University of Aberdeen

A HISTORICAL SKETCH OF ENGINEERING FLUID MECHANICS IN ABERDEEN 1946 – 2006.

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1. 1946 – 1969.

The Department of Engineering had been founded in 1923. Until 1946 it focussed on the teaching of undergraduates, and on some contacts with engineering companies in the Aberdeen area. It was equipped with a multi-purpose laboratory for teaching solid and fluid mechanics (incompressible flows only) in quite large scale fixed equipment.

Figure 1
A portrait of Jack Allen in 1970

In 1946, after a wartime period in which the Department was led by Dr James Grassie and the sole Engineering Chair was left vacant, Dr Jack Allen[1] (Figure 1) was appointed to the Jackson Chair. He remained Head of Department until 1970 and began a strong tradition in civil engineering hydraulics in Aberdeen. His approach to the subject was based on techniques learnt at Manchester University as a student and lecturer there. He had been taught by A.H. Gibson[2] who had himself been a pupil of Osborne Reynolds (1842 – 1912). Allen's primary interest was in the application of dimensional analysis to practical engineering problems, usually via physical hydraulic models [1].

Professor Allen dedicated a lot of time and laboratory space to studies of Aberdeen harbour and to shoaling in the estuary of the River Tay (he was engineering advisor to the River Tay Commissioners for some years). The work on Aberdeen harbour was limited in its impact on engineering work there because the accommodation available for model studies constrained the model scales that could be chosen and this, to some extent, undermined the authority of the findings. When he began work on the Tay estuary problem, he undertook the supervision of a very large model of the estuary located in the premises of the Dundee Harbour Board and operated a second, smaller model (Figure 2) in parallel in his department at Aberdeen. The second model was used to examine the difficulty of appropriate scaling, in particular the scaling of sediment movements in the estuary.

Figure 2
The scale model of the River Tay estuary (taken from Townson, 1967)

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[1] Hager, W. H., *Hydraulicians in Europe 1800-2000: a biographical dictionary of the leaders in hydraulic engineering and fluid mechanics.* IAHR Publications, 2003, page 633
[2] Hager, W. H., *ibid*, page 671

During the post-war decades, the development of hydro-electric generating stations in Scotland was actively pursued by Government and this presented many flow problems beyond the experience of the designers and constructors. Many such problems, particularly concerning spillway flows, were examined at Aberdeen and other universities, and increasingly at the newly-founded Hydraulics Research Station at Wallingford. Prof Allen, as a member of the Steering Committee of HRS and a leading member of the quite tight-knit group of "Professors of Hydraulics" in UK universities, was most influential in the selection of, and approach to, problems in this programme.

A number of graduate students worked under Jack Allen's supervision during this period. J.D. Lawson (later Professor of Hydraulics at Victoria University, Melbourne and President of IAHR) worked on the model study of Aberdeen harbour. Lawson's doctoral work focussed on the principles governing choice of scale in hydraulic modelling and he was able to elucidate these using three river weir models (Figure 3) before going on to investigate the complex problems of the choice of horizontal and vertical scale for the Aberdeen Harbour model.

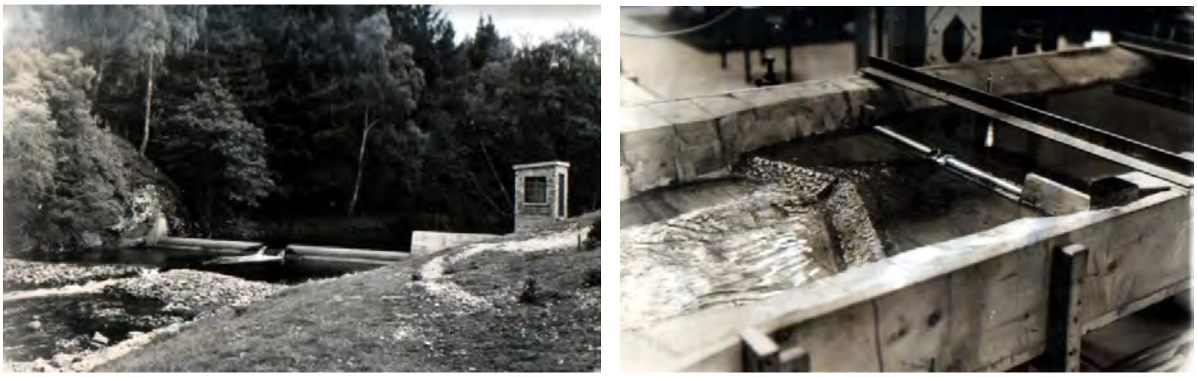

Figure 3
View of weir on the River Erradochit together with a scale model of the weir constructed in the Aberdeen Laboratory
(taken from Lawson, 1951)

Several contributions of general, rather than site specific, interest arose from the Tay estuary programme and the surrounding fundamental studies. H. Thorpe reported useful, and often neglected, findings on particle settling in the presence of a cloud of similar particles. J.M. Townson applied Method of Characteristics to tidal flows [2]. J.A. Webster produced a numerical model of a coastal tidal flow (before advances in computer technology made this comparatively straightforward). He established criteria of stability and consistency in tidal calculations and ranked eight published theories then advocated as the basis for such calculations. D.W. Knight, working on the Tay estuary model, examined the selection of lightweight granular materials for the simulation in model studies of sediment movements in unsteady, non-uniform shallow flows. He later continued to do distinguished work elsewhere, both on sediment transport and on tidal flows, e.g. [3], and is presently Professor of Hydraulics at the University of Birmingham.

Figure 4
The "hydraulics group" and friends, 1968. *From right to left:* Mr J. Low (Dept. Superintendent), D.W. Knight, Prof. J. Allen, K.C. Imrie, J.F. Robbie (behind), G.D. Matthew, J.M. Townson, B.B. Willetts, unidentified visitor.

In connection with hydro-electric studies, G.D. Matthew[3] advanced the calculation of flow over curved spillway (or weir) crests [4]. J.F. Robbie, under the supervision of Matthew, calculated oscillatory flow in hydro-electric installations [5] (and continued for some years after 1970, in Aberdeen, to develop surge tank prediction methods). Figure 4 shows a group, including some of these authors, in the Marischal College Laboratory in 1968.

2. 1970 – 1990.

Following the retirement of Professor Allen, the Jackson Chair of Engineering was held for seven years by T.M. Charlton, a distinguished structural engineer who was also Head of the Department. During his tenure a second engineering chair was created and filled, in succession, by two electrical engineers. The second of these, J.R. Smith, succeeded Charlton in the Headship. The Jackson Chair was filled, but the tradition of linking this chair to the Headship had been broken. There has followed a period in which a number of people have been appointed to the Headship in fairly rapid succession, each for a fixed term. Only one of them so far has been a civil engineer. Between 1983 and 1985, the department moved its base from the premises in Marischal College that it had occupied for 60 years, to Old Aberdeen. There it was allocated space in buildings formerly dedicated exclusively to Chemistry and Physics. In

[3] Hager, W. H., *ibid*, page 697

consequence the old hydraulics laboratory, which was cluttered with 1920's fixed equipment, but did have three floors in height for the creation of experimental head of water, was exchanged for a room on one floor with only duct space for water circulation under the floor. A single tank, of limited volume was installed two floors above for the purposes of the surge tank studies of J.F. Robbie.

The principal research themes in the period 1970 – 1990 were sediment transport and unsteady flows in pipe systems. The period also saw an accelerating introduction of improved methods of measurement and data handling. In 1980 we were using laser Doppler anemometry (LDA) with digital data logging, and also high speed film techniques with manual extraction of data from the film images. By 1990, fairly generous funding by the Research Councils enabled the introduction of Particle Image Velocimetry (PIV) which has continued to be an important measurement method for a wide range of flow types up to the present day.

During the 1970's studies of unsteady pipe flows were driven by the pumped storage phase of the development of hydro-electric power in the UK. This quickly progressed, in the procedures of the generating boards, from the basic diurnal switching of flow direction from generating to pumping and back, to very rapid switching in and out to provide extra power at times of peak demand. The rapidity with which valve operations followed one another meant that initial flow conditions for a particular opening or closure might well be dynamic because surge oscillations resulting from the preceding operation had not died out. Thus, computational procedures that had been adequate for the simple diurnal switching regime had to be reviewed and refined, progressively so as the design speed of valve operation rose to provide more and more sophisticated "peak lopping". Work in the department used the largest physical models that could be accommodated of schemes in development, to validate developments in procedures of computation that could be used to model the full scale installation numerically. Particular complications concerning surge shaft stability were investigated by Anderson [6] and work was reported on the assessment of simulation models including both hydraulic and electrical (generator) components [7].

The rather persistent theme of sediment transport sprang from the early work of B.B. Willetts concerning the disturbance and subsequent motion of bed grains by fluid-generated forces. This work had begun in water, with river mechanics in mind, but quite quickly bifurcated, so that experiments were conducted in both air and water. The digression into air/particle systems began because of the experimental advantages and became dominant for some years because the progress made was so encouraging. The main thrust was to understand the fundamentals of the subject better, but fruitful practical applications also occurred in both transporting media.

Soon after 1970, following an approach by The North East of Scotland Water Board (NESWB), a study was made of conditions at water intakes constructed in (under the surface layer) gravel bed rivers. Such intakes were adopted to avoid damage to salmon swimming in the vicinity of the intake. However, sucking water downwards into the bed radically modifies the boundary layer sediment behaviour and bed composition. Physical model studies were done for the NESWB and, after its demise, for Grampian Region on the siting and operation of two projected intakes (one of which was built and now supplies much of Aberdeen's water). Non site-specific work was done by M.E. Drossos [8] and by A.G. McLean [9, 10], both supervised by Willetts, on the prediction of the boundary layer and sediment effects.

Later in the decade, physical model studies were undertaken by D. Inglis for schemes to develop a new harbour in Fair Isle and to modify the harbour at Buckie. Inglis had worked on Allen's model of Aberdeen harbour as an undergraduate 20 years earlier.

Figure 5
The wind tunnel as it was in the laboratory at King's College.

Studies of wind erosion were sparked by a "common room" question about the process from W. Ritchie of the Department of Geography and developed into two decades of fruitful work funded by NERC[4], SERC[5], NATO and several travel grants from other bodies. A boundary layer wind tunnel (Figure 5) capable of handling blown sand was designed and built in Aberdeen and copied, with modifications, elsewhere. An extensive international collaboration involved scientists from several countries and academic specialisms. The research led to joint publications with Danish statisticians, geomorphologists and meteorologists.

The first work completed in the wind tunnel was a study by C.J. Phillips of deposition of blown sand at a porous barrier [11] (with digressions into snow fence deployment). Meanwhile, C.G. Murray used both wind tunnel and flow channel techniques to determine the lift force exerted on a sphere fixed in the shear flow near to a flow boundary at a wide range of Reynolds Number [12].

Figure 6
An image of a grain impact taken using a high speed cine camera. A sequence of such images were analysed to provide a statistical account of the nature of the impact of a saltating sand grain with a bed of loose sand. Later the approach was extended to examine multiple grain sizes and also the erosive impact of large particles on crusted soils.

During much of the 1980s the wind tunnel was occupied by a study of the influence of grain size, shape and density on the transport rate of wind blown sand. Particularly close attention was paid to the collision of saltating grains with the bed (Figure 6). It was postulated that, while the saltation path for grains of compact shape was susceptible to deterministic prediction, inter-saltation collisions were not, because of the complexity of the bed at the collision site. It was decided, therefore, to

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[4] The Natural Environment Research Council of the UK
[5] The Science and Engineering Research Council of the UK (now EPSRC)

build a statistical base for incorporating collisions in a model of the saltation cloud while the saltation paths were calculated from physical principles. This proved a successful formula and a successful model was achieved, M.A. Rice having assembled the collision data and I.K. McEwan incorporated them statistically in the saltation cloud model [13, 14].

3. 1990 – 2005.

Some changes of emphasis occurred in the four or five years surrounding 1990. The interest in hydro-electric power ended with the departure of Robbie. His replacement, T. O'Donoghue, brought a keen interest in coastal wave mechanics, which has blossomed in Aberdeen to include coastal sediment behaviour. Meanwhile the group working on uni-directional sediment transport began to apply in water the techniques developed in air during the previous decade. There was also a vigorous new interest in river system overbank flows. These new interests introduced new collaborations involving European countries and New Zealand [15, 16]. The changes brought a new spread of activity, but this did not happen in one year: many initiatives of the earlier decade continued along with fresh activities. (The three sections of this report are an artificial device to trace more clearly the historical trends.)

For the purposes of a meeting in Denmark in 1990 of the people known to be working on sand transport by wind [17], a paper was prepared to review work done in the preceding decade and recommend future research directions [18]. These included examinations of the interactions of "splash functions", the surface grain size distribution, grain cohesion (including surface crusting), spatial variations developed as the bed is exposed to saltation, and of the response of the saltation cloud to temporal variations in the near-bed wind. Having produced a sound model of the saltation cloud [13, 14] and used it in conjunction with the experimentally-based splash function in an aeolian sand transport model, the group in the department was well placed to embark on studies of these complexities. A series of papers appeared examining inter-saltation collision [19, 20], selective grain dislodgement [21] and erosion of soil crusts [22]. Work was also reported on incorporating some of these issues in numerical models of sand transport [23, 24, 25, 26].

In parallel with this aeolian work, interest developed in the problem of bed armouring in stream flows [27, 28]. This focussed on the development with time of surface layer grain size distribution (in response to the different dislodgement rates of different size fractions) and the linked changes of bulk grain transport rate. The physics of grain dislodgement is much less well understood in water than in air, so the task of modelling the transport process is much more difficult. Experimental work by M. Gallagher on the near-bed flow structures and related grain response began to address the understanding deficit. In addition, a numerical approach using discrete particles was used to address various problems in a way that complemented the experimental work. The initial development of this approach was undertaken by B.J.E. Jefcoate [29] and was then taken forward by J.G.C. Heald [30, 31] (Figure 7).

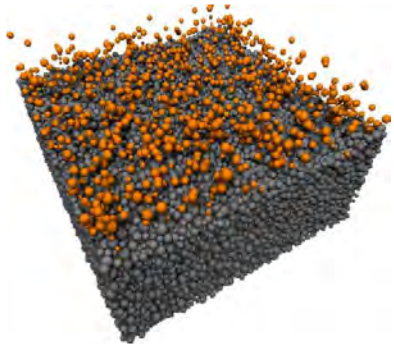

Figure 7
These images show a mixed size sediment bed which was formed using the discrete particle model developed in the Department of Engineering. This proved to be an important tool for enhancing understanding of the complex behaviour of individual particles in various sediment systems. The left image shows a deep bed of a mixed grain size sediment, and the right image shows a more uniform sediment at an instant during simulated bed-load transport.

The Department was involved in a major UK universities investigation of the resistance to flow in river systems in flood conditions, i.e. when overbank flow develops. The Aberdeen contribution concerned overbank flow with a meandering inner channel. It involved large scale experiments at HR Wallingford (the Flood Channel Facility, Figure 8) and close collaboration with the universities of Bristol and Glasgow. Consequently, many of the resulting publications are jointly authored with people from those universities [e.g. 32, 33, 34]. Design of the large Wallingford facility was informed by smaller scale experiments done at Aberdeen by R.I. Hardwick and P. Rameshwaran [35]. While access remained available to the HR Wallingford facility, the opportunity was taken to pursue the stream-bed armouring studies at larger scale than had been possible in the Aberdeen laboratory. This programme of work has recently been incorporated in a substantial review of overbank flow predictions, comparing British and Japanese practice. Half of the authors are Japanese and the review [36] is edited by McEwan from Aberdeen and Professor S. Ikeda from the Tokyo Institute of Technology.

Figure 8
The Flood Channel Facility at the Hydraulics Research Wallingford (HR Wallingford Ltd) in 1988. The Department of Engineering was one of a number of UK universities which were involved in a large programme of work (1983 – 1999) which attempted to elucidate the hydraulics and sediment behaviour of compound channels.

The arrival of O'Donoghue in 1990 restored to the Department a research interest in coastal problems that had been absent since the departure of Professor Allen. He began with studies of wave kinematics in front of reflective coastal structures. This led to experiments on the behaviour of sediments influenced by these flows (and fruitful common ground with the fluvial work going on elsewhere in the laboratory). The work of G. Clubb [37] and others [38] on

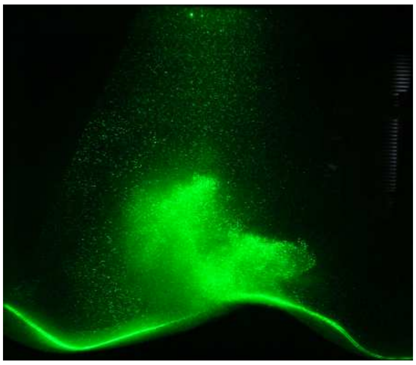

Figure 9
Particle Image Velocimetry (PIV) measurement of flow around vortex ripples formed under wave action; flow illumination is produced by an argon laser.

Figure 10
The Aberdeen Oscillatory Flow Tunnel generates oscillatory flows with periods and amplitudes equivalent to full-scale waves; working section is 10m long, 0.75m high and 0.3m wide.

vortex ripples (Figure 9) and S. Wright [39, 40] on the behaviour of mixed sediments in sheet flow conditions was based in a new facility, the Aberdeen Oscillatory Flow Tunnel (Figure 10). This facility is one of the few of its kind in the world and is able to generate oscillatory flows with periods and amplitudes equivalent to the periods and amplitudes of near-bed flows generated by full-scale sea waves.

In the period around 1995 two lecturers, both from Serbia, were appointed in close succession. A. Deletic worked on problems related to sustainable urban drainage [41] before moving in 2003 to Monash University, Melbourne. Her colleague, D. Pokrajac has worked extensively on spatially-averaged flow problems since her arrival in Aberdeen. A particular focus, together with her student C. Manes, has been the study of the interface between a turbulent free stream and a porous boundary [42, 43]. J.R. Reese also joined the staff in the period 1995 to 2000 before moving to King's College, London and then to Mechanical Engineering at the University of Strathclyde where he is presently the Weir Professor of Thermodynamics and Fluid Mechanics.

The problems of the UK water industry with respect to pipeline leakage were beginning to attract considerable attention in the late 1990's. In response to this, McEwan and O'Donoghue began working on new approaches to leak location. As a result of this work, a new approach to leak sealing and location was developed using mechanical "platelets". These are injected into a flow upstream of a leak and are transported downstream until they are drawn into the leak thus providing a seal. If required, the particles can be marked with a tracer, to facilitate later leak location. This approach was initially tested in a flow loop in the Aberdeen laboratory and the promise of the approach resulted in the formation of a company, Brinker Technology Ltd, in 2002. To date the company has had notable success [44] in applying the new technology in the oil and gas and water industries.

4. The Future

The appointment of V.I. Nikora to a Chair in Environmental Fluid Mechanics marks the beginning of a new era. His work was already very well known to the Department through his collaboration, first with McEwan and then with Pokrajac, on the application of spatially-averaged flow methodology to problems in open channel flow. Indeed Nikora has led an international group which has sought to apply the methodology of spatial averaging in open channel hydraulics. Nikora's appointment has strengthened the Environmental Hydraulics

Group's work on rough-bed hydrodynamics and eco-hydraulics, two areas identified in RAE 2001 as key directions for the group's research.

Figure 11
A view of the Aberdeen Open Channel Facility (AOCF) which has recently been constructed in the laboratory.

In addition to Nikora, Y. Guo joined the Department in 2002. His work focuses on gravity currents and mixing in estuaries and other problems of stratified flow. S. He joined in 2005, broadening the group's research to include more mechanical engineering fluid mechanics. He's research includes unsteady turbulent pipe flow, buoyancy-induced flow and heat transfer, and the development and application of computational fluid dynamics.

In the past few years the Fluid Mechanics Laboratory at King's College has benefited from the addition of major new facilities. The most recent of these are the Aberdeen Oscillatory Flow Tunnel (AOFT), the Aberdeen Open Channel Facility (AOCF) (Figure 11) and the Aberdeen University Flow Loop (AUFL), all of which have strengthened further the capacity of researchers at Aberdeen to continue to contribute substantially to national and international research programmes in fluid mechanics.

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