SINIMS Oil and Gas Workshop

DRAFT: Notes of presentations and discussions

ICMS, Edinburgh, 11 March 2002

1 Welcome and Introduction to Faraday Partnerships

Paul Moseley welcomed the participants and described the aims of the meeting as being to ensure that companies know how to access the mathematical expertise in universities, and that mathematicians in universities know what areas the oil and gas sector is interested in. The Smith Institute is one of the 18 Faraday Partnerships, which all work to the Faraday Principles:

1. To promote active flows of people, industrial technology and innovative business concepts amongst the science and technology base and industry,

2. To promote the partnership ethic in industrially relevant research organisations, business and the innovation knowledge base,

3. To promote core research that will underpin business opportunities,

4. To promote business-relevant post-graduate training, leading to life-long learning.

The characteristics of the Faraday Partnerships are that they focus on industrial sectors of national or regional economic importance as identified by Foresight, they have core funding from government (DTI/DEFRA) and research councils (EPSRC/PPARC), they are structured around hub partners sharing a common vision, and they employ Technology Translators to ensure the effective exploitation of research. The Faraday Partnership web site is at http://www.faradaypartnerships.org.uk/ which has links to the web site of each.

2 Smith Institute

David Allwright described the aim of the Smith Institute Faraday Partnership as being to enable companies of all sizes to benefit from the commercial potential of mathematics and computing in their industrial activity and planning. Some of the different possible mechanisms for collaboration were described:

1. *EPSRC*[1] *funding:* 14 industry-driven core research programmes are being established with the core EPSRC funding available to the Faraday Partnership. These are designed to create long-term advantages for industry. Dissemination of the results of the research will be through publication and open meetings. One of these core research proposals is in the oil and gas industry: a collaboration between Schlumberger Cambridge Research and Loughborough University on the inverse problem of seismic surveying, and specifically on how to incorporate and update quantitative estimates of the uncertainty in the estimated subsurface structure.

   EPSRC funding for collaborative projects can also be accessed through responsive mode (*ie* submitting a proposal at any time to be refereed by a panel), or managed mode (*ie* submitting a proposal in response to a call for proposals in a specific area). In the case of collaborative proposals to EPSRC, the industrial collaborator contributes to the proposed project, but this need not include a direct cash contribution — often the company's commitment is in terms of the time of its staff, making experimental data or facilities available, or providing access to proprietary software.

2. *DTI core funding:* The DTI funding to the Faraday Partnerships provides for the employment of Technology Translators, running workshops, and other infrastructure needed to generate the activity that is the partnership's aim.

3. *CASE studentship projects:* These are PhD projects in which a company proposes a research topic and a student works on it for his or her PhD, based in the University but spending some of the time working in the company. The financial commitment of the company is (a minimum of) £ 4400 a year, for the 3 years of the PhD project.

4. *TCS*[2]*:* In this scheme, a recent graduate or postgraduate works in the company for 2 years on an agreed project, with academic supervision, with TCS providing approximately 60% of the salary for a small company (or 40% for a large company). In the TCS Awards 2000, one of the the winning projects was between Concept Systems and Heriot Watt on improving seismic surveying for the oil and gas industry, and a sheet describing this project was available.

5. *SMART awards:* These provide companies with funding towards the costs of developing new products.

6. *Workshops:* Open workshops have been held by the Smith Institute in a number of areas, reflecting the diversity of applications of mathematics, including the topics of food, weather forecasting for risk management, resource management in distributed environments, guided wave photonics, electromagnetic compatibility, tissue engineering, violent mechanics, microwave cooking, nonlinear signals, inverse problems, dynamical instabilities in lasers, and others. The core research proposals have originated in these open workshops, with the proposal mentioned in point **??**. above arising from the Inverse Problem workshop. Alternatively, where confidentiality is an issue, a company may host a closed workshop with an appropriate group of academics.

7. *Study Groups:* A Study Group is an intensive working week where a group of over 50 academics meet together to work on 6–8 problems posed by the industrial participants. This year's UK Study Group is at Lancaster University over 2–5 April, and information is available from the Smith Institute website at www.smithinst.ac.uk.

8. *MSc projects:* Students doing masters courses generally have to do a dissertation, over a period of 3–6 months, and this can be on a project proposed by a company. The Smith Institute is in touch with a number of appropriate courses and coordinates the presentations of industrial projects to students. Some recent MSc student projects proposed by the oil and gas industry have been on the measurement of 2-phase flow, and on the pricing of meters for 2-phase flow.

Overall, the activity of the Smith Institute Faraday Partnership involves 30 current and planned projects, 70 companies and 25 universities, with a value over £ 3 M in excess of DTI investment in the Faraday Partnership, contributing to both emerging and traditional technologies. Current and forthcoming events were outlined, including the SINIMS workshop series

1. 16-Jan-2002: Technical textiles
2. 30-Jan-2002: Optoelectronics
3. 13-Feb-2002: Health, Medicine and Biotechnology
4. 25-Feb-2002: Food and Agriculture
5. 11-Mar-2002: Oil and Gas
6. 24-Apr-2002: Semiconductors

3 Applications of Mathematics in the Oil and Gas Industry

Dugald Duncan began by reminding the workshop that it is estimated that linear programming cuts 5% from the costs of the petroleum industry worldwide. Optimization continues to be important to the industry, and there are active optimization research groups working in Edinburgh and Dundee Universities. He went on to describe 3 different collaborative projects between Heriot Watt University and gas and oil companies.

3.1 Modelling the British Gas transmission network

A CASE student, with British Gas as the collaborative partner, had worked on a 1-dimensional simplified model of the gas transmission network. At the time, British Gas had a model that handled slow changes well, but was not satisfactory when simulating the effects of sudden changes — *eg* ruptures, or the start-up of a gas-fired power station. The project was on automatic selection of 'fast' regions, using fine discretization only on them, and tying together the fast and slow regions correctly. This enabled the existing model to be extended so that it could also handle sudden changes efficiently.

3.2 Well test analysis

A TCS programme with Edinburgh Petroleum Services had won the 1999 prize for the Best Application of Technology and Knowledge. The project was on the interpretation of the data from a simple well test in which the well is closed, allowed to reach equilibrium, then opened, and the pressure and flow are recorded as it recovers to normal operation. The aim of the project was to determine from this the damage and permeability around the well. The outcome of the project was that the company chose to take on the TCS Associate permanently, thereby getting a highly skilled new employee, and that the company had improved sales of its 'PanSystem' parameter fitting software.

3.3 Overlapping grid methods

This project involved a postdoctoral research assistant funded by EPSRC, working on a collaborative project with Edinburgh Petroleum Services. The aim was to develop methods for the numerical solution of the pressure equation in an oil reservoir, superimposing a polar grid around a well on top of an existing mesh for the reservoir. The aim was to make the numerical simulation cheap enough to harness it into an optimizer that is trying to fit to measured data. Software for this was demonstrated, calculating the pressure drop when the well

3.4 Other areas and conclusions

Dugald Duncan mentioned again the TCS programme (of Heriot Watt and Concept Systems) on the positioning of seismic survey lines, that had won a TCS prize. This project involved the use of statistical analysis to reduce the errors in the estimates of streamer positions. Another TCS project, with Heriot Watt and Edinburgh Petroleum Services, has been on multiphase flow in well bores. Further obvious areas of collaboration are the applications of wave scattering theory to the seismic, ultrasonic and electromagnetic scattering problems that arise in the oil and gas industry. The generic applicability of mathematics is its power: one key unlocks many apparently different problems — the same equation is involved for the pressure in an oil reservoir, the diffusion of oxygen in nuclear fuel, and the contamination of ground water by waste. Furthermore, applied mathematics in Scotland has a strong track record of collaborating in many ways with industry and delivering the goods.

4 Halliburton

4.1 Energy Services Group

Greg Jackson described the structure of Halliburton, a US company, consisting of an Energy Services Group, and an Engineering and Construction Group. There are two research centres in the US, and one in Holland. The Energy Services Group is a group of companies, including Halliburton Energy Services (HES), Landmark Graphics Corporation (software house), Wellstream, and Halliburton Subsea. Most PSLs (Product Service Lines) are headquartered in the US, and each puts forward its own projects for funding. However, Greg Jackson is part of a 'Solutions Group' or 'Solutions Team' in the ESG aiming to apply technology and skills from each PSL across the whole of the Group, breaking down the divisions and exploiting the synergy in the company in an integrated way. For instance, hydraulic control systems are developed for various different applications and this expertise is to be coordinated. The ESG is concerned with reservoir modelling, seismic interpretation and data management, reservoir optimization, well bore management and so on, and many of the issues are in decision-making and project management.

4.2 Quantitative Risk Assessment in well operations

Each stage of drilling a well is subject to uncertainty: drilling, casing, narrow drilling, casing, logging, fitting liner and so on. The amount of non-productive time (NPT) has to be estimated and is used in decision-making. (In the North Sea, 70% of the drilling costs are due to the time.) There are minimum, likely, and maximum figures for each stage. There is also the possibility of a drill train wreck, which results in a bimodal distribution of NPT. Packages like At Risk or Crystal Ball are used to generate Monte-Carlo trials and estimate the distribution. Paul Moseley said QinetiQ has a risk assessment package being marketed now. The actual time for drilling can deviate widely from the expected time that was predicted, and in one example a job estimated to take 10 days took 6 months. Dugald Duncan asked whether the individual events were treated as independent or whether conditional probabilities were used. Greg Jackson said they were effectively treated as independent. The concept of a 'Safety Factor' was introduced: if an event has probability 0.2 of occurrence, but we can only tolerate a probability of 0.05, then the safety factor is 0.25, *ie* the probability of occurrence must be reduced by this factor in order to bring it down to the tolerable level. At present the safety factors for different events are combined assuming independence.

The point was made that disasters typically result from a number of individual risks occurring in sequence over the preceding period. In practice, Halliburton's staff may be working offshore, and will be entering data on events into a QRA system as they happen and observing how the resulting risks change. The aim is to have an Expert System that advises what to do in any eventuality. If risks rise to the point where a job becomes no longer viable, one also wants to know what mitigating steps can be taken to reduce the risks, and whether those steps will be effective. One problem is that the estimation of probabilities, particularly *low* probabilities, can be very subjective. Failures of QRA systems tend to be either in the wrong assessment of probabilities, or in completely missing events. It is essential to have people who go through the history of events, particularly extreme events, and accumulate the experience that can be learned from them.

Ken McKinnon said that one of the lessons from the Challenger disaster was to look at trigger events and follow through their consequences probabilistically. Also he drew attention to the fact that a system can have failed components that do not show up until something else fails. This can be easier to deal with than correlated events.

4.3 Flexible pipes

Neville Dodds (Wellstream) spoke about the flexible pipes that are manufactured by Wellstream and used, for instance, to connect a manifold to a floating platform. The pipes have a complex multilayered structure, with a central stainless steel carcase constructed from interlocking steel sections, surrounded by a polymer layer, then a layer to resist hoop stress, another polymer layer, a tensile layer consisting of spirally wound steel wires, then other shielding and protective layers to keep the seawater out. Cathodic protection against corrosion is provided. A new product development is a reinforced thermoplastic liner/pipe, which may sell to other industries as well as offshore oil and gas.

The pipes have to be designed and tested to the American Petroleum Institute Standard API17J. The design involves choosing the right materials as well as the detailed physical structure of layers, thicknesses, angles and so on. The pipe must behave acceptably during installation as well as during use, must have correct thermal behaviour (to avoid waxing), must resist gas penetration, must be within the safe stress criteria for each material involved, and must not be subject to upheaval buckling when it lies on the seabed. Its resistance to axial compression must be tested, and also its wear and fatigue properties, and there is always a push to go to deeper water (perhaps 1500–2000 m) so a collapse analysis must be performed. One of the failure modes is where the carcase layer buckles but without losing its interlock.

The testing is done using finite element codes, and also sometimes a hydraulic rig. At the end of the day a customer will always want to see results from at least one physical test, but physical testing is expensive and so it would be advantageous to move to computer testing as far as possible. Finite element codes are run both globally (looking at all effects) and locally looking at individual layers. The reinforced thermoplastic pipe involves Aramid (?) in its construction, and designs have to be tested for creep rupture. The lifetime analysis of this involves extrapolating on a log-log graph from measurements taken over 10,000 hours to a lifetime of 20 years.

Some of the questions posed were —

1. Are there new approaches to some of the parts of this process ?
2. Can we move to less reliance on physical testing ?

4. Can the reliability analysis be simplified rather than having to deal with the detailed structure of each layer ?

5. How can the existing acquired knowledge on the properties of individual layers be integrated into the design process ?

6. How can further improvement or optimization of the design be achieved ?

Julian Hall asked whether non-uniform pipes were constructed (*eg* with parameters varying along the length of a riser according to the depth when installed). Apparently this is not done at present.

5 Nan Gall Technology Ltd

Alan Fleming described the features of down-hole data logging equipment produced by Nan Gall Technology. In general terms, the systems are contained in a stainless steel housing which is deployed and then recovered by wire. That wire is not used for power or data transmission — the system inside the housing is battery powered and entirely self-contained. Data is logged onto memory within the system, and is then downloaded onto a PC after recovery. One of the difficulties is the high temperatures (up to 175 °C) and pressures and the hostile environment in which the devices must operate. These limit, for instance, the amount of memory that can be installed in the devices.

Systems are modular, so units can be connected for whatever sensors are required, *eg* temperature, flow, density and so on.

5.1 Tuning fork density meter

Solartron manufacture a density meter that uses a vibrating tuning fork as the sensing element, with piezoelectric driver and pickup. Nan Gall Technology wish to use this in a down-hole device, but it will be closer to the housing than the clearance that Solartron recommend. What effect will this have on density measurement ? A further point is that Solartron recommend operating the device at the upper 3 dB point of its resonance curve (*ie* where the displacement response lags 135° behind the forcing, or equivalently the velocity lags 45° behind the forcing) on the grounds that this produces a resonant frequency depending only on density, not on viscosity. However, on a simple $F = m\ddot{x} + v\dot{x} + kx$ analysis, the upper 3dB point does appear to depend on v and therefore on the viscosity. The resonant frequency is over 1 kHz, so the acoustic wavelength is much larger than the bore diameter and device size, so the flow can be treated as incompressible.
[Note: This problem was subsequently presented at the European Study Group with Industry, and the report will be made available via www.smithinst.ac.uk]

5.2 Cement bond logging

Acoustic sensing is used to monitor the quality of the cement bond between the well casing and the rock. A transducer in the Nan Gall device emits pings which reflect from the casing/cement/rock structure and the received echo waveform is recorded. However, because of the limited memory available, it is important to extract the important features from this waveform in real time, rather than record the whole of it. It seemed likely that a selection of sample waveforms would need to be studied to take this further.

5.3 Other applications

Other areas of interest to Nan Gall Technology are

1. Modelling the flow past sensors;
2. Acoustic response modelling, *eg* for an ultrasonic flow meter;
3. Data compression.

6 Highland Geology Ltd

John Nicholson described the problems of interpreting the (sometimes incomplete or flawed) data in seismic sections, considered as bitmaps. He presented a section from Himachal Pradesh in northern India where the Indian and Asian plates meet and complex structures are found. There are good prospects for exploration here, but the sections are difficult to interpret and more needs to be done to improve success rates. Even an improvement of success rates from 1 in 10 to 1 in 9 would be well worth achieving. There are many faults in the geological structure, and it would be good to have a software tool to assist geologists in the interpretation of the sections. The aim is for tools that would speed up an expert structural geologist, help someone who knows what they are doing, and also help a relative novice. In the example shown, John Nicholson identified the roof and floor of a thrust zone where a triangle of rock from one side is being forced into the layers from the other side. Highland Geology already has a SMART award application submitted to carry out some work towards this. One strategy outlined by John Nicholson was first to use a 'tracer' that will coalesce features locally in the sections, producing perhaps 5000 traces — short coalesced alignments of received signal — and then use another approach, possibly a genetic algorithm, to coordinate those traces together and make a first pass at the interpretation of them. Recognising the boundaries and traces is good but the crucial part really is relating them to the knowledge that an expert structural geologist has to get an interpretation. One test of an interpretation is whether it can be undeformed back into a simple parallel stratified sequence. However, a region with many faults makes this difficult: it is not just a matter of identifying the faults but joining them up — identifying which were originally a single fault that has since been split up by a transverse fault.[3] The software could interact with the user, allowing the user to point-and-click on the screen to identify any immediately recognisable features. John Nicholson recognised that developing a genetic algorithm is an empirical approach, and requires considerable expertise in its implementation.

Paul Moseley asked whether there were any rules about the kind of interpretation sought. John Nicholson replied that yes, there are certain standard geological structures, that can be combined in certain standard ways, so there is a set of rules about what is structurally allowable. The difficult part is deciding which of the structurally allowable interpretations fits best to the given sectional data.

Dugald Duncan asked what can be got from sections *across* the domain. (The section shown was just 2-dimensional). John Nicholson said that within a domain there is usually one direction of predominant motion, so that sections across that are deforming in a consistent way.

Ken McKinnon asked whether it was important to have algorithms that would still work well on incomplete data, and John Nicholson said Yes.

Greg Jackson said that a CAT scan expert system gives the user several different outcomes, with probabilities. Julian Hall said maybe a system could give the user 20–30 possible outcomes to scan through for the user to say Yes/No to each. Perhaps the outcomes will fall into broad groups, each group being variations on some basic themes.

[3] The problem of taking a Rubik cube on which someone has done 5 random twists, and attempting to restore it by doing the reverse twists in the reverse order, was mentioned in

It was pointed out that there is considerable historic data available, of seismic sections where subsequent work has elucidated the correct structural interpretation. Not much current use is made of this data, but it could be a valuable resource for testing and validating algorithms. It was pointed out that a Genetic Algorithm requires not just a 'genetic code' expressing the geological rules of deformation, but also a 'fitness function', evaluating how well a given interpretation matches to the sectional data under investigation. It should not be underestimated how much work would be involved in constructing such a fitness function — which is used in weeding out the 'unfit' structures from the population that the Genetic Algorithm works with.

7 Halliburton Subsea R&D

Sebastien Moindrot described two problems:

7.1 Towing a pipeline bundle

Bundles of pipes are towed in an approximately horizontal configuration between two tugs. The weight per unit length of the pipe is controlled by adding ballast chains, and the aim is that the angle of inclination of the pipe should give lift as it is pulled through the water — 'as if it were flying'. A survey vessel is positioned between the tugs to monitor the pipe position with transponders. When the bundle is in position it is lowered to the seabed. It is found that a length of about 7.5 km can be towed safely in this way, but that if a longer length is towed then it develops a wave deformation, the reason for which is unknown. One theory is that the wake of the leading section of pipe forms a turbulent approximately cone-like region, and that the aft section of the pipe, passing through this region, does not receive adequate lift. Currently Halliburton's software does not allow for this effect.

The cable dynamics equations used were shown, but they included forcing terms $\sin \omega t$ whose origin was not clear. It was reported that QinetiQ had said that with ballast chains attached every 8 m along the bundle, the problem of an 8 km bundle was too complex. However, with such a separation of lengthscales, the mathematical technique of homogenization should enable the problem to be treated on an intermediate lengthscale that resolves the overall shape, but where the detailed structure of where the ballast chains are attached has become homogenized into correct parameters for the model on that intermediate lengthscale.

7.2 Deep water heave resonance

When a large load (say 50 tonnes) is being lowered to the seabed on a long cable, it is lowered by a special crane that includes a control mechanism to compensate for the heave of the ship. However in deep water (*eg* 3000 m) a vertical vibration can develop such that the ship and the load lose phase and the cable snaps. The reason for this is unknown: it can occur even when there is only small amplitude wave action, and the workshop considered that it was likely to be some resonant interaction between the heave-compensation mechanism of the crane and the propagation of elastic waves up and down the cable. It seemed likely from the description that these are longitudinal elastic waves, which will travel up and down the cable and will reflect off both the load and the crane arm. Halliburton wish to know what damping or other mechanisms to introduce to prevent this phenomenon.

8 Summing up

Paul Moseley thanked all those speaking and participating, and indicated that the workshop report will be issued first in draft form to the speakers, and then in its final approved form. Participants were invited to stay for further discussion over wine, kindly provided by ICMS.

9 Participants

Allwright, David (Smith Institute)
Bolam, Geoffrey (Halliburton Wellstream)
Byatt-Smith, John (Edinburgh University)
Dart, Tracey (International Centre for Mathematical Sciences)
Dendrinos, Spyridon (Edinburgh University)
Dodds, Neville (Halliburton Wellstream)
Duncan, Dugald (Heriot-Watt University)
Fidler, Darren (Heriot-Watt University)
Fleming, Alan (Nan Gall Technology)
Hall, Julian (Edinburgh University)
Henderson, Gordon (Edinburgh Petroleum Services)
Jackson, Greg (Halliburton Subsea)
Knops, Robin (Heriot-Watt University)
Lacey, Andrew (Heriot-Watt University)
Moindrot, Sebastien (Halliburton ESG/Subsea)
Moseley, Paul (Smith Institute)
Nicholson, John (Highland Geology Ltd)
Parker, David (Edinburgh University)
Perthuisot, Nicolas (Halliburton Subsea)
Qiu, Yiqi (Heriot-Watt University)
Ruffert, Maximilian (Edinburgh University)
Subbey, Sam (Heriot-Watt University)
Waugh, Andrew (Heriot-Watt University)
Wilson, Stephen (Heriot-Watt University)