NEWSLETTER 40
EUROPEAN MECHANICS SOCIETY
December 2011

President's Address

Some fresh news from the E-CAero initiative. Thanks to the support of the European Commission two meetings have been co-organized with aeronautics-related European societies: A EUCASS-EUROMECH Mini-symposium or "Advanced Numerical Methods for Turbulent Flows" was held within the 4th European Conference for Aerospace Sciences of EUCASS in Saint Petersburg last July. A EUROMECH-ECCOMAS-EUCASS joint mini-symposium on "Modeling of Aeronautics Materials" was also organized during the 12th European Mechanics of Materials Conference which took place in Paris in August 2011. Additional jointly sponsored events are being planned in 2012 and members are invited to consult our website for further information.

Members have been encouraged by e-mail to submit nominations for the EUROMECH Fluid Mechanics prize and Solid Mechanics prize. We also solicit nominations for the election of new EUROMECH Fellows in Fluid or/and Solid Mechanics. Detailed instructions for the preparation of nomination packages are available herein and on the website. The awards will be officially conferred in July 2012, on the occasion of the European Solid Mechanics Conference in Graz, and in September 2012 at the European Fluid Mechanics Conference in Rome. I invite you to participate in the nomination process for these awards. The deadline for receiving nominations is January 15, 2012.

Please get involved!

Patrick Huerre
President, EUROMECH

EUROPEAN MECHANICS SOCIETY

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EUROMECH Young Scientist Prize Paper

"Modelling Oscillations of Zona Pelucida before and after Fertilization"

Andjelka Hedrih won the ENOC 2011 Young Scientist Prize, awarded at the 7th European Nonlinear Dynamics Conference held in Rome, Italy, 24-29 July 2011

Andjelka Hedrih[1]

Abstract

Zona pellucida (ZP), an acellular mantel of mammalian oocyte, changes its thickness and elastic properties before and after fertilization. To describe changes in the mechanical properties of *ZP* and its oscillatory behaviour, we use the discreet continuum method and model *ZP* as a discreet spherical net with nonlinear elastic and visco-elastic connections. A mathematical model of nonlinear free and forced vibrations is presented. Material particles in the net move in three orthogonal directions, each exhibiting asynchronous multi-frequency vibrations. The resultant nonlinear dynamics of the space trajectory are presented in the form of generalized Lissajous curves. We use two methods to obtain an approximate solution to three independent subsystems of nonlinear differential equations. These are Lagrange's method of variation constants and the asymptotic method of Krilov-Bogolyubov-Mitropolyskiy. From the spherical net *ZP* model we conclude that it is possible for different types of multi-frequency oscillations to appear in *ZP* before fertilization, ranging from purely periodic to purely chaotic-like regimes. Synchronized regimes of the knot's mass particle motion in the spherical *ZP* net are favourable kinetic states for possible successful penetration of spermatozoid through *ZP* and fertilization. Chaotic-like motion of *ZP* glycoproteins is an unfavourable kinetic state for spermatozoid penetration of *ZP*. This model is suitable for describing oscillatory behaviour of all mammalian oocytes that consist of three *ZP* glycoproteins.

1. Introduction

Zona pellucida (ZP) is an acellular 3D extracellular coat, made of 3 sulfated glycoproteins in mice: *ZP*1, *ZP*2, and *ZP*3. It surrounds all mammalian oocyte, ovulated eggs, and embryos up to the early blastocyst stage of development [1,2]. *ZP* is a very important structure in the process of oogenesis, fertilization, and preimplantation development. The process of fertilization is a result of composed multiphase interactions between oocyte and spermatozoa and leads to structural modifications in the sperm head and *ZP* [3, 4]. During the oocyte growth and maturation, *ZP* changes its thickness. It is thickest in fully-grown oocyte [2]. Also, *ZP* elasticity differs before and after fertilization. Upon fertilization *ZP* undergoes a "hardening" process (increased resistance to proteolytic enzymes) in order to prevent subsequent sperm from penetrating. It has been speculated that *ZP* hardening is due to *ZP*-glycoprotein modification after fertilization triggered by exocytose of cortical granules of oocyte. After fertilization, *ZP* is thinner and has visco-elastic properties [5-10]. Mechanical *ZP* hardening may be evaluated by changes in *ZP* elasticity. Experimental data obtained for the Young's modulus of oocyte and embryo *ZP* for the same species are subject to variations in measurement techniques and theoretical models [5-9]. Despite the different values of Young's modulus and hardening rates of *ZP* before and after fertilization, results show that *ZP* is stiffer after fertilization [10]. As the hardening ratio of *ZP* in each oocyte is unpredictable and depends on the amount of cortical granules released into the peryvitelin space and oocyte activation (maturation, fertilization), and as all experimental data suggest that *ZP* has visco-elastic properties after fertilisation, we decided to develop a nonlinear oscillatory model to describe changes in the mechanical properties of *ZP*.

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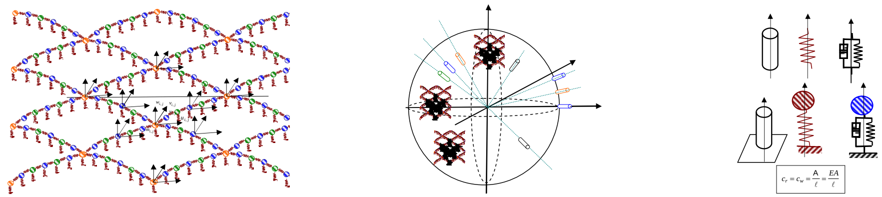
2. Oscillatory model of the ZP

Inspired by the Wassarman mouse *ZP* model [1, 2] and 3D structural changes of *ZP* on SEM analysis [3, 4] we developed a new model of *ZP*. The purpose of the model is to describe thickness and consistency changes of *ZP* before and after fertilization and to define possible kinetic parameters of *ZP* glycoprotein before and after fertilization. We considered oocyte with *ZP* as a biomechanical oscillator.

2.1 *Basic assumption*

ZP is composed of sulfatided glycoproteins interconnected in a specific manner to create a mash-like 3D structure. The ratio of *ZP*2:*ZP*3 in mice is close to 1:1, whereas *ZP*1:*ZP*2-*ZP*3 is 1:5. *ZP*2 and *ZP*3 have fibril structure. They are interchangeably connected, making fibril structures that are cross-linked with *ZP*1. We modelled *ZP* as a nonlinear net that envelops the oocyte (Fig. 1 a* and b*). Using the method of discreet continuum [11, 12], we modelled *ZP* as a discrete system of material particles of different masses interconnected with massless nonlinear-elastic or visco-nonlinear-elastic elements in a specific manner. Material mass particles correspond to *ZP* glycoproteins in the Green *ZP* model [1] (Fig. 1. a* and b*). Each material particle has three degrees of freedom and is connected to the surface of the sphere with a standard light nonlinear-elastic element in the radial direction and can oscillate in the radial direction as well as in the circumferential and meridional directions. The spherical net consists of orthogonal chains in the meridional and circumferential directions with knot mass particles at the intersection knots. As experimental data suggest that under mechanical stress *ZP* exhibits elastic to plastic transition [8], we made two models of the *ZP* net (before and after fertilization). The difference between these two models is in the coupling of the material particles of the *ZP* net: before fertilization we considered that these particles are interconnected with ideally elastic massless springs; after fertilization they are interconnected with visco-elastic elements (Fig. 1.c*). The *ZP* net is considered to be a nonlinear and conservative mechanical system before fertilization, and nonlinear and non-conservative after fertilization.



a* b* c*

Fig. 1: a* Part of the *ZP* network on a part of the sphere (oocyte). Orange (*ZP*1), blue (*ZP*2) and green (*ZP*3) represents *ZP* proteins. The network is identical in the circumferential and meridional directions. Axis shows directions of movements of *ZP* proteins. Each *ZP* protein is connected to the sphere with elastic springs that can oscillate in the radial direction. b* Model of *ZP* spherical surface that shows the radial direction of the axes of constructive elements of the model - *ZP* proteins. c* Visco-nonlinear-elastic element

The spherical net has the same structure in the circumferential and meridional directions and is concentric with the oocyte that we suppose to be rigid.

Material particles in one chain are coupled by standard light elements (with elastic or visco-elastic properties). Each of these elements and the basic properties of the material stress-strain constitutive relations [13-17] are defined and determined mathematically.

We considered that displacements of the mass particles in directions orthogonal to the chain in the spherical surface are smaller then in the direction of the chain and so it is acceptable to neglect these components.

3. Governing system of non-linear differential equations of the system oscillations.

Each material particle of the discreet *ZP* net has, generally, three degrees of freedom and three generalized independent coordinates. Before fertilisation, the discreet *ZP* spherical chain net consists of elements that have ideally nonlinear-elastic properties and the system oscillates with $n=3K$ degrees of freedom and with n eigenfrequencies in ideal conditions. K is the total number of mass particles in the spherical net. As we neglected orthogonal displacements for other mass particles in chains, the number of degrees of freedom is equal to $n=2K+N$ where N is the number of knot mass particles involved in the cross coupling between two corresponding chains in the meridional and circumferential directions at the spherical net. According to this approximation, with a distortion caused by spermatozoa, material particles in our mathematical model oscillate in an $n=2K+N$ eigenfrequency regime.

If we assume that the *ZP* net system is homogeneous and non linear, and by introducing the following denotations: $\omega_{(w)0}^2=\frac{c_{(w)}}{m}$, $\omega_{(u)0}^2=\frac{c_{(u)}}{m}$, $\omega_{(v)0}^2=\frac{c_{(v)}}{m}$, $h_{i,j}=\frac{F_{i,j}}{c_{(w)}}$, $\tilde{h}_{i,j}=\frac{\tilde{F}_{i,j}}{c_{(w)}}$, $\tilde{\omega}_{(w)}^2=\frac{\tilde{c}_{(w)}}{m}$, $\tilde{\omega}_{(u)}^2=\frac{\tilde{c}_{(u)}}{m}$, $\tilde{\omega}_{(v)}^2=\frac{\tilde{c}_{(v)}}{m}$, $2\delta_{(w)0}=\frac{b_{(w)}}{m}$, we obtain:

a* for nonlinear conservative system and for free oscillatory regimes (nonlinear model before fertilization) governing system of differential equations

$$\ddot{w}_{ij}+\omega_{(w)0}^2 w_{ij}=-\tilde{\omega}_{(w)}^2 w_{ij}^3 . \qquad (1)$$

$$\ddot{u}_{ij}+\omega_{(u)0}^2\left(-u_{i-1.j}+2u_{i.j}-u_{i+1.j}\right)=+\tilde{\omega}_{(u)}^2\left(u_{i+1.j}-u_{i.j}\right)^3-\tilde{\omega}_{(u)}^2\left(u_{i.j}-u_{i-1.j}\right)^3 \qquad (2)$$

$$\ddot{v}_{ij}+\omega_{(v)0}^2\left(-v_{i.j-1}+2v_{i.j}-v_{i.j+1}\right)=+\tilde{\omega}_{(v)}^2\left(v_{i.j+1}-v_{i.j}\right)^3-\tilde{\omega}_{(v)}^2\left(v_{i.j}-v_{i.j-1}\right)^3 . \qquad (3)$$

We can suppose that spermatozoids are in state of discontinued contacts with the spherical *ZP* net, in the form of periodical repeated impacts. These forced regimes of the model we take as a phase just before fertilization. The final positions and final velocities of material particles before fertilization are taken as initial conditions for the next regime of the *ZP* net.

b* for nonlinear non conservative system and for forced oscillatory regimes (nonlinear non conservative system after fertilization):

$$\ddot{w}_{ij}(t)+2\delta_{(w)0}\dot{w}_{ij}+\omega_{(w)0}^2 w_{ij}(t)=-\tilde{\omega}_{(w)}^2 w_{ij}^3(t)+h_{i,j}\cos\left(\Omega_{ij}t+\alpha_{ij}\right)+\tilde{h}_{i,j}\cos\left(\tilde{\Omega}_{ij}t+\tilde{\alpha}_{ij}\right). \qquad (4)$$

$$\ddot{u}_{ij}+\omega_{(u)0}^2\left(-u_{i-1.j}+2u_{i.j}-u_{i+1.j}\right)=+\tilde{\omega}_{(u)}^2\left(u_{i+1.j}-u_{i.j}\right)^3-\tilde{\omega}_{(u)}^2\left(u_{i.j}-u_{i-1.j}\right)^3 \qquad (5)$$

$$\ddot{v}_{ij}+\omega_{(v)0}^2\left(-v_{i.j-1}+2v_{i.j}-v_{i.j+1}\right)=+\tilde{\omega}_{(v)}^2\left(v_{i.j+1}-v_{i.j}\right)^3-\tilde{\omega}_{(v)}^2\left(v_{i.j}-v_{i.j-1}\right)^3 . \qquad (6)$$

The mechanical impact of spermatozoa causes perturbation of the equilibrium state of the *ZP* elastic spherical chain net and it starts to oscillate. It can be considered that a spermatozoid transfers a part of its kinetic energy to the *ZP* net, which changes its initial state.

4. Solutions of the governing system of non-linear differential equations of the system free oscillations

By using known solutions of linear differential equations [11-16], we obtain solutions for the **multi-frequency time functions for free vibration:**

a* for mass particle displacements in chains in the meridional directions

$$u_{ij}(t)=\sum_{s=1}^{N_u} C_{(u)j}\sin i\phi_{js}\cos\left(\omega_{(u)j(s)}t+\alpha_{(u)j(s)}\right), i=1,2,3,....N_u , j=1,2,3,4,...M_u . \qquad (7)$$

b* for mass particle displacements in chains in the circumferential directions

$$v_{ij}(t)=\sum_{r=1}^{N_v} C_{(v)i}\sin j\vartheta_{ir}\cos\left(\omega_{(v)i(r)}t+\alpha_{(v)i(r)}\right),\ i=1,2,3,....N_v ,\ j=1,2,3,4,...M_v . \qquad (8)$$

$C_{(u)j}$ and $\alpha_{(u)j(s)}$ in Equation (7), and $C_{(v)i}$ and $\alpha_{(v)i(r)}$ in Equation (8) are unknown integral constants, amplitudes and phases determined by initial conditions. φ_{js} and ϑ_{ir} are characteristic numbers depending on corresponding chain boundary (ends) conciliations [11-16].

In free linear system regimes, we have the following cases of the mass particle free vibrations:

1 each knot's mass particle has three orthogonal displacements in three directions:*

$$w_{ij}(t) = A_{(w)ij}\cos\left(\omega_{(w)0}t + \alpha_{(w)ij}\right),$$
$$i = i_{N1}, i_{N2} i_{N3}, \ldots. i_{Nk},\ j = j_{M1}, j_{M2}, j_{M3}, j_{M4}, j_{M15}, j_{M1}, \ldots. j_{Mk}. \qquad (9)$$

knot's mass particle displacements in radial directions:

$$u_{ij}(t) = \sum_{s=1}^{N_u} C_{(u)j}\sin i\phi_{js}\cos\left(\omega_{(u)j(s)}t + \alpha_{(u)j(s)}\right),$$
$$i = i_{N1}, i_{N2} i_{N3}, \ldots. i_{Nk},\ j = j_{M1}, j_{M2}, j_{M3}, j_{M4},,,\ldots. j_{Mk}. \qquad (10)$$

knot's mass particle displacements in chains in the meridional directions

$$v_{ij}(t) = \sum_{r=1}^{N_v} C_{(u)i}\sin j\vartheta_{ir}\cos\left(\omega_{(v)i(r)}t + \alpha_{(v)i(r)}\right),$$
$$i = i_{N1}, i_{N2} i_{N3}, \ldots. i_{Nk},\ j = j_{M1}, j_{M2}, j_{M3},,\ldots. j_{Mk}. \qquad (11)$$

knot's mass particle displacements in chains in the circumferential directions.

The trajectory of each simple mass particle in chains in the meridional/circumferential directions is along the plane/surface trajectory. It is the resultant of two orthogonal non-synchronic vibrations, one single frequency and one multi-frequency in the meridional/circumferential direction. The trajectory is in the form of generalized plane Lissajous curves.

5. Approximation of the solutions of governing sub-system of non-linear differential equations in particular cases for free and forced vibration regimes in radial directions

a* ***Free nonlinear vibration*** We note that nonlinearity is small and also that damping is small. By using Lagrange's method of variation constants, or by using the Krilov-Bogolyubov-Mitropolyski method for the first asymptotic approximation of the solution, we then obtain the following solutions [17-19]:

a* Final first asymptotic approximations of the solutions without conservative system dynamics, for $\delta_{(w)} \neq 0$, which correspond to radial displacements of mass particles, are in the following form:

$$w_{ij}(t) = R_{(w)ij}(t)e^{-\delta_{(w)}t}\cos\left\langle t\sqrt{\omega_{(w)0}^2 - \delta_{(w)}^2} - \frac{3}{16}\frac{\tilde{\omega}_{(w)}^2}{p_{(w)0}\delta_{(w)}}\left(e^{-2\delta_{(w)}t} - 1\right)\left[R_{(w)ij}\right]^2 + \varphi_{(w)0ij}\right\rangle. \qquad (12)$$

b* Final first asymptotic approximations of the differential equation solutions for the conservative system, for $\delta_{(w)} = 0$, which correspond to radial displacements of mass particles, are in the following form:

$$w_{ij}(t) = R_{(w)ij}(t)e^{-\delta_{(w)}t}\cos\left\langle t\left[\omega_{(w)0} + \frac{3}{8}\frac{\tilde{\omega}_{(w)}^2}{\omega_{(w)0}}\left[R_{(w)ij}\right]^2\right] + \varphi_{(w)0ij}\right\rangle. \qquad (13)$$

The corresponding first approximation to the frequency for nonlinear conservative system free vibration is in the form: $\omega_{(w)0(non-li)} = \omega_{(w)0} + \frac{3}{8}\frac{\tilde{\omega}_{(w)}^2}{p_{(w)0}}\left[R_{(w)ij}\right]^2$.

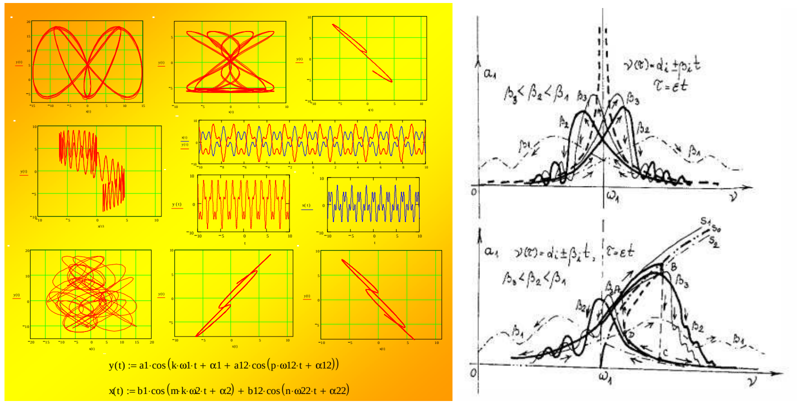
Frequencies for the initial amplitude and for nonlinear vibration in the first asymptotic approximation are not isochronous. The interdependence between frequency and amplitude for the specified nonlinear dynamics is of the parabolic type. This formula also bounds the stationary single frequency, free non-linear, regime, and the resonant forced regime described by the first asymptotic approximation. In the real system, damping should be taken into account.

c* **Forced non-linear vibration in the radial direction:** first asymptotic approximations of the differential equations for amplitude and phase are [17-19]:

$$\dot{R}_{(w)ij} = \frac{h_{i,j}}{\left(\omega_{(w)0} + \Omega_{ij}\right)}\sin\varphi_{(w)ij}(t)$$
$$\dot{\varphi}_{(w)ij}(t) = \omega_{(w)0} - \Omega_{ij} + \frac{3}{8}\frac{\tilde{\omega}_{(w)}^2}{p_{(w)0}}\left[R_{(w)ij}\right]^2 - \frac{h_{i,j}}{\left(\omega_{(w)0} + \Omega_{ij}\right)\left[R_{(w)ij}\right]}\cos\varphi_{(w)ij}(t). \qquad (14)$$

where $\Phi_{(w)ij}(t) = \omega_{(w)0}t + \varphi_{(w)ij}(t)$. $R_{(w)ij}(t)$ and $\varphi_{(w)ij}(t)$ are functions of time.

The previous system of differential equations with respect to the amplitude and phase are valid for the case where the external excitation frequency $\Omega_{ij} \approx \omega_{(w)0}$ is in the resonant interval of the eigenfrequency of the linearized system (see Fig. 2.b* and [17-19]).



a* b*

Fig. 2. a* Possible generalized Lissajous curves to illustration the knot mass particle trajectory-summarized non synchronous two frequency vibration displacements in two orthogonal directions in the spherical surface of the net: in meridional and circumferential directions with component time history graphs: periodic attractors, chaotic-like motion, synchronized and asynchronized cases. (Radial displacement is not included). b* Sketches of amplitude frequency forced vibrations for linear

(upper) and nonlinear (lower) cases and for stationary and non-stationary forced vibration regimes in the frequency interval around the resonant eigenfrequency for linearized system dynamics

6. Qualitative analysis of the vibration regimes of the mass particle in knots and in chains of the ZP spherical net.

We can use current software tools to solve Equations (14) and present results graphically. Illustrations of the knot mass particle trajectory in two orthogonal directions on the spherical surface are given in Fig. 2.a* in the form of generalized Lissajous curves - periodic attractors and chaotic-like attractors - in meridional and circumferential directions. The third orthogonal component, the knot radial displacement, is not included.

For illustration of the possible motion in the radial direction we use sketches of forced vibration in single-frequency regimes for linear (upper) and nonlinear (lower) cases and for stationary and non-stationary forced vibration regimes in the frequency interval around the resonant eigenfrequency for linearized system dynamics, using knowledge from Ref [17-19]. Such sketches are shown in Fig.2.b* for the radial displacement of a mass particle.

It is necessary to add the knot radial displacement to the displacements in other directions, to obtain generalized Lissajous curves in three-dimensional space. The component displacements of the knot mass particle are very important for consideration of a resultant ”swinging'' motion in the spherical *ZP* net and correlation with spermatozoid target motion and its impact on the net's mass particles, or the passage between mass particles for penetration of *ZP* and fertilization of the oocyte. This chaotic–like motion of mass particles in the spherical *ZP* net is unfavourable for spermatozoid penetration of the *ZP* net. Probably, spermatozoids will finish by impacting mass particles and unsuccessfully return to the starting position. If we consider possible favourable kinetic parameters for spermatozoids to pass through the *ZP* net, then a periodic mass particle trajectory is a better state then chaotic-like trajectory of the mass particles in the spherical *ZP* net.

7. Concluding Remarks.

To describe changes in the mechanical properties of ZP before and after fertilization, we use the discreet continuum method and model ZP as a discreet net with nonlinear elastic connections. Elements in this discreet net correspond to the ZP proteins. An oscillatory model of the *ZP* net after ovulation (before fertilization) is considered conservative, homogenous and nonlinear and oscillates in a free regime. Couplings between material particles are ideally elastic.

During fertilization, one sperm successfully penetrates the *ZP* net and polyspermy bloc occurs. The system dynamics are then non-conservative, nonlinear, and homogeneous with visco-elastic properties and the system oscillates with forced multi-frequency vibrations for a short period of time. First approximations to the displacements of material particles in the *ZP* net are expected to be in the form of generalized Lissajous space curves before fertilization. After fertilization they are expected to have chaotic-like motion as well as periodic motion. An oscillatory model of the discreet spherical *ZP* net could explain why it is possible for only one spermatozoid to penetrate the *ZP* - those that oscillate in a resonance with the *ZP* net. Further numerical analysis of parametric coupling between kinetic parameters of model, as well as resonance stages, is needed. Our further studies will be to improve the model with a multiple-layered net system and to consider free and forced vibrations of the system when it is placed in a fluid, as occurs in natural biological systems. Many other intriguing questions remain open, such as conditions for resonance and, synchronization of the movements of the material particles in the spherical ZP net.

8. Acknowledgements

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EUROMECH Young Scientist Prize Paper

"Durability-based Data Reduction for Multibody System Results and its Applications"

Christoph Tobias won the ENOC 2011 Young Scientist Prize, awarded at the 7th European Nonlinear Dynamics Conference held in Rome, Italy, 24-29 July 2011

Christoph Tobias[1], Denis Matha[2] and Peter Eberhard[1]

Abstract

In this paper a method for data reduction for multibody system (MBS) results is considered. This method is called online damage calculation. It delivers a scalar assessment criterion called damage value for time-dependent MBS results, which is continuously updated during MBS runtime. The usage of the online damage calculation is particularly suitable, when results characterizing loads, such as forces acting on an MBS component or stresses in an MBS component, are processed. The major advantage of the online damage calculation is the associated data reduction. In applications like the design of wind turbines, considerable disk space can be saved.

1. Introduction

A typical field of MBS application is the calculation of time-dependent mechanical quantities, such as forces and moments acting on an MBS component over long time intervals, taking nonlinearity into account [Schiehlen, 1997; Simpack, 2010]. Those quantities are often used in subsequent calculations, such as finite element (FE) and/or durability analyses, to determine the component's strength. The component's strength itself is usually characterized by a scalar value, like the maximum stress value or the damage value [Bannantine, Corner and Handrock, 1990]. This procedure is accompanied by a data flow, which can involve storing a huge amount of internal and external data, especially when investigating long time intervals.

2. Motivation

The need for a durability-based data reduction and associated difficulties are exemplified by the application shown in Fig. 1. The simulation of offshore wind turbines is usually carried out using an MBS model. Random excitation by wind and sea causes loads, such as the bending moment in the mounting of a blade or in the tower base, to be applied to components.

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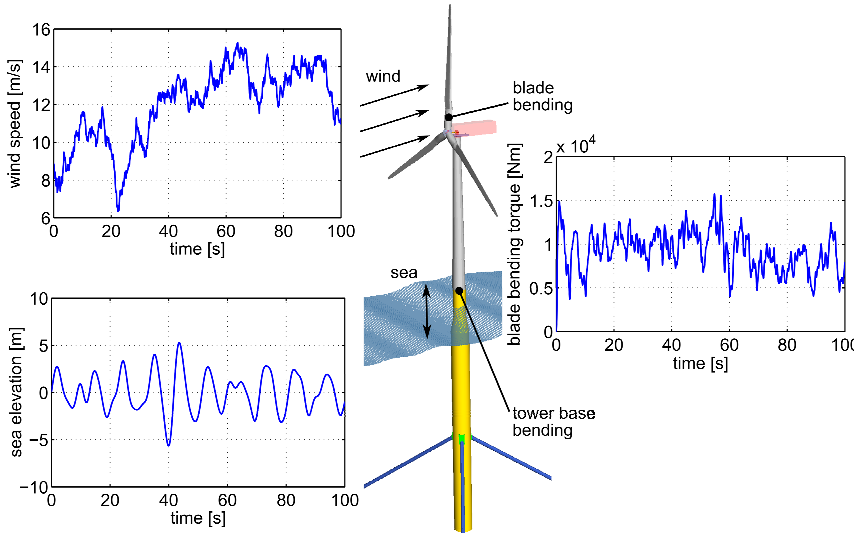

Fig. 1: MBS model of an offshore wind turbine with example system loads (wind and sea) and component loads (blade bending moment)

The plots of typical excitation profiles and the resulting blade bending moment show that data post-processing is expedient. Principal reasons are 1) that the assessment of time-dependent loads applied on components is almost impossible due to their irregular characteristics and 2) that the amount of produced data is very large. Typical simulations are carried out for 600 seconds and approximately 50 component loads are of interest. If, in addition, different wind and sea profiles have to be investigated, the accumulated data volume can quickly amount to several Gigabytes for this kind of application.

Durability-based data reduction is one possibility for data condensation and delivers scalar criteria for the durability-based assessment of loads which are output by an MBS. The basic ideas behind it are summarised in the next section.

3. Online Damage Calculation

Generally, the equations of motion of a mechanical system can be written as a set of differential-algebraic state equations (DAE) which comprises the ordinary differential equations $\mathbf{f}(\mathbf{x},\mathbf{u},\boldsymbol{\lambda})$ and the implicit algebraic constraint equations $\mathbf{c}(\mathbf{x},t)$, yielding the descriptor form of an

MBS, see e.g. [Eich and Führer, 1999]. Here **x** denotes the states, i.e. positions and velocities, **u** denotes the excitation vector, e.g. applied forces, **λ** denotes the constraint forces and moments, and t is time. The output vector **y** can be calculated via a set of linear algebraic measurement equations $\mathbf{g}(\mathbf{x},\mathbf{u},\boldsymbol{\lambda})$. The evaluation of the associated

state equations $\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x},\mathbf{u},\boldsymbol{\lambda})$ with $\mathbf{c}(\mathbf{x},t) = \mathbf{0}$ and (1)

measurement equations $\mathbf{y} = \mathbf{g}(\mathbf{x},\mathbf{u},\boldsymbol{\lambda})$ (2)

allows the determination of any interesting entry $y_i = y_i(t)$ of the output vector. The loading on an MBS component is usually characterized by outputs like forces and moments, which act on it.

3.1 Rainflow Counting with the Four-Point-Algorithm

If a linear relation between the applied loading on an MBS component and the stresses inside this component is assumed, the loading can be regarded as the determining quantity in terms of durability, see e.g. [Clormann and Seeger, 1986]. It has further been shown, that so-called 'hysteresis cycles' in the load signal are especially crucial for the fatigue process of a component, see e.g. [Vormwald, 1989; Haibach, 2006]. The identification of hysteresis cycles in the applied load signal is therefore of high importance.

For this purpose, rainflow counting techniques, first proposed by [Endo and Matsuishi, 1968], can be used. Among several algorithms for rainflow counting, the so-called 'Four-Point-Algorithm' [Amzallag et al, 1994] turns out to be best-established and has high performance, see e.g. [Barkey et al, 2007]. Since the algorithm proposed in this paper is based on the Four-Point-Algorithm, a brief description of it is beneficial. Fig. 2 is an outline diagram of the process. This is followed by an explanation of the principal mathematical features.

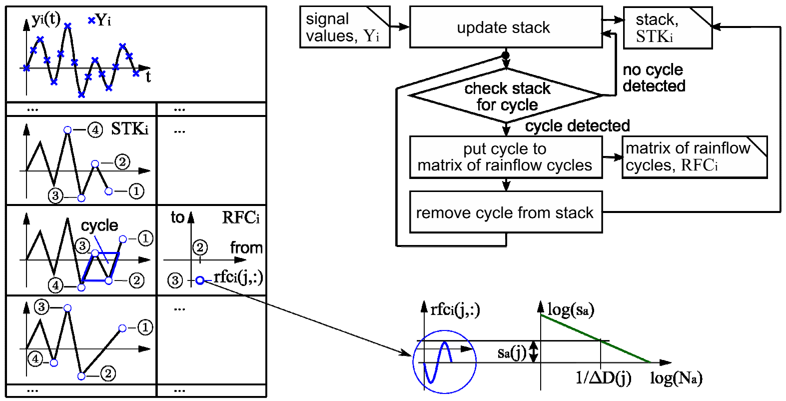

Fig. 2: Rainflow cycle counting with the Four-Point-Algorithm and calculation of a damage contribution

After the calculation of the entire load signal via the MBS measurement Equation (2), the associated signal value set:

$$Y_i = \left\{ y_i\left(t_j\right) \mid j = 1,2,...,n_{Yi};\ y_i\left(t_j\right) \in IR \right\} \qquad (3)$$

with t_j denoting the measurement points in time and n_{Yi} denoting their number, is initially filtered for turning points. Subsequently, a stack STK_i is filled with the first four turning points. These points are checked for a load hysteresis cycle. Such a cycle is detected, when points ② and ③ lie inside the ordinate range, which is spanned by ① and ④. If no cycle is detected, the stack is filled with the next turning point and the updated first four points in the stack are checked in the same manner. The left subplot of Fig. 2 shows an intermediate, already filled, stack for a sample set of signal values. Previously, the four-point-check did not detect a cycle. But in a next step, with an updated stack, the criterion for a cycle is fulfilled. The from- and to- values of the cycle are stored in the so-called 'matrix of rainflow cycles' and afterwards deleted from the stack. If possible, as shown in the bottom left subplot of Fig. 2, the check for a cycle is carried out with preceding points in the stack. If not, the stack is expanded with the next turning point. Thus, the Four-Point-Algorithm moves through the data Y_i step by step. Finally, this process yields the matrix of rainflow cycles RFC_i, which is mathematically also a set:

$$RFC_i = \left\{ \left(rfc_i(j,1), rfc_i(j,2)\right) \mid\ j = 1,2,...,n_{RFCi};\ rfc_i(j,:) \in IR \right\}. \qquad (4)$$

This matrix contains pairs of from- and to- values of all n_{RFCi} hysteresis cycles in the load signal. The remaining stack is called the residue RES_i of the rainflow counting:

$$RES_i = \left\{ res_i(j) \mid\ j = 1,2,...,n_{RESi};\ res_i(j) \in IR \right\}. \qquad (5)$$

It contains n_{RESi} points. There are several possibilities to extend the matrix of rainflow cycles with data from the residue, like the Cloormann-Seeger method, [AFNOR, 1993], or half-cycle counting [ASTM, 1985].

The upper right subplot of Fig. 2 shows a simplified flow chart of the entire original Four-Point-Algorithm proposed by [Amzallag et al, 1994].

3.2 *Damage Accumulation*

The effect of the cycles $rfc_i(j,:)$ on the fatigue process can be quantified by means of a damage accumulation. Based on material tests, it turns out, that the relation between the amplitude of a load hysteresis cycle s_a and the number of bearable cycles until failure N_a can often be expressed by simple empirical equations, like the Basquin-equation, see the left part of Equation (6) and [Bannantine, Corner and Handrock, 1990] for references:

$$N_a = N_E\left(\frac{s_a}{s_E}\right)^{-k} \quad \Leftrightarrow \quad \Delta D(j) = \frac{1}{N_a(j)} = \frac{1}{N_E}\left(\frac{s_a(j)}{s_E}\right)^{k} \quad \Rightarrow \quad D = \sum_{j=1}^{n_{RFCi}} \Delta D(j) . \quad (6)$$

Here, N_E, s_E and k are material parameters based on test results. In the log-scale, the Basquin-equation appears as a straight line, see the lower right subplot of Fig. 2. For each load amplitude s_a in RFC_i, which can be derived by:

$$s_a = s_a(j) = 0.5 \cdot \mathrm{abs}\left(rfc_i(j,1) - rfc_i(j,2)\right), \quad (7)$$

a so-called damage contribution $\Delta D(j)$, see the middle part of Equation (6), can be calculated. The step is also illustrated in the lower right subplot of Fig. 2. Subsequently, in the right part of Equation (6), all damage contributions are accumulated to a total damage value $D = D_i$, which is a scalar assessment criterion for the data Y_i in terms of durability.

3.3 *Adaptation to Multibody System Simulation: Online Damage Calculation*

The described process has one serious drawback. The amount of data produced is usually very bulky. If MBS simulation is carried out over long time intervals, the number of measurement points n_{Yi} is usually very high, e.g. approximately 10000 in the application mentioned in Section 2, see also [Matha, 2009]. Therefore, an adaptation of the Four-Point-Algorithm to MBS simulation is proposed here. This adapted algorithm calculates damage values during the runtime of the MBS, i.e. 'online', and the storage of load data Y_i can be set aside. Fig. 3 shows a flow chart of this adaptation, where additional functional blocks are double framed.

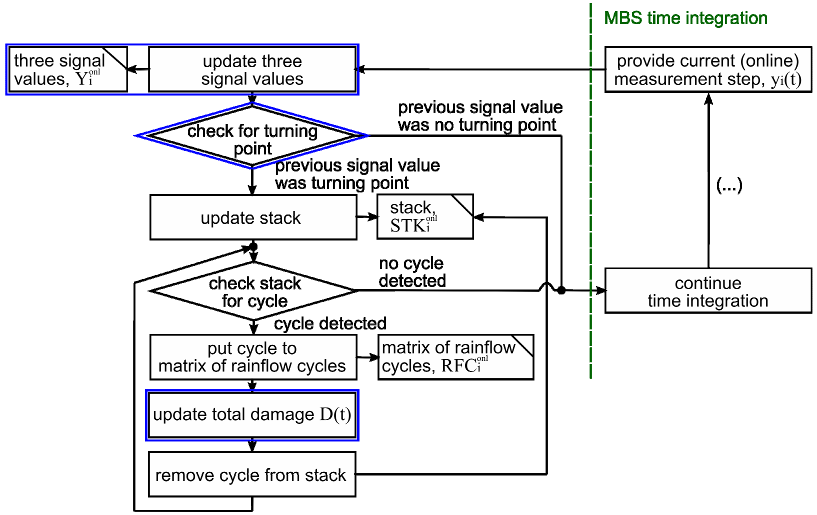

Fig. 3: Adapted Four-Point-Algorithm with online damage calculation

The online damage calculation interfaces the MBS time integration. After each time step of the time integration of Equation (1), yielding the current states $\mathbf{x}(t)$, the measurement Equation (2) has to be solved. The current interesting signal value $y_i(t)$ can be forwarded to the online damage calculation. It is stored in an array Y_i^{onl} consisting of three signal values: The current, the previous and the next-to-last signal value. Accordingly, the algorithm checks whether the previous signal value was a turning point. This can be done by a comparison of the slopes between the three signal points. If a turning point is detected, the native Four-Point-Algorithm, which is described in Section 3.1 and Fig. 2, can be activated. Henceforth, the stack and the matrix of rainflow cycles vary dynamically during the runtime of the MBS, a fact which is indicated by the superscript 'onl' in STK_i^{onl} and RFC_i^{onl}. Those sets are characterized by an MBS time-dependent number of elements, e.g. $n_{RFCi}^{onl} = n_{RFCi}^{onl}(t)$. If the algorithm detects a cycle in the signal, a damage contribution according to Equation (6) is calculated immediately. The previously computed total damage can then be updated. If no cycle is detected or the previous signal value was not a turning point, the MBS is requested for the next measured signal value.

The online damage calculation is based on three signal values Y_i^{onl}, i.e. $n_{Yi}^{onl} = 3$, which depend on the online output of the MBS time integration and not on the entire signal value data Y_i. Furthermore the storage of the rainflow cycle matrix is optional. These two properties allow the online damage calculation to be very efficient regarding data storage. The relevant scalar damage value $D(t)$ can be output directly during the MBS time integration. Its end value is the only relevant value to be stored.

4. Example Application: Design of Wind Turbines

Wind energy specific certification standards [IEC, 2005], issued by the International Electrotechnical Commission, require the manufacturer of new wind turbines to submit results of extensive numerical simulations of defined design load cases (DLC) to prove the structural viability of the turbine. These load cases comprise all possible operational and failure conditions a wind turbine is likely to experience in its 20 year lifetime, amounting to approximately 1000 to 3000 single load simulations with 2-60 minute duration each. Extreme and fatigue loads of all relevant parts of the turbine need to be analyzed for each load case separately, e.g. blade root bending forces and moments and tower base loads for normal turbine operation, see also Fig. 1.

Fatigue analysis is required in terms of damage equivalent loads (DELs). The damage equivalent load value for one load channel is denoted by DEL_i. It can be derived directly from the damage value D_i of Equation (6) by:

$$DEL_i = \left(\frac{N_E D_i}{n_{RFCi}} \right)^{1/k} . \qquad (7)$$

It characterizes a constant load amplitude, whose n_{RFCi}–times occurrence causes the same damage as the investigated (irregular) load signal.

In conventional post-processing tools, the high resolution load data Y_i from one load case, comprising e.g. 10 hours real time simulations, are loaded in random access memory and rainflow counting is performed. The results are extrapolated and weighted according to the on-site wind speed probability distribution and DELs are computed. The online damage calculation presented in this paper offers a computationally efficient method to reduce significantly the memory requirements of a typical load case analysis. Table 1 shows the disk space advantage, for a standard production design load case for a representative turbine (NREL 5MW Baseline WT, see also [Matha, 2009]) with normal wind and wave conditions.

Table 1: Disk space advantage of online damage calculation compared to conventional post- processing

DLC [IEC, 2005]	number of sims.	necessary disk space: conventional post-processing	necessary disk space: online damage calculation	ratio
DLC 1.1	120	120x3MB = 360MB (bin.)	120x6KB = 720KB (asc.)	≈5.0x10^2
		120x7.7MB = 924MB (asc.)		≈ 1.3x10^3

Besides simulations for certification purposes, extensive load case analysis is performed during the design of a turbine, to evaluate the performance of design changes of mechanical and structural components, or to assess different control strategies. Relative comparisons of DELs are e.g. used as major criteria for the performance of different controller setups. Fig. 4 shows a sample DEL-comparison between an active control solution, a blade pitch-controlled tower feedback controller (TFC) and a passive mass damper (PMD) for the tower base bending moment of an offshore wind turbine, see also [Fischer and Kühn, 2010]. The computed DEL values are normalized with respect to reference values without any modification (index 'ref'). Availability of wind turbines is defined as the ability to operate when the wind speed is higher than the wind turbine's cut-in wind speed and lower than its cut-out speed.

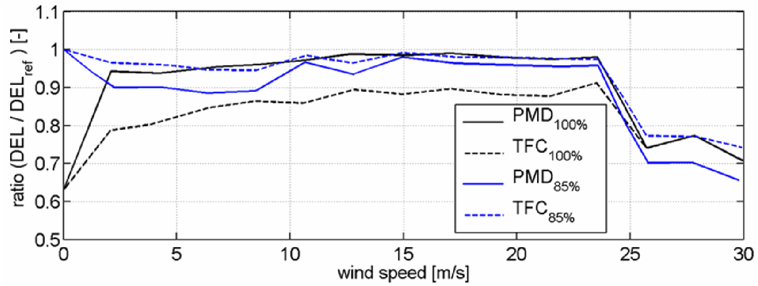

Fig. 4: Relative change in DEL of tower base bending moment for different control concepts and cases of availability (with $N_E = 2x10^6$ and $k = 4$)

Both the PMD and TFC concept lead to a significant reduction in fatigue loading at the tower base for all wind speeds. For an availability of 100%, the damage reduction by the TFC is greater than by the PMD. This is due the fact that the impact of increased aerodynamic damping from the TFC with active blade pitch control during operation is enormous and acts as a damping device for the high hydrodynamic loading. For an availability of 85%, the PMD reduces the lifetime damage to a greater extent than the TFC, since the TFC does not operate when the turbine is not in operation (15%). Therefore, for lower availabilities common for current offshore wind farms, the active TFC system is not competitive with the passive PMD device in reducing the lifetime damage, as the passive system is always operating independent of the turbine availability.

For such studies, the immediate availability of fatigue DEL results after a simulation without post-processing is also beneficial to speed up the design process and make analysis more convenient.

5. Conclusions

The online damage calculation, which is proposed in this paper, is an appropriate method for durability-based data reduction of MBS results. The main advantage of this algorithm is its low data storage and therefore disk space requirements. Furthermore, the algorithm delivers a scalar durability assessment for load channels immediately after the MBS simulation, without any post-processing. The online damage calculation can be used advantageously in several areas of application, such as the design of wind turbines or structural optimisation based on durability values [Tobias and Eberhard, 2010]. It has been demonstrated that the online damage calculation can be implemented successfully using commercial MBS code [Tobias and Eberhard, 2011].

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EUROPEAN MECHANICS SOCIETY

EUROMECH Young Scientist Prize Paper

"Chaos in Idealized Body-Fluid Interactions"

Johan Roenby won the EUROMECH Young Scientist Prize, awarded at the ENOC Conference held in Rome, 24-29 July 2011

Johan Roenby[1]

Abstract

Our goal is to understand the fundamental dynamics of bodies moving through fluids. In particular we wish to understand the interaction of a body with vortices in the fluid. We derive an idealized model for such interactions, where the equations of motion are a finite set of nonlinearly coupled ordinary differential equations for the body and vortex motion. We investigate these solutions numerically and analytically with emphasis on transitions between integrable, regular, and chaotic motion. Using Poincaré sections generated from numerical solutions, we discover several transitions between chaotic and regular dynamics. A mechanistic understanding of these transitions is obtained by investigating the numerical solutions near the transitions and by comparing the motion to special integrable solutions.

1. Introduction

Immersed in fluids as we are here on Earth – whether in the air of the atmosphere or the water of the ocean - the problem of a body moving through a fluid is a pretty important one. A key phenomenon attached to such motion is the generation and shedding of vortices from the body. Once generated, these spinning structures have a tendency to remain intact for quite a while, moving with the flow almost as if they were material, rather than structural, in nature. They may exert significant forces on bodies in their proximity. For the offshore oil industry, vortex induced vibrations of the vertical riser pipelines, bringing oil from the seabed to a platform, is a dangerous issue that may have catastrophic consequences, if care is not taken. For a swimming person, or a flying insect for that matter, the job is largely a matter of controlling their interaction with the vortices generated, as they move through their respective fluids.

2. The idealized body-vortex model

To study the fundamental interaction of such body-vortex interactions we now present an idealized model, which we believe captures at least some of the essential dynamical features. The model is a combination of two classical problems, namely, the motion of point vortices in an unbounded ideal (i.e. incompressible and inviscid with constant density, ρ_f) fluid in the plane, and the free motion of a rigid body in a similar environment. The former problem was born in Helmholtz' seminal 1858 paper [1], while the latter problem dates back to the work of Kirchhoff and Kelvin around 1870 [2]. A sketch of the combined system is shown in Fig.1.

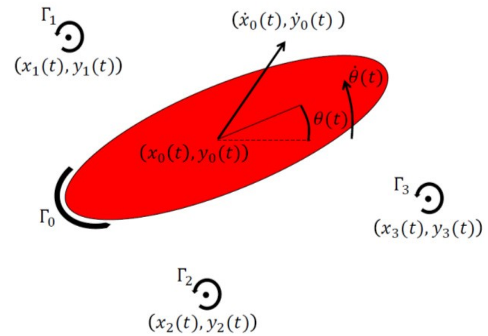

Fig. 1: Sketch of the model investigated in this paper. N point vortices of strengths $\Gamma_1, \dots, \Gamma_N$ move around in an unbounded ideal fluid also containing a freely moving rigid body with circulation Γ_0 around it.

Point vortices in ideal fluid

The point vortices may be thought of as delta functions in the vorticity field at positions (x_α, y_α), $\alpha = 1, \dots, N$, much like point masses and charges are delta functions in the mass and charge density fields studied in classical gravitational and electromagnetic theory. A point vortex induces a velocity field in the surrounding fluid making the fluid spin around it as indicated with arrows in Fig.1. The speed of this tangential flow is inversely proportional to the distance. The constant of proportionality is termed the vortex strength, and is identical to the circulation around the vortex. The vortex strengths, $\Gamma_1, \dots, \Gamma_N$, of the N vortices are parameters of our model that may be chosen at will to mimick a situation of interest. The conservation of these quantities follows from Kelvin's circulation theorem. This conservation law of course also means that our model does not describe the mechanisms of vortex generation at the boundary of a body. Nor does it describe the gradial dissipation of vorticity due to viscous effects. While these are important aspects of body-vortex interactions, it nevertheless makes sense to turn our focus for a moment to the dynamic interplay in the time window after the vortices have been generated and before they are dissipated.

Body motion in ideal fluid

To represent the motion of the body we attach a coordinate system to it, at position (x_0, y_0) relative to the laboratory frame, with the abscissae of the body-fixed frame and the laboratory frame making an angle θ. In Fig.1 we show an elliptic body, but the body may have any shape as long as the region it occupies is simply connected.

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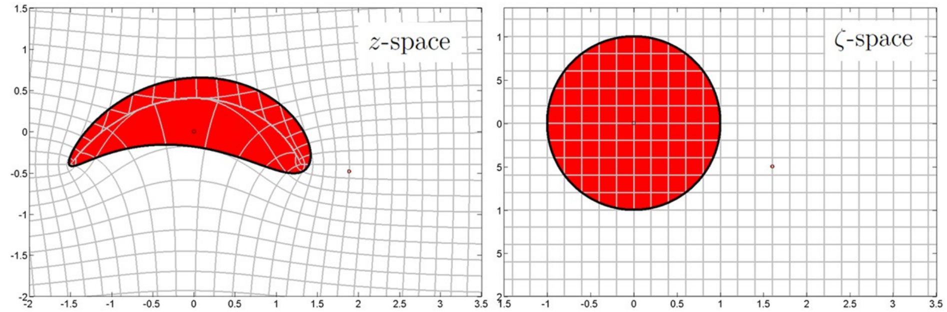

Fig. 2: Example of a conformal mapping from the complex ζ-plane to the complex z-plane such that the exterior of the unit circle in the ζ-plane maps to the exterior of a Joukowski shaped body in the z-plane.

By the Riemann mapping theorem any such body shape $\mathcal{C}$ may be obtained by a conformal mapping,

$$z = z_0 + f(\zeta)e^{i\theta},$$

from a circle in the ζ-plane, i.e., $\mathcal{C} = z_0 + f(\{|\zeta| = 1\})e^{i\theta}$. Here $z = x + iy$ is the position in the plane in complex notation, while $z_0 = x_0 + iy_0$ is the complex body position. An example of a conformal mapping is shown in Fig.2.

Because the body is assumed rigid, the conformal mapping $f(\zeta)$ is independent of time. The body motion is described by the time dependence of $z_0(t)$ and $\theta(t)$. The body velocity is represented by the time derivatives of these coordinates, $(\dot{x}_0(t), \dot{y}_0(t), \dot{\theta}(t))$. The velocity vector $(\dot{x}_0, \dot{y}_0)$ may be decomposed into its components in a coordinate system aligned with the body. These body-aligned coordinates we denote by hats. In complex notation, we then have $\hat{v}_1 + i\hat{v}_2 = (\dot{x}_0 + i\dot{y}_0)e^{-i\theta}$.

The velocity field induced in the fluid by the body motion is a linear superposition of the three instantaneous velocity "components", $\hat{v}_1(t)$, $\hat{v}_2(t)$, and $\omega(t) = \dot{\theta}$, multiplied by special "shape functions", or unit velocity fields, if you will. These unit velocity fields are constant in time and are uniquely determined by the shape of the body represented by $f(\zeta)$. They may be obtained by solving the Laplace equation for the velocity potential in the fluid, imposing the impermeability boundary condition on the (moving) body contour, and requiring the flow to die out at infinity. We note that potential flow theory allows slip at the body contour. Thus, the velocity field due to the body motion is only defined up to a constant that specifies the circulation around the body. This circulation is denoted by Γ_0 in Fig.1, and is yet another parameter that may be chosen at will in our model. The total circulation along a contour enclosing all the vortices and the body is denoted by

$$\Gamma = \sum_{\alpha=0}^{N} \Gamma_\alpha.$$

Equations of motion

With the body position, orientation, and linear and angular velocity specified, and with the circulation around the body specified, and the positions and strengths of the N vortices specified (Fig.1) the fluid flow can be uniquely determined. Since the boundary value problem we must solve to find this instantaneous flow is linear, the flow is simply a superposition of the flow due to the body motion, and the flow due to the vortices (in the presence of the body). In complex notation the fluid velocity may be written,

$$\overline{u(z,t)} = \frac{e^{-i\theta(t)}}{f'(\zeta)}\left[\hat{v}_1(t)w_1'(\zeta) + \hat{v}_2(t)w_2'(\zeta) + \omega(t)w_3'(\zeta) + \frac{\Gamma}{2\pi i}\frac{1}{\zeta} + \sum_{\alpha=1}^{N}\frac{\Gamma_\alpha}{2\pi i}\left(\frac{1}{\zeta - \zeta_\alpha(t)} - \frac{1}{\zeta - 1/\overline{\zeta_\alpha(t)}}\right)\right].$$

Here the bars denote complex conjugation, primes denote differentiation with respect to $\zeta = f^{-1}(\tilde{z})$, where the position in the body-fixed frame is denoted with a tilde, i.e., $\tilde{z} = (z - z_0)e^{-i\theta}$. Likewise the positions of the α'th vortex in the ζ-plane is $\zeta_\alpha = f^{-1}(\tilde{z}_\alpha)$, where the corresponding body-fixed position is $\tilde{z}_\alpha = (z_\alpha - z_0)e^{-i\theta}$. The functions $w_j = \phi_j + i\psi_j$ for $j = 1,2,3$, are the unit complex potentials associated with body motion.

By the theory of Lin[3], the motion of a point vortex may be obtained by subtracting its own singular contribution from the above velocity field in the following way,

$$\overline{\dot{z}_\alpha(t)} = \lim_{z \to z_\alpha(t)}\left(\overline{u(z,t)} - \frac{\Gamma_\alpha}{2\pi i}\frac{1}{z - z_\alpha(t)}\right), \quad \alpha = 1, \dots, N.$$

Taking this limit, one finds

$$\overline{\dot{z}_\alpha} = \frac{e^{-i\theta}}{f'(\zeta_\alpha)}\left[\hat{v}_1 w_1'(\zeta_\alpha) + \hat{v}_2 w_2'(\zeta_\alpha) + \omega w_3'(\zeta_\alpha) + \frac{\Gamma}{2\pi i}\frac{1}{\zeta_\alpha} - \frac{\Gamma_\alpha}{2\pi i}\left(\frac{1}{2}\frac{f''(\zeta_\alpha)}{f'(\zeta_\alpha)} + \frac{1}{\zeta_\alpha - 1/\overline{\zeta_\alpha}}\right) + \sum_{\beta \neq \alpha}^{N}\frac{\Gamma_\beta}{2\pi i}\left(\frac{1}{\zeta_\alpha - \zeta_\beta} - \frac{1}{\zeta_\alpha - 1/\overline{\zeta_\beta}}\right)\right], \quad \alpha = 1, \dots, N, \tag{1}$$

where the sum runs from $\beta = 1$ to N skipping α. For simplicity of notation we have dropped the explicit specification of time dependency.

The above equations are valid for any motion of the body, whether free, forced, or confined to a specified trajectory. As mentioned, we will mainly be interested in the case of free body motion. By free we mean that the only force on the body is that due to the instantaneous pressure distribution along its surface. Another way to put it is that the total linear and angular momentum of the fluid plus body, considered as one unified system, must be constants of the motion. Since no energy is added to, or extracted from, the unified system, the total energy is also conserved. We may write these conservation laws as:

Linear impulse: $P = \rho_f \int_{fluid} u dA + \int_{body} \rho u dA - \infty$

Angular impulse: $L = \rho_f \int_{fluid} (z \times u) dA + \int_{body} (z \times \rho u) dA - \infty$

Interaction energy: $E = \rho_f \int_{fluid} \frac{1}{2}|u|^2 dA + \int_{body} \frac{1}{2}\rho|u|^2 dA - \infty$

For fluids extending to infinity and containing point vortices there are singular terms in the momentum and energy integrals above. Discarding these terms (symbolized by the "$-\infty$" terms above), and keeping only "interaction terms", we get the impulses (instead of the momenta) and the interaction energy.

In the above expressions the integrals over the entire plane are split into an integral over the fluid region, and an integral over the area occupied by the body. The linear impulse has two components, $P = (P_1, P_2)$, while the angular impulse, L, an the interaction energy, E, are scalars. The fluid density ρ_f is constant, but the internal mass distribution of the body, ρ, may be chosen at will. This choice determines the dynamic response of the body via the resulting body mass, center of mass, and moment of inertia, respectively,

$$m = \int_{body} \rho dA, \quad \tilde{z}_{cm} = \frac{1}{m}\int_{body} \rho \tilde{z} dA, \quad I_0 = \int_{body} \rho |\tilde{z}|^2 dA.$$

Using the fluid velocity field described above, and the rigid body motion, $u = \dot{x}_0 + i\dot{y}_0 + i\omega(z - z_0)$, in the body integrals, the impulses may be calculated. Because the velocity field, $u(z,t)$, only depends linearly on the body velocity components, $(\hat{v}_1, \hat{v}_2, \omega)$, so will the linear and angular impulses, (P_1, P_2, L). Therefore the resulting equations for (P_1, P_2, L) in terms of the dynamical variables $(x_1, y_1, \ldots, x_N, y_N, x_0, y_0, \theta, \hat{v}_1, \hat{v}_2, \omega)$ may be inverted to obtain expressions for $(\hat{v}_1, \hat{v}_2, \omega)$ in terms of the remaining dynamical variables with (P_1, P_2, L) as parameters determined by the initial conditions. The resulting body velocity equations read

$$\begin{pmatrix} \hat{v}_1 \\ \hat{v}_2 \\ \omega \end{pmatrix} = M^{-1}\left[\begin{pmatrix} \hat{P}_1 \\ \hat{P}_2 \\ L - z_0 \times P \end{pmatrix} - \rho_f \Gamma \begin{pmatrix} \hat{y}_0 \\ -\hat{x}_0 \\ \frac{1}{2}|z_0|^2 \end{pmatrix} + \rho_f \sum_{\alpha=1}^{N} \Gamma_\alpha \begin{pmatrix} -\tilde{y}_\alpha + \psi_1(\zeta_\alpha) \\ \tilde{x}_\alpha + \psi_2(\zeta_\alpha) \\ \frac{1}{2}|\tilde{z}_\alpha|^2 + \psi_3(\zeta_\alpha) \end{pmatrix}\right]. \quad (2)$$

Here M is a constant 3x3 matrix, the so-called virtual mass matrix, determined by the body shape and mass distribution,

$$M = \begin{pmatrix} m + \rho_f A_{11} & 0 & -m\tilde{y}_{cm} + \rho_f A_{13} \\ 0 & m + \rho_f A_{22} & m\tilde{x}_{cm} + \rho_f A_{23} \\ -m\tilde{y}_{cm} + \rho_f A_{13} & m\tilde{x}_{cm} + \rho_f A_{23} & I_0 + \rho_f A_{33} \end{pmatrix}$$

The elements of the added mass matrix appearing here are

$$A_{jk} = -\frac{1}{2i}\oint_{|\zeta|=1} \overline{w_j(\zeta)} \frac{dw_k}{d\zeta} d\zeta, \quad j,k = 1,2,3.$$

The hats appearing in Equation 2 denote components in the aligned coordinates, i.e.

$$\hat{P}_1 + i\hat{P}_2 = (P_1 + iP_2)e^{-i\theta} \text{ and } \hat{x}_0 + i\hat{y}_0 = (x_0 + iy_0)e^{-i\theta}.$$

The important thing to note is that Equations 1 and 2 constitute an autonomous set of coupled ordinary differential equations for the time derivatives of the body and vortex positions. We have effectively exploited the conservation of linear and angular impulse to get rid of the equations for the linear and angular body acceleration, thus reducing the dimension of phase space from $2N + 6$ to $2N + 3$. Given the classical character of this system, it is quite surprising that almost no work was done on this type of coupling during the 20th century. Only recently were the equations fully derived in [4] and [5]. Here the Hamiltonian nature of the equations was also demonstrated, with the interaction energy, E, serving as the Hamiltonian, if a clever choice is made for the independent phase space coordinates. A number of minor errors and ambiguities were clarified in [6], from where the present form of the equations is taken.

3. Integrability and chaos

At first sight the full system of equations may seem a little overwhelming and difficult to analyze. There are, however, a number of integrable limiting cases that one may study to gain insight into the dynamics. For instance if all the vortices are "turned off", we are back at the Kirchhoff-Kelvin equations for a free body moving in an unbounded ideal fluid. This system is well-known to be completely integrable with the body either rocking or tumbling through the fluid depending on its shape and initial velocity. If instead we let the body shrink to a point, we end up at the $N + 1$ point vortex problem (provided $\Gamma_0 \neq 0$), which is well-known to be completely integrable for $N + 1 \leq 3$. Further special cases exist when the linear impulse P and the total circulation Γ both vanish. For details see [7].

A body and a single point vortex

Here we will focus on the case where a body interacts with a single vortex. It can be shown that when the body is circular (and of uniform mass distribution ρ_b) then this problem is completely integrable [8]. For integrable systems, there is typically a two-dimensional reduced system of phase space coordinates in which the solution orbits may be plotted as the contours of an energy landscape. For our system a convenient set of coordinates turns out to be the vortex position relative to the body. Fig.3 shows an example of such an energy landscape, where $\Gamma_0 = -1$, $\Gamma_1 = 1$, $\rho_f = 1$, and $\rho_b = 4$.

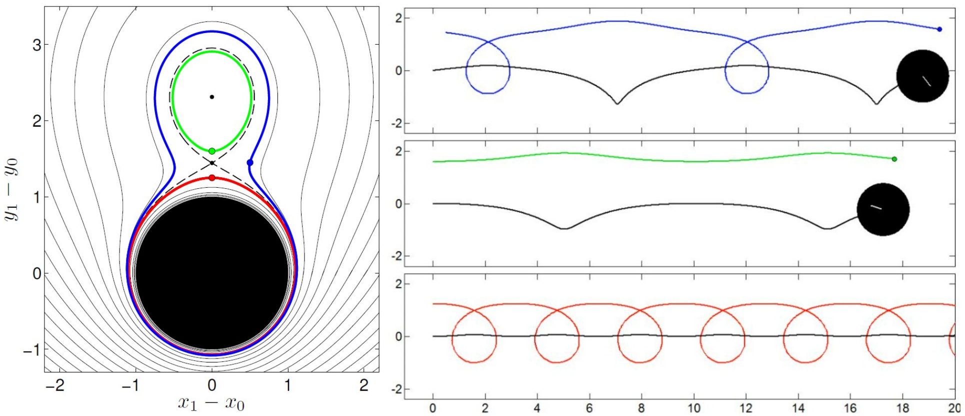

Fig. 3: Left: Contours of the energy function E in the reduced phase space spanned by the vortex position relative to the body, $(x_1 - x_0, y_1 - y_0)$, for a system of one vortex and a circular body (black circle). In this example $\Gamma_0 = -1$, $\Gamma_1 = 1$, $\rho_f = 1$, and $\rho_b = 4$. Three orbits have been colored. Right: The body (black) and vortex (colored) trajectories for the corresponding colored solutions in the left panel. The body-vortex pair starts at the left side and travels to the right.

Basically, there are three types of unsteady motion as demonstrated with the three colored contours in the figure. The corresponding trajectories of the body and vortex are shown in Fig.3(right). In all cases the body and vortex travel through the fluid in the direction of the linear impulse, P, in this case pointing in the positive x-direction. For two of the three types of motion (red and blue) the body and vortex also orbit around each other, while for the last type (green) they simply travel alongside through the fluid with small undulations in their relative positions. The division into these three types of motion is caused by the existence of a stable and an unstable relative equilibrium solution (small black dots in Fig.3, left panel), where the body and vortex simply move steadily through the fluid in the direction of P without moving relative to each other. If we added a perturbative noise to the stable solution, the motion would be essentially unaltered except for small irregular undulation in the relative body-vortex position. The qualitative behavior would not differ significantly from the periodic behavior observed in the undisturbed state. If, however, we were to add noise to the system in the unstable steady state, this would cause the motion to shift randomly between the three types of motion shown with color in Fig.3. The choice of type would be determined by the particular value of the noise as the system approaches the saddle point.

In Fig.4 we show the body-vortex trajectories for an initial configuration very close to the unstable equilibrium state. The irregular character of the trajectories is, however, not the result of adding noise to the system. Rather we have made the body slightly elliptic. The crucial difference here is that for a completely circular body its rotation decouples completely from the fluid.

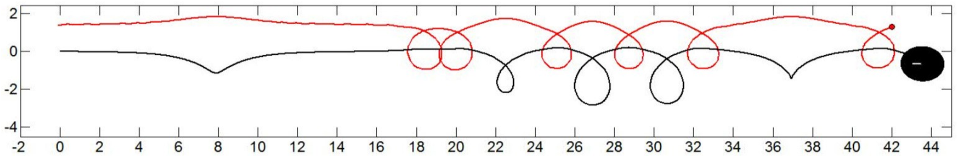

Fig. 4: Trajectories of body (black) and vortex (red) for a body-vortex pair started near the unstable equilibrium in Fig.3(left), but with the body being slightly elliptic. The pair travels from left to right.

No velocity field is generated by rotation of the body (because of the slip condition) and in turn, the fluid cannot alter the angular rotation of the body. As soon as the body becomes slightly elliptic, as in Fig.4, this no longer holds. Any small rotation of the body will generate a small velocity field in the fluid. This clearly affects the vortex, and thus serves effectively as a random perturbation to the vortex motion, causing the irregularity observed in Fig.4.

Poincaré sections

To demonstrate that the behavior observed in Fig.4 is actually chaotic we generate Poincaré sections. These are generated by numerically calculating a large number of solution orbits with different initial conditions, and then plotting the orbit intersections with some chosen surface in phase space. One must make sure that the chosen surface is actually crossed by the calculated solution and one should also take care when choosing the family of orbits to include in the Poincaré section. We may choose our laboratory coordinates such that the elliptic body always starts at the origin with its major axis aligned with the abscissa. It turns out that for our particular system the phase space plane defined by $\theta = 2\pi n$ for $n \in \mathbb{Z}$ is a convenient choice of intersection surface. The question remains which orbits we should include in the Poincaré section. Here it turns out that the solutions are ordered in 1-parameter families where all members of a given family have the same values of the four constants of motion, (P_1, P_2, L, E).

For instance the positions marked by dots along one of the contours in Fig.5(left) are initial vortex positions relative to the body where (for the right choice of initial body velocity) the solutions will have the same impulses and energy. Calculating long time series for these 21 solutions and plotting the position of the vortex relative to the body every time the body returns to its original orientation one obtains the Poincaré section in Fig.5(right). As is evident from this figure, the slight eccentricity of the body renders the solutions near the unstable relative equilibrium in Fig.3(left) chaotic, while those near the stable equilibrium and those further from the body are still regular. This behavior we now understand from our previous discussion of disturbing solutions near the stable and unstable equilibria of the integrable system with a circular body.

To demonstrate how chaos gradually takes over as the body eccentricity is increased, we plot in Fig.6 an eccentricity scan. In the upper left corner, we start with a circular body, and in the lower right corner we end up with a very flat ellipse. The Poincaré sections are generated like Fig.5(right) with the one exception that we choose to plot the points in a three dimensional

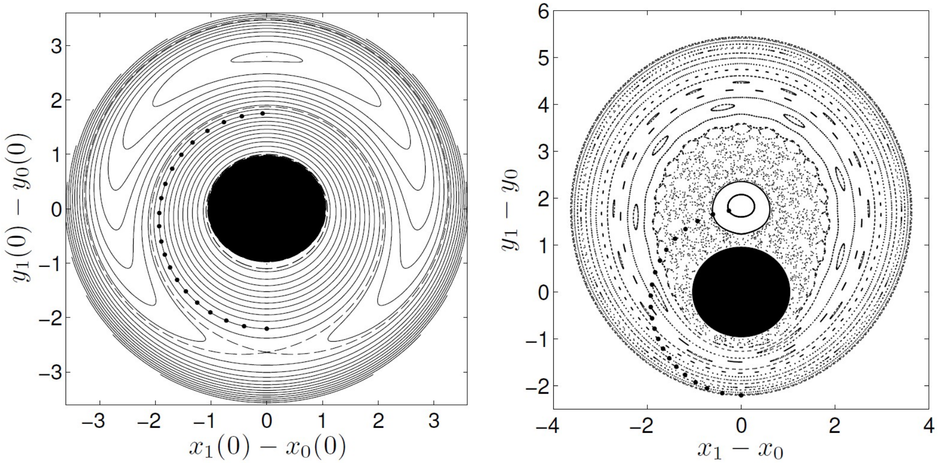

Fig. 5: Left: Contours demonstrating the 1-parameter families of solutions having the same values of the four constants of motion, (P_1, P_2, L, E). Solutions where the vortex is initially placed at different positions along one of these contours may have the same values of (P_1, P_2, L, E), if the body initial velocity is chosen properly. Right: Poincaré section generated from the 21 initial conditions marked by dots in the left panel. See text for further

reduced phase space spanned by the body velocity coordinates, $(\dot{x}_0, \dot{y}_0, \dot{\theta})$ rather than the two dimensional phase space spanned by $(x_1 - x_0, y_1 - y_0)$. It is evident how the increased coupling between the vortex and the rotational motion of the body makes a still larger fraction of the solutions chaotic. Nevertheless, even for the very flat ellipse in the lower right panel at least a single regular solution still persists. The pictures of such “pockets” of regularity in a chaotic “ocean” (and from Fig.5(right), chaotic regimes in an otherwise smooth “flow”) may be useful to keep in mind, when analyzing real flow data, where sudden transitions between smooth and apparently random states are often observed.

4. Concluding remarks

We have shown how a finite dimensional model, tractable to analysis by tools form dynamical system theory, may be derived for the interaction of a rigid body in a fluid containing vortices. The system is Hamiltonian with four constants of motion: The two components of the total fluid plus body linear impulse, the corresponding angular impulse, and the kinetic energy associated with the body-fluid interaction. The system of a circular body of uniform mass interacting with a single point vortex is completely integrable, essentially due to the decoupling of the fluid motion and body rotational motion. Breaking this “symmetry”, e.g., by making the body slightly elliptic, the system exhibits chaos, especially near an unstable solutions of the integrable circle-vortex system. There are many other interesting cases to analyze, e.g. the interaction of a free body with two point vortices. For more details on such cases the reader is referred to [8].

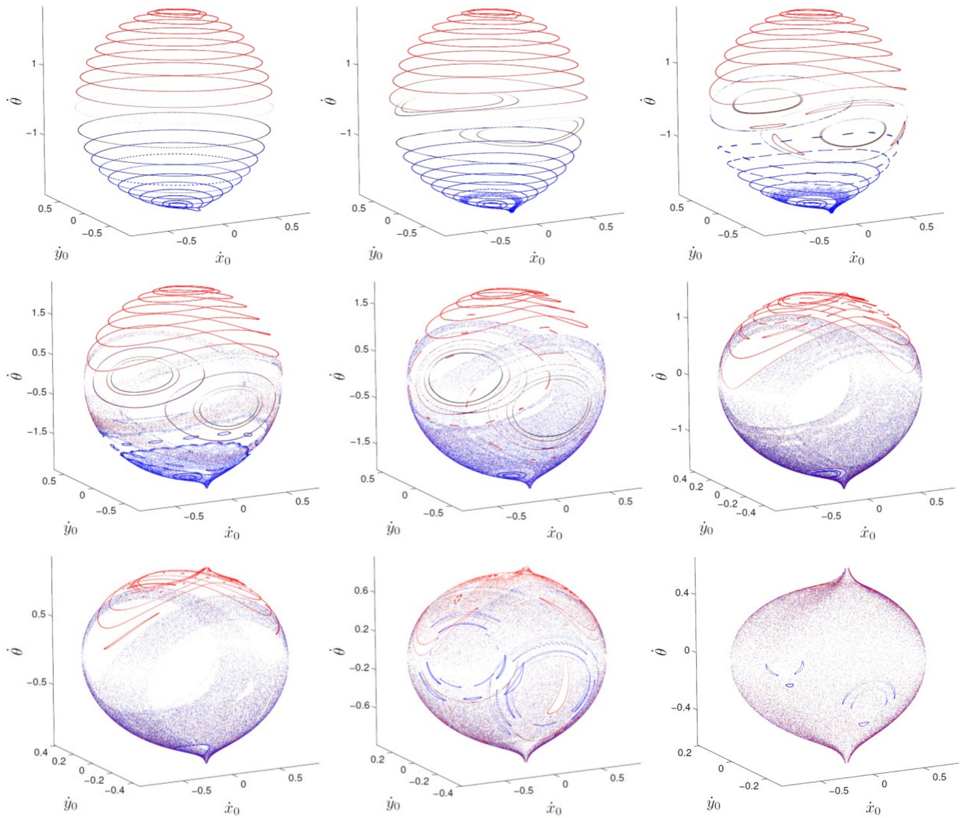

Fig. 6: Poincaré sections for a body-vortex pair with $\Gamma_0 = -1$, $\Gamma_1 = 1$, $\rho_f = 1$, and $\rho_b = 1/4$. Points correspond to intersections of solution orbits with the plane $\theta = 2\pi n$, $n \in \mathbb{Z}$. The points are plotted in a reduced phase space spanned by the body velocity coordinates $(\dot{x}_0, \dot{y}_0, \dot{\theta})$. From left to right and top to bottom the eccentricity of the body is gradually increased, such that the upper left panel corresponds to a circular body and the lower right corner corresponds to a “cigar shaped” body.

Dedication

This paper is dedicated to the memory of my dear supervisor, Hassan Aref, who died, suddenly and way too soon, from an aortic dissection on September 9, 2011.

5. References

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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.

EUROMECH - European Mechanics Society

NOMINATION FORM FOR FELLOW

NAME OF NOMINEE: ....

OFFICE ADDRESS: ....

....

EMAIL ADDRESS: ....

FIELD OF RESEARCH: ....

Fluids: ☐ Solids: ☐

NAME OF SPONSOR 1: ....

OFFICE ADDRESS: ....

....

....

EMAIL ADDRESS: ....

SIGNATURE & DATE: ....

NAME OF SPONSOR 1: ....

OFFICE ADDRESS: ....

....

....

EMAIL ADDRESS: ....

SIGNATURE & DATE: ....

EUROMECH- European Mechanics Society: Fellow Application

EUROPEAN MECHANICS SOCIETY

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;
- Sponsor'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

EUROPEAN MECHANICS SOCIETY

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 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:

- 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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EUROPEAN MECHANICS SOCIETY

EUROMECH Conferences in 2012

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.

ESCM8
8th European Solid Mechanics Conference
DATE: 9-13 July 2012
LOCATION: Graz, Austria
CONTACT: Prof. G.A. Holzapfel
E-MAIL: holzapfel@tugraz.at

EFMC9
9th European Fluid Mechanics Conference
DATE: 9-13 September 2012
LOCATION: Rome, Italy
CONTACT: Prof. Roberto Verzicco
E-MAIL: verzicco@uniroma2.it

EUROMECH Conferences Reports

"7th European Nonlinear Dynamics Conference (ENOC 2011)"

July 24 - 29 2011, Rome, Italy

Chairperson: Prof. Giuseppe Rega

Although the name ENOC (European Nonlinear Oscillations Conference) is still used as the historical abbreviation, the European Nonlinear Dynamics Conferences aim to cover the complete field of Nonlinear Dynamics, including Multibody and Stochastic Dynamics and coupling to Stability, Identification, Control and (Structural) Optimization. During recent decades, the field of nonlinear dynamics has been evolving rapidly, with applications to a wide variety of engineering systems. These have been made possible by the use of sophisticated computational techniques, employing powerful concepts and tools for the study of dynamical systems, bifurcation and chaos theory.

Two main general issues characterize the present research framework:

- The need to overcome the limitations inherent in the archetypal single- or few degree-of-freedom models mostly considered in the past, and to deal with real systems;
- The increased interest in exploiting nonlinear dynamics modelling and analysis for designing physical and engineering systems, and controlling their nonlinear and complex behaviour.

The aim is towards:

- developing more reliable reduced-order models for the analysis of the real high-dimensional systems and processes encountered in technical applications;
- obtaining further meaningful hints for model validation from calibrated experimental investigations;
- generalizing concepts and techniques for the analysis of new complex behaviours;
- exploring the implications of nonlinearity and chaos in the design and operating conditions of advanced systems, as well as requirements for their control.

Overall, it is important to remember how difficult and involved is the passage from simple models to actual engineered systems, with their inherent complexity.

ENOC 2011 aimed at bringing together a wide variety of specialists, in order to:

- show the latest achievements;
- foster future directions for development;
- exchange experience;
- stimulate further interaction, by in-depth exploration of both theory and recent applications of nonlinear dynamics

Topics

The topics of ENOC 2011 included, but were not limited to:

- Models and methods (analytical, numerical, geometrical, symbolic,
- experimental) in nonlinear dynamics;
- Qualitative and quantitative analysis of nonlinear dynamic systems;
- Nonlinear dynamics of continuous, discontinuous and hybrid systems;
- Bifurcations and chaos;
- Nonlinear stochastic systems;
- Nonlinear dynamic phenomena;
- Control of oscillations and chaos;
- Applications in mechanics at different scales, and real problems from any branch of engineering science including: mechanical, civil, electronic, electrical, communication, medical, materials;
- Cross-disciplinary topics from: applied mathematics, physics, biophysics, genetics, nanotechnology, finance, medicine and earth sciences.

"8th EUROMECH Fluid Mechanics Conference (EFMC8)"

13–16 September 2010, Bad Reichenhall, Germany

Chairperson: Prof. Nikolaus Adams, Lehrstuhl für Aerodynamik und Fluidmechanik, Technische Universität München, Germany.

The conference was attended by 510 researchers from around the world, including 173 researchers under the age of 35. The main purpose of the Conference was to bring together researchers with a common interest in fluid mechanics. The 380 oral presentations in 11 sessions covered the entire range of topics in fluid mechanics including the theoretical, computational and experimental areas of the discipline. Each of the oral presentations (12 minutes) in these sessions was followed by time for questions and further discussion.

In addition, 5 minisymposia were hosted, focusing on the topics of Fluid-structure interaction, Geophysical processes, Reactive flows, Particle methods in fluid dynamics, and EUCASS-EUROMECH mini-symposium on Flow Control. In these minisymposia, a number of invited papers were presented by experienced researchers, with the aim of providing training to early-stage researchers in these particular areas of fluid mechanics research.

Furthermore, seven plenary lectures were presented by internationally-recognized researchers, and J. Hinch was awarded the EUROMECH Fluids Prize and gave the EUROMECH Fluids Lecture entitled "A perspective of Batchelor's research in Micro-hydrodynamics".

The two coffee breaks and the lunch that took place each day provided many opportunities for further discussion, interaction and networking. This was also the first large-scale meeting to take place in the Royal Spa House, Bad Reichenhall, a town renowned for its art and culture as well as its thermal springs. Much positive feedback was received by the organisers regarding the facilities, the organisation of the event and the quality of the papers presented. The conference banquet was held at the Konzertrotunde of the Royal Spa House.

The website http://efmc8.aer.mw.tum.de/ remains live, at which abstracts of all presentations, together with the presentations of the plenary lecturers can be found.

EUROMECH Colloquia in 2012

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 Chairman. Proceedings are not normally published. Those who are interested in taking part in a Colloquium should write to the appropriate Chairman. Number, Title, Chairperson or Co-chairperson, Dates and Location for each Colloquium in 2010, and preliminary information for some Colloquia in 2011 and 2012, are given below.

514. New trends in Contact Mechanics
Chairperson: Dr. Michel Raous
Directeur de Recherche CNRS
Laboratoire de Mécanique et d'Acoustique
31, Chemin Joseph Aiguier
13402 Marseille Cedex 20, France
Email : raous@lma.cnrs-mrs.fr
Co-chairpersons: Prof. Peter Wriggers
Dates and location: 27-31 March 2012, Cargese, Corsica, France
http://euromech514.cnrs-mrs.fr/

524. Multibody system modelling, control and simulation for engineering design
Chairperson: Prof. Ben Jonker
University of Twente, Faculty CTW
Mechanical Automation
P.O. Box 217 – Building Horst
7500 AE Enschede, The Netherlands
Email : J.B.Jonker@utwente.nl
Co-chairpersons: Prof. Werner Schiehlen
Dates and location: 27 February-1 March 2012, Enschede, The Netherlands
http://www.utwente.nl/ctw/euromech524/

528. Wind Energy and the impact of turbulence on the conversion process
Chairperson: Dr. Joachim Peinke
Institute of Physics & ForWind
University of Oldenburg
D 26111 Oldenburg, Germany
Email: peinke@uni-oldenburg.de
Co-chairpersons: -
Dates and location: 22 - 24 February 2012, Oldenburg, Germany

532. Time-periodic structures:current trends in theory and application
Chairperson: Dr. Fadi Dohnal
Institute for Structural Dynamics
Department of Mechanical Engineering
Technische Universität Darmstadt
Petersenstr. 30, 64287 Darmstadt, Germany
Email: dohnal@sdy.tu-darmstadt.de
Co-Chairperson: Prof. Dr. J. J. Thomsen
Dates and location: 27-30 August 2012, TU Darmstadt, Germany
http://www.sdy.tu-darmstadt.de/euromech532

533. Biomechanics of the Eye
Chairperson: Dr Rodolfo Repetto
Department of Civil Environmental and Architectural Engineering,
University of Genoa
Via Montallegro 1, 16145, Genoa, Italy
Email: rodolfo.repetto@unige.it
Co-Chairpersons: Jennifer Siggers, Alessandro Stocchino, Michael Girard
Dates and location: July 2012, University of Genoa, Italy

534. Advanced experimental approaches and inverse problems in tissue biomechanics
Chairperson: Prof. Stéphane Avril
Ecole Nationale Supérieure des Mines
158 cours Fauriel, 42023 SAINT-ETIENNE cedex 2
Email: avril@emse.fr
Co-Chairperson: Prof. Sam Evans
Dates and location: 29-31 August 2012, Saint-Etienne, France
http://euromech534.emse.fr/

535. Similarity and Symmetry Methods in Solid Mechanics
Chairperson: Prof. Jean-François Ganghoffer
LEMTA - ENSEM
2, Avenue de la Forêt de Haye, BP 160
54504 Vandoeuvre Cedex France
Email: jean-francois.Ganghoffer@ensem.inpl-nancy.fr
Co-Chairperson: Dr. Ivailo Mladenov
Dates and location: 6 - 9 June 2012, Varna, Bulgaria

536. Nanobubbles and micropancakes
Chairperson: Dr. James Seddon
University of Twente
Faculty of Science and Technology
Physics of Fluids, P.O. Box 217
7500 AE Enschede, The Netherlands
Email: j.r.t.seddon@utwente.nl
Co-Chairpersons: Dr. Detlef Lohse , Dr. Elisabeth Charlaix
Dates and location: 13 - 17 February 2012, Les Houches, France

537. Multi-scale Computational Homogenization of heterogeneous structures and materials
Chairperson: Prof. Julien Yvonnet
Université Paris-Est, Laboratoire Modélisation et Simulation Multi Echelle (UMR CNRS 8208)
5 Bd Descartes, 77454 Marne-la-Vallée cedex 2, France
email: julien.yvonnet@univ-paris-est.fr
Co-Chairpersons: Dr. Marc Geers, Dr. Frederic Feyel
Dates and location: 26-28 February 2012, Université Paris-Est, France
http://msme.univ-mlv.fr/euromech-colloquim-537/

538. Physics of Sports
Chairperson: Prof. Christophe Clanet
Laboratoire d'Hydrodynamique (LadHyX)
Ecole Polytechnique
91128 Palaiseau cedex, France
Email: christophe.clanet@ladhyx.polytechnique.fr
Co-Chairperson: Prof. Metin Tolan
Dates and location: 3-6 April 2012, Ecole Polytechnique, Paris, France
http://events.polytechnique.fr/home/physics-of-sports/#KLINK

539. Mechanics of Unsaturated Porous Media:Effective stress principle from micromechanics to thermodynamics

Chairperson: S. Majid Hassanizadeh
Department of Earth Sciences
Faculty of Geosciences
Utrecht University
P.O. Box 80021
3508 TA Utrecht, The Netherlands
Email : hassanizadeh@geo.uu.nl
Co-Chairperson: Ehasan Nikooee

Dates and location: 27-30 August 2012, Utrecht University, The Netherlands
http://www.geo.uu.nl/hydrogeology/Colloquium2012/Euromech_main.html

540. Advanced Modelling of Wave Propagation in Solids

Chairperson: Dr. Radek Kolman and Prof. Miloslav Okrouhlík
Institute of Thermomechanics AS CR, v. v. i.
Academy of Sciences of the Czech Republic
Dolejškova 1402/5
182 00 Prague 8, Czech Republic
Email: kolman@it.cas.cz
Co-Chairperson: Arkadi Berezovski

Dates and location: 1-3 October 2012, Prague, Czech Republic
http://ec540.it.cas.cz./

EUROMECH Colloquia Reports

EUROMECH Colloquium 511
““Biomechanics of Human Motion. New Frontiers of Multibody Techniques for Clinical Applications”
9-12 March 2011, Ponta Delgada, Azores, Portugal
Chairperson: Prof. Jorge A.C. Ambrósio

The construction of biomechanical models suitable for analysis and prediction of human motion requires contributions from many fields of engineering. Several issues are still to be investigated before such models can reach the status of medical applications, which is the main target of the intended worldwide research. Such issues include formulations able to describe the systems with different levels of detail, equipment used for the kinematic and kinetic data acquisition, methodologies for data processing, fast analysis eventually based on optimization algorithms. It is important for the biomechanics of human motion that the physiological data used to build models, including anatomical joints, muscles, soft and hard tissues, contact description, merit functions for motion activities, etc., can be validated at a subject-specific level in order to be able to generate realistic results.

EUROMECH Colloquium 511 addressed the scientific topics that contribute to correct mechanical and physiological modelling, and analysis of biomechanical models for human body motion. The scientific scope of the Colloquium covered:

- the data acquisition methods and procedures and their merits and shortcomings in the light of the models used and type of analysis required;
- the specifications for the construction and use of reliable biomechanical models; the specific modelling needs for anatomical joints, muscles and soft tissues;
- the description of the internal and external contact between anatomical segments or with the environment;
- the analysis of internal forces and muscle forces in the human body models; the muscle mechanics;
- the solution of the redundant muscle force sharing problem and the quantification of motion tasks objective functions and mechanical and physiological constraints;
- the suitability of the numerical methods used for each type of analysis or the use of the biomechanical motion analysis in clinical, training, physical rehabilitation of equipment development.

Particular topics addressed in the Colloquium were:

- Biomechanical modelling;
- Multibody formulations for biomechanics;

- Finite element analysis in human motion;
- Kinematic and kinetic data acquisition;
- Optimization in biomechanics of human motion;
- Muscle modelling;
- Stability analysis;
- Motor control;
- Contact mechanics in biomechanics.

With the presence of 81 participants from 18 countries, the Colloquium took place during full working days in which 64 presentations were delivered. A small scientific committee, including the organizers and 6 other leading scientists, selected the presentations from more than 90 submissions, and organized them in a thematic form. This ensured not only the consistent flow of the different topics but also discussion and exchange of ideas. All presentations were supported by abstracts. Some full-length papers were contributed in a voluntary basis. The Colloquium was run with single track sessions and the time reserved for discussion was managed flexibly, in order to allow for the exchange of ideas.

Lunch periods lasting 1½ hours, with tables of 4-6 participants, allowed continuation of scientific discussions. The scientific programme was complemented with a social programme that encouraged further discussion and helped foster relations. Two events involved all the participants and accompanying persons: the banquet held on the last day of the Colloquium, and a tour on the following day.

Resulting from the excellent scientific quality of the Colloquium, the authors of selected presentations have been offered the opportunity to produce a full-length paper after the Colloquium, or to edit their paper produced for the Colloquium CD (not obligatory), and to submit it for inclusion in a Special Issue of the journal Multibody System Dynamics (ISI Impact factor 1.8). This will be guest edited by F. Van Der Helm, A. Kecskeméthy, M. Silva and P. Flores. The papers will be peer-reviewed and, if accepted, published in the Special Issue.

EUROMECH Colloquium 526
"Patterns in Soft Magnetic Matter"
21 - 23 March 2011, Dresden, Germany
Chairperson: Dr. Adrian Lange

Euromech Colloquium 526 was devoted to the most recent development and research into pattern formation in soft magnetic matter in Europe. This covers areas such as surface instabilities and patterns of magnetic fluids, instabilities of elastic magnetic matter, including magnetic gels, and flow instabilities of magnetorheological fluids. It was the goal of the colloquium to discuss highlights and recent developments in this research field during the previous two or three years.

There were nearly 40 participants from 10 different European countries, who gave 27 oral presentations, among them three invited plenary talks from Prof. Jean-Francois Berret (Paris), Prof. Miklos Zrinyi (Budapest), and Dr. Philip J. Camp (Edinburgh). The combination of the number of participants and the duration of two and a half days provided enough time for informal discussions in small as well as in larger groups. Presentations were scheduled so that discussions could continue as desired after an oral presentation.

Among the most frequent issues addressed in the talks and in the discussions, two are described below.

Description of the Rosensweig instability
The Rosensweig instability describes the phenomenon that a flat horizontal layer of magnetic fluid becomes unstable, creating a hexagonal arrangement of peaks if the applied magnetic induction, oriented vertically to the initially flat surface, passes a certain threshold. One approach to solve numerically the underlying equations is a direct simulation. That approach was represented by Prof. Boudouvis (Greece) and Dr. Olga Lavrova (Byelorussia). The results of another approach with a model equation of the Swift-Hohenberg type were given by Dr. David Lloyd (Great Britain). Between them an intense discussion developed about the advantages and drawbacks of the respective approaches. As a confirmation of their arguments experimental results, presented by Dr. Reinhard Richter and Thomas Friedrich (both from Germany), were brought into the debate. Thus this particular surface instability could be analysed from quite different points of view.

Swelling of a magnetic gel under the influence of a uniform magnetic field
Whether this phenomenon happens, and if yes in which way, were questions raised during the opening day of the colloquium by Rudolf Weeber (Germany). His results from computer models predict a directed shrinking of the gel in an external magnetic field. That such a

shrinking, as one of several possible macroscopic reactions, can be observed experimentally, was shown by Prof. Zrinyi (Hungary) in his review about the interaction of magnetic gels and magnetic fields on the second day of the Colloquium. In his talk about the microscopic structures of ferrogels on the last day, Dr. Philip Camp (Great Britain) noted that this type of macroscopic deformation is not observed if only affine translations of particles are allowed in quasi-continous computer simulations. However, these simulations could reproduce the elastic properties of an anisotropic magnetic gel, as shown by Prof. Miklos Zrinyi on the previous day. In this way, the issue of ferrogel swelling was under active discussion during the entire Colloquim, which helped to reduce the gap between experimental studies and numerical models of these systems, and deepen understanding of magneto-elastic coupling.

EUROMECH Colloquium 527
"Shell-like Structures - Nonclassical Theories and Applications"
22-26 August 2011, Wittenberg,Germany
Chairperson: Prof. Holm Altenbach

Shell-like structures arise in civil and aerospace engineering as basic elements of construction. Such structures are used not only as models for analysis in other branches of engineering, but also in medicine. New applications are primarily related to new materials - instead of steel or concrete, one has now to analyse sandwiches, laminates, foams, nano-films, biological membranes, etc. The new trends in application demand improvement of the theoretical foundations of shell theory, since new effects must be taken into account. For example, in the case of small-size shell-like structures (nano-tubes) the surface effect plays an important role in the mechanical analysis of these structural elements.

EUROMECH Colloquium 527 was organized at the Leucorea (Lutherstadt Wittenberg, Germany). An international forum of 62 experts from 18 countries discussed the new trends, including representatives from the new areas of research and application. The focus of the Colloquium was on the following problems:

- new theories (based on two-dimensional field equations but describing non-classical effects);
- new two-dimensional constitutive equations (for materials like sandwiches, foams, etc. and which can be combined with the two-dimensional shell theory equations);
- identification of the two-dimensional constitutive equations;
- complex structures (folded, branching and/or self-intersecting shell structures, etc.);
- shell-like structures on different scales (for example: nano-tubes) or very thin structures (similar to membranes, but having a compression stiffness).

In addition, phase transitions in shells, specific problems of photovoltaic structures and refined shell thermodynamics were discussed by the participants. Each participant received a copy of "Shell-like Structures - Nonclassical Theories and Applications" (editors: Holm Altenbach & Victor A. Eremeyev), published by Springer. It contains 48 papers (750 pages), most of which were presented during the Colloquium, and gives an excellent overview of the topics discussed.

EUROMECH Colloquium 529
"Cardiovascular fluid mechanics"
27-29 June 2011, Cagliari, Italy
Chairperson: Prof. Giorgio Querzoli

The fluid mechanics of the cardiovascular system have been studied extensively in recent decades. Many successful studies of hemodynamics at sites of physiological interest are reported in the literature. Nevertheless, the contribution of fluid dynamics to progress in the medical disciplines is still at an early stage. The transfer of physical, mathematical and engineering concepts into clinical practice (medical reality), the information needed and the answers sought, can be quite different to those commonly required in other technical fields.

The task of effective transfer between disciplines is challenging. It requires a profound interdisciplinary approach and the careful combination of a qualitative understanding of fluid dynamics with quantitative techniques of analysis. The Colloquium combined advanced research teams concerned with cardiovascular fluid mechanics, fundamental fluid dynamics, vortex dynamics, and fluid-structure interaction issues. It stimulated interaction with clinical teams from around the world that represented about 20% of the participants. To this end, the two invited lectures were given by two physicians, both leading scientists involved in cardiovascular fluid dynamics. This interdisciplinary approach showed that greater contributions from cardiovascular fluid mechanics modelling to future clinical practice are feasible.

The scientific sessions were dedicated to the major topics of cardiovascular fluid dynamics:

- Cardiac vortex dynamics;
- Endovascular devices (stents);
- Genesis and growth of atherosclerosis;
- Flow in aneurisms;
- Basic models and novel applications of PIV and echo-PIV.

A special session with invited speakers was devoted to heart valves. Every presentation was followed by discussion, demonstrating lively interest and the need for working together to address such novel topics. A round table, open to all participants, stimulated wide-ranging interdisciplinary discussion.
Overall, the presentations and the debates demonstrated how several topics need further advancement. They can then contribute to a deeper understanding of physiology and support future clinical applications. At the same time, topics where fluid dynamics is not expected to play a relevant role, or a role not related to clinical issues, were identified. The formation of vortices emerged as the principal flow phenomenon requiring fluid dynamics study in cardiovascular systems.

The debates also contributed to development of communication between scientists having mathematical, engineering or physical backgrounds with those having a more medical background. It was envisaged that scientists involved in biological fluid dynamics should have some training in clinical structure. They can then build an understanding of the physics involved and develop a common language for the medical environment, where their studies will eventually find application.

EUROPEAN MECHANICS SOCIETY

EUROMECH Colloquium 531
"Vortices And Waves: Identifications And Mutual Influences"
21-24 June 2011, Moscow,
Chairperson: Prof. Yuli D. Chashechkin

EUROMECH Colloquium 531 was organized jointly by the Institute for Problems of Mechanics of the RAS and M.V. Lomonosov Moscow State University. The aim of Colloquium 531 was to present active research in this important field and to allow discussion of all aspects of current laboratory, numerical and analytical studies and collect significant results into a unified pattern that will foster future cooperation.

It is well known that vortices and waves are long-lived periodic motions (coherent features) in both industrial and geophysical fluid flows and are the subject of long-standing theoretical (analytical and numerical) and experimental investigations. They exist simultaneously and conjointly, propagate and transport energy and matter. For instance, the heat and solute or suspended tracer fluxes associated with waves and vortices are essential in Earth atmosphere and ocean dynamics. While studies of waves unify all branches of mechanics, vortices are specific to fluid mechanics. However, the boundary between vortices and strong non-linear waves is fuzzy and needs more precise definition. The complex vortex-vortex or wave-vortex interactions are important aspects of flow evolution and are subject to intense experimental and theoretical (analytical and numerical) study. Their nonlinear dynamics are rich and pertain both to the final stage of unstable laminar flow evolution and to fully developed turbulence.

Colloquium 531 was announced as an important forum for discussion of the following themes:

- Models of vortex and wave flows;
- The formation and evolution of vortices in homogeneous, stratified and /or rotating fluids;
- Formation of complex vortex flows;
- Interaction of vortices with the gravitational, inertial, internal or acoustic waves;
- The formation of vortices by interacting waves;
- and related phenomena.

The Colloquium was open to specialists with theoretical, industrial and environmental backgrounds. Abstracts were presented by 41 scientists from 7 European countries.
Organization of the Colloquium was supported by the Russian Academy of Sciences, which allocated a grant to support participation by young scientists, and the Russian Foundation for Basic Research (Grant 11-01-06018).

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 cooperation 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.

European Journal of Mechanics - A/Solids

ISSN: 0997-7538

The *European Journal of Mechanics A/Solids* continues to publish articles in English in all areas of Solid Mechanics from the physical and mathematical basis to materials engineering, technological applications and methods of modern computational mechanics, both pure and applied research.
The following topics are covered: Mechanics of materials; thermodynamics; elasticity; plasticity; creep damage; fracture; composites and multiphase materials; micromechanics; structural mechanics; stability vibrations; wave propagation; robotics; contact; friction and wear; optimization, identification; the mechanics of rigid bodies; biomechanics.

European Journal of Mechanics - B/Fluids

ISSN: 0997-7546

The *European Journal of Mechanics B/Fluids* publishes papers in all fields of fluid mechanics. Although investigations in well established areas are within the scope of the journal, recent developments and innovative ideas are particularly welcome. Theoretical, computational and experimental papers are equally welcome. Mathematical methods, be they deterministic or stochastic, analytical or numerical, will be accepted provided they serve to clarify some identifiable problems in fluid mechanics, and provided the significance of results is explained. Similarly, experimental papers must add physical insight in to the understanding of fluid mechanics. Published every two months, EJM B/Fluids contains:

- Original papers from countries world-wide
- Book reviews
- A calendar of scientific meetings