Inaugural meeting of "Mathematical Challenges of Nonlinear Waves and Interfacial Dynamics" SIG

Department of Mathematical Sciences
School of Science, Loughborough University

25-26 September 2017

Welcome to the inaugural meeting of the Special Interest Group in "Mathematical Challenges of Nonlinear Waves and Interfacial Dynamics"! The meeting is held at Loughborough University from Monday 25th September to Tuesday 26th September 2017. For further information please contact Dr E. Renzi (e.renzi@lboro.ac.uk).

Programme

25 September 2017, 12:00–17:30: PhD and Early Career Researchers Training Day

26 September 2017, 08:45–16:30: Research Day

Venue

Room U005, Brockington Extension, Loughborough University. See
`https://maps.lboro.ac.uk/?l=brockington-extension`

Travel

Loughborough is at the heart of England in the northern most part of the county of Leicestershire and being centrally placed it is well served by road, rail and air.
`http://www.lboro.ac.uk/about/find-us/`

If you travel by rail, once at Loughborough's railway station you are just ten minutes away from the campus. From here there is a regular bus service provided by Kinchbus.
`https://www.kinchbus.co.uk/services/sprint`

Accommodation

Invited Speakers are offered to stay at the Burleigh Court Hotel, which is conveniently located inside our campus. `http://www.burleigh-court.co.uk`

PhD Students and Early Career Researchers will be staying at the University Lodge, our short-stay accommodation on campus.
`http://www.lboro.ac.uk/services/accommodation/short-stay/lodge/`

Information for speakers

Speakers will have 40 minutes for their lectures/presentations, plus 10 minutes for questions and changeover. We advise speakers to please upload their presentation on our system during the break before their session.

ECR Training Day
Monday 25 September

12:00 – 13:00	Registration and Lunch (U.004)
13:00	**Welcome** – *E. Renzi (SIG Leader)*

SESSION 1 (U.005)

13:01	***Invited Lecture*: Physical oceanography: an applied mathematician's approach** *Prof. Robin Johnson – Newcastle University*
13:50	***Invited Lecture*: The complex dynamics of multilayer shear flows** *Anna Kalogirou – University of East Anglia*
14:40	***PhD Students and ECR Poster Pitches***
15:00 – 15:40	Refreshments and Poster Display (U.004)

SESSION 2 (N.004 & U.005)

15:40	***Workshop*: Mathematical Techniques with MATLAB (N.004)** *E. Renzi & D. Sibley – Loughborough University*
16:30	***Panel Discussion*: how can the UKFN support ECRs? (U.005)** *SIG Steering Committee, PhD Students and ECRs*

Research Day
Tuesday 26 September 1/2

08:45 – 09:00	Registration (U.004)
09:00	**Welcome** – *A. Archer (HoD), E. Renzi (SIG Leader)*

SESSION 1 | CHAIR: K. KHUSNUDTINOVA (U.005)

09:01	***Invited Talk:* Integrable Turbulence for Soliton and Breather Gases Using Finite Gap Theory: Applications to Ocean Surface and Internal Waves** *Prof. A. Osborne – Nonlinear Waves Research Corp*
09:50	***Invited Talk*: The Quantification of Internal Soliton Velocities for Offshore Engineering** *G. Jeans – Oceanalysis Ltd*
10:40 – 11.10	Refreshments and Poster Display (U.004)

SESSION 2 | CHAIR: G. EL (U.005)

11:10	***Invited Talk:* Inkjet and laser hybrid processing for series interconnection of thin film photovoltaics** *A. Brunton – M-Solv Ltd*
12:00	**Modelling the evaporation of nanoparticle suspensions from heterogeneous surfaces** *Prof. A. Archer – Loughborough University*

12:50 – 14:00	**Lunch and Poster Display (U.004)**

SESSION 3 | CHAIR: A. ARCHER (U.005)

14:00	***Invited Talk:* Electrohydrodynamic control of multi-fluid systems at small scales** *R. Cimpeanu – University of Oxford*
14:50	***Invited Talk:* Solitary waves under elastic plates** *E. Parau – University of East Anglia*
15:40	***Panel discussion***

16:20 – 16:30	**Poster Prize, SIG Handover and Close**

25 Sept
13:01
U005

Physical oceanography: an applied mathematician's approach

Prof Robin Johnson
Newcastle University

In this talk we present the problem, based on the Euler equation, which is at the heart of any mathematical description of the motion of our oceans. This involves the prescription of a suitable model for the fluid (i.e. inviscid but with vorticity), together with an appropriate set of boundary conditions (and it will be assumed that associated initial data consistent with our solutions exist). We will give a brief description of some flows that are encountered in our oceans and which may be tackled by systematic methods. The approach is based on classical ideas of fluid mechanics, involving non-dimensionalisation and scaling, leading to a reasonable and suitable reduction of the system that is amenable to further analysis. The aim is to show that such methods, which involve relatively little conventional 'physical oceanographic modelling', can uncover some fundamental processes that underpin many of the observed movements of the oceans. However, in addition to approximate (asymptotic) versions of the various problems of interest, we find that this systematic approach also enables some relevant and useful exact solutions of the system to be generated.

In particular, we will show how problems can be formulated (and solved, typically in an asymptotic sense) that relate to: linear waves in the presence of a thermocline over an arbitrary flow (appropriate for flow near the Pacific Equator); exact solutions associated with (1) the Antarctic Circumpolar Current and, (2), a corresponding equatorial flow; a three-dimensional flow, with a thermocline, appropriate to a neighbourhood of the Pacific Equatorial Undercurrent; a representation of gyres of any size.

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25 Sept
13:50
U005

Controlling the complex dynamics of multilayer shear flows using surfactants

Dr Anna Kalogirou
School of Mathematics, University of East Anglia

The flow of multiple superposed layers of viscous liquids, known as multi-layer flow, is of central importance in the rapidly burgeoning field of microfluidics. The ability to manipulate flows of this type is fundamental; one possible approach is by using chemical additives known as surfactants, which can greatly influence such flows especially at small scales. This lecture will present a theoretical study that utilises mathematical modelling and numerical computations to scrutinise the effect of insoluble surfactants on the stability of multi-layer shear flows in channels. Understanding stability is essential for efficient flow control in applications where (stable) uniform films or (unstable) interfacial waves are desired. The complex flow dynamics will also be discussed, as well as the underlying physical mechanisms responsible for the formation of interfacial waves.

Integrable Turbulence for Soliton and Breather Gases Using Finite Gap Theory: Applications to Ocean Surface and Internal Waves

26 Sept
09:01
U005

Prof Alfred R. Osborne

Nonlinear Waves Research Corporation, Alexandria, VA, U.S.A.

Recent experimental results have verified the occurrence of *soliton turbulence* and *breather gases* in random oceanic surface waves [Costa, et al, 2014] and internal waves [Osborne, 2010]. Soliton turbulence was predicted theoretically by Zakharov [1971] many years ago as *weak wave turbulence.* Here I give an overview of the development of a *completely integrable soliton turbulence theory* for the Korteweg-deVries (KdV) and Kodomtsev-Petviashvili (KP) equations using periodic finite gap theory (FGT) [Belokolos, et al, 1994]. Likewise I develop a similar theory for the nonlinear Schrödinger (NLS) equation in 1+1 for *breather turbulence.* The above integrable cases are computed *without resort to closure arguments*, as the evolution of the power spectra are computed exactly using FGT. Extension of the method to *asymptotically integrable theories* for the perturbed KdV and NLS equations gives the solutions in terms of Abelian functions [Baker, 1897, 1907]. Here the closure comes with application of Lie transforms to carry the approach to asymptotically higher order [Kodama, 1985a, b] [Fokas and Liu, 1995]. A turbulent theory for the nonintegrable 2+1 NLS equation is also explored using FGT and a perturbation scheme first suggested by Poincaré [1891]. In all of the above theories the *solitons* and *breather trains* are the natural *coherent structures* in the integrable/quasi-integrable flows. Comparisons of the theoretical results to oceanic data sets are given. The hyperfast numerical methods for simulating the physical wave fields are based on Riemann theta functions: These are quasiperiodic Fourier series that naturally contain the coherent structures in the Riemann spectrum. Thus the analytical expressions for the time evolution of the correlation function and the power spectrum explicitly contain these coherent structures.

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Belokolos, E. D., A. I. Bobenko, V. Z. Enol'skii, A. R. Its and V. B. Matveev, *Algebro-Geometric Approach to Nonlinear Integrable Equations* [Springer-Verlag, Berlin, 1994].

Fokas, A. S. and Q. M. Liu, Asymptotic integrability of water waves, *Phys. Rev. Lett.* 77(12), 2347-2351, 1996.

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Osborne, A. R., *Nonlinear Ocean Waves and the Inverse Scattering Transform* [Academic Press, Boston, 2010] 976 pages.

Poincaré, H., *New Methods of Celestial Mechanics, 1. Periodic and asymptotic solutions*, American Institute of Physics, Ed. by Daniel L. Goroff (translation of: *Les méthods nouvelles de la méchanique* céleste, originally published 1892) 1993.

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26 Sept
09:50
U005

The Quantification of Internal Soliton Velocities for Offshore Engineering

Dr Gus Jeans
Oceanalysis Ltd

Some recent advances and future challenges in the quantification of internal soliton velocities for offshore engineering are described. Large amplitude solitary internal waves produce strong, rapidly varying fluid velocities that may cause hazards to offshore operations in several regions of the world. Nonlinear Fourier Analysis techniques, developed by Professor Alfred R. Osborne, were recently used for the first time to quantify these velocities in offshore engineering. Soliton quantification was undertaken using methodologies and software from the Nonlinear Fourier Analysis Spectral Tools (NFAST) Joint Industry Project.

Solitons require rapidly sampled in-situ data for reliable quantification. Such measurements are typically of very short duration compared to the time scales needed for engineering quantification. Similarly, numerical models capable of representing solitons are computationally expensive, and thus have limited capabilities for efficiently developing the long-term simulations required to supplement in-situ data. NFAST aims to address these issues by enabling new Hyperfast Nonlinear Fourier Analysis computational techniques.

Interface displacements, derived from temperature measurements, were the primary input to soliton quantification. Associated current speeds were estimated from relevant theory and validated with available measured current data. Application of NFAST codes produced a synthetic dataset of soliton amplitudes and speeds with an effective duration of approximately 100 years, a period that is considerably greater than the duration of available measured data. This provided extreme values consistent with extrapolation of the measured soliton data, but with a considerable reduction in uncertainty.

So far all NFAST functionality is based upon the well known KdV equation. However the offshore industry has interests in locations where the seawater density interface can be closer to the seabed than the sea surface. In these circumstances, downward solitons transform into upward solitons and other complex coherent structures can exist. These require the Gardner equation for mathematical description. The mathematical challenges associated with extending Nonlinear Fourier techniques to incorporate Gardner physics has been recently identified by Professor Osborne.

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26 Sept
11:10
U005

Inkjet and laser hybrid processing for series interconnection of thin film photovoltaics

A. Bruton
M-Solv Ltd

Inkjet deposition can be a complementary technology to laser ablation to enable new processes. One such process is the One step interconnect for thin film photovoltaics, which is an improved method for series interconnection. The standard series interconnection process consists of three laser scribes between the deposition of the three key cell layers; transparent front contact, absorber layer and the metallic back contact. The one step interconnect allows the series interconnection to occur after the deposition of all layers significantly simplifying the manufacturing process. This is achieved by inkjet printing of conductive and insulative materials concurrently with depth selective laser scribes. The one step interconnect process has been shown to make effective interconnects on cadmium telluride photovoltaics with fill factors > 60%. The benefits are many and include the reduction of capital equipment costs, reduced panel wastage and potentially improved material performance. The process is fully scalable and production ready.

Modelling the evaporation of nanoparticle suspensions from heterogeneous surfaces

26 Sept
12:00
U005

Prof Andrew Archer

School of Mathematics, Loughborough University

We present Monte Carlo (MC) and Dynamical Density Functional Theory (DDFT) grid-based models for the drying of drops of a nanoparticle suspension upon a heterogeneous surface. The models consists of a generalised lattice-gas in which the interaction parameters in the Hamiltonian can be varied to model different properties of the materials involved. We show how to correctly choose the interactions, to minimise the effects of the underlying grid so that hemispherical droplets form. We also include the effects of surface roughness to examine the effects of contact-line pinning on the dynamics. When there is a 'lid' above the system, which prevents evaporation, equilibrium drops form on the surface, which we use to determine the contact angle and how it varies as the parameters of the model are changed. This enables us to relate the interaction parameters to the materials used in applications. The model has also been applied to drying on heterogeneous surfaces, in particular to the case where the suspension is deposited on a surface consisting of a pair of hydrophilic conducting metal surfaces that are either side of a band of hydrophobic insulating polymer. This situation occurs when using inkjet printing to manufacture electrical connections between the metallic parts of the surface. The process is not always without problems, since the liquid can dewet from the hydrophobic part of the surface, breaking the bridge before the drying process is complete. The MC model reproduces the observed dewetting, allowing the parameters to be varied so that the conditions for the best connection can be established. We show that if the hydrophobic portion of the surface is located at a step below the height of the neighbouring metal, the chance of dewetting of the liquid during the drying process is significantly reduced.

Electrohydrodynamic control of multi-fluid systems at small scales

26 Sept
14:00
U005

Dr Radu Cimpeanu

Mathematical Institute, University of Oxford

With sizes not exceeding a few centimetres and usage ranging from blood sample analysis to cooling devices and integrated circuit components (and far beyond), liquid systems at small scales play an indispensable part in our lives. Their production and maintenance however is a highly sensitive and expensive process. This body of research focuses on eliminating these drawbacks by creating efficient mechanisms that do not use any moving parts and do not require the presence of an oncoming flow.

We analyse electrostatic control procedures in simple geometrical configurations, such as channels containing layers of immiscible fluids. Stability theory guides the imposition of voltage distributions that efficiently manipulate the fluid-fluid interface and harness the classical instabilities arising in such systems. We then formulate nonlinear asymptotic models that enable the study of the interfacial motion far beyond the level of small perturbations. Finally, we implement state-of-the-art computational tools based on the volume-of-fluid method in both two- and three-dimensional contexts to steer these arguments towards practical applications involving microfluidic mixing, pumping and directed polymer assembly.

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26 Sept
14:50
U005

Solitary waves under elastic plates

Dr Emilian Părău
School of Mathematics, University of East Anglia

Computations of nonlinear hydroelastic waves travelling at the surface of an ideal fluid covered by a thin ice plate are presented. The continuous ice-plate model is based on the special Cosserat theory of hyperelastic shells satisfying Kirchoff's hypothesis. Two-dimensional solitary waves are computed using boundary integral methods and their evolution in time and stability is analysed using a pseudospectral method based on FFT and in the expansion of the Dirichlet-Neuman operator. When the ice-plate is fragmented, a new model is used by allowing the coefficient of the flexural rigidity to vary spatially. The attenuation of solitary waves is studied by using time-dependent simulations.

Poster
U004

Mathematical modelling of water filtration and purification devices

Antonios Parasyris[1*], Marco Discacciati[1], Diganta B. Das[2]
[1]Department of Mathematical Sciences, Loughborough University [2]Chemical Engineering Department, Loughborough University

In this work we consider the mathematical modelling of an innovative user-centred, portable, low cost, un-powered domestic water filtration device to filter micron and submicron size particulates [5]. The filtration process occurring in this device is modelled by multi-physics problems involving both incompressible fluid flows and porous media flows. We explore two different approaches in this work, namely (i) the Navier-Stokes/Darcy coupled problem with imposition of the so-called Beavers-Joseph-Saffman condition [1,3,4] at the interface between free fluid and porous domain and (ii) Navier-Stokes/Brinkman coupled equation [2].

We compare these two approaches, discuss their suitability to model our water purification device, and present numerical simulations of representative working configurations of the device. Our work constitutes a first step towards optimal design of the water filtration device.

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The first author acknowledges the support of the EPSRC Doctoral Training Programme

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Inkjet technology: controlling droplet formation

Poster U004

Evangelia Antonopoulou
University of Leeds

In drop-on-demand inkjet printing individual drops are ejected from the nozzle by a pressure impulse applied to the printhead. Initially the drop remains connected to the printhead by a ligament and subsequently thins and breaks off due to the surface-tension driven Rayleigh-Plateau instability. As a consequence, print quality, is critically dependant on both the waveform of the pressure impulse and on fluid properties such as viscosity and surface tension. We present some initial results where we look at how the waveform affects drop formation for a Newtonian fluid. Future work is to look at the effects of dynamic surface tension. The rapid expansion of the free surface during jetting means that if surfactants are present on the surface, local areas of surface will be depleted of surfactants leading to surface tension gradients.

Energy Harvesting from Water Waves

Poster U004

Federica Buriani (Supervisors: Dr E. Renzi, Dr A. Soltoggio, Dr I. Phillips)
Loughborough University

Energy from ocean waves possesses an excellent potential as a clean source of renewable energy. Device types that represent current wave energy converters (WECs) have continually improved during the last couple of decades. However, there remain a number of technical challenges that need to be overcome to increase the performance and hence the commercial competitiveness of wave power devices in the global energy market. For example, an important engineering challenge is the exploitation of wave energy in areas with short fetch length due to the limited wave resource. A **amp-type wave energy system for micro-tidal environments** may offer a reliable solution. It consists of a wave ramp with a crest above Mean Water level, a reservoir and a low-head hydropower converter, the Hydrostatic Pressure Wheel (HPW). Two series of 1:20 scale experiments were conducted at Southampton University to assess the functionality of the reservoir itself, and to determine the overall wave-to-shaft efficiency. The availability of a cost-effective hydropower converter for very low head differences completes the power conversion chain, and a complete system now appears realistic! The ramp and reservoir WEC is particularly suited to micro-tidal environments, even if the wave resource is limited.

Other technical challenges include the need to reduce sheer size, complexity and the use of costly design components which make ocean energy not cost-effective and safe compared to other renewable energy sources. A **flexible piezoelectric wave energy harvester** may be a great alternative solution. It is an innovative concept of electromechanical ocean energy converter for low-power applications. It harvests electrical energy from flexible deformations and vibrations induced by waves and currents. We analyse the interaction of linear water waves with a flexible piezoelectric structure submerged in water of finite depth. The converter consists of two piezoelectric layers (PVDF) attached to a flexible membrane structure (silicone rubber). We implement a mathematical model in a Matlab code in order to identify the numerical solutions of the system and to determine all the quantities of engineering interest.

Poster U004

Multilayered Flows in the Shallow Water Limit: Formulation and Stability

Francisco de Melo Viríssimo, Paul A. Milewski
Department of Mathematical Sciences, University of Bath

In this poster, we will formulate and discuss the problem of density stratified interfacial flows in the shallow water limit. This type of flow occurs in nature with the atmosphere and ocean as prime examples [8], [3].

Mathematical studies of these are particularly important, since wave motion tends not to be resolved by most numerical climate models due to their fast scales, and thus need to be understood and parameterized [7]. For example waves may break and dissipate energy or mix the underlying fluids and affect the very medium in which they are propagating [9], [6]. Consequently this research will both increase the understanding of internal waves, and have an impact on future climate models.

We will focus our attention on the two and three-layer flows, without the so-called *Boussinesq approximation* which requires small density differences. This is a simplified model for geophysical situations, but it is not too simplified: the model has both *barotropic* (fast waves affecting the whole fluid uniformly) and *baroclinic* modes (slower waves with more internal structure) [2].

The governing equations will be derived and the dynamics of their solutions will be studied from both analytical and numerical points of view, particularly the issue of whether the solutions maintain hyperbolicity (i.e. wave-like behaviour) [5], [1].

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[4] F. de Melo Virssimo and P. A. Milewski, Three-layered shallow water flows: examples, dynamics and stability. *In preparation.* 2017.

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Kinetic Monte Carlo and Hydrodynamic Modelling of Droplet Evaporation

Poster U004

Mounirah Areshi, Andrew Archer, Dmitri Tseluiko
Department of Mathematical Sciences, Loughborough University

We present the first steps in developing a model for liquid droplets evaporatively dewetting from a solid surface. The model consists of a generalised lattice-gas (Ising) model, which enables us to relate how macroscopic quantities like the contact angle and surface tension depends on the microscopic interaction parameters between the particles and with the solid surface. The particle dynamics is implemented via a kinetic Monte-Carlo scheme, which incorporates the diffusive dynamics within the droplet and also the evaporative dynamics. We present preliminary results for the spreading and dewetting of droplets and the effects of evaporation, and how this behaviour depends on the temperature and the microscopic interaction parameters.

How will driver-less cars affect traffic flow?

Poster U004

Paul Alexander
Imperial College London

Traffic flow has been studied mathematically since the 1920s and tries to optimise the problem of transporting large amounts of vehicles in the most efficient way. Each vehicle reacts to the events around it in different ways and speeds, enhancing the complexity of the subject. When we have a collection of cars together several phenomena appear is certain situations, for example: waves of slowing vehicles travel along motorways with no apparent incident and shock waves form which can move backwards or forwards. Understanding how the phenomena form and evolve can lead to their control and a smoother journey from A to B.

Several models are used to study this topic; some take a microscopic viewpoint, modelling each individual car and implementing a cellular automata scheme for example. On the other end of the scale, a macroscopic viewpoint considers the traffic as a fluid and forms differential equations in terms of the densities. However this area is still developing and for the moment there is no satisfactory general theory.

The ideal image of traffic flow is one in which vehicles merge seamlessly and move collectively, a real possibility with the advancements in driverless cars, but will this bring the end of traffic jams? What about the transition period when humans and computers commute together? Is this more environmentally friendly?

My poster aims to give a brief preliminary overview of the subject and investigate how the introduction of driverless cars might affect the flow of traffic in certain cases through the use of simple analysis and computer models.

Delegate list

Delegate Name	Delegate Surname	Institution
Adam	Brunton	M-Solv Ltd
Al	Osborne	Nonlinear Waves Research Corp
Andrew	Archer	Loughborough University
Anna	Kalogirou	University of East Anglia
Antonios	Parasyris	Loughborough University
Daniel	Ratliff	Loughborough University
David	Sibley	Loughborough University
Dmitri	Tseluiko	Loughborough University
Emilian	Parau	University of East Anglia
Emiliano	Renzi	Loughborough University
Evangelia	Antonopoulou	University of Leeds
Federica	Buriani	Loughborough University
Francisco	de Melo Virissimo	University of Bath
Gennady	El	Loughborough University
Gus	Jeans	Oceanalysis Ltd
Hanyu	Yin	Loughborough University
James	Herterich	University College Dublin
Karima	Khusnutdinova	Loughborough University
Matthew	Tranter	Loughborough University
Matthew	Moore	University of Oxford
Michael	Dallaston	Coventry University
Mounirah	Areshi	Loughborough University
Noura	Alharti	Loughborough University
Paul	Milewski	University of Bath
Paul	Alexander	Imperial College London
Prof. Robin	Johnson	Newcastle University
Radu	Cimpeanu	Imperial College London
Ricardo	Barros	Loughborough University
Sergio	Maldonado	University of Southampton
Soroush	Abolfathi	Coventry University
Tao	Gao	UCL