Universität des Saarlandes

Fakultät 6.1 Mathematik

Lehrstuhl für angewandte Mathematik

AG Volker John

Workshop on VMS 2008

Saarbrücken, June 23 - 24, 2008

Organization

Volker John

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Sponsors of VMS 2008

DFG high priority program Efficient Mathematical Modeling in Fluid Mechanics and Meteorology (MetStröm)

Deutsch–Französische Diskurs der Universität des Saarlandes

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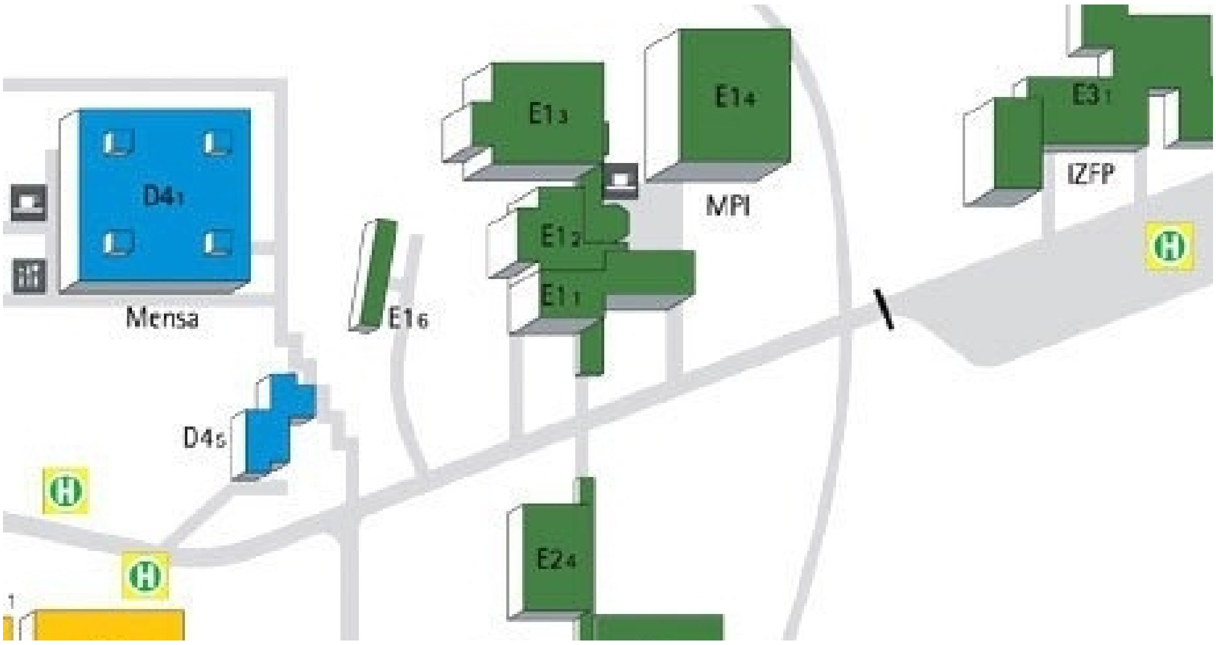
General Information

- position plan of the university of Saarbrücken

- detail position plan of the faculty of mathematics and computer science



- the workshop will take place in **building E 1.1 conference room 407**

- departure time of the bus lines to the central station / to the city from bus stop **Universität Mensa**:

clock hour	bus lines					
	101	102	109	111	112	124
13	25 55	15 45	05 35	11 41	00 30	06 36
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19	25 55	15 45	05			06 36
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	direction					

- position plan for the dinner

Book of Abstracts

Suitability/Entropy/LES

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Some issues related to suitable weak solutions of the NSE are reviewed. Connection between suitability, entropy and LES are made. A proposal for a LES model based on suitability is made. The principle of method is tested numerically on non-smooth transport equations and nonlinear conservation equations.

Error Estimates in Large Eddy Simulations

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In the last years considerable progress has been made in the development of LES for turbulent flows. The use of filter functions, turbulence models for the Reynolds stress tensor, and numerical schemes to solve the arising LES models give rise to modelling and numerical errors. Both sources of errors can interact. It is essential for the interpretation of LES to develop a rigorous error analysis for a detailed decomposition of numerical and subgrid modelling contributions. Even when using the model that current practice considers best for a particular application, often the relibility of the model's predictions is not assessed. Turbulence models can display sensitivity with respect to certain model parameters and numerical realizations of it. We quantify the effects arising from adequate subgrid modelling and numerical solution according to a chosen output quantity of interest. Our goal is to estimate the contributions of the subgrid model and the numerical method to a user specified quantity of interest which can be expressed as space-time functionals of turbulent quantities.

Minimal stabilization techniques for incompressible flow

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In this talk, the focus is on finite element methods with mimimal stabilization techniques for incompressible flows in the sense of [1]. In particular, we consider div-stable approximations of velocity-pressure which are subject to a discrete Babuska-Brezzi compatibility condition. An implicit time semidiscretization of the incompressible Navier-Stokes problem together with a Newton-type linearization within each time step leads to auxiliary Oseen-type problems.

First we discuss that an additional pressure stabilization (of PSPG type) is not required for the classical residual-based stabilization of the Oseen problem [2]. Moreover, we derive conditions which allow to suppress the streamline upwinding (SUPG) stabilization for laminar flows as well. Then, the so-called div-div stabilization of the divergence free constraint is critically reviewed. In the second part, we extend the previous observations to the stabilization via local projection, see [3].

In the last part of the talk, we address the variational multiscale approach by means of local projection stabilization. Moreover, we report some recent experience with a finite volume method with minimal stabilization techniques for LES/DES of turbulent flows, see [4].

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Taus for systems

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In this talk we propose a general design condition to compute the matrix of stabilization parameters in stabilized finite element approximations of different problems involving systems of equations. The idea is to approximate the equation for the subscales in the variational two-scale splitting of the problem by replacing the differential operator by an algebraic one. This algebraic operator is precisely the inverse of the stabilization matrix and it is designed by imposing that its norm bounds from above the norm of the continuous operator. In the case of systems, it is crucial to obtain a proper scaling of the equations so that the operator norm is dimensionally meaningful. The approximate bound for the continuous operator is obtained from a Fourier analysis of the problem posed on the element subdomains.

The general concept presented is applied to different systems of equations, including the linearized incompressible Navier-Stokes equations, the Stokes problem written in stress-displacement-pressure form, the linearized magneto-hydrodynamic equations and the linearized shallow water flows. In all the cases, the proper scaling is discussed and a design for the stabilization matrix is proposed, always trying to obtain an expression as simple as possible. Stability and convergence results are stated for all the problems analyzed, showing the correctness of the design proposed.

Some achievements in multiscale subgrid modelling

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Computing turbulence by General Galerkin methods

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We present our work on the General Galerkin (G2) method [4,6] for computing turbulent incompressible and compressible flow. G2 is a stabilized finite element method with a posteriori error control of chosen output functionals and with adaptive mesh refinement. In particular, no turbulence modeling is used, but only regularization from the G2 numerical stabilization with error control. Turbulent boundary layers are not resolved, but are modeled by a skin friction boundary condition [5]. The G2 method is presented for a range of problems, and connections are made to blowup of smooth Euler solutions [2], the dâĂŹAlembert paradox [3] and turbulent boundary layer separation [1]. The G2 method is implemented in the open source (FEniCS) project Unicorn [7].

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FEM multigrid techniques and LCR formulation for viscoelastic high We number flows

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Similar to high Re number flows which require special discretization and solution techniques to treat the multiscale behaviour, viscoelastic fluids are very difficult to simulate for high Weissenberg (We) numbers ("elastic turbulence"). While many researchers believe that the key tools are appropriate stabilization techniques for the tensor-valued convection-reaction equation for the extra stress, we explain the concept of log conformation representation (LCR) which exploits the fact that the conformation tensor is positive definite and of exponential behaviour. Together with appropriate FEM techniques and nonlinear Newton/linear multigrid solvers for the resulting fully implicit monolithic approaches, significantly higher We numbers seem to be reachable than compared with the standard formulation.

Computational error-analysis for large-eddy simulation

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The properties of turbulent flows have intrigued scientists and engineers for centuries. These days, numerical simulation is developing into a viable tool to help understand and control turbulence. However, flow properties may be modulated due to modeling and numerical errors and their nonlinear accumulation. This is a particular complicating factor for multiscale modeling of turbulence in large-eddy simulation where coarse meshes and significant sub-filter fluxes arise simultaneously.

Through a systematic parameter-study of LES of homogeneous isotropic turbulence an appreciation of individual error sources and their interactions can be obtained. This 'error-landscape' approach will be discussed and exploited for minimization of the total error. Attention will be given to induced error behavior associated with finite volume and with discontinuous Galerkin methods.

An Algebraic Variational Multiscale-Multigrid Method for Large Eddy Simulation of Turbulent Flows

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An algebraic variational multiscale-multigrid method for large eddy simulation of turbulent flows will be proposed in this presentation. For this purpose, level-transfer operators from plain aggregration algebraic multigrid methods [7] are employed for variational multiscale large eddy simulation [5,6,4]. In contrast to earlier approaches based on geometric multigrid methods [3], this purely algebraic strategy for scale separation obviates any coarse discretization besides the basic one. Operators based on plain aggregation algebraic multigrid, in contrast to smoothed aggregation algebraic multigrid [9], provide a projective scale separation, enabling an efficient implementation of the proposed method, among other things. A Fourier analysis for a simplified model problem reveals that the spectral properties of projective scale-separating operators may indeed provide diffusive modeling effects very close to the classification of an ideal fine-scale diffusivity by preserving low frequencies, in contrast to non-projective (i.e., smoothed) scale separations. Results obtained from applications of the proposed method to turbulent flow examples will be shown, comparing them to results produced by the well-established and widely-used traditional LES [8] based on a dynamic Smagorinsky model [2] and to the residual-based variational multiscale method for large eddy simulation recently proposed in [1].

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Optimal control in fluid mechanics by finite elements with symmetric stabilization

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There are two main possibilities for the numerical computation of optimal control problems with constraints given by partial differential equations: One may consider first the discretized problem and then build the optimality condition. The other possibility is to formulate first the optimality condition on the continuous level and then discretize. Both approaches may lead to different discrete adjoint equations because discretization and building the adjoint do not commute in general. This type of inconsistency takes place when conventional stabilized finite elements for flow problems, as for instance, streamline diffusion (SUPG), is used, due to its non-symmetry. Consequently, the computed control is significantly affected by the way of defining the discrete optimality condition. Hence, there is a need for symmetric stabilization so that discretization and building the adjoint commute. We formulate the use of this kind of stabilization and give a quasi-optimal a priori estimate in the context of optimal control problems for the Oseen system. In particular, we show that local projection stabilization and edge-oriented stabilization result to be quasi-optimal for optimal control problems.

The local projection method applied to inf-sup stable discretisations of the Oseen problem

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The standard Galerkin discretisation of the Oseen problem may suffer from two shortcomings. The generally dominating convection leads to spurious oscillations in the discrete velocity. In order to get a stable pressure approximation, two different strategies can be followed: either a pressure stabilisation term is used or the approximation spaces for velocity and pressure are chosen such that an inf-sup compatibility condition is fulfilled.

We will focus on the latter case where no pressure stabilisation is needed. Hence, we are faced only with the instability caused by dominated convection.

Our main objective is to analyse the convergence properties of the one-level approach of the local projection stabilisation applied to inf-sup stable discretisations of the Oseen problem. Moreover, we propose new inf-sup stable finite element pairs approximating both velocity and pressure by elements of order r. In contrast to the 'classical' equal order interpolation, the velocity components and the pressure are discretised by different elements. We show the discrete inf-sup condition for these finite element spaces and prove an error estimate of order $r+1/2$ uniformly in the viscosity and the reaction coefficient.

On the choice of the stabilization parameter of the local projection method

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I will discuss the development of the variational multiscale (VMS) approach for solving partial differential equation systems arising in fluid dynamics. The background is this: Any reasonable method utilizing functions capable of resolving the exact solution will obtain it. However, in numerical analysis we typically employ finite-dimensional spaces of functions that are unable to give good approximations for many fluid dynamical problems of practical interest. In addition, the basic variational methods (e.g., Galerkin) are not as reasonable as often assumed in the finite-dimensional setting. Stability, present in the continuous setting, is often not inherited for typically utilized finite-dimensional subspaces. The possibilities are to improve the function spaces, improve the variational methods, or both. Improving the spaces is possible but difficult. It has been a pathway to attaining stability for simpler problems. For more complex problems, enhancing the stability of the variational method, without upsetting its consistency, has been a more practical direction. This is the essence of so-called stabilized methods. But stability is not the only issue in computational fluid dynamics (CFD). In modeling turbulence, the effects of unresolved scales on resolved scales must also be accounted for.

VMS is a paradigm that derives directly from the variational formulation of the partial differential equations. In very simple situations it coincides with stabilized methods, but in more complicated cases it is richer. In addition to providing additional stability, it accounts for the effects of unresolved scales, and thus is a general framework for turbulence modeling as well as the derivation of CFD methods.

Recent research in VMS concerns comparisons with stabilized methods, calculation of the fine-scale GreenâĂŹs function, the use of continuous and discontinuous function spaces, minimizing the error in various measures, approximating discontinuities, the fine-scale field as error estimator, geometrically inspired approximations, weak boundary conditions, and turbulence modeling. In my talk I will sample from some of these recent developments and emphasize the use of VMS as a theoretical means for developing turbulence models. In particular, I will present a formulation of LES that is derived entirely from the Navier-Stokes equations without recourse to any external ad hoc devices, such as eddy viscosity models, and I will demonstrate the effectiveness of the ideas through numerical examples.

Convergence of Discontinuous Galerkin methods by compactness with application to Navier–Stokes equations

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Discontinuous Galerkin (DG) methods have received extensive interest in the past decade, in particular because of the flexibility they offer in the implementation of nonconforming meshes and variable polynomial order. Their natural links with Finite Volume (FV) schemes also makes them amenable to a local conservative formulation involving numerical fluxes. Following the usual finite element approach, the convergence analysis of DG methods is usually performed using interpolation properties of the exact solution, which in turn requires more regularity than the continuous problem may offer. In this talk, we will present a different approach, closer in spirit to the convergence analysis for FV schemes, relying on a compactness argument and discrete Sobolev embeddings.

Explicit Discontinuous Galerkin Schemes for Direct and LES Simulation

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Our research objectives are the construction and application of accurate and efficient schemes for unsteady flow problems. Motivated by the work of Collis et al., we focus our research on modal discontinuous Galerkin schemes for compressible Navier-Stokes equations with the ultimate aim to combine this discretization with VMS-LES.

To take care of the second order terms, a new weak formulation is introduced, where two integrations by parts are used to circumvent the need for resorting to a mixed finite element formulation. Accounting for the mixed hyperbolic/parabolic character of the compressible Navier-Stokes equations a numerical approximation of the viscous fluxes based on an approximate Riemann solver is used, yielding a discretization with optimal (experimental) order of convergence. The resulting spatial DG polynomial is expanded in time, using a local Cauchy-Kovalevskaya (CK) procedure. This approximative space-time solution is used to evaluate the volume and surface integrals in space and time. A main feature of this explicit space-time discretization is the possibility to introduce time accurate local time stepping. We drop the common global time step and propose for a time-dependent problem that any grid cell runs with its own time step, determined by the local stability restriction.

We apply this numerical discretization to several test cases, such as the two dimensional simulation of a mixing layer and a three dimensional simulation of the flow past a sphere.

Discontinuous Galerkin finite element methods for hyperbolic nonconservative partial differential equations

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In this presentation a new space-time discontinuous Galerkin finite element (DGFEM) formulation will be discussed for partial differential equations containing nonconservative products, such as occur in dispersed multiphase flow equations. Standard DGFEM formulations cannot be applied to nonconservative partial differential equations. We therefore introduce the theory of weak solutions for nonconservative products into the DGFEM formulation leading to the new question how to define the path connecting left and right states across a discontinuity. The effect of different paths on the numerical solution is investigated and found to be small. We also introduce a new numerical flux that is able to deal with nonconservative products. The scheme is applied to two different systems of partial differential equations. First, we consider the shallow water equations, where topography leads to nonconservative products. Second, a simplification of a depth-averaged two-phase flow model is discussed. This model contains more intrinsic nonconservative products.

Local projection methods for convection-diffusion equations

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The aim of this talk is to discuss stabilization of finite element discretizations of convection-diffusion equations based on local projections. This technique has been introduced in [1] for the Stokes equations and become very popular during the last decade. An extension to transport problems was proposed in [2] and investigated in many papers later. Originally, the local projection method was designed as a two-level approach since the projection space was considered on a coarser mesh. Recently, a one-level approach was introduced in [3] based on using higher order polynomials rather than refining the triangulation. In the talk, we shall review theoretical results on both the one-level and the two-level approaches of the method and then we shall concentrate on the relation of the local projection methods to residual based discretizations. In particular, we shall show that the stabilization of the fine scales introduced by the local projection term leads to the stability with respect to the SUPG norm. The theoretical results will be accompanied by results of numerical experiments.

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On the choice of the stabilization parameter of the local projection method

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In case of the local projection stabilization for convection diffusion equations we discuss the choice of the stabilization parameter depending on the meshsize and the polynomial degree of the finite element space.

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