50% by raising the gas temperature to 1800 K. But the maximum temperature that the first-stage turbine blades can stand is 1200 K, and they would *melt* in a gas stream at 1800 K were they not cooled by an internally supplied flow of cooling air at 800 K, supplied from the compressor. 800 K is hardly "cool", but it is well below the required blade temperature.

So it is necessary to maximise heat transfer *from* the blade to the coolant, and minimise it *to* the blade from the combustor gas, and this leads to a very complex blade structure. Air not only cools the blade on its internal surfaces, but is also fed through bleed holes into the external boundary layer (film cooling), thereby reducing heat flow from the outside (Figure 1).

*(Continued on page 34)*

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## Keep it Cool! 38 Years of Gas-Turbine Research cont.

*(Continued from page 33)*

The founding of the Oxford group can be traced back to Douglas Holder who, from a background of hypersonics at the National Physical Laboratory, came here to be Head of Department from 1961 until his untimely death in 1977. He brought Don Schultz with him, and the two realised that the shock-tube techniques developed for high-speed aerodynamic research could easily be applied to study flow over turbine blades. It was Don Schultz and Terry Jones, a physicist by background, who with Holder's encouragement actually started the group in 1968, and by 1973 there were 12 people in it. Martin himself had joined in 1973-4, having originally come here, with an electrical engineering background, to do a DPhil in plasma physics.

It was clear by then that the work was going to need a lot more space than could be found on the Keble Road triangle. As it happened, Oxford's electricity generating station, originally built in 1897 down by the river at Osney, was finally abandoned as obsolete in 1969, and Holder persuaded the University to buy the building in 1974. It took a lot of work to adapt it for its new use, not least because thermal power stations are designed to lose heat, and this one did, very effectively in winter!

The first tunnel to be installed there was the "isentropic light piston tunnel", conceived by Terry Jones, in which a volume of air is first compressed isentropically by a fast-moving piston, driven by a compressed-air supply applied to the other side. A valve then opens

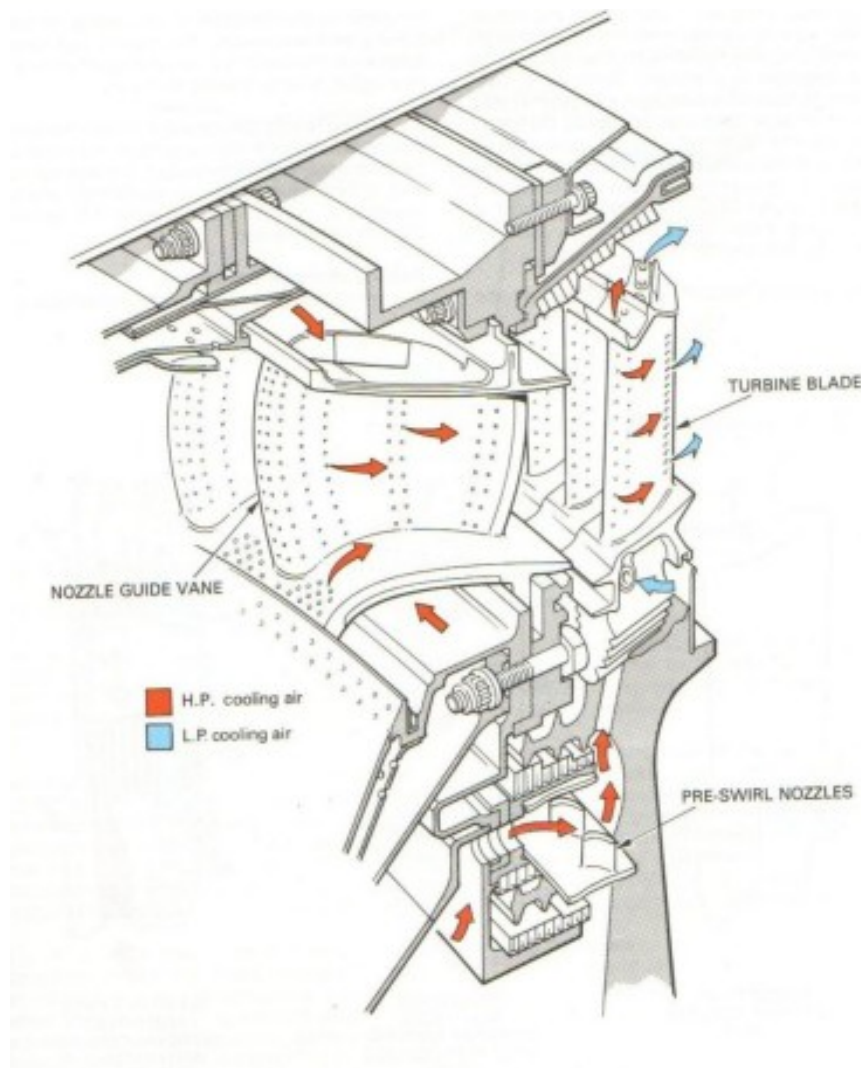


Figure 1: Cooling air flow in a high pressure turbine

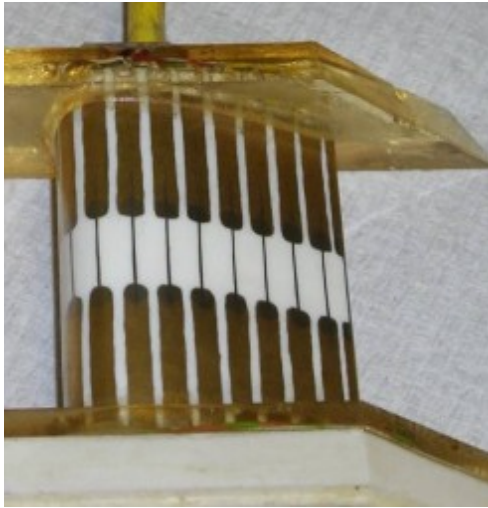


Figure 3: Thin film heat transfer gauges: early Macor blade (left), later 3-D blade (right)

and the hot air flows over a cascade of blades and down into a dump tank, giving a uniform flow for about 0.1–0.4 seconds (see Figure 2 overleaf). Martin built the amplifiers for the instrumentation, and the data was recorded by a PDP11 computer, running off two floppy discs. The experiment was *simulating* the flow of gas at 1800 K over blades at 1100 K, but this could be done adequately with a flow of air at 450 K over blades at room temperature, 300 K, giving the same ratio of absolute temperatures, provided the Reynolds and Mach Numbers also matched.

But with this apparatus they would be simulating a steady flow, whereas in the real turbine the rotor blades are sweeping past a row of stator blades, which introduces all manner of transients: shock waves, blade wakes etc. The cascade of turbine blades in the tunnel was stationary, but the transients could be generated by sweeping a series of wires across the upstream flow, mounted radially on a disc rotating at 20,000 rpm. They learnt much about the nature of the transient flows that resulted.

The heat transfer instrumentation was based on platinum film resistance gauges (Figure 3, above), painted and fired, pottery-fashion, on to blades of Macor, a machinable glass ceramic (and therefore an electrical insulator). The heat transfer to the blade can be deduced from the temperature rise history indicated by the gauges as the hot air flows past them in the 0.4 second run.

The next stage was to put an actual turbine rotor into the tunnel. This was a joint project between Don Schultz and Roger Ainsworth, who had originally graduated from Oxford, and then returned after periods at Rolls-Royce and Harwell. In its brief test run the rotor accelerated from 6000 to 9500 rpm. The blades for it had to be of metal, to withstand the stresses, so the platinum gauges were sputtered on to insulating Kapton film, which was then wrapped around the blades. This was capable of withstanding accelerations of 6000 g. The electrical signals were brought out through slip-rings, but had to be electronically buffered first, and the electronics too had to be capable of withstanding the accelerations. They put semiconductor pressure gauges on the rig too, to study the aerodynamics. They were particularly interested in measuring what happened between the blade tips and the surrounding casing.

The group was then asked to build a significantly larger such tunnel, of 1.2 m diameter, for the National Gas Turbine Establishment at Pyestock (now part of QinetiQ). Originally this just had a stator, but a rotor was added in 1991, capable of 10,000 rpm, with a patented "Turbobrake" to hold its speed constant. The "run time" was 0.4 s.

The above work all concerned heat transfer from the external gas to the blades. Studies of the internal cooling processes were begun by

(Continued on page 36)

## Keep it Cool! 38 Years of Gas-Turbine Research cont.

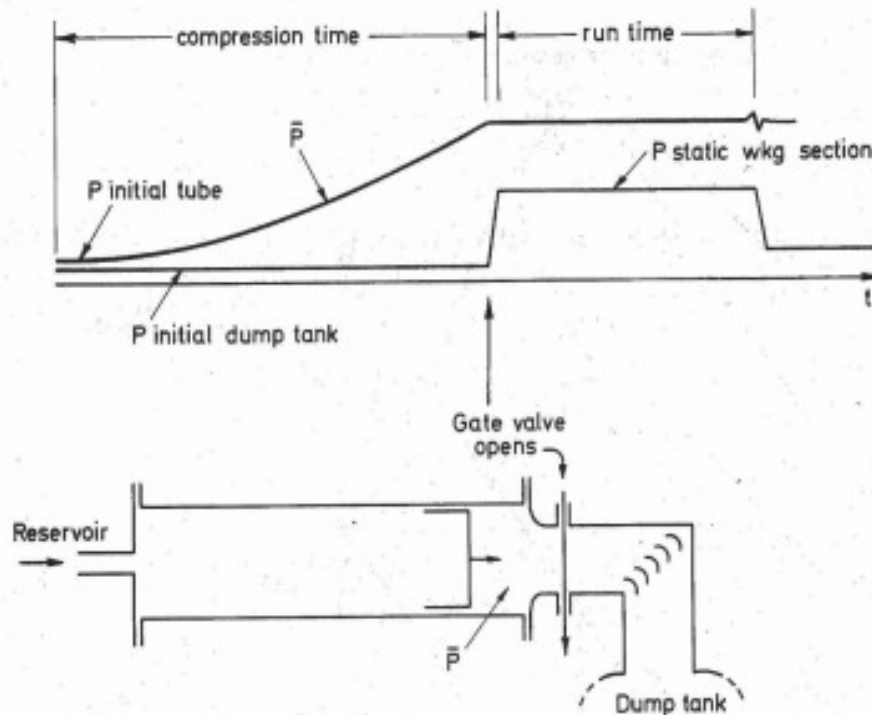


Figure 2: Isentropic Light Piston Tunnel, invented by Terry Jones in 1970

(Continued from page 35)

Terry Jones in 1983, and continued by Peter Ireland, who has now left to join Rolls-Royce, and by David Gillespie, to whom Martin was indebted for information on the work. Terry adopted "thermochromic" liquid crystals for this purpose. These change colour at known temperatures. A combination of two or more types, with different transition temperatures, and some complicated data-processing, permitted heat-transfer rates to be deduced from relatively cheap experiments. In the blade itself, cooling air is fed to the interior, and some is directed perpendicularly on to internal surfaces, or on to "pedestals" between surfaces, cooling them by "impingement". The rest is bled into the external boundary layer, thus cooling it and reducing heat transfer there (Figure 4). The photochromic crystals are particularly useful for studying impingement cooling, using specially designed rigs (since one can hardly film what is going on inside a blade).

A recent line of research had been directed to the cooling of the blade leading edge by a pattern of intersecting bleed holes, but the

details of this were still confidential.

A rather different line of work at about this time concerned flight tests of the external flow around an engine nacelle, to see what could be discovered about the laminar-to-turbulent transition. Film resistance thermometers were used again, since turbulent flow produces temperature fluctuations. The tests were done on a Fokker VFW614 airliner, a convenient aircraft for the purpose since the nacelles are above the wing and visible from the cabin windows. The Oxford group went on many successful test flights and were encouraged to learn that the laminar boundary layer seemed quite robust against engine vibration and noise.

Another tunnel, built in 1982, was the "blowdown tunnel", with which certain aerodynamic tests could be done much more cheaply than with a continuously operated tunnel needing many megawatts to run it. In 1990 Gary Lock and Shengmin Guo put an annular cascade of 36 nozzle guide vanes into it, to do both aerodynamic and heat transfer tests at the same time. The blades were



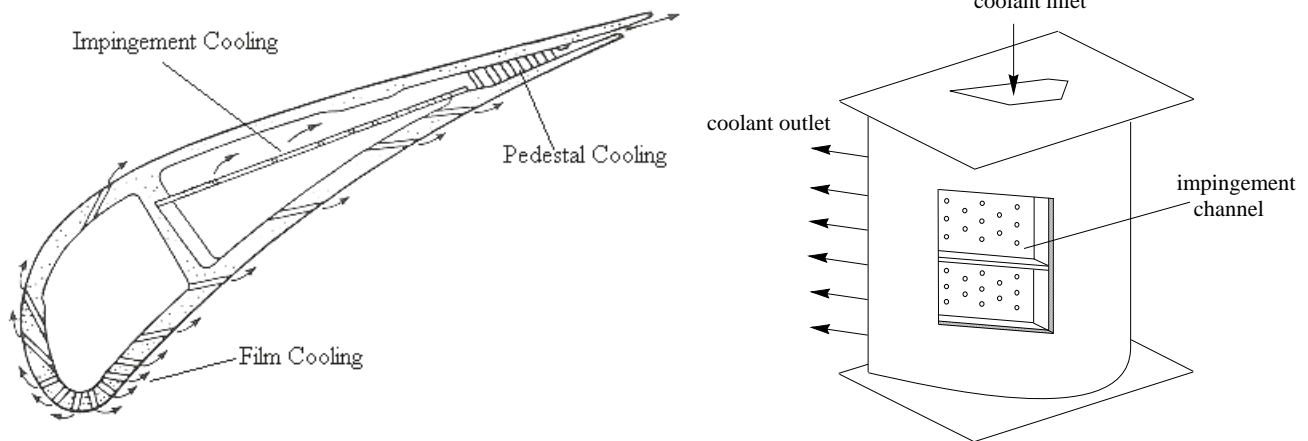


Figure 4: Turbine vane cooling

heated but the gases were at room temperature. To get the correct density ratio between coolant and mainstream gas, he used a mixture of sulphur hexafluoride and argon for the former, an option now closed off because of the "greenhouse gas" properties of  $\text{SF}_6$ . Reynolds and Mach Numbers matched those of the engine, but the tunnel used 38 kg/s of air at 2 bar and room temperature whereas the engine being simulated used 120 kg/s at 32 bar and 1750 K.

An interesting development in 1998 led to a patent for a new shape of bleed hole, called a "console" (**converging slot hole**), which starts with a circular cross-section on the inside of the blade, but changes to a narrow slot at the outside, reducing in cross-sectional area on the way. A row of such holes looks like a continuous slot on the outside, but still leaves enough metal on the inside to preserve the structural integrity of the blade. The wall of the "console" is made up of a family of straight lines, so it can be drilled by a laser. The coolant leaves the blade in a single sheet rather than in numerous separated jets, as happens with cylindrical holes, which leads to a significant improvement in the cooling of the external surface. (See Figure 5 overleaf.)

Another topic of interest was the study of leakage past the tips of rotor blades. The tip clearance on a real engine is so small that it is difficult to measure what happens there, but the large low-speed "architectural" wind tunnel used for many years by Colin Wood became available on his retirement in 2003 and gave

an opportunity to scale the whole thing up enormously – the "largest turbine cascade in the world". The cascade was 4 m long with a blade chord of 1 m, and the tip clearance became 30 mm. Gas velocities there were measured by correlation between successive photographs of particles in the flow, and heat transfer at the tip by heating it electrically, and observing temperature with an infra-red camera inside the blade.

There are many places in a turbine where the need to allow for thermal expansion means that there are annular gaps between stationary and rotating parts where axial leakage can take place, with resulting loss of efficiency. The classic way to reduce such leakage is the "labyrinth seal", but it can almost certainly be improved on. The first attempt by the group was the "brush seal", in which the space is filled with thin wires, attached to one part and sliding over the other, rather like a brush. This makes for a much more tortuous gas path, but has some weaknesses. Better is the "leaf seal", in which the bristles of the brush are replaced by leaves, long in the axial direction but thin tangentially. This arrangement, it appears, may not only have a very long life, but also very little friction, since the presence of the gas causes the leaves to ride just clear of the rotor surface. (See Figure 6 overleaf.)

Other topics touched on were Tom Povey's mass-flow measurement system, and his supersonic cascade ("the smallest turbine

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## Keep it Cool! 38 Years of Gas-Turbine Research cont.

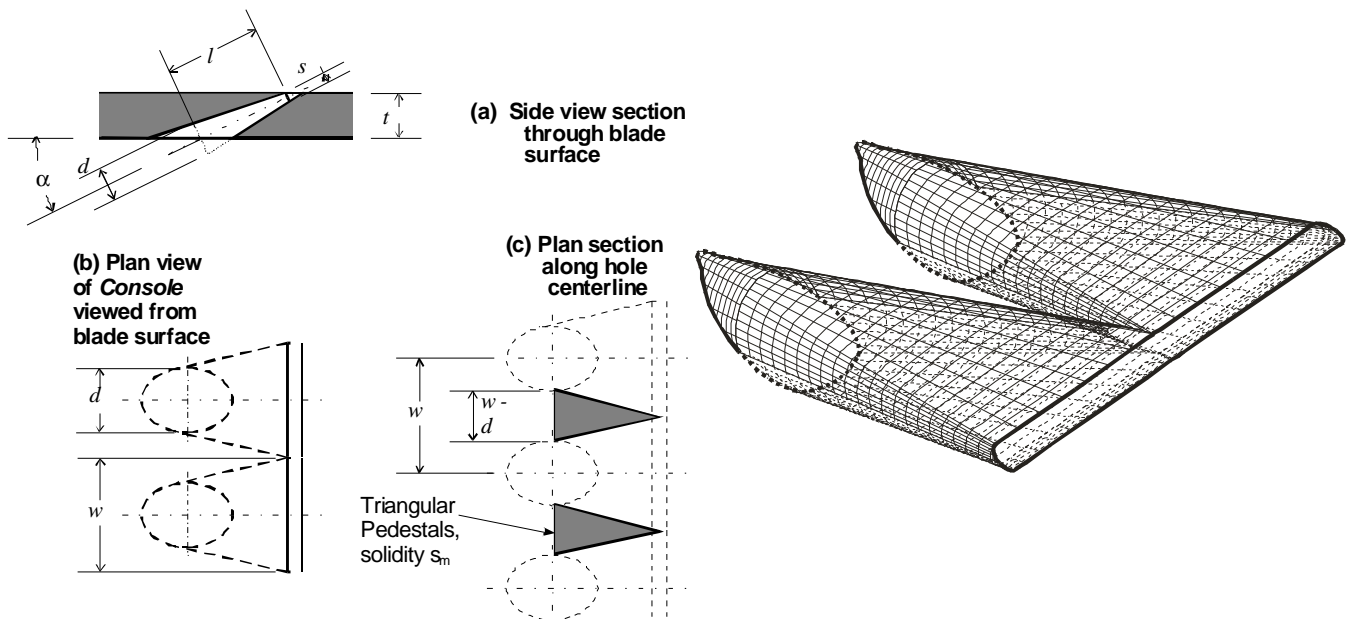


Figure 5: Console cooling holes

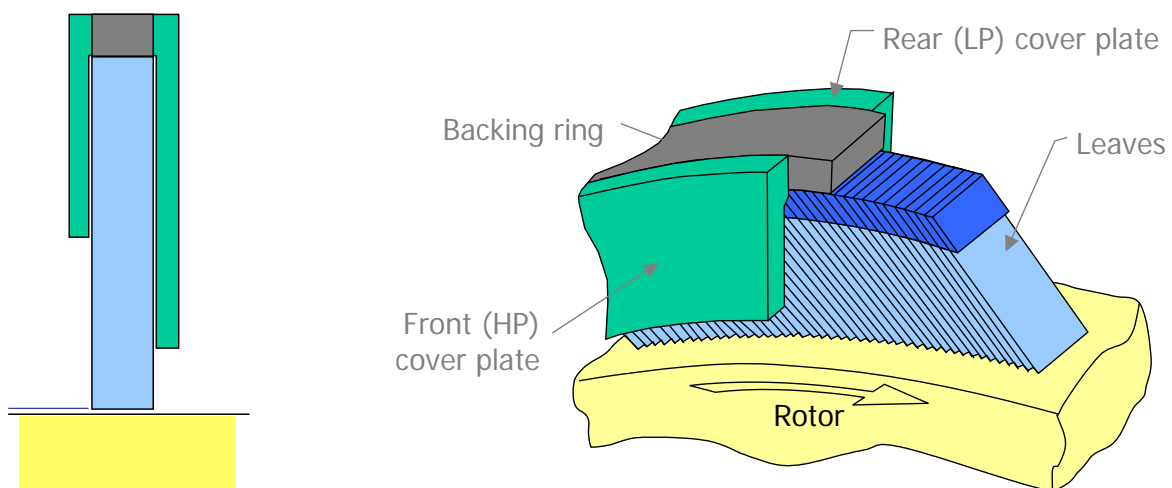


Figure 6: The leaf seal

(Continued from page 37)

cascade in the world"); and his "annular sector facility" which uses a "de-swirl" element to get a good representation of a complete blade ring with just a short six-bladed sector. There was Peter Ireland's work on lightweight air-to-air heat exchangers; and Alex Matthews' work using the hypersonic gun-tunnel to study scramjets and also the potentially disastrous consequences of a combustion-chamber burn-through.

Martin went on to acknowledge their debt to the group's sponsors, primarily Rolls-Royce of course but including many others; to list some of the honours and awards received over the years; to say what he thought were the main contributory elements of their successes (Table 1); and finally to offer the group and its new leader, Phil Ligrani, his best wishes for the future in their new home in the Axis Point building.

- Strong group community spirit with sympathetic leadership
- Continuity of experience and knowledge of the academics and technical staff
- Ability to attract and motivate high ability DPhil Students
- Brilliant dedicated Research Assistant and Technician support
- Long association with major gas turbine manufacturer
- Use novel solutions to problems such as short duration wind tunnels
- Invent and use own novel instrumentation
- Innovate, innovate
- Enjoy the research and the company of a great crowd of people – I did!

**Table 1: Recipe for success**

## Motor Racing Meets Robotic Pets

*Simon Turner (Lincoln 1984-92)*

Those with a good memory may recall a small media flurry in early 2001 concerning a large British robotic dog called RoboDog, which featured in various newspapers and TV news programmes, and even had a star turn on Richard and Judy.

Although the media mostly concerned themselves with RoboDog's striking appearance and assorted tricks (headstands, playing football,

reading e-mails etc.), it was really intended to be a technology demonstration for a fledgling British engineering company that was interested in using the materials and techniques common in motorsport in a different arena, namely robotic devices.

RoboScience was set up by Nick Wirth, the former Simtek Formula 1 team owner and Benetton F1 chief designer, who was looking for a

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**Figure 1: The RoboScience RS-01 RoboDog (in car, right, for scale)**

## Motor Racing Meets Robotic Pets cont.

*(Continued from page 39)*

new challenge during a sabbatical from the topsy-turvy and insular world of motor racing. He had long been interested in robotics, and after becoming intrigued by the Sony Aibo robotic dog (an expensive and technologically impressive toy, around 20 cm tall), decided that making a much larger version — roughly the size of a real Labrador dog — would be a good media-friendly way to show off the possibilities offered by the use of modern materials (carbon fibre composites, Kevlar etc.) and design techniques in robotics. The idea for the RS-01 RoboDog was born.

### The challenge

The engineering challenges of making large quadrupeds are significant: weight increases with size cubed, which with longer legs means that the motor torques required at the joints increase quartically. The Aibo weighs 1.5 kg: using traditional materials to produce something the size of RoboDog (around 70 cm) would have produced a robot weighing over 30 kg, which would have had prohibitive power requirements. By contrast, RoboDog only weighed 12 kg, making it able to operate for a couple of hours between recharges, as well as performing its popular "tricks" (headstands and press-ups with a five-year-old child on its back, which both require enormous amounts of power).

RoboDog was created in a remarkably short time — just seven months from conception to having a walking robot — by a small distributed team of people specialising in particular areas of the project, collaborating across three counties via the Internet. The author's involvement was with computing and control, which is the main focus of this article: to attempt to describe the entire project would require rather more pages than are available!

RoboDog's light weight came from a combination of factors: a monocoque exoskeleton made from carbon fibre and Kevlar provided a chassis that was extremely light and strong; the leg joints (which were subsequently patented) combined hinge, gearbox and motor in a single unit

that was both small and lightweight (albeit somewhat noisy in the prototype form that appeared in RoboDog), and capable of sustaining high torque for a considerable time; and the electrical system was highly efficient, combining modern battery technology with minimal power requirements to keep the weight down as much as possible. The batteries were mounted in the lower half of the body, to keep the centre of gravity low; the area above this was where all the electronics, computers, peripheral boards etc. were mounted, with cables running through the hollow legs or the middle of the neck tube.

To fit in with the low-power requirement, the power electronics and on-board computers needed to be highly efficient. An early decision was made to use standard systems and interfaces as much as possible, to avoid reinventing the wheel, and for the high-level control software to run on a separate computer, communicating with the robot's on-board systems wirelessly.

The on-board power electronics controlled the high-torque (and high-current) 24 V DC joint motors to position the limbs, each motor/electronics combination forming a distributed position-control servo system. The electronics were designed in-house, but with a control interface that mimicked the pulse-driven interface of standard radio-control servos<sup>1</sup>. This had two immediate benefits:

- (a) microcontroller-based commercial systems were available that provided easy control of multiple servos from a single computer, and which could therefore also be used to control the robot's "servos";
- (b) the electronics and the control software could be developed and tested separately, using a standard radio-control

<sup>1</sup> Servo position is controlled by pulse width modulation (PWM): voltage pulses of between 1 and 2 ms in duration are sent to the servo at regular intervals (e.g. 50 Hz), with the width of the pulse determining its position. The exact relationship between pulse width and position varies from servo to servo, but a stop-to-stop range of around 1-2 ms is typical.



transmitter and receiver to drive the electronics in place of the software, while the software operated a set of inexpensive hobby servos in place of the actual robot.

However, it was found that the 50 Hz frequency of the incoming servo control PWM signal produced an unpleasant buzzing sound from the motors, so the final version of the electronics put the incoming pulses through a sample-and-hold circuit, from which hardware PID control was used to produce a 25 kHz PWM output signal, fed to the motors via a full-bridge FET driver.

Power for the robot came from 44 Sanyo Twicell NiMH cells, arranged in two parallel arms of 22 series cells, giving a 27 V battery with 7000 mAh capacity (and a maximum discharge rate of 21 A — around 570 W — when needed!)

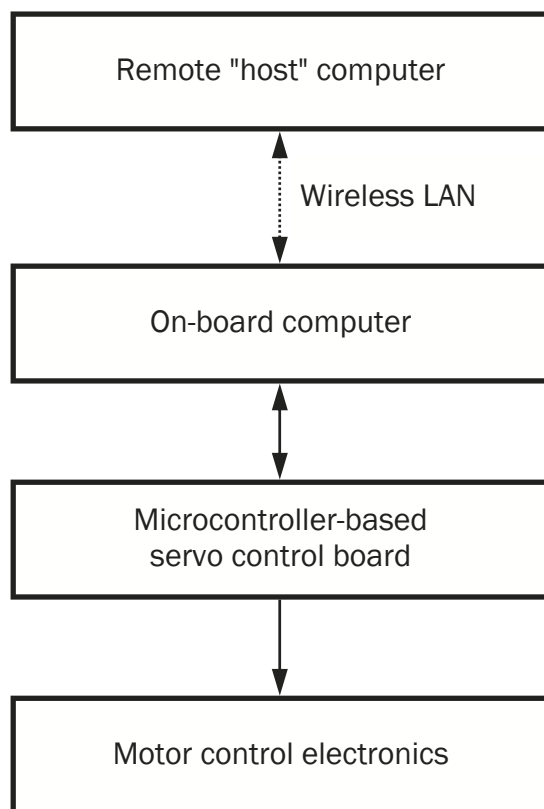


Figure 2: Block diagram of RoboDog's control scheme

With the Sony Aibo already well known (as well as having been the inspiration for the project), it was decided that RoboDog should offer Aibo-like functionality to provide high-tech appeal;

but the tight timescale and small budget meant that this would have to be done as simply as possible, using off-the-shelf equipment and tools whenever available (rather than doing things from first principles), while retaining intellectual property rights.

The system specification was as follows:

- control 16 servos simultaneously to allow all types of movement
- vision, to allow a ball to be tracked, located and kicked in real time
- sonar, for collision avoidance
- basic local navigation
- voice activation
- speech synthesis for communications
- automatic recovery from falling over

In addition to the real-time software, a computer simulation of the robot's kinematics was also written to allow gait and pose design and analysis (i.e. to work out which servos needed to move where, and when, to allow the dog to walk, sit down etc.). Motion was achieved while remaining statically stable, by keeping three feet on the ground at all times, with the centre of gravity lying within the triangle thus formed; the fourth leg was then repositioned to form another triangle, then one or more of the currently-supporting legs was moved until the centre of gravity crossed the boundary into the new triangle, at which point the robot would fall into the new stable position and the cycle could start again. High-speed motion was statically unstable, relying on momentum to keep the robot moving in the desired direction without falling over.

The software was used to define "motion sequences": lists of joint angles that were needed at particular times to achieve the desired motion. These were processed by the dog's on-board computer, and could be either used alone, or used consecutively to achieve more complex movements from simple building blocks. (If the starting pose of a sequence did

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## Motor Racing Meets Robotic Pets cont.

*(Continued from page 41)*

not match the finishing pose of the previous one, a smooth transition was automatically made between them.)

### A walking Windows PC

RoboDog was a walking Windows 98 PC (strictly, Windows 98 Second Edition, which was the first to support USB devices properly). This platform was chosen because of its familiarity, ease of interacting with external hardware (e.g. USB devices and wireless network cards), and the availability of commercial software packages to provide additional functionality; also, all the software could be developed and tested on existing PCs. There were some concerns: Windows is not known for being a real-time software platform! The version running on RoboDog was stripped down to only those parts absolutely necessary for its operation, and actually proved quite capable of controlling the robot without significant hiccups, provided that the main control software was the only task running.

As has already been mentioned, the on-board computer needed to be small, lightweight and with minimal power requirements. A PC/104 format system was used (about 10 cm square and 4 cm deep, with two linked boards): this operated from a 5 V power supply and consumed only around 10 W when running, providing a modest amount of computing power (a 266 MHz Pentium processor with 64 MB of RAM) and all the necessary input/output connections (serial, USB, a PC card slot and audio). It communicated with the external host PC (whose job it was to do the high-level control) over an 11 Mbps wireless network, using the TCP/IP protocol on which the Internet runs.

The necessary sensor inputs were all achieved using off-the-peg commercial hardware:

- the vision requirement was met by removing the innards from an inexpensive USB webcam, with the camera mounted in the head (behind the "visor"), and the captured image frames then streamed to the remote host PC over the wireless LAN;

- a small sonar sensor was mounted in the nose, providing an analogue voltage corresponding to straight-ahead distance with an update frequency of 10 Hz;
- a small solid-state digital compass, which could be interrogated by a computer over an RS-232 serial connection, was mounted in between the front shoulders;
- voice activation was provided by a commercial voice-recognition board, which could be trained to recognise two-word patterns (an initial "attention" word followed by a variable command word) and report any pattern that had been recognised with an eight-bit digital output, giving a potentially vast vocabulary of commands;
- a two-axis accelerometer provided two analogue voltages corresponding to forward and sideways acceleration, which could be used to sense which way was "down", and thereby detect if the robot had fallen over and initiate recovery as appropriate.

Speech synthesis was provided by an inexpensive "shareware" Windows program, which would read out any provided text using the computer's soundcard. Connected to a loud-speaker mounted in the chest, this gave RoboDog a pleasingly deep and appropriately artificial-sounding voice; opening and closing the jaw at the start and end of the speech produced a convincing effect. One minor issue was the software's tendency to recognise the abbreviations for American states, meaning that instances of "OK" in the text had to be changed to "okay" to prevent them being read as "Oklahoma"!

### Do it yourself if you have to

The main requirement for the low-level control software was, of course, controlling the 16 servos in the robot: three on each leg (shoulder/hip rotation in two axes, plus elbow/knee rotation); fore and aft movement of the neck; left/right panning of the head; opening and closing

the mouth; and of course wagging the tail left and right! The twelve leg servos and the neck were actually the RoboScience-designed power electronics units appearing to be servos; the head rotation, jaw and tail used conventional radio-control servos.

Servo control initially appeared to be straightforward: a commercial microcontroller board was purchased that claimed to control 16 servos simultaneously, and provide eight inputs of analogue-to-digital conversion (ADC), using a simple system of single-byte commands and responses over an RS-232 serial connection to the main computer. The level of control over the servos was excellent: for each servo, one could define speed and acceleration and a position, and the microcontroller would then send an appropriate sequence of pulses to the servo to make it move smoothly from its current position to the new target, accelerating up to the defined speed and decelerating again at the other end. When the movement was complete, the system would send a response back to the main computer to tell it that the servo had reached its target.

Sadly, although apparently well regarded in the hobby robotics world, this system turned out to be unable to live up to its impressive specifications: it became erratic when used even moderately hard, with servos jumping instead of moving smoothly, end-of-motion trigger events failing to happen, ADC readings failing to occur or being mixed up etc. By the time this became apparent, and investigation had shown that the fault was endemic rather a problem with our particular board, the development of the control software was well advanced and the design required the level of control that the board had claimed.

After further research failed to turn up any other products with equivalent specifications, there was no alternative but to produce a replacement in-house; fortunately an acquaintance was an experienced embedded software engineer, who took a basic commercial microcontroller board and produced a system capable of controlling eight servos in the desired manner, using exactly the same serial command bytes as the unreliable commercial system. Using two of these new boards provided a

properly working drop-in replacement for the original system, requiring almost no software changes, with the added benefits of providing 16 channels of ADC instead of the original eight, and the ability to handle the serial communications with the compass, reporting its readings as a virtual analogue voltage. This relieved the PC from having to communicate directly with the compass, and the additional ADC meant that the full range of outputs from the voice activation unit could be used as well as the sonar, accelerometers etc.

### **Making a dumb robot appear smart**

A robot is not much use without higher-level control telling it what to do. RoboDog on its own could only start up, boot into Windows 98 and sit there waiting for a connection to be made to it over the wireless LAN, very much like an Internet mail or web server — in fact its communication protocols were designed along the same lines as the Internet protocols HTTP, FTP, SMTP etc., being largely text-based so that a human could log in and command the robot without needing any special software; this was very useful during the development phase.

If a connection was made, the robot's servo control could be activated, individual joints could be moved to arbitrary positions, and motion sequences (produced by the kinematics software described above) could be loaded and processed — by moving the servos at the necessary speeds to achieve the specified joint angles at the specified times — to make it execute a particular series of motions: but this did not provide the desired football-playing, disaster recovery, navigation, voice control etc.

The so-called "host PC" (HPC) provided the "smarts" for the robot, since its on-board systems were not powerful enough: the internal control software was responsible for making the servos move to their desired positions in the required time, receiving and re-broadcasting frames of video captured from the webcam, and polling and reporting the various ADC inputs. The HPC software was responsible for connecting to the robot, loading motion scripts, monitoring the ADC values, receiving and processing the video stream, using the

*(Continued on page 44)*

## Motor Racing Meets Robotic Pets cont.

*(Continued from page 43)*

compass for navigation, and all the other features expected of the complete package. Most aspects of this were very simple in operation, but the overall effect was quite impressive.

- Voice command:** the two-stage voice recognition board would set its eight digital outputs to a binary code indicating the command that had been recognised; when in voice-command mode, the HPC software would note the changes in the relevant ADC values, then send a pre-programmed sequence of instructions (appropriate to the command) to the robot. A helpful aspect of the on-board voice unit was a diagnostic LED mounted at the top of the tail, which lit up when a command was being recognised: the initial "attention" word (which was, rather predictably, "RoboDog") made the LED light up, and if the next word was also recognised, it would flash off and then on again: if not, it would go off. This made the operator's task much easier, as a command could simply be repeated on the odd occasions where changing acoustics prevented it from being recognised.
- Ball-tracking vision:** ball recognition was done on the simple basis of recognising the particular colour of the ball: all the pixels in the image that appeared to be ball-coloured were noted, and if enough of them were found to suggest that the ball was in view, the centroid of the pixels was calculated to give an estimate of the ball's position in the image. The neck and head servos were then moved at high speed to attempt to get the centroid in the middle of the frame; this real-time tracking system, although crude, was very effective. To allow for variable lighting, a simple training exercise was performed by the human operator at the beginning of each demonstration, to define the colours that were considered ball-coloured; if the environment was such that the background also contained these colours, a
  - differently coloured ball could be used instead.
- Playing football:** with the dog in a particular known stance, its ball-tracking system was used to find the ball and position it in the middle of the video frame. Since the head's position relative to the ground plane was known, including the angle of the neck, the angle between the head and the ball — and hence (knowing the size of the ball) its distance from the dog — could be calculated. The dog was then repositioned using a collection of pre-prepared motion sequences with known effects, and the ball's relative position recalculated; once in the correct position, one foot was swept forward to kick the ball, and the dog would then open its mouth, look from side to side, wag its tail and wiggle its hindquarters to convey its pleasure.
- Navigation and collision avoidance:** an "arena" was defined in the HPC software and the robot's initial position noted. Compass readings and gait-derived odometry allowed simple navigation by dead reckoning; this could be misled by slippery floors (spoiling the odometry) and variable magnetic fields, but it worked well enough to allow RoboDog to parade around a platform, making corrections to its heading before setting off on the next stage. Collision avoidance, when activated, was quite simple: if the nose-mounted sonar detected an object within a programmed distance in front of the dog, the HPC would simply stop it dead in its tracks.
- Disaster recovery:** although it never actually happened except as a demonstration, by monitoring the values being sent by the two-axis accelerometer it was possible to determine if the dog had fallen over, and if so, on to which side: a pre-programmed recovery sequence was then initiated that moved the legs on opposite sides of the body to roll it upright, then



tucked them under the body and extended them to stand the dog up again. This was demonstrated to a sceptical journalist at the official launch at the IMechE, to considerable hilarity from the other journalists present!



Figure 3: RoboDog doing one of its trademark headstands



Figure 4: 90° joint ranges allowed unusual movements

### Epilogue

Sadly, although RoboDog was a success at demonstrating the technology, RoboScience's next project — the RS-10, an autonomous mini-helicopter camera platform to get overhead views of scenes without the expense or intrusiveness of a full-scale helicopter — was shelved after getting to the test rig stage, when a market research exercise showed that there

was apparently no demand for such a thing; it is interesting to note that devices much like this are now appearing on the market, seven years later, so perhaps the idea was simply too far ahead of its time.

Investment became harder to find in the wake of the 9/11 terrorist attacks, and RoboScience was eventually put into hibernation while those involved concentrated on other things. Nick Wirth is now back in motor racing, with his eponymous Wirth Research company providing the technical developments behind Honda's American sportscar programme; the author is currently working with Nick on another form of robotics, namely a hexapod motion platform for a racing car simulator.

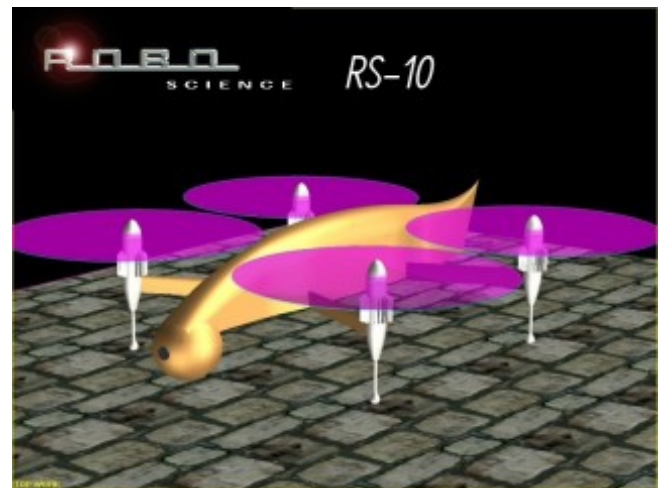


Figure 4: Concept illustration of the RS-10

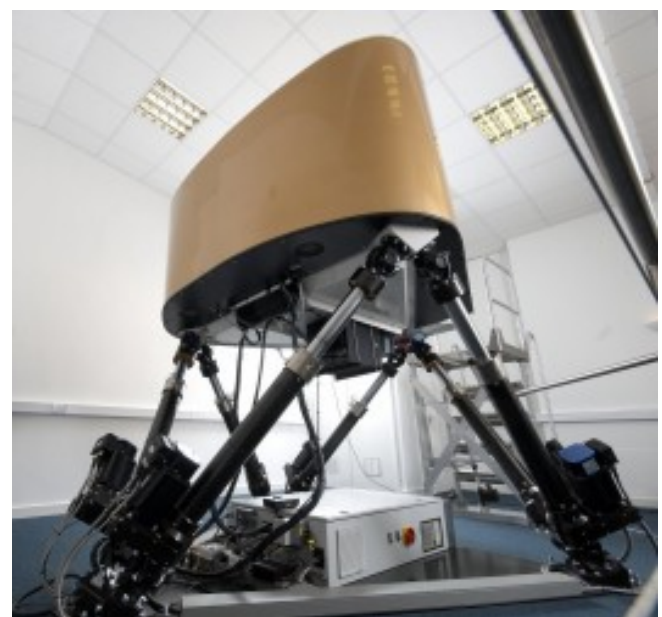


Figure 5: Wirth Research's hexapod simulator

## One Hundred Years of Engineering Science at Oxford, 1908–2008

Alistair Borthwick

### Introduction

Over the past year, the Department has been celebrating the Centenary of Engineering Science at Oxford. This article gives a brief historical background to the Department, before describing various activities that have taken place in 2007–08 to commemorate the centenary.

Before the Department was formally established, the University of Oxford had a long tradition of producing engineering scientists and applied mathematicians whose influence on the development of mechanics was felt worldwide. These included Richard of Wallingford (c.1292–1336), Leonard Digges (c.1515–c.1559), Robert Boyle (1627–91), Robert Hooke (1635–1703), and William Froude (1810–79). Richard of Wallingford constructed an astronomical clock. Digges invented the surveyor's theodolite. Boyle and Hooke contributed to the development of the inverse law relating gas volume to pressure. Boyle was one of the first to write an engineering textbook, *Hydrostatical Paradoxes, Made out by New Experiments (For the Most Part Physical and Easie)*, which was hot off the press in 1666. Robert Hooke made many notable contributions to the science of mechanics including his famous law relating tensile force to extension. Hooke realised that the optimum shape of an arch was that of an inverted catenary, and wrote this as the following Latin phrase in 1675, "*ut pendet continuum flexile, sic stabit contiguum rigidum inversum*". Froude designed skew bridges constructed from brickwork, helped devise and patent the atmospheric railway, investigated the reduction of lateral forces on curved rails, frictional resistance on ships, steam expansion, and even the soaring of birds. Froude's ideas on scale modelling are still taught to engineers throughout the world. He invented a hydraulic dynamometer that was exploited by Heenan & Froude, now Froude Hofmann Ltd. Froude's name is immortalised in his non-dimensional number,  $Fr = u/\sqrt{gd}$ , where  $u$  is a characteristic

velocity,  $g$  is the acceleration due to gravity and  $d$  is a characteristic length. The Froude number is used to characterise gravity dominated flows in naval architecture, ship engineering, civil engineering, mechanical engineering, environmental engineering, and even geophysics. And of course, the Froude number appears in [HLT] *Engineering Tables and Data*! Froude also developed an actuator disc concept for the ideal air propeller, leading to the Froude-Finsterwalder equation relating velocity to thrust (of a propeller blade). Scott Draper, Guy Houlsby, and Martin Oldfield recently used this concept to analyse the momentum exchange across a tidal flow turbine.

By the late 1800s, the University began to recognise the importance of Engineering as a discipline, and after quite a long struggle, both financial and cultural, approved the Oxford Professorship in Engineering Science in 1907. Charles Frewen Jenkin (1865–1940) was elected on 21 May 1908, the date the Department could be thought of as coming into existence. Meanwhile a Diploma in Scientific Engineering and Mining Subjects was offered from 1905 to 1914, without a single Diploma awarded! The Honour School of Natural Science (Engineering Science) commenced in 1909. The first student graduated in 1910. Jenkin led the Department until he retired in 1929. His successor, Richard Vynne Southwell (1888–1970), was an aeronautical engineer who made a significant contribution to the development of the stiffness method of structural analysis and invented the numerical method of successive relaxation for solving elliptic partial differential equations. Southwell became Rector of Imperial College, London in 1942, where he supervised Oleg Zienkiewicz, who played a key role in the development of the finite element method. Meanwhile, Brian Spalding, who graduated from the Department in 1944, helped develop the finite volume method (at Imperial College, London), which revolutionised computational fluid dynamics. In 1944, Alexander Thom (1894–1985) became the third Head of Department and Professor of Engineering Science until he

retired in 1961. Thom was succeeded by Douglas Holder, Peter Wroth, Michael Brady, David Clarke, Rodney Eatock Taylor, and Richard Darton.

The 100 years of the Department were marked by a very successful series of lectures, an engineer being awarded an honorary doctor of science degree, a garden party, a debate on power generation and its use for the future, a photographic competition, and a conference for young coastal scientists and engineers. Lord Jenkin, grandson of Charles Frewen Jenkin, was the Patron of the Centenary. The events commenced appropriately on the Jenkin Day (Saturday 15 September 2007), with a brace of lectures. In his morning lecture, *Keep it cool! 38 years of gas-turbine research*, Martin Oldfield described heat transfer measurements in novel wind tunnels in the Southwell Building at Osney, used to study the cooling of gas turbine blades. In the afternoon, Sir Vivian Ramsey gave the Jenkin Lecture titled *Law and Engineering: resolution of technology disputes* in which he outlined the history of arbitration, discussed case histories illustrating the liability (or non-liability) of engineers, and reported on the four current methods used for resolving disputes.<sup>1</sup>

A series of 12 Centenary Lectures were held over the academic year. The first, by Allan Chapman on *"The Greatest Mechanick of this Present Age: Dr Robert Hooke and the Origins of Engineering Science in Oxford"*, described the historical scientific foundations upon which the Department is based. In Chapman's words, "When his Oxford friend, John Aubrey, described Hooke as the 'Greatest Mechanick' of the Age, he acknowledged Hooke's genius as an experimentalist. For Hooke, the whole of nature was a great machine or engine in motion, the deepest truths of which could be uncovered by means of ingeniously contrived instruments. For in the 1650s, Oxford's 'Ingeniosi' of the future Royal Society were beginning to revolutionise our sense of 'natural knowledge' and coming to envisage ways of applying it to the 'Relief of Man's Estate'." Allan Chapman is an accomplished historian of

science, and one of the country's greatest proponents of engineering science. His lecture illustrated Hooke's major achievement as the first scientist to focus on experiments, using precision instrumentation. In addition to viewing the on-line recording of the lecture, SOUE members are recommended to read Chapman (2005, 2008) for further information. The success of Allan Chapman's lecture set the scene for the remaining lectures, and also began to establish a group of attendees who though not directly related to the Department could justifiably be called *Friends of Engineering Science*!

The second lecture was given by David Brown on *William Froude — A Sacred Duty to Doubt*. The lecture considered the life of and influences on William Froude, covering his early years, his decision to read Classics and Mathematics at Oriel College (where older brother Hurrell was his tutor), his correspondence on proof in science and religion with Cardinal Newman (another former tutor), followed by his career as engineer and local worthy. After graduating, Froude became a trainee with Palmer, then assistant to IK Brunel, retiring in 1846 at age 36 to take care of his father and the family estates. Froude became a JP, a Harbour commissioner, and designed a self-propelled scraper to clean the water mains in Torquay. In 1856, Froude returned to work with IK Brunel on the design of the Great Eastern. In 1861, Froude's theory of ship rolling was published, based on tests carried out in a tank in the basement of a house in Torquay. Froude then began his work on scale modelling, which reached fruition in the 1870s. His research methodology followed the principle that "It is our sacred duty to doubt each and every proposition put to us — including our own." For example, as David Brown reported during the lecture, Froude argued with Newman that Newton's law of gravity could not be taken as an absolute but rather a fit to the evidence. The lecture was kindly sponsored by Froude Hofmann Ltd, the company founded on the basis of Froude's invention of a hydraulic dynamometer. David Brown spent all his working life with the Royal Corps of Naval Constructors and was Vice-

<sup>1</sup> Reports of both these lectures are included in this issue of SOUE News



## One Hundred Years of Engineering Science at Oxford, 1908–2008 cont.

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President of the Royal Institution of Naval Architects for many years. Although David Brown sadly passed away earlier this summer, the lecture and book (Brown 2006) remain as fitting tributes to both lecturer and subject. Taking the first sentence of Brown's lecture notes, "The Proverbs tell us that there are some things too wonderful to know, one of which is the way of a ship in the midst of the sea."

Following the theme of water, Jane Smallman gave the third lecture titled *Hydraulic Engineering – How we use hydraulics to solve real life engineering problems*. This lecture provided a fascinating insight into how modern research ideas are translated into practical solutions of maritime problems encountered in civil and environmental engineering. Dr Smallman used a series of case studies to illustrate her talk. She indicated how laboratory tests and numerical simulations provide complementary information on the physics of the extremely complicated flows that characterise rivers, estuaries, and coastal waters. Her presentation reminded the audience of the grand challenge problems of modelling turbulent, possibly stratified free surface flows with sediment transport and changing bed morphodynamics. Jane Smallman is the Managing Director of HR Wallingford Ltd.

Christopher Pugsley presented *Engineers at War*, an illuminating lecture on the civil engineering aspects of military engineering. His lecture gave a comprehensive overview of the interaction between military and civil engineering from ancient times to the present day. It is pertinent to note what the Oxford English Dictionary has to say about the words *engine* or *engineering*. The Shorter OED defines the noun *engine* as (1) mother wit, genius, (2) ingenuity, artfulness, trickery, (3) an instance or product of ingenuity, a contrivance, plot, a snare, wile, (5) a machine or instrument used in warfare, and (6) an engine of torture! Similarly, the OED defines the verb *to engine* as follows: (1) to contrive, plan, (2) to take by craft, ensnare; (3) to put on the rack (as experienced

by many a student in a tutorial!); (4) to supply with engines. Finally, the OED defines an *engineer* as (1) one who contrives, designs, or invents; an inventor, a plotter; (2) one who designs and constructs military engines and works; and (3) one who designs and constructs works of public utility. These definitions indicate the historical overlap between military and civilian engineering. Dr Pugsley's talk provided many illustrations of this overlap, whereby military engineers have designed roads, fortifications, devices by which to lay siege to castles, pontoon bridges, mulberry harbours, Nissen huts, etc. Dr Pugsley is Senior Lecturer in War Studies at the Royal Military Academy Sandhurst, having previously been a Lieutenant Colonel in the New Zealand Army.

The fifth lecture focused on the Serlio Frame. Guy Houlsby spoke on *An Early Structural Engineering Problem – the Oxford Connection*. In an enthralling historical account, Professor Houlsby traced the history of the Serlio Frame from its appearance c.1270. The Serlio Frame is a particular form of reciprocal structure that uses interlocking beams to span space, each beam being shorter than the overall span dimension. Houlsby delved deep into medieval literature to show the audience some of the earliest examples of the Serlio Frame, driven by the practical problem of how to span a floor using wooden beams from trees that are too short. He took the audience on a virtual tour of stately homes and castles in Europe and China, highlighting a variety of reciprocal structures that were typically used for ceilings. He discussed the pioneering work of John Wallis (1616–1703), the Savilian Professor of Geometry at Oxford, who analysed the structural behaviour of a Serlio Frame by idealising it into a nodal framework, using symmetry to simplify the problem, considering the force balance of each member, solving 25 simultaneous equations exactly to determine the overall load reaction of the frame, and then carrying out a more detailed analysis of the most heavily stressed members. On this evidence, Wallis may justifiably be considered the father of modern structural analysis.



Professor Houlsby showed photographs indicating that a Wallis lattice frame may have been used for a ceiling in the Bodleian Tower. Unfortunately, the frame was dismantled and replaced by a concrete slab in the early 1960s; the wood was stored in the Bodleian underground bunker before travelling to the Examination Schools where it seems to have disappeared. A structural tragedy.

Lecture Six jumped forward into modern times, consisting of a talk by Julian Morris titled *Motion Capture*. This highly entertaining and personal talk began with Dr Morris telling several amusing and pertinent anecdotes about his experiences as a DPhil student in the early 1970s working in John O'Connor's orthopaedic engineering group. Dr Morris discussed the techniques of motion capture for orthopaedic purposes whereby indicators are stuck on legs, gait video film recorded, and the images analysed to reveal the underlying skeletal mechanisms. The lecture examined the evolution of the motion capture company, Oxford Metrics (now OMG plc), founded by Dr Morris in 1984. He described how, by means of engineering ingenuity and awareness of market trends and client needs, the company has grown to be the world's leading supplier of motion capture and visual geometry systems for life sciences, entertainment, and engineering applications. Dr Morris showed how more than 200 motion capture cameras were used simultaneously to film the movement of marked actors for certain sequences in the recently released film, *Beowulf*. After sophisticated analysis, the reanimated characters looked (and moved) in an uncannily realistic fashion.

In April 2008, the Institute of Biomedical Engineering opened in Headington, close to the Churchill Hospital. With this in mind, the seventh lecture by Professor Lionel Tarassenko was given on *Advances in Biomedical Engineering*. The lecture chronicled the development of biomedical engineering as a discipline at Oxford, starting with the early pioneering work of John O'Connor in orthopaedic engineering (leading to artificial knees), and Brian Bellhouse in biofluid mechanics (blood flow, kidney dialysis, and

membrane filters). Over the past twenty years, biomedical engineering has enjoyed rapid growth, partly because of improvements in body scanners based on X-rays, ultrasound, and medical resonance imaging. Professor Tarassenko took the audience on a virtual tour of the new IBME, listing research into medical imaging by Professor Sir Michael Brady, Professor Alison Noble, Dr Julia Schnabel, and Dr Vicente Grau; drug and vaccine delivery by Professor Brian Bellhouse and Dr Fred Cornhill; tissue engineering by Professor Zhangfeng Cui and Dr Cathy Ye; biofluid mechanics by Dr Yannis Ventikos and Dr Stephen Payne; orthopaedic engineering by Dr Amy Zavatsky and Dr Mark Thompson; biomedical measurement systems by Dr Penny Smith; ultrasonic sniper and tracer bubble approaches to treating tumours as well as means of keeping transplant organs alive by Dr Constantin Coussios; eyeball mechanics by Dr Harvey Burd; vascular stents by Dr Zhong You; and Lionel Tarassenko's own research in biosignal analysis and its applications. For example, Professor Tarassenko drew attention to the Department's remarkable success story regarding spin-off activities in the biomedical area. Professor Bellhouse's research into supersonic flow led to the establishment of Powderject Pharmaceuticals. An impressive number of patents have been awarded, followed by several companies including BioSignals Ltd, e-San Ltd (now t+ Medical), Fusion7D™, Mirada Solutions (now part of Siemens), Afuson, etc., etc. In conclusion, Professor Tarassenko looked forward to the IBME contributing technological solutions for the hospital of the future and for personalised healthcare. In our quest for the *elixir of life*, we may have cause to be grateful to the Biomedical Engineers!

The eighth lecture was undoubtedly one of the most popular. Dr Alastair Howatson described *A History of Engineering Science at Oxford*, first drawing inspiration from the endeavours of engineering scientists predating the Department, and then outlining the considerable difficulties experienced by those campaigning to establish engineering as a separate discipline. By 1886 engineering was

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## One Hundred Years of Engineering Science at Oxford, 1908–2008 cont.

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being taught at Oxford, but it took until 1908 for Charles Frewen Jenkin to be elected the first Professor of Engineering Science. Jenkin had high qualifications in mathematics and considerable industrial experience. The lecture then covered the steady development of the Department during the first half of the 20th Century, followed by rapid expansion from the 1950s onwards. In addition to the lecture, an immensely readable detailed account of the history of the Department is given in the book, *Mechanics in the University: A History of Engineering Science at Oxford* by Alastair Howatson (on sale from the Department).<sup>2</sup>

Professor Carlos Ruiz gave the next lecture on *Designing for Strength: A Century of Solid Mechanics Research in Oxford*. He commenced by defining solid mechanics as "the study of the behaviour of deformable solids under mechanical and thermal loads". He then went on to consider the research undertaken by Charles Frewen Jenkin, the first Professor of Engineering Science. Jenkin followed the experimental tradition established by Robert Hooke of emphasising the practical application of research to the design of machines and structures. Jenkin had considerable talents; his research activities included soil mechanics, thermal properties, history of science, vibrations, and electrical engineering. He helped design and construct an electromagnetic high frequency testing machine. According to Professor Ruiz, it was thanks to Jenkin's foresight that solid mechanics at Oxford has a strong scientific basis, combining theoretical formulation and exact experimental work to provide answers to problems encountered in industry. Using a gentle but wry sense of humour, Professor Ruiz described the historical development of solid mechanics in Oxford over the past 100 years, including research into fatigue, impact, crack growth, fracture, polymers, plasticity, and viscoplasticity. The lecture concluded with an appraisal of research currently being undertaken in the Department, and noted that

Solid Mechanics at Oxford is distinctive for the excellent collaboration between the researchers, its emphasis on meticulous experimental work, appropriate mathematical analysis, and industry-driven motivation. The lecture was sponsored by Rolls-Royce, who also support the University Technology Centre for Solid Mechanics in the Department.

The tenth lecture had a strong nano-Cornish flavour. In *Innovation, Spin-out Companies and Nanotechnology*, Professor Peter Dobson drew a distinction between invention and innovation. In his words, "Innovation is what happens between the invention stage and the generation of revenue arising from the invention." Peter Dobson underlined the importance of optimising the innovation process in order that the UK prosper as a knowledge economy. He described Begbroke Science Park where high technology companies formed as spin-off enterprises are located side by side with university research staff working on interdisciplinary projects. Professor Dobson indicated that it was vital to understand the dynamics of the innovation process while assessing the obstacles that can slow down or even prevent innovation occurring. To illustrate the lecture, Professor Dobson discussed the case histories of Oxonica plc (a company that specialises in making nanoparticles) and Oxford Biosensors Ltd (manufacturers of a hand-held device based on enzyme-functionalised microelectrode arrays). Professor Dobson rounded off the lecture by examining recent developments in nanotechnology that will impact on many areas, including medicine and the environment.

The penultimate centenary lecture on *Engineering for Sustainable Development* was presented by Professor Roland Clift CBE, Distinguished Professor of Environmental Technology and Founding Director of the Centre for Environmental Strategy at the University of Surrey. Professor Clift discussed the various concepts and definitions of sustainable development, starting with the Brundtland (1987) definition, "Sustainable development ... meets the needs of the present without

<sup>2</sup> And reviewed in this issue of SOUE News

compromising the ability of future generations to meet their own needs". He proposed that sustainable development comprises aspects of engineering efficiency, economics, and equity, and embodies an important ethical principle that includes the concept of responsibility to present and future generations. Professor Clift explained that this ethical principle has significance not just for the practice of engineering but for the role of the individual engineer. According to *des Jardins: Environmental Ethics*, the word *ethics* refers to the general beliefs, attitudes or standards that guide customary behaviour. Professor Clift carefully drew the distinction between ethics and religious belief, noting that ethics is a branch of philosophy, not of religious studies. He discussed the trans-boundary consequences of acid rain and the global dimensions of climate change. Using specific cases, his lecture explored how sustainable development affects the way in which the technical skills of the engineer should be deployed. The cases included manufactured goods such as mobile phones, imported "out of season" fruit and vegetables, transport bio-fuels, and uranium mining in Northern Australia. Professor Clift then classified the three ages of the engineer as: Mark I heroic materialist; Mark II supplying human needs; and Mark III steward of the global commons (i.e. the honest broker). In his final words, "The sustainability agenda does not change the tools of the engineer but it does change what it means to be authentic as an engineer. In some applications, engineering must be a normative discipline."

Professor Sir Michael Brady presented the final centenary lecture on *Information Engineering: where we have been and where we may be going*. The introduction by Professor Ron Daniel was memorable for a short Proctorial performance in Latin, as seen at degree ceremonies. Professor Daniel noted that whereas he shared a similar name with R.Daneel [Olivaw], a robot in an Arthur C Clarke novel, Sir Mike Brady's name resembled that of the bradypus, a three-toed sloth, also called the ai in Latin America owing to the high-pitched cry the bradypus emits when agitated. In Ron Daniel's words, "I was the new lecturer in

robotics with the same name as Arthur Clarke's robotic hero, and here was our new Professor of Information Engineering and his namesake was ai. What could stop us?" And indeed what could? Brady commenced the lecture by summarising his initial involvement with Information Engineering via signal analysis, machine learning, image analysis, robotics, artificial intelligence, leading eventually to the establishment of the immensely successful Robotics Research Laboratory. When he arrived in 1985 as Professor of Information Engineering, the Department's combined computing power was less than that of any of Brady's graduate students at MIT. By the late 1980s however, his researchers had brought Autonomous Guided Vehicles (AGVs) to life. The AGVs usually rolled around the basement of the Jenkin Building, but were occasionally released in public places; on one occasion, an autonomous guided vehicle served drinks at a Royal Society soirée. His work led to innovative scanning technology for free ranging navigation, and a company: Guidance Ltd that provides autonomous navigation systems, marine sensors, and electronic monitoring systems. Following from the research on AGVs, Paul Newman and Hugh Durrant-Whyte invented Simultaneous Location and Mapping (SLAM), whereby a system builds its own map of the environment using its senses. Taking an example of a robot crawling around the Keble triangle, Brady showed how AGVs could move around closed loops and the software use iterative techniques to eradicate accumulated surveying errors. Professor Brady then discussed how Paul Newman has mapped part of the ocean bed with the aid of enormous tuning forks and also developed a sophisticated radar-based system for aligning supply vessels with offshore platforms. He described how Penny Smith has measured the texture of the ocean bed by means of wavelet analysis of ultrasound data and is also using ultrasound to develop navigation aids for the partially sighted. Turning to signal processing, he demonstrated the exciting work being undertaken by Stephen Roberts to unscramble different sound sources, providing the audience with an example of mixed classical music, jazz, and noise. Brady then discussed a joint project

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## One Hundred Years of Engineering Science at Oxford, 1908–2008 cont.

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with zoologists that had shown counter-intuitively that birds navigate by following arterial roads rather than by instinct. He described the data fusion work of Lionel Tarassenko on the status of hospital patients that is leading to much better patient interventions, and thus saving lives. Novelty detection, invented by Tarassenko, is being applied by Rolls-Royce for jet engine health monitoring. In the area of visual tracking, Andrew Blake began developing advanced techniques in the 1990s for tracking objects in a cluttered environment, following earlier work on gait by Julian Morris. Using active vision, David Murray and Ian Reid have developed motion understanding for surveillance, navigation, and augmented reality (adding animated images to real images, an example being Ewoks on the rampage!). Brady then considered one of the defining moments of English civilisation in the late 20th Century, the controversial goal scored by Geoff Hurst against Germany in the 1966 World Cup Final. Andrew Zissermann and Ian Reid applied stereo projective geometry to compute the trajectory of the ball and concluded that the goal should not have been awarded. For a while afterwards, Mike Brady had to run a gauntlet of hate mail from distraught England supporters and was even denounced by the Guardian! It is the author's view that modern Computational Fluid Dynamics will show that the ball did cross the line thanks to a fluid instability ... Recently, Zissermann and Reid have demonstrated that it is possible to obtain highly accurate three-dimensional geometrical reconstructions from paintings and photographs using stereo vision and projective geometry. In 1994, Professor Brady's interest moved towards medical imaging. His team began to look for means to enhance images, with applications to breast cancer, heart abnormalities, and Parkinson's disease. He described how the ability to fuse image data from different sources (e.g. MRI and ultrasound) on to a common frame had been developed, and taken up in practice through Mirada Solutions (now part of Siemens). He also talked about a system for the

multidisciplinary team management of cancer treatment, which records not only decisions, but also why they have been made. He showed recent research aimed at understanding and identifying tumour growth (using spheroids to model malignant cores) and the link to DNA, indicating how it can help clinicians to make informed decisions. Other work is modelling the take up of drugs by organs. He then described *in vivo* soft tissue biomechanics measurements by Professor Alison Noble and her co-workers aimed at identifying tumours via their density. Alison Noble is also making major advances in functional cardiac image analysis, in particular foetal cardiology. Professor Brady then considered a rather different application of his image analysis techniques – the decipherment of wood and lead tablets from Roman Britain, whereby shadow stereo imaging was used to amplify information on surface incisions in the material. At this point, Professor Brady changed tack, away from the operational aspects of Information Engineering, and towards its definition. It appears that Information Engineering has its early origins in thermodynamics, communication theory, statistics, and business. Essentially Information Engineering involves uncertainty, application and users. So does Engineering Science. By *Bradyian logic* therefore, Engineering Science *is* Information Engineering. Professor Brady then speculated on what the future might hold in a world of Information Engineering. He noted that computing is growing at a faster rate than at any previous time, and Moore's Law still holds. Grid computing will become a utility like water, gas and electricity. Distributed computing is set to revolutionise our lives. Quantum computing is on the horizon. Future problems for Information Engineering Science include climate change and the carbon economy, energy for a world with a rapidly increasing population, assisted health care for an ageing population, and crime and the infeasibility of custodial sentences. He concluded his lecture with an example of an electronic monitoring tag produced by Guidance Ltd (the latter of considerable interest to Deans and former



Junior Proctors wishing to place student offenders under college arrest). Professor Brady's lecture demonstrated the very rapid evolution of the Department over recent years, and provided a magnificent climax to the series of twelve Centenary lectures.

In early April, the Department hosted the Fourth Conference for Young Coastal Engineers and Scientists. The aim of the conference was to help promote an integrated coastal research community, whereby young researchers and practitioners from different disciplines (e.g. oceanography, geography, geology, engineering, and marine science) are brought together to discuss physical coastal processes. In his opening address Professor Borthwick set the scene by looking at the influence of William Froude (1810–79), Thomas Brooke Benjamin (1929–95) and Howell Peregrine (1939–2007), all of whom had Oxford connections, on our understanding of coastal wave hydrodynamics, before highlighting recent research activities centred around the UK Coastal Research Facility at Wallingford. Professor Paul Taylor then gave the keynote Peregrine Lecture on *Giant Waves on the Open Sea: Mariners' tall tales or alarming fact?* He used photographs and film clips to illustrate the potentially disastrous consequences of giant waves as they impact large ships and offshore structures. He discussed an incident during WWII, when the Queen Mary, which was carrying about 15,000 troops, was hit by a wall of water and nearly capsized. In his lecture, Professor Taylor answered questions about the frequency of occurrence of so-called freak waves, what physics drives such waves, and whether a wall of water is plausible. (This lecture was repeated by Paul Taylor on 13 May as the Gresham Lecture.) Next, a total of 22 short presentations were made on many aspects of coastal processes, including hydrodynamics, nearshore sediment transport, morphological evolution, coastal engineering and management. A poster exhibition was also held. Prizes were awarded for the best presentation and poster. The Conference Dinner was held at St Edmund Hall. The following day, HR Wallingford Ltd hosted a tour of its major coastal and maritime modelling facilities (predominantly located in the

appropriately named Froude Modelling Hall). The conference was truly international: its *Book of Abstracts* relates to contributions from 130 researchers and practitioners from America, Asia, Australia, and Europe.

On 24 April 2008, the Department hosted a Centenary Debate on *Challenges of Power Generation and Use for the Future*. Lord May of Oxford and Professor Roland Clift CBE were the main speakers. Basil Kouvaritakis kept order from the chair. Participants included students and teachers from local schools as well as undergraduates from the Department. Lord May indicated that although world food production and life expectancy had improved, population growth and carbon emissions were having dire impacts, particularly on the climate. Roland Clift highlighted the need to cut emissions, but warned that a cultural shift was required in order for energy to be used efficiently. After listening to the speeches, the students were split up into focus groups where mini-debates were held. Each group elected a leader who made a short address to a panel of judges on how sustainable power generation could be achieved. Lord May and Professor Clift summed up the conclusions, and prizes (contributed by Sharp) were then awarded to those students judged to have made the best contribution to the debate. Afterwards, many of the students took part in an egg breaking experiment in the Information Engineering Building.

During Hilary and Trinity terms, a Centenary Photographic Competition was held, entitled *Engineering Science: capture the essence of engineering in an image*. The photographs were judged by Dr Hazel Rossotti (Fellow of St Anne's in Chemistry and an accomplished photographer), Dr Marius Kwint from the Department of the History of Art, Professor Rodney Eatock Taylor (who read Mechanical Sciences and Fine Arts at Cambridge), and Lord Browne of Madingley. Dr Frank Payne won first prize with his entry "Visions of Engineering" — a stunning photograph that simultaneously captured St Paul's cathedral, the millennium bridge, and a modern aircraft flying overhead (all of which have some connection with

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## One Hundred Years of Engineering Science at Oxford, 1908–2008 cont.

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engineering science at Oxford!); the photograph is reproduced on the back page. Heather Burrage and Alice Thurston received second prizes for outstanding photographs of the Hoover Dam, and an engine.

The Lubbock Day on 15 May commenced with the usual student project exhibition, followed by two mini lectures: *Personalised Healthcare: The role of Biomedical Engineering in Disease and Treatment Modelling* by Dr Yiannis Ventikos; and *The role of Information Engineering in Clinical Decision Making* by Professor John Fox. After prizes were presented to the winners of the photography competition and project exhibition, Lord Browne of Madingley (and President of the Royal Academy of Engineering) presented the Lubbock Lecture, *On Being an Engineer*. In the lecture, Lord Browne described technical, political, socio-economic, and environmental issues faced by BP engineers in constructing the Baku-Tbilisi-Ceyhan pipeline that links oil fields in the Caspian Sea to a port on the Mediterranean Sea. The pipeline is more than 1000 miles long and passes through Azerbaijan, Georgia, and Turkey. The talk examined the multifaceted role of the modern project engineer where interdisciplinary skills become paramount. Lord Browne emphasised the necessity to teach engineers about business, politics, and policy. In an unusual feat of bravery, Lord Browne set aside about half the lecture time to host a lively question and answer session about what it means to be an engineer. Two versions of the lecture were published, one in the *Financial Times* (Browne 2008a), the other in *Ingenia* (Browne, 2008b)<sup>3</sup>.

On 28 June 2008, the Centenary Garden Party was held at Keble College, and attended by more than 500 guests, many of whom were SOUE members. Speeches were made by Dr John Hood (Vice-Chancellor of the University of Oxford), Lord Jenkin (The Patron), and Professor Richard Darton (Head of Department and President of the Institution of Chemical

Engineers). Professor Borthwick acted as Master of Ceremonies. In addition to Pimms and lemonade, champagne, and sandwiches, the partygoers were treated to various pieces of live music performed by a mixture of departmental staff and friends, including choral music directed by Dr Stephen Payne and classical music orchestrated by Professor Basil Kouvaritakis. During the course of the afternoon the Head of Department presided over the launching ceremony of the book, *Mechanicks in the Universitie: A History of Engineering Science at Oxford* by Dr Alastair Howatson. Signed copies were provided by the author on request to many alumni. Hopefully, this will be as popular a work as the renowned HLT! Meanwhile, video films were shown on Information Engineering, followed by a recording of Dr Howatson's lecture on the History of the Department. Exhibits at the Centenary Garden Party included a fan blade provided by Rolls-Royce, oil paintings of Robert Hooke by Rita Greer, the Wallis table constructed as part of a fourth year project undertaken by Kate Halliwell and supervised by Professor Paul Taylor and Dr Tony Blakeborough, drawing instruments that once belonged to Professor Frewen Jenkin, copies of some early examination papers, and a display supplied by Froude Hofmann.

Very kindly, the Museum of the History of Science at Oxford decided to exhibit an early example from 1925 of the "Oxford Astrolabe" designed by Charles Frewen Jenkin for educational use. Later Watson & Sons Ltd of High Holborn, London manufactured and sold the astrolabe, as well as publishing Jenkin's book *The Astrolabe: its construction and use*. The exhibition of the "Oxford Astrolabe", which was originally used to demonstrate principles of spherical astronomy, coincided with the launch of Alastair Howatson's book. Various publications have been (or are being) written concerned with the Centenary. These include the book and paper by Alastair Howatson (2007, 2008), a paper by Allan Chapman (2008), two articles by Lord Browne (2008 a,b), and two papers by Borthwick (2008 a,b).

<sup>3</sup> And a third in this issue of SOUE News

I hope you have enjoyed reading this extended article about the Centenary activities, and hope that the Department's efforts in biomedical engineering will result in many of us surviving until the bicentenary in 2108!

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Special mentions must be made of Alastair Howatson who gave a lecture, wrote a book, and had a short article published on the history of the Department, and the artist Rita Greer who is painting a picture of Robert Hooke, which she has graciously offered to donate to the Department. Lord May of Oxford and Roland Clift participated in the debate. Thanks are also due to Allan Chapman, David Brown, Jane Smallman, Christopher Pugsley, Guy Houlsby, Julian Morris, Lionel Tarassenko, Carlos Ruiz, Pete Dobson, Roland Clift and Mike Brady for their centenary lectures. Sir Vivian Ramsey presented the Jenkin Lecture, preceded by Martin Oldfield. Lord Browne of Madingley gave the Lubock Lecture, preceded by Yiannis Ventikos and John Fox. Paul Taylor gave the Peregrine Memorial Lecture at the Conference for Young Coastal Engineers and Scientists, and HR Wallingford Ltd hosted the tour of the Froude Modelling Hall.

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The winning entry in the Centenary Photographic Competition: "Visions of Engineering" by Dr Frank Payne

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