EUROPEAN MECHANICS SOCIETY

Newsletter 32

November 2007

President's Address

Three types of awards currently exist to acknowledge the scientific achievements of members of our community. The *EUROMECH Fluid* and *Solid Mechanics Prizes* are awarded to colleagues who have made "outstanding and fundamental research accomplishments in Mechanics". The status of *EUROMECH Fellow* is given to members who have "contributed significantly to the advancement of mechanics and related fields". Both of these awards are traditionally conferred on the occasion of the EUROMECH Fluid Mechanics (EFMC) and EUROMECH Solid Mechanics (ESMC) Conferences. EFMC will be held in Manchester in September 2008 and *I would like to encourage you to reserve some of your time to nominate a particularly deserving colleague for the Fluid Mechanics Prize or for access to Fellow status*. Details of the nomination procedure are specified elsewhere in this newsletter or may be consulted online (www. euromech.org). Please note that the deadline for submission of the nomination packages is *January 15, 2008*.

Finally two *Young Scientist Prizes* are given out for the best oral or poster presentations at each EUROMECH Conference in the EFMC, EMMC, ENOC, ESMC and ETC series, upon the recommendation of the associated conference committee.

Now is the time to make submissions for EUROMECH Colloquia to be held in 2009 and 2010. We count on your active involvement to submit proposals in exciting areas of fluid and solid mechanics, either at the core of our discipline or at the interface with other fields of the physical, engineering and biological sciences. May I remind you that EUROMECH grants 2000 Euros as "seed money" for the organization of a EUROMECH Colloquium.

Finally, let me mention that thanks to the expertise of Doctor Sara Guttilla, our website has become an efficient and reliable communication tool for all aspects of EUROMECH activities. Be sure to look it up if you wish to know more about our society.

Patrick Huerre

President, EUROMECH

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EUROMECH Solid Mechanics Prize Lecture

" Impacts in Multibody Systems"

Werner Schiehlen won the EUROMECH Solid Mechanics Prize 2006 awarded at the sixth European Solid Mechanics Conference Budapest, Hungary

Werner Schiehlen[1] , Robert Seifried[2]

Abstract

Impacts in multibody systems are characterized by periods of free motion and short intervals of unilateral contact between bodies. During the contact period energy is lost what is macro-mechanically considered by the coefficient of restitution. However, this coefficient cannot be computed within the multibody systems approach. It will be shown how the coefficient of restitution can be evaluated on a different time scale using solid mechanics models including elasticity. Moreover, it turns out that the coefficient of restitution may be uncertain if several impacts occur during the contact period. Then, only the statistical properties like mean value or midrange point, respectively, can be used to estimate the motion of the system. The computational results are also validated by experiments.

1. Introduction

The method of multibody systems allows the dynamical analysis of machines and structures see, e.g., References [1-3]. Many devices in mechanical engineering subject to impacts are modeled as unilateral constraints using the multibody system approach and the coefficient of restitution found from measurements, see Pfeiffer and Glocker [4,5]. Thereby the coefficient of restitution represents the kinetic energy loss during impact. In this paper a multi-scale method is presented for the computation of the coefficient of restitution considering wave propagation. Based on References [6-9] different models are presented for the impact period: a continuum model and a modal model combined with elastostatic Hertzian contact resulting in a boundary approach, linear modal models combined with pre-computed and

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concurrently computed finite elements in the contact region, and a completely nonlinear finite element model.

For the experiments a special test bench is designed using Laser-Doppler-Vibrometers for velocity and displacement measurements on a fast and slow time scale.

2. Multibody System Dynamics

The method of multibody systems allows the dynamical analysis of machines and structures, see References [1,2]. A multibody system is represented by its equations of motion as

$$\mathbf{M}(\mathbf{y})\ddot{\mathbf{y}} + \mathbf{k}(\mathbf{y},\dot{\mathbf{y}}) = \mathbf{q}(\mathbf{y},\dot{\mathbf{y}}) \tag{1}$$

where $\mathbf{y}(t)$ is the global position vector featuring f generalized coordinates, $\mathbf{M}$ the inertia matrix, $\mathbf{k}$ the vector of Coriolis and gyroscopic forces and $\mathbf{q}$ the vector of the applied forces. The continuous motion of the multibody system might be interrupted by collision. Collisions with non-zero relative velocity result in impacts and impact modeling is required.

Using the instantaneous impact modeling the motion of a multibody system is divided into two periods with different initial conditions, see e.g. Glocker [4] or Pfeiffer and Glocker [5]. During impact the equations of motion (1) have to be extended by the impact force F which is assumed to act in normal direction to the impact points,

$$\mathbf{M}(\mathbf{y})\ddot{\mathbf{y}} + \mathbf{k}(\mathbf{y},\dot{\mathbf{y}}) = \mathbf{q}(\mathbf{y},\dot{\mathbf{y}}) + \mathbf{w}_N F. \tag{2}$$

The vector $\mathbf{w}_N$ projects the impact force from the normal direction of the impact on the direction of the generalized coordinates. Due to the assumption of infinitesimal impact duration, the velocity changes in a jump, whereas the position remains unchanged. The equation of motion during impact is then formulated on velocity level,

$$\lim_{t_e \to t_s} \int_{t_s}^{t_e} (\mathbf{M}\ddot{\mathbf{y}} + \mathbf{k} - \mathbf{q} - \mathbf{w}_N F)dt = \mathbf{M}(\dot{\mathbf{y}}_e - \dot{\mathbf{y}}_s) - \mathbf{w}_N \Delta P = \mathbf{0}, \tag{3}$$

where the indices s and e mark the start and end of the impact, respectively. In the limit case $t_e \to t_s$ the quantities $\mathbf{M}$ and $\mathbf{w}_N$ are constant and all but the impact forces vanish due to their limited amplitudes. However, the infinitely large impact force F yields a finite force impulse ΔP which results in the jump of the generalized velocities and the non-smooth behavior. The impact force F and, therefore, the impulse ΔP are still unknown. The coefficient of restitution e provides additional information for the assessment of the impulse. Using the kinetic coefficient of restitution due to Poisson, the impact duration is divided into a compression and a restitution phase. The compression phase starts at time t_s and ends with time t_c , which is marked by the vanishing relative normal velocity. The restitution phase starts at time t_c and ends at t_e . The kinetic coefficient of restitution is defined as the ratio of the impulses ΔP_c and ΔP_r during the compression and restitution of the impact, respectively. An impact with e = 1 is called elastic and indicates no energy loss, whereas a impact with e = 0 is called plastic or inelastic and indicates maximal energy loss, resulting in a permanent contact. However, it should be noted, that the terms 'elastic' and 'plastic' describe here only the impact behavior and have little to do with the material behavior. As shown in Reference [9] the impulse during the compression phase reads as

$$\Delta P_c = \frac{-\dot{g}_{Ns}}{\mathbf{w}_N^T \mathbf{M}^{-1} \mathbf{w}_N} \tag{4}$$

where $\dot{g}_{Ns}$ is the relative normal velocity of the contact points before impact. The total impulse during impact follows as

$$\Delta P = \Delta P_c + \Delta P_r = (1+e)\Delta P_c \tag{5}$$

and using Eq. (3) the generalized velocities after impact can be computed. In the case of more than one impact occurring simultaneously in the system, the corresponding equations have to be solved simultaneously resulting in linear complementarity problems (LCPs), see Pfeiffer and Glocker [4].

The impact modeling using Poisson's coefficient of restitution is a very efficient method for treating impacts in multibody systems if the coefficient of restitution is known. The coefficient of restitution is usually found by experiments or it is known from experience. However, the coefficient of restitution may be evaluated numerically by additional simulations on a fast time scale, too, see References [7-9]. This results in a multi-scale simulation approach. The simulation on the slow time scale is interrupted by an impact. Then, for the impact, a detailed simulation with deformable bodies is performed on a fast time scale including elastodynamic wave propagation and elastic-plastic material phenomena. The generalized coordinates and velocities before impact are used as initial conditions for the simulations on the fast time scale. These simulations are limited to the impact duration and from the time-continuous impact force F the resulting impulse ΔP is computed. The kinetic coefficient of restitution follows as

$$e = \frac{\Delta P_r}{\Delta P_c} = \frac{\Delta P - \Delta P_c}{\Delta P_c} = -\frac{\mathbf{w}_N^T \mathbf{M}^{-1} \mathbf{w}_N \Delta P}{\dot{g}_{Ns}} - 1, \tag{6}$$

see Reference [9] for more details. The coefficient of restitution is now fed back to the slow time scale. Then, the generalized velocities $\dot{\mathbf{y}}_e$ after impact are computed using Eq. (3-5).

3. Elastodynamic Contact Models of Rod-like Bodies

Impact problems may be decomposed into two parts: the contact itself and the resulting wave phenomena. The contact is a highly nonlinear problem limited to a small region, while the resulting wave phenomena are considered as a linear problem throughout the entire bodies. Therefore, models combined of two submodels are proposed. The local elastic deformation resulting from the impact may be simulated using the Herztian elastostatic contact law, while the global elastodynamic behavior of the colliding bodies is described either by wave propagation theory or modally reduced linear FE-models, respectively. Thus, the contact region is treated as a boundary layer, see also References [6,7]. Alternatively the impact may be investigated using a nonlinear finite element model for the entire bodies.

3.1 Elastodynamic contact using wave propagation

Using the equation of motion for elastodynamics and solving them by D'Alembert's approach for wave propagation is a very time efficient method to simulate impacts on the fast time scale, as shown by References [6,10]. However, this approach is limited to geometrically simple bodies, such as the longitudinal impact of a sphere on a rod as shown in the following. The longitudinal waves u(x,t) in a rod are governed by the partial differential equation

$$\frac{\partial^2 u(x,t)}{\partial t^2} = c^2 \frac{\partial^2 u(x,t)}{\partial x^2} \quad \text{with} \quad c = \sqrt{\frac{E}{\rho}} \tag{7}$$

where c represents the wave speed, E and ρ are the rod's Young's modulus and density, respectively. According to D'Alembert's approach the general solution of Equation (7) reads as

$$u(x,t) = f(x - ct) + g(x + ct) \tag{8}$$

where f and g are real functions representing a forward and a backward traveling wave, respectively. Using Equation (7) and (8) with the dynamic boundary condition

$$-EA\frac{\partial u(0,t)}{\partial x} = F(t) \tag{9}$$

for the struck end, the impact of a sphere on a rod is modeled, where the contact force F(t) between the sphere and the rod is described by the Hertzian elastostatic contact law, see e.g. Goldsmith [11] or Johnson [12],

$$F(t) = \max[0, k\delta(t)^{3/2}] \tag{10}$$

The contact stiffness k and the indentation δ(t) for the contact between a sphere and a plane surface read as

$$k = \frac{4\sqrt{R_s}}{3\left(\frac{1-\nu_s^2}{E_s} + \frac{1-\nu^2}{E}\right)} \quad \text{and} \quad \delta(t) = x_s(t) - u(0,t) \tag{11}$$

where R_s, E_s, E, ν_s, ν are radius, Young's modulus and Poisson`s ratio of the sphere and the rod, and $x_s(t)$ describes the sphere's position. The good agreement of this analytical model with experimental results is shown in Reference [6]. Here, force-free boundary conditions are used for both bodies. The influence of different boundary conditions is discussed in Reference [13].

3.2 Elastodynamic contact using modal approach

For a known impact force, e.g. from the Hertzian contact law, Eq. (11), the wave propagation in arbitrarily shaped bodies can be simulated using linear FE models, see e.g. Reference [14]. The linear equations of motion read as

$$\mathbf{M}\ddot{\mathbf{u}} + \mathbf{K}\mathbf{u} = \mathbf{F} \tag{12}$$

where **M**, **K**, **u**, **F** are the mass matrix, stiffness matrix, the vector of the nodal displacements, and the force vector including the impact force, respectively. An overall small element size is required for wave propagation, resulting in FE models with many degrees of freedom *n*. The system behavior of a linear system can be described by a superposition of its eigenmodes, see e.g. Bathe [15]. In modal analysis only the *m* lowest eigenmodes are considered and the displacement is approximated by

$$\mathbf{u}(t) = \mathbf{\Phi}\mathbf{x} \quad \text{with} \quad \mathbf{\Phi} = \left[\phi_1 \ldots \phi_m\right] \tag{13}$$

where $\mathbf{x}$ is the vector of the m modal coordinates and ϕ_i are the first m eigenvectors of the original linear FE model. Plugging Eq. (13) in Eq. (12) and premultiplying with $\mathbf{\Phi}^T$ the reduced modal equations of motion remain

$$\ddot{\mathbf{x}} + \overline{\mathbf{K}}\mathbf{x} = \mathbf{\Phi}^{\mathbf{T}}\mathbf{F} \quad \text{with} \quad \overline{\mathbf{K}} = \mathrm{diag}\{\omega_1^2 \ldots \omega_m^2\} \tag{14}$$

representing the modal model of an elastic body. While Eq. (12) consists of n coupled equations, Eq. (14) consists of m decoupled equations which can be integrated very efficiently using a central difference method. Combining this modal model with a pre-computed or concurrently computed FE-model of the contact region, respectively, yield an efficient approach to simulate impacts involving elastic and elastic-plastic material behavior, see References [8,9] for more details.

3.3 Elastodynamic contact using nonlinear finite elements

For the investigation of elastodynamic impact phenomena on the fast time scale involving bodies with more complex geometric shapes resulting in more complex contact conditions, numerical methods such as the FEM have to be used. Detailed information and the theoretical background of FE contact is available in the literature e.g. References [16-20].

For simulating impacts using FEM, the modeling of the contact itself, as well as the consideration of the resulting wave propagation phenomena, are critical issues. Therefore, great attention has to be paid on in the choice of simulation parameters, such as spatial discretization, time step size and penalty factor, see Reference [14]. It turns out that the choice of the penalty factor and the discretization of the contact area have a significant influence on the time response of the calculated impact force. Especially the independence of the results from the choice of the penalty factor has to be checked by additional simulations. Moreover, the evaluation of the resulting wave propagation in the elastic bodies requires a small element size.

The impact problems investigated in this paper show according to measurements wave phenomena up to *50kHz*, and following Reference [14], their correct evaluation in FE programs requires a time step size of $10^{-6}s$ and an overall small element size of *3 to 5 mm*. However, the contact radius is much smaller, about *1 to 2 mm*. Thus, a very fine discretization of the contact region is used in order to catch the contact and the resulting stresses accurately. Figure 1 shows the mesh near the contact region for the longitudinal impact of a steel sphere (radius *15mm*) on an aluminum rod (radius *10mm*, length *1000mm*) using two-dimensional rotational symmetric elements in ANSYS [21] connected with node-to-segment contact elements and a penalty formulation.

The impact of the steel sphere on the aluminum rod shown in Figure 1 is used as benchmark problem where the steel sphere impacts with initial velocity

0.3m/s on the resting aluminum rod. The impact force computed with the three presented elastodynamic models is shown in Figure 2. The different models are labeled according to the section in which they are presented. The impact force shows the very good consistency of all three models.
In Table 1 the computation times are summarized. It turns out, that D'Alembert's approach for wave propagation combined with the Hertzian as well as the modal model combined with Hertzian contact law are much more efficient than the nonlinear finite element model. Such a separation of contact phenomena and structural dynamics is denoted as boundary approach.

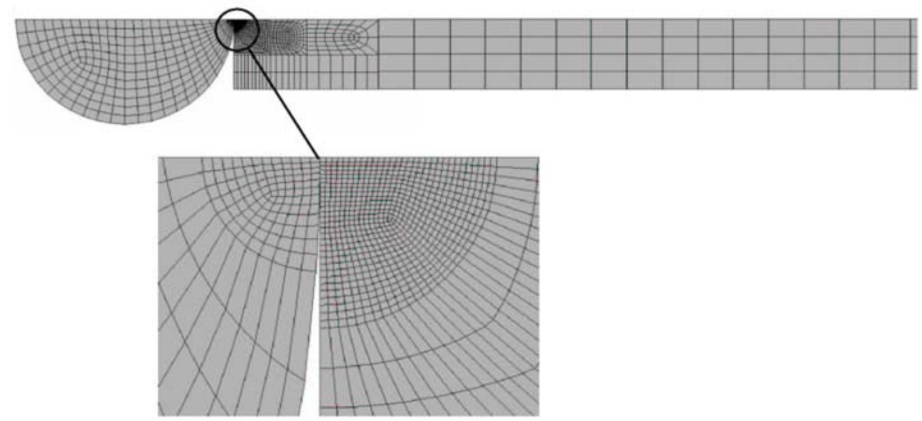

Fig. 1: Finite element model of the sphere to rod impact showing the first 100mm of the rod.

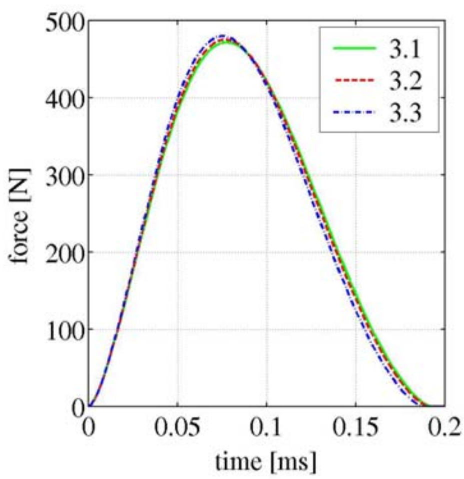

Fig. 2: Impact of the steel sphere on the rod with elastic material using different models.

Tab. 1: Computation times for the different models.

	coeff. of restitution	computation time [s]
3.1 wave equations + Hertzian contact	0.644	0.11
3.2 modal model + Hertzian contact	0.639	0.03
3.3 nonlinear finite element model	0.633	462

4. Elastodynamic Contact Models of Beam-like Bodies

The impact on a beam features multiple impacts which are caused by the strong bending vibrations of the beam, resulting from the first impact. The multiple impacts are the source of the uncertainty of the coefficient of restitution. Since more than one successive impact occur within a short time period efficient numerical methods for impact simulation on the fast time are even more important than for single impacts.

4.1 Comparison of Numerical Models

As in Section 3 the simulation results using the different numerical models are compared and discussed now. Table 2 summarizes the coefficients of restitution and computation times of the simulations for the impact of a steel sphere (*radius* = 15*mm*) on an elastic aluminum rod (*radius* =10*mm; length* = 1000*mm*) with initial velocity 0.2*m/s*. This shows again the good agreement of the modal models with FE-contact and the complete FE-model. It turns out that the complete FE-model is very time consuming. By using modal models the computation times can be reduced significantly. Using the modal model with concurrently computed FE-contact the computation time can be reduced by 97%. Using the modal model with pre-computed FE-contact the computation time can be reduced further, however the computation time for the force-displacement diagram has to be considered, which takes in this case about 1000*s*. This shows clearly, that for a larger and complex impact system, such as the transverse impact on a beam, the modal model with pre-computed FE-contact is the most efficient approach.

Tab. 2: Comparison of numerical models for sphere to beam impact.

model	coeff. of restitution	computation time [s]
modal model+ pre-computed FE-contact	0.717	16
modal model+concurrently computed FE-contact	0.700	2422
complete nonlinear FE-model	0.707	80564

4.2 Experimental Validation

For the experimental validation of the simulation results an experimental setup, originally developed by Hu et al. [6, 22], was adapted to beam impacts, see Figure 3. The sphere and beam are suspended with thin Kevlar wires in a frame as pendula. The sphere is released by a magnet from a predefine height and it impacts on the beam along its symmetry line. Two Laser-Doppler-Vibrometers are used for displacement and velocity measurement of sphere and beam in the central line of impact. Figure 4 shows for the initial velocity v = 0.276*m/s* the measured and simulated displacement of sphere and beam, as well as the velocity of the sphere. It is obvious from measurement and simulation, that within a few milliseconds several impacts occur. Figure 4 shows a very good agreement for the first impact as well as consistently a second impact after *4ms*. However, for the successive impacts significant differences may occur resulting in an overall uncertainty. For the impact with an initial velocity v = 0.276*m/s* the second impact yield only to a small velocity change. Therefore, after 5.2*ms* a third impact occurs, which results in a large velocity change of the sphere. In this case experiment and simulation agree very well. This is also reflected by the good agreement of the measured and simulated coefficients of restitution which are $e_m = 0.664$ and $e_s = 0.687$, respectively. However an impact with the initial velocity v = 0.287*m/s* shows in the simulation a much stronger second impact than in the experiment. This results in a very different behavior of the following motion. Consequently the coefficient of restitution computed from measurement and simulations differ strongly and are $e_m = 0.620$ and $e_s = 0.334$. For a impact with initial velocity v = 0.303*m/s* the experiment proves that sphere is in rest after the second impact and a third impact occurs after 5.7*ms*. In the simulation the second impact is stronger as the one in the experiment. Thereby the sphere rebounds and no further impact occurs in the simulation. Measurement and simulation yield hereby nearly identical coefficients of restitution of $e_m = 0.230$ and $e_s = 0.243$.

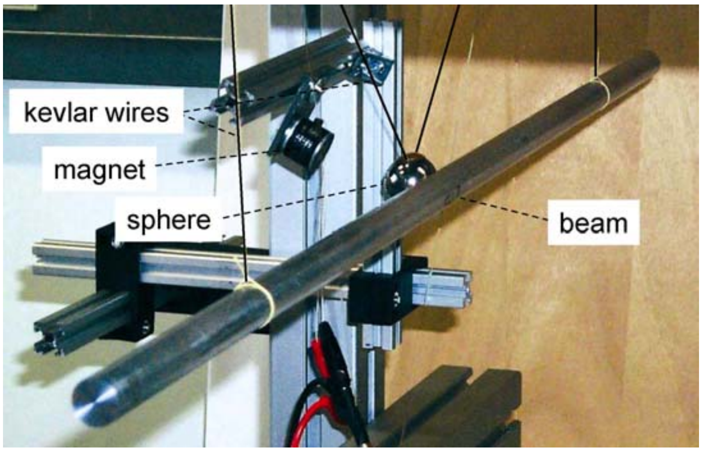

Fig. 3: Experimental setup for sphere to beam impact.

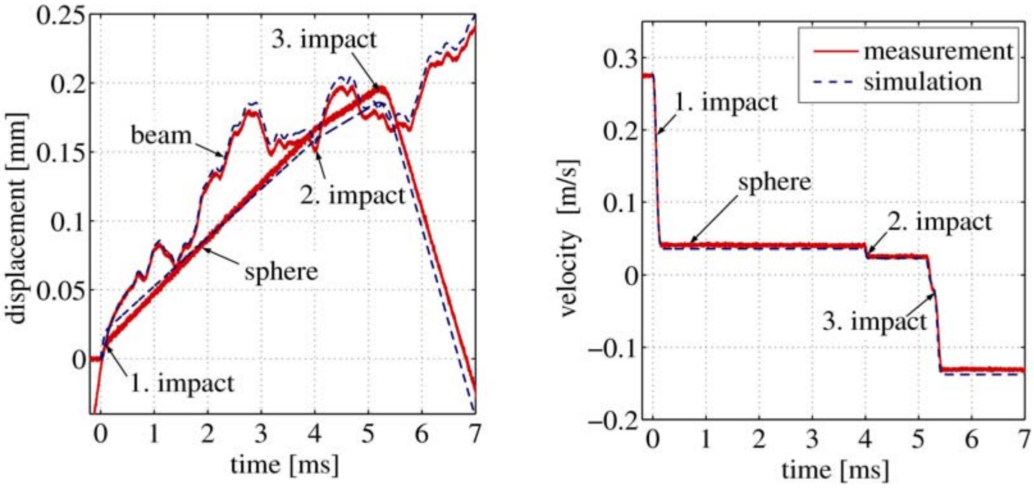

Fig. 4: Impact on beam with initial velocity v = 0.276m/s.

4.3 Analysis of the Coefficient of Restitution

In Figure 5 simulated and measured coefficients of restitution are presented for 53 different initial velocities of the sphere. Due to the multiple impacts the coefficient of restitution depends strongly on the initial velocity, however, without showing a clear pattern but strong uncertainty, see Reference [23]. The coefficients of restitution are in the range e = 0.07 - 0.73. Small differences of the simulated and measured motion of beam and sphere after the first impact result in very different behavior of the successive impacts. As a result, the investigated impacts show significant differences for both the measured and simulated coefficients of restitution, for different initial velocities.

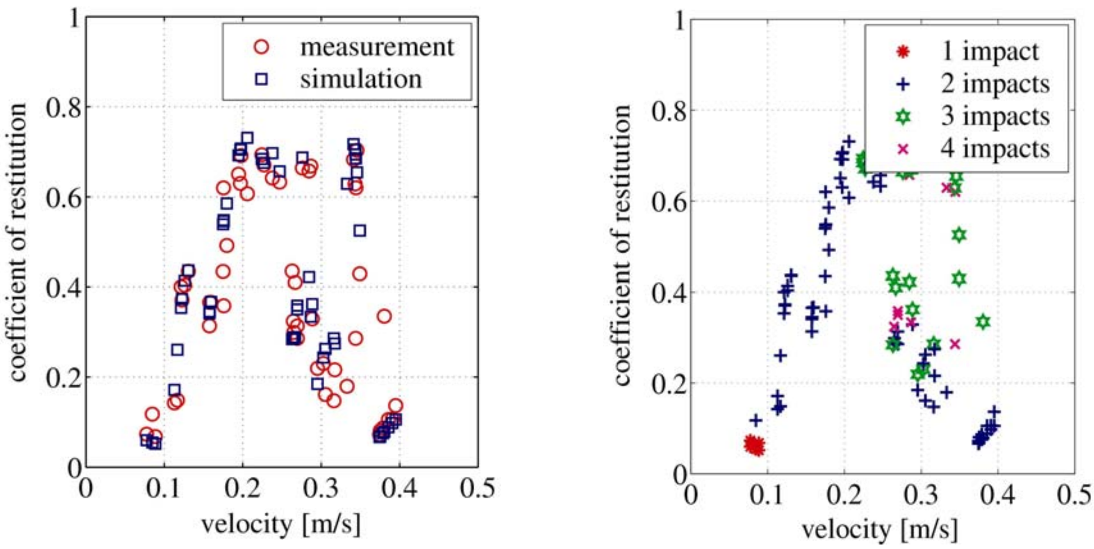

Fig. 5: Multiple impacts on an elastic aluminum beam.

In the right plot of Figure 5 the numbers of multiple impacts are indicated for simulation and measurements. It turns out that only for very low velocities one impact occur. For higher velocities 2, 3 or 4 successive impacts occur, however no relationship between the coefficient of restitution and the number of multiple impacts is obvious.

For the discussion of the chaotic behavior statistical methods will be used. The relative cumulative frequency or the probability, respectively, is shown in Figure 6 for four velocity classes, see Table 3. From these data the relative frequency or probability density, respectively, is obtained, see Figure 7. It turns out that the frequency distribution is completely non-Gaussian, and the range characterizing the statistical dispersion is increasing with the relative velocity of the impact, while midrange point and mean value coincide fairly well, see Table 4.

In class 1 one or two impacts occur where the one impact regime results in very strong structural waves corresponding to a very low coefficient of restitution. If a second impact occurs then some of the wave energy is regained and the coefficient of restitution is higher. In class 2 mainly two impacts occur with medium coefficients of restitution. In class 3 three and more impacts take place with a larger range of the coefficient of restitution. In class 4 the higher velocities result in two impacts, both of them producing very strong structural waves.

The interaction between the rigid sphere and the flexible beam is a mechanical phenomenon characterized by the micro-scale of the contact and the phase shift of the waves traveling in the beam resulting in an overall chaotic behavior on the macro-scale of the impacting bodies.

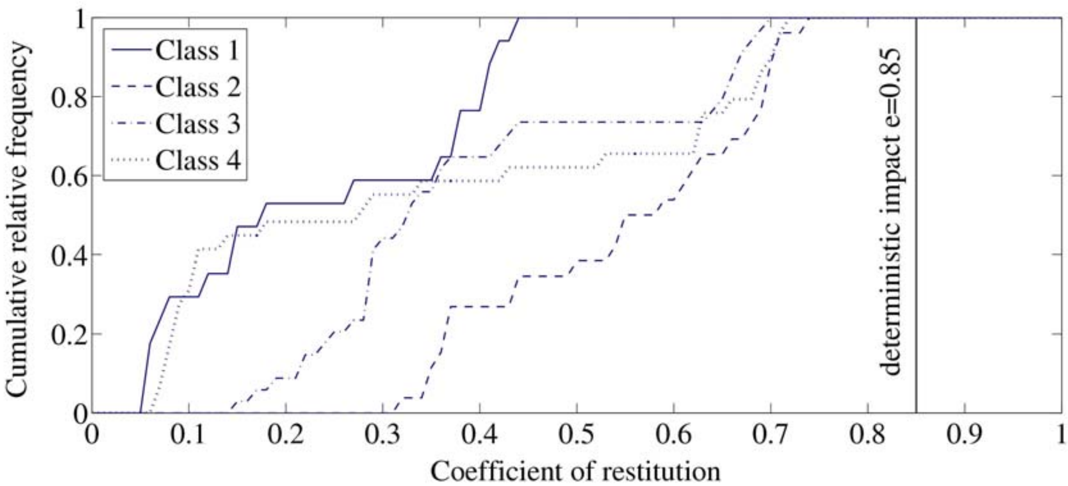

Fig. 6: Cumulative relative frequency or probability, respectively.

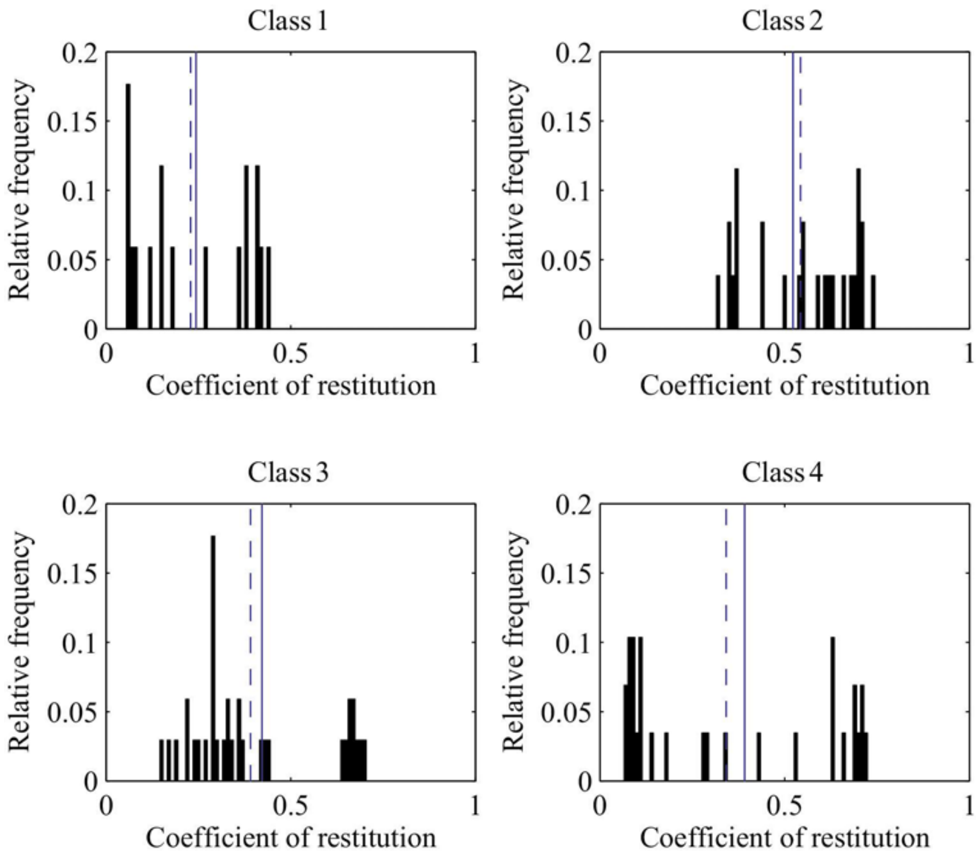

Fig. 7: Relative frequency or probability distribution, respectively
(- - mean value, — midrange point)

Tab. 3: Classification of velocities used for simulations.

Class	Velocity
1	$0.05m/s \leq v < 0.14m/s$
2	$0.14m/s \leq v < 0.23m/s$
3	$0.23m/s \leq v < 0.32m/s$
4	$0.32m/s \leq v < 0.41m/s$

Tab. 4: Statistical evaluation of data of coefficient of restitution.

Velocity class	1	2	3	4
Mean value	0.229	0.543	0.392	0.342
Midrange point	0.244	0.522	0.422	0.392
Range	0.383	0.471	0.550	0.650

5. Conclusions

Multibody systems with impacts can be analyzed efficiently if the coefficient of restitution is known. Using a multiscale simulation approach the coefficient of restitution is evaluated numerically on a fast time scale. For the simulation on the fast time scale the phenomena of wave propagation within the bodies due to impact and elastic-plastic deformation at the contact region are presented by different numerical models, which are based on wave propagation, modal approach and nonlinear finite elements, respectively. The accuracy of the simulation results is verified by extensive measurements using Laser-Doppler Vibrometers for displacement and velocity measurements.
Simulations are carried out for impacts of a steel sphere on an aluminum rod with high yield stress representing a purely elastodynamic contact. It turns out that a substantial amount of initial kinetic energy is transformed into waves for the impact on slender bodies resulting in a low coefficient of restitution.

Measurements and simulations for the transverse impact of a steel sphere on an aluminium beam show multiple successive impacts within a very short time period, resulting in a uncertain behavior of the coefficient of restitution. For the evaluation of the numerical and experimental data, a statistical approach using mean value and dispersion of the coefficient of restitution underlines the chaotic behavior of the beam's structural vibrations. The statistical range is increasing with the relative velocity of the impact. However, the mean value or midrange point, respectively, may be used to solve the corresponding multibody dynamics problem.

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EUROMECH Fluid Mechanics Fellow 2006 Paper

"ICE"

Grae Worster was named Fellow of EUROMECH at the sixth EUROMECH Fluid Mechanics Conference held in Stockholm, June 2006

M. Grae Worster[1]

1. Introduction

Ice is one of the most powerful agents on Earth: frost causes weathering of rocks; glacial ice sheets carve the landscape; ice is implicated in the electrification of thunderclouds; and it moderates our climate both globally and locally. The fact that we live on a partially frozen globe means that the enormous heat capacity associated with the change of phase between water and ice (it takes 80 times as much heat to melt ice as to raise the temperature of the resulting water by one degree Celsius) alone keeps us from becoming too hot or too cold. In concert with other agents, ice plays more intriguing moderating roles. Snow covered surfaces reflect 80–90% of incoming solar radiation; open sea water only 5%. The resulting ice-albedo feedback can lead to a snowball Earth or to a hot, ice-free Earth if unchecked by other processes. For example, freezing of the oceans in high latitudes increases the salinity of the surface waters, driving deep circulation of the ocean: the poleward heat transport from equatorial regions carried by the return flow, helps to check the advance of the ice cover. In this short essay, I am principally concerned with the flow of ice and flows associated with the phase change between water and ice. We shall see that fluid mechanics plays a central and often surprising role in determining the formation and demise of ice and mediating its effects in many geophysical settings.

2. Frost damage

Most of us encounter natural ice in the form of snow and frost. We are only too aware of the damage caused by frost when we see cracked flower pots, burst pipes or pot holes in our roads. The usual suspect is the well known expansion that occurs as water freezes to form ice (ice is about 10% less dense than water) but this is not the whole story nor even the main part of it.

Consider a spherical, water-filled cavity in an impermeable, rigid rock. If the temperature T is reduced to a value below 0°C then the water would like to become ice. However, in order to do so it would need to expand, which it can't in a rigid cavity. In consequence, the pressure will increase to a very high value at which the pressure-dependent freezing temperature of the water in the cavity is equal to T. The relationship between freezing temperature and pressure p is given by the Clausius-Clapeyron equation

$$L(T_m - T)/T_m = (p - p_m)\left(1/\rho_i - 1/\rho_w\right), \qquad (1)$$

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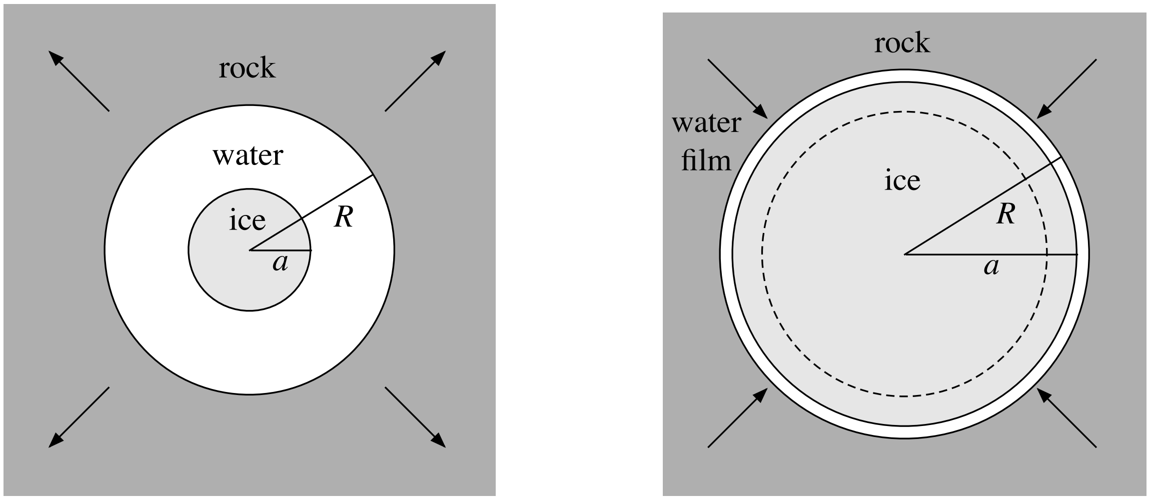

Figure 1. (a) As ice grows in a water-filled cavity in a porous rock, expansion causes water to flow out of the cavity through the rock. The pressure is elevated inside the cavity and drives the flow but has negligible influence on the elastic rock. (b) When ice fills the cavity, dispersion forces maintain a thin film of unfrozen, supercooled water between the ice and the rock. The dispersion forces pushing between ice and rock lower the water pressure in the film, which causes water to be sucked into the cavity which then expands. The dashed circle shows the initial position of the cavity wall. Relative displacements are not drawn to scale.

where T_m is the freezing temperature at reference pressure p_m ($T_m = 0°\mathrm{C}$ at $p_m = 1$ atm), ρ_i and ρ_w are the densities of ice and water, and L is the latent heat of fusion. At $-1°\mathrm{C}$ the pressure in our fictitious cavity

$$p = p^* \equiv \rho_i L(\Delta T/T_m)(\rho_w/\Delta\rho), \tag{2}$$

where $\Delta T = T_m - T$ and $\Delta\rho = \rho_w - \rho_i$, would be about 140 atm, easily enough to crack open a rock! But how did a cavity in an impermeable rock become filled with water in the first place? The rock must necessarily be permeable and that same permeability can relieve the pressure and allow ice to grow. Because of this, in most circumstances the pressure caused by expansion on freezing is wholly inadequate to deform the rock.

If the surrounding rock is modelled as a uniform porous medium, for example, then the pressure field associated with the Darcy flow caused by expansion on formation of ice in the cavity satisfies Laplace's equation, and it is readily shown that the pressure in the cavity is

$$p = (\nu\Delta\rho a^2/\Pi R)\dot{a}, \tag{3}$$

where ν is the kinematic viscosity of water, Π is the permeability of the rock, R is the radius of the cavity and a is the radius of a spherical ice formation centred in the cavity (figure 1a). To a very good approximation, the temperature field also satisfies Laplace's equation and conservation of heat at the ice–water interface is expressed by the Stefan equation

$$\rho_i L\dot{a} = -kT_r(a) = k(T - T_\infty)/a. \tag{4}$$

Equations (1), (3) and (4) can be solved for $a(t)$ but more interestingly we can use them to show that the pressure in the cavity is

$$p = p^* \, x/(x + K), \tag{5}$$

where $x = a/R$, $K = (\rho_i/\Delta\rho)^2(L/c_pT_m)(L\Pi/\nu\kappa)$, c_p is the specific heat capacity and κ is the thermal diffusivity. The highest pressure in the cavity, reached when $x = a$, is now $p^*/(1 + K)$. The value of K is approximately $10^{20}\,\Pi$ m^{-2}. So in sandstones with $\Pi \approx 10^{-14} - 10^{-16}$ m^2 or limestones with $\Pi \approx 10^{-16} - 10^{-18}$ m^2, the highest pressure reached is only about $10^{-6}p^* - 10^{-2}p^*$, or at most 1 atm. Only in granites with $\Pi \approx 10^{-18} - 10^{-20}$ m^2 can the pressure become appreciable. Of course, our calculation is for a special geometry and situation but it illustrates the point that expansion often simply drives unfrozen water away from the freezing ice without a significant rise in pressure.

However, once the cavity is almost filled with ice, dispersion forces between the ice and rock molecules, mediated by those in the intervening water, act to push ice and rock apart and to keep a thin film of water unfrozen between the two. While unbalanced by elastic stresses in the rock, these dispersion forces cause the water pressure to lower in the film, which sucks more water from the surrounding saturated rock to expand the cavity (figure 1b). This process is inescapable and pushes on the rock with a pressure of about 10 atm at -1°C. It is this that inexorably fractures the rock. The dynamics of such fracture, which takes place in non-spherical, lenticular cavities, involves a fascinating interplay of thermodynamics, including the intermolecular dispersion forces, elastic solid mechanics and fluid mechanics [1].

3. Collapsing ice sheets

A significant proportion of the bedrock of Antarctica is below sea level. The weight of the ice sheet, several kilometers thick, ensures that it remains in contact with the bedrock inland. However, as the ice sheet flows and thins towards the coast it can eventually float on the ocean to form an ice shelf. The locus of points at which ice sheet becomes ice shelf is called the grounding line of the shelf. Significant attention is currently focused on grounding lines, particularly since recent models suggest that if the grounding line recedes to a location where the bedrock slopes downwards inland then its position will be catastrophically unstable, receding rapidly inland as the ice sheet accelerates into the ocean. The recent IPCC report contains a footnote to the effect that their predictions of sea-level rise make no allowance for the potential collapse of the ice sheets because there is currently insufficient understanding of their dynamics.

Ice sheets are typically modelled using shallow-ice models: lubrication theory with non-Newtonian (usually power-law) rheology. With the same approach, ice shelves are governed by extensional-flow equations, there being negligible tangential stress exerted on them by either atmosphere or ocean.

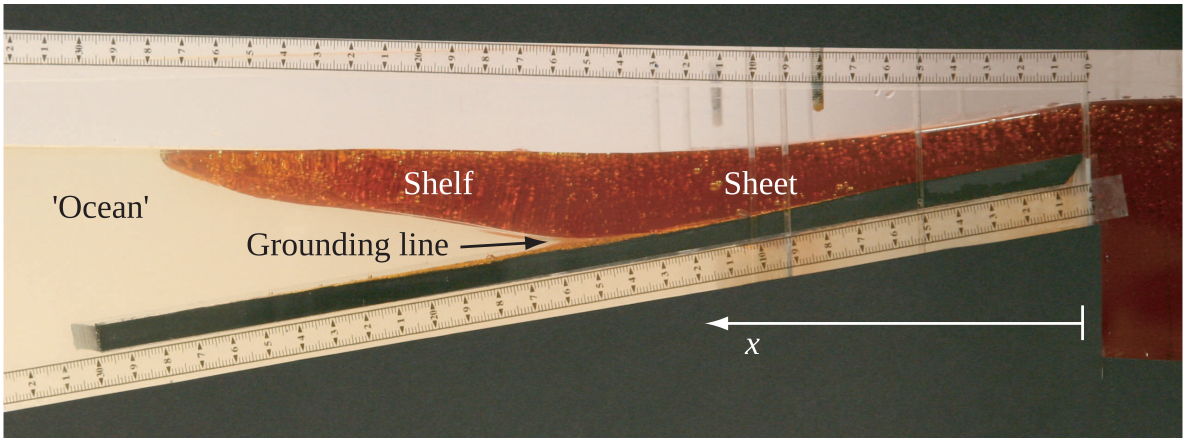

Figure 2. Photograph of an experiment in which a sheet of golden syrup flows down a slope into a denser 'ocean' of potassium carbonate solution and floats off to form a shelf. In this experiment the reservoir at the right was supplied with a constant flux of syrup. Experiment by R. Robison with H.E. Huppert and MGW.

The position of the grounding line is then a free boundary between the dynamically and mathematically distinct regions of sheet and shelf.

To explore fundamental aspects of this problem, we are conducting a series of conceptually simple laboratory experiments in which a 'sheet' of viscous fluid (golden syrup) flows down a slope into a denser 'ocean' (aqueous solution of potassium carbonate) to form a 'shelf' (figure 2). For given input flow rates, viscosities and density contrasts between 'ice' and 'ocean', we can measure the evolution of the grounding line and compare our measurements with our theoretical predictions.

Lubrication theory applied to the sheet shows that

$$h_t = -q_x = (gH^3 h_x/3\nu)_x \qquad \text{in} \qquad 0 < x < a(t), \tag{6}$$

where h is its height above sea level, H is its thickness to the bedrock, ν is its viscosity, g is the acceleration due to gravity and $a(t)$ is the horizontal position of the grounding line. At the grounding line, we apply a floatation condition

$$\rho_i g h(a) = \rho_w g' b(a), \tag{7}$$

where $g' = g(\rho_w - \rho_i)/\rho_w$ and $b(x) = H - h$ is the local depth of the ocean, and balance the depth-integrated longitudinal stress

$$4\nu(q_x + gH^2 h_x^2/2\nu) = g'H^2/2 \tag{8}$$

on either side of the grounding line (e.g. [2]). These equations combine to give an evolution equation for the grounding line

$$(b_x \rho_w g'/\rho_i g - h_x)\dot{a} = gH^2 h_x^2/2\nu - g'H^2/8\nu. \tag{9}$$

If the sheet is supplied by a constant flux q_0 upstream then the grounding line reaches a steady position

$$a = (\rho_i/\rho_w)(6\nu q_0/g)^{1/3}(g/g')^{1/6}/b_x. \tag{10}$$

This combined theoretical and experimental approach is allowing us to test fundamental aspects of the theoretical modelling such as the balance of longitudinal stress (equation (8)), where a lot of current research and debate is focused.

4. Ice in the ocean

Heat transfer from ocean to atmosphere in polar regions has two potential effects on the local density of the ocean: if the water is above its freezing temperature then it will cool and become denser; if at its freezing temperature then ice will form and the remaining water will become more saline and hence more dense without appreciable change in temperature. For a given heat flux F to the atmosphere, the buoyancy fluxes resulting from cooling and freezing are respectively

$$B_C = \alpha g F / c_p \qquad \text{and} \qquad B_F = \beta S_0 g F / L, \tag{11}$$

where α and β are the linear density coefficients for temperature and salinity respectively, and S_0 is the salinity of the ocean. The ratio of these buoyancy fluxes

$$B_F / B_C = \beta S_0 c_p / \alpha L \approx 10 - 20 \tag{12}$$

given values typical of the polar oceans. These simple considerations show that the highest buoyancy fluxes in polar oceans occur when there is simultaneously a high heat flux and ice formation. Such conditions are maintained in polynyas, for example, where newly formed ice crystals are blown by strong winds so that the relatively warm ocean is continually exposed to the cold atmosphere. Antarctic polynyas are responsible for the world's densest, most saline abyssal waters. Similarly high buoyancy fluxes also occur in marginal ice zones and during the initial refreezing of leads. If the summer-time extent of Arctic sea ice continues to recede then the Arctic Ocean will be characterized much more by thin, first-year sea ice, with a consequent increase in the importance of salt-driven convection.

The salt flux (hence buoyancy flux) associated with freezing of the oceans is much more complicated to assess once a layer of consolidated sea ice has formed. Sea ice is a mushy layer [3, 4], a reactive porous medium of pure ice crystals bathed in concentrated brine. Whether and how quickly that brine can drain into the oceans depends on intricate physical interactions between fluid flow and phase change in the interior of the sea ice. In particular, flow from cooler to warmer regions of sea ice causes the ice crystals that form its matrix to dissolve. That increases the local permeability and the flow, which becomes focused into narrow brine channels (figure 3). The fluid dynamics of this process is governed principally by a Rayleigh number

$$R_m = (1 + L / c_p m S_0)\, \beta g \Delta S \Pi h / \kappa \nu, \tag{13}$$

where m is the slope of the freezing temperature variation with salinity. This Rayleigh number, which is characteristic of convection in mushy layers, reflects

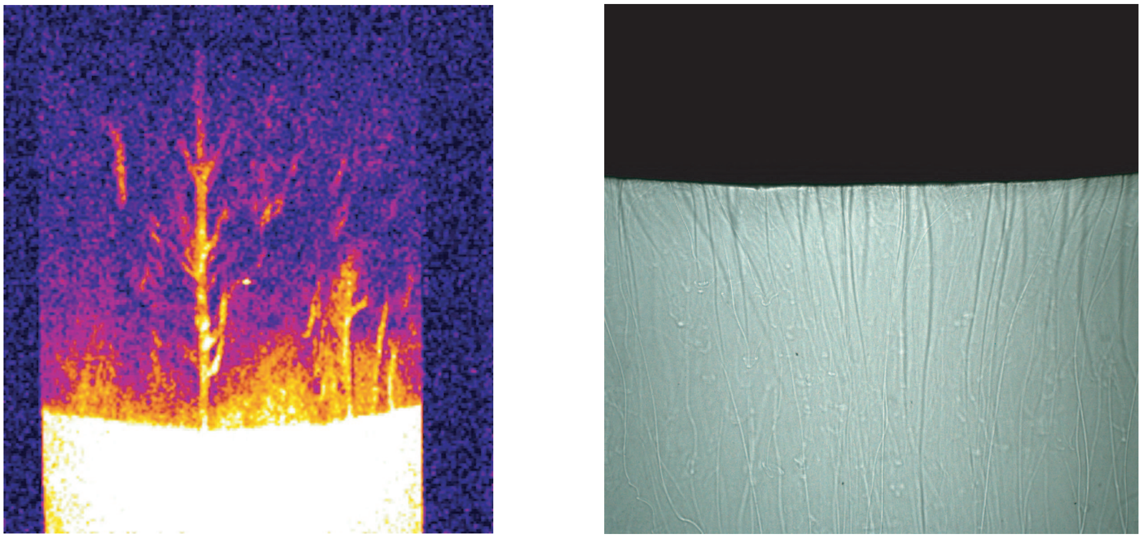

Figure 3. (a) MRI image of the interior of a convecting mushy layer showing a large vertical dissolution channel with side branches and a number of smaller channels [5]. (b) Shadowgraph image of plumes of brine emanating from brine channels in laboratory grown sea ice [6].

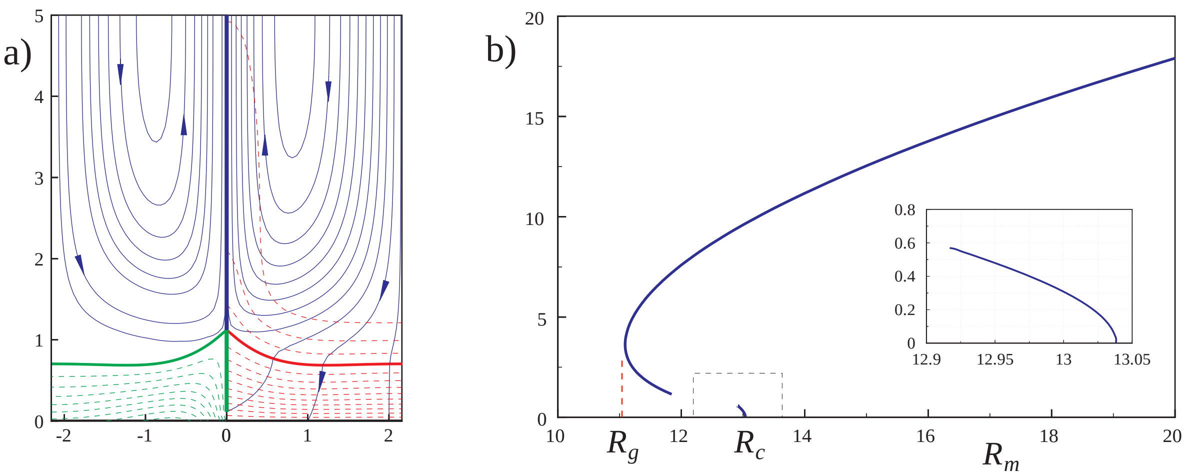

Figure 4. (a) Streamlines (thin solid curves), isotherms (dashed curves on right) and contours of solid fraction (dashed curves on left) calculated for steady solidification of a binary alloy [7]. The thick solid curve shows the interface between the mushy layer (below) and liquid region (above). Liquid flows through the mushy layer, some of it returning via a chimney (thick vertical line) in the mushy layer to emerge as a plume in the liquid region. (b) A measure of the strength of the convective flow as a function of the Rayleigh number R_m. The subcritical bifurcation to weak convection in the mushy layer from the linear critical point R_c is shown enlarged in the inset. The upper branch relates to states in which convection causes dissolution channels (chimneys) to form in the mushy layer, as shown in (a). The minimum Rayleigh number at which steady convection can occur is given by R_g.

the facts that the flow is in a porous medium of permeability Π, that the buoyancy is dominated by salinity variations ΔS, and that the dissipation of that buoyancy is effected by phase change mediated by the thermal field with diffusivity κ. The prefactor $(1 + L/c_p m S_0)$ reflects the fact that the effective heat capacity of mushy layers is dominated by the internal release or absorption of latent heat.

Detailed theoretical and numerical analyses have been made of convection in mushy layers (figure 4) and many of their properties have been verified experimentally [8]. However, it remains a challenge to develop a dynamical model of the salt (buoyancy) fluxes from sea ice simple and robust enough to be incorporated into large-scale climate models.

5. Conclusion

We have seen that ice plays a significant role in many environmental processes and is of great interest to engineers, geoscientists and physicists. It is also of great importance in biology (ice algae account for more than half of Arctic marine primary production), medicine (for cryo-preservation of cells and tissue) and chemistry (some ozone-destroying aerosols originate from frost flowers on sea ice) to give but a few examples. And for the applied mathematician and fluid dynamicist, the study of ice involves interesting challenges in free-boundary problems and diverse nonlinear interactions between flow and structure.

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EUROMECH Fellows: Nomination Procedure

The EUROMECH Council was pleased to announce the introduction of the category of **EUROMECH Fellow**, starting in 2005. The status of Fellow is awarded to members who have contributed significantly to the advancement of mechanics and related fields. This may be through their original research and publications, or their innovative contributions in the application of mechanics and technological developments, or through distinguished contribution to the discipline in other ways.

Election to the status of Fellow of EUROMECH will take place in the year of the appropriate EUROMECH Conference, EFMC or ESMC respectively. The number of fellows is limited in total (fluids and solids together) to no more than one-half of one percent of the then current membership of the Society.

Nomination conditions:

- The nomination is made by **two sponsors** who must be members of the Society;
- Successful nominees must be members of the Society;
- Each nomination packet must contain a completed Nomination Form, signed by the two sponsors, and no more than four supporting letters (including the two from the sponsors).

Nomination Process:

- The nomination packet (nomination form and supporting letters) must be submitted **before 15 January** in the year of election to Fellow (the year of the respective EFMC or ESMC);
- Nominations will be reviewed before the end of February by the EUROMECH Fellow Committee;
- Final approval will be given by the EUROMECH Council during its meeting in the year of election to Fellow;
- Notification of newly elected Fellows will be made in May following the Council meeting;
- The Fellow award ceremony will take place during the EFMC or ESMC as appropriate.

Required documents and how to submit nominations:
Nomination packets need to be sent before the deadline of **15 January** in the year of the respective EFMC or ESMC to the President of the Society. Information can be obtained from the EUROMECH web page **www.euromech.org** and the Newsletter. Nomination Forms can also be obtained from the web page or can be requested from the Secretary-General.

NOMINATION FORM FOR FELLOW

NAME OF NOMINEE:………..………………………………………………………….…

OFFICE ADDRESS:…………………..………………………………………………....

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EMAIL ADDRESS:………..…………………………………………………………..

FIELD OF RESEARCH: ……………………………………………………………..

Fluids: ☐ Solids: ☐

NAME OF SPONSOR 1: ..………...………………………………………………………

OFFICE ADDRESS:…………………..……………………………………………..…

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EMAIL ADDRESS:……………………………………………………………………

SIGNATURE & DATE: ……………………………………………………………………

NAME OF SPONSOR 2: ..………...……………………………………………………….

OFFICE ADDRESS:………..………..……………………………………….………..….

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EMAIL ADDRESS:…………………………………………………………………….

SIGNATURE & DATE: …………………………………………………………………….

SUPPORTING DATA

- Suggested Citation to appear on the Fellowship Certificate (30 words maximum);
- Supporting Paragraph enlarging on the Citation, indicating the Originality and Significance of the Contributions cited (limit 250 words);
- Nominee's most Significant Principal Publications (list at most 8);
- NOMINEE'S OTHER CONTRIBUTIONS (invited talks, patents, professional service, teaching etc. List at most 10);
- NOMINEE'S ACADEMIC BACKGROUND (University Degrees, year awarded, major field);
- NOMINEE'S EMPLOYMENT BACKGROUND (position held, employed by, duties, dates).

SPONSORS' DATA

Each sponsor (there are two sponsors) should sign the nomination form, attach a letter of recommendation and provide the following information:

- Sponsor's name;
- Professional address;
- Email address;
- Eponsor's signature/date.

ADDITIONAL INFORMATION

Supporting letters (no more than four including the two of the sponsors).

TRANSMISSION

Send the whole nomination packet to:

Professor Patrick Huerre
President EUROMECH
Laboratoire d'Hydrodynamique, École Polytechnique
91128 Palaiseau Cedex, France
E-mail: huerre@ladhyx.polytechnique.fr

EUROMECH Prizes: Nomination Procedure

Fluid Mechanics Prize
Solid Mechanics prize

Regulations and Call for Nominations

The *Fluid Mechanics Prize* and the *Solid Mechanics Prize* of EUROMECH, the European Mechanics Society, shall be awarded on the occasions of Fluid and Solid conferences for outstanding and fundamental research accomplishments in Mechanics.

Each prize consists of 5000 Euros. The recipient is invited to give a Prize Lecture at one of the European Fluid or Solid Mechanics Conferences.

Nomination Guidelines:

A nomination may be submitted by any member of the Mechanics community. Eligible candidates should have undertaken a significant proportion of their scientific career in Europe. Self-nominations cannot be accepted.
The nomination documents should include the following items:

- A presentation letter summarizing the contributions and achievements of the nominee in support of his/her nomination for the Prize;
- A curriculum vitae of the nominee;
- A list of the nominee's publications;
- At least two letters of recommendation.

Five copies of the complete nomination package should be sent to the Chair of the appropriate Prize Committee, as announced in the EUROMECH Newsletter and on the Society's Web site www.euromech.org Nominations will remain active for two selection campaigns.

Prize committees

For each prize, a Prize Committee, with a Chair and four additional members shall be appointed by the EUROMECH Council for a period of three years. The Chair and the four additional members may be re-appointed once. The committee shall select a recipient from the nominations. The final decision is made by the EUROMECH Council.

Fluid Mechanics Prize

The nomination deadline for the Fluid Mechanics prize is **15 January in the year of the Fluid Mechanics Conference**. The members of the *Fluid Mechanics Prize and Fellowship Committee* are:

- A. Kluwick (Chair)
- O. E. Jensen
- D. Lohse
- P. Monkewitz
- W. Schröder

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Solid Mechanics Prize

The nomination deadline for the Solid Mechanics prize is **15 January in the year of the Solid Mechanics Conference**. The members of the *Solid Mechanics Prize and Fellowship Committee* are:

- W. Schiehlen (Chair)
- H. Myhre Jensen
- N.F. Morozov
- M. Raous
- B. A. Schrefler

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EUROMECH Conferences in 2008, 2009

The general purpose of EUROMECH conferences is to provide opportunities for scientists and engineers from all over Europe to meet and to discuss current research. Europe is a very compact region, well provided with conference facilities, and this makes it feasible to hold inexpensive meetings.

The fact that the EUROMECH Conferences are organized by Europeans primarily for the benefit of Europeans should be kept in mind. Qualified scientists from any country are of course welcome as participants, but the need to improve communications within Europe is relevant to the scientific programme and to the choice of leading speakers.

A EUROMECH Conference on a broad subject, such as the ESMC or the EFMC, is not a gathering of specialists all having the same research interests. Much of the communication which takes place is necessarily more in the nature of imparting information than exchange of the latest ideas. A participant should leave a Conference knowing more and understanding more than on arrival, and much of that gain may not be directly related to the scientist's current research. It is very important therefore that the speakers at a Conference should have the ability to explain ideas in a clear and interesting manner, and should select and prepare their material with this expository purpose in mind.

2008

EMMC11
11th EUROMECH-MÉCAMAT Conference
DATES: 10 – 14 March 2008
LOCATION: Turin, Italy
CONTACT: Prof. J.F. Ganghoffer, Prof. F. Pastrone
E-MAIL: jfgangho@hotmail.com, pastrone@dm.unito.it

ENOC6
6th EUROMECH Nonlinear Oscillations Conference
DATES: 30 June–4 July 2008
LOCATION: St. Petersburg, Russia
CONTACT: Prof. Alexander L. Fradkov ,
E-MAIL: fradkov@mail.ru

EFMC7
7th EUROMECH Fluid Mechanics Conference
DATES: 14 – 18 September 2008
LOCATION: Manchester, UK
CONTACT: Prof. Peter Duck,
E-MAIL: duck@ma.man.ac.uk

2009

EETC12
12th EUROMECH European Turbulence Conference
DATES: 7 – 10 September 2009
LOCATION: Marburg, Germany
CONTACT: Prof. Bruno Eckhardt
E-MAIL: bruno.eckhardt@Physik.Uni-Marburg.de

ESMC7
7th European Solid Mechanics Conference
DATES: August 2009
LOCATION: Lisbon, Portugal
CONTACT: Prof. Jorge Ambrosio
E-MAIL: jorge@dem.ist.utl.pt

EUROMECH Colloquia in 2008

EUROMECH Colloquia are informal meetings on specialized research topics. Participation is restricted to a small number of research workers actively engaged in the field of each Colloquium. The organization of each Colloquium, including the selection of participants for invitation, is entrusted to a Chairperson. Proceedings are not normally published. Those who are interested in taking part in a Colloquium should write to the appropriate Chairperson. Number, Title, Chairperson or Co-chairperson, Dates and Location for each Colloquium in 2008 are given below.

EUROMECH Colloquia in 2008

495. Advances in Simulation of Multibody System Dynamics
Chairperson: Prof. Dmitry Pogorelov
Department of Applied Mechanics
Bryansk State Technical University
b.50 let Oktyabrya, 7
241035 Bryansk, Russia
Phone: +7 4832 568637; Fax: +7 4832 568637
Email: pogorelov@tu-bryansk.ru
Co-Chairperson: Em. Prof. Dr.-Ing. Werner Schiehlen
Date and location: 18 - 21 February 2008, Bryansk, Russia
Website: http://umlab.ru/euromech/callforpapers.htm

496. Control of Fluid Flow
Chairperson: Prof. Peter Schmid
Laboratoire d'Hydrodynamique (LadHyX)
Ecole Polytechnique
F-91128 Palaiseau, France
Phone: +33 1 69 333780; Fax: +33 1 69 333030
e-mail:peter.schmid@ladhyx.polytechnique.fr
Co-Chairperson: Dan Henningson
Date and location: 19 - 21 May 2008, Paris, France

497. Recent Developments and New Directions in Thin-Film Flow
Chairperson: Prof. Stephen K. Wilson
Department of Mathematics, University of Strathclyde,
Livingstone Tower, 26 Richmond Street
Glasgow, G1 1XH, UK
Phone: +44(0)141 548 3820; Fax: +44(0)141 548 3345
E-Mail: s.k.wilson@strath.ac.uk
Co-Chairperson: Dr. Brian R. Duffy,

Date and location: Summer 2008, Edinburgh, UK

498. Nonlinear Dynamics of Composites and Smart Structures
Chairperson: Prof. J. Warminski
Lublin University of Technology
Department of Applied Mechanics
Nadbystrzycka 36
20-618, Lublin, Poland
Ph: +48 81 538 4197; Fax: +48 81 538 4205
E-mail: j.warminski@pollub.pl
Co-Chairperson: Prof. M. P. Cartmell
Date and location: 21 – 24 May 2008, Kazimierz Dolny, Poland
Website: http://www.ndcs.pollub.pl/

499. Nonlinear Mechanics of Multiphase Flow in Porous Media: Phase Transitions, Instability, Non Equilibrium, Modeling
Chairperson: Mikhail Panfilov
LEMTA-ENSEM
2, av. de la Foret de la Haye
BP 160
F-54504 Vandoeuvre-les-Nancy Cedex, France
Ph: +33 3 83595697, Fax: +33 3 83595616
E-mail: mikhail.panfilov@ensem.inpl-nancy.fr
Date and location: 9 - 12 June 2008, Institut National Polytechnique de Lorraine, Nancy, France
Website: http://lemta.ensem.inpl-nancy.fr/euromech.html

500. Non-smooth Problems in Vehicle Systems Dynamics - Analysis and Solutions
Chairperson: Prof. Per Grove Thomsen
Technical University of Denmark
Richard Petersens Plads 321
DK-2800 Kgs. Lyngby, Denmark
Ph: + 45 45253073, Fax : +45 45932373
E-mail: pgt@imm.dtu.dk
Co-Chairperson: Prof. Hans True
Date and location: 17 - 20 June 2008, Danish Technical University, Lyngby, Denmark

501. Mixing of Coastal, Estaurine and Riverine Shallow Flows
Chairperson: Prof. Maurizio Brocchini
Istituto di Idraulica e Infrastrutture Viarie,
Università Politecnica delle Marche,
60131 Ancona, Italy

Ph: +39 071 220 4522, Fax: +39 071 220 4528
E-mail: m.brocchini@univpm.it
Co-Chairperson: Prof. GertJan van Heijst
Date and location: 8 - 11 June 2008, Istituto di Idraulica e Infrastrutture Viarie, Ancona, Italy

502. Reinforced Elastomers: Fracture Mechanics Statistical Physics and Numerical Simulation
Chairperson: Prof. G. Heinrich
Leibniz Institut für Polymerforschung Dresden e. V.
Postfach 120411
01005 Dresden, Germany
Ph: +49 0 351 4658 360, Fax: +49 0 351 4658 362
E-mail: gheinrich@ipfdd.de
Co-Chairperson: Prof. Erwan Verron
Date and location: 8 – 10 September 2008, Leibniz Institut für Polymerforschung Dresden e.V., Germany

EUROMECH Colloquia Reports

EUROMECH Colloquium 483

"Non-linear Vibrations of Structures"

9 - 11 July 2007, University of Porto, Portugal

Chairperson: Prof. P.L. Ribeiro, Universidade do Porto, Portugal

Co - Chairperson: Prof. Marco Amabili Universitá di Parma, Italy.

Amongst the different types of non-linearities found in structural vibrations, one of the most important is non-linearity due to large displacements, i.e., geometrical non-linearity. Geometrically non-linear vibrations of structures was the theme of *EUROMECH Colloquium 483*, which was held at the Faculty of Engineering, University of Porto. Topics covered included:

- Beams, Cables, Plates and Shells;
- Bifurcations and Stability;
- Chaotic Vibrations;
- Energy Pumping;
- Fluid-structure Interactions;
- Non-linear Modes;
- Vibration Isolation;
- Reduced Order Modelling.

A few presentations involved applications in diverse fields where geometrical non-linearity is important, including:

- Aerospace Engineering;
- Automotive Engineering;
- Bridge Dynamics;
- Musical Instruments.

Analytical, numerical and experimental studies were presented and discussed.

There were 68 participants from 22 different countries and six continents. Younger and senior researchers attended. There were two phases of revision and selection from 94 abstracts. The members of the Scientific Committee were: Alexander Vakakis (Greece), Balakumar Balachandran (USA), Chuh Mei

(USA), Hans Troger (Austria), Jan Awrejcewicz (Poland), Jon Juel Thomsen (Denmark), José Antunes (Portugal), Marian Wiercigroch (UK), Maurice Petyt (UK), Paulo B. Gonçalves (Brasil) and Yukinori Kobayashi (Japan). Five invited or keynote lectures of about 40 minutes were presented: by: José V. Antunes (Portugal, Opening Lecture), Bernd Krauskopf (United Kingdom), Christophe Pierre (Canada), Karl Schweizerhof (Germany) Hiroshi Yabuno (Japan). 61 oral communications of 20 minutes were also presented.

The colloquium was intensive, with presentations of good quality and interesting discussions. The extended abstracts of the contributions were published in a book of proceedings. A few papers based on contributions to the colloquium will be published in a special issue of the *Journal of Sound and Vibration*.

We would like to thank the sponsoring and supporting institutions, the secretariat, the authors, the participants, the scientific committee and the remaining referees for their contribution to the success of this meeting.

EUROMECH Colloquium 488

"The Influence of Fluid Dynamics on the Behaviour and Distribution of Plankton"

13 - 15 June 2007, University of Liverpool, UK

Chairperson: Dr. David Lewis, University of Liverpool, UK

Co – Chairperson: Dr. Rachel Bearon, University of Liverpool, UK

Aquatic micro-organisms have evolved a bewildering variety of different adaptations and exhibit a wealth of survival strategies for thriving in their marine environment. Until comparatively recently most research has tended to focus on the micro-organisms themselves, in isolation from the fluid dynamical regime governing their surroundings. The aim of this Euromech Colloquium was to redress this balance, by encouraging presentations that investigated the role played by fluid dynamics on the behaviour (swimming, feeding and hydro-mechanical signalling on small scales), population growth (resource competition on intermediate scales) and spatial distribution (aggregations and patchiness over a range of scales) of the Plankton (in its broadest sense from bacteria to fish larvae). Most importantly, the meeting was designed to bring together researchers from a diverse range of fields (fluid dynamics, oceanography and planktonic biology) in order that they should interact and make new contacts to further advance knowledge of the field, which by necessity must be interdisciplinary in nature.

Altogether around 40 participants attended the meeting, which contained 29 oral presentations and five posters. There were six invited speakers, namely Rudi Strickler (University of Wisconsin), Thomas Kiørboe (Danish Institute for Fisheries Research), Tim Pedley (University of Cambridge), Jon Pitchford (University of York), Adrian Martin (National Oceanography Centre, Southampton) and Øyvind Fiksen (University of Bergen). Considerable time was set aside for both formal and informal discussions to identify key unresolved problems as well as future collaborative possibilities. An outline of the topics raised is given below:

Wednesday June 13th.

Rudi Strickler began the meeting with a bravura performance, focussing on how calanoid copepods can advect prey close to their mouth parts by generating feeding currents. He included some spectacular videos of copepods in action, which revealed an astonishing level of sophistication for such minute creatures in their ability to sense and handle different types of prey. The video of one particular copepod constantly re-orientating a slightly too large food particle in order to finally ingest it was remarkable. Other speakers in the morning followed up on this theme, by looking at numerical simulations of planktonic micro-organisms interacting with each other, both in low Reynolds number flows and when subject to small scale turbulence. The problem of how planktonic predators are able to perceive and capture their prey formed part of a lively discussion.

In the afternoon, Thomas Kiørboe gave a presentation on the energetics of pelagic copepods swimming in different flows. This focussed first on the different swimming strategies employed by male and female copepods in order to find/attract a mate. The presentation then moved on to examine the trade-off between a copepod's optimal foraging strategies to find prey, as against the increased danger of encountering larger predators in so doing. This is an unusual and welcome extension to this type of analysis, which tends to focus on prey foraging in isolation. An additional theme, taken up in follow up presentations, was how planktonic micro-organisms can secrete chemical cues in order to signal to one another. Of particular note in this session was a contributed presentation from Roman Stocker who described a novel experimental setup for visualising tactic plankton in microfluidic devices. Several new collaborations with conference particpants were identified to utilise this elegant experimental setup to explore a number of theoretical predictions.

Thursday June 14th.

Tim Pedley began the second day by presenting a talk on the collective behaviour of swimming micro-organisms. In addition to summarizing the striking collective behaviour which can occur due to the interaction of swimming and gravitational forces (e.g. bioconvection and gyrotaxis), Tim presented several new results. Firstly, the importance to collective motion of including a force-dipole (stresslet) to represent the intrinsic swimming motions was explored. Of particular note to the biologists, was the difference between 'pullers' (e.g. algal cells performing a breast-stroke) and 'pushers' (e.g. bacteria propelled by a posterior flagella bundle). New work on spherical 'squirmers' included numerical analysis on the cell-cell interactions, which was followed up in a latter presentation, and analytic work developing the Lighthill/Blake analysis to incorporate rotation, in light of the experimental work by Ray Goldstein (Cambridge), of *Volvox*, a spherical colony of green cells clinging to a semi-transparent spherical ball of mucilage. Other talks in the session considered the distribution and aggregation of swimming plankton in fluid flows, with several talks focussing on bioconvection.

In the afternoon Jon Pitchford presented a lively and somewhat controversial talk on the stochastic modelling of recruitment of fish larvae to the adult phase. The talk covered a great deal of material and resulted in an interesting debate. There followed a number of talks involving the role of turbulent mixing in plankton group behaviour and on population growth. Ed Codling gave a particularly interesting presentation on how, at sufficiently low turbulent levels, a certain amount of group cohesion can reduce navigational errors of a school of fish.

Friday June 15th.

On the last day Adrian Martin presented a talk on plankton patchiness over large scales (1-100km). He made some very important points on the difficulties of observing patchiness, and how data samples from cruise ships can lead to ambiguous results unless post processing procedures are carefully employed. He also raised more philosophical questions concerning how well, if ever, the current generation of non-linear coupled biological-physical models can possibly make robust predictions of plankton patchiness, given that there are so many small-scale processes, often fundamental in patch formation, which must be parameterised or averaged in some imperfect manner. Adrian made the important point concerning how one compares the detailed output of a model with many parameters, with a model based on just a few. There are statistical methods for making just such an assessment, but there seems to be a general lack of awareness amongst the modelling community of their existence. Follow up talks also concentrated on the mechanisms underlying planktonic patch formation over a variety of different length scales.

The last invited talk by Øyvind Fiksen looked at the migration patterns of fish larvae along the Norwegian coast. He discussed a variety of different of swimming strategies that the larvae might adopt in order to give them the best chance of survival. His results were somewhat inconclusive, and produced a lively debate. The remaining talks consisted of an interesting summary of some experimental results of the formation of plankton patches in a reservoir and some speculative ideas on adapting gyrotaxis models in simple shear flows to include the effects of small scale turbulence.

From this summary one can see that a wide variety of topics were examined, many fascinating results presented and lots of open questions debated. Most importantly, many vibrant informal discussions took place, which resulted in many new collaborative possibilities being identified. As this was one of the key aims of the colloquium, we both feel very satisfied with meeting. It remains for us to thank Euromech, the London Mathematical Society and the staff of the Carnatic Halls complex of the Liverpool University, for all their financial and organisational support towards the smooth running of the Colloquium. Many participants have expressed their thanks and support for the professional way things were handled. We in turn would like to express our thanks to all our participants who helped to make it such an enjoyable experience.

EUROMECH Colloquium 490

"Dynamics and Stability of Thin Liquid Films and Slender Jets"

19 – 21 September 2007, Imperial College, London, UK

Chairperson: Dr. Omar K. Matar, Imperial College, London, UK

Co – Chairpersons:
Dr. Richard V. Craster, Imperial College London, UK
Dr. Andreas Münch, University of Nottingham, UK
Dr. Thomas P. Witelski, Oxford University, UK

This Colloquium involved 66 participants (including some postgraduate students and postdoctoral researchers) from a wide range of disciplines (Mathematics, Physics, Chemistry, Chemical Engineering and Mechanical Engineering). The Workshop featured 8 plenary lectures (50 minutes + 10 minutes for questions) and 32 regular talks (15 minutes + 5 minutes for questions). The talks and lectures covered a range of topics, which were divided into three days as follows:

- Dynamics of Driven Films;
- Instabilities, Rupture and Breakup;
- Applications and Frontiers.

A range of topics was examined over the three days, which included:

- The effect of phase changes on thin film dynamics;
- The effect of surface-active additives on thin film stability;
- The effect of non-Newtonian rheology on the flow of thin films and the stability of jets and threads;
- The dynamics of isothermal and heated falling films;
- The formation of singularities during the rupture of thin films, the breakup of jets and threads and the motion of a contact line;
- The effect of electric fields and substrate flexibility on thin film dewetting;
- Flows of industrial, daily-life and biological relevance (e.g. heat transfer in micro-pipes, the motion of cells and the manufacturing of glass tubing).

The sessions were chaired by the Colloquium organisers. Each day culminated in a lively discussion chaired by two of the organisers, which summarised the most important points raised during the day and provided a look at the open problems in the field. This format worked very well and a number of open problems were identified as being important. These include:

- Surfactant-assisted "super-spreading" of droplets on hydrophobic substrates;

- The breakup of jets and threads in the presence of strongly non-Newtonian rheology (visco-elasticity in particular);
- The motion of contact lines.

EUROMECH Colloquium 491

"Vortex Dynamics from Quantum to Geophysical Scales"

11 –14 September 2007, University of Exeter, UK

Chairperson: Dr. Andrew D. Gilbert, University of Exeter, UK

Co – Chairpersons:
Dr. Konrad Bajer, Institute of Geophysics, Warsaw University, Poland,
Prof. Carlo F. Barenghi, School of Mathematics, University of Newcastle, U.K

The aim of this colloquium was to bring together researchers interested in the unifying theme of vortex dynamics. Vortices are an inherent property of fluid motions over a vast range of scales, and issues of stability, structure and properties unite researchers in a wide range of fields.

The colloquium was centred around invited lectures. The first set covered quantum vortices and quantum fluid turbulence, given by Ladislav Skrbek, Makoto Tsubota and Tomasz Lipniacki. These covered theoretical and experimental studies and included discussion of the relationship between classical Kolmogorov turbulence and quantum turbulence at temperatures for which the vorticity is quantised on the atomic scale. There was also discussion of the role of vortices in Bose-Einstein condensates and how these can be created by stirring.

Moving up to larger scales, the second set of invited lectures covered both classical vortex dynamics, given by Stephane Le Dizes, Tony Leonard and Koji Ohkitani, as well as two-dimensional turbulence (David Dritschel), relevant to geophysical phenomena. Issues of vortex stability were covered, and how secondary instability can give rise to complex fluid flows, and transition to turbulent states. Mathematical aspects, in particular the use of Clebsch variables, were discussed, together with the relationship between the Kolmogorov spectrum and possible singularities arising in the Euler equation.

As well as the invited lectures, all participants who wished to speak were given a 30-minute slot, and there were also 5 posters, given by PhD students. Participants enjoyed a wide variety of talks, with lively discussion. We can highlight a few sample topics here:

- How the flow on gas giants such as Jupiter gains its banded structure;
- How one can categorise the topological structure of vortices and magnetic flux tubes;
- Adaptive numerical methods for two-dimensional vortex simulations,
- Vortices in plasmas;
- Use of Clebsch variables for describing fluid states;

- The role of vortices in insect flight;
- Field theoretical approaches to vortex dynamics;
- Instability, critical layers and cat's eyes;
- Singularities in the Euler equation;
- Roll vortices and rotors in atmospheric flows.

Overall there were 48 participants, including 8 PhD students who were subsidised. The conference took place using the facilities of the Harrison Building at the University of Exeter, with a conference dinner at the nearby National Trust property Killerton House, which boasts an impressive house and garden. The participants gave positive feedback on the running and scientific content of the meeting.

In view of the many new developments in the field of vortex dynamics, and its applications to all areas of fluid mechanics, a conference on a related topic is suggested in 2 - 4 years time. Recent related conferences included "Vortex Dynamics and Field Interactions", Paris 2004 (Euromech 448) "Tubes, Sheets and Singularities in Fluid Dynamics", Zakopane 2001 (IUTAM/NATO ARW).

We were grateful for additional funding from the London Mathematical Society and the scientific publisher Taylor and Francis, through the Centre for Geophysical and Astrophysical Fluid Dynamics of the University of Exeter.

EUROMECH Colloquium 492

"Shear-banding phenomena in entangled systems"

3 –5 September 2007, University College London, London, UK

Chairperson: Dr. Helen J. Wilson, University College London, UK.

Co – Chairpersons: Dr. M. P. Lettinga, Research Centre Juelich, Germany

Certain entangled fluid systems, in particular those containing wormlike micelles of surfactant molecules, exhibit a phenomenon called *shear-banding* in which regions having different fluid properties spontaneously appear within the flow of a single fluid. This area first came into prominence during the Newton Institute programme (Cambridge, UK) on the Dynamic of Complex Fluids, January – June 1996. At that stage the generic picture considered two static shear-bands with an interface whose normal was in the flow gradient direction, and models were beginning to be proposed which could effectively model this scenario. Over the intervening years this picture has changed, with the theoretical prediction of an instability to 2D waves, experimental observations of banding in a different direction, and controversy over the use of stress-diffusion to regularise the governing equations. Given the importance of these fluids outside the laboratory, particularly in oil recovery, it was clear that more detailed discussions were needed.

The colloquium was attended by 27 scientists of whom 22 gave presentations. Each half-day session had approximately 90 minutes scheduled for discussion, and in every case this time was used to the full, with active discussion both during and after the talks.

Points which were discussed repeatedly included:

- *Turbidity*

In several of the experiments, observations of shear-banding were produced by scattering some form of light off the interface between the shear bands. The only reason such scattering would occur is if there is a difference in turbidity (or opaqueness) between the two bands. Observations seem to predict that the higher shear-rate band is turbid, although ideally a combination of PIV and direct observation would be used to comfirm this. The question arose as to exactly what structures in the high-shear band are causing the turbidity.

- *Steady bands?*

There are plenty of published works on shear-banding which show evidence of steady, stable bands, most of which pre-date the work presented at this colloquium. However, there are issues with time-averaging (in, for example, NMR experiments) or spatial averaging (in stress birefringence) which mean these may have been observations of fluctuating systems, reported as steady.

The question arose as to whether there has, in fact, been **any** observation of steady shear bands; one participant claimed to have seen them in polymer melts but most had seen fluctuations in all their systems. Related to the turbidity question above, there was discussion as to whether in fact a steady high-shear rate band exists at all or whether this is a fluctuating, transient state.

- *Shear-banding in different systems*

There were a variety of interpretations of the definition of shear-banding, with participants presenting very different phenomena in very different systems. Possible alternative sources of shear-banding included granular media, entangled polymer melts, and partially aggregated networks of carbon nanotubes.

- *Stress diffusion*

Stress diffusion is now largely accepted as a necessary physical mechanism to regularise shear-banding systems and allow communication between the bands. However, until now there have not been any estimates of the magnitude of the diffusion constant, ***D***. The first detailed coupling of models to experiments is now happening and allows us to predict the size of ***D***, but the size of this estimate is seen to vary strongly according to whether or not the model includes strong coupling between microstructure and concentration. Further work is needed to design an experimental paradigm which could make clear observations of ***D***.

- *Normal stresses*

There was discussion of the role of normal stress differences, both in interfacial instabilities and within the high-shear band itself. It was argued that very high alignment should produce extremely high values of N_1, perhaps providing a mechanism for instability within the high-shear band. Preliminary theoretical work on systems in which the high-shear band would be intrinsically unstable, though, had produced no superficially steady flows at all, so this theory needs further work.

- *Vorticity banding*

There were several observations and some theoretical efforts in the realm of vorticity banding, in which the normal to the interface between bands is in the vorticity direction. These observations were in some cases similar to the Taylor rolls seen in a purely elastic curvature-drived instability in Couette flow; however in one case there was an observation of different phases (identified by turbidity again) swapping places periodically. After much discussion of these observations, still no mechanism had been proposed. Other observations, of a steady wave-like form on the standard interface, can now be predicted well by the simple fluid models like Johnson-Segalman.

- *Observation of shear-banding from flow curves*

Both theory and experiment showed that a shear-banding system could produce a relatively smooth monotonic observed flow curve even with only moderate diffusion. This opened further questions about what exactly we mean by shear-banding; along with the discussions of vorticity banding above, it became clear that a range of phenomena need to be encompassed within the general shear-banding heading. Distinctions between phase transitions, elastic instabilities and constitutive instabilities become blurred in real, physical systems. Couplings between all of these will be needed to fully explain observations.

The meeting was extremely active in terms of discussion and was described in the summary presentation by Prof. Cates as “the best conference I've been to in 10 years”. It is clear that a follow on meeting will be necessary; Prof. Cook is planning such a meeting in Autumn 2009 at the University of Delaware. Beyond that, in a few years’ time it will probably be appropriate to organise a minisymposium on shear-banding at one of the major rheological conferences.

EUROMECH Colloquium 493

"Interface Dynamics, Stability and Fragmentation"

29-31 August 2007, Strasbourg, France

Chairperson: Prof. Emmanuel Villermaux, Université de Provence, Marseille, France

Co – Chairpersons Prof. J.Hinch and E.J. Hopfinger

Context

EUROMECH Colloquium 493 was held within the Congrès Français de Mécanique, 2007 (CFM2007). The aim was to integrate the Colloquium into CFM2007 and at the same time make the Colloquium more visible. The integration was demonstrated in three common plenary lectures by E.J. Hinch, D. Quéré and E. Guazzelli, and in opening the Colloquium to CFM participants and vice-versa. For instance, the Colloquium attracted participants from the foam, turbulence and drop and bubble sessions, while the Colloquium participants attended some talks in CFM sessions of interest. Nevertheless, the number of participants in the Colloquium remained high throughout its duration and hardly ever dropped below 50.

Attendance and financial balances

There were 51 invited and selected, registered participants in EM-Colloquium 493, coming from 8 different countries: France 27, USA 8, UK 6, Spain 5, The Netherlands 2, India 1, Singapore 1.

Those who wished to participate in CFM sessions, before the beginning of the Colloquium, registered through the CFM. Otherwise, 27 of the 51 registered participants declared themselves not to be EUROMECH or AFM members and paid the non-member registration fee.

The registration fee was 150 Euros for EUROMECH or AFM members. This fee included the Colloquium material with a booklet of abstracts, lunch, coffee breaks and free public transportation. In addition the banquet was offered at 45 Euros, which was well below the actual costs. The costs could be kept low because of the effective integration with CFM. Financial support was given to 8 participants at their request and to invited speakers. EUROMECH supported the Colloquium by giving an allowance of 1000 Euros.

Scientific scope

The scientific scope of EUROMECH 493 was interfacial instabilities, breakup and fragmentation. Those phenomena are ubiquitous in nature and industry. Examples abound in agricultural sewage, diesel engines and liquid propellant combustion, foam formation over the ocean, volcanic eruptions and tephra, sprayed paint and cosmetics, ink jet printers, microfluidic and novel devices, or inertial confinement fusion.

The emphasis was mainly on non-miscible, liquid-liquid or liquid-gas interfacial phenomena with surface tension. The topics covered included:

- Stability analysis of inviscid, viscous and non-Newtonian fluids;
- Large deformations;
- Self-similar shapes;
- Singularities;
- The statistical properties of the sizes of fragments.

These were considered using experiments, theory and numerical analysis.

The aims of the Colloquium were twofold. First, we wanted to gather together the community working worldwide on these subjects and give an opportunity to discuss the advances in this area, which have been numerous recently, on for example the fundamentals of break-up and singularities. Secondly, we wanted to provide an opportunity for this community to mix with representatives of other areas such as combustion and reactive interfaces, lasers or low temperature physics, with the hope of developing new subjects, methods and directions.

All speakers were treated equally and allotted 20 minutes per presentation. The questions were always numerous, sometimes intense, an atmosphere reinforced by the presence of most of the leaders in the field who took an active part in the discussions. Among the questions which where lively debated were:

- The role, or absence of role of surface tension on the formation of concentrated jets by cavity collapse;
- The nature of the pinch-o singularity for lenticular, quasi two-dimensional bridges;
- The role of noise on jet breakup;
- The generic character of drop size distributions in sprays and their relation to ligament dynamics;
- The critical role of the rheology and constitutive equations for polymeric fluids breakup.

The participants were clearly happy to meet, and again the general context of the CFM going on in parallel was very positive in this respect. These smaller meetings embedded in a larger manifestation seem to be appreciated. As for the Colloquium itself, one participant from Cambridge (UK) publicly thanked the organizers for the opportunity he had to meet researchers from another country (Irvine, USA) working on his topic, another from Chicago, (USA) said while starting her talk that this was for her “the ideal meeting’’, and another from Twente (The Netherlands) said that the event was, for him, “the highlight of the year”.

Given the wealth of new results appearing rapidly in this area, a follow-up meeting would probably be welcome in about two years.

Objectives of EUROMECH, the European Mechanics Society

The Society is an international, non-governmental, non-profit, scientific organisation, founded in 1993. The objective of the Society is to engage in all activities intended to promote in Europe the development of mechanics as a branch of science and engineering. Mechanics deals with motion, flow and deformation of matter, be it fluid or solid, under the action of applied forces, and with any associated phenomena. The Society is governed by a Council composed of elected and co-opted members.

Activities within the field of mechanics range from fundamental research on the behaviour of fluids and solids to applied research in engineering. The approaches used comprise theoretical, analytical, computational and experimental methods. The Society shall be guided by the tradition of free international scientific co-operation developed in EUROMECH Colloquia.

In particular, the Society will pursue this objective through:

- The organisation of European meetings on subjects within the entire field of mechanics;
- The establishment of links between persons and organisations including industry engaged in scientific work in mechanics and in related sciences;
- The gathering and dissemination of information on all matters related to mechanics;
- The development of standards for education in mechanics and in related sciences throughout Europe.

These activities, which transcend national boundaries, are to complement national activities.

The Society welcomes to membership all those who are interested in the advancement and diffusion of mechanics. It also bestows honorary membership, prizes and awards to recognise scientists who have made exceptionally important and distinguished contributions. Members may take advantage of benefits such as reduced registration fees to our meetings, reduced subscription to the European Journal of Mechanics, information on meetings, job vacancies and other matters in mechanics. Less tangibly but perhaps even more importantly, membership provides an opportunity for professional identification; it also helps to shape the future of our science in Europe and to make mechanics attractive to young people.