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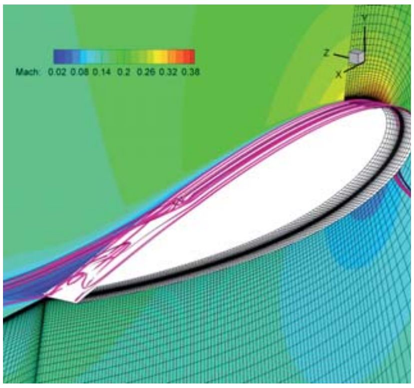

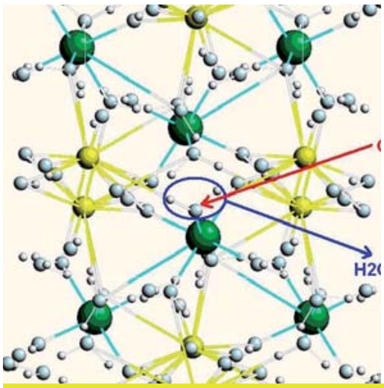

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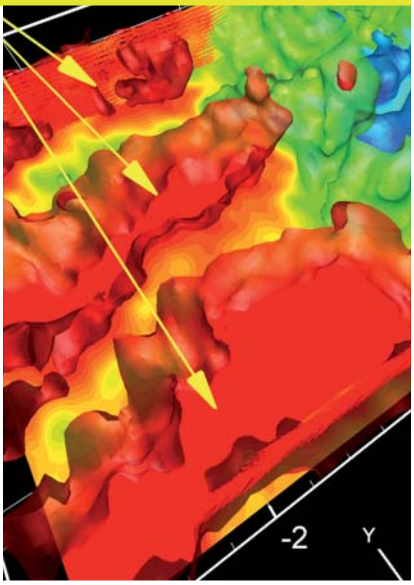

Annual Report & Research Programme

J.M.Burgerscentrum

Research School for Fluid Mechanics

TUD, TUE, UT, RUG, RUN, UL, WUR, UU

ANNUAL REPORT & RESEARCH PROGRAMME 2009-2010

JM Burgerscentrum
Research School for Fluid Mechanics

TUD, TUE, UT, RUG, RUN, UL, WUR, UU

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Contributions of the participating groups, Industrial Advisory Board and Contactgroups. Final editing : Prof.dr.ir. G Ooms and Mrs. I Hoekstein of the JM Burgerscentrum.

Design and lay-out : I Hoekstein
Printed by : NIVO, Delft

Preface

Prof.dr.ir. G Lodewijks
Chairman of the JMBC Board

Prof.dr.ir. G Ooms
Scientific Director

It was with great sadness that we heard about the passing away of prof.dr. Jorrit Mellema on September 5, 2009. He was a passionate and very cautious reseacher. He was an involved and loyal colleague, and an inspiring and critical mentor for his students. Jorrit Mellema was a man of values and character, whose work over the years has been of importance for the JMBC.

As in preceding years this annual report of the J.M. Burgerscentrum (JMBC) provides an overview of the activities of our research school during last year (2009) and a plan of action for the coming year. The core of the report consists of the description of the research projects, carried out by the JMBC groups. In each report the relevant information (title, theme, staff involved, project aim, achievements, publications, funding source, application, etc.) is given. Also some research highlights are presented. Besides the important progress in research the report describes the advanced graduate course program offered by the JMBC. Finally it provides general information about the research school, such as goals, organization, relation with industries and technological institutes.

The JMBC and FOM organized a successful workshop on 19 June2009. Representatives from industry, institutes, academia and from research funding organizations discussed new challenges in fluid mechanics during this workshop. The goal was to learn about each other's problems, research questions and state-of-the-art knowledge, and to pinpoint options for collaboration. In the morning focused 10-minute presentations were given by representatives from industries, TNO and research institutes about problems they encounter on the topic of fluid mechanics. In the afternoon, parallel workshops were organized by academic groups to present themselves and their expertise and discuss ideas for new research programs with the participants. The outcome of this day was a 'landscape report' dealing with existing problems and ideas for potential new research collaborations and programs.

The scientific directors of EM (the national research school for solid mechanics) and of the JMBC have jointly submitted a graduate school proposal to NWO. They did this at the request of the boards and management teams of the JMBC and EM. The idea behind our proposal is that the two research schools (JMBC and EM) will be responsable for a graduate school on fluid and solid mechanics (if the proposal is approved by NWO). We feel that this could contribute to the (already good) name of our research schools.

The Burgersdag 2010 at Twente University was a great success. Despite the cold wheather and snow there was a record number (240) of participants. The event was opened by the rector of Twente University. Prof. Jim Wallace (University of Maryland) gave an interesting Burgers Lecture. Prof. Rob Mudde (TU-Delft) and dr. Herman Wijshoff (Océ) presented their work at the end of the day. The largest part of the Burgersdag was devoted to 12 minute-presentations by PhD-students during two parallel sessions. There was again a common session at the end of the day, during which the winner of the best presentation and the best poster was announced by prof. Gabriel Lodewijks. The participants enjoyed the Burgersdag. The JMBC received many enthousiastic reactions after the event.

The organization of the course program of the JMBC is one of the most important activities of our research school. For a PhD-student it is essential to deepen his/her knowledge in fluid mechanics to a level significantly higher than that of person with a MSc-degree in fluid mechanics.

The PhD-degree courses of the JMBC fulfill this purpose. The deepening of knowledge is not restricted to the area of fluid mechanics, to which the research project of the PhD-student belongs. The idea of the PhD-degree courses is to continue the formal training of the PhD-student in a number of areas in the field of fluid mechanics, but on a post-graduate level. After the PhD-degree the PhD-student must be able to quickly acquaint him(her)self with a new area of fluid mechanics and solve problems in that area. Interesting courses were again organized during last year by JMBC staff. The participation by PhD-students, post-docs and staff from industries and technological institutes was good. We are very thankful to the JMBC staff, that organized the courses.

Members of JMBC groups were very successful in their work during last year. We mention in particular the appointment of prof. Detlef Lohse to Simon Stevin Meester 2009 by the Netherlands Foundation of Applied Sciences.

Due to the enthusiasm and the combined knowledge, skills and facilities of the participating research groups, the JMBC remains to be a very stimulating, multidisciplinary environment for advanced research in fluid mechanics and for the education of talented graduate and postgraduate students. The board and the management team of the JMBC highly value the large effort of the staff of the JMBC in reaching the goals of the research school.

Prof.dr.ir G Lodewijks	Prof.dr.ir. G Ooms
Chairman of the JMBC-Board	*Scientific Director*

CONTENTS

Contents

Organisation

Organisation

The JM Burgerscentrum (JMBC) is the Dutch research school for fluid mechanics. The Delft University of Technology is the coordinating university. The main goals of the JMBC are:

- Stimulation of co-operation of the participating groups with respect to their research efforts. It is the desire to be one of the leading institutes for fluid mechanics in the world.
- Organization of advanced courses for PhD-students. Researchers from industries and technological institutes also attend these courses.
- Co-operation with industries and technological institutes. The aim is to promote the use of up-to-date knowledge on fluid mechanics for solving practical problems.
- Strengthen the contacts between Dutch fluid mechanics research groups at universities and the international fluid mechanics community.

About 60 professors with their groups participate in the JMBC. These groups are located at the Delft University of Technology, Eindhoven University of Technology, University of Twente , the University of Groningen, the Radboud University of Nijmegen, Leiden University, Wageningen University and Utrecht University. They are from a number of disciplines; such as Civil Engineering; Mechanical Engineering; Maritime Technology; (Applied) Physics; Aerospace Engineering; Applied Mathematics and Chemical Technology. The professors with their senior staff form the council of project leaders, which meets regularly. There are about 250 PhD-students in the JMBC.

The JMBC has a scientific director who is responsible for the management of the research school; the JMBC secretary assists him. Three times per year he justifies his actions to the Board of the JMBC, and asks the Board for advice with respect to proposed new activities. He is also assisted by the Management Team, which consists of the local directors from the Delft University of Technology (also responsible for the group at the University of Leiden), Eindhoven University of Technology (also responsible for the groups at the University of Nijmegen, Wageningen University and Utrecht University) and the University of Twente (also responsible for the group at the University of Groningen).

The research projects carried out by the JMBC-groups have been ordered in a number of research themes. The reason for this ordering is to present in each theme a combination of projects which have coherence. The themes are:

- Complex dynamics of fluids
- Complex structures of fluids
- Mathematical and computational methods for fluid flow analysis.

The JM Burgerscentrum has many good contacts with industries and technological institutes in The Netherlands. For that reason there is an Industrial Advisory Committee (IA), in which Unilever, Gasunie, Corus, Philips, AKZO-Nobel, Teijin Twaron, Shell, DOW Benelux, ASML, DSM and Océ participate. A Programme Committee (PC) also exists with the following members: NLR, NMI/VSL, TNO-Science and Industry, TNO-Defence and Safety, TNO-Oil - and Energy Industry, MARIN, Deltares, KEMA, ESTEC and ECN/NRG. The IA and PC meet twice per year with the scientific director to discuss new activities of relevance to industries and technological institutes.

Each year (also in 2009) there are many scientific contacts with research groups in other countries. For that reason there are often external visitors to the JMBC groups. JMBC staff also regularly visits foreign fluid-mechanics groups, and presents their work at international conferences. The number of publications from JMBC staff in well-known scientific journals is considerable.

Together with Engineering Mechanics (the research school on solid mechanics) the JMBC forms the Centre for Fluid Solid Mechanics. This Centre has been recognized as a centre of excellence in The Netherlands and has received significant funding by the Dutch Government for stimulating new research areas in fluid and solid mechanics.

The JMBC has attracted top-experts in different fields of fluid mechanics to the JMBC. These experts have been appointed as JMBC-professors or Centre-of-Excellence professor at the three Technological Universities and are financed by the Boards of the Technological Universities or by the Centre for Fluid and Solid Mechanics. They contribute considerably to the achievements of the research school.

An important activity of the JMBC is the organisation of the annual meeting of the research school (Burgersdag). This year about 240 persons attended the meeting. The theme of the meeting was research by JMBC PhD-students.

Overview of the contribution of the participating groups of the JMBC

University and (sub)faculty	Project leaders	Scientific staff (fte)	Support staff (fte)	PhD students (fte)
TUD				
Mechanical Engineering	J Westerweel, JCR Hunt, G Ooms, B Eckhardt	6.2	2.0	13.6
	BJ Boersma	1.0	-	8.0
Marine Technology	RHM Huijsmans, TJC van Terwisga	1.0	0.3	4.8
	C van Rhee	-	-	-
Applied Mathem. Analysis	C Vuik, P Wesseling	3.0	-	5.6
	AWH Heemink	1.9	-	2.4
Multi-Scale Physics	HEA van den Akker, S Sundaresan, AP Siebesma, HJJ Jonker, CR Kleijn, RF Mudde, RAWM Henkes, DJEM Roekaerts	13.0	7.8	22.6
Physics of Nuclear Reactors	THJJ van der Hagen	1.1	-	2.0
DelftChemTech	M-O Coppens	1.9	0.5	2.4
Aerospace Engineering	H Bijl, F Scarano, PG Bakker	6	2	13
Civil Eng. & Geosciences	GS Stelling, WSJ Uijttewaal	6.5	-	11.2
TUE				
Applied Physics	AA Darhuber, F Toschi, MEH van Dongen	2.1	3.0	12.0
	GJ van Heijst, H Kelder, HJH Clercx, BJ Geurts	4.2	1.1	8.0
Mechanical Engineering	LPH de Goey, RSG Baert LEM Aldén	4.4	2.0	10.6
	JJH Brouwers	1.2	-	4.8
	AA van Steenhoven	2.9	2.0	6.0
Mathematics and Computer Science	RMM Mattheij, F Toschi	2.5	0.5	2.4
	CJ van Duijn, JJM Slot	2.3	-	1.6
Biomedical Engineering	FN van de Vosse	0.8	-	3.2

University and (sub)faculty	Project leaders	Scientific staff (fte)	Support staff (fte)	PhD students (fte)
UT				
Chemical Engineering	JAM Kuipers	2.0	1.8	10.8
Applied Physics	WJ Briels	2.4	-	5.6
	D Lohse, A Prosperetti, L van Wijngaarden, R Verzicco	8.0	3.3	14.6
	F Mugele	4.2	2.0	5.6
Mathematical Sciences	EWC van Groesen	0.9	-	1.6
	JJW van der Vegt, HJH Clercx, BJ Geurts	5.7	-	8.0
Mechanical Engineering	HWM Hoeijmakers, A Hirschberg	2.0	-	7.0
	ThH van der Meer	0.8	0.4	4.0
	S Luding	2.4	-	2.4
Water Engineering & Manag.	SJMH Hulscher	5.3	-	13.6
RUG				
Chemistry	HB Levinsky	0.9	-	2.4
Mathematics	AEP Veldman	1.5	-	4.8
RUN				
Applied Molecular Physics	JJ ter Meulen, W van de Water	2.4	1	3.2
UL				
Mathem. and Natural Sciences	M van Hecke	1.7	-	-
Mathematical Institute	B Koren	-	-	-
WUR				
Biometris	J Molenaar	0.2	-	0.8
Experimental Zoology Group	JL van Leeuwen	0.5	-	0.8
UU				
Physics and Astronomy	LRM Maas	0.2	-	0.8

The calculation of fte's is based on:
Professor 0,4 fte | Associated professor and assistent professor 0,5 fte | post-doc 1,0 fte | PhD-student 0,8 fte

Overview of university participants

University	Scientific staff (fte)	Support staff (fte)	PhD-students (fte)
TUD	39.3	12.6	88.6
TUE	19.4	7.6	37.2
UT	35.7	8.2	64.8
RUG	2.4	-	7.2
RUN	2.4	1.0	3.2
UL	1.7	-	-
WUR	0.7	-	1.6
Total	101.6	29.4	202.6

The actual number of PhD students during 2007 was approx. 250

INDUSTRIAL BOARD

For the last time I will have the privilege to write a few introductionary words for the Annual Report of the J.M. Burgers Center, the research school for fluid dynamics in The Netherlands. I have been a member of the Industrial Advisory Board of the J.M. Burgers center from the very beginning as a research school “avant la lettre”. The reputation of the center has grown immensely, nationally and internationally. Also the numbers of PhD students at the different universities have increased from year to year. The environment of the J.M. Burgers center has been changed gradually over time as well. Within a time frame of 15 to 20 years the financing of the universities has been changed from a matter of course to a struggle for life, in the meantime a number of large companies in the Netherlands closed their corporate research laboratories. As holds true for the same big companies, the Dutch universities have to focus. For academia that means that they have to take their responsibility to society and have to find answers to the main issues of today, such as sustainability, climate change, healthy environment, rising of the sea level, growing population, spread of wealth, efficient use of energy, alternative energy sources, food production, transport, clean water supply for everybody. I am confident that the J.M. Burgers Center will contribute to the quest for a better world as fluid dynamics, ranging from large scale turbulence of earth atmosphere to micro fluid dynamics embedded in diagnostic medical devices, from detailed experimental work to the use of parallel computing, will be key for solving the problem areas mentioned.

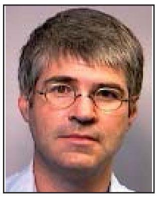
From this place I would like to complement all scientists that have contributed to the present Annual Report. The activities in the JM Burgers Centrum are presented in a coherent way, as well as in the other issues of the J.M. Burgers center such as the Research Program, the Course Program and the JMBC Newsletter. In that way the JMBC presents itself as the main organization on fluid dynamics in the Netherlands. Know that your Annual Report will be on many desks in and outside the universities. It will serve as a look-up document to see what is going on in your organization and it will definitely generate new contacts and maybe also new research initiatives. The Burgers day of 2010 organized at the University of Twente was again a great event, giving a podium to PhD students to show their results either during an oral presentation or during poster sessions.

In the Industrial Advisory Board/Program Committee are represented: AKZO-Nobel, Teijin-Twaron, DSM, Gasunie, Corus, Philips, Oce, Rijkswaterstaat, Shell, Unilever, Dow Benelux, ASML, TNO-Industry and Technology, VSL, KEMA, MARIN, TNO-Defence and Saftey, ESA/ESTEC, Deltares, NLR, ECN-NRG. The names and addresses of the representatives of these companies in the Board are listed in the who and where section of this report. Especially, I would like to encourage PhD-students but also the permanent staff to take the opportunity to contact one of us when information about one of the participating companies is needed, e.g. when applying for a job or to look for support for a new research initiative.

Last but not least, I would like to respectful recognize the work of the bureau of the JMBC, Professor Gijs Ooms and Mrs. Ilse Hoekstein-Philips for the professional and careful issuing of the official documents and organizing the events of the research school.

Dr.ir. JF Dijksman
Philips Research Laboratories
Eindhoven
Chairman of the Industrial Advisory Board

Prof.dr.ir. AE Mynett
Deltares & UNESCO-IHE
Chairman of the Industrial Advisory Board



Prof.dr.ir. RAWM Henkes
Delft University of Technology

Contactgroup "Multiphase Flow"

The objective of the Contactgroup Multiphase Flow is to stimulate interaction and collaboration between researchers, developers, and users in the area of multiphase flow from universities, institutes and industries. This is done through organizing regular meetings (once or twice per year) aimed at getting to know each other's activities and to learn about developments and applications of multiphase flow technology. This will provide a good forum to identify the needs of the users and to bring to the attention new possibilities for applying multiphase flow research results. Industry, a research institute or a university in turn act as host of the meetings. The program consists of a series of lectures on a specific theme and a visit of some of the local multiphase flow facilities. Examples of themes covered are: dynamic multiphase flows, multiphase flows with surface-active agents, multiphase flow measurements and innovation with multiphase flow. In the 4th quarter of 2009 we organized a one day meeting at the Shell Technology Centre Amsterdam on the theme "Multiphase flow with heat tranfser".

Prof.dr.ir. AEP Veldman
University of Groningen

Contactgroup "Computational Fluid Dynamics (CFD)"

The purpose of the contactgroup CFD is to give CFD-researchers and users of CFD in universities, laboratories and industries in The Netherlands and Belgium the opportunity to get to know each other and to get acquainted with each other's work. In 2009 no meeting was arranged. The next meeting, in cooperation with the contactgroup "Multiphase Flow", will be held at TNO in Delft on May 20, 2010.

Prof.dr. DJEM Roekaerts
Delft University of Technology

Contactgroup combustion

The JMBC has groups active in combustion research at the universities of Delft, Eindhoven, Groningen, Nijmegen and Twente. The contactgroup combustion is an informal network between these groups. The groups play an important role in the organisation of the symposia of the Dutch section of the Combustion Institute, which is part of the international Combustion Institute, an international forum for scientific combustion research. These groups also have formed the STW-platform 'Clean and Efficient Combustion' to enhance the mutual collaboration between the different groups and to interest more industrial parties for the fundamental research on combustion.

The groups of the JMBC active in combustion research contributed to the organisation of the European Combustion Meeting which was held in April, 2009 in Wien, Austria. A large number of posters from JMBC groups were presented.

The COMBURA (Combustion Research and Application) symposium, was held on October 16, 2009, as a joint initiative of the Platform Clean and Efficient Combustion, the NVV (Nederlandse Vlamvereniging, and the Dutch Section of the Combustion Institute. A first key note lecture, titled "Towards high efficiency engines" was held by Prof. Bengt Johansson, Lund University, Sweden. A second key note lecture on "MILD combustion" was presented by Prof. Roman Weber, University Clausthal, Germany.

In January 2010 there has been a joint meeting of the platform Clean and Efficient Combustion and the Program Committee of the STW Perspectief Programma Clean Combustion Concepts. Around that time, for all projects of the CCC program good candidates had been selected and all projects started.

Contactgroup "Lattice-Boltzmann techniques"

The contactgroup "Lattice-Boltzmann techniques" was established in 2002. It has initiated the JMBC course "Particle-based modeling". The lattice-Boltzmann research in the Netherlands covers a broad spectrum of applications. To mention a few: flow and scalar transport in porous media, biological flows, suspension dynamics, chemically reacting flows, turbulent flows. Lattice-Boltzmann schemes are part of the family of particle-based simulation techniques. In the lattice-Boltzmann method, (fictitious) particles move and collide on a regular lattice. With the proper collision rules and lattice topology, such a system mimics the dynamics of a real fluid. The power of the method lies in the geometrical flexibility, in the locality of its computational operations (intrinsic parallelism), and in the intuitive way in which multicomponent fluids can be represented.

Prof.dr. F Toschi
Eindhoven University of Technology

Prof.dr.ir. BJ Boersma
Delft University of Technology

Contactgroup "Turbulence" -

The objective of the contactgroup turbulence is to organize meetings between researchers of the J.M. Burgers Centre active in the field of turbulence. The purpose of these meetings is give the AIO/OIO's and other university researchers the opportunity to present their research results in an informal atmosphere and at the same time to promote a discussion on these results. The meetings also strengthen the contact between the researchers of the J.M. Burgers Centre and allows exchange of results and experience. Activities in 2009 : organisation of the Turbulence Course.

Prof.dr.ir. J Westerweel
Delft University of Technology

Dr. M Versluis
University of Twente

Contactgroup "Experimental Techniques"

The Contact Group Experimental Techniques forms a platform where experiments and experimental techniques can be discussed and evaluated. The main function of the contact group is to organize meetings in which the practice of experimenting can be discussed. An important contribution of the contact group is the organization of the JMBC course on Experimental Techniques in Fluid Mechanics. The course is very popular among the JMBC members as it gives a broad overview of advanced experimental techniques commonly used in fluid mechanics laboratories. The next course will be held 26-29 April 2010 at the University of Twente.

Contactgroup "Biological Fluid Mechanics"

More and more research is conducted at the border between biology and fluid mechanics. This happens within many disciplines, from physiology (e.g. the interaction between blood flow and vessel walls) to aerodynamics (e.g. flapping flight). However, all deal with the interaction between fluids and a complex, changing geometry. One of the main challenges is to bridge the gaps between physics (esp. fluid mechanics) and medical and health sciences. To stimulate this relatively young field of research and bring together researchers, a new contact group was started in 2006. While the contactgroup is formally a part of the J.M. Burgerscentrum, the participation from researchers from non-affiliated universities, medical centers and institutes is encouraged. Recent activities include mini-symposia in Wageningen (Experimental Zoology Group) and Eindhoven (in combination with the JMBC course on Bio-fluid Mechanics).

The Bio-Fluid Mechanics course (March 2009: about 40 participants) was jointly supported by the JM Burgers Centre and the ERCOFTAC organization by advertising the course amongst their members, via the website and by some financial means.Topics included: a recap of basics of fluid mechanics, external flows (swimming and flying, interaction of plankton and turbulence), internal flows (microcirculation, hemodynamics in large arteries, flow in flexible tubes, respiratory system, etc.). Examples of relevant experimental techniques, as well as simulation techniques were discussed.

Finally, members of the contactgroup are active in the definition of a new FOM-program in the bio-fluid mechanics field.

Prof.dr.ir. AA van Steenhoven
Eindhoven University of Technology

Dr.ir. C Poelma
Delft University of Technology

Prof.dr. F Mugele
University of Twente

Prof.dr. J den Toonder
Philips Research
Eindhoven University of Technology

Prof.dr.ir. J Westerweel
Delft University of Technology

Prof.dr. JM Wallace
University of Maryland

Contact group "Microfluidics"

The contact group "Microfluidics" was established in 2005 with a first meeting in Delft. The purpose of the contact group is to bring together students and postdocs interested in fluid dynamic aspects of microfluidics and give them a regular forum for presenting their results and exchanging ideas.

Topics of interest include wetting and capillarity-driven flows, two-phase flow, drop generation and emulsification, contact line dynamics, flow visualization and measurement techniques. In April 2009, contact group members organized the first JMBC course "Capillarity-driven flows in microfluidics". Furthermore, as special session "Microfluidics, wetting, and thin film flows" at the joint FOM-JMBC-industry meeting "Changing Flows" in June 2009.

In October 2009, the contact group came together for a scientific meeting in Delft and with presentations from students and postdocs on their recent work. This meeting also witnessed the first participation from biologically motivated users of microfluidics, leading to an interesting extension of the previous spectrum of activities within the contact group.

For 2010, two additional scientific progress meetings are planned, to be held in Twente in spring and (presumably) in Eindhoven in fall.

Burgers Program for Fluid Dynamics at the University of Maryland

Inspired by the intellectual heritage of J.M. Burgers, the mission of the Burgers Program for Fluid Dynamics at the University of Maryland is to enhance the quality and international visibility of the research and educational programs in fluid dynamics and related areas at the University of Maryland in partnership with the J.M. Burgerscentrum (JMBC) in The Netherlands. Fluid dynamics in this context is viewed to include a broad range of dynamics, from nanoscales to geophysical scales, in simple and complex fluids. The establishment of the Burgers Program for Fluid Dynamics was celebrated with an inaugural symposium at the University of Maryland in November 2004. At the second Burgers Symposium James Wallace gave a talk commemorating the legacy of Frans T. M. Nieuwstadt. The interdisciplinary Burgers Program encompasses over 70 faculty members spread over 22 different units in the College of Computer, Mathematical and Physical Sciences, the College of Chemical and Life Sciences and the A. James Clark School of Engineering. For detailed information go to http://www.burgers.umd.edu/.

Burgers Visiting Faculty and Student Exchanges - In 2003 the Burgers Program created a Burgers Visiting Professorship in fluid dynamics. We have been able to attract distinguished professors from universities abroad to spend up to a year at the University of Maryland working with our faculty and their graduate students. The first Burgers Visiting Professor was Bruno Eckhardt, Professor of Theoretical Physics from Phillips Universität in Marburg, Germany. He spent the 2004-2005 academic year with us. In 2005-2006 we enjoyed the visits of two Burgers Associate Professors: Dr. Sasa Kenjeres of J. M. Burgers Center in the Netherlands and Dr. Serge Simoëns of the Ecole Centrale de Lyon in France. In May 2007 Prof. Jerry Westerweel, Director of the Laboratory for Aero and Hydrodynamics of Delft University of Technology was our Burgers Visiting Professor for three months. In the spring of 2008 Prof. Willem van de Water of the Eindhoven University of Technology visited our Program to work with Prof. Wolfgang Losert of our Physics Dept. for 2 ½ months. In addition, several graduate students from JMBC have had visits of several months at Maryland. Faculty from the University of Maryland are encouraged to spend a sabbatical at one of the Dutch Universities associated with JMBC. For instance, Kenneth Kiger, who was a speaker at the Burgersdag 2006, earlier had spent a sabbatical year with the JMBC research group in Delft.

Burgers Lectureship - We have also initiated an annual Burgers Lecture which is given by a distinguished visitor who comes to the campus for several days or even weeks in November. This is always the keynote lecture at our annual Burgers Symposium, which takes place in the week before the annual Division of Fluid Dynamics meeting of the American Physical Society. In 2003 Prof. Frans Nieuwstadt, then Director of the Laboratory for Aero and Hydrodynamics of Delft University of Technology, was our lecturer. Since then, Prof. Bruno Eckhardt , Prof. Charles Meneveau of Johns Hopkins University, Prof. Gijs Ooms, Chairman of the Burgers Center in the Netherlands, Prof. Detlef Lohse of Twente University, Prof. Wim van Saarloos of Leiden and Prof. Kees Vuik of Delft have been our Burgers Lecturers.

Annual Graduate Student/Post-doctoral Fellow Showcase with Johns Hopkins University - In collaboration with the Center for Applied and Environmental Fluid Mechanics of Johns Hopkins University, the Burgers Program has put on an annual graduate student/post-doctoral fellow showcase symposium in the spring of each year, beginning in April, 2005. The venue for the symposium alternates between sites each year. After a keynote address by a faculty member from the visiting institution, students and research associates give short presentations on their research. Members of the fluid dynamics community from around the region are invited to attend the symposium with the hope that the presentations will interest these attendees and create employment opportunities for the presenters.

Tutorial School on Fluid Dynamics - This new initiative will be inaugurated in late May 2010, with plans to offer it every year. The subject of the first School is Turblence. The level of instructions is aimed a level beyond that of a first graduate course in the subject area. Almost 40 graduate student and post-doc participants from the U.S. and other coutries, including nine from JMBC, will attend.

Fluid Dynamics Reviews seminars - This seminar series, which has continued for over forty years at the University of Maryland, has been incorporated into the Burgers Program. It is supported by the Minta Martin research fund. The format allows for faculty and their students and post-docs from the Burgers Program as well as for visitors to give presentations five or six times per semester. The seminar series has sponsored the visits of a long list of very distinguished speakers over the many years it has been a part of the campus' intellectual life.

TRAINING PROGRAMME

Training Programme

Purpose of the PhD programme

The purpose of the PhD-programme of the JM Burgerscentrum is the development of PhDstudents into independent researchers in the field of fluid mechanics. To reach this goal a thorough and fundamental knowledge of fluid-mechanics phenomena and their mathematical and numerical modelling is required, as well as the ability to further develop this knowledge and to apply it to solve scientific and technical problems. An important part of the PhD-programme consists of the execution of a scientific research project under the supervision of an expert of the JMBC.

A smaller part, of the order of half a year, consists of the participation in courses. This part, the training programme, is described below.

Structure of the training programme

The training programme gives a framework, in which individual training schemes can be developed. It contains the following three components:

- MSc-degree courses
- PhD-degree courses
- Workshops, summer schools, seminars.

The different components are meant for broadening or deepening of knowledge, and also for specialisation in certain areas of fluid mechanics. Individual training programmes are composed from elements of the three components. In the next paragraphs the three components are discussed.

Master-degree courses

The MSc-degree courses are meant for PhD-students (or other interested persons), who have no earlier formal training in fluid mechanics. The courses will bring those PhD-students to the same level of knowledge in fluid mechanics as PhD-students who did receive their MSc-degree in fluid mechanics.
The courses are usually selected from the advanced courses of the study programme for the MSc-degree. The number of ECTS points for the MSc-degree courses to be included in an individual training programme depends on the MSc-study programme of the individual. Usually it is about 10 to 15 ECTS points.

JMBC-PhD courses

For a PhD-student it is essential to deepen his knowledge in fluid mechanics to a level significantly higher than that of person with a MSc-degree in fluid mechanics. The PhD-degree courses of the JM Burgerscentrum fulfil this purpose. The deepening of knowledge is not restricted to the area of fluid mechanics, to which the research project of a PhD-student belongs. The idea of the PhD-degree courses is to continue the formal training of the PhD-student in a number of areas in the field of fluid mechanics, but on a post-graduate level. After the PhD-degree the PhD-student must be able to quickly acquaint him (her) self with a new area of fluid mechanics and solve problems in that area.

In consultation with the supervisor a PhD-student can decide to follow more courses. The number of ECTS points connected to the PhD-degree courses must at least be 9. The content of the courses is composed in such a way, that the courses can be followed by all PhD-students (independent of their knowledge from their MSc-degree programme). The different PhD-degree courses of the JM Burgerscentrum are usually given once every two years, dependent on the number of participants. The courses are concentrated in time, usually during one week.

The courses are given by the senior staff members of the JM Burgerscentrum, but also by (internationally well-known) guest lecturers. They determine the number of ECTS points for their course.
The courses can contain several elements: theoretical training, own work, demonstrations, etc. An active role of the participants is stimulated.

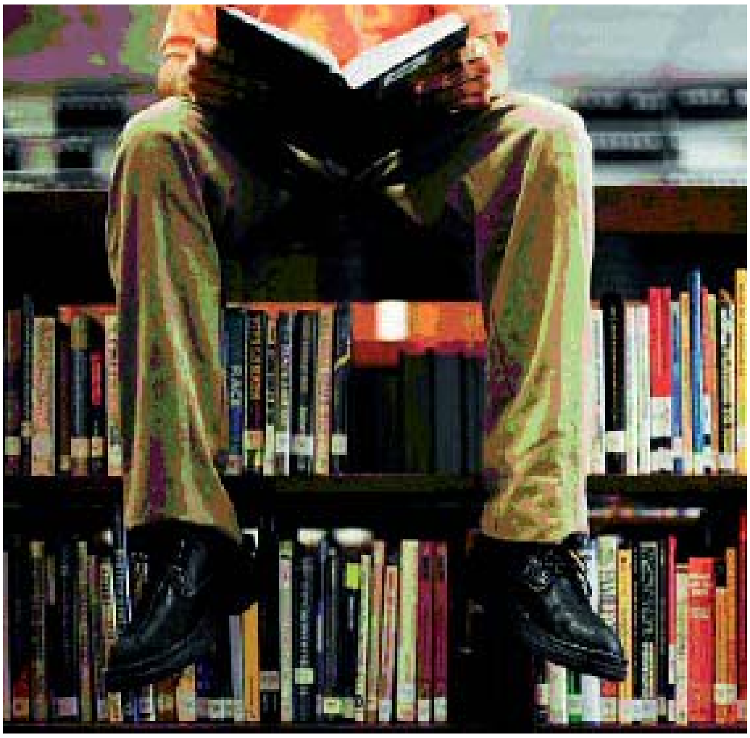
Workshops, summer schools, seminars or courses of other organisations

Besides MSc-degree courses and PhD-degree courses there is also a less-structural part of the training programme of the JM Burgerscentrum, consisting of workshops, summer schools and seminars. They can be very valuable for the education of the PhD-student, and will usually be in the area of fluid mechanics to which the research project of the PhD-student belongs. It is, in particular, recommended that a PhD-student participate in summer schools. Another component can be courses, not organised by the JM Burgerscentrum but by another organisation (courses from the Von Karman institute, ERCOFTAC, EUROMECH, etc.). The number of ECTS points of this part of the training programme will on average be 9.

Course Programme

Each year the JM Burgerscentrum issues a course programme with the details of the training programme for the coming year. An overview is also given on www.jmburgerscentrum.nl.

HIGHLIGHTS

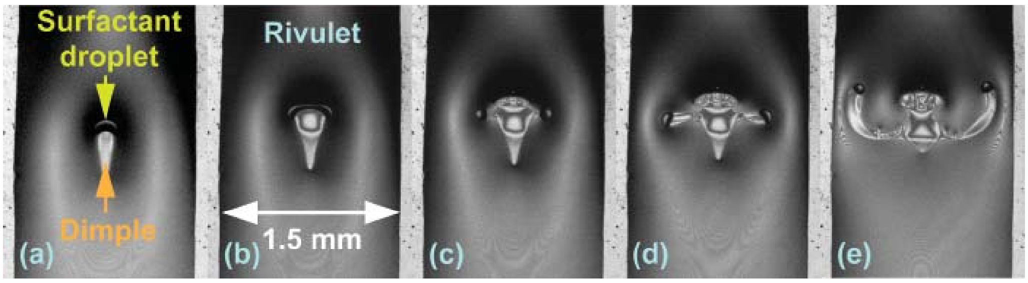


Mobilization and self-propulsion of surfactant droplets on thin liquid films

D Sinz, J Zeegers and AA Darhuber (TUE)

The phenomenon of self-propelling droplets has attracted considerable attention recently. We observed self-propelling surfactant droplets at the air-liquid interface of thin liquid films deposited on chemically patterned surfaces. Different types of motions are identified, depending on initial and boundary conditions. Figure 1(a) shows a surfactant droplet traveling along a liquid rivulet of width 1.5 mm. Behind the moving droplet a locally thinned region is observed in the rivulet height profile as indicated by the optical interference fringes in the microscope images. In subsequent frames [Fig. 1(b-e)] the droplet shape becomes more elongated and eventually breaks up into two or more daughter droplets. The initial trajectory of the two main daughter droplets is essentially perpendicular to the rivulet direction. When they approach the edges of the rivulet [Fig. 1(d,e)] their trajectories curve upwards, followed by an oscillatory mode of propagation along the rivulet. In additional experiments we observed single droplets in a straight or meandering as well as an intermittent motion.

The driving force of these self-propelling droplets is the Marangoni stress induced by the non-uniform surfactant surface distribution Γ (x,y,t) around the droplets, which is affected by the material properties of both liquids, the geometry of the chemical patterning and any external flow of the base liquid. We currently systematically investigate the influence of rivulet height, surfactant droplet volume and base liquid composition in an attempt to identify the detailed mechanism of surfactant droplet self-propulsion.



Identification of the bottom topography in a large scale tidal model of the European continental shelf

MU Altaf, AW Heemink, M Verlaan (TUD)

The adjoint method has often been used for the calibration of large scale numerical flow models. Here a number of unknown parameters is introduced into the numerical model. Using the given data these parameters are identified by minimizing a cost function that measure the difference between model results and data (observations). The drawback of the adjoint method is the programming effort required for the implementation of the adjoint model code. In this research, we have developed a method of parameter estimation based on model reduction using Proper Orthogonal Decomposition (POD) for a large scale shallow sea model of the entire European continental shelf. The POD based method shifts the minimization problem into lower dimensional space and avoids the implementation of the adjoint of the tangent linear approximation of the original nonlinear model [1].

The Dutch continental shelf model DCSM is used in the Netherlands to forecast the storm surges in the North Sea. Performance of the DCSM regarding the storm surges is influenced by its performance in forecasting the astronomical tides. The tidal data can be used to improve the model results. The POD based calibration approach is used for the estimation of the bottom topography for the newly developed DCSM with approximately 10^6 operational grid points. The main findings are: (1) A low dimensional model of much smaller size can be constructed as compared to the original model. (2) An overall improvement of more than 50% is obtained with respect to the initial DCSM. (3) The POD calibration approach efficiently solves the minimization problem without the burden of implementation of the adjoint code. The validation experiments also show similar improvements as in the calibration experiments.

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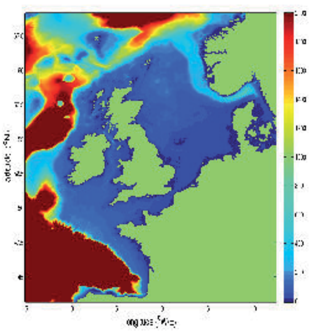
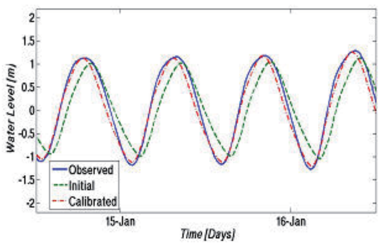




	Calibration dataset (cm)	Validation dataset (cm)
Before calibration	21.75	19.94
After calibration	10.55	9.86

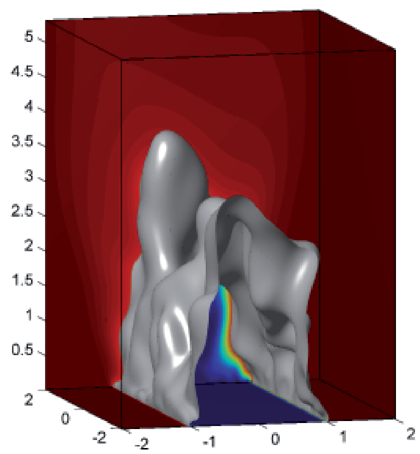
Figure Left DCSM bathymetry in meters. Bathymetry greater than 2000m is shown as 2000m. The North Sea is much shallower, with maximum depth around 200m. Figure Right waterlevel timeseries at tide gauge station Delfzijl for two days period from observations, DCSM before and after calibration. Table Right RMSE results for the DCSM, before and after calibration.

Modeling combustion with flamelet-generated manifolds

JA van Oijen, RJM Bastiaans, LMT Somers and LPH de Goey (TUE)

Numerical simulation of combustion has become an important tool in the design and optimization process of modern gas turbines and engines. The ever more strict emission limits are the main driving force for the development of new combustion concepts based on future sustainable fuels. Numerical modeling of combustion is a challenging task. The many different chemical components and reactions introduce a wide range of length and time scales, which demand special solvers. Due to the enormous computational costs, application of detailed reaction models is limited to simple one-dimensional laminar flow problems. In order to simulate turbulent combustion in real engine geometries, reduction techniques have to be used which simplify the chemistry model without losing (too much) accuracy. A very efficient method is the Flamelet-Generated Manifold (FGM) method developed at TU/e. Since the FGM method was introduced by Van Oijen, it has been systematically analyzed and its application range has been extended to cover almost all combustion modes in existing engines and gas-turbine combustors. Many academic and industrial research groups have adopted the FGM method, because of its simplicity, efficiency and accuracy. The concentrations of both major and minor species are accurately predicted while the computation time is reduced by two orders of magnitude. The method is valid for laminar and turbulent combustion up to the thin reaction zone regime, in which the chemical reaction layer is perturbed but not broken by turbulent flow structures.

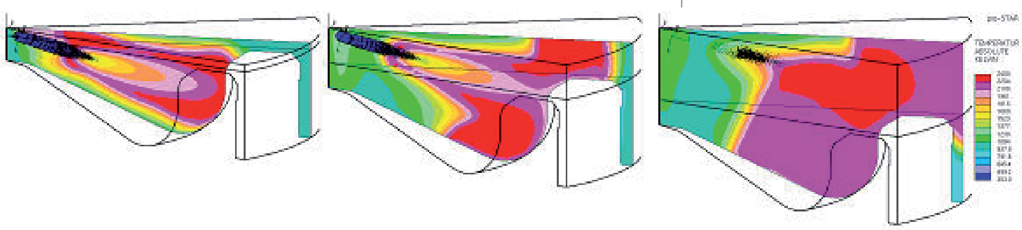
To face major challenges with respect to climate change and energy supply, new combustion concepts emerge and a transition from fossil fuels to future sustainable fuels has commenced. These new combustion technologies produce energy from future fuels such as biodiesel and hydrogen, with substantially enhanced efficiency, less noise and tremendously reduced pollutant emissions. Going by the names such as FLOX, MILD, HEC, and PCCI, these new technologies are applied in furnaces, turbines and engines. Widespread implementation is however hampered by a lack of fundamental knowledge of this new combustion regime. In several new research projects at TU/e, these combustion technologies - utilizing future fuels - are investigated with a central role for the FGM method.



DNS of a premixed turbulent bunsen flame on a slot burner

The use of hydrogen-rich fuels, for instance, is studied in lean premixed gas turbine combustors. To deal with strong thermo-diffusive effects related to the high diffusivity of hydrogen, the FGM method is extended. In other projects, FGM is used to investigate the PCCI (Premixed Charge Compression Ignition) concept for heavy-duty engines. Furthermore, Van Oijen received very recently a VIDI grant to explore the application of FGM in this new exciting combustion regime. The knowledge and models resulting from these projects enable the design of ultra-clean combustion devices for the conversion of future fuels.

Three snapshots of a simulation of combustion in a diesel engine showing the temperature distribution and fuel spray



Comprehensive models for dense gas-solid fluidized beds

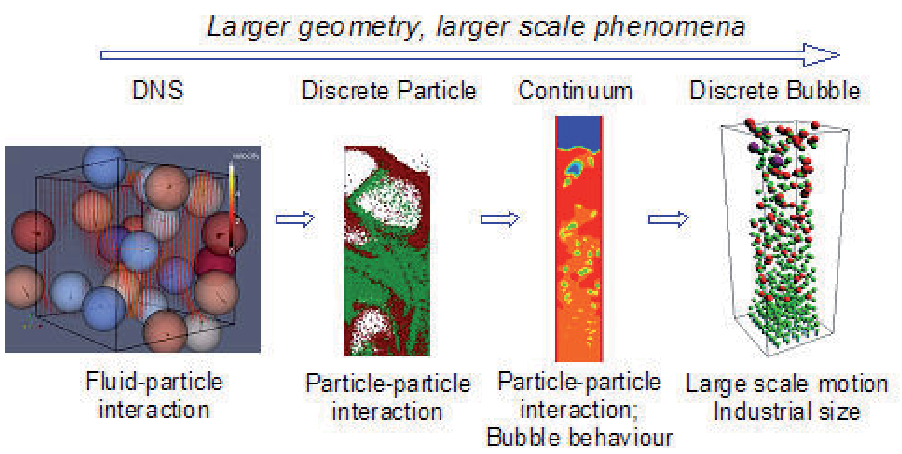
JAM Kuipers (UT)

Dense gas-solid fluidized beds are currently applied for a great variety of physical and chemical industrial processes. However, it is well known that dense gas solid flows are notoriously complex and its phenomena difficult to predict. Although great research efforts have been spent so far trying to understand and describe the intricate and scientifically interesting phenomena occurring in such dense gas-solid flows, a reliable comprehensive model for describing these multi-phase flows is still missing. In fact, the phenomena occurring at macro-scale (> 1 meter) are dictated by the particle-particle and particle-gas interactions occurring at the micro-scale (< 1 mm). A full understanding of the micro-scale phenomena is thus indispensable for defining reliable macro-scale models. This can be accomplished by using a multi-scale modeling based on small scale first principle models used to derive closure equations for the larger scale models (Fig. 1).

Such an approach is by now recognized as the most rigorous and viable pathway to obtain a full understanding of dense gas-solid flow, and has become very topical in chemical engineering science.

This approach, successfully applied at FCRE, foresees four levels of description of the gas-solid flow. **(I) Direct numerical simulation (DNS)** model, in which the gas phase is solved on a grid much smaller than the size of the particles, so the flow between the spheres is fully resolved. **(II) The discrete particle model (DPM)**, where each particle is treated separately. In this case the numerical grid is larger than the size of the particles, so the gas-particle interaction has to be calculated from effective drag force closures. **(III) The two-fluid model (TFM)**, in which both the solid and the gas phases are considered as interpenetrating continua. **(IV) The discrete bubble model (DBM)** in which the solid phase is considered as a continuous phase, similar to the treatment of the TFM.

A comprehensive approach should consider the exchange of heat, momentum and energy, and the effects of polydispersity, heterogeneity, and domain geometries, at all levels of modeling, and it should be validated by one-to-one experiments. Such an approach is being carried out at FCRE within an ERC advanced grant project recently granted on Multi-scale modeling of mass and heat transfer in dense gas-solid flows. It is worth mentioning that a similar multi-scale approach is also used for the description of gas-liquid flows.



Biofluiddynamics of swimming and flight

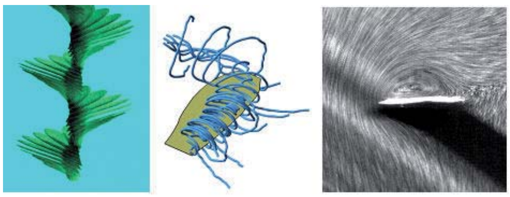
JL van Leeuwen, D Lentink, UK Müller*, JGM van den Boogaart (WUR)

The complex architectural and behavioural solutions found in animals and plants are the results of a long evolutionary process in which fitness is optimized through natural selection. We investigate relationships between form and function to explain structural changes on evolutionary and developmental time scales[1,8]. From an evolutionary perspective, we aim to unravel the functional relevance of the structural designs and associated motion patterns and how they develop during the life history of an organism. In one line of research, we study the hydrodynamics of swimming in larval fish, in relation to the architectural organisation and remodelling of muscles and skeleton in larval and juvenile fish through effects of mechanical load (including training) on the molecular regulation of growth[2,7]. To understand the nature of the mechanic loads that induce architectural changes we need to study the structure fluid interactions. In another line of research we study the comparative fluid dynamics of fish swimming and flight in birds, insect and plant seeds[3,4,5]. In particular, similar selection pressures (e.g. generation of high lift force) are expected to result in the convergent evolution of fluid dynamic solutions.

Leading edge vortices elevates lift of nature's wings

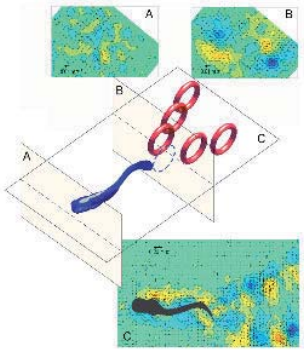
As they descend, the autorotating seeds of maples (Figure 1) and some other trees generate unexpectedly high lift, but how they attain this elevated performance is unknown. To elucidate the mechanisms responsible, we measured the three-dimensional flow around dynamically scaled models of maple and hornbeam seeds[3]. Our results indicate that these seeds attain high lift by generating a stable leading-edge vortex (LEV) as they descend. The compact LEV, which we verified on real freely-flying specimens, allows maple seeds to remain in the air more effectively than do a variety of nonautorotating seeds. LEVs also explain the high lift generated by hovering insects, bats, and possibly birds, suggesting that the use of LEVs represents a convergent aerodynamic solution in the evolution of flight performance in both animals and plants. To understand why the LEVs generated by flapping animal and spinning seed wings are stable we performed a dimensional analysis of the Navier–Stokes equations for translating, spinning and flapping wings[4,5]. This analysis shows that the Rossby number is of order one for flapping animal wings and spinning seed wings, which induces an Ekman-like boundary layer on the wing near its center of rotation. This prediction is confirmed by a series of experiments we performed using a robot-actuated wing. Together the dimensional analysis and experiments show that the stability of LEVs on both spinning plant and flapping animal wings is mediated by the rotational Coriolis and Centripetal accelerations induced in the boundary layer near the surface of the wing.

From left to right: Descending maple seed, streamlines showing the leading edge and tip vortex, and visualization of a cross-section of the leading edge vortex above a freely rotating seed in a vertical wind tunnel[3].



COMPLEX VORTEX DYNAMICS OF ZEBRA FISH SWIMMING

Fish larvae, like many adult fish, swim by undulating their body. However, their body size and swimming speeds put them in the intermediate flow regime, where viscous and inertial forces both play an important role in the interaction between fish and water. To study the influence of the relatively high viscous forces compared with adult fish, we mapped the flow around swimming zebrafish (*Danio rerio*) larvae using two-dimensional digital particle image velocimetry (2D-DPIV) in the horizontal and transverse plane of the fish7. Fish larvae initiate a swimming bout by bending their body into a C shape. During this initial tail-beat cycle, larvae shed two vortex pairs in the horizontal plane of their wake, one during the preparatory and one during the subsequent propulsive stroke. When they swim `cyclically', fish larvae generate a wide drag wake along their head and anterior body. The flow along the posterior body is dominated by the undulating body movements that cause jet flows into the concave bends of the body wave. Patches of elevated vorticity form around the jets, and travel posteriorly along with the body wave, until they are ultimately shed at the tail near the moment of stroke reversal. Behind the larva, two vortex pairs are formed per tail-beat cycle (the tail beating once left-to-right and then right-to-left) in the horizontal plane of the larval wake. By combining transverse and horizontal cross sections of the wake, we inferred that the wake behind a cyclically swimming zebrafish larva contains two diverging rows of vortex rings to the left and right of the mean path of motion, resembling the wake of steadily swimming adult eels. When the fish larva slows down at the end of a swimming bout, it gradually reduces its tail-beat frequency and amplitude, while the separated boundary layer and drag wake of the anterior body extend posteriorly to envelope the entire larva. This drag wake is considerably wider than the larval body. The effects of the intermediate flow regime manifest as a thick boundary layer and in the quick dying-off of the larval wake within less than half a second.



A 3D reconstruction of the flow field behind a swimming zebrafish larva7. The red rings represent vortex rings. Vorticity maps A, B, C are shown of different cross-sections through the flow field as obtained by PIV.

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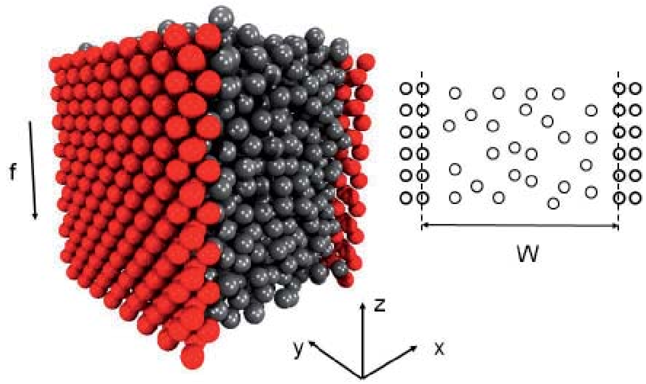
ANISOTROPY OF A FLUID CONFINED IN A NANOCHANNEL

RM Hartkamp, S Luding (UT)

Strongly confined fluids can show non-Newtonian properties, such as a normal stress difference [1] or oscillations in the density profile [2]. Our understanding of these phenomena is still very limited. For problems on nanoscopic scale, the continuum approximation breaks down and a particle based method is required. Molecular dynamics (MD) simulations are used in order to study the flow behavior of fluid in a nanochannel. Here, we simulate a noble fluid (Argon) in a slit of approximately 16 atom diameters in width.

Figure 1 shows the system geometry with the liquid atoms (grey) confined between face centered cubic (fcc) wall layers (red). The interactions between atoms are modeled by a Lennard-Jones potential. A constant body force acts on the fluid in the negative z-direction, causing the fluid to flow. Periodic boundaries keep the number of particles in the simulation constant and a thermostat maintains constant system temperature. Using kinetic theory and the virial stress formulation, we can study macroscopic properties from the collection of microscopic data, after coarse-graining.



Simulated system, liquid argon (grey) confined between fcc wall layers (red).

Deriving a constitutive model begins with analyzing the stress and the strain tensors. The eigenvalues of the stress tensor are the principal stresses $\sigma_3 \leq \sigma_2 \leq \sigma_1$

The principal stresses correspond to mutually perpendicular directions, called principal directions, where one has no shear stresses. The relation between the principal stresses gives us information about the (objective) stress anisotropy in the system and from the eigenvectors of the stress tensor, the principal orientation can be obtained. The principal stress in combination with the principal orientation form the fundamental building blocks for a new constitutive model.

We present an expression for stress anisotropy (equation 1), which is given as the ratio between the normal stress difference and the hydrodynamic pressure of the system. $p = (\sigma_1 + \sigma_2 + \sigma_3)/3$

$$S_D = \frac{\sigma_1 - \sigma_3}{2p}$$

Figure 2 shows the stress anisotropy across the channel; the anisotropy is approximately zero in the middle of the channel and increases towards the channel walls. Near the walls, oscillations are superimposed on an approximately linear trend. Compared to the density profile presented in [1], the oscillations in anisotropy have a higher frequency and the amplitude damps out more quickly. The orientation ϕ fluctuations on the other hand, remain clearly visible further away from the wall. The difference $\phi - \pi / 4$ quantifies the deviation from Newtonian behavior. A more extensive study of the stress anisotropy and the eigensystem orientation are needed in order to understand them and to formulate a constitutive model.

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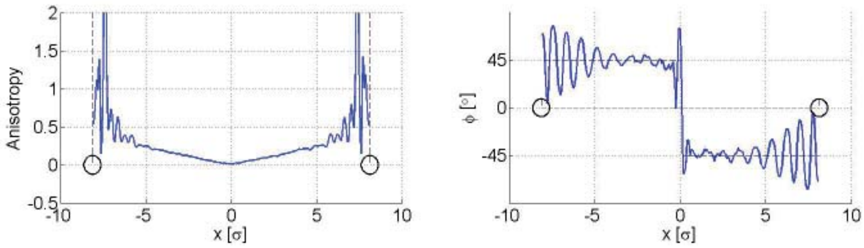


Stress anisotropy and the eigensystem orientation across the channel for a reduced body force of f=0.1. The location of the wall particles is indicated by black circles.

3D Imaging of granular suspensions

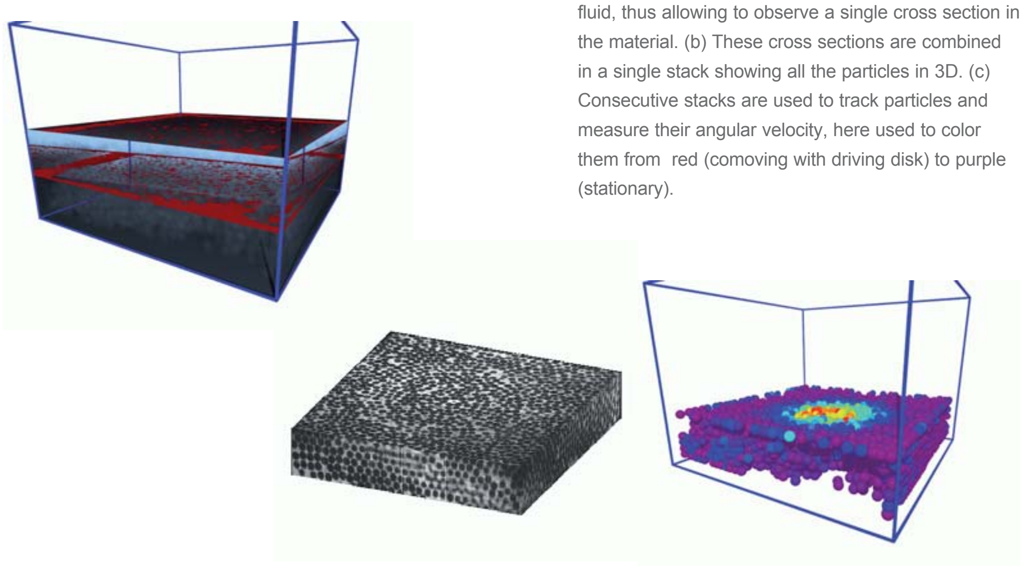
JA Dijksman, E Wandersman, M van Hecke (UL)

There is no general framework to describe the flows of granular media (sand) or suspensions (mud), despite a vast body of work motivated both by industrial applications and by fundamental questions regarding disordered media. Experimentally, a major obstacle is that one cannot observe the average flow or individual particle motion inside the material --- only flow at the boundaries can be observed.

In close collaboration with Wolfgang Losert from the University of Maryland, we have developed an “index matched scanning” technique, which allows us to study the full 3D structure and flow of grains suspended in a liquid. This technique works as follows. First, transparent particles are immersed in transparent fluid of the same optical index, thus creating a fully transparant medium. Second, small amounts of fluorescent dye are added to the liquid. and the material is illuminated by a laser sheet. Third, a simple CCD camera can now image a cross section of the material --- in which particles appear dark and the fluid as bright (Fig. 1a). We focus on particles that are denser than the fluid, so that they settle and, at least superficially, resemble ordinary dry granular materials.

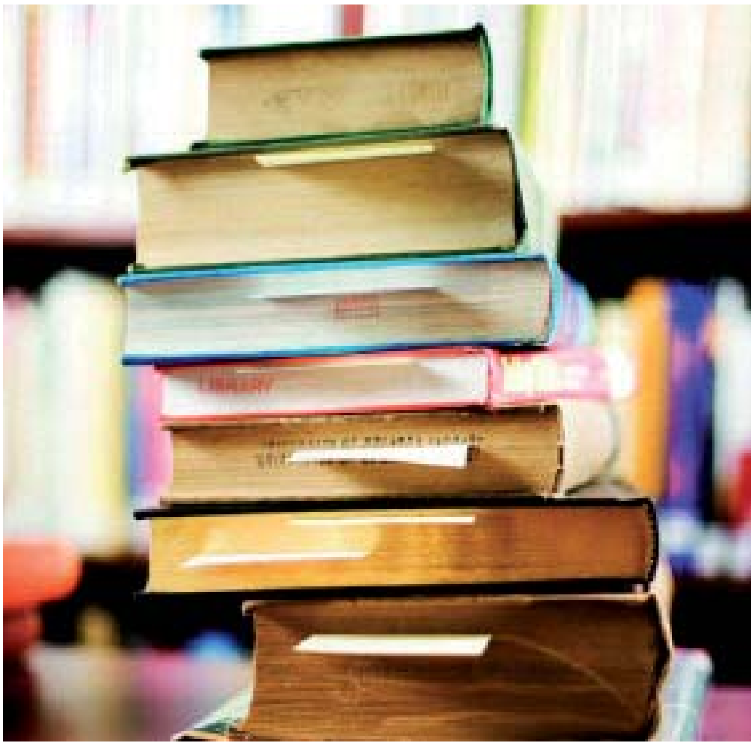
We have used this index matched scanning technique to study the mean flow properties of suspensions in a split-bottom shear cell, where the suspension is driven by a rotating disk at the bottom of a square box. By combining 3D maps of the flow field, obtained by a PIV type method, with rheology, we found that slowly driven suspensions act as dry granular flows, whereas fast driven suspensions behave as a Newtonian fluid --- hence slow dry granular flows can be mapped to slow flows of settling suspensions.

Fig 1. (a) A laser sheet excites fluorescent dye in the fluid, thus allowing to observe a single cross section in the material. (b) These cross sections are combined in a single stack showing all the particles in 3D. (c) Consecutive stacks are used to track particles and measure their angular velocity, here used to color them from red (comoving with driving disk) to purple (stationary).



We have developed the technique further, enabling us to track all individual particle positions in three dimensions. We therefore rapidly scan the laser sheet and take images of the subsequent layers in rapid succession --- present scan rates reach around 100 slices per second. From these cross sections we build up three dimensional ''still images''(Fig 1b). We then use particle tracking techniques to reconstruct the motion of all the particles. This allows us to measure quantities such as particle diffusion, velocity fluctuations and the local density field in unprecedented detail. For example, in Fig. 1c we have colored all the tracked particles by their angular velocity --- strong fluctuations are seen, and these have a different character than those observed at the free surface. With these technique we will probe the relation between particle fluctuations and granular rheology in detail, aiming at solving the age-old question: how does sand flow?

Research



Research

Introduction

The research programme of the JMBC has been ordered in research themes and focal points. The reason for this ordering is to present a combination of projects which have coherence, either in terms of physical models or in terms of mathematical methods.

The main themes are:

1. Complex dynamics of fluids
2. Complex structures of fluids
3. Mathematical and computational methods for fluid flow analysis

Description of the research themes

1. Complex dynamics of fluids

Fluid flows in the environment or in industrial applications are almost always characterised by some form of complexity. Frequently it is this complexity that makes the flow an interesting topic of research. Below we will sketch several examples of such flows and flow phenomena which form research topics carried out in the various groups of the J.M. Burgerscentrum.

The first form of complex dynamics which comes to mind is turbulence in contrast to a laminar flow. Here complexity appears in the form of strong non-linearity. Due to its chaotic behaviour turbulence can be considered as the archetype of a complex flow, and - being far from solved - turbulence will remain a strong focal point of research in the coming period. Turbulence research traditionally addresses the following questions:

- what are the physical processes and interactions governing turbulence,
- how can they be quantified and described mathematically,
- how to predict turbulence and turbulent flow for particular configurations, and
- how to control and manipulate turbulence?

Future research in this field in particular will focus on laminar-to-turbulent and reverse transition, effects of thermal buoyancy, unsteadiness, compressibility and rotation, and on the interaction with chemical reactions. The rol of turbulence in energy conversion processes and equipment are regarded as an intriguing field of applications.

Complexity may also appear in the form of a combined flow of various phases. When these phases are immiscible, phenomena such as free surface flows occur. These may appear in the form of various wave phenomena, for instance on an unobstructed water surface, but also in a confined geometry of a pipe.

Another type of such flow of immiscible phases is when one of the phases is distributed in the form of small particles, bubbles or droplets in the other continuous phase. Various combinations of phases may be selected and each has its own particular problems. This class of flows, generally denoted as dispersed multi-phase flow, at the moment forms a strong focal point of research within the JMBC. The combination of phases that are miscible leads to other interesting problems such as mixing, and - depending on the fluids that take part in the mixing - chemical reactions or combustion.

Finally, complexity of the flow can also appear through its boundary conditions. For instance the flow geometry can strongly influence the flow characteristics by means of straining, shearing and distortion. An example is the wake behind a body in a shearing or straining flow.

Furthermore, the exact formulation of boundary conditions can have a consequence for the type of flow characteristics that appear.

An example is the free convection above a flat surface with a variable the conductivity. Geometry constraints on the flow are also dominant also when one considers a flow in 2D versus3D. Here one should take as an example the quite different characteristics of 2D turbulence versus 3D-turbulence.

An increasingly important JMBC research activity within Theme 1 is aero-acoustics, aimed at the identification and quantification of acoustic sound sources in internal and external flows. Such sources can be related to unsteady vortex shedding, turbulence, combustion and flow-structure interaction. In general there is a strongly non-linear mutual interaction between sound source and acoustic field. The applications and technical implications show a great diversity. The JMBC is actively involved in vortex sounds in ducts, musical instruments (like the flute and the organ pipe), human speech, acoustics in burner stabilized flames, sound generation by turbulent flames, with much attention to analytical and numerical modelling of these flows.

The flow cases mentioned above, which are by no means an exhaustive list of complex fluid flow phenomena, form research topics in the various groups in the J.M. Burgers Centre.

The tools to carry out this research are primarily numerical and experimental. The numerical techniques used to compute flow phenomena are direct and large eddy numerical simulation, turbulence modelling and computational fluid dynamics. The experimental techniques used nowadays are mostly based on various forms of laser diagnostics (e.g. like PIV and PTV for flow measurements and CARS, LIF and Cavity Ring-Down Spectroscopy for temperatures and concentrations). Experiments, simulations and analytical theories in the field of fluid flow analysis complement each other - perhaps more than in other branches of physics. Future research will inevitably make use and take advantage of combined techniques and their complementing roles. Both the research topics themselves and the research techniques to carry out these investigations, form the basis of a strong collaboration within the J.M. Burgerscentrum.

2. Complex structures of fluids

Research in this Theme deals with complex structures of flow, formed in the presence of particles, drops, or bubbles, i.e., two- or even multi-phase flow. Two-phase flow is of paramount importance in contemporary science and technology.

One can readily cite a multitude of examples: the production and transport of oil (where bubbles are purposely injected to help lift thick heavy oil to the surface, or arise due to the release of dissolved gases), energy generation (where boiling is the key process in producing the steam to drive turbines), the chemical industry (where gas-liquid reactors rely on bubbles to increase the contact area between the phases), the oceans (where breaking-wave generated bubbles are important sinks for atmospheric CO_2), sedimentation (where sinking sand particles determine the structure oF our coasts), food-industry, and many others.

The challenge in single-phase flow is to understand the complicated dynamics which is generated by the Navier-Stokes equation. In two-phase flow, even the underlying dynamical equations are often not known. E.g., it is not understood why bubbles repel each other when they are close to each other.

But even when the microscopic interactions are known, it is often not clear how the macroscopic structure evolves from this microscopic interaction and the response to external forces.

In many cases instabilities are involved in the macroscopic structure formation process. Very complex self-organising patterns can evolve out of these instabilities. An important example is cluster formation in sedimentating particles and coherent structures in bubble columns and fluidised beds.

Related topics are flow-controlled nucleation and droplet growth processes in high-pressure natural gas, which have important technical applications in the natural gas industry. Different JMBC groups are involved in the design of new types of condensate separators and in the numerical description of swirling supersonic two-phase flows, while a dedicated facility has been developed in order to investigate these condensation processes in a well-defined way experimentally.

How to theoretically describe such a complex system? Two types of approaches have been described in literature: In the first type of approach, the particles/bubbles/drops are treated essentially as points, while no attempt is made to simulate their detailed response to the liquid dynamics.

The advantage of this approach is that many particles/bubbles/drops can be treated, but the price to be paid is a lot of ad-hoc modelling. Fluid dynamical simulations in which the particles/bubbles/drops are modelled through averaged equations also belong to this first type of approach. In the second type of approach the detailed interactions of the particles/bubbles/drops with the flow is simulated, paying the price that - at present - the surrounding flow can not really be turbulent and that only “a few” objects can be treated, in particular, when the interfaces are allowed to deform, i.e., for free boundary problems (drops and bubbles).

One of the main objectives for the research in two-phase flow must be to bridge the gap between these two types of approaches and to carry out a detailed investigation of the interaction between one or a few particles/bubbles/ drops and a nontrivial flow field. Another objective must be to better understand the macroscopic structure formation process out of the microscopic interactions, and thus the instabilities in two-phase flow. It is evident that these objectives can only be achieved through a joint experimental, theoretical, and numerical approach.

On the experimental side, the challenge has always been to monitor and document as much information on the dynamics of the flow field as possible. Through the huge advances in bothdigital imaging techniques and information technology (see Research Theme 3), the field is now flourishing, and the research on two-phase flow will strongly benefit from this. The same is to be expected from the advances with numerical techniques (see Research Theme 4), as brute force numerics will not be sufficient to address the problem of structure formation in two-phase flow. New algorithms and techniques are required and moving toward parallel computing will be essential.

3. Mathematical and computational methods for fluid flow analysis

Advanced mathematical and computational techniques have become indispensible instruments for the description and understanding of complicated flow phenomena. This approach to fluid mechanics has evolved into a full-fledged counterpart to the experimental approach and provides new insight in complex flow physics, in for instance turbulence, combustion, multi-phase and rheological flows.

The use of computational flow models is supported with analytical techniques, which provide deeper insight in canonical flow problems, and strongly interacts with advanced experimental techniques, which are capable of measuring and visualizing complex three-dimensional unsteady flow fields. These techniques require advanced post-processing of the flow field data to understand the flow dynamics and have developed into a research subject in itself. Here tools from non-linear dynamical systems theory can be useful, as well as the decomposition of flow data through POD and wavelet analysis.

The rapid increase in computational power has significantly stimulated the use of computational techniques in flow analysis, but the development of better algorithms has been the most important source for improved numerical techniques for flow analysis.

Many flows are, however, simply too complex for computational techniques and flow modelling remains an essential issue. Compromises have to be found between the inaccuracies in flow modelling and computational constraints. In areas such as turbulent flow simulation much progress has been made through refined modelling via Large-Eddy Simulation (LES) and Direct Numerical Simulation (DNS). There is also an interest for stochastic methods, such as the use of the Langevin equation for the velocity. In the other areas the same trends have become feasible, e.g. PDF modelling in combustion and Brownian Dynamics in rheology.

It can be foreseen that the improvements in numerical algorithms and the growing computational power will open up new applications of flow analysis in other disciplines, such as chemistry, biomedicine and structural mechanics, and will continue to grow in importance. This will be stimulated by the development of new numerical techniques which can efficiently capture flow structures with large differences in length and time scales, the continuous increase in computing power, and by exploiting computational fluid dynamics in multi-physics applications.

Focal points in the research programme

Four “focal points” have been selected from the three research themes, which receive special attention. A brief description of these “focal points” is given below.

1. Bio fluid mechanics

Most biological organisms live in a flowing medium (air or water). Nature has found solutions for fluid mechanical problems which enable fish to swim fast or cellular organisms to propel. These solutions are intriguing to understand and may lead to new solutions for technical problems. Similarly, fluid flow is essential inside the human body, where the blood is pumped around and the air is inhaled.

Deposition of aerosols in the lung, sound production by speaking, atherosclerotic plaque formation at well determined positions, gene activation at cellular levels are all more or less determined by fluid mechanic processes.

Finally, diagnostic and therapeutic techniques make use of fluid mechanic and heat transfer insights. The development of heart valves and the monitoring of temperatures inside the body during operations are examples for that.

Although most of the above mentioned problems can be solved with known physical principles, the complicated geometrical structures and the combination of phenomena (for example the transitional flow of non-Newtonian media in elastic bifurcating channels like blood vessels and airways) form an exciting new area for the development of advanced numerical and experimental techniques. Due to the geometry, three-dimensional unstructured meshes are to be used and the most efficient solvers are required to solve the flow at the relevant dimensionless parameters. Micro-PIV systems are needed to analyse the flow field in micro-vessels and fast optical techniques will enlighten the perfusion in permeable tissues.

New physical insights are needed for several areas, especially in multidisciplinary science. Some examples are given: The combination of fluid mechanics and solid mechanics is apparent in the phenomena at the focal folds where the unsteady flow separation is strongly influenced by the complex movement of the structure. Many modern uses of micro-bubble ultrasound contrast agents rely on the highly nonlinear response of the bubbles to a driving ultrasonic field and a quantitative model is lacking. The heat transfer processes in the anaestesized body are strongly determined by control mechanisms that are only globally known. Drag reduction occurs at the skin of several fish and reverse transition from turbulent to laminar flow is present in the nasal cavity and stenotic blood vessels; the relation with the wall structure is unclear.

Fluid mechanical parameters stimulate the activation of genes in cells, with striking downstream effects - unexplained. The interaction between the non Newtonian mucus layer in the airways and the oscillating airflow during cough is undescribed. The settlement and growth of settlements in aquatic ecosystems require the combination of advanced flow and mass transport models. As we have noted, research on this topic is extremely diverse and complex, because it involves a large number of different areas of expertise and advanced techniques. Therefore, this theme is an excellent area for collaboration between research groups inside and outside the fluid-mechanics community.

2. Granular matter

Granular matter exhibits many fascinating phenomena and is attractive both from a fundamental and an applied point of view. Its economic potential is enormous: it has been estimated that no less than 40 percent of the capacity of the industries that process granular matter is wasted due to problems connected to the handling of these materials.

Depending on the situation, granular matter can behave similar to a solid, a liquid, or a gas. E.g., when dry sand is poured, it acts as a fluid. The pile on which it is poured is solid-like, stabilised by forces in between the sand beeds. These forces organise themselves in tree-like networks. Finally, when dry sand is strongly shaken or fluidized through a gas stream, it behaves gas-like.

The transition from one to the other regime can be very sudden and the dynamics of such a transition is very rich. When in a gas-like or fluid-like state, the granular particles can all the locally sudden cluster. In many applications this can lead to serious problems, as whole production lines get stuck or the free available surface of some heterogenous catalysator all the sudden gets to small. So it is crucial to better understand the transition to the clustered state in order to avoid it.

The origin of the potential to cluster lies in the inelasticity of the particle-particle collision: If two particles collide, they loose kinetic energy and will thus stay closer to each other, trapping even further particles in the developing cluster.

Even without the phase transitions granular dynamics is difficult to understand. For the fluidised phase the brute-force approach is molecular dynamical simulations, based on some interaction potential between the particles. If this potential is chosen realistically (i.e., rather hard), the time step of advancing the numerical simulation can only be extremely slow, making this approach inpracticable. Better results have been obtained with either (unrealistically) soft potentials or with event driven codes. The ultimate goal must be to achieve at some continuum description, similar to the Navier-Stokes equation for fluid dynamics. Though considerable success in this direction has meanwhile been achieved, the problem is far from being solved. One of the main questions is how to pick the boundary conditions for such a continuum field.

One of the current physical questions one wants to answer is: How do average velocity profiles and velocity fluctuations look like in granular flow? On the experimental side, tomographical methods have turned out to be very successful to reveal these questions. Another intriguing problem of granular dynamics is size segregation. The most famous example presumably is the so called “Brazil nut” effect: In vibro-fluidised granular material big particles tend to “swim” to the top. Two explanations compete. The original interpretation was that the smaller particles can easier fall into gaps which the big ones are leaving when jumping up.

In this way the big particles would be pushed towards the top. The second explanation is based on convection roles and channels which would form, which are too small for the big particles to dive down again, so that they must stay on the top. Both of these interpretations are challenged by the recent discovery of an inverse Brazil nut effect which pushes big particles to the bottom.

Finally, we would like to mention the interaction of granular matter ("sand") with water, which often leads to pattern formation, e.g., the famous sand ripples on the beach. On a larger scale, this interaction is crucial (in particular for the Netherlands) for the protection of the coastline.

3. Measurement techniques

Optical diagnostics become more important for the investigation of flows. The principal differences with conventional methods, such as hot-wire anemometry, is that these optical methods can be considered as non-intrusive and that they provide data on the instantaneous spatial structure of the flow field. These optical methods can be divided into two categories: one in which the flow information is extracted from tracer particles added to the fluid (seeded flows), and one in which the fluid information is extracted from the fluid itself (spectroscopic methods).

Seeded flows

The motion of the flow can be detected by adding to the fluid very small tracer particles that are small enough to consider the method as non-intrusive. Essentially the motion is recorded by measuring the displacement of the tracers between to recordings taken with a small time delay. These methods are collectively known as particle image velocimetry, or PIV. In its most basic implementation, the fluid motion is recorded in a planar cross section of the flow, yielding between 103 and 105 velocity vectors per image, with a precision better than 1%. By using stereoscopic recording, it is possible to measure all three velocity components in a plane. This can now be considered as a standard configuration that can be applied for a broad range of applications, ranging from creeping flows to transonic flows.

The challenge in the near future is to further extend the capabilities of these methods:

- Combination of PIV methods with other (optical) diagnostics makes it possible to determine more complex flow properties. For example, the combination of PIV with measurements of the concentration field or temperature field makes it possible to directly measure scalar flux and heat flux;
- Currently under development is a PIV method that can be used for the investigation of two-phase flow, in which one fluid (viz., liquid) is seeded with tracer particles, and the second fluid (viz., bubbles, droplets, or solid particles) is observed simultaneously. Here the challenge is to obtain measurements in a flow system with very strong optical aberrations due to the second phase;
- One major challenge is to be able to measure the full three-dimensional flow field.

Within the JMBC a photogrammetric technique is developed and applied to various flow problems, and a 3D holographic recording method for PIV is under development.

Spectroscopic methods

The development of laser diagnostic techniques is essential for detailed non-intrusive studies of physical and chemical processes in reactive and non-reactive gas flows. At the University of Nijmegen various sensitive detection techniques have been developed and applied to different systems, such as laminar flames, optically accessible diesel engines and non-reactive turbulent flows. Most of these techniques are molecule specific, such as Laser Induced Fluorescence (LIF) detection, Cavity Ring Down Spectroscopy (CRDS) or Raman scattering, which allows for the determination of molecular concentrations. By the application of optical imaging techniques using CCD camera's two-dimensional density distributions can be determined with high spatial and temporal resolution.

The obtained data are used to validate numerical model calculations, which are being performed by other collaborating JMBC groups. For the study of non-reactive flows both Rayleigh and Raman scattering is applied to characterise the density distribution close to boundaries, whereas filtered Rayleigh scattering and Molecular Tagging Velocimetry (MTV) are used for nonseeding velocity measurements. Recently a new promising MTV technique has been developed at Nijmegen, Air Photolysis And Recombination Tracking (APART), which can be used also at high pressure (at least up to 40 bar) to measure velocities with very high spatial resolution. This latter technique is applied for the study of turbulence in collaboration with the groups of Nieuwstadt and Van de Water.

In the near future these laser techniques will be further improved and applied to both combustion and non-reactive flow research. At the University of Groningen LIF, CARS, infrared Cavity Ringdown Spectroscopy and spontaneous Raman scattering are being used for quantitative characterisation of the physics and chemistry of combustion processes, specifically pollutant formation and ignition processes, at atmospheric and reduced pressure.

4. Advanced Numerical Techniques

An essential tool in studying flow problems is computational fluid dynamics (CFD). CFD is a collective term for a large number of numerical techniques, often each with its own area of application. The last decades have shown a growing knowledge of the fundamental concepts of CFD, and the efficiency of numerical algorithms has progressed at a considerable pace. It is foreseen that this growth will continue for some time.

Although much emphasis is on turbulent flows at high Reynolds number and multi-phase or reacting flows (which are posing the more challenging problems from a physical point of view), insights in simpler problems may be equally useful and often even essential for constructing stable and efficient methods, to be used in more general contexts. Of the latter kind one should mention basic progress in iterative methods and in discretisation approaches. Iterative developments have shown widespread use of multigrid methods and special fast solvers for large linear systems. Combination with implicit time-integration can deal with the issue of stiffness in e.g. reacting flow.

Discretisation methods are challenged by complex geometries and moving boundaries, and by large ranges of length- and time scales. Within the JMBC both Cartesian and unstructured (adaptive) grid approaches are being pursued to deal with the geometric and topological challenges. The (structured) Cartesian grid approach is combined with local grid refinement based on defect correction. The scale resolution problem is tackled e.g. by symmetry-preserving finitevolume methods (with a benign behaviour on underresolved flow features) and by space-time discontinuous finite-element methods (offering flexible spatial and temporal grid adaptation). Also unified algorithms for low-Mach number flow are under development. Further, following a different discretisation philosophy, Lattice-Boltzmann methods are being studied, which possess potential advantages in multi-phase flow simulation. Another important tool in enabling the computations to be performed in a ‘reasonably limited’ time is parallellisation. Besides a more straightforward use of multiprocessors where the parallelism is taken care of by the compiler, a variety of domain decomposition techniques is in development. In particular within a context where different flow modelling is used in the individual subdomains, research will open up interesting applications, e.g. in turbulent flow simulation where a mixture of RaNS, LES and/or DNS modelling can be envisaged.

Review of progress in research projects

As agreed by the project leaders of the JMBC only doctoral thesis, (contributions to) books, and publications in scientific journals and in proceedings of conferences with a referee system, are given in the output for each project. Only 2009 publications are taken up in the project descriptions.

An important output for various JMBC-groups is in the form of special reports for industries, technological institutes, etc. Those reports are not mentioned in the output of the projects. For more information, please contact the relevant project leaders. A list of all the projects can be found at the end of this book.

Fluid Mechanics

Prof.dr.ir. J Westerweel

Prof.dr.ir. BJ Boersma

Prof.dr. JCR Hunt

Prof.dr.ir. G Ooms

The group of prof. J Westerweel in the section fluid mechanics consist of the following collaborators: prof.dr.ir. BJ Boersma, dr. R Delfos, prof.dr. JCR Hunt, prof,dr.ir. G Ooms, dr. R Lindken, dr.ir. C Poelma, and dr.ir. MJBM Pourquie. The common theme of the research in this group is turbulence and complex flows, such as multiphase flows, microfluidics and biological flows. The research is aimed at fundamental aspects of flows, but always with a clear connection to a practical application or process in industry. This research is carried out by modern experimental methods, such as particle image velocimetry, and by modern numerical methods, such as direct numerical simulation and large-eddy simulation. In most research experimental and numerical methods are combined.

The turbulence research aims at the interaction of turbulence with other processes, such as mixing and chemical reactions, dispersion of small particles, entrainment, aeroacoustics, and polymer drag reduction. A purely fundamental investigation is the transition to turbulence in a pipe flow. Multiphase flows include liquid/liquid dispersions, the interaction between particles and bubbles in a turbulent liquid , and drag reduction in bubbly flow. An example of a three-phase flow is to investigate the use of gas bubbles to capture small particles in a turbulent liquid. This fundamental investigation is related to a mixing and purification process in steel production. About half of the group is active in the area of (multiphase) microscale flows, i.e. microfluidics. This includes investigation of separation methods and (rapid) mixing in microfluidic devices. Mixing is investigated using various geometries, external forces (e.g., electroosmotic flow and acoustic forcing) and actuators. Recently a new stereoscopic micro-PIV system was developed and applied to the investigation of three-dimensional microfluidic flows. Other activities include the development of liquid/liquid microreactors for sample treatment and detection of DNA.

More recent we began to investigate microscale cardiovascular flows. The aim is to investigate the relation between differentiation and adaptation of tissues to fluid mechanical forces. This provides fundamental knowledge to understand the mechanisms of certain diseases, such as atherosclerosis. This research is carried out in close collaboration with medical groups at the universities of Leiden and Rotterdam.

Investigation of complex flow patterns in a moving immersion lens droplet (Contact line control during wetting & dewetting)

Project Aim

This project aims to visualize and investigate the complex flow patterns that occur in a confined Couette flow that resembles a moving droplet of an immersion lens geometry, and to understand how this interacts with the dynamics of the moving contact line. We will make use of the newly developed stereoscopic micro particle image velocimetry (μ-PIV), as well as numerical simulations to gain a better understanding of the various flow patterns that occur at intermediate flow Reynolds numbers. The results should lead to strategies that can achieve flow control and to optimized design of a moving immersion lens.

Progress

We perfomed for the first measurements of the internal flow of a moving droplet in the high Reynolds number regime (Re>>1), by means of 3D Particle Tracking Velocimetry. This measurement technique is capable of simultaneously measuring all three velocity components in the volume flow. The accuracy of the measurements gives only around one micron error, relatively. Furthermore, the total error of the mass conservation in the droplet is about 5% w.r.t the inlet flow. Eventually, we have obtained the complex flow patterns in the immersion lens droplet when the droplet has a wedge shape at the rear. That exhibits a complex, but symmetric, flow pattern. The main flow is converging to the rear of the droplet, but there is a small region with reversed flow at the corner of the droplet. There is a birfucation point where two different flow patterns meet each other.

Dissertations

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Scientific Publications

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Projectleaders

J Westerweel, BJ Boersma, G Ooms, JCR Hunt, B Eckhardt

Researchtheme

Complex dynamics of fluids

Participants

H Kim, J Westerweel, S Grosse, M Franken

Cooperations

ASML, UT, TU/e

Funded

FOM

1st - 2nd 100% 3rd -

Start of the project

2008

Information

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Precipitation in a microchannel

Projectleaders
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Researchtheme
Complex dynamics of fluids

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GJ Witkamp, J Westerweel

Cooperations
API-TUD

Funded
DC-SIP, JMBC Burgerscentrum,
Microned
1st 100% 2nd - 3rd -

Start of the project
2005

Information
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Project Aim

The aim of the project is to implement a chemical reactor on a microscale device. The process is an anti-solvent precipitation reaction which is a model for more complex chemical processes in industry that involve toxic components or exothermic reactions. The objective is to control the process and to integrate transport, mixing and separation on a single microfluidic device.

Progress

In microfluidics the channel geometry is often not circular or square due to the manufacturing difficulties associated with the small scales. In differently shaped channels the spreading of precipitate is different than expected based on theory. Therefore effort has been put on how a stack of precipitate (simulated by a sample plug of fluid) moves through an arbitrary shaped microchannel. A model for the dispersion has been developed for pressure-driven and electroosmotic flow and successfully tested both experimentally and numerically. From the theory also a minimum dispersion velocity for any arbitrary shaped channel can be determined, which is of importance for example DNA-sampling in microdevices. Furthermore it is investigated how a converging-diverging channel geometry together with a pressure-difference and electroosmotic flow applied can separated small particles both in size and in charge. For this the charge of the particles is changed by changing the pH of the working fluid. The small particles here are used as a model for small crystals formed during a precipitation reaction.

Dissertations

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Scientific Publications

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Steps to turbulence: patterns in pipe flow

Project Aim

Recently theoretical/numerical investigations have shown the existence of flow patterns in the form of non-linear traveling waves, which are exact solutions of the Navier-Stokes equations. Although these structures are unstable, they were confirmed by experiments and has given rise to a new view on transition in pipe flow. The aim of the current project is to explore this new and exciting development by studying these traveling waves in a turbulent pipe flow in a setup with slowly reducing Reynolds number. For the measurements a state-of-the-art high speed stereo PIV system will be used to determine the role of the traveling waves in the dynamics of turbulence.

Progress

In 2008 the characteristic lifetime of localized turbulence was measured. These results were used to submit a manuscript to the Journal of Fluid Mechanics, which is now accepted and in press. Furthermore the methods used in that investigation were used to identify the exact location of decay of localized turbulence together with a high speed stereoscopic PIV system. This allowed for a detailed investigation of the flowstructures during the decay process.

Dissertations

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Scientific Publications

1. D.J. Kuik, C.Poelma, J. Westerweel. Experimental Observation of the Decay of Localized Turbulence in Pipe Flow. SIAM – Applications of Dynamical Systems. Salt Lake city, USA 2009.
2. D.J. Kuik, C.Poelma, B.Hof & J. Westweel. Direct quantitative measurement of the life time of localized turbulence in pipe flow. TSFP-6, Seoul, Korea 2009.
3. D.J. Kuik, C.Poelma, J. Westerweel. The decay process of localized turbulence. ETC-12, Marburg, Germany 2009.

Projectleaders
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Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
-

Funded
FOM, Dynamics of Patterns,
1st - 2nd 100% 3rd -

Start of the project
2007

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ARTIC: Nature-inspired micro-fluidic manipulation using artificial

Projectleaders
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Researchtheme
Complex dynamics of fluids

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Cooperations
PHILIPS, IMTEK, Liquids Research Ltd. (LRL), University of Groningen, University of Bucharest, University of Bath and Eindhoven University of Technology

Funded
European Project, Philips.
1st 25% 2nd 50% 3rd 25%

Start of the project
2006

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Project Aim

The overall objective of this project is to explore, develop and validate a novel micro-fluidic process and technology on the basis of polymeric micro-actuators inspired by the natural ciliates, that can be fully integrated within a complete micro-fluidic system. The artificial cilia are supposed to be actuated by electro-magnetic or fields.

Progress

The measurement set-up to evaluate the cilia response on the actuation field and to perform phase locked PIV measurements during actuation has been established and tested. The field strength and rotation sense for certain current inputs can be reconstructed for all measurements. The release procedure for optimal cilia performance is still under investigation. A numerical 2D model has been developed to investigate the effect of metachronal cilia motion.

Dissertations

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Scientific Publications

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THE HEMODYNAMICS OF VASCULAR REMODELLING

PROJECT AIM

Fluid mechanics plays a critical role in the formation and adaption of vascular networks. The wall shear stress has been identified as one of the key parameters in this interaction. This project will focus on the quantification of flow conditions relevant for angiogenesis and vascular adaption. With a recently developed micro-PIV method for in-vivo measurement of blood flow, it is possible to measure instantaneous flow and wall shear stress data. This micro-PIV system will be used for in-vivo measurements of the vitelline network and cardiovascular system in chicken embryos.

PROGRESS

For micro-PIV measurements, the DOC (Depth of Correlation) is a vital parameter: it defines the measurement volume. This measurement volume thickness can be large with resprect to the geometry under investigation, leading to significant averaging. Studying a vessel network demands low microscope magnifications (i.e. large field-of-view). With most microscopes, lowering the magnification will result in a lower numerical aperture and eventually to a larger DOC. To get better insight in how measured velocities relate to the actual velocity when gradients are present, the accuracy of the micro-PIV method has been investigated experimentally. An in vitro experiment has been performed in a known reference flow: a glass capillary is used to model the blood vessel. With the micro-PIV system, measurements have been performed for different magnification for two different types of microscopes. The outcome is a generalized method to predict the underestimation of the maximum velocity under different conditions.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. 8th INTERNATIONAL SYMPOSIUM on PARTICLE IMAGE VELOCIMETRY, Melbourne, Australia, August 25-28, 2009.

PROJECTLEADERS

J Westerweel, BJ Boersma, G Ooms, JCR Hunt, B Eckhardt

RESEARCHTHEME

Complex dynamics of fluids

PARTICIPANTS

Astrid Kloosterman, Christian Poelma, Jerry Westerweel

COOPERATIONS

Leiden University MC and Erasmus MC Rotterdam

FUNDED

TUD

1st 100% 2nd - 3rd -

START OF THE PROJECT

2008

INFORMATION

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Ship drag reduction by air lubrication

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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J Westerweel, D Lohse
Cooperations
Delft University of Technology,
Twente University, PPG industries,
MARIN
Funded
STW, PPG, MARIN
1st 87% 2nd - 3rd 13%
Start of the project
2009
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Project Aim

The aim of this project is to enhance the effects of air lubrication on frictional drag significantly, by improving our knowledge on the detailed mechanisms and its scale effects. With this knowledge the effectiveness of air lubrication should be increased in order to make application on ships feasible.

Progress

The commercial shear stress sensor has been tested in order to use it in frictional drag measurement in two-phase flow. Defined some characteristics of the sensor in water and water-air flows. Preliminary tests in two-phase pipe flow have been made.

Dissertations

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Scientific Publications

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Ship drag reduction by air lubrication

Project Aim

The aim of this project is to enhance the effects of air lubrication on frictional drag significantly, by improving our knowledge on the detailed mechanisms and its scale effects. With this knowledge the effectiveness of air lubrication should be increased in order to make application on ships feasible.

Progress

Numerical simulations are performed of turbulent channel flow with Lagrangian point bubbles. Bubble concentration profiles can be described by a Rouse parameter which decribes the effects of buoyancy and turbulent mixing. A direct force sensor is developed which measures skin friction forces on a 150mm diameter disk. It is designed to operate in a low flow velocity regime of 0.1 to 1 m/s. A zero pressure gradient boundary layer is created in a water channel and force measurements and stereo PIV measurements on two phase boundary layer flows are scheduled.

Dissertations

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Scientific Publications

1. Harleman M, Delfos R, Westerweel J, Terwisga T van, Characterizing a boundary layer flow for bubble drag reduction, Progress in Wall Turbulence conference, Lille April 21-23 2009.

Projectleaders
TJC van Terwisga, J Westerweel, D Lohse

Researchtheme
Complex dynamics of fluids

Participants
O Sverkhovskyi, D van Gils, M Harleman

Cooperations
TUD, UT, PPG Industries, MARIN

Funded
STW, PPG, MARIN
1st - 2nd 87% 3rd 13%

Start of the project
2007

Information

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Identification and modification of acoustic sources in a turbulent flow past a cavity

Projectleaders
J Westerweel, BJ Boersma,
G Ooms, JCR Hunt, B Eckhardt

Researchtheme
Complex dynamics of fluids

Participants
V Koschatzky, BJ Boersma,
J Westerweel

Cooperations
-

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2007

Information
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Project Aim

Identification and modification of acoustic sources in a turbulent flow past a cavity and development of a strategy to reduce sound emission.

Progress

In the last year we focused on the development of techniques that can allow us to estimate the radiated sound from experimental high speed PIV data. In particular we worked on the application of two different acoustic analogies to our experimental data. Results showed a good general agreement between the estimate from the two methods and the measured sound while each of the two methods seems to approximate better the measured sound in a different range of frequencies. Further investigation is in progress.

Dissertations

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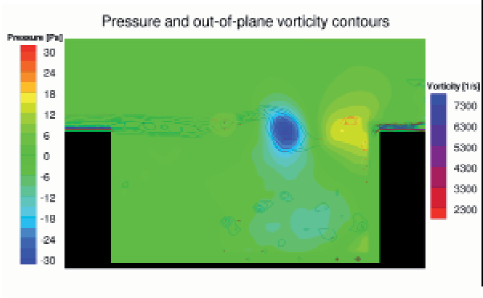
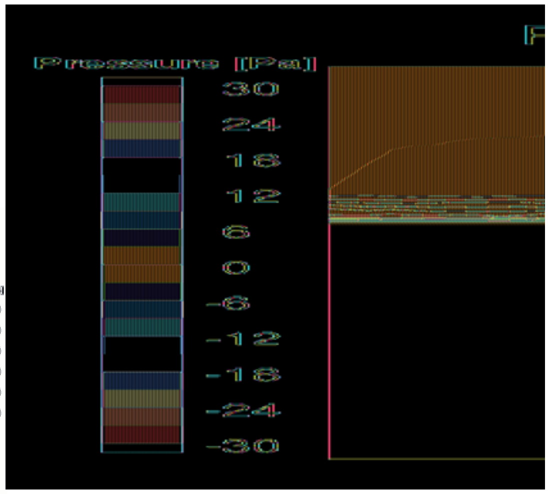
Scientific Publications

1. V. Koschatzky, R. Delfos, B.J. Boersma, and J. Westerweel, "Boundary layer influence on cavity noise generation," Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, September 7-10, 2009, Marburg, Germany, Vol. 132, 2009.
2. V. Koschatzky, B.J. Boersma, F. Scarano and J. Westerweel, "High speed PIV applied to aerodynamic noise investigation", 8th International Symposium on Particle Image Velocimetry -PIV09, 2009.





Study of droplet dynamics and turbulence modification in two-phase flows by means of DNS

Project Aim

The goal of this project is on understanding droplet dynamics and turbulence modification in the clustering regime St~1. We will consider droplets whose characteristic size is significantly larger than the Kolmogorov length scale, whence they can not be modeled as point droplets. In particular we are interested in situations leading to break-up and coalescence of these droplets. We intend to perform direct numerical simulations on a turbulent channel flow with a large number of droplets.

Progress

Since our goal is to simulate a large number of droplets, the efficiency of the original code must be improved. Therefore we implemented a local marker method to capture the interface, a multi-dimensional parallelization and a two-level preconditioner for the conjugate gradient method based on deflation. These improvements show a large speed up (around a factor 4.5 for a benchmark simulation of a gravity-driven droplet-droplet collision), which make simulations with a large number of droplets possible. A start is made with the implementation of the coalescence model, which will be validated against existing results.

Dissertations

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Scientific Publications

1. E.R.A. Coyajee and B.J. Boersma, Numerical simulation of drop impact on a liquid-liquid interface with a multiple marker front-capturing method. J. Comput. Phys. 228 (2009) 4444-4467.

Projectleaders

J Westerweel, BJ Boersma, G Ooms, JCR Hunt, B Eckhardt

Researchtheme

Complex dynamics of fluids

Participants

M Kwakkel, W-P Breugem, BJ Boersma

Cooperations

-

Funded

TUD

1st 100% 2nd - 3rd -

Start of the project

2008

Information

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Flotation and de-mixing of turbulent 3-phase flows

Projectleaders
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G Ooms, JCR Hunt, B Eckhardt

Researchtheme
Complex dynamics of fluids

Participants
N Warncke, R Delfos

Cooperations
Dr. Lifeng Zhang, Missouri University of Science & Technology

Funded
STW, Corus RT&D
1st - 2nd 75% 3rd 25%

Start of the project
2007

Information
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Project Aim

The aim of this research proposal is to investigate how large gas bubbles rising through a turbulently flowing liquid-particle suspension interact with the particles of the suspension. More specifically, we will investigate how the solid particles adhere to the surfaces of the bubbles, or get entrapped in the wakes of the bubbles, both leading to an upward transport of the particles. This mechanism, called flotation, is primarily investigated by experimental methods.

Progress

In 2009 several measurements (simultaneous planar, 2-phase PIV/PTV of the wake of a spherical cap) have been performed and analyzed.
The concentration measurements show no significantly increased particle concentration in the near-wake for St<1, a result which is confirmed by the (within the marigins of error) zero particle flux into the wake, integrated from the interpolated particle velocity normal to the wake boundary. These results have been presented at the ETC12 in September 2009. To investigate interface effects of bubbly flotation, a new setup has been made to trap single gas bubbles. This facility allows for similar 2-phase measurements as those already done but with a real gas bubble. Furthermore, a cooperation on this topic has been established with Dr. Zhang.

Dissertations

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Scientific Publications

1. Warncke, Delfos, Westerweel: “Particle transport in turbulent wakes behind spherical caps”, Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, Springer Proceedings in Physics, Vol. 132, p. 513-516.

Nanoscale contact line dynamics based on TIRFM

Project Aim

The aim of the project is to visualize and understand the behavior of a contact line at a nanoscale. A measurement method is to be developed in order to measure contact angles at the nanoscale. The method should allow the contact angle, contact angle hysteresis, droplet coalescence and movement of a droplet over a nano-structured surface to be studied at a nanoscale under varying conditions. Experiments will give insight in the way contact line instabilities occur and how these can be prevented.

Progress

A measurement method is developed in order to study nanoscale contact line dynamics. The method is based on total internal reflection fluorescence microscopy (TIRFM). This technique uses the evanescent wave produced by the total internal reflection of light to illuminate a thin layer of liquid within the penetration depth of the evanescent field. An atomic force microscope (AFM) is used to calibrate the penetration depth of the evanescent wave using a particle attached probe. By using the intensity distribution near the interface of the droplet, in combination with the calibrated evanescent wave it is possible to reconstruct the interface of a droplet at a nanoscale.

Dissertations

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Scientific Publications

-

Projectleaders

J Westerweel, BJ Boersma,
G Ooms, JCR Hunt, B Eckhardt

Researchtheme

Complex dynamics of fluids

Participants

MJZ Franken, C Poelma,
J Westerweel

Cooperations

ASML, UT, TU/e

Funded

ASML
1st - 2nd - 3rd 100%

Start of the project

2008

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Basis for the biological responses due to instationary fluid motion during random positioning

Projectleaders
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G Ooms, JCR Hunt, B Eckhardt

Researchtheme
Complex dynamics of fluids

Participants
C Leguy, R Delfos, C Poelma,
J van Loon, M Pourquie

Cooperations
VU medisch centrum, Amsterdam
NLR-Amsterdam, Bioclear,
Groningen.

Funded
NWO-SRON
1st - 2nd 100% 3rd -

Start of the project
2009

Information
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Project Aim

To understand the role of gravity in biological systems one may decrease it going into free-fall conditions such as available on various platforms. However, these experiments are expensive. Thus, techniques, like Random Positioning Machines (RPM), are now widely used within the biological arena to simulate micro-gravity environment. These instruments generate random movements so that gravitational effects cancels out over time. However, comparative studies performed with the RPM machine were unable to reproduce the clear-cut space flight results. These differences may be explained by undesirable stresses acting on the cultured cells. The objective of this study is to predict and map fluid flow behavior and suspended particle motion in an RPM culture container in relation to its shape and movement.

Progress

Within the proposed study we address the former issues via Computational Fluid Dynamics (CFD), and experimentally using Particle Image Velocimetry (PIV). We will assess the flow- and the deformation/stress field in the interior of a tank of fluid in instationary rotation. In the fisr t part off this project, an initial set-up based on thermo-conducted flow with a PIV system has been developed and a DNS computational fluid dynamics model that incorporates the centrifugal and coriolis forces have been implemented.

Dissertations

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Scientific Publications

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Development and application of volumetric velocity measurement techniques

Project Aim

Development and application of volumetric velocity measurement techniques based on digital holographic imaging and tomographic imaging. The methods will be employed in the investigation of turbulent and instationary flows at both large scales and small scales. The results will be compared with those obtained from numerical simulations. The project interacts with ongoing research on the role of coherent flow structures in turbulent flows and small-scale flows.

Progress

Tomographic PIV set-up has been assembled and tested in measurements of a zero-pressure-gradient turbulent boundary layer over a flat plate. Good agreement in statistics is achieved with data from other sources. One of the goals is to relate recently reported in literature modulation of small scale motion by large scale motion to the distribution of eddies with respect to local large scale shear layers. Evaluation of the experimental data is still work in progress. Meanwhile, a series of experiements is being prepared to investigate flow over rough elements like fence.

Dissertations

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Scientific Publications

1. Delfos R., Semin N.V., Harleman M. Drag Reduction estimate based on Stereo PIV Measurements of the Wake behind a Modified Ahmed Body. Advanced Model Measurement Technology for EU Maritime Industry, 1-2 September 2009. Nantes, France.

Projectleaders
J Westerweel, BJ Boersma, G Ooms, JCR Hunt, B Eckhardt

Researchtheme
Complex dynamics of fluids

Participants
N Semin, C Poelma, G Elsinga, J Westerweel

Cooperations
-

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2008

Information

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DYNAMICS OF COHERENT STRUCTURES IN TURBULENT BOUNDARY LAYERS

PROJECTLEADERS
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G Ooms, JCR Hunt, B Eckhardt

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
GE Elsinga

COOPERATIONS
The University of Melbourne
German Aerospace Center, DLR

FUNDED
FOM
1st - 2nd 100% 3rd -

START OF THE PROJECT
2008

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PROJECT AIM

The time evolution of flow topology and coherent structures in turbulent boundary layers are investigated experimentally. In this study time-resolved tomographic PIV will be employed measuring the three-dimensional velicty distribution at both large scales and small scales, which allows evaluating the velocity gradients in space and time. Results are used to obtain charateristic time-scales for flow topology, study the interaction of hairpin vortices and describe the organization of small- and large-scale motions.

PROGRESS

Time-resolved tomographic PIV measurements were performed in the water tunnel. Analysis of the data yielded information on the average Lagriangian evolution of local flow topologies, as well as their characteristic time-scale [1]. Further, the tomographic PIV technique was combined with a tracking of the individual tracer particles. Using this approach the flow velocities in both Lagrangian and Eulerian frames of reference can be accessed simultaneously [4]. The accuracy of the tomographic-PIV technique was assessed also and practical guideline for its application were developed [3]. Finally, high Reynolds number experiments have revealed a very large-scale spanwise organization in addition to the known streamwise organization [2].

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. G.E. Elsinga and I. Marusic (2010) “Evolution and lifetimes of flow topology in a turbulent boundary layer.” Physics of Fluids 22, 015102.
2. G.E. Elsinga, R.J. Adrian, B.W. van Oudheusden and F. Scarano (2010) “Three-dimensional vortex organization in a high Reynolds number supersonic turbulent boundary layer.” Journal of Fluid Mechanics 644, 35-60.
3. G.E. Elsinga, J. Westerweel, F. Scarano and M. Novara (2009) “On the velocity of ghost particles.” 8th International Symposium on Particle Image Velocimetry, Melbourne, Australia, paper PIV09-0035.
4. A. Schröder, R. Geisler, K. Staack, A. Henning, B. Wieneke, G.E. Elsinga, F. Scarano, C. Poelma and J. Westerweel (2009) “Lagrangian and Eulerian aspects of a turbulent boundary layer flow - An investigation using time-resolved tomographic PIV.” Progress in Wall Turbulence: Understanding and modeling, Lille, France.

Marine Technology

Prof.dr.ir. RHM Huijsmans

Prof.dr.ir. TJC van Terwisga

Seakeeping and Manoeuvring - prof. RHM Huijsmans

Research of the Chair of Ship motions and manoeuvring is at present focused on the following areas: 1. Non-linear behaviour of fast craft in waves; 2. Extreme wave events in relation to stationary floating structures; 3. Very Large Floating Structures at sea; 4. Prediction of manoeuvring forces based on CFD methods.

High speed ships traveling in waves experience large amplitude motions which can lead to strong non-linear effects in the loads on the hull girder. These non-linear effects are due partly to the large changes in the wetted part of the hull in waves and partly due to non-linear pressure effects. Extreme wave events (breaking waves etc.) can lead to high impact loads on stationary floating structures , e.g. bow loads on Floating Production and Storage vessels for the oil industry. Hydrodynamic analysis of such behaviour is now moving towards application of CFD methods to determine the local flow at the bow. In order to simulate open sea conditions, the CFD region will be connected to an outer region which will be described by potential flow methods. This will allow waves to enter the region local to the bow and reflected waves to travel away from the bow thus minimizing reflections from the CFD boundary. Very Large Floating Structures are being investigated world-wide for various applications such as airports and for floating cities. This research is aimed at developing a novel concept of a large floating structure based on the use of air cushions to support the structure and distribute the wave loads thus optimizing both motion behaviour and structural costs. Manoeuvring models for ships have traditionally been based on equations of motions using experimentally determined drag, mass and lift coefficients. This research aims to investigate the applicability of CFD methods in determining the hydrodynamic coefficients for existing mathematical models. Use is made of a RANS code developed by MARIN and modified to accomodate oblique flow.

Propulsion and Resistance - prof. T van Terwisga (part time)

Research at the Chair of propulsion and resistance is focussed on three areas: 1. Cavitating Flows; 2. Ship-Propeller-Engine system in Service Conditions; 3. Drag reduction through air lubrication.

Cavitation remains an important field of investigation in Marine Technology. Almost all propellers in operation show cavitation in some but mostly in all working conditions. Cavitation often is an important source of vibrations and sometimes even cavitation erosion. Cavitation on propellers should therefore be controlled as much as possible in both the design and during operations. As cavitation often appears to be extremely unsteady and unstable, this poses a continuing challenge to designers and research groups. The more so because an acceptable cavitation control and a high propulsive efficiency are often conflicting requirements. The Delft Cavitation Tunnel has proven to be a strategic tool for enhancing our understanding of the physics and engineering characteristics. There are currently two PhD projects addressing this issued: One on unsteady sheet cavitation (E.J. Foeth) and another on propeller radiated pressure fluctuations (E.v.Wijngaarden).Ship-Propeller-Engine system analysis and simulation is important to reduce e.g. radiated noise from the propeller and to reduce wear of the propulsion system during its operation. To this end, a close cooperation exists with the section of Marine Engineering. There is currently a PhD project concerned with the development of a model podded propeller for testing in operational conditions (G. Oosterhuis), and a recent PhD project on improved propulsion control for Naval Vessels (A.Vrijdag). Initiatives in the third area on Drag reduction through air lubrication are currently under way.

Seakeeping of high speed ships - The development of a 3D time domain boundary element method (FAST II)

Project Aim

The aim of the FAST II phd project is to develop comprehensive and efficient mathematical tools for the evaluation of (nonlinear) motions of high speed vessels. The result of the phd-project will be a fully validated numerical tool for the evaluation of motions and loads of high speed ships operating in waves based on a time domain potential flow boundary element method.

Progress

In 2009 the code implementation of the numerical tool has been finalised and the numerical verification and validation have been initiated. In addition towing tank experiments have been setup and carried out to provide additional validation data. The tank tests encompass motion and acceleration responses of a two 1/20 models of contemporary high speed patrol ship designs in regular and irregular head waves. Preliminary results of the verifications show that the code implements the mathematical model succesfully. Validation is ongoing.

Dissertations

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Scientific Publications

1. Jong, P. de and Walree, F. van, The development and validation of a time-domain panel method for the seakeeping of high speed ships. In Proceedings of the 10th International Conference on Fast Sea Transportation, Athens, Greece, 2009.

Projectleaders

RHM Huijsmans

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

P de Jong, JA Keuning

Cooperations

-

Funded

Marin, Royal Netherlands Navy Damen Shipyards, Royal Schelde Group

1st - 2nd - 3rd 100%

Start of the project

2005

Information

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Numerical Analysis

Prof.dr.ir. C Vuik

Prof.dr.ir. P Wesseling

The research program of the Numerical Analysis group of TUD belongs to the field of computational science and engineering. We concentrate on the development and application of computing methods to the applied sciences. The focus is on mathematical models relying heavily on partial differential equations, such as occur in fluid dynamics. But we also consider similar mathematical models arising in other fields, for instance materials science and reservoir engineering, usually in cooperation with domain experts. A specialty is problems involving partial differential equations with moving internal boundaries, such as occur in bubbly flows and in phase transition problems. To diminish computing time in large-scale applications, iterative methods for solving large systems of algebraic equations are developed further, using deflation, multi-block, preconditioning and multigrid techniques.

Modeling healing of epidermal wounds and bone fracture

Project Aim

The aim is simulate bone healing and healing of epidermal wounds

Progress

A mathematical model involving wound contraction (as a result of formation of a fibroblast tissue in a deep wound), angiogenesis (formation of capillaries) and wound closure (closure of the epidermis) has been formulated in terms of coupling of the processes. The model consists of visco-elastic equations with a set of nonlinear diffusion-reaction equations. Finite element methods combined with IMEX time integration schemes have been used. Further, a visco-elastic model has been analyzed mathematically and for some cases analytic solutions have been constructed. Finally, a mathematical analysis for a bone-ingrowth model has been carried out.

Dissertations

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Scientific Publications

1. E. Javierre, F.J. Vermolen, C. Vuik, S. van der Zwaag. A mathematical analysis of physiological and morphological aspects of wound closure. Journal of Mathematical Biology, 59 (2009) 605-630.
2. F.J. Vernolen, E. Javierre. A suite of continuum models for different aspects in wound healing. In A. Gefen (Ed.), Bioengineering of chronic wounds (studies in mechanobiology, Tissue Engineering and Biomaterials 1, Berlin-Heidelberg: Springer Verlag, 127-166, 2009.
3. F.J. Vermolen, A. Andreykiv, E.M. van Aken, J.C. van der Linden, E. Javierre, A. van Keulen. A suite of mathematical models for bone ingrowth, bone fracture healing and intra-osseous wound healing. In Barry Koren & Kees Vuik (Eds.), Advanced computational methods in science and engineering (Lecture notes in computational science and engineering, 71) , Berlin-Heidelberg: Springer Verlag, 289-314, 2009.
4. F.J. Vermolen, E. Javierre. On the construction of analytic solutions for a diffusion-reaction equation with a discontinuous switch mechanism. Journal of computational and applied mathematics, 231 (2), 2009, 983-1003.
5. F.J. Vernolen. Simplified finite-element model for tissue regeneration with angiogenesis. ASCE Journal of Engineering Mechanics, 135 (5), 2009, 450-460.

Projectleaders
FJ Vermolen, S van der Zwaag

Researchtheme
Complex dynamics of fluids

Participants
FJ Vermolen, PA Prokharau

Cooperations
Old Dominion University, Norfolk, USA; Centro de Investigacion Biomedica en Red en Bioingenieria, Zaragoza, Spain

Funded
DCMAT, Senternovem (NWO)
1st 75% 2nd 25% 3rd -

Start of the project
2003

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.....

Mathematical and computational methods for fluid flow analysis

Projectleaders
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Researchtheme
Complex dynamics of fluids
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Cooperations
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Funded
European Office of Aerospace Research and Development / U.S. Air Force Office of Scientific Research
1st 20% 2nd - 3rd 80%
Start of the project
2003
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Project Aim

The purpose of the proposed research is the mathematical and algorithmic development of smoothness-increasing accuracy-conserving filters with application to post-processing and visualizing discontinuous Galerkin simulation results.

Progress

This year has focused on the mathematical development of the local filter for post-processing near a boundary as well as more computationally efficient integration schemes. For filtering a discontinuous Galerkin (DG) solution near a boundary, a linear combination of 4k+1 B-Splines are used, which essentially doubles the number of B-Splines used in a boundary region. This increases the order of accuracy in those regions as well as improves the magnitude of the errors. For evaluating the convolution kernel used by the filter, we established error bounds on the effect of inexact integration. We established that it is possible to perform more efficient integration by ignoring the B-spline kernel breaks and only consider the element breaks in the DG solution.

Dissertations

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Scientific Publications

1. P. van Slingerland, J.K. Ryan, C. Vuik, “Smoothness Increasing Accuracy Conserving Filtering Applied to Streamline Visualisation of DG Solutions”, Technical Report 09-06, Delft University of Technology, Delft, Netherlands, 2009.

Bacterial self-healing of concrete

Project Aim

The aim is to simulate self-healing of concrete.

Progress

A mathematical model for the bacterial sealing of a crack in concrete structures is being constructed. A paper on this topic has been submitted. Further, an analytic model has been developed to predict the probability that a crack hits an encapsulated particle in a concrete structure.

Dissertations

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Scientific Publications

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Projectleaders
FJ Vermolen

Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
Corusgroup (Aluminium),
Department of Materials Science
and Engineering

Funded
DCMAT
1st 50% 2nd 50% 3rd -

Start of the project
2003

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PROJECTLEADERS
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RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
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COOPERATIONS
Corusgroup (Aluminium), Department of Materials Science and Engineering
FUNDED
DCMAT
1st 50% 2nd - 3rd 50%
START OF THE PROJECT
2003
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PROJECT AIM

The aim is to simulate processes occurring during heat treatments of metals.

PROGRESS

A multi-dimensional model for the dissolution of multicomponent lamellar cementite (pearlite) has been constructed. A paper is being written about this topic in collaboration with researchers from materials science. The model takes into account geometrical issues. Further, a model for the evolution of the statistical particle size distribution has been developed. The model has been extended with mechanical effects.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. E. Javierre, F.J. Vermolen, C. Vuik, P. Wesseling, S. van der Zwaag. Computing interfaces in diverse applications. In H.A. Mang & J. Periaux (Eds.), New computational challenges in materials, structures and fluids, Berlin, Springer, 327-340, 2009.

Mathematical methods for flow in porous media

Project Aim

The aim is to develop and analyze mathematical models for multi-phase fluid flow, flow of polymeric solutions and foam penetration in porous media. The most important application is oil recovery from underground reservoirs. For some cases we are interested in the qualitative characteristics, like the existence of travelling waves and free boundaries, of the solutions of the equations involved in the models.

Progress

A paper about phase segregration (spinodal decomposition) is being written. A numerical method for the multi-component case in a more-dimensional setting has been accomplished. Further, a Finite Element scheme has been developed for the solution of a stress-enhanced diffusion equation in collaboration with prof Bruining. This equation involved very rapidly changing nonlinear diffusive terms and cross derivatives with respect to time and spatial variables. Papers have been submitted about these two topics. Further, the lastmentioned model will be extended in the framework of a jointly supervised MSc-project (with prof. Bruining). Further, a mathematical model for bacterial soil fortification has been investigated numerically.

Dissertations

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Scientific Publications

1. F.J. Vermolen, M. Gholami-Gharasoo, P.L.J. Zitha, J. Bruining. Numerical solutions of some diffuse interface problems: The Cahn-Hilliard equation and the Model of Thomas and Windle. International Journal for Multiscale computational engineering, 7 (6), 2009, 523-543.

Projectleaders

FJ Vermolen, C Vuik

Researchtheme

Complex dynamics of fluids

Participants

F Vermolen, C Vuik, J Bruining,
PLJ Zitha, WH van Wijngaarden

Cooperations

TUD/ Applied Earth Sciences, TUE

Funded

TUD
1st 50% 2nd - 3rd 50%

Start of the project

2000.

Information

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PROJECTLEADERS
C Vuik, A Segal
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
C Vuik, A Segal, JM Tang,
R Nabben
COOPERATIONS
TU Eindhoven, Sepra, TNO-Science and Industry, TU Berlin
FUNDED
TUD, TNO-TPD, BRICKS
1st 25% 2nd 25% 3rd 50%
START OF THE PROJECT
1996
INFORMATION
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PROJECT AIM

The purpose it to improve efficiency of solution methods in computational fluid dynamics, porous media flow and related applications. The DICCG (deflated preconditioned conjugate gradients) method will be developed further. The method will be generalized such that reliable termination criteria can be applied. Domain subdivision methods will be developed to make DICCG applicable.

PROGRESS

The SEPRAN code is parallelized and works efficiently on parallel platforms. More and more users are simulating with the parallel version. This leads to useful feedback in order to enhance the solver. Theoretically the deflation acceleration is compared with an additive coarse grid correction and a balancing Neumann Neumann preconditioner. It appears that the deflation method leads to the fastest convergence, whereas the work per iteration is less or equal to the other methods. Many (in)compressible Navier-Stokes equation solvers use a splitting method to solve the discretized equation. In many applications, especially in bubbly flows, the pressure equation takes most of the time to be solved. One of the reasons is the jump in the density in gas and water. Multi grid methods can be used but some difficulties remain if the size of the bubbles is very small. In this project the pressure equation is solved by the deflated ICCG method. After optimization it appears that the resulting method is 4-5 times faster than the ICCG method. We plan to make a better choice of the projection vectors and try to combine it with domain decomposition and parallel computing. Currently we implement the method on GPU processors.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. T. Geenen, M. ur Rehman, S.P. MacLachlan, G. Segal, C. Vuik, A.P. van den Berg, W.Spakman. Scalable robust solvers for unstructures FE geodynamic modeling applications: Solving the Stokes equation for models with large localized viscosity contrasts Geochemistry Geophysics Geosystems, 10, pp. 1-12, 2009.
2. J.M. Tang, R. Nabben, C. Vuik, Y.A. Erlangga. Comparison of Two-Level Preconditioners Derived from Deflation, Domain Decomposition and Multigrid Methods Journal of Scientific Computing, 39, pp. 340-370, 2009.

Solution methods for Navier-Stokes problems

Project Aim

New preconditioners for the discretized Navier-Stokes equations will be developed. Parallel deflation methods will be included.

Progress

The discrete Navier-Stokes equations are solved by the SIMPLE(R) iteration method. To decrease the very large number of iterations, we have proposed multigrid and Krylov accelerated versions: GCR-SIMPLE(R). The properties of these methods are being investigated for simple two-dimensional flows and three-dimensional flows in industrial glass melting furnaces. These methods are generalised to a colocated discretization and combined with the deflated multiblock approach and parallel computing. Now we try to generalize these solvers to our FEM discretization (SEPRAN) and compare our methods with the recently developed methods given by Elman, Wather, Sylvester, Benzi, Reusken and Schilders. It appears that MSIMPLER, a new variant of SIMPLER, leads to the fastest results. We also develop a solver based on the Schu complement and multigrid. This method is scalable and leads to very good results for geophysical applications.

Dissertations

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Scientific Publications

1. T. Geenen, M. ur Rehman, S.P. MacLachlan, G. Segal, C. Vuik, A.P. van den Berg, W.Spakman. Scalable robust solvers for unstructures FE geodynamic modeling applications: Solving the Stokes equation for models with large localized viscosity contrasts Geochemistry Geophysics Geosystems, 10, pp. 1-12, 2009.
2. M. ur Rehman, C. Vuik, G. Segal. SIMPLE-type preconditioners for the Oseen problem. Int. J. Num. Meth. In Fluisd, 61, pp. 432-452, 2009.
3. B. Koren, C. Vuik. Advanced Computational Methods in Science and Engineering, Springer, Berlin, 2010.

Projectleaders

C Vuik

Researchtheme

Complex dynamics of fluids

Participants

CW Oosterlee, C Vuik, P Wesseling, A Segal, M ur Rehman

Cooperations

TNO-Science and Industry, GMD, CPS University of Zaragoza, Sepra

Funded

STW, TUD, TNO-Science and Industry, Nuffic-HEC

1st 25% 2nd - 3rd 75%

Start of the project

1992

Information

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The calculation of acoustic modes in a combustion chamber

Projectleaders
C Vuik
Researchtheme
Complex dynamics of fluids
Participants
MB van Gijzen
Cooperations
GLG Sleijpen (UU), F Nicoud (Université Montpellier, Fr), C Sensiau (CERFACS, Fr)
Funded
TUD, Funding for a traineeship by CERFACS.
1st 10% 2nd - 3rd 90%
Start of the project
2005-2008
Information
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Project Aim

The purpose is to enable the computation of unstable acoustic modes in a combustion chamber. To this end the Jacobi-Davidson method will be extended for nonlinear eigenproblems that arise when the material properties depend on the eigenvalues.

Progress

The project has been initiated in the summer of 2005. In the context of the traineeship the Jacobi-Davidson Method for quadratic problems has been implemented in the combustion code AVSP of CERFACS. Initial tests show a significant improvement in performance.

Dissertations

-

Scientific Publications

-

Numerical methods for industrial flow problems

Project Aim

Develop numerical methods for industrial flow problems.

Progress

A new method to solve multi-phase fluid flow problems is developed. Dynamic modeling of thermal processes with phase transition by means of the density-enthalpy phase diagram for spatially homogeneous systems. Until now, preliminary results for two spatial dimensions have been obtained. This method eliminates the requirement of different sets of equations for various phases and necessitates fewer assumptions. For spatial domain discretization, we use finite elements. Recently it appears that the required time slep is very small. This motivates our research to develop time integration methods which allow large time steps.

Dissertations

-

Scientific Publications

1. Ibrahim, F.J. vermolen, C. Vuik, D. Hegen (pdf, bibtex). Application of the density-enthalpy method to the multi-phase flow through a porous medium Thermodynamics of phase changes, Namur, May 24-27, 2009 Editors: F. Dupret and M. Papalexandris CDROM, pp. 1-4 Universite catholique de Louvain, Louvain, 2009.

Projectleaders
C Vuik, FJ Vermolen

Researchtheme
Complex dynamics of fluids

Participants
Ibrahim, Vermolen, Vuik

Cooperations
TUD, TNO Science and Industry

Funded
Nuffic
1st 25% 2nd - 3rd 75%

Start of the project
2007

Information

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Rigorous modelling of optical recording

Projectleaders
C Vuik
Researchtheme
Complex dynamics of fluids
Participants
C Vuik, JH Brusche, A Segal
Cooperations
TNW, Philips
Funded
STW, Philips
1st - 2nd 50% 3rd 50%
Start of the project
2002
Information
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Project Aim

Modelling of (re-) writing of optical disks. Writing is modeled by a melting and solidification of a phase change layer. Rewriting is done by a recrystallization.

Progress

A mathematical model has been developed to describe writing on optical storage disks. The moving boundary that occurs can be modeled as a Stefan problem. New features in this problem are: a complicated layered 3D structure and the occurrence of a high energy source term. We solve the problem by a variant of the enthalpy formulation. To increase accuracy we have implemented a local refinement strategy into our finite element discretization (SEPRAN).

Dissertations

-

Scientific Publications

1. J.H. Brusche, A. Segal, C. Vuik. An efficient numerical method for solid-liquid transitions in optical rewritable recording International Journal for Numerical Methods in Engineering, 77, pp. 702-718, 2009.

Development of an immersed boundary method implemented on cluster and grid computers, application to the swimming of fish

Project Aim

Development of numerical methods for grid computing application to simulation of swimming of fish.

Progress

The project started at the end of 2006. Two implementations of the preconditioned Conjugate Gradient method for solving large sparse linear systems of equations on a (local) heterogeneous computing grid were studied, using GridSolve as grid middleware. This was applied to a 3D bubbly flow problem. Then we experimented with using an asynchronous parallel iterative algorithm as a preconditioner with promising results, again using GridSolve. This approach/technique was then implemented in the CRAC middleware, which allows for direct communication between the processes. Experiments using the CRAC implementation were conducted on the DAS-3 supercomputer, which is a cluster of five geographically separated clusters. Initial tests with asynchronous deflation techniques were also conducted, with promising results.

Dissertations

-

Scientific Publications

1. T.P. Collignon and M.B. van Gijzen. Solving Large sparse linear systems efficiently on grid computers using an Asynchronous iterative method as preconditioner. Delft University of Technology, Reports of the Department of Applied Mathematical Analysis, report 08-08.
2. T.P. Collignon, M.B. van Gijzen. Parallel scientific computing on loosely coupled networks of computers. Submitted to: Advanced Computational Methods in Science and Engineering, LNCS (book chapter).

Projectleaders
C Vuik

Researchtheme
Complex dynamics of fluids

Participants
TP Collignon, MB van Gijzen

Cooperations
B Koren, (L&R, CWI), Yunus Hassen (CWI)

Funded
TU (DCSE)
1st 100% 2nd - 3rd -

Start of the project
2006

Information

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Efficient solvers for advection diffusion reaction equations

Projectleaders
C Vuik, C Kleijn

Researchtheme
Complex dynamics of fluids

Participants
C Vuik, S van Veldhuizen, C Kleijn

Cooperations
TUD/TNW/MSP, TNO Science and Industry, CWI

Funded
DCSE, TNO Science and Industry
1st 90% 2nd - 3rd 10%

Start of the project
2004

Information
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Project Aim

Development of efficient solvers for chemical vapour deposition reactors. The large system of non-linear coupled partial differential equations is very stiff. So efficient time discretization methods are developed. The resulting non-linear systems should be solved very efficiently in order to compute the solution within a reasonable time.

Progress

Nowadays, many generally applicable simulation codes are available for computational fluid dynamics. However, most of these codes are unsuited for the simulation of chemically reacting flows. This is due to the numerical stiffness of the coupled systems of advection-diffusion-reaction equations that occur. Currently, we try to solve the system by the Euler backward method, which implies that nonlinear systems have to be solved for each time step. It appears that in some situations the Newton-Raphson method only converges if very small time steps are used. After using the Projected Newton-Raphson method we get good convergence results. We are able to solve 17 species on a 3dimensional geometry with a grid of 50x50x50 grid points in a reasonable time (some hours CPU time). Applications are chemical vapor deposition machines and solid oxide fuel cells.

Dissertations

1. Van Veldhuizen, S. (2009, February 13). Efficient numerical methods for the instationary solution of laminar reacting gas flow problems.

Scientific Publications

-

Rigorous modeling of 3D wave propagation

Project Aim

The aim is to develop efficient parallel iterative solvers for the Helmholtz problem. In order to estimate the layered structure of the earth crust seismic methods are used. The layer structure is used as input for porous media flow simulations.

Progress

A special preconditioner has been developed, which in a special combination of Krylov subspace and multigrid methods has resulted in a hundredfold increase in computing speed for the Helmholtz equation, describing wave propagation. Application in seismics has been very successful, and has generated much interest from the oil exploration industry, especially after a comparison with an industrial code in an application to a practical problem posed by industry. For the first time, realistic three-dimensional applications become feasible. This has already been realized on a single-processor machine for medium-sized problems.

Dissertations

-

Scientific Publications

-

Projectleaders

C Vuik, CW Oosterlee

Researchtheme

Complex dynamics of fluids

Participants

C Oosterlee, C Vuik, D Lahaye,
A Sheikh

Cooperations

TUD Chem.Tech, Philips, Shell, NLR

Funded

SenterNovem, NLR, Nuffic
1st 25% 2nd - 3rd 75%

Start of the project

2001

Information

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Development of an immersed boundary method implemented on cluster and grid computers, application to the swimming of fish

Projectleaders
C Vuik
Researchtheme
Complex dynamics of fluids
Participants
TP Collignon, MB van Gijzen
Cooperations
B Koren, (L&R, CWI), Yunus Hassen (CWI)
Funded
TU (DCSE)
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Start of the project
2006
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Project Aim

Development of Numerical Methods for Grid computing Application to simulation of swimming of fish.

Progress

The project started at the end of 2006. Two implementations of the preconditioned Conjugate Gradient method for solving large sparse linear systems of equations on a (local) heterogeneous computing grid were studied, using GridSolve as grid middleware. This was applied to a 3D bubbly flow problem. Then we experimented with using an asynchronous parallel iterative algorithm as a preconditioner with promising results, again using GridSolve. This approach/technique was then implemented in the CRAC middleware, which allows for direct communication between the processes. Experiments using the CRAC implementation were conducted on the DAS-3 supercomputer, which is a cluster of five geographically separated clusters. Initial tests with asynchronous deflation techniques were also conducted, with promising results.

Dissertations

-

Scientific Publications

1. T.P. Collignon, M.B. Gijzen, Fast Iterative Solution of Large Sparse Linear Systems on Geographically separated (cluster) DIAM Report 09-12, Delft University of Technology, Delft, The Netherlands. ISSN 1389-6520 (2009).

Mathematical Physics

Prof.dr.ir. AW Heemink

The central research direction of the group is the mathematical modeling of physical phenomena using (partial) differential equations. The research is application driven and includes the modeling phase, analysis of the model and the numerical implementation of the model. The focus is now more and more on the research themes:

Inverse modeling and data assimilation

Data assimilation methods are used to combine the results of a large scale numerical model with the measurement information available in order to obtain an optimal reconstruction of the dynamic behavior of the model state. Many data assimilation schemes are based on solving the Euler-Lagrange equations. A recursive algorithm to solve this two-point boundary value problem can be derived and results in the well-known Kalman filtering algorithm. Variational data assimilation is also a powerfull method, but requires the implementation of the adjoint (of the tangent linear approximation) of the numerical model. In a serie of externally funded PhD projects the mathematical algorithms have been developed and applied in a number of real life applications:

- Tidal flow models (funding: Rijkswaterstaat)
- Atmospheric-chemistry modeling (funding: NWO, TNO, RIVM).
- Oil reservoir modeling (Funding: Shell, TNO).

Perturbation methods for partial differential equations

The main focus within this theme is to develop perturbation methods to analyse initial value problems and initial-boundary value problems for partial differential equations. The applications are in a variety of fields, such as: the wind flow (or rain-wind) induced oscillations of bridges, high-rise buildings, or of overhead power transmission lines; the vibrations of conveyor belts; and the morphodynamics in tidal embayments.

High performance computing and parallel algorithms

This research theme aims to design efficient and scalable parallel algorithms and apply high performance computing technology to applications, such as the storm surge forecasting and pollutant transport in North Sea or rivers. Domain decomposition and grid partitioning is an effective approach for parallel simulation of models described by partial differential equations. Sparse matrices typically occur in numerical simulation of problems described by partial differential equations. One of our research focus is on designing parallel algorithms for solving sparse matrix systems. Lagrangian models, often also called particle models, for transport problems in coastal waters, can deal with steep gradients of concentration. Because the movements of the particles are largely independent from each other, so particle models are very suited for parallel and distributed computing. We have developed parallel models for transport problems of the Dutch coastal water (e.g., Wadden sea). Currently, a particle model with adaptive time steps is being developed, besides the derivation of the numerical scheme the additional challenge is to maintain a good load balance in an adaptive scheme. Grid computing is the next step of development in high performance computing.

Data assimilation in CFD

Project Aim

Large scale numerical models are often used for prediction problems. These models however are however far from perfect. The model predictions can be improved by assimilating measurements into the model using a Kalman filter. A serious problem with this approach is that the standard filter algorithm imposes a very large burden on the computer. In order to obtain a computationally efficient filter, simplifications have to be introduced. Model reduction is a corner stone in developing sub-optimal scheme's. In this project new sub optimal algorithms to solve large scale Kalman filtering problems are developed: The Reduced Rank SQuare Root (RRSQRT) algorithm, the Partially Orthogonal Ensemble Kalman filter (POEnKF) and a number of variants. Both theoretical aspects (convergence theorem) as well as a number of practical applications (tidal flow prediction in coastal waters, air pollution prediction problems and reservoir engineering).

Progress

We have applied the various new filter algorithms in the large scale atmospheric-chemistry transport model EUROS of RIVM to reconstruct the Ozone distribution in the atmosphere. We also developed a model reduction methodology for large scale numerical groundwater flow models in corporation with TNO. New PhD projects around the theme "Smart Wells" in corporation with the faculty CiTG, MIT and Shell have started. In these PhD project we will develop and apply model reduction and filtering techniques for assimilating data into multi-phase flow models in order to solve reservoir engineering problems. New application areas are also ecological coastal sea models and morphodynamic models.

Dissertations

1. J.R. Rommelse, Data assimilation in reservoir management, Januari 19, 2009, promotoren: A.W. Heemink, J.D. Jansen.
2. J. H. Sumihar, Two-sample Kalman filter and system error modelling for storm surge forecasting, October 19, 2009, promotoren: A.W. Heemink, M. Verlaan.

Scientific Publications

1. Inverse Shallow-Water Flow Modeling Using Model Reduction , Altaf MU, Heemink AW, Verlaan M. International Journal for Multiscale Computational Engineering, Volume: 7, Issue: 6, Pages: 577-594, 2009.
2. The ensemble particle filter (EnPF) in rainfall-runoff models. van Delft G, El Serafy GY, Heemink AW. Stochastic Environmental Research and Risk Assessment, Volume: 23, Issue: 8, Pages: 1203-1211, 2009.
3. Multiscale ensemble filtering for reservoir engineering applications. Lawniczak W, Hanea R, Heemink A, et al. Computational Geosciences, Volume: 13, Issue: 2, Pages: 245-254, 2009.
4. Wave height prediction at the Caspian Sea using a data-driven model and ensemble-based data assimilation methods. Zamani A, Azimian A, Heemink A, et al. Journal of Hydroinformatics, Volume: 11, Issue: 2, Pages: 154-164, 2009.
5. A multi-component data assimilation experiment directed to sulphur dioxide and sulphate over Europe. Barbu AL, Segers AJ, Schaap M, et al. Atmospheric Environment, Volume: 43, Issue: 9, Pages: 1622-1631, 2009.

Projectleaders
AW Heemink

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
R Hanea, A Barbu, UM Altaf, MP Kaleta, N van Velzen, JH Sumihar, M Verlaan, AW Heemink, JD Jansen, I Garcia, JC Pelc

Cooperations
Deltares, RIVM, Shell, MIT, TNO, Vortech

Funded
Deltares, Shell, TNO, NWO
1st 20% 2nd 20% 3rd 60%

Start of the project
2001

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Perturbation methods for partial differential equations

Projectleaders
AW Heemink

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
WT van Horssen, HM Schuttelaars, JLA Dubbeldam, M Rafei, SV Ponomareva, MC ter Brake, O Chernetskky, OV Pischans'kyy, SH Sandilo

Cooperations
-

Funded
TUD
1st 80% 2nd - 3rd 20%

Start of the project
2003

Information
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Project Aim

The main focus within this project is to develop and to apply perturbation methods to analyze initial value problems and (initial)boundary value problems for partial differential equations. The applications are in a variety of fields, such as: the wind or rain-wind induced oscillations of elastics structures (such as bridges, high-rise buildings, and overhead power transmission lines); the vibrations of conveyor belts; the morphodynamic evolution of coastal systems (such as beaches, and estuaries); and the dynamics of polymers in shear flow.

Progress

In 2009 the applicability of different types of perturbation methods was investigated. For problems with boundary damping, for nonselfadjoint problems, for weakly nonlinear problems, and for problems with variable coefficients all kinds of computational aspects have been studied by using perturbation methods, methods from dynamical system theory, numerical methods, and stochastic methods.

Dissertations

1. S.V. Hageraats-Ponomareva, On aspects of vibrations of axially moving continua. Promotor: A.W. Heemink, and co-promotor: W.T. van Horssen, TU-Delft, June 11, 2009.

Scientific Publications

1. Horizontally viscous effects in a tidal basin: Extending Taylor's problem. Roos PC, Schuttelaars HM. Journal of Fluid Mechanics, 640, pp. 421-439, 2009.
2. Global analysis of a piecewise linear Liénard-type dynamical system. Gaiko VA, van Horssen WT. International Journal of Dynamical Systems and Differential Equations 2 (1-2), pp 115-128, 2009.
3. On the transversal vibrations of an axially moving continuum with a time-varying velocity: Transient from string to beam behavior. Ponomareva SV, van Horssen WT. Journal of Sound and Vibration 325 (4-5), pp 959-973, 2009.
4. On the effect of the bending stiffness on the damping properties of a tensioned cable with an attached tuned-mass damper. Hijmissen JW, van den Heuvel NW, van Horssen WT. Engineering Structures 31 (5), pp. 1276-1285, 2009.
5. A piecewise linear dynamical system with two dropping sections. Gaiko VA, van Horssen WT. International Journal of Bifurcation and Chaos 19 (4), pp. 1367-1372, 2009.
6. On the multiple scales perturbation method for difference equations. Van Horssen WT, ter Brake MC. Nonlinear Dynamics 55 (4), pp. 401-418, 2009.
7. Stress relaxation of star-shaped molecules in a polymer melt. Dubbeldan JLA, Molenaar J. Macromolecules 42 (17) pp. 6784-6790, 2009.
8. Two-dimensional perturbations in a scalar model for shear banding. Dubbeldam JLA, Olmsted PD. European Physical Journal E 29 (4) pp. 363-378, 2009.
9. Comment on 'Anomalous dynamics of unbiased polymer translocation through a narrow pore' and other recent papers by DPanja, GBarkema, and RBall. Dubbeldam JLA, Milchev A, Rostiashvili VG, Vilgis TA. Journal of Physics Condensed Matter 21 (9), art. no. 098001, 2009.
10. Polymer translocation through a nanopore: A showcase of anomalous diffusion. Milchev A, Dubbeldam JLA, Rostiashvili VG, Vilgis TA. Annals of the New York Academy of Sciences 1161, pp. 95-104, 2009.

11. Subsurface characterization using a cellular automaton approach. Schuttelaars HM, Dekking FM, Berentsen C. Mathematical Geosciences 41 (5), pp. 491-508, 2009.
12. The influence of tidal currents on the asymmetry of tide-dominated ebb-tidal deltas. van der Vegt M, Schuttelaars HM, de Swart HE. Continental Shelf Research 29 (1), pp. 159-174, 2009.
13. Feedback between residual circulations and sediment distribution in highly turbid estuaries: An analytical model. Talke SA, de Swart HE, Schuttelaars HM. Continental Shelf Research 29 (1), pp. 119-135, 2009.
14. Initial growth of phytoplankton in turbid estuaries: A simple model. de Swart HE, Schuttelaars HM, Talke SA. Continental Shelf Research 29 (1), pp. 136-147, 2009.
15. Analytical study of transverse distribution of along-channel and transverse residual flows in tidal estuaries. Huijts KMH, Schuttelaars HM, de Swart HE, Friedrichs CT. Continental Shelf Research 29 (1), pp. 89-100, 2009.

Stochastic differential equations for transport modeling

Projectleaders
AW Heemink
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
AW Heemink, HX Lin,
E Deleersnijder
Cooperations
Deltares, Louvain-la-Neuve
Funded
Deltares, NUFFIC
1st 20% 2nd - 3rd 80%
Start of the project
2002
Information
HX Lin
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Project Aim

Stochastic particle models are developed for simulating transport processes in coastal waters. Higher order numerical methods for approximating the stochastic differential equation have been analysed and implemented to improve the performance of the model. Here attention has been concentrated on the treatment of the vertical dimension of the model. Furthermore, the variance reduction techniques control variates and importance sampling have been investigated to increase the efficiency of Monte Carlo applications of the particle model.

Progress

In the project we have focused on the concept of reverse time diffusion. Using this concept the efficiency of Monte Carlo methods for stochastic differential equations can be improved by generating both forward as reverse time realizations of the process. In corporation with prof. Delhez and prof. Deleersneider a general residence time theory have been developed using the adjoint formalism. The reverse time approach has been used to compute the residence time in coastal waters. Finally adaptive numerical schemes for stochastic differentiel equations have been developed and analysed too.

Dissertations

-

Scientific Publications

1. Charles, W.M., Berg, E. van den, Lin, H.X., Heemink, A.W., Adaptive stochastic numerical scheme in parallel random walk models for transport problems in shallow water. Mathematical and computer modelling, 50(7-8), 1177-1187, 2009.

PROJECT AIM

The research aims at the design and implementation of high performance and parallel algorithms for sparse matrix computations. The applicability and limitations of the grid computing technology will also be investigated.

PROGRESS

In the project financed by the EU on the application of Grid Computing, the research focuses on power flow simulation of large electrical power systems. Work on multi-level preconditioning methods and Jacobian-free preconditioned Krylov type methods are currently under study for power flow analysis.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Lin, H.X., Trends and Challenges in High Performance Computing (keynote), Proceedings of the 8th international symposium on distributed computing and applications to business, engineering and science, Q. Guo, Y. Guo (eds.), Publishing House of Electronics Industry, Wuhan, China, 16-19 October 2009. pp. 1-4.
2. Sips H.J., Epema D., Lin, H.X. (eds.), Proceedings of the 15th International Euro-Par conference on Parallel Processing, LNCS volume 5704, Springer, 2009.
3. Xu, S.M., Lin, H.X., Xue, W., Wang, K., Utilizing CUDA for Preconditioned GMRES solvers, Proceedings of the 8th international symposium on distributed computing and applications to business, engineering and science, Q. Guo, Y. Guo (eds.), Publishing House of Electronics Industry, Wuhan, China, 16-19 October 2009. pp. 8-12.

PROJECTLEADERS

AW Heemink

RESEARCHTHEME

Mathematical and computational methods for fluid flow analysis

PARTICIPANTS

HX Lin, SM Xu

COOPERATIONS

Tsinghua University, China, UNL Lisbon, Portugal, GUCAS, China

FUNDED

EU, Nuffic

1st 50% 2nd - 3rd 50%

START OF THE PROJECT

2005

INFORMATION

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Flexible computational methods for transport applications

Projectleaders
AW Heemink
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
P Wilders, AW Heemink, MA Badri
Cooperations
Deltares, Isfahan University
Funded
EEMCS, Isfahan University
1st 100% 2nd - 3rd -
Start of the project
1999
Information
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Project Aim

Our aim is to apply and develop flexible numerical methods for transport applications in real-life large-scale environmental studies.

Progress

In 2009 a start was made with including oil spill modeling. Here, the focus is on the Persian Gulf. A flow estimation procedure for the Persian Gulf has been developed and some preliminary oil spill simulations have been carried out.

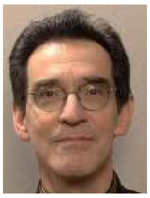
Dissertations

-

Scientific Publications

-

Multi-Scale Physics



Prof.dr.ir. HEA van den Akker

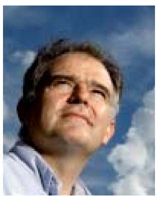
Prof.dr.ir. CR Kleijn

Prof.dr.ir. RAWM Henkes

Prof.dr.DJEM Roekaerts

Prof.dr.AP Siebesma

Prof.dr. RF Mudde



Prof.dr.H Jonker

Prof.dr.S Sundaresan

The Department of Multi-Scale Physics (MSP) is dealing with Industrial and Environmental Processes. MSP aims at a better understanding, a better description and - especially in industry - a better control of these processes. MSP wishes to contribute in this way to more sustainable industrial processes and a more sustainable earth.

The research interests at MSP are organized around five themes. These themes are intended to focus and communicate the research activities of the Department and are in no way indicative of a further subdivision. People in the department may move from one theme to another from time to time, depending on developments in interests. The themes and the contact persons for each theme are:

Clouds, Climate and Air Quality (prof. Harm Jonker)
Computational Reactor Engineering (prof. Harry van den Akker, head of department))
Reactive Flows & Explosions (prof. Dirk Roekaerts)
Thermal & Materials Processes (prof. Chris Kleijn)
Multi-Phase Flows (prof. Robert Mudde)

We consider flow and transport phenomena over a wide range of time and length scales in their mutual dependence. E.g. we study the interaction of molecular transport of heat and mass, chemical reactions, turbulent eddies, bubbles, drops and particles, and flow and convective transport at the scale of the vessel or at a long range. To do so we exploit a wide variety of advanced computational and experimental tools.

The type of industrial processes we have expertise about comprises plants of any commercial scale in which liquids, gases and solids are processed and manufactured. Our expertise relates to the fluid flow aspects and the heat and mass transport phenomena vital to such processes.

Operations such as mixing and separation processes, combustion, heating and cooling, coating, deposition and precipitation processes, absorption and adsorption, and chemical processes are among our themes of research and teaching. Examples of such plants and processes are abundantly present in the process industries (chemicals, food, pharmaceuticals), but also in the oil and gas industry and in the energy sector (biomass, nuclear, solar). A special topic of interest, associated with the public domain as well as with industrial processes, concerns safety and the risks of explosions.

Many environmental processes have much in common with industrial processes as the same flow and transport phenomena and concepts are at the basis of both. In particular we are dealing with are the life cycle of clouds and the dispersion of pollutants in the environment (air quality).

Clouds play a crucial role in climate and the response of clouds in a changing climate is one of the most pressing unknowns. Therefore we do fundamental research on cloud dynamics and cloud microphysics to improve parameterizations in weather and climate models, using detailed numerical simulation, laboratory experiments, analysis of aircraft, and satellite observations.

Micro-mixing and fast chemical reactions in turbulent flows

Project Aim

Predicting the yield of competing chemical reactions in turbulent flow in process equipment is relevant for process optimization and waste reduction. Computational methods of the Lattice Boltzmann type are being assessed, applied, developed and improved. Large eddy simulations of the turbulent flow at the reactor scale have been coupled to a filtered density (FDF) formulation of the reactive scalar transport equations.

Progress

The PhD thesis of Eelco Van Vliet (2003) is at the basis of these studies now being continued with support of NWO Chemical Sciences. The aim is to speed up the computational simulations by making use of smart tabulation techniques and a Lagrangian Monte Carlo solver. The role and impact of micro-mixing models is to be investigated as well.

Dissertations

-

Scientific Publications

-

Projectleaders

HEA van den Akker

Researchtheme

Complex dynamics of fluids

Participants

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Cooperations

-

Funded

NWO/CW

1st - 2nd 100% 3rd -

Start of the project

1998

Information

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Projectleaders
HEA van den Akker
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
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Cooperations
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Funded
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Start of the project
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Project Aim

In this project, we aim at making models for computationally simulating turbulent flows redundant. A Lattice-Boltzmann (LB) technique is used for carrying out a Direct Numerical Simulation (DNS) of the turbulent flow in a baffled vessel driven by a Rushton turbine. This project is a continuation and extension of our earlier simulation research started in 1990 (A. Bakker, RANS-based simulations); a milestone along this path was the development of LES on the basis of LB (Derksen & Van den Akker, 1999).

Progress

The DNS we conducted at SARA for a Reynolds number of 7,300 comprised some 3 billion grid points. Currently, we are making detailed comparisons between the DNS results, LDA data, and earlier and new LES results as to turbulent stirred vessels. The idea is to see whether we can come up with improved sub-grid scale models for LES.

Dissertations

-

Scientific Publications

-

Development and optimization of Lattice-Boltzmann techniques

Project Aim

This project is at the background of various more specific projects and comprises our efforts in developing and improving our computational tools. In addition to the common Finite-Volume (FV) techniques, we particularly exploit and develop lattice-Boltzmann techniques which generally are computationally more efficient than FV techniques.

Progress

We are continuously improving our Lattice-Boltzmann (LB) techniques for simulating both single-phase and multi-phase flows. This applies to LES as well as DNS. Recently, we made a start with developing a LB solver for a DNS of gas-liquid dispersions including coalescence and re-dispersion phenomena.

Dissertations

-

Scientific Publications

-

Projectleaders
HEA van den Akker

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
M Kamali, JJJ Gillissen, S Sundaresan

Cooperations
Princeton University

Funded
TUD, STW Green & Smart Process Technologies
1st 45% 2nd 30% 3rd 25%

Start of the project
2001

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Computational multi-scale approach of micro-structured Fischer-Tropsch reactors

Projectleaders
HEA van den Akker

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
M Kamali, JJJ Gillissen, S Sundaresan

Cooperations
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Funded
TUD, STW Green & Smart Process Technologies
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Start of the project
2001

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Project Aim

In an attempt to improve the current fixed-bed technology for the Fischer-Tropsch Gas-to-Liquid process, the effect of micro-structuring on product yield is investigated. In this project, the focus is on computationally simulating the intimate flow and transport phenomena, along with the chemical process producing liquid hydrocarbons from synthesis gas with the help of a catalyst, at the micro-scale, i.e. in the millimeter-scale channels in various types of structured packings.

Progress

An essential element in the micro-scale processes is the interaction between the gas and liquid phases in the mm-scale channels of the structured packings. This is most effectively described by means of Lattice-Boltzmann (LB) techniques. On the basis of a literature study, we opted for a method due to Shan and Chen (2003) who propose to include an inter-molecular force, expressed as the gradient of a potential which is a function of the local fluid density. The form of the potential function dictates the resulting (non-ideal) equation of state. When operated in the subcritical temperature range, the non-ideal fluid comprises two coexisting states (phases) each having a different density. In addition to this density bifurcation, the interaction potential also provides a means of controlling the interfacial tension between the different phases. A next step is to incorporate hydrodynamic forces into the LB-scheme.

Dissertations

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Scientific Publications

-

Multi scale modelling of flow and chemical breakthrough in protective garments

Project Aim

The goal of this project is to develop predictive models for the protective behaviour and thermal comfort of Nuclear-Biological-Chemical protective textiles, with a special focus on chemical breakthrough. We will study air flow, heat and mass transfer through the textile at multiple scales, ranging from that of the textile fibres and carbon partciles to that of an entire person, in combination with the penetration of both gaseous and liquid toxic components.

Progress

2D simulations have shown how the particle mutual distances are a determing factor for the level of protection and comfort given to the wearer. The level of disorder of the carbon particles wihtin a single layer is another important parameter which has to be taken into account: ordered carbon particles can offer a better protection with respesct to disrodered particles while placed in similar layers containing the same number of particles.

Dissertations

-

Scientific Publications

-

Projectleaders
CR Kleijin

Researchtheme
Complex dynamics of fluids

Participants
D Ambesi

Cooperations
TNO Defence and Security

Funded
1st - 2nd - 3rd 100%

Start of the project
2009

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Multi-scale modelling of molecular phenomena in plasma-assisted thin film deposition

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
Prof.dr. B.J.Thijsse (TUD-WbMT)
Prof.dr.ir. M.C.M.van de Sanden (TUE, TN)
Funded
Delft Centre for Computational Science & Engineering
1st 100% 2nd - 3rd -
Start of the project
2004
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Project Aim

This project aims to developing a comprehensive simulation model for the multi-scale hydrodynamics and physicochemistry of thin film deposition in an expanding thermal plasma jet reactor. The plasma jet, which is generated at near atmospheric pressure, supersonically expands into a near-vacuum environment. The challenge is to link continuum (CFD) gas flow simulations in the low Knudsen number regions, to molecular (DSMC) gas flow simulations in the high Knudsen number regions.

Progress

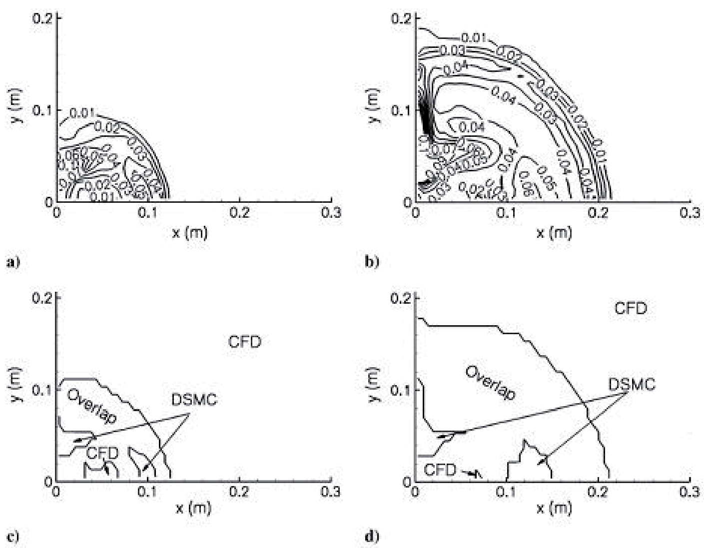
The project was completed with the successful defense of the PhD thesis "Multi-Scale modeling of gas flows with continuum-rarefied transitions" by Giannandrea Abbate in January 2009.

Dissertations

1. G. Abbate, Multi-Scale modeling of gas flows with continuum-rarefied transitions (January 2009, promotors C.R. Kleijn and B.J.Thijsse).

Scientific Publications

1. G. Abbate and C.R. Kleijn. Hybrid Continuum/Molecular Simulations of Transient Gas Flows with Rarefaction. AIAA Journal, 47(7), 2009, pp 1742-1749.
2. G. Abbate, B.J. Thijsse and C.R. Kleijn. Hybrid Navier-Stokes/DSMC simulations of gas flows with rarefied-continuum transitions. In: Koren, B., Vuik, K. (Eds.), Advanced Computational Methods in Science and Engineering, Series: Lecture Notes in Computational Science and Engineering , Vol. 71, Springer, 2010, ISBN: 978-3-642-03343-8, pp. 403-436.



Hybrid CFD-DSMC simulation of gas expansion from high pressure to vacuum through a circular hole. Upper figures show the local Knudsen number after 0.2ms and 0.5 ms, lower figures show the regions were CFD and DSMC are applied for the same time instances.

Hybrid RANS/LES simulations of turbulent flows over hills and complex urban areas with dispersion of pollutants

Project Aim

This project is part of the long-term investigations at our Department of Multi Scale Physics aimed at the mathematical modeling and numerical simulations of environmental flows and turbulent dispersion. In this particular project we focus our investigation at the turbulent flows over complex terrains and urban areas (street canyons) partially covered with vegetation and with different sources of the passive scalar (point, line, area concentration source).

Progress

Several extensions of standard two-equation eddy-viscosity turbulence models have been investigated, which are expected to eliminate some well-known deficiencies of the standard models relevant for accurate predictions of environmental flows. These include effects of surface roughness through generalized wall functions, a redefined TKE production, a time-scale limiter and a hybrid RANS/LES approach. Another novelty is an efficient representation of blocked flow regions for mimicking built objects. The accuracy and robustness of these models in a structured non-orthogonal Navier-Stokes solver have been investigated. We simulated the flow and spreading of traffic pollution in urban street canyons at lab- and full-scale, and found good agreement with available measurements. Recently, we started to study flow and turbulence around the TU Delft campus. Also we tested few variants of the models that incorporate effects of trees on velocity and turbulence. Further investigations including a novel hybrid RANS/LES approach are currently under development.

Dissertations

-

Projectleaders

S Kenjeres, K Hanjalic, CR Kleijn

Researchtheme

Complex dynamics of fluids

Participants

S Kenjeres, K Hanjalic, CR Kleijn

Cooperations

-

Funded

TU Delft, KNAW

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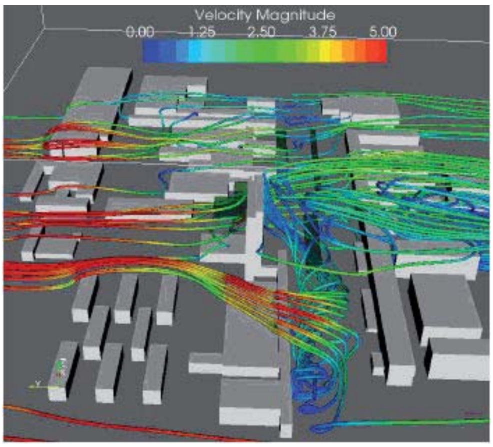
Scientific Publications

1. Kenjeres, S., Hanjalic, K. (2009),"Invited Review: Tackling Complex Turbulent Flows with Transient RANS", Fluid Dynamics Research, Vol.41, 012201, 32 pp, (doi:10.1088/0169-5983/41/1/012201).
2. Kenjeres, S, ter Kuile, B. and Tan, L. (2009), "Numerical Simulations of Canopy Vegetation Influence on Flow, Turbulence and Passive Scalar Dispersion in Street Canyons", Proceedings of the XXII International JUMV Automotive Conference, Science and Motor Vehicles with Exhibition, April 14-16, Belgrade, Serbia, Paper NMV0905, pp.1-19.



Flow patterns over TU Delft campus.

Dynamic behavior of Taylor flow in microchannel networks for large scale processing (experimental study)

Projectleaders
CR Kleijn, MT Kreutzer
Researchtheme
Complex dynamics of fluids
Participants
HA Duong
Cooperations
TU Eindhoven (JC Schouten), Wageningen University (R Boom), OSPT-IROP (DSM, Shell, DOW, Akzo-Nobel, Unilever, TNO)
Funded
STW, OSPT-IROP IROP (DSM, Shell, DOW, Akzo-Nobel, Unilever, TNO)
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Project Aim

In microfluidic platforms, segmentation of a stream of liquid is achieved by injection of a second immiscible phase. Segmented flow – known for its low axial dispersion and rapid micromixing – is useful in the production (Process-on-a-Chip) and analysis (Lab-on-a-Chip) of (bio)chemical species. In this project, we study the generation and transport of droplets and bubbles in microfluidic networks that comprise a large number of parallel microchannels. The aim is to understand how to form and distribute streams of bubbles or droplets in such networks.

Progress

- An open-source CFD code, OpenFOAM, was implemented to perform transient three-dimensional (3-D) numerical simulations of two-phase flow in microchannels.
- Preliminary 3-D simulations were performed to study to formation of bubbles at microfluidic T-junctions. These simulations show good qualitative agreement with experiments performed in our lab.

Dissertations

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Scientific Publications

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Numerical simulations and modeling of magneto-dynamo effects in turbulent regimes

Project Aim

This project was partially funded by the EC MAGDYN project (2001-2005) dealing with experimental and numerical studies of magnetic dynamo effects. The final goal of our contribution is to have fully coupled simulations of fluid flow and magnetic fields under realistic conditions, which should capture self-excitation of the magnetic field. This fundamental study of the fluid flow, turbulence and electromagnetic fields interactions can provide new insights into mechanism of the magnetic dynamo that is believed to be behind the origins of planetary magnetic fields (including Earth's magnetic field).

Progress

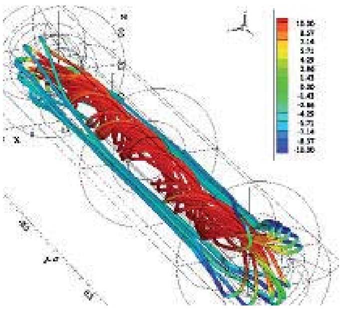
The development of a fully coupled Navier-Stokes/Maxwell solver in complex 3D geometries is completed, and full-scale simulations of the Riga dynamo experimental setup have been performed. Because of the high Re number (3.5x106), the T-RANS approach is used. Both direct (through momentum equations) and indirect (through additional 'magnetic' terms in the turbulence transport equations) fluid flow/turbulence/electro-magnetic interactions are taken into account. Significant improvements in predictions of the magnetic field growth rate are obtained compared to the more common uncoupled solutions with kinematic solver. The fully coupled simulations captured for the very first time the saturation regime in turbulent flow, in excellent agreement with available experimentally recorded growth rates and frequencies.

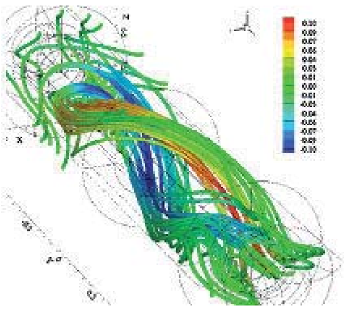
Dissertations

-

Scientific Publications

1. Kenjeres, S. (2009), "Hybrid Simulations of Two-Way Coupled Turbulent Magnetohydrodynamic Flows", International Journal for Multiscale Computational Engineering, Vol. 7, No.6, pp.545-558.
2. Kenjeres S. (2009), "Recent Achievements in Multi-Scale Modelling and Simulations of Magnetofluiddynamic Phenomena: From Origin of Planetary Magnetic Field to Improved Magnetic Drug Targeting", Proceedings of the 7th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, ExHFT-7, June 28 - July 03, 2009, Krakow, Poland, Eds. J. S. Szmyd, J. Spalek, T.A, Kowalewski, KL-11, pp. 159-177 (ISBN 978-83-7464-235-4).





Visualizations of the mean-flow (-left) and self-generated and self-sustained magnetic field (-right) in a fully two-way coupled T-RANS/DNS simulations of the Riga dynamo. Kenjeres and Hanjalic (2008).

Projectleaders
S Kenjeres

Researchtheme
Complex dynamics of fluids

Participants
S Kenjeres, K Hanjalic, S Renaudier, F Stefani, A Gaialitis, G Gerbeth

Cooperations
TU Dresden; Institute of Physics, Riga; FZR Rossendorf, Dresden; University of Grenoble; University of Maryland, College Park

Funded
EC, KNAW, TU Delft
1st 25% 2nd 25% 3rd 50%

Start of the project
2002

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Experimental and numerical investigations of turbulent flows over complex surface with heat transfer and emission of passive scalars

Projectleaders
S Kenjeres, CR Kleijn
Researchtheme
Complex dynamics of fluids
Participants
S Kenjeres, R Von Rohr, C Wagner, S Kuhn
Cooperations
R Von Rohr, ETH Zurich
Funded
ETH Zurich, TU Delft, ERCOFTAC, HPC-Europa
1st 50% 2nd - 3rd 50%
Start of the project
2003
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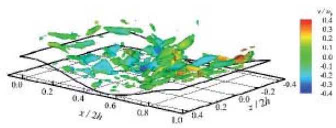
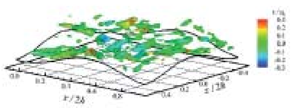


Coherent structures in an instantaneous velocity field for a forced convection case over 2D (-above) and 3D (-below) wavy wall extracted by lambda_2 criteria colored by the vertical velocity component – results from a dynamic LES, Carsten, Kenjeres and von Rohr (2009).



Project Aim

This is a joint project between Dept. of Multi Scale Physics at the TU Delft and the Laboratory for Transport Processes and Reactions of Prof. von Rohr at ETH Zurich. The project addresses the combined experimental and numerical study of turbulent flows over complex surfaces with heat transfer and distribution of passive scalars. The final goal is to perform in parallel state-of-the-art experiments (stereo PIV, LIF, TLC) and numerical simulations (LES, hybrid RANS/LES, DES, RANS) for different wall configurations over a range of Reynolds numbers and intensities of the wall heat flux and scalar emissions.

Progress

Measurements of turbulent forced and mixed convection flow and heat transfer over two-dimensional sinusoidal heated walls for 20<Re<30000 and 0<Ri<5000 have been performed at ETH Zurich. The first sets of numerical simulations have been performed at TU Delft – including a newly developed 4-equation elliptic relaxation RANS model and LES with dynamical Smagorinsky model. Comparison between experiments and results of RANS and LES (first and second-order statistics as well as local and integral distributions of Nusselt numbers and wall-friction coefficients) for Re=5600 demonstrated an excellent mutual agreement, as well as with spectral DNS results from literature. Dynamical LES have been performed for mixed convection situations at Re=20 – 2000, and the role of the coherent structures in wall heat transfer has been analyzed.

Dissertations

-

Scientific Publications

1. Kuhn, S., Kenjeres, S. and von Rohr, R. P. (2008), "Simulations of mixed convection over complex surfaces: a dynamical LES approach", Proceedings of the 7th International ERCOFTAC Symposium on Turbulence Modelling and Measurements, ETMM-7, 4-6 June 2008, Limassol, Cyprus, Vol.1, pp.262-267.
2. Wagner, C., Kenjeres, S. and von Rohr, R. P. (2008), "Comparative assessment of LES, DES and elliptic-relaxation based RANS for forced convection over wavy surfaces", Proceedings of the 7th International ERCOFTAC Symposium on Turbulence Modelling and Measurements, ETMM-7, 4-6 June 2008, Limassol, Cyprus, Vol.1, pp.256- 261.
3. Wagner C., Kenjeres S. and P. Rudolf von Rohr (2008), "Large-Eddy Simulations of Wall-Heat Transfer in Forced Convection over Two- and Three-Dimensional Wavy Surfaces", In the Proceedings of the 5th European Thermal-Sciences Conference, Eindhoven, 18-22 May, The Netherlends. Eds. Stoffels, G.G.M., van der Meer, T.H. and Steenhoven, A.A., ISBN-978-90-386-1274-4, Paper No. FCV-16, pp.1-8.
4. Kuhn S., Rudolf von Rohr P. and Kenjeres S. (2008), "Computational study of mixed convection over complex surfaces: comparative assessment of dynamical Large Eddy and Detached Eddy Simulations", In the Proceedings of the 5th European Thermal-Sciences Conference, Eindhoven, 18-22 May, The Netherlends. Eds. Stoffels, G.G.M., van der Meer, T.H. and Steenhoven, A.A., ISBN-978-90-386-1274-4, Paper No. MCV-6, pp.1-8.

Modelling of interface evolution in advanced welding

Project Aim

To develop computational models for the prediction of the influence of hydrodynamics on the interface evolution in advanced welding processes.

Progress

The project has started in September 2009.

Dissertations

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Scientific Publications

-

Projectleaders
CR Kleijn, S Kenjeres

Researchtheme
Complex dynamics of fluids

Participants
A Kidess, S Kenjeres, CR Kleijn

Cooperations
Prof. Ian Richardson (both TU Delft Materials Science & Engineering) University of Leicester; University College Dublin; University of Oxford, Norwegian Institute of Science and Technology; Royal Institute of Technology Stockholm; Ecole Polytechnique Federale de Lausanne; Corus UK, TWI; Frenzak; Poland Institute of Welding

Funded
EU-FP7
1st - 2nd - 3rd 100%

Start of the project
2009

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Numerical simulations and experiments of electromagnetically driven turbulent flows

Projectleaders
S Kenjeres, CR Kleijn

Researchtheme
Complex dynamics of fluids

Participants
S Kenjeres, K Hanjalic, CR Kleijn

Cooperations
TU Dresden; Institute of Physics, Riga; FZR Rossendorf, Dresden; University of Grenoble; University of Maryland, College Park

Funded
KNAW, TU Delft
1st 25% 2nd 75% 3rd -

Start of the project
2001

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Project Aim

Numerical simulations and modeling of thermal and magnetic convection at very high Rayleigh and Hartmann numbers has long been a serious challenge because of the profound effects that buoyancy and Lorentz forces have on the reorganization of the vortical structures, and because of the extreme thinning of the wall boundary layers which requires high numerical resolution. The aim of this study is to develop physically well-based and numerically efficient approaches to tackle problems of highly turbulent thermal and magnetic convection in complex geometries.

Progress

Targeting accurate predictions of heat transfer at very high Ra numbers, the performance of T-RANS with a low-Re 3-equation sub-scale model and hybrid seamless RANS/LES have been compared to well-resolved LES in the $10^7<Ra<10^9$ range. Whilst the application of conventional coarse grid LES resulted in 50% under-prediction of Nusselt at Ra=109, the T-RANS results showed excellent agreement for heat transfer with both well-resolved LES ($10^7<Ra<10^9$) and experiments ($10^6<Ra<10^{16}$). In order to sensitize the T-RANS approach to high-frequency instabilities, different ways of hybrid seamless RANS/LES merging have been investigated. It is demonstrated that the new hybrid approach is capable of capturing a significantly larger portion of the fine-structure spectrum than possible with T-RANS, whilst also returning accurate predictions of heat transfer and turbulence statistics. In addition to T-RANS approach, a magnetically extended SGS model in LES framework has been applied in an intermediate range of Ra numbers (up to $Ra=10^{10}$).

Dissertations

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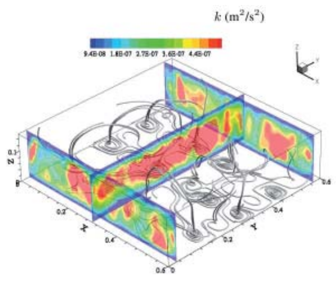
Scientific Publications

1. Kenjeres, S. (2009), “Large-Eddy Simulations of Targeted Electromagnetic Control of Buoyancy Driven Turbulent Flow in a Slender cavity”, Theoretical and Computational Fluid Dynamics, Vol.23, pp.471-489. (DOI 10.1007/s00162-009-0124-7).
2. Kenjeres, S., Verdoold, J., Tummers, M. J., Hanjalic, K. and Kleijn, C.R. (2009), “Numerical and Experimental Study of Electromagnetically Driven Vortical Flows”, International Journal of Heat and Fluid Flow, Vol.30, pp.494-504 (doi:10.1016/j.ijheatfluidflow.2009.02.014).
3. Kenjeres, S. (2008), “Electromagnetic Enhancements of Turbulent Heat Transfer”, Physical Review E, Vol.78,066309, 5 pp, (doi: 10.1103/PhysRevE.78.066309).
4. Kenjeres, S., (2009) “Electromagnetic enhancement of turbulence and wall-heat transfer in buoyancy-driven conductive fluids: magnetically extended LES approach”, Proceedings of the 6th International Symposium on Turbulence, Heat and Mass Transfer, Sept 14-18, Rome, Italy, Eds. K. Hanjalic, Y. Nagano and S. Jakirlic; Begell House Inc., New York, Wallingford (U.K.)/ICHMT. ISBN 978-1-56700-262-1, pp.977-980.



LES of the turbulent Rayleigh-Benard convection inside of a finite aspect-ratio enclosure subjected to localized electromagnetic fields, $Ra=10^9$, Pr=7, |B|=1 T, applied DC current of I=10 A. Stream-traces (-gray tubes) and contours of the turbulent kinetic energy in three characteristic planes.

Numerical modeling and simulations of blood flow and magnetic particles in simplified and realistic arterial geometries: towards optimized magnetic drug delivery

Project Aim

One of the main problems of chemotherapy is often not the lack of efficient drugs, but the inability to precisely deliver and concentrate these drugs in affected areas. Failure to provide localized targeting results in an increase of toxic effects on neighboring organs and tissues. One promising method to accomplish precise targeting is magnetic drug delivery. Here, a drug is bound to a magnetic compound injected into the blood stream. The targeted areas are subjected to an external magnetic field that is able to affect the blood stream by reducing its flow rate. In these regions the drug is slowly released from the magnetic carriers. Consequently, relatively small amounts of a drug magnetically targeted to the localized disease site can replace large amounts of the freely circulating drug. At the same time, drug concentrations at the targeted site will be significantly higher compared to the ones delivered by standard (systemic) delivery methods. We believe that mathematical modeling and numerical simulations can significantly contribute to further advancements of this technique.

Progress

We have developed a comprehensive mathematical model for simulations of blood-flow under the presence of strong non-uniform magnetic fields. The model consists of a set of Navier-Stokes equations accounting for the Lorentz and magnetization forces, and a simplified set of Maxwell's equations (Biot-Savart/Ampere's law) for treating the imposed magnetic fields. The relevant hydrodynamic and electro-magnetic properties of human blood were taken from the literature. The model is then validated for different test cases ranging from a simple cylindrical geometry to real-life right-coronary arteries in humans.

The time-dependency of the wall-shear-stress for different stenosis growth rates and the effects of the imposed strong non-uniform magnetic fields on the blood flow pattern are presented and analyzed. It is concluded that an imposed non-uniform magnetic field can create significant changes in the secondary flow patterns, thus making it possible to use this technique for optimisations of targeted drug delivery.

Dissertations

-

Scientific Publications

1. Kenjeres S. (2009), "Recent Achievements in Multi-Scale Modelling and Simulations of Magnetofluiddynamic Phenomena: From Origin of Planetary Magnetic Field to Improved Magnetic Drug Targeting", Proceedings of the 7th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, ExHFT-7, June 28 - July 03, 2009, Krakow, Poland, Eds. J. S. Szmyd, J. Spalek, T.A, Kowalewski, KL-11, pp. 159-177 (ISBN 978-83-7464-235-4).

Projectleaders
S Kenjeres

Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
ERASMUS MC Rotterdam,
ETH Zurich

Funded
TUD
1st 100% 2nd - 3rd -

Start of the project
2006

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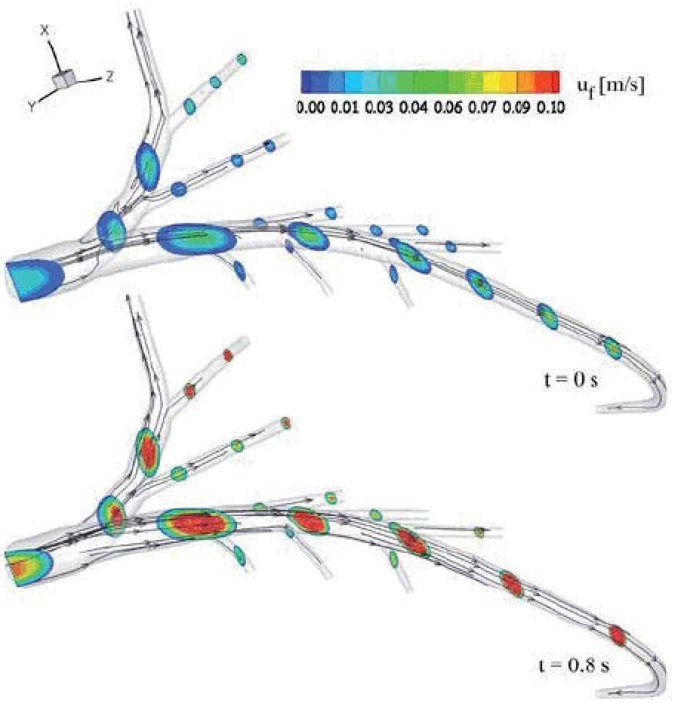
2. Kenjeres, S. and Cohen Stuart, D, C. (2009), “Computational Simulations of Magnetic Particle Capture in Simplified and Realistic Arterial Flows: Towards Optimized Magnetic Drug Targeting”, IFMBE Proceedings of the 11th International Congress of the IUPESM, World Congress 2009, Medical Physics and Biomedical Engineering, Sept 7 – 12, Munich, Germany, Vol.25, Eds. Doessel, Schlegel, Springer, Berlin, ISBN 978-3-642-03897-6, ISSN 1680-0737, pp.1-4.
3. Haverkort, J. W., Kenjeres, S. and Kleijn, C. R. (2009),”Computational Simulations of Magnetic Particle Capture in Arterial Flows”, Annals of Biomedical Engineering, Vol.37, No.12, pp. 2436-2448. (DOI:10.1007/s10439-009-9786-y).
4. Haverkort, J.W., Kenjeres, S. and Kleijn, C.R. (2009),”Magnetic particle motion in a Poiseuille flow”, Physical Review E 80, 016302, pp.1-12 (DOI:10.1103/PhysRevE.80.016302).



Stream-traces and contours of the velocity magnitude at specific planes in the realistic left coronary artery (LCA) at two different time instants of the pulsating cycle.

Hydrodynamics of weld pools and its influence on weld structure

Project Aim

To gain a fundamental understanding, through modeling & experiments, of the influence of hydrodynamics on the formation & structure of fusion weld pools, both for laser and arc welding.

Progress

Several relevant aspects in weld pool hydrodynamics have been implemented in the open source CFD code OpenFOAM, namely transient 3-D heat conduction, melting of a solid metal, free surface flow, and Marangoni effects due to surface tension gradients. These aspects have been integrated into a model for the simulation of laser weld pool hydrodynamics. It was found that Marangoni effects have a very strong influence on the liquid metal flow in the weld pool and consequently on the shape and structure of the weld. Transient changes in the temperature distribution of the weld pool surface were found to lead to flow reversal during the welding process, in a qualitatively close agreement with experimental observations. Additionally, the free surface deformation is affected by the weld pool flow direction, which also depends on the sign of the temperature gradient of surface tension.

Dissertations

-

Scientific Publications

1. C.X. Zhao, V. van Steijn, I.M. Richardson, C.R. Kleijn, S. Kenjeres, Z. Saldi. Unsteady interfacial phenomena during inward weld pool flow with an active surface oxide. Science and Technology of Welding and Joining 14 (2), 2009, pp. 132-140 .
2. C.X. Zhao, Ian M Richardson, S.Kenjeres, C.R.Kleijn and Z Saldi. A stereo vision method for tracking particle flow on the weld pool surface. Journal of Applied Physics 105, 2009, # 123104.
3. Z.S. Saldi, C. Zhao, S. Kenjeres, I.M. Richardson, C.R. Kleijn. Numerical and Experimental Investigations of Marangoni Driven Flow Reversals in Liquid Steel Welding Pools. In: J.S. Szmyd, J. Spałek, T.A. Kowalewski (eds.) Proceedings of the 7th Word Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, 28 June – 03 July 2009, Krakow, Poland ISBN 978-837464-235-4, pp. 1961-1968.

Projectleaders
CR Kleijn, S Kenjeres

Researchtheme
Complex dynamics of fluids

Participants
Z Saldi, S Kenjeres, CR Kleijn

Cooperations
NIMR, Chuangxin Zhao, MSc,
Prof. Ian Richardson (both TU Delft Materials Science & Engineering),
Dr. Tim Peeters, Dr. Eelco van Vliet,
Dr. René Duursma (Corus)

Funded
Materials Innovation Institute
(formerly Netherlands Institute for Metals Research)
1st - 2nd - 3rd 100%

Start of the project
2006

Information

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Multi-scale modelling of reacting gas flows in micro-fluidic systems

Projectleaders
CR Kleijn
Researchtheme
Complex dynamics of fluids
Participants
F La Torre
Cooperations
MicroNed, TNO Defence and Security, TNO Science and Industry TU Delft Dept. Aerospace Engng.
Funded
MicroNed
1st - 2nd - 3rd 100%
Start of the project
2006
Information
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Project Aim

The goal of this project is to develop numerical simulation tools, based on hybridizations of classical CFD and Direct Simulation Monte Carlo, for reacting gas flows in microfluidic systems. The special focus of the project will be on the study of micro thrusters and micro combustors.

Progress

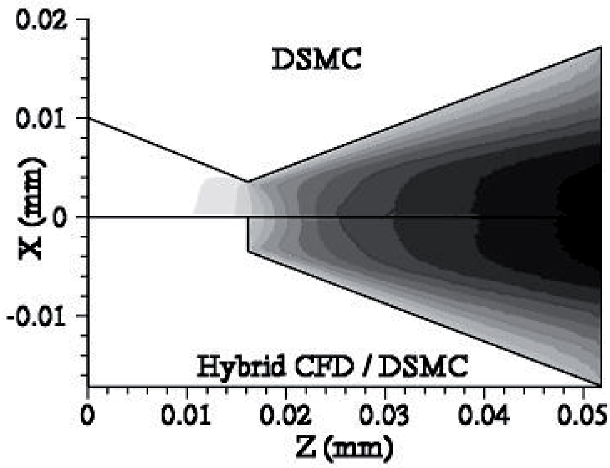
A computational study has been performed on the hydrodynamics of MEMS fabricated convergent-divergent micro-nozzles with thrusts in the μN range. At these small dimensions, the gas flow in the divergent is rarefied. Hybrid simulations have therefore been performed, in which continuum based CFD is performed in the convergent part of the nozzle, and molecular DSMC simulations are performed in the divergent part of the nozzle. Relating to the estimated value of the Knudsen number, a study of the optimum location of the interface between the two methods is being carried on. It has been demonstrated that using CFD simulations in both the convergent and divergent leads to inaccurate results, even if slip flow boundary conditions are employed. Predicted thrusts were found to sensitively depend on the thermal and momentum accommodation coefficients of the gas molecules on the nozzle walls.

Dissertations

-

Scientific Publications

1. Federico La Torre, Sasa Kenjeres, Chris R. Kleijn, and Jean-Luc P. A. Moerel Evaluation of Micronozzle Performance through DSMC, Navier-Stokes and Coupled DSMC/Navier-Stokes Approaches. Lecture Notes in Computer Science 5544, pp. 675-684.
2. F. La Torre, S. Kenjeres, C.R. Kleijn, J.L.P.A. Moerel. The Influence of Surface Effects on the Thrust of Micronozzles Studied by DSMC and Continuum Methods. In: J.S. Szmyd, J. Spałek, T.A. Kowalewski (eds.) Proceedings of the 7th Word Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, 28 June – 03 July 2009, Krakow, Poland. ISBN 978-837464-235-4 , pp. 1749-1756.



Comparison of Mach number contours from the solution obtained by full DSMC, and by DSMC in the divergent only with inlet boundary conditions in the throat plane obtained from CFD.

Transport phenomena and chemical reactions in chemical vapor deposition processes

Project Aim

In this project, we study the coupled modelling of hydrodynamics, transport phenomena and chemical reactions (in the gas phase and at the surface) in chemical vapour deposition (CVD) reactors for thin film manufacturing. This involves the solution of large numbers of strongly coupled and stiff, transient convection-diffusion-reaction equations for the many reactants, intermediates and reaction products.

Progress

The project was completed with the successful defense of the PhD thesis "Efficient numerical methods for the instationary solution of laminar reacting gas flow problem" by Sander van Veldhuizen in February 2009.

Dissertations

1. S. van Veldhuizen "Efficient numerical methods for the instationary solution of laminar reacting gas flow problems." (February 2009, promotors C. Vuik and C.R. Kleijn).

Scientific Publications

1. S. van Veldhuizen, C. Vuik, and C.R. Kleijn. On numerical issues in time accurate laminar reacting gas flow solvers. In: Koren, B., Vuik, K. (Eds.), Advanced Computational Methods in Science and Engineering, Lecture Notes in Computational Science and Engineering , Vol. 71, Springer, 2010, pp. 47-78.

Projectleaders
C Vuik, CR Kleijn

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
S van Veldhuizen

Cooperations
TU Delft – EWI (C Vuik)
Univ. Nijmegen (P Hageman, PK Larsen), TNO Science and Industry (AM Lankhorst, BD Paarhuis, PJPM Simons), ASMI (HJCM Terhorst)

Funded
Delft Centre for Computational Science and Engineering
1st 100% 2nd - 3rd -

Start of the project
2004

Information

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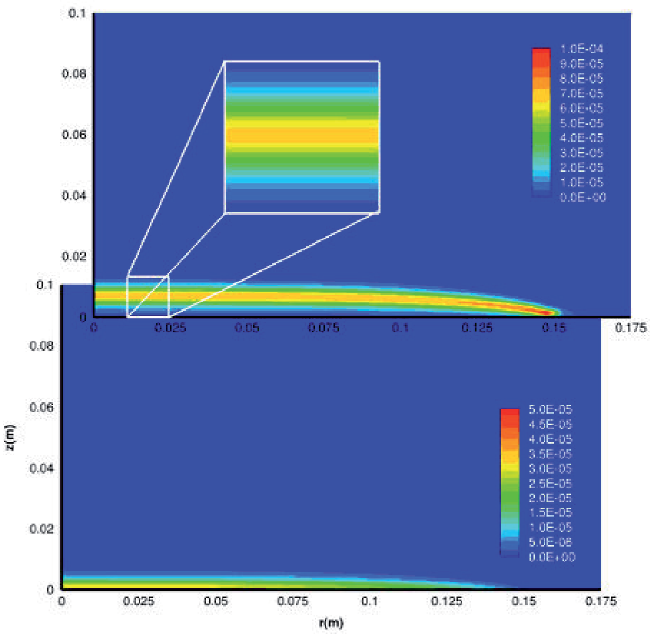

Computed concentration profiles of the H2SiSiH2 intermediate species in silicon CVD from SiH4, for wafer temperature *Ts* = 900 K (bottom) and *Ts* =1100 K (top).

Formation and transport of bubbles in microfluidic systems

Projectleaders
CR Kleijn, MT Kreutzer
Researchtheme
Complex dynamics of fluids
Participants
V van Steijn
Cooperations
EJR Sudhölter (TUD-DCT)
Funded
Delft Centre for Sustainable Industrial Processes (DCSIP)
1st 100% 2nd - 3rd -
Start of the project
2005
Information
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Project Aim

In microfluidic platforms, segmentation of a stream of liquid is achieved by injection of a second immiscible phase. Segmented flow – known for its low axial dispersion and rapid micromixing – is useful in the production (Process-on-a-Chip) and analysis (Lab-on-a-Chip) of (bio)chemical species. In this project, we study the generation and behaviour of droplets and bubbles in microfluidic systems, and their use in reducing detection times of microfluidic biosensors.

Progress

- We have shown that the breakup of a confined gas thread in a cross-flowing stream of liquid is initiated, not by a Plateau-Rayleigh instability, but by liquid that flows from the tip of the thread to the neck where pinch-off occurs, see reference below.
- We have developed a theoretical model to precisely predict the size of bubbles and droplets created in microfluidic T-junctions. Our model explains why the size of bubbles and droplets strongly depends on the shape of a T-junction, and teaches how the shape can be tuned to obtain the desired size.
- In collaboration with Jena university, we have studied how the dynamics of droplets forming at microfluidic junctions is influenced by the elasticity of the feed lines.
- We have studied how bubbles can be made to oscillate in microfluidic channels using piezoelectric actuation at frequencies up to 20Hz.

Dissertations

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Scientific Publications

1. Volkert van Steijn, Chris R. Kleijn, and Michiel T. Kreutzer. Flows around confined bubbles and their importance in triggering pinch-off. Phys. Rev. Letters 103, #214501 (2009), pp. 214501-1 - 214501-4.

Dynamic behavior of Taylor flow in large microchannel networks for large scale processing (experimental study)

Project Aim

In microfluidic platforms, segmentation of a stream of liquid is achieved by injection of a second immiscible phase. Segmented flow – known for its low axial dispersion and rapid micromixing – is useful in the production (Process-on-a-Chip) and analysis (Lab-on-a-Chip) of (bio)chemical species. In this project, we study the generation and transport of droplets and bubbles in microfluidic networks that comprise a large number of parallel microchannels. The aim is to understand how to form and distribute streams of bubbles or droplets in such networks.

Progress

The project has started in October 2009.

Dissertations

-

Scientific Publications

-

Projectleaders

CR Kleijn, MT Kreutzer

Researchtheme

Complex dynamics of fluids

Participants

X Yang

Cooperations

TU Eindhoven (JC Schouten),
Wageningen University (R Boom),
OSPT-IROP (DSM, Shell, DOW,
Akzo-Nobel, Unilever, TNO)

Funded

Chinese Scholarship Council
TU Delft
1st 20% 2nd - 3rd 80%

Start of the project

2009

Information

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Performance of foamers for deliquification of gas wells

Projectleaders
RAWM Henkes, RF Mudde
L Portela
Researchtheme
Complex structures of fluids
Participants
PhD student to be selected,
RAWM Henkes, L Portela,
RF Mudde
Cooperations
NAM/Shell
Funded
TUD, NAM
1st 25% 2nd - 3rd 75%
Start of the project
2010
Information
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Project Aim

This project is a combined experimental/modeling study on the performance of foamers for deliquification of gas wells as used in the gas and oil industry. The reduction of the reservoir pressure for maturing fields will cause that gas wells will start to accumulate liquid (water, condensate). The use of proper foamer chemicals will mix the liquid and gas into a foam, which decreases the hydrostatic head in the well and re-establishes the flow. The study includes flow experiments using a 12 m, 5 cm diameter facility.

Progress

Project started in 2010.

Dissertations

-

Scientific Publications

1. M.L. Evers, V.L. van Beusekom, and R.A.W.M. Henkes, "Appearance and mitigation of density waves in continueously gas-lifted oil wells", Proc. 14th Int. Conf. on Multiphase Production Technology, pp 281-293, 2009.

Liquid accumulation in nearly horizontal pipelines with multiphase flow at low gas production rates

Project Aim

The project aims at improving the basic understanding of a key aspect of multiphase flow in pipelines as used in the gas and oil industry, which is the liquid accumulation in systems under turndown operational conditions. The experimental lab configuration will consist of a V-shaped piece of pipeline, representing the low spot. The turbulence levels will be measured using Laser-Doppler Anemometry. The experimental data will be used to improve the one-dimensional models used in the gas and oil industry, as well as in the next generation type of models, based on three-dimensional Reynolds Averaged Navier Stokes (RANS) equations.

Progress

Project started in 2010.

Dissertations

-

Scientific Publications

-

Projectleaders
RAWM Henkes, RF Mudde, L Portela

Researchtheme
Complex dynamics of fluids

Participants
M Birvalski

Cooperations
Shell

Funded
TUD, Shell
1st 25% 2nd - 3rd 75%

Start of the project
2010

Information
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Long liquid slugs in stratified gas/liquid flow in horizontal pipes

Projectleaders
RVA Oliemans, RF Mudde, RAWM Henkes
Researchtheme
Complex structures of fluids
Participants
U Kadri, RVA Oliemans, RF Mudde, RAWM Henkes
Cooperations
Shell, TNO, DSM
Funded
STW
1st - 2nd 100% 3rd -
Start of the project
2003
Information
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Project Aim

The aim of the project is to study the properties and behavior of long liquid slugs, which can occur in horizontal tubes, when operating in the stratified flow regime at relatively high liquid levels. The project includes measurements in a 2" tube with a total length of 137 m using dedicated measurement equipment to detect the growth and structure of the long liquid slugs. Furthermore, the dynamic modeling of these two-phase flow phenomena will be undertaken.

Progress

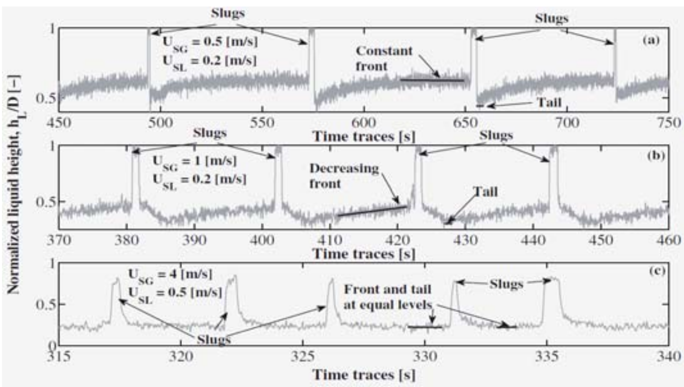
In 2009 U. Kadri completed his PhD work. A mechanistic model was developed to predict the average slug length. Furthermore the difference between the vertical and axial growth time of a wave crest was used to model the transition from stratified flow to roll-waves or slug flow. The models properly describe that the slug flow regime in the flow pattern map shrink at increasing pressure. A proof- of-concept postdoctoral research has been carried out in the first quarter of 2010. The research aimed at providing a method for reducing the negative effects of the long slugs in horizontal pipes. The method is based on increasing the slug frequency of the downstream long slug (and thus on reducing the slug length) through disturbing the flow at the inlet. For the validation of the method, experiments were carried out in a 137 m long air-water horizontal pipe flow with an internal diameter of 0.052 m. The results show that increasing the slug frequency by about 40% results in a decrease of the slug length by 25 to 33%.

Dissertations

1. U. Kadri, Long liquid slugs in stratified gas/liquid flow in horizontal and slightly inclined pipes, PhD Thesis, TU Delft, 2009.

Scientific Publications

1. U. Kadri, R.F. Mudde and R.V.A. Oliemans, M. Bonizzi, P. Andreussi, On the evolution of waves into roll-waves and slugs in gas-liquid horizontal pipe flow. Int. J. Multiphase Flow 35, 1001-1010, 2009.
2. U. Kadri, M.L. Zoeteweij, R.F. Mudde and R.V.A. Oliemans, A growth model for dynamic slugs in gas-liquid horizontal pipes. Int. J. Multiphase Flow 35, 439-449, 2009.
3. U. Kadri, R.F. Mudde and R.V.A. Oliemans, Slugs, turbulence and the butterfly effect. Proceedings 14th International Conference on Multiphase Production Technology, Cannes, France, 14, pp. 319-330, 2009.



Tree slug types can be distinguished in our flow experiments for water/air.

Dynamic behaviour of a Multi-burner Excess Enthalpy Combustion (MEEC) system for industrial process furnaces - Single burner setup

Project Aim

Excess Enthalpy Combustion (EEC, also known as flameless combustion) is a new combustion technology that promises higher efficiencies, higher product qualities and lower emissions. Although EEC has already been used in industry, many problems remain to be solved before this technology can be used in furnaces where a large number of burners are needed to deliver the required thermal input. Especially fundamental knowledge is needed regarding the dynamic behaviour of this type of novel regenerative burners. The main objective of the project is to generate practical knowledge and design rules for EEC systems in a combined experimental and computational approach.

Progress

The dataset of several flames (for different jet Reynolds numbers and coflow temperatures) on velocities and temperatures (measured with LDA and CARS) has been completed. Additionally, the composition of the coflow was analysed with flue gas measurements. An extensive study on influences of jet Reynolds number, fuel composition and coflow temperatures has been carried out, by monitoring the time resolved flame chemiluminescence. Based on this study, a description of the stabilization mechanism was formulated. The experimental setup has been modified such that it can generate a periodically starting jet, switching on and off each second. A device was built that controls this switching and exports the digital time relative to the pulse (running at 10 KHz),to generate phase-averaged velocity measurements. These measurements show excellent reproducibility of the jet response.

Dissertations

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Scientific Publications

1. E. Oldenhof, M.J. Tummers, E.H. van der Veen and D.Roekaerts, Ignition kernel statistics of Delft Jet-in-Hot-Coflow flames, in proceedings of the at 4th European Combustion Meeting, (CD-rom), P. Szentannai (Ed.), Vienna University of Technology, 14-17 April, 2009, Vienna, Austria, P810176 (6 pages).
2. E. Oldenhof, M.J. Tummers, E.H. van Veen and D. Roekaerts, Auto-ignition processes in the stabilisation region of the jet-in-hot-coflow flames, in book of abstracts, the COMBURA symposium, 2009, Utrecht: Technology Foundation STW, p. 18-19.

Projectleaders
DJEM Roekaerts, MJ Tummers

Researchtheme
Complex dynamics of fluids

Participants
E Oldenhof, P Sathiah,
MJ Tummers, EH van Veen,
DJEM Roekaerts

Cooperations
W de Jong, B Danon, ES Cho
(Process & Energy, TU Delft, 3mE)
A Dreizler (TU Darmstadt)

Funded
STW, NVV, WS
Wärmeprozesstechnik, Fluent, TNO
1st - 2nd 80% 3rd 20%

Start of the project
2006

Information
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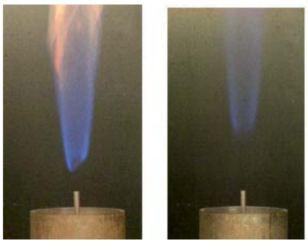
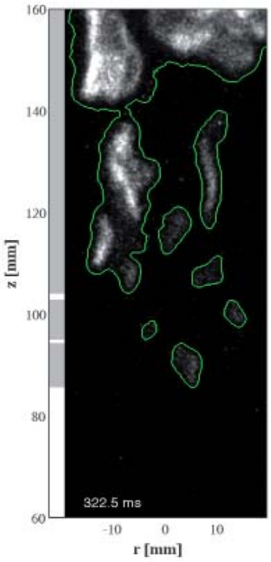
jet in cold air versus jet in hot coflow





snapshot of ignition kernels in the jet-in-hot-coflow flame

Modeling and modification of HNF and HNF-based propellants

Projectleaders
DJEM Roekaerts, MJ Tummers
Researchtheme
Complex dynamics of fluids
Participants
OE Dragomir, MJ Tummers,
EH van Veen, DJEM Roekaerts
Cooperations
TNO Defence, Security and Safety
(AEDM van der Heijden)
Funded
STW, TNO, APP
1st - 2nd 50% 3rd 50%
Start of the project
2003
Information
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Project Aim

Hydrazinium nitroformate (HNF) is a high-energy oxidizer, which can be used in solid rocket propellant formulations. The burn rate characteristics of the HNF oxidizer need to be tailored since the increase of the burn rate with pressure is too high for practical applications. The aim of the proposed study is to obtain knowledge on the combustion behavior of HNF oxidizer and HNF-based propellants to successfully manipulate the relation between pressure and burn rate by means of a catalyst.

Progress

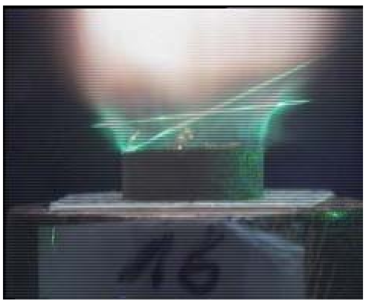
The work has focused on understanding the condensed phase decomposition and the gas phase combustion of neat HNF. Data from several spectroscopic experiments including infrared and mass spectrometry allowed identification of the gaseous species that evolve from both the condensed phase and the gas phase of burning HNF. The results of these spectroscopic measurements gave sufficient insight in the mechanisms of decomposition and combustion of HNF. Ammonium metavanadate (AMV) was proposed as a potential burn rate modifier and turned out to have a significant effect on the burning rate of HNF in the low pressure range (0.1 – 2 MPa). Although AMV is found to be incompatible with HNF, its positive catalytic effect gives leads for the selection of a compatible burn rate modifier, which has a similar effect as AMV.

Dissertations

1. Otilia Dragomir, Experimental investigation on hydrozynium nitroformate (HNF) combustion and its modification, PhD Thesis, Delft University of Technology, 2009.

Scientific Publications

1. O.E. Dragomir, M.J. Tummers, E.H. van Veen, A.E.D.M. van der Heijden and D.J.E.M. Roekaerts (2009). Condensed phase decomposition and gas phase combustion of hydrazinium nitroformate, Combustion and Flame, 156, 1810-1817.



Flameless combustion conditions and efficiency improvement of single- and multi-burner-FLOXTM furnaces in relation to changes in fuel and oxidizer composition

Project Aim

The objective is to investigate both experimentally and computationally the impact of changes in fuel and oxidizer composition on flameless combustion. To reach the flameless combustion regime the air (and/or fuel) streams are diluted with hot combustion products with a temperature sufficiently high for the combustion process to be stable and occurring in a distributed reaction zone. The details of this combustion process will be investigated in a jet-in-hot-coflow configuration and in a new single-burner furnace. After successful validation the computational models will be used to quantify on the basis of sound physical understanding, the heat flux patterns and emission levels in flameless combustion systems of interest for the industrial partners.

Progress

Luis Arteaga Mendez started working on the project in October 2009. In the initial period of the project a literature study was made on the use of hydrogen as fuel (component) in furnaces. A start was made with the design of the new single burner furnace.

Dissertations

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Scientific Publications

1. D. Roekaerts, M.J.Tummers and W. de Jong, Flameless combustion conditions and efficiency improvement of single- and multi-burner-FLOXTM furnaces in relation to changes in fuel and oxidizer composition , in book of abstracts, the COMBURA symposium, 2009, Utrecht: Technology Foundation STW.

Projectleaders
DJEM Roekaerts, MJ Tummers

Researchtheme
Complex dynamics of fluids

Participants
LD Arteaga Mendez, EH van Veen

Cooperations
TU Delft, Section Energy Technology (W de Jong)

Funded
Technology Foundation STW, Corus, Shell, NVV, Numeca Int., TNO
1st 25% 2nd 50% 3rd 25%

Start of the project
2009

Information

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Dynamic behaviour of a Multi-burner Excess Enthalpy Combustion (MEEC) system for industrial process furnaces - Single burner setup

Projectleaders
W de Jong (3mE), BJ Boersma (3mE), DJEM Roekaerts (TNW-3mE)

Researchtheme
Complex dynamics of fluids

Participants
E-S Cho, B Danon

Cooperations
M Tummers (TNW-MSP), E van Veen (TNW-MSP), E Oldenhof (TNW-MSP), P Satiah (TNW-MSP)

Funded
STW, NVV, WS Wärmeprozesstechnik, Fluent, TNO
1st - 2nd 80% 3rd 20%

Start of the project
2005

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Project Aim

Excess Enthalpy Combustion (EEC, also known as flameless combustion) is a new combustion technology that promises higher efficiencies, higher product qualities and lower emissions. Although EEC has already been used in industry, many problems remain to be solved before this technology can be used in furnaces where a large number of burners are needed to deliver the required thermal input. Especially fundamental knowledge is needed regarding the dynamic behavior of this type of novel regenerative burners. The main objective of the project is to generate practical knowledge and design rules for EEC systems in a combined experimental and computational approach.

Progress

A test campaign at the 3x100 kWth multi-burner FLOXTM furnace has been carried out. Variations of burner position and firing mode (parallel versus staggered) were made. Parrallel firing appeared to be more advantageous in view of CO, NOx emission reduction and furnace heat transfer efficiencies. Also, parallel mode shows better temperature uniformity in the furnace, which shows that in parallel mode the temperature distribution is more uniform and better mixing is established. Additionally, the flue gas O2 percentage has been varied. Increasing the O2 percentage leads to higher NO and lower CO emissions and a decreasing efficiency. The most optimal configuration is chosen and design rules for multiburner flameless oxydation furnaces have been suggested. CFD simulations performed for a two burner pair furnace at KTH confirmed the observed improved heat transfer and decreased NOx trends for parallel firing compared to staggered firing.

Dissertations

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Scientific Publications

1. Cho, E.-S., Danon, B., Arteaga Mendez, L.D., De Jong, W. and Roekaerts, D.J.E.M. (2009) Characteristics of Multi-Burner Positioning and Operation Mode in a FLOXTM Furnace, paper published at the website of the 1st International Conference on Sustainable fossil Fuels for Future Energy –S4FE 2009, July 4-9, Rome , Italy.
2. Danon, B., Cho, E.-S., Arteaga Mendez, L., de Jong, W. and Roekaerts, D.J.E.M. (2009) "Emission measurements in a Multi-Burner FloxTM Furnace", paper submitted to the 4th European Combustion Meeting, Vienna, 14-17 April 2009, paper number 810113.
3. De Jong, W., Cho, E.-S., Danon, B., Arteag Mendez, L.D. and , Roekaerts, D.J.E.M. (2009) "Experimental research towards the role of burner positioning and firing configuration in a 3x100 kWth multi-burner excess enthalpy combustion furnace", in book of abstracts, the COMBURA symposium, 2009, Utrecht: Technology Foundation STW.

PROJECT AIM

Development of statistical models for turbulent gaseous flames. The fundamental problem to be addressed is the interaction between the turbulence, chemical reaction and radiation. The main line of investigation is the development of Monte Carlo PDF methods, including models for micromixing.

PROGRESS

A computational study has been made of bluff-body stabilized turbulent jet flames with strong turbulence-chemistry interaction (Sydney Flames HM1 and HM3). The wide range of scales in the problem is described using a combination of a standard second moment turbulence closure, a joint scalar transported probability density function (PDF) method and the Reaction-Diffusion Manifold (REDIM) technique. The latter provides a reduction of a detailed chemistry mechanism, taking into account effects of laminar diffusion. In an a priori test it is evaluated to what extent the single shot experimental data are located on the reaction-diffusion manifold. Next, computed spatial profiles of mean and variance of independent and dependent scalar variables and profiles of conditional averages and variances (conditional on mixture fraction) are compared to the experimental results. The quality of these predictions is interpreted in relation to the a priori analysis. In general, simulations using the REDIM approach for reduction of detailed C2-chemistry confirm earlier findings for micro-mixing model behavior, obtained with a skeletal C1-mechanism. Nevertheless it is concluded that the experiments show important features that are not described by the currently used REDIM.

DISSERTATIONS

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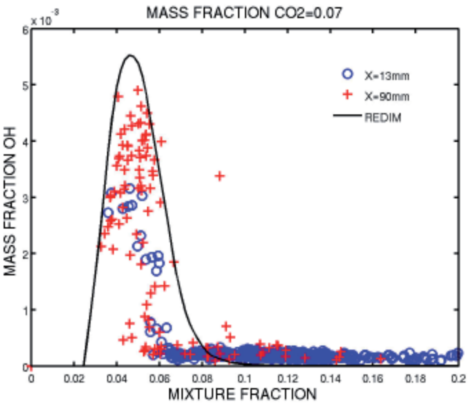
SCIENTIFIC PUBLICATIONS

1. D. Roekaerts, B. Merci, B. Naud, and U. Maas (2009) Elimination of Fast Modes in the Coupled Process of Chemistry and Diffusion in Turbulent Nonpremixed Flames: An Application of the REDIM Approach, Int. J. Multi-Scale Computational Engineering, 7(6), 2009, 487-508, DOI: 10.1615/IntJMultCompEng.v7.i6.20.
2. B. Merci, B. Naud, D. Roekaerts, and U. Maas,(2009) Joint scalar versus joint velocity-scalar PDF simulations of bluff-body stabilised flames with REDIM, Flow, Turbulence and combustion, 82 (2009) 185-209, DOI 10.1007/s10494-008-9162-2.



PROJECTLEADERS

DJEM Roekaerts

RESEARCHTHEME

Mathematical and computational methods for fluid flow analysis

PARTICIPANTS

B Merci (Univ. Ghent, Belgium),
B Naud (Ciemat, Madrid, Spain),
U Maas (Univ. Karlsruhe)

COOPERATIONS

-

FUNDED

TUD

1st 100% 2nd - 3rd -

START OF THE PROJECT

2001

INFORMATION

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Heavy fuel-oil combustion in a HiTAC Boiler

Projectleaders
DJEM Roekaerts, MJ Tummers
Researchtheme
Complex dynamics of fluids
Participants
HRC Rodrigues
Cooperations
UTwente (ThH van der Meer)
Funded
STW, Stork Thermeq, Shell Global Solutions
1st - 2nd 100% 3rd -
Start of the project
2009
Information
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Project Aim

To aim of this project which is executed in collaboration with University Twente and industrial partners Stork Thermeq and Shell is to develop the application of High temperature Air combustion (HiTAC) in heavy fuel oil combustion in a boiler. The main objective of the contribution of Delft University of Technology is to the project is to do labscale experiments to elucidate the physical characteristics of flameless turbulent spray combustion. Non-intrusive, optical measurement techniques will be used to determine gas-phase velocity, droplet velocity, droplet velocity and size distribution in a specially designed burner. This will generate a database which will be used to validate numerical codes capable to assist a new boiler design.

Progress

In flameless spray combustion fluid mechanics and chemical kinetics aspects are coupled in a very complex manner. At the onset of the project a literature study was conducted to identify the main physical quantities of interest in (flameless) spray combustion. This was used as input during the design a new spray combustion burner based on the Jet-in-Hot-Coflow concept. The burner allows for good control of the boundary conditions for velocity, temperature etc, which is relevant for a proper comparison between results of computations and experiments.

Dissertations

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Scientific Publications

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Gaseous dispersion in a road tunnel with obstacles

Project Aim

The objective of the investigation is to understand the formation of flammable mixtures after an accidental release of a “heavy gas” in a road tunnel with traffic. To reach the objective a combined experimental/numerical investigation will be carried out in which the dispersion of a heavy fluid in a ventilated channel with obstacles is studied. On the basis of the concentration measurements for a system with model fluids it is possible to describe the generation of flammable mixtures in real systems for a series of relevant conditions of the ventilation fluid velocity, injected fluid velocity and density, distance between the obstacles, size and arrangement of the obstacles on the channel floor, etc.

Progress

An experimental set up has been built to study the formation of mixtures within the flammability limits. An array of cubes mounted on the floor of a straight channel simulates traffic in a road tunnel. The accidental release of a gaseous material is simulated by a jet issuing from a nozzle in the channel floor. The jet injects a heavy fluid into the ventilated channel, after which the transient behavior of the concentration field in the channel is measured. Mean and fluctuating concentrations were measured along various lines in the channel by using laser induced fluorescence. Time-resolved PIV was used to study the flow field. The experimental data was then compared to the results of numerical simulations by TNO.

Dissertations

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Scientific Publications

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Projectleaders
DJEM Roekaerts, MJ Tummers
Researchtheme
Complex dynamics of fluids
Participants
J Verdoold, MJ Tummers
Cooperations
TNO (A van der Heijden,
I Trijssenaar-Buhre, R van der Welle
e.a.)
Funded
TNO Defence, Security and Safety
1st - 2nd - 3rd 100%
Start of the project
2007
Information
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Flameless combustion conditions and efficiency improvement of single- and multi-burner-FLOXTM furnaces in relation to changes in fuel and oxidizer composition

Projectleaders
BJ Boersma (3mE), W de Jong (3mE), DJEM Roekaerts (TNW-MSP, 3mE)

Researchtheme
Complex dynamics of fluids

Participants
E-S Cho, PhD vacancy

Cooperations
M Tummers (TNW-MSP), E van Veen (TNW-MSP), LD Arteaga Mendez (TNW-MSP)

Funded
Technology Foundation STW, Corus, Shell, NVV, Numeca Int., TNO
1st 25% 2nd 50% 3rd 25%

Start of the project
2009

Information
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Project Aim

The objective is to investigate both experimentally and computationally the impact of changes in fuel and oxidizer composition on flameless combustion. To reach the flameless combustion regime the air (and/or fuel) streams are diluted with hot combustion products with a temperature sufficiently high for the combustion process to be stable and occurring in a distributed reaction zone. The details of this combustion process will be investigated in a jet-in-hot-coflow configuration and in a new single-burner furnace. After successful validation the computational models will be used to quantify on the basis of sound physical understanding, the heat flux patterns and emission levels in flameless combustion systems of interest for the industrial partners.

Progress

A PhD student, Gerasimos Sarras, was selected who will start in March 2010. He will concentrate his studies on CFD model development. Later a post-doc will perform related tests for a burner pair operating on alternative gases (both oxidizer and fuel) using the 3x100 kWth flameless oxidation furnace.

Dissertations

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Scientific Publications

1. D. Roekaerts, M.J.Tummers and W. de Jong, Flameless combustion conditions and efficiency improvement of single- and multi-burner-FLOXTM furnaces in relation to changes in fuel and oxidizer composition , in book of abstracts, the COMBURA symposium, 2009, Utrecht: Technology Foundation STW.

Thermodynamic and gas-dynamic aspects of a BLEVE

Project Aim

For a proper risk analysis of accidents in road tunnels accurate estimates of the chances and effects of these accidents is required. This project aims at contributing to a better understanding of the accident known as BLEVE, or boiling liquid expanding vapour explosion. The thermodynamic and fluid dynamic aspects, in particular of the rapid vapourisation after a sudden decrease of pressure will be investigated by a combination of modeling and experiments. The insights gained will be used in predictive models for maximum overpressure in case of an accident and will contribute to the safe evaluation of existing road tunnels and design of future ones.

Progress

BLEVE is a problem of two-fluid two-phase compressible flow with heat/mass transfer in superheated states. The transport equations, the E.O.S. (Equation of State), the numerical scheme and the source term modeling are of the same order of importance in its simulation. Our first complete numerical system was finished in 2009 which consists of

1.Equal-Velocity-Unequal-Temperature Euler equations;
2.Peng-Robinson-Stryjek-Vera E.O.S.;
3.Particle-path scheme of Method of Characteristics;
4.Relaxation time models of the interfacial heat/mass fluxes.

The computation results reveal that (1) Particle-path can capture the shock and the rarefaction wave with satisfactory accuracy, therefore it is not necessary to artificially track the waves; (2) The pressure drop after the rarefaction wave keeps varying in its propagation due to the non-equilibrium between the liquid and the vapour; (3) The influence of two free parameters, the initial liquid pressure and the relaxation time, can be clearly observed and reasoned; (4) Although the relaxation time model is qualitatively correct only, its prediction of the maximum pressure which is about approx. 1/3 as high as the prediction of TNO method is still a proof of TNO method's conservativeness. In future, the relaxation time model will be replaced by non-equilibrium thermodynamics model in which the interfacial heat/mass fluxes are solved by coupling the energy conservation and the mass conservation following Kjelstrup and Bedeaux. The Particle-path scheme will be replaced by a Finite Volume Method for higher dimensional computations.

Dissertations

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Scientific Publications

1. M.Xie and D. Roekaerts, Predicting the pressure peak from a boiling liquid expanding vapour explosion, in book of Abstracts, 9th Netherlands Process Technology Symposium, October 20-21, 2009, Veldhoven, The Netherlands, 1 page.
2. M. Xie and D. Roekaerts, On the need for experimental data sets for BLEVE model validation, Report TU Delft, MSP, 2009, 31 pages.

Projectleaders
DJEM Roekaerts
Researchtheme
Complex dynamics of fluids
Participants
M Xie, DJEM Roekaerts
Cooperations
TNO Defence, Security and Safety
(AC van den Berg, J Weerheijm)
Funded
Centrum Ondergronds Bouwen,
Delft Cluster (Rijkswaterstaat, TNO, TUDelft)
1st 50% 2nd - 3rd 50%
Start of the project
2006
Information

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A laboratory experiment to study the effect of turbulence on droplet growth and size distributions in clouds

Projectleaders
HJJ Jonker, M Tummers
Researchtheme
Complex dynamics of fluids
Participants
T Chatterjee, HJJ Jonker,
M Tummers, R Mudde, L Portela
Cooperations
Prof.Dr.J.Hunt (J.M.Burgers Center for Fluid Mechanics & University College London), Dr. W.Grabowski (NCAR, Boulder,Colorado,U.S.A)
Funded
NWO/ALW
1st - 2nd 100% 3rd -
Start of the project
2007
Information
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Project Aim

The aim of the project is to increase the understanding of cloud microphysics, in particular the effect of turbulence on droplet growth and coalescence in convective clouds which affect both the optical properties of clouds and the formation of precipitation. Issues like preferential concentration, turbulence enhanced settling velocities and turbulence enhanced collision coalescence will be addressed. Phase Doppler Anemometry (PDA) is to be used for simultaneously measuring droplet velocities and droplet size distributions.

Progress

The experimental set up has been designed and implemented to produce droplets and to study the behavior in a turbulent environment. During the last year, several sets of measurements have been carried out with Phase Doppler Anemometry (PDA) to investigate and quantify the role of turbulence on the droplet collision rate. By traversing the PDA system, droplet velocities and droplet size statistics can be obtained in different parts of the flow. On comparing these distributions at different positions, the droplet growth by collisions can be studied as well as the effects of evaporation by comparing the results for an open system with a closed one. This helped us in drawing up some inferences. New measurements have been carried out recently with the existing laboratory facility using a PIV set-up which enables one to study the spatial structure of droplet clusters.

Dissertations

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Scientific Publications

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High resolution modeling of deep cumulus convection

Project Aim

A realistic representation of deep cumulus clouds remains one of the most challenging problems in atmospheric modeling. Numerical Weather Prediction and climate models, in which deep convection is parametrized, tend to predict the onset of deep convection too early during the day. We will investigate the transition from shallow clouds to deep convection using the Dutch Atmospheric Large Eddy Simulation (DALES) model. The simulation results of DALES will be used to determine the relative roles of gradual moistening of the cloud layer and the organisation of the boundary layer below cloud base.

Progress

The thermodynamical and dynamical equations have been adjusted so that they apply to a large range of temperature and pressure conditions. Previous versions of DALES were targeted at shallow convection and used the Boussinesq approximations. In order to be able to simulate deep convection, the mass conservation law was modified to use a height dependent density. Since the behavior of ice particles which form during deep convection is very different from liquid water, a scheme for clouds containing both rain and ice has been implemented. A first LES case study for deep convection has been performed.

Dissertations

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Scientific Publications

-

Projectleaders
HJJ Jonker, AP Siebesma

Researchtheme
Complex dynamics of fluids

Participants
SJ Böing, HJJ Jonker, AP Siebesma, SR de Roode

Cooperations
KNMI, Dr. W.Grabowski (NCAR, Boulder,Colorado,U.S.A)

Funded
TUD

1st 100% 2nd - 3rd -

Start of the project
2009

Information
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Cloud-climate feedback: the role of boundary layer clouds

Projectleaders
SR de Roode, HJJ Jonker,
AP Siebesma

Researchtheme
Complex dynamics of fluids

Participants
J van der Dussen, SJ Böing,
E Jones, SR de Roode, HJJ Jonker,
AP Siebesma

Cooperations
KNMI, + 12 other EU partners
involved in EUCLIPSE

Funded
EU
1st - 2nd - 3rd 100%

Start of the project
2010

Information
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Project Aim

The cloud response due to the enhanced greenhouse effect remains the largest source of uncertainty in climate model projections of a future climate. The EU-funded Cloud Intercomparison, Process Study & Evaluation Project (EUCLIPSE) aims to reduce the uncertainty in the representation of cloud processes and feedbacks in the new generation of Earth System Models (ESMs). This sub-project will use the Dutch Atmospheric Large-Eddy Simulation model to study in detail turbulent flows in cloudy atmospheres. Central question is how the vertical atmospheric stability controls the spatial coverage and depth of low clouds like stratocumulus and shallow cumulus.

Progress

Candidate (Johan van der Dussen) has been selected and hired.

Dissertations

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Scientific Publications

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Eddy covariance observations of methane and nitrous oxide: Towards more accurate estimates from ecosystems

Project Aim

The main objective is to check the hypothesis whether atmospheric eddy covariance flux measurements can substantially contribute to a decrease in the uncertainty of the annual emission estimates of methane (CH4) and nitrous oxide (N2O) from ecosystems compared to estimates based on chambers only. This hypothesis will be tested using continuous field measurements, laboratory experiments and literature studies.

Progress

The project was in the end phase in 2009. Consequently, the work was mainly related to publications and presentations. Four articles were published and another one was submitted. Presentations were given at several international conferences, e.g. NitroEurope meeting (Sweden), chamber workshop (Finland), NCGG-5 conference (Wageningen) and iLEAPS conference (Australia). A dissertation was written which will be defended in June 2010. The main conclusion of this project is that eddy covariance flux measurements can substantially contribute to a decrease in the annual estimates of CH4 and N2O from ecosystems. If appropriate data processing methods are used and data coverages above 80% are attained, uncertainties in annual balances could be even smaller than 10%. The emissions of both gases are realy significant in comparison to the emission of CO2 at our study site a managed peat area. They contribute for two-third to the total terrestrial greenhouse gas emission.

Dissertations

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Scientific Publications

1. Kroon, P. S., A. Hensen, H. J. J. Jonker, H. G. Ouwersloot, A. T. Vermeulen and F. C. Bosveld, 2009: Uncertainties in eddy covariance flux measurements assessed for CH4 and N2O observations. Agric. For. Meteorol., doi:10.1016/j.agrformet.2009.08.008.
2. Kroon, P. S., A. Schuitmaker, H. J. J. Jonker, M. J. Tummers, A. Hensen and F. C. Bosveld, 2009: An evaluation by laser Doppler anemometry of the correction algorithm based on Kaimal co-spectra for high frequency losses of EC flux measurements of CH4 and N2O. Agric. For. Meteorol., doi:10.1016/j.agrformet.2009.08.009.
3. Schrier-Uijl, A. P., P. S. Kroon, P. A. Leffelaar, J. C. van Huissteden, F. Berendse and E. M. Veenendaal, 2009: Methane emissions in two drained peat agro-ecosystems with high and low agricultural intensity. Plant Soil, doi:10.1007/s11104-009-0180-1.
4. Schrier-Uijl, A. P., P. S. Kroon, A. Hensen, P. A. Leffelaar, F. Berendse and E. M. Veenendaal, 2009: Comparison of methane and carbon dioxide fluxes at small scale and large scale measured by eddy covariance and a closed chamber method in a grass ecosystem on peat. Agric. For. Meteorol., doi:10.1016/j.agrformet.2009.11.007.

Projectleaders
A Hensen (ECN), HJJ Jonker

Researchtheme
Complex dynamics of fluids

Participants
PS Kroon (TU Delft & ECN), HJJ Jonker (TU Delft), A Hensen (ECN), AT Vermeulen (ECN), AP Schrier Uijl (WU), MJ Tummers (TU Delft), A Schuitmaker (TU Delft), HG Ouwersloot (TU Delft & WU), WH van 't Veen (ECN), FC Bosveld (KNMI)

Cooperations
Wageningen University (the Netherlands), University of Amsterdam (the Netherlands), KNMI (the Netherlands), Aerodyne Research Inc. (Boston, USA)

Funded
Dutch research program Climate Changes Spatial Planning (www.klimaatvoorruimte.nl)
European CarboEurope program (www.carboeurope.org)
Energy research Centre of the Netherlands
1st - 2nd - 3rd 100%

Start of the project
2005

Information

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High resolution regional climate modeling of convection and precipitation over the Netherlands

Projectleaders
AP Siebesma, HJJ Jonker,
SR de Roode
Researchtheme
Complex dynamics of fluids
Participants
E Jones, J Van der Dussen,
SJ Böing, SR de Roode, HJJ Jonker,
AP Siebesma
Cooperations
KNMI, WUR
Funded
Kennis voor Klimaat
1st - 2nd - 3rd 100%
Start of the project
2010
Information
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Project Aim

Operations at the Amsterdam airport Schiphol are very sensitive to critical weather conditions, like fog, low level clouds, heavy rainfall and strong winds, and sudden changes in these conditions. Changes in our future climate will have its impact on the variability of the weather at Schiphol Airport and on the frequency and intensity at which extreme events will occur. The objective of this project is to evaluate and to improve the capability of a new high resolution weather forecast model HARMONIE to represent and resolve mesoscale systems over the Netherlands such as: isolated convective cells, cold-air outbreaks, squall lines and the precipitation associated with these systems.

Progress

Candidate (Emily Jones) has been selected and hired.

Dissertations

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Scientific Publications

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Physics of Nuclear Reactors

Prof.dr.ir. ThJJ van der Hagen

Mission

The reactor physics department contributes to the development of sustainable nuclear energy such that it can play a major role in the global energy production. To this end, we focus on new and innovative nuclear reactors with improved efficiency, a high degree of safety, flexibility, and with a reduced waste production.

Research

Research in the department can be divided into three categories:

1. Thermal Hydraulics of Nuclear Reactors
   - Experimental research on stability of natural circulation Boiling Water Reactors with enhanced safety features.
   - Numerical analyses of thermal-hydraulic phenomena in new reactors like the SBWR and others. This also includes method and code development.
   - Thermo-Siphon research.
2. Reactor Physics Analysis of New Reactor Designs
   - VHTR: Design and analysis of a gas-cooled Very High Temperature Reactor for hydrogen production. Focus on core design and safety/transient analysis.
   - GCFR: Design and analysis of a Gas-Cooled Fast Reactor with a self-generating core and reduced waste production.
   - ADS: Dynamics analysis and development of reactivity measuring methods for Accelerator Driven Systems.
   - MSR: Design and Analysis of a Molten Salt Reactor with a high-conversion and/or breeding fuel cycle. Focus on core design, fuel cycle analysis, and dynamics and safety analyses.
   - Exotic designs, like the Fluidized Bed Reactor with a fast neutron spectrum, the CANDLE burnup reactor, and reactors for new applications.
3. Methods and Codes for Reactor Physics and Particle Transport
   - Development and application of electron-photon-neutron particle transport, possibly coupled to other codes like CFD.
   - Development and application of Monte Carlo transport methods possibly coupled to other codes like deterministic transport codes, and CFD.
   - Development and application of new reactor physics methods, like -mode calculations, coupled time-dependent neutronics and thermal-hydraulics, etc.
   - Development of methods to reduce leakage of nuclides from a geological disposal site.

Experimental and numerical investigation of cross flow in a rod bundle geometry

Project Aim

To develop a deep understanding of the inter sub-channel cross flow in a vertical rod bundle geometry. The project aim is motivated by the existance of the cross flow in the core of light water nuclear reactors and its effect on the local power production and the heat transfer from the fuel rods to the coolant due to different feedback mechanisms. During the project the existance and origin of the large scale vortices near the channel gap interface and their role towards the cross flow mixing will be investigated.

Progress

The experimental investigation of cross flow and corresponding inter channel mixing had been performed as a function of gap geometry and Reynolds numbers. 2D Particle Image Velocimetry (PIV) and Laser Doppler Anemometry (LDA) are used for flow pattern identification, whereas a tracer injection method is used for the quantification of inter channel cross flow mixing. The experimental results show a street of alternating vortices on either side of the gap, separated by zones of high cross flow. These vortices have a constant average size at higher Re numbers and their axial velocity scales with the superficial velocity. At higher Re numbers the spanwise velocity fluctuations in the gap region, a measure of cross flow, scales linearly with the superficial velocity. The tracer injection experiments has also confirmed these findings. For turbulent flows, the large scale vortices dominates the inter-channel cross flow mixing over turbulent mixing. Furthermore, the gap hydraulic diameter is identified as geometric parameter govening the cross flow mixing. Based on the experimental findings, at present the modeling phase is underway.

Projectleaders

THJJ van der Hagen, RF Mudde

Researchtheme

Complex structures of fluids

Participants

A Mahmood, M Rohde

Cooperations

PNR/RID (TUDelft), Multi-Scale Physics (TUDelft)

Funded

HEC/NUFFIC, TUDelft.

1st 50% 2nd 50% 3rd -

Start of the project

2006

Information

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Dissertations

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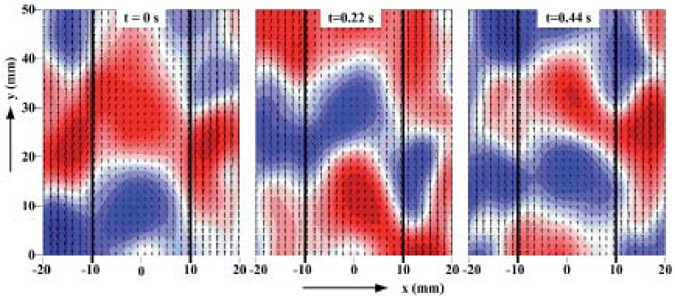
Scientific Publications

1. Contribution of Large Scale Coherent Structures towards the Cross Flow in Two Interconnected Channels, , A.Mahmood, M. Rohde, T.H.J.J. van der Hagen, Rob F. Mudde, The 13th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-13), Kanazawa City, Japan, September 27-October 2, 2009.



Experimentally found instantaneous flow fields at three time instants. Vertical black lines indicate the location of the gap region, arrow length scales with the local fluid velocity. The background color indicates the cross direction and magnitude of the cross flow. *Re=3436, V_{sup}=14.5 cm/s, gap height=2 mm*

The natural circulation driven supercritical water nuclear reactor: a fundamental stability study

Projectleaders
M Rohde
Researchtheme
Complex structures of fluids
Participants
M Rohde, C T'Joen
Cooperations
EU HPLWR Consortium/University of Pisa
Funded
NWO (Veni Grant)
1st - 2nd 100% 3rd -
Start of the project
2007
Information
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Project Aim

One of GEN-IV reactor concepts is the so-called supercritical water reactor (SCWR), in which supercritical water is used to cool the nuclear core. This would result in a higher thermal efficiency. An important topic that needs to be studied is the reactor stability. In this project the possibility of cooling the SCWR by natural circulation is considered. This enhances the inherent safety of the reactor, since perturbations in the flow are weakened by the density response in the core (negative feedback). A consequence, however, is that the physics become more complicated. Hence, studying (and guaranteeing) stability of such a system will become a great challenge.

Progress

An experimental facility 'DeLight' was designed and constructed at the Delft University of Technology. This facility is a scaled version of the European concept of the SCWR, named the HPLWR and can operate in both natural and forced circulation mode. To lower the pressure and temperatures a scaling fluid was used, Freon R-23. This fluid matches the behaviour of supercritical water very good. The design was based on a new set of scaling rules in which the friction distribution is kept constant throughout the loop, rather than the absolute values, easing some of the restrictions. In parallel a simulation code was developed using COMSOL in which the core or the full loop is modeled one-dimensionally. This code was used to study the effect of the scaling rules and will be used to model the stability behaviour and the impact of various parameters. Initial experiments revealed instabilities similar to those in a boiling water reactor.

Dissertations

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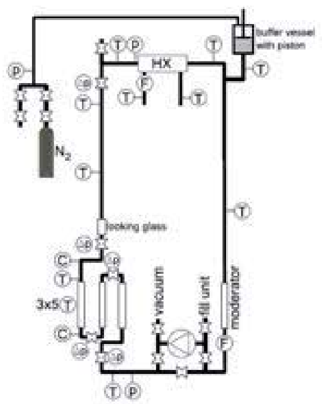
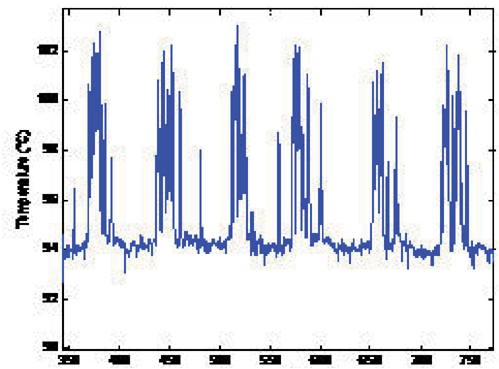
Scientific Publications

1. Fluid-to-fluid modeling of supercritical water loops for stability analysis, Marcel, CP; Rohde, M; Masson, VP, van der Hagen, T.H.J.J, International Journal of Heat and Mass Transfer, 52 (21-22), 5046-5054.
2. Rohde, M., van der Hagen, T.H.J.J., Downscaling the supercritical water reactor to an experimental facility by using a scaling fluid, Proceedings of NURETH-13, September 27 - October 2, 2009, Kanazawa, Japan.
3. Rohde, M., van der Hagen, T.H.J.J., Downscaling the supercritical water reactor to an experimental facility by using a scaling fluid, Proceedings of the 4th International Symposium on Supercritical Water-Cooled Reactors, March 8-11, 2009, Heidelberg, Germany.





DeLight Setup (left) and a measured temperature trace during instable operation showing strong periodic variations.

DelftChemTech

Prof.dr.ir. M-O Coppens

Our research objective is to introduce conceptually new approaches to address the development of sustainable chemical technologies that are in harmony with nature, and are, as such, both efficient and effective. Problems studied are typically fundamental in nature, yet society-driven, with practical applications in mind.

Inspiration is drawn from universal, hierarchical patterns, networks and symmetries present in nature, such as self-similarity, which link the micro- and the macro-scale in a very efficient, scalable way. The “architecture” and thermodynamics of nature and the life sciences are the basis for new, rational designs of porous materials and processes. Applications include catalysis, separations, chemical reactor engineering, and controlled delivery. Natural structures are taken as a lead, and not as a dogma for optimality – hence nature-inspired, and not always bio-mimetic.

At the heart of these rational, nature-inspired designs lies a better understanding and control of physico-chemical phenomena spanning multiple length and time scales. For this reason, much of our attention goes to the development of mesoscopic theories and hierarchical, statistical mechanical modelling approaches.

In the context of the JMBC, current research topics include (much in collaboration between M.-O. Coppens and J.R. van Ommen):

- novel ways to “structure” fluidized beds and other multiphase reactors
- characterization of multiphase flow using novel statistical techniques
- self-assembly and pattern formation

Analytical and computational work are combined with experiments.

Other research focuses on:

- rational design and synthesis of hierarchical porous materials
- effects of heterogeneity on transport in porous materials, for catalysis, separations and controlled release (rough mesoporous materials, zeolites, protein crystals and ion channels), in particular using statistical mechanical simulations and analytical calculations.
- non-equilibrium thermodynamics

STRUCTURING SLURRY BUBBLE COLUMNS

PROJECT AIM

Our goal is to develop a strategy that realizes dynamic structuring of the flow in the slurry reactors in order to allow operation at set points that are with the current steady-state operation out of reach. The dynamic structuring will create more freedom for operation that can be tuned towards high selectivity, reduced energy input per unit product, increased transfer rates and smaller equipment.

PROGRESS

We have investigated uniform gas injection using a needle sparger as a structuring methodology to reduce backmixing in slurry bubble columns. Using optical probes, we determined the gas fraction and the bubble behavior in 2D and 3D slurry bubble columns with a uniform gas injection. Experimental results for air-water-glass beads indicate that a strong reduction in the vortical structures has been achieved and the homogeneous flow regime can be extended beyond 30% gas fraction. Increasing the solids concentration decreases the gas fraction and widens the bubble velocity distribution. Furthermore, we show by modelling that the reduced backmixing leads to a major improvement of the conversion in case of Fischer-Tropsch synthesis.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. JR van Ommen, PJ Hamersma, N Hooshyar, RF Mudde., Strucutring slurry bubble columns: a first step, proceedings of the 8th World congress of chemical engineering, 2009.

PROJECTLEADERS
PJ Hamersma, RF mudde,
JR van Ommen

RESEARCHTHEME
Complex structures of fluids

PARTICIPANTS
Nasim Hooshyar

COOPERATIONS
-

FUNDED
DUT
1st 100% 2nd - 3rd -

START OF THE PROJECT
2008

INFORMATION

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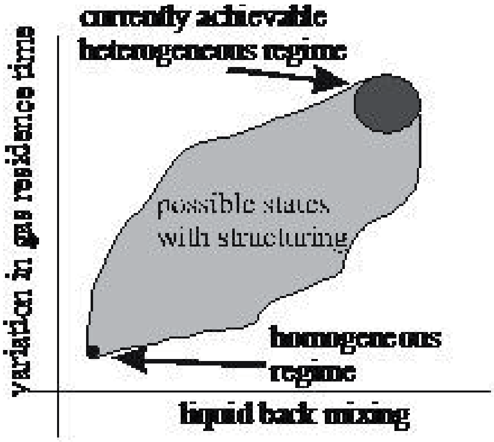

Structuring gas-solid fluidized beds

Projectleaders
JR van Ommen, M-O Coppens
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
Bashar Hadi
Cooperations
Prof. Rhodes (Monash University), prof. Kuipers and co-workers (Twente University), Dr. van Wachem (Imperial College)
Funded
Rhodia
1st - 2nd - 3rd 100%
Start of the project
2004
Information
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Project Aim

This projects aims at imposing structure on gas-solids fluidized beds, with the following advantages:

- A reduction in bubble size, which leads to better mass transfer;
- In addition, a reduced bubble size leads to less erosion, attrition, and elutriation;
- A structured system is easier to model and to scale-up;
- More independent variables facilitate model validation;
- A structured system offers more possibilities to adjust the process during operation.

Progress

Structuring can be done either by modifying the gas supply or by interfering in the particle phase. In both cases, either the dynamics can be changed or the configuration can be altered. This yields a total of four different possibilities:

1. Oscillating the gas supply;
2. Varying the interparticle forces, which is conveniently done using an AC electric field;
3. Distributing the gas supply over the height of the bed;
4. Varying the particle size distribution and other distributed particle properties.

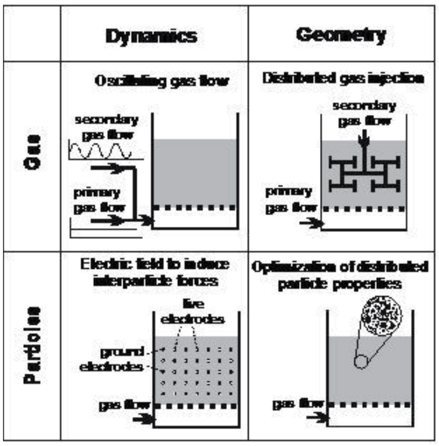
All these four possibilities have been investigated in the past years. Each possibility has its own typical applications for which it is the best choice. Currently, we are focussing on method 1 and 3 with the aim of improving heat transfer and drying.

Dissertations

-

Scientific Publications

1. Akhavan, A., van Ommen, J.R., Nijenhuis, J., Wang, X.S., Coppens, M.-O., Rhodes, M.J., 'Improved drying in a pulsation-assisted fluidized bed', Industrial & Engineering Chemistry Research, 48, pp. 302-309, 2009.
2. van Ommen, J.R., Nijenhuis, J., Coppens, M.-O., 'Reshaping the Structure of Fluidized Beds', Chemical Engineering Progress, 105(7), 49-57, 2009.



AERODYNAMICS

Prof.dr.ir. H Bijl

Prof.dr. F Scarano

Prof.dr.ir. PG Bakker

The research in the Aerodynamics Group involves fundamentals of Fluid Dynamics and its applications to aerodynamic problems of relevance in Aerospace Engineering systems.

The activities cover boundary layer research in low speed and high-speed flows, including re-entry aero-thermodynamics, complex unsteady flows, fluid-structure interaction problems and aeroacoustics.

The group works in close connection with the Wind Energy section for the investigation of rotor blade aerodynamics. Specific flow control strategies by passive (e.g. vortex generators) and active means (suction, plasma actuators) are explored for their application in flow transition and separation delay.

The experimental research is supported by the Aerodynamics Laboratories, which cover flow simulation range from incompressible to hypersonic regime. Emphasys is given to the development and application of image based advanced flow diagnostic techniques like Tomographic PIV, Background Oriented Schlieren, InfraRed Thermography.

The study of Fluid-Structure interactions and of unsteady flow simulation drive the development of efficient simulation tools for 3D-unsteady viscous flows (e.g. adaptive meshing, mimetic methods, multiscale computation of turbulence). Applications range from flapping wings and micro aerial vehicle aerodynamics to aircraft flutter and unsteady loads on wind turbines. The research on CFD also covers quantification of uncertainties in aerodynamics problems simulation.

FLOVIST: Flow visualization inspired aeroacoustics by time resolved tomographic particle image velocimetry

Projectleaders
F Scarano

Researchtheme
Complex dynamics of fluids

Participants
Valerio Lorenzoni, Peter Moore, Matteo Novara, Daniele Violato, Sina Ghaemi.

Cooperations
Nationaal Luchtvaart Laboratorium (NLR), German Aerospace Centre (DLR)

Funded
European Research Council (ERC)
1st - 2nd - 3rd 100%

Start of the project
2008

Information
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Project Aim

Development of advanced experimental techniques for the aeroacoustic analysis of turbulent flows of relevance in aerodynamics. The research is based on the extensive use of advanced flow diagnostics and in particular of time-resolved 3D velocimetry by Tomography. The technique is based on acoustic source detection and sound emission modelling based on acoustic analogies. The applications cover aircraft aerodynamics (trailing-edge noise and cavities) propulsion (jet noise) and include the area of wind turbines (rotor blade tip and trailing aerodynamics).

Progress

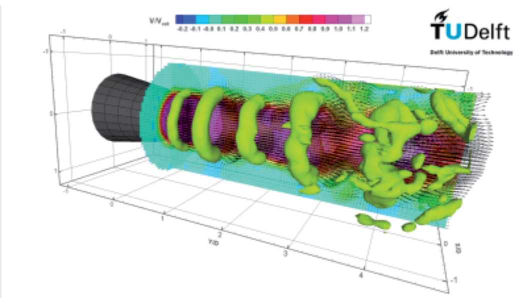
Advances in Tomographic PIV. In 2009 a novel approach to the tomographic reconstruction of 3D particle fields has been extended to particle fields in motion (motion tracking enhanced MART). Numerical performance evaluation predicts order of magnitude improvements in terms of maximum particle concentration and measurement precision. Ongoing experimental assessment. Time resolved analysis of transitional jets. A facility has been developed for water jet tomography. Experiments performed by high-speed tomographic PIV were performed which describe the dynamical evolution of the three-dimensional transition. The data is intended to serve for acoustic source identification and noise prediction from subsonic jets. Sound production from vortex-structure interactions (collaboration with NLR). The tonal noise produced by the interaction of a Karman wake with a NACA0012 airfoil is investigated by time-resolved Tomo-PIV, velocity-pressure reconstruction technique coupled with Curle's analogy.

Dissertations

-

Scientific Publications

1. Lorenzoni V, Tuinstra M, Moore P, Scarano F, Aeroacoustic analysis of a rod-airfoil flow by means of time-resolved PIV, 15th AIAA/CEAS Aeroacoustics Conference, Miami, (US).
2. Novara M, Scarano F, Ghost intensity reduction by means of Motion Tracking Enhanced MART, 9th Int. Symp. On PIV, Melbourne (AU).
3. Violato D, Scarano F, Moore P, Rod-airfoil flow investigation by time-resolved Tomo-PIV for aeroacoustics, 9th Int. Symp. On PIV, Melbourne (AU).
4. Haigermoser C, Scarano F, Onorato, Investigation of the flow in a circular cavity using stereo and tomographic particle image velocimetry, Exp. Fluids 46: 517-526.
5. Scarano F, Poelma C, Three-dimensional vorticity patterns of cylinder wakes, Exp. Fluids, 47: 69-83.



Laminar jet from circular nozzle, Re_D = 5,000
Fluid: water; D = 10 mm; V_{exit} = 0.42 m/s
Axial and exit cross section velocity vector slices
Vortex visualization by Q iso-surfaces (Q=1.2)
Tomographic PIV measurements
Framing rate = 1,000 Hz

Application of non-intrusive aerodynamic loads measurements to unsteady compressible flows

Projectleaders
F Scarano, BW van Oudheusden
Researchtheme
Complex dynamics of fluids
Participants
Daniele Ragni, Sina Ghaemi
Cooperations
German-Dutch wind tunnels consortium (DNW), National Luchtvaart Laboratorium (NLR)
Funded
Dutch Technology Foundation (STW)
1st 10% 2nd 80% 3rd 10%
Start of the project
2008
Information
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Project Aim

The PIV technique is extended to the high-speed regime by means of specific developments on particle tracers technology. The resulting technique is combined with data post-processing methods to quantify the instantaneous planar pressure field. The method is applied to airfoils in transonic flows, space launcers (ARIANE V type) and more recently on propellers. The final objective is the scale-up of the procedure for possible application in the industrial wind tunnels of the German-Dutch consortium DNW.

Progress

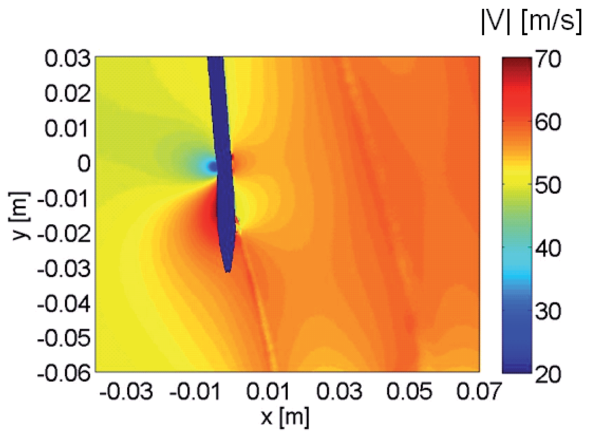
In 2009 important advances are obtained on particle tracers technology with the development of a seeding production technique based on spark generation between metal electrodes. Particles response time of 300 nanoseconds has been measured in experiments, approximately 10 times less than conventional tracers. Particle image velocimetry has been used to determine the aerodynamic force around a NACA airfoil in the transonic regime. Favourable comparison is obtained with respect to conventional measurement techniques. Experiments are under preparation for the application of the planar pressure imaging method to an aircraft propeller operating close to Mach 1 at blade tip. The configuration to be considered for a scale up of the technique in industrial wind tunnels is under evaluation.

Dissertations

-

Scientific Publications

1. Ragni D, Ashok A, van Oudheusden BW, Scarano F, Surface pressure and aerodynamic loads determination of a transonic airfoil based on particle image velocimetry, Meas. Sci. Technol. 20.
2. RagniD , Schrijer FFJ, van Oudheusden BW, F. Scarano, On the determination of PIV particle tracers response time by shock wave tests, 9th Int. Symp. On PIV, Melbourne (AU).



PIV image of a propeller running at 21000 rpm, with contours of 3D phase loced velocity magnitude as extracted from a vertical plane at 3/4 propeller radius

PIV-based non-intrusive determination of unsteady aerodynamic loads

Project Aim

In the project novel non-intrusive experimental approaches are developed and applied to determine the aerodynamic loads on objects from flow velocity data measured with particle image velocimetry (PIV). This is achieved by combining the flow field information with basic momentum principles. Apart from looking at the fundamental principles (notably 3D flow effects) the project will also address the development of practical procedures, in terms of hardware solutions, experimental arrangements and data post-processing, in order to make it a technique that can be applied relatively routinely in fluid-dynamic research. The primary area of application is in low-speed aerodynamics and industrial fluid dynamics. The extension of the method to the high-speed flow regime will also receive attention, in view of its relevance for industrial aeronautics.

Progress

1) Experimental investigation of the unsteady flow around a (stationary) bluff body (square cross-section prism) using a high-repetition-rate PIV system, with the objective to obtain instantaneous pressure fields and unsteady integral loads. Accurate pressure reference data were obtained for validation, using fast-response pressure transducers. Acquisition of both planar and volumetric (“thin-tomo”) PIV data, to assess the impact of 3D flow information. Theoretical investigation and assessment of different pressure integration schemes.

2) Experimental investigation of the steady transonic flow around a NACA 0012 airfoil in the TST transonic-supersonic wind tunnel. Determination of pressure fields (surface pressure) and aerodynamic coefficients. Further evaluation of error sources and impact of pressure integration method, especially in view of the accuracy of the drag value inferred from a wake-defect integration approach.

Dissertations

-

Scientific Publications

1. D. Ragni, A.Ashok, B.W. van Oudheusden, F. Scarano: Surface pressure and aerodynamic loads determination of a transonic airfoil based on particle image velocimetry, Measurement Science & Technology , Vol.20 (2009), No.7, 074005.
2. R. de Kat, B.W. van Oudheusden, F. Scarano: Instantaneous pressure field determination around a square-section cylinder using time-resolved PIV, AIAA-2009-4043, 39th AIAA Fluid Dynamics Conference and Exhibit, San Antonio, USA, 22-25 June 2009, 10 pp.
3. R. de Kat, B.W. van Oudheusden, F. Scarano: Instantaneous pressure field determination in a 3D flow using time-resolved thin-volume tomographic PIV, 8th Int. Symp. on PIV (PIV09), Melbourne, Australia, 25-28 Aug. 2009, 4 pp.
4. B.W. van Oudheusden: PIV-based forces and pressure measurements. VKI Lecture Series 2009-01 Recent advances in particle image velocimetry. Ed: F.Scarano and M.L. Riethmuller. ISBN-978-2-930389-89-3. The Von Kármán Institute for Fluid Dynamics, Rhode-Saint Genèse, Belgium, 26-30 January 2009.

Projectleaders
BW van Oudheusden, F Scarano

Researchtheme
Complex dynamics of fluids

Participants
R de Kat, D Ragni

Cooperations
DNW, NLR

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2006

Information

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Aerodynamic characterization and control of unsteady shock-wave boundary layer interactions

Projectleaders
BW van Oudheusden, F Scarano
Researchtheme
Complex dynamics of fluids
Participants
RA Humble, LJ Souverein, ZZ Sun
Cooperations
FP-6 STREP “UFAST”,
IUSTI (Université d’Aix-Marseille – CNRS, UMR N°6595)
Funded
UFAST
1st 65% 2nd - 3rd 35%
Start of the project
2004
Information
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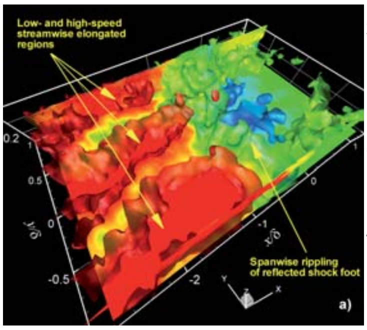

Tomographic PIV investigation of a SWBLI : instantaneous 3D flow field showing the modification of the interaction front by the large-scale structures in the incoming turbulent boundary layer.

Project Aim

The project deals with the experimental investigation of unsteady shock-wave boundary layer interactions (SWBLI), in particular at the low supersonic regime. PIV is used as the primary diagnostic tool in order to characterize the instantaneous spatial organization of the flow, and the impact of boundary layer perturbance on the interaction (flow control). The study is intended to provide a verification data base as well as more advanced theoretical models for this type of flows.

Progress

Further experimental characterization of a turbulent SWBLI at Mach 2 and Mach 1.7 using PIV. Statistical analysis of the flow fields (mean velocity profile and turbulence quantities). Unsteady flow organization approached with the POD analysis method and conditional statistics, and with dual-PIV experiments to determine time scales. Cooperation with the IUSTI laboratory (Marseille) regarding the effect of interaction strength and Reynolds number on the flow topology and unsteadiness characteristics (reflected shock frequency in particular). Flow control investigations based on microramps (TUD) and microjets (IUSTI). Results have been reported at conferences and at the progress meetings of the FP-6 research program UFAST. A continuation of the work with emphasis on interaction flow control has been initiated by the appointment of a new PhD student.

Dissertations

1. R.A. Humble: Unsteady flow organization of a shock wave boundary ayer interaction. Ph.D. thesis, TU Delft, 18 Feb. 2009.

Scientific Publications

1. R.A. Humble, G.E. Elsinga, F. Scarano, B.W. van Oudheusden: Three-dimensional instantaneous structure of a shock wave/turbulent boundary layer interaction. J. Fluids Mech. 622 , 2009, 33- 62.
2. L.J. Souverein, B.W. van Oudheusden, F. Scarano, P. Dupont: Application of a dual-plane particle image velocimetry (PIV) technique for the unsteadiness characterization of a shock wave turbulent boundary layer, Measurement Science & Technology , Vol.20 (2009), No.7, 074003.
3. R.A. Humble, F. Scarano, B.W. van Oudheusden: Unsteady aspects of an incident shock wave/turbulent boundary layer interaction, J. Fluids Mech, vol.. 635, (2009), pp. 47-74.
4. P.L. Blinde, R.A. Humble, B.W. van Oudheusden, F. Scarano: Effects of micro-ramps on a shock wave / turbulent boundary layer interaction, Shock Waves (2009) 19:507-520.
5. R.A. Humble, F. Scarano, and B.W. van Oudheusden: Unsteady Flow of a ShockWave/Turbulent Boundary Layer Interaction, IUTAM BOOKSERIES Volume 14 - IUTAM Symposium on Unsteady Separated Flows and their Control, Eds. Marianna Braza and K. Hourigan, 2009, ISBN 978-1-4020-9897-0, Springer, pp. 289-300.
6. R.A. Humble, G.E. Elsinga, B.W. van Oudheusden: Time Series Analysis of a Shock Wave/ Turbulent Boundary Layer Interaction using a Dynamical Systems Approach, AIAA-2009-3713, 39th AIAA Fluid Dynamics Conference and Exhibit, San Antonio, USA, 22-25 June 2009.

7. P.L. Blinde, R.A. Humble, B.W. van Oudheusden, F. Scarano: Effects of micro-ramps on a shock wave / turbulent boundary layer interaction, AIAA-2009-3714, 39th AIAA Fluid Dynamics Conference and Exhibit, San Antonio, USA, 22-25 June 2009.
8. L.J. Souverein, P. Dupont, J.-F. Debiève, J.-P. Dussauge B.W. van Oudheusden, F. Scarano: Effect of interaction strength on the unsteady behavior of shock wave boundary layer interactions, AIAA-2009-3715, 39th AIAA Fluid Dynamics Conference and Exhibit, San Antonio, USA, 22-25 June 2009.

Generic multi-scale simulation tools for numerical engineering : new simulation techniques for flows interacting with transforming structures

Projectleaders
H Bijl, AH van Zuijlen, M Gerritsma, S van der Zwaag

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
JJ Kreeft, V Kazemi Kamyab

Cooperations
Corus, Philips Applied Technologies, Numeca Int., Ansys

Funded
STW
1st - 2nd 75% 3rd 25%

Start of the project
2008

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Project Aim

The project aims at the development, implementation and application of generic numerical algorithms for multi-scale modeling and fluid-structure interaction, for problems where gas or fluid flows interact with material structures being cooled through a phase transformation. The project currently consists of two parts:

1) Thermal coupling of flows and structures
2) Mimetic multi-scale simulation

Progress

1) Thermal coupling of flows and structures

Thermal coupling between two domains has been analyzed for a system of coupled Laplace equations in 1-D. Various implicit time integration schemes were used to advance the solution in the sub-domains with the interface equations being used as boundaries conditions for the sub-domains- in particular the Dirichlet–Neumann formulation was utilized. Emphasis was given to the accuracy and stability of the partitioned methods. Both loosely and fully coupled partitioned methods were examined. The Backward Euler is unconditionally stable but is only first order accurate, while loosely coupled partitioned methods with implicit multistage RK time integration schemes (i.e. IMEX and ESDIRCK) provide higher accuracy but stability becomes an issue at large time steps. The instabilities can be resolved by using sub-iterations with under-relaxation.

2) Mimetic multi-scale simulation

A mimetic framework is developed for elliptic and hyperbolic problems and convection-diffusion problems. Mimetic schemes make a distinction between topology dependent and metric dependent parts of the problem, which is an important feature in multi-scale modeling. The mimetic framework is combined with a new variant of the spectral element method. First results show that conservation is guaranteed even on highly deformed meshes combined with an exponential convergence. The method results in a finite-volume-like method with spectral accuracy.

Dissertations

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Scientific Publications

-

Efficient Navier Stokes based simulation of non-linear aeroelasticity and validation of the aeroelastic solver by means of experiments

Project Aim

To couple a Navier Stokes based flow solver (RANS) to a non-linear aeroelastic structural model, whereby the main focus is on improving the accuracy of the solution and reduce the computational time in order to enable aeroelastic RANS computations for wind turbines. Furthermore, validation of the aeroelastic solver is a key-issue.

Progress

In the first period of 2009 the focus was on the implementation of solution based mesh adaptation for unsteady flows in the NUMECA flow solver. This work is not finished yet, but will be continued in 2010. After three months the focus was completely on the experiments. Two experiments have been prepared and conducted. The first experiment comprised measurements for the unsteady flow around a fixed wing with a prescribed oscillating flap. In the second experiment the same wing was suspended by a double spring system allowing for free pitch and/or plunge motions of the wing. The motions were fully initiated by the interaction between the flow and the wing with prescribed flap motions. The first experiment is partially post-processed in 2009.

Dissertations

-

Scientific Publications

1. J.J.H.M. Sterenborg, A.H. van Zuijlen, H. Bijl. “Solution based mesh adaptation applied to fluid structure interaction computations”, 47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition, January 2009. AIAA 2009-581.
2. J.J.H.M. Sterenborg, A.H. van Zuijlen, H. Bijl. “Towards Solution Based Mesh Adaptation For Fluid Structure Interactions”, International Conference on Adaptive Modeling and Simulation, ADMOS2009, May 2009. Adaptive Modeling and Simulation 2009, p. 189 – p.192.
3. J.J.H.M. Sterenborg, A.H. van Zuijlen, H. Bijl. “Mesh adaptation for unsteady flows and fluid structure interaction”, International Conference on Computational Methods for Coupled Problems in Science and Engineering, Coupled Problems 2009, June 2009.

Projectleaders

H Bijl

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

JJHM Sterenborg, H Bijl, AH van Zuijlen

Cooperations

Numeca International, ECN, WMC

Funded

SenterNovem, EOSLT-04001 (INNWIND)

1st - 2nd - 3rd 100%

Start of the project

2008

Information

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ENVIRONMENTAL FLUID MECHANICS

Prof.dr.ir. GS Stelling

Prof.dr.ir. WSJ Uijttewaal

The Environmental Fluid Mechanics Group performs fundamental, process-oriented research on fluid flow problems of practical relevance in water management, environmental engineering, hydraulic engineering and coastal engineering. To enhance the potential of practical applications, the section not only aims at writing publications, as far as scientific output is concerned, but also at the production of software that is available via internet. An example is the software package SWAN (Simulating Waves Nearshore). Free surface flow models based upon unstructured grids are in preparation and will be released in coming years. Within this philosophy the research program encompasses the following main items:

- Free surface waves with topics such as: Generation and prediction of squall oscillations and harbour seiches, dynamics of surf beat and the Wave model SWAN
- Shallow flows, transport and sedimentation with the following topics: turbulence and flow structures in rivers and its flood planes, stability and transport under waves and currents of rock elements in cover layers consisting of loose, granular material,
- Transport of suspended particulate matter with topics such as: advanced, experimental and numerical work concerning particle-turbulence interaction as well as flocculation and sedimentation processes
- Numerical model development with topics such as: development of the non-hydrostatic models for the investigation of dam breaks including inundations, short wave problems, near field plume discharges, stratified flows, and local scour near dams, unstructured grids via finite volume methods and finite element methods and development of large scale integrated 1d/2d rainstorm drainage/flooding model applicable to rural and urban areas.

Floc size distribution and settling velocity of cohesive sediment

Project Aim

Cohesive sediments flocculate and generate a distribution of differently sized flocs. The small fraction of this distribution, microflocs, is mainly responsible for light extinction and turbidity while the large one, macroflocs, plays a major role in sediment settling and harbor and waterways siltation. The aim of this research is to investigate the physical and chemical processes leading to flocculation. The effect of all influencing factors such as the physico-chemical properties of the sediment and of the suspension and the hydrodynamic conditions are investigated both numerically and experimentally.

Progress

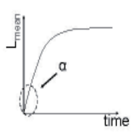
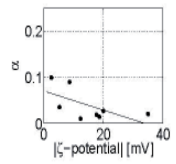
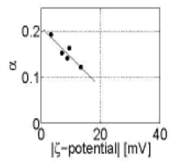
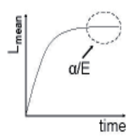
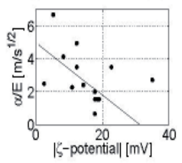
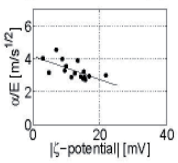
A Population Balance Equation (PBE) has been developed to model the flocculation process. The PBE models the processes of aggregation and breakup and includes two parameters which have been tuned using the results of the jar tests performed in the first part of the project. The values of the parameters α and E tuned for different kaolinite and mud suspensions are shown in Figure 1 as a function of the absolute value of the zeta-potential. The parameter for aggregation α, i.e. the sticking probability of particles after collision, was found to increase with the zeta-potential of the particles decreasing in absolute value. The same trend has been observed for the ratio between the parameters for aggregation and breakup. The zeta-potential is a measure for the charge of the particles: when their charge decreases, particles are more likely to flocculate.

Dissertations

-

Scientific Publications

1. F. Mietta, C. Chassagne and J.C. Winterwerp, 2009. Flocculation of kaolinite by turbulent shear as a function of its electrokinetic properties. Journal of Colloid and Interface Science, 336 (1) pp. 134-141.
2. C. Chassagne, F. Mietta and J.C. Winterwerp, 2009. Electrokinetic study on kaolinite suspensions. Journal of Colloid and Interface Science, 336 (1) pp. 352-359.

Parameter	Derivation	Kaolinite	Western Scheldt mud
α	Initial growth rate 	$\alpha = 0.071 - 0.002 \lvert\zeta\rvert$ 	$\alpha = 0.208 - 0.0065 \lvert\zeta\rvert$ 
α/E	Equilibrium L_{mean} 	$\frac{\alpha}{E} = 5.01 - 0.16 \lvert\zeta\rvert$ 	$\frac{\alpha}{E} = 4.17 - 0.07 \lvert\zeta\rvert$ 

Variation of the parameters with the absolute value of the zeta-potential for kaolinite and mud saline suspensions at pH > 8.

Projectleaders

GS Stelling, JC Winterwerp

Researchtheme

Complex dynamics of fluids

Participants

F Mietta, C Chassagne, JC Winterwerp, GS Stelling, WSJ Uijttewaal

Cooperations

DELTARES

Funded

STW

1st - 2nd 100% 3rd -

Start of the project

2005

Information

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Tsunami modeling with unstructured mesh

Projectleaders
G Stelling
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
Haiyang Cui, JD Pietrzak, GS Stelling
Cooperations
Alfred Wegener Institute for Polar and Marine Research
Funded
Alfred-Wegener-Institute
Water Research Center Delft
1st 50% 2nd - 3rd 50%
Start of the project
2007
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Project Aim

Since the Indian Ocean Tsunami many countries have contributed to the development of tsunami warning systems in the Indian Ocean. A German-Indonesian Tsunami Early Warning System (GITEWS) (www.gitews.de, is currently under active development. One of the aims of this project is the development of accurate numerical models with which to simulate the propagation, flooding and drying, and run-up of a tsunami. This is done not only for forecasting purposes, but also for detailed scenario studies, in order to assess the regions most at risk from future tsunamis.

Progress

An unstructured grid, finite volume ocean model has been developed which can easily be incorporated into the existing TsunAWI code, offering flexibility to the user. The accuracy of the new model has been validated by a series of test cases. A paper about this new model is under writing. Another paper on a scenario study by using the new model, is under preparation.

Dissertations

-

Scientific Publications

-

Surf wave dynamics in the coastal environment

Project Aim

Present state of the art wave models are still insufficiently accurate regarding shallow water dissipation and non-linear interactions in the coastal zone. This project will focus on three main areas; improvement of modelling capabilities of physical processes in the coastal zone, procurement, utilisation and dissemination of high quality datasets and the development, testing and dissemination of new source terms for third generation wave models.

Progress

Research on the improvement of the source terms for triad wave interactions and depth-limited wave breaking are being currently carried out. These are being tested and implemented in the SWAN wave model for calibration and verification. Both the steady and unsteady ONR testbed are being reviewed and updated for utilisation and dissemination. Analysis of spectral evolution will be carried out by the USACE and Shell IEP.

Dissertations

-

Scientific Publications

-

Projectleaders

GS Stelling, G van Vledder,
J Hanson, LH Holthuijsen, K Ewans

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

D Hurdle, M Zijlema, M Christou,
K Hathaway, J Salmon

Cooperations

Alkyon Hydraulic Consultancy & Research, US Army Corps of Engineers, Shell International Exploration and Production

Funded

Office of Naval Research, USA
1st - 2nd - 3rd 100%

Start of the project

2010

Information

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Fine sediment dynamics in the Markermeer

Projectleaders
JC Winterwerp, WSJ Uijttewaal
Researchtheme
Complex dynamics of fluids
Participants
M de Lucas Pardo, JC Winterwerp, WSJ Uijttewaal, T van Kessel
Cooperations
Members of the “Cluster Slib” from DELTARES and within the ANT project. PHD’s team from the ANT project. Cooperation within the BwN project.
Funded
Building with Nature (ECOSHAPE)
1st - 2nd - 3rd 100%
Start of the project
2009
Information
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Project Aim

The objetive of this work is to set up a long-term balance for the suspended fine mineral and organic sediments for the Markermeer. As this is not possible without further understanding of the relevant physical processes (water-bed exchange processes) and the use of a numerical model, a second and third objective of the research is to increase our understanding of water-bed exchange processes, and the set-up of a numerical model of fine sediment in the Markermeer, respectively. A fourth objective is to contribute to the overall understanding of the Markermeer eco-system in a general sense, and to assess measures to reverse the unfavorable trends of the last decades.

Progress

A literature survey about existing descriptions of the Markemeer is being carried out. Also previous research in the cohesive sediments field has been studied. The field campaign to support the research has been prepared within this first stage of the research. When the field campaign will be finished and the sediments from the lake collected flocculation experiments both in Jar Tests and in a settling column will be performed. The preparation for such a set of experiments has been done also since the project started last September. Finally, and due to the collaboration with other institutes and organizations, regular meeting have been attended, towards the embedment of this particular project in a bigger research context.

Dissertations

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Scientific Publications

-

The morphodynamic modeling of intertidal areas

Project Aim

The objective of the project is to improve the morphodynamic modeling of intertidal areas, focusing on model improvement and better model usage. As the morphodynamic and hydrodynamic processes cover a wide range of time and length scales, a multiple-scale approach is required. Typical challenges in model improvement are the proper simulation of velocities in shallow water areas and coupling between hydrodynamics and morphodynamics on the different scales. Processes that steer the morphodynamics are tidal flow, wind-driven flow, waves and wave-induced currents. An analysis of these processes for a specific estuary (like Eastern Scheldt in the Netherlands) will lead to a better model usage. It is aimed to find an optimum in the number of processes included, time and spatial resolution and simulation time to obtain an accurate representation of the morphodynamic evolution of intertidal areas.

Progress

A commencement of a literature study of processes in estuaries, alternative existing, numerical solutions for the multi-scale problem and of flooding and drying procedures is being made. Time is also used to understand the subtleties of the new sub-grid method of Casulli 2008 including an afterthought of GS Stelling. This is currently being implemented in a shallow water solver and will be applied in several test cases.

Dissertations

-

Scientific Publications

-

Projectleaders
G Stelling

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
ND Volp, BC van Prooijen

Cooperations
NIOO, Deltares, Rijkswaterstaat

Funded
Building with Nature
1st - 2nd - 3rd 100%

Start of the project
2009

Information
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Coastal ocean modeling

Projectleaders
GS Stelling, JD Pietrzak
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
O Kleptsova, JD Pietrzak, GS Stelling
Cooperations
-
Funded
Speerpunt Water
1st 100% 2nd - 3rd -
Start of the project
2005
Information
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Project Aim

The project aims to develop a new coastal model based on unstructured grids. The model is to be suitable for the investigation of flow phenomena, such as the development and behavior of river plums and associated transport processes in the Dutch and other coastal zones. New discretization of the shallow water equations are being developed and deeper insight gained into the numerical properties and modeling capabilities of this new class on models.

Progress

New Eulerian advection scheme is developed. While imposing a restriction on the time step, this scheme conserves momentum also in the cells containing the free surface. In the 2Dcase the conservation of momentum is achieved automatically. However, special attention is required in the multilayer case, where a vertical structure of the flow can be erroneously introduced. This scheme is suitable for simulation of such phenomena as flooding and drying in the presence of multiple z-layers. Accurate simulation of flooding and drying are important for dam break problems and tsunami simulations.

Dissertations

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Scientific Publications

1. O. Kleptsova, J. D. Pietrzak, and G. S. Stelling. On the accurate and stable reconstruction of tangential velocities in C-grid ocean models. OCEAN MODELLING, 28(1-3, Sp. Iss. SI):118–126, 2009.

A SPECTRAL SHALLOW-WATER WAVE MODEL WITH NONLINEAR ENERGY- AND PHASE EVOLUTION

PROJECT AIM

The project aim is to develop a conceptual extension of spectral energy wave models with a spectral phase evolution to model diffraction and triad wave-wave interactions. Applications require an extreme flexibility in spatial resolution which can be achieved with unstructured computational grids. The first application of such a grid is a coupling with the ocean circulation model ADCIRC to improve the hurricane prediction capability for New Orleans.

PROGRESS

Marcel Zijlema has made SWAN applicable for unstructured grids and the code has been released to the public domain. Since november 2008, Pieter Smit has studied the conceptual and numerical options to extend SWAN with a spectral phase evolution equation. Presently the most promising alternative is being investigated for monochromatic waves in situations of combined refraction and diffraction.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Zijlema, M, “Multiscale Simulations Using Unstructured Mesh SWAN Model for Wave Hindcasing in the Dutch Wadden Sea”, Proceedings Int. Conf. Coastal Dynamics 2009, Tokio, World Scientific, Paper No. 2: 1-12.
2. Zijlema, M, 2009, “Application of UnSWAN for wave hindcasting in the Dutch Wadden Sea”, Proceedings 11th Int. Workshop on Wave Hindcasting and Forecasting Oct 2009, Halifax.

PROJECTLEADERS
LH Holthuijsen, GS Stelling

RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis

PARTICIPANTS
GS Stelling, LH Holthuijsen, M Zijlema, N Booij, RJ Labeur, PB Smit

COOPERATIONS
University of Notre Dame, Indiana, United States of America

FUNDED
Office of Navel Research.
1st - 2nd - 3rd 100%

START OF THE PROJECT
2006

INFORMATION

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Non-hydrostatic modelling of geophysical flows by a stabilized finite element method

Projectleaders
G Stelling
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
RJ Labeur, GN Wells
Cooperations
Svasek BV
Funded
TUD
1st 100% 2nd - 3rd -
Start of the project
2001
Information
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Project Aim

Development of a finite element flow model for practical computation of the water motion through or around hydraulic engineering structures such as weirs, sluices, harbor dams or outfalls. As these objects may have complex geometries, the finite element method, which allows a high degree of grid flexibility, is particularly useful. Typically, the associated types of flow have small length scales and significant vertical velocities. Hence, the full non-hydrostatic pressure has to be taken into account while also detailed processes such as turbulent dissipation should be included.

Progress

Finilization and publication of dissertation.

Dissertations

1. Dissertation RJ Labeur, June 2009: "Finite element modelling of non-hydrostatic flow and transport in environmental fluid mechanics".

Scientific Publications

1. Labeur, R.J. and G.N. Wells (2009) Interface stabilised finite element method for moving domains and free surface flows. Computer Methods in Applied Mechanics and Engineering 198, pp. 615-630.

Bed and form resistance in rivers at high water stages

Project Aim

The river flow within flood planes is difficult to forcast because of the complex flow geometry founded by main channel and groyne fields. In the flood plane there are many obstacles and landforms, which requires high demand for numerical modeling. Due to large computational domain and limitation of computer capacity, complete details can generally not be resolved. This study focuses on correct representation of resistance elements in a numerical simulation and consistent behavior towards high water stages. A number of prosesses related to vegetation, weirs and bed- forms will be studied in great detail in order to come to an improved implementation of physical processes.

Progress

A Literature study about the current modeling approach and their perfomances is being carried out.The energy head loss due to submerged and emerged vegetated dikes and groynes has been modeled by The expansion loss form drag model and has been compared with the experimental data.A series of Experiments has been performed in the Laboratory of Environmental Fluid Mechanics of Delft University of Technology. In these experiments blockage due to vegetation has been varied and different shapes of vegetation and groynes have been tested. New Experiments are in progress to investigate the structure of the flow over the oblique vegetaed groynes and other complex phenomena related to it .

Dissertations

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Scientific Publications

1. Ali, S., Uijttewaal, W.S.J. (2009). “Form drag due to vegetated weir-like obstacles interpreted as expansion losses” Proceedings of the 33rd IAHR Congress on water engineering for sustainable environment, Vancouver, British Columbia, Canada.

Projectleaders

WSJ Uijttewaal, GS Stelling

Researchtheme

Complex dynamics of fluids

Participants

Shahid Ali

Cooperations

Deltares, Ministry of Transport, Public Works and Water Management

Funded

NUFFIC

1st - 2nd - 3rd 100%

Start of the project

2007

Information

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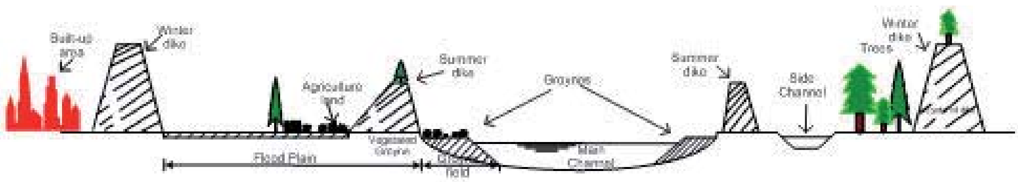
A typical cross section of the lowland rivers in the Netherlands



Development of a quasi-3D morphodynamic model and its application to meander processes at high curvature

Projectleaders
HJ de Vriend, WSJ Uijttewaal
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
W Ottevanger, K Blanckaert, CJ Sloff
Cooperations
Deltares (Netherlands), EPFL (Switzerland), IGB (Germany)
Funded
STW (NWO)
1st - 2nd 100% 3rd -
Start of the project
2008
Information
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Project Aim

Development of a quasi-3D morphodynamic model which is valid for sharply curved river bends, such that high spatial and temporal scales may be simulated. Subsequently, the quasi-3d model will be be validated using laboratory and field measurements, as well as more detailed software models (LES, RANS), Finally the model will be used for fundamental research into the processes (momentum redistribution, secondary flow, bank and bed shear stresses) and the dynamics (river bed adaptation, bank erosion and accretion, planform development) of meandering rivers (at high curvature).

Progress

Implementation and validation of a 1D non-linear meander flow model with a laboratory and a field case valid for sharply curved flows. Presently a 1D non-linear equation for the adaptation of the transverse bed-slope is being developed also valid for high curvature . Combined with the previous flow model and a model for bank erosion and accretion model this will lead to a 1D meander model which is valid at high curvature.

Dissertations

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Scientific Publications

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An environmental fluid dynamics laboratory in the field: river flow and meandering

Project Aim

The research project aims at a better understanding and prediction of shallow shear flows under conditions that are relevant for natural rivers. To that end the step has to be made towards high Reynolds numbers and towards field measurements. An important aspect of this project is the application of measurement techniques in the field for obtaining information about the flow structures. It is intended to generate a data-set for model validation which includes turbulence properties and bed forms.

Progress

Field experiments were perfomed on submerged groynes. This has resulted in a data-set which is now available for a detailed analysis. Parallel to the data analysis a start has been made with the numerical modelling which requires state of the art techniques. New experiments were executed on river bends in Italy and Germany showing the importance of secondary circulation in relation to the bend curvature.

Dissertations

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Scientific Publications

1. Blanckaert, KJF, Schnauder, I, Sukhodolov, A, Balen, W van & Uijttewaal, WSJ (2009). Meandering: Field experiments, laboratory experiments and numerical modeling. In CA Vionnet, MH Garcia, EM Latrubesse & GME Perillo (Eds.), Proceedings of the 6th IAHR symposium on river, coastal and estuarine morphodynamics (RCEM 2009), Santa Fe, Argentina (pp. 863-875). Leiden: CRC Press/Balkema.

Projectleaders
WSJ Uijttewaal

Researchtheme
Complex dynamics of fluids

Participants
KJF Blanckaert, W Ottevanger, W van Balen

Cooperations
IGB-Berlin Germany

Funded
NWO
1st - 2nd 100% 3rd -

Start of the project
2009

Information

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Large-eddy flow simulation for the prediction of bank erosion and transport processes in river bends

Projectleaders
WSJ Uijttewaal, GS Stelling, K Blanckaert
Researchtheme
Complex dynamics of fluids
Participants
W van Balen
Cooperations
EPF Lausanne, Switzerland
Funded
STW
1st - 2nd 100% 3rd -
Start of the project
2005
Information
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Project Aim

The research program aims at gaining insight into the physics of bend flows and improving engineering tools, by means of a combined experimental-numerical (EPF Lausanne – TU Delft) research methodology. Main goals of the numerical part (LES) are the completing of the data from the experimental part (pressure fields and shear stresses), the broadening of the parameter space (mainly towards physical relevant geometries, like rivers) and the investigation and parameterisation of the results.

Progress

The present research on curved open-channel flows finished recently. Many simulations have been performed of these kind of flows, for many geometric and hydraulic conditions. The focus of the research has mainly been on features of the secondary flow, the bed shear stresses and turbulence. The simulations were of the LES-type and were conducted using a finite-volume numerical code with an Immersed Boundary Method incorporated to be able to deal with complex geometries (see figure 1). The results have extensively been validated with experimental data and have led to a broad image of curved open-channel flows in general. This, hereby, also facilitates further development of sound physics-based parameterizations of key bend flow phenomena.

Dissertations

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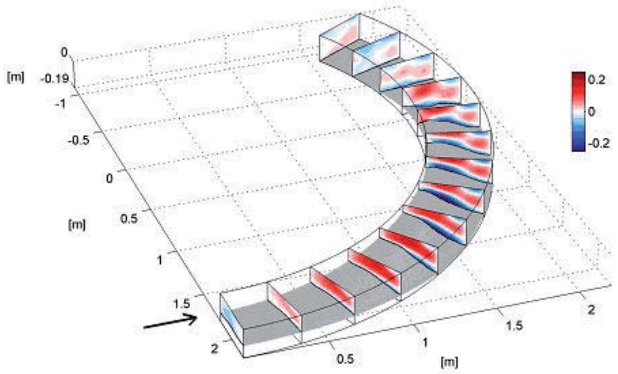
Scientific Publications

1. W. van Balen, W.S.J. Uijttewaal and K. Blanckaert (2009), Large-eddy simulation of a mildly curved open-channel flow, J. Fluid Mech. 630, pp. 413 - 442.
2. W. van Balen, K. Blanckaert and W.S.J. Uijttewaal (2009), Analysis of the role of turbulence in curved open-channel flow at different water depths by means of experiments, LES and RANS, conditionally accepted by J. Turbulence.
3. W. van Balen, W.S.J. Uijttewaal and K. Blanckaert (2009), A parameter study on curved open-channel flows by means of experiments and large-eddy simulations, submitted to J. Geoph. Res.
4. W. van Balen, W.S.J. Uijttewaal and K. Blanckaert (2009), Large-eddy simulation of a curved open-channel flow over topography, submitted to Phys. Fluids.

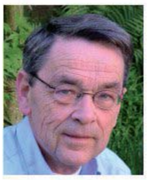


Curved open-channel flow over topography: time-averaged transverse velocities in meters per second, visualizing the secondary flow motion development along the flume.

Mesoscopic Transport Phenomena

Prof.dr.ir. AA Darhuber

Prof.dr.ir. F Toschi



Prof.dr.ir. MEH van Dongen (em)

In 2006 prof. M.E.H. (Rini) van Dongen retired as head of the research group Gas Dynamics and obtained emeritus status. In 2007 prof. Anton Darhuber was appointed as his successor. Prof. A. (Mico) Hirschberg was interim leader of the group Gas Dynamics in 2006 and 2007. On January 1, 2008 the research group Gas Dynamics was officially renamed into Mesoscopic Transport Phenomena (MTP). On January 1, 2009 the head of the group Low-Temperature Physics (LTE) prof. A.T.A.M. (Fons) de Waele retired and LTE became a part of MTP. Therefore, currently three major lines of research coexist in MTP: the first corresponds to the activities of the former group Gas Dynamics, i.e. research on aero-acoustics and condensation phenomena; the second involves fluid dynamics at small lengthscales, where interfacial typically dominate over inertial effects. The third corresponds to the activities of the former group Low-Temperature Physics, i.e. research on thermo-acoustics.

In September 2008, prof. Federico Toschi was appointed professor in the Department of Applied Physics and became a member of MTP. He is working in the field of statistical physics, fluid dynamical turbulence and micro-/nanofluidics. In February 2009, Jens Harting was appointed Assistant Professor in the group MTP. His expertise rests with large-scale Lattice Boltzmann simulations of suspension dynamics as well as micro- and meso-scale flows.

The research activities related to gas dynamics concern the study of wave phenomena in gases. Aero-acoustics is the study of the interaction between sound and flows. The research concerns the study of wave generation by elementary processes in flows, with the focus on confined flows and sound generation by vortices. This work has many important industrial applications. Condensation phenomena are studied using gas-dynamical devices such as expansion wave tubes to obtain fundamental information about the physics of nucleation and droplet growth in complex gas mixtures. This involves the development of models for the properties of molecular clusters in the nanometer range at extreme conditions far below the freezing point, for which bulk liquid properties are unknown.

Research in the area of micro- and nano-fluidics comprises both fundamental and application-inspired topics ranging from fluid physics at nano-scales to manufacturing processes of optoelectronic devices. Current and commencing projects concern dip- and die-coating of chemically patterned substrates, flows driven by temperature and concentration gradients, as well as flows involving phase changes.

Research activities of the former group LTE concern pulse-tube refrigeration, thermoacoustics, and vortex cooling. These topics have a common thermodynamic and hydrodynamic background. They provide cooling without moving parts in the cold regions of the system. All topics address new physical questions in gas dynamics with the aim of unraveling basic working principles.

Non-equilibrium condensation in real gases

Project Aim

The formation (nucleation) and growth of droplets in high-pressure natural gas-like mixtures is studied in an expansion wave tube facility. In this facility nucleation and droplet growth are separated in time, which enables an accurate determination of nucleation rates and droplet growth rates. Knowledge about these processes is relevant for condensate separation in natural gas.

Progress

The project has formally ended with the thesis defense by V. Holten in December 2009. Some additional publications are in preparation.

Dissertations

1. Vincent Holten, Water Nucleation-Wave tube experiments and theoretical considerations, PhD thesis, Technische Universiteit Eindhoven, 2009.

Scientific Publications

1. V. Holten and M.E.H. van Dongen, Comparison between solutions of the general dynamic equation and the kinetic equation for nucleation and droplet growth, J. Chem. Phys., 130, 014102, 2009.

Projectleaders
AA Darhuber, MEH van Dongen

Researchtheme
Complex dynamics of fluids

Participants
MEH van Dongen, V Holten,
A Hirschberg

Cooperations
ITM-CAS-Prague, Un. Twente-Dept of Eng. Technology

Funded
STW, TU/e
1st 25% 2nd 50% 3rd 25%

Start of the project
2002

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PROJECTLEADERS
AA Darhuber, F Toschi

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
A.Hirschberg, M.E.H.van Dongen, B. Sleutjes, H.Duric(Philips),X.Pelorson (IPG, Fr), A.M. Van Hirtum (IPG, Fr), F.M.R. van Uittert, J.F.H.Willems.

COOPERATIONS
Institut Polytechnique de Grenoble (IPG,Fr), Université du Maine (Le Mans, Fr), RUG, Philips, University of Southampton (UK).

FUNDED
CNRS
1st 100% 2nd - 3rd -

START OF THE PROJECT
1998

INFORMATION
A Hirschberg
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PROJECT AIM

Using in-vitro experiments we study the effects of the interaction between air flow and oscillations of flexible walls at conditions relevant for speech and cough. Goal is the development of physical models which can support the diagnostics of pathologies by means of signal analysis.

PROGRESS

The focus of the current reseach is on the modeling of fricative sounds and the monitoring of respiratory sounds for clinical applications.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

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Flow-induced pulsations in gas transport systems : prediction, prevention and influence on volume flow measurements

Project Aim

The quantitative prediction of unsteady shedding of vortices in confined flows and of the interaction of these vortices with acoustic waves. Prediction of self-sustained flow-instabilities in high-pressure gas transport systems and the impact of such instabilities on volume-flow measurements. Recently the focus of the project has shifted to fundamental aspects of the design of mufflers and the whistling of corrugated pipes. Main focus is the detailed modelling of the flow at corrugations. Applications range from musical toys to oscillation in water level of rivers with groynes.

Progress

Within the frame work of the European project Aether, the study of G.Kooijman on grazing flow along perforated walls has been extended to the case of mixed grazing-bias flow. Also the aero-acoustical response of complex pipe systems has been considered, The focus has been on a multiple side-branch system with up to 20 side-branches. Within the framework of a new STW project [initiated in october 2008] the whistling of a multiple side-branch system with shallow cavities has been considered as a model for a corrgated pipe. In addition experiments with a shallow water analogy have been initiated.

Dissertations

-

Scientific Publications

1. Testud P., Auregan Y., Moussou P. & Hirschberg A. , The whistling potentiality of an orifice in a confined flow using an energetic criterion, J. Sound and Vibration, 325, 769-780 (2009).

Projectleaders

AA Darhuber, F Toschi

Researchtheme

Complex dynamics of fluids

Participants

A Hirschberg, MEH van Dongen, HWM Hoeijmakers, D Tonon, G Nakiboglu, E Sauvage, JFH Willems, FMR van Uittert, P Testud (EDF), Y Auregan (LAUM)

Cooperations

Gasunie, TNO-TPD, Shell, NLR, Nmi, UT, UT, VKI, Philips, Elster-Instromet, EDF, LAUM, (Universite du Maine, fr), LMS (Be), University of Cambridge, CErfacs (Fr), TU Munchen, KU Leuven, LTU (Lulea, Sw), IST (Lisbon, Pt), Rolls Royce (UK), Alstom (Ch), Polyu (Hong Kong).

Funded

STW and European Community (Marie Curie)

1st 20% 2nd 50% 3rd 30%

Start of the project

2002

Information

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Blood in motion

Projectleaders
F Toschi, J Harting
Researchtheme
Complex dynamics of fluids
Participants
F Toschi, J Harting, F Janoschek, F Mancini (guest MSc student)
Cooperations
ACB Bogaerds, FN van de Vosse (Biomed. eng.); PD Anderson, HEH Meijer (Mech. eng.)
Funded
TU/e High Potential Research Program (2009)
1st 100% 2nd - 3rd -
Start of the project
2009
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Project Aim

Blood may be treated as a dense suspension of red blood cells in blood plasma. Typical length scales vary over several orders of magnitude. Current computational models treat blood as a homogeneous fluid or model a limited number of cells at high resolution. Our aim is to bridge the gap between both approaches with a simplified yet still particulate method of high efficiency. We will develop phenomenological cell-cell and cell-wall interaction models based on experimental and numerical work done by other groups on the single-cell level and provide a link to flow properties at larger scales which might be used to improve continuous blood models.

Progress

During the starting phase of the project we established links to our cooperation partners at TU/e and potential further collaboration partners at UC London and IAC Rome. We introduced the project to the scientific community at conferences in the Netherlands and abroad. At the same time, we successfully applied for a DECI-5 computing time grant and enabled our existing simulation code to scale up to fractions of millimeters on massively parallel supercomputers. Large numbers of cells are crucial in order to obtain statistically relevant information. Later on, we analyzed the shear-rate dependency of bulk properties like the nematic order of cells and the viscosity for a preliminary suspension with purely repulsive interaction potentials. The next steps consisted in the development of an appropriate additional attractive interaction which accounts for cell aggregation. The implementation and comparison of different attraction models is part of our current work.

Dissertations

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Scientific Publications

-

Lattice-Boltzmann methods for contact line dynamics

Project Aim

The project aims at the development, validation and use of the lattice-Boltzmann method for the simulation of various geometries where contact line dynamics is relevant. These problems arise due to the complex geometric structure of the geometry, like in the immersion lithography and the ink-jet printhead.

Progress

The literature related to the lattice-Boltzmann method, wetting and dewetting phenomenon and contact angle has been reviewed. A 2-dimensional lattice Boltzmann code has been developed and tested for simple flow cases, e.g. Poiseuille flow and contact angle determination at the solid-liquid-vapor contact.

Dissertations

-

Scientific Publications

-

Projectleaders
F Toschi
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
S Srivastava
Cooperations
ASML, Océ
Funded
FOM
1st - 2nd 100% 3rd -
Start of the project
2009
Information
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Population dynamics in turbulent flows

Projectleaders
F Toschi

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
P Perlekar, F Toschi

Cooperations
Prof. R. Benzi, Prof. D.R. Nelson, Prof. M. Jensen.

Funded
TUE
1st 100% 2nd - 3rd -

Start of the project
2009

Information
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Project Aim

Population dynamics deals with the study of birth, death and growth processes of biological species. These processes are severely affected by the local ecosystems, by the presence of nutrients, and by the local population density. Turbulence is normally known to increases mixing and diffusion; but, remarkably, population dynamics in a turbulent environment shows the localization (e.g. patchy regions of planktons on the ocean surface). The aim of the present project is to study the interplay of these two mechanisms to understand population dynamics of species in turbulent environments.

Progress

We have completed a study of population dynamics of single specie in a turbulent surface flows. Our study clearly brings out the role of turbulence on the patchiness of the turbulent population (see Fig. 1). The next step is to understand how mutation and fixation in population dynamics is effected by presence of turbulence.

Dissertations

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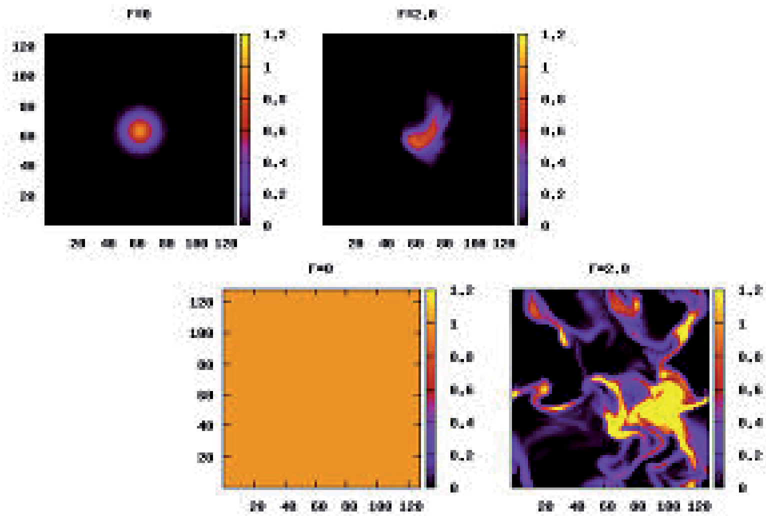
Scientific Publications

-

(Top frame) Initial population evolution (L: No flow, R: Turbulent flow); (Bottom frame) Steady state population distribution (L: No flow, R: Turbulent flow).



The vortex tube as a tool in sustainable energy production

Project Aim

Developing a vortex tube swirling flow system to separate condensate out of gas flow.

Progress

This project has just started end of 2009. We are currently working on development of the measurement equipment and analyzed the effect of swirling flow on droplets with a simple modeldescription.

Dissertations

-

Scientific Publications

-

Projectleaders

J Zeegers

Researchtheme

Complex dynamics of fluids

Participants

R Liew, J Zeegers

Cooperations

.....

Funded

1st - 2nd 80% 3rd 20%

Start of the project

2009

Information

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MICROCOOLER

PROJECTLEADERS
J Zeegers, HJM ter Brake
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
Y Li, J Zeegers, HJM ter Brake
COOPERATIONS
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FUNDED
MicroNed
1st - 2nd 100% 3rd -
START OF THE PROJECT
2005
INFORMATION
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PROJECT AIM

Design, analysis and development of a small scale thermoacoustic traveling wave cooler.

PROGRESS

In 2009 the general model analysis of the acoustics in the cooler has been finished. Start was made with the design of an experimental system. After the design was completed drawings have been made of the engine itself by our engineers. The central workshop services of TU/e have constructed a thermoacoustic cooler system which was being tested in the past months. The PhD is writing the thesis, and relevant papers. Now a measurement programme with the cooler is implemented and evaluation and comparison with models of the cooler system is to be expected before july 2010.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

-

Engineering the morphology of organic (semi-)conductor layers

Project Aim

The investigation and optimization of the hydrodynamics of die-coating to fabricate active layers of organic light emitting diodes (OLEDs) of uniform thickness and composition based on solution-processing. Means to enhance the influence of surface energy patterns at high coating speeds will be explored as well as methods for mitigation and elimination of evaporation-driven material redistribution.

Progress

Experiments re. evaporation of nominally pure liquids on chemically patterned surfaces were conducted and results agree qualitatively with numerical simulations. Numerical simulations have been performed to calculate the evaporative flux in the gas phase using a prescribed height profile and in the liquid phase to obtain the dynamic evolution of the height profile with a prescribed evaporative flux. A self-consistent simulation coupling both domains is in progress. We conducted experiments regarding dip- and die-coating of chemically patterned surfaces. We performed numerical simulations regarding the dewetting dynamics on these surfaces to study the influence on film thickness homogeneity over large areas. So far a qualitative correspondence with experimental results has been achieved.

Dissertations

-

Scientific Publications

-

Projectleaders
AA Darhuber

Researchtheme
Complex dynamics of fluids

Participants
AA Darhuber, BJ Brasjen, JA Vieyra Salas

Cooperations
Holst Centre Eindhoven

Funded
DPI
1st 25% 2nd - 3rd 75%

Start of the project
2007

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Energy and light - how microfluidics can make a difference
Subproject: surfactant-assisted enhanced oil-recovery

Projectleaders
AA Darhuber
Researchtheme
Complex dynamics of fluids
Participants
AA Darhuber, J Zeegers, J Harting, M Hanyak, D Sinz.
Cooperations
Shell International Exploration and Production B.V.
Funded
STW
1st 25% 2nd 65% 3rd 10%
Start of the project
2008
Information
AA Darhuber
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Project Aim

Systematic investigation and modeling of the surfactant induced flows at micro- and nanoscales. Quantification of the spreading dynamics of surfactants on liquid films in various geometries, ranging from simple test cases to natural porous media. Development of strategies how to use surfactants to increase oil recovery rates.

Progress

Using both experiments and numerical simulations, we studied surfactant spreading on thin liquid films deposited on chemically patterned surfaces. On liquid rivulets, upon which a droplet of surfactant is deposited, a rim develops in the rivulet height profile that is moving away from the deposited surfactant droplet. It is located just behind the leading edge of the surfactant, and to good approximation the rim position x_rim(t) follows a power law behavior x_rim ~ t^b, where the spreading exponent b quantifies the displacement efficiency of a given surfactant. Experiments conducted for both soluble and insoluble surfactants are in semi quantitative agreement with the numerical simulations.

Dissertations

-

Scientific Publications

-

Dewetting of ultrathin water layers on hydrophobic surfaces

Project Aim

The aim of this project is to study the physics of dewetting of submicron thick aqueous layers on partially wetting surfaces. Such thin water layers can arise from viscous entrainment when moving a meniscus at speeds exceeding ~0.5 m/s e.g. over a photoresist covered silicon wafer in the context of immersion lithography as is currently being developed by ASML. The evaporation of these films causes technological difficulties, as cooling due to the large latent heat of evaporation of water leads to inhomogeneous thermal contractions of the wafer that diminish the desired overlay accuracy in the few nm range. At the focus is the question whether the dewetting and break-up process of the water layer into droplets can be influenced regarding the size distibution and arrangement of the resulting droplets.

Progress

A literature survey is in progress, first numerical simulations regarding spontaneous break-up dynamics of model liquids have been performed. First steps towards controlled experiments have been taken.

Dissertations

-

Scientific Publications

-

Projectleaders

AA Darhuber

Researchtheme

Complex dynamics of fluids

Participants

AA Darhuber, J Zegers, C Berendsen

Cooperations

ASML, Océ

Funded

FOM

1st - 2nd 100% 3rd -

Start of the project

2010

Information

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Composite stacked organic semiconductors: materials processing towards large area organic electronics

Projectleaders
AA Darhuber
Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
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Dick Broer and Cees Bastiaansen, Dept. of Chem. Eng. & Chemistry, TU/e, N. Stingelin-Stutzman, Imperial College, London, UK
Funded
DPI
1st - 2nd - 3rd 100%
Start of the project
2009
Information
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Project Aim

Characterization and optimization of solution-based growth of organic semiconductor crystals.

Progress

We investigated of the morphology of solution-based crystal growth in the vicinity of receding contact lines of a volatile solvent. We systematically study the influence of coating speed, solution concentration and evaporation conditions and were able to support the experimental results by scaling relations.

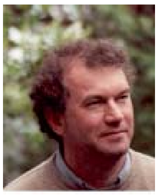
Dissertations

-

Scientific Publications

-

Vortex Dynamics and Turbulence



Prof.dr.ir. GJF van Heijst

Prof.dr. HJH Clercx

Prof.dr. H Kelder

Prof.dr.ir. BJ Geurts

The research in this section concerns transport phenomena, in particular as occurring in turbulent flows. An important line of approach is that vortex dynamics, in which elementary processes are studied in rather isolated configurations. Special attention is given to the influence of body forces associated with background rotation and density stratification. Such situations are met in industrial settings and also within the framework of geophysical fluid dynamics. In addition to transport in turbulent flows, the dynamics of granular media and 3D viscous mixing is studied.

The following main lines of research can be distinguished:

1. Spectral and transport properties of 3D turbulence
2. Dispersion in quasi-2D turbulence
3. Atmospheric physics
4. Granular media and viscous mixing

In most of these themes the research approach is a combination of laboratory experiments, numerical simulation, and theoretical modelling.

Lagrangian dispersion in geophysical flows

Project Aim

It is the aim of this research project to develop a better insight in the role of stratification on fluid particle dispersion by direct numerical simulation of forced stratified turbulence with constant mean background density gradient. Additionally, the role of the dispersion of either heavy (aerosols) or light (plankton) inertial particles in forced stratified turbulence will be investigated.

Progress

This project has been finished with the thesis by M. van Aartrijk (Oct. 2008).

Dissertations

-

Scientific Publications

1. Aartrijk, M. van, Clercx, H.J.H. - Dispersion of heavy particles in stably stratified turbulence. Phys. Fluids, 21(3), 033304-1/14 (2009).
2. Aartrijk, M. van & H.J.H. Clercx, Forces on light particles in stratified turbulence, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 501-504, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).

Projectleaders

GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme

Complex dynamics of fluids

Participants

HJH Clercx, M van Aartrijk, A Dominquez-Guadarrama, W Kramer

Cooperations

Prof V Armenio (Univ. Trieste, Italy), Prof E Meiburg (UCSB, USA), Dr KB Winters (Scripps, USA).

Funded

NWO-VICI

1st - 2nd 100% 3rd -

Start of the project

2004

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PROJECTLEADERS
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts

RESEARCHTHEME
Complex dynamics of fluids

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LPJ Kamp, RR Trieling,
RAD Akkermans, AR Cieslik

COOPERATIONS
Prof DC Montgomery (Dartmouth College, USA), Dr MG Wells (Yale, USA)

FUNDED
FOM
1st - 2nd 100% 3rd -

START OF THE PROJECT
2005

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PROJECT AIM

It is the aim of this research project to develop a better insight in the spectral and transport properties of quasi-two-dimensional flows, the dynamics of vortices in shallow fluid layers, and the effects of domain boundaries (solid walls) on (quasi-)2D turbulence. For this purpose, substantial effort will be put in the further development of sophisticated flow measurement techniques such as high-resolution PTV and stereo-PIV.

PROGRESS

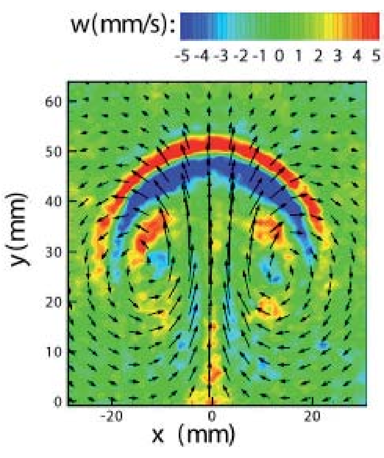
Recent experiments on a dipolar vortex in a homogeneous shallow fluid layer have shown complex 3D structures during the generation stage and during its subsequent evolution. In the last year we have focused on the same vortex flow, but now in a stable two-layer configuration, which was believed to be an improvement over the single-layer setup. Experimentally, Stereoscopic-PIV is used to measure all three components of the velocity field in a horizontal plane and 3D numerical simulations provide the 3D velocity and vorticity fields over the entire flow domain. Remarkably, the experimental results, supported by numerical simulations, show to a large extent the same 3D structures and evolution as previously seen in the single-layer case.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Cieslik, A.R., R.A.D. Akkermans, L.P.J. Kamp, H.J.H. Clercx & G.J.F. van Heijst - Dipole-wall collision in a shallow fluid, Eur. J. Mech. B/Fluids, 28, 397-404 (2009).
2. Clercx, H.J.H. & G.J.F. van Heijst -Two-dimensional Navier-Stokes turbulence in bounded domains, Appl. Mech. Rev., 62, 020802-1/25 (2009).
3. Heijst, G.J.F. van & H.J.H. Clercx – Studies on quasi-2D turbulence – the effect of boundaries, Fluid Dyn. Res. 41, 064002-1/18 (2009).
4. Akkermans, R.A.D., L.P.J. Kamp, H.J.H. Clercx & G.J.F. van Heijst, The 3D structure of a dipole in a shallow two-layer fluid, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 289-292, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).



Dipolar vortex in a two-layer fluid after the forcing has stopped. Measurement at mid-depth of the top layer (vectors: horizontal velocity, colour: vertical velocity).

The sling-effect: droplets in turbulence

Project Aim

To study the dynamical behaviour of droplets in a turbulent flow by using droplets that are tagged through phosphorescence. A zero-mean flow turbulence device will be constructed and the statistics of small-scale preferential concentration will be measured.

Progress

The project started 1 October 2009. The laser-induced tagging technique has been successfully applied.

Dissertations

-

Scientific Publications

-

Projectleaders
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts

Researchtheme
Complex dynamics of fluids

Participants
GJF van Heijst, W van de Water,
H Bocanegra-Evans

Cooperations
NJ Dam

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2009

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Passive tracer transport in confined rotating turbulence

Projectleaders
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts
Researchtheme
Complex dynamics of fluids
Participants
HJH Clercx, GJF van Heijst,
RR Trieling, LJA van Bokhoven
Cooperations
Prof C Cambon (ENS Lyon, France),
Prof A Tsinober (Univ. Tel Aviv,
Israel).
Funded
FOM
1st - 2nd 100% 3rd -
Start of the project
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Project Aim

The aim of this research project is the numerical and experimental investigation of the statistical properties of turbulence with high background rotation. In the experiments the confined turbulent flow will be generated by electromagnetic forcing and its characteristics will be investigated by means of a series of SPIV measurements at different rotation rates. The numerical investigations are focussed on the role of background rotation on vorticity statistics.

Progress

In This project has been concluded with the PhD thesis by L.J.A. van Bokhoven (Nov. 2007).

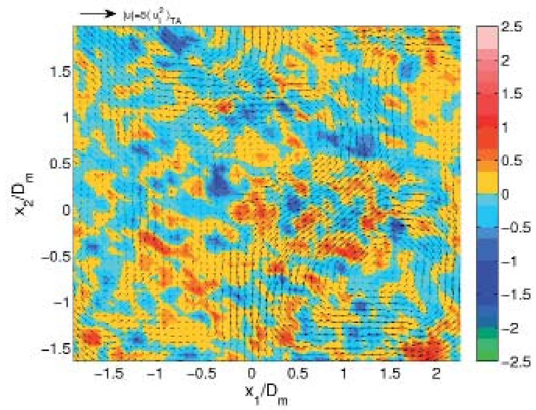
Dissertations

-

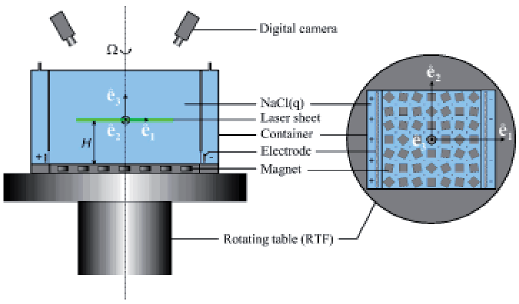
Scientific Publications

1. Bokhoven, L.J.A. van, H.J.H. Clercx, G.J.F. van Heijst & R.R. Trieling – Experiments on rapidly rotating turbulent flows, Phys. Fluids 21, 096601 1-20 (2009).
2. Heijst, G.J.F. van & H.J.H. Clercx - Laboratory modelling of geophysical vortices, Ann. Rev. Fluid Mech., 41, 143-164 (2009).

Snapshot of turbulent velocity field. Rotation rate is 10 rad/sec. Vectors show normalized in-plane turbulent velocity and colours show normalized out-of-plane turbulent velocity.



Side and top view of the experimental setup. Turbulence is generated in the central compartment of the container using electromagnetic forcing.



How to stir turbulence

Project Aim

The best way to create homogeneous and isotropic turbulence in a wind tunnel is through using a grid. However, the achievable Reynolds numbers are small. Much stronger turbulence can be reached through active grids. Active grids are ideally suited to modulate turbulence in space-time and offer the exciting possibility to tailor turbulence properties by a judicious choice of the space-time stirring protocol.

Progress

Homogeneous shear turbulence (HST) is characterized by a constant gradient of the mean velocity and a constant turbulence intensity. It is the simplest anisotropic turbulent flow thinkable, but can not be generated easily. We describe a technique for generating HST using an active grid only. Our active grid consists of a grid of rods with attached vanes which can be rotated by servo motors. We control the grid by prescribing the time-dependent angle of each axis. As a further application of this idea we demonstrate the generation of a simulated atmospheric boundary layer in a wind tunnel which has tunable properties. This method offers a great advantage over the traditional one, in which vortex-generating structures and roughness elements need to be placed in the wind tunnel.

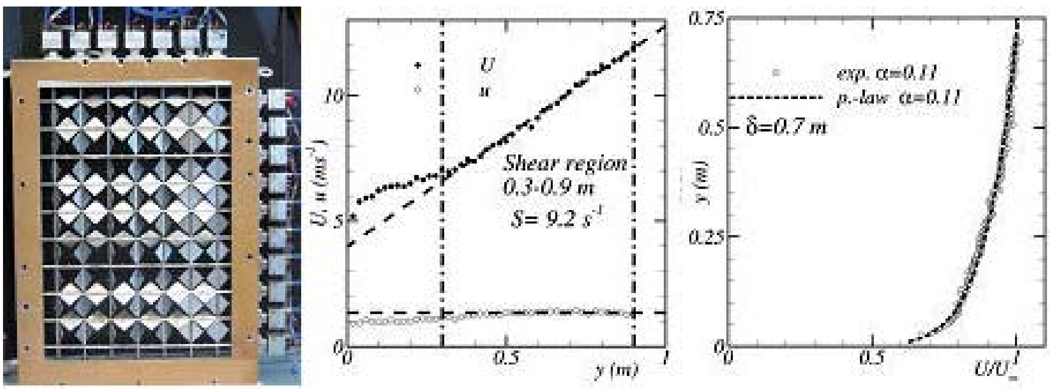
Dissertations

-

Scientific Publications

1. Cekli, H.E. & W. van de Water, Response of periodically modulated turbulence, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 237-240, Editor: B. Eckhardt (Springer),7-10 September Marburg, Germany (2009).

Left: A photograph of the active grid. Middle: HST, mean velocity and turbulent fluctuating velocity profiles. Right: The simulated atmospheric boundary layer.



Projectleaders

GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme

Complex dynamics of fluids

Participants

GJF van Heijst, W van de Water, HE Cekli

Cooperations

-

Funded

FOM

1st - 2nd 100% 3rd -

Start of the project

2007

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PROJECTLEADERS
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H Kelder, BJ Geurts
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
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LPJ Kamp, RR Trieling, AR Cieslik,
RAD Akkermans
COOPERATIONS
Prof DC Montgomery (Dartmouth College, USA), Dr MG Wells (Yale, USA)
FUNDED
FOM
1st - 2nd 100% 3rd -
START OF THE PROJECT
2005
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PROJECT AIM

It is the aim of this research project to develop a better insight in the spectral and transport properties of quasi-two-dimensional flows, the dynamics of vortices in shallow fluid layers, and the effects of domain boundaries (solid walls) on (quasi-)2D turbulence. For this purpose, substantial effort will be put in the further development of sophisticated flow measurement techniques such as high-resolution PTV and stereo-PIV.

PROGRESS

This project has been concluded with the thesis by A.R. Cieslik (Jan. 2009).

DISSERTATIONS

1. Cieslik, A.R. - Three-dimensionality of shallow flows. PhD thesis, Eindhoven University of Technology, The Netherlands, 2009.

SCIENTIFIC PUBLICATIONS

1. Cieslik, A.R., L.P.J. Kamp, H.J.H. Clercx & G.J.F. van Heijst – Meandering streams in a shallow fluid layer, Europhys. Lett., 85, 54001-1/6 (2009).
2. Cieslik, A.R., R.A.D. Akkermans, L.P.J. Kamp, H.J.H. Clercx & G.J.F. van Heijst - Dipole-wall collision in a shallow fluid, Eur. J. Mech. B/Fluids, 28, 397-404 (2009).
3. Cieslik, A.R., L.P.J. Kamp, H.J.H. Clercx & G.J.F. van Heijst, The 3D character of decaying turbulence in a shallow fluid layer, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 293-298, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).

Experiments on Lagrangian statistics in rotating turbulence

Project Aim

It is the aim of this research project to develop insight in the Lagrangian statistics of rotating turbulence and the single- and pair-dispersion properties of small particles in rotating turbulence. For this purpose an existing 3D Particle Tracking Velocimetry method will be made suitable for rotating turbulence experiments.

Progress

The influence of the background rotation on the Eulerian and Lagrangian description of confined turbulence is investigated through Particle Tracking measurements in an electro-magnetically forced turbulent flow. The analysis of the latest datasets revealed interesting large-scale features of the flow field. The increase of rotation rate induces vertical coherency of the fluid motion (in terms of velocity, velocity derivatives, Eulerian spatial and temporal auto-correlations of velocity), till at the maximum rotation rate of 5 rad/s we observed a quasi-2D flow dominated by stable counter-rotating vertical tubes of vorticity (left figure). Exception is the 2 rad/s run, for which we observed an anomalous behaviour for all the features investigated: at this rotation rate, the vertical vortex tubes fluctuate in the measurement domain with much higher amplitude and on a longer time scale than any other experiment. The detailed description of large- and small-scale features of rotating turbulence also includes single-particle dispersion analysis, and the Lagrangian auto-correlations of velocity (right figure) and acceleration.

Dissertations

-

Scientific Publications

1. Del Castello, L., H.J.H. Clercx, R.R. Trieling & A. Tsinober, Table-top rotating turbulence: an experimental insight through particle trackinging, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 431-434, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).

Projectleaders

GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme

Complex dynamics of fluids

Participants

HJH Clercx, L Del Castello

Cooperations

Prof C Cambon (ENS Lyon, France), Prof A Tsinober (Univ. Tel Aviv, Israel). W Kinzelbach (ETH Zuerich, Switzerland), B Luethi (ETH Zuerich, Switzerland)

Funded

NWO-VICI

1st - 2nd 100% 3rd -

Start of the project

2005

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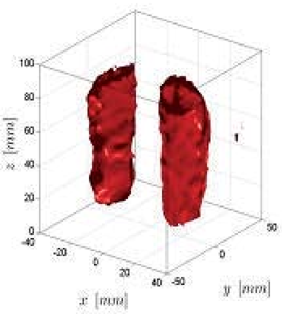

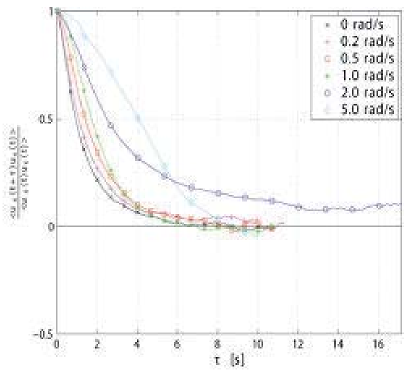

Effects of rotation in quasi two-dimensional turbulence in a thin fluid layer

Projectleaders
GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts
Researchtheme
Complex dynamics of fluids
Participants
GJF van Heijst, LPJ Kamp, RR Trieling, M Duran-Matute
Cooperations
-
Funded
CONACYT
1st - 2nd - 3rd 100%
Start of the project
2006
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Project Aim

The aim of the project is to gain insight in the dynamics of vortex structures in a shallow fluid layer under the influence of background rotation. The project combines laboratory experiments and numerical flow simulations.

Progress

To understand the dynamics of a turbulent flow in a shallow layer subjected to background rotation, it is important to first understand the dynamics of vortex structures, which are the building blocks of the turbulent flow. For this reason, we have conducted an experimental study of a dipolar vortical structure which is forced electromagnetically in a shallow layer. In particular, we characterized the flow along the dipole axis by measuring the Reynolds number Re as a function of the Chandrasekhar number Ch (the ratio of Lorentz to viscous forces). We found Re ~ Chα, with the scaling exponent α ranging from α =1 (viscous regime) to α = 1/2 (advective regime). This scaling is in good agreement with theoretical predictions. As a next step, we will perform experiments on a rotating table to determine the effects of rotation on the scaling of the Reynolds number as a function of the Chandrasekhar number and on the symmetry of the flow.

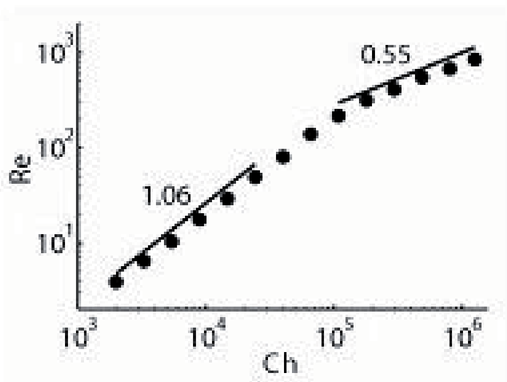
Dissertations

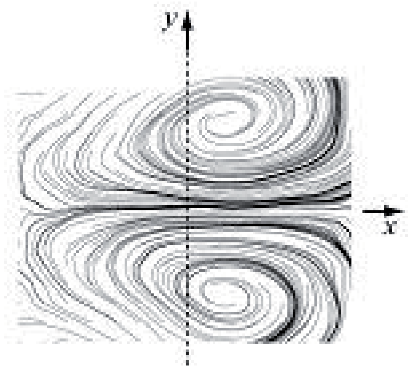
-

Scientific Publications

1. Duran-Matute, M., L.P.J. Kamp, R.R. Trieling & G.J.F. van Heijst - Inertial oscillations in a confined monopolar vortex subjected to background rotation, Phys. Fluids 21, 116602, 1-13 (2009).
2. Heijst, G.J.F. van & H.J.H. Clercx - Laboratory modelling of geophysical vortices, Ann. Rev. Fluid Mech., 41, 143-164 (2009).

Left: Measured values of the Reynolds number *Re* as a function of the Chandrasekhar number *Ch*. Bullets: experimental data. Solid lines: fits with exponents 1.06 (viscous regime) and 0.55 (advective regime).
Right: Flow lines tangential to the horizontal velocity components at mid-depth in the central 30x30 cm^2 region of the tank for *Ch* = 8 10^5. The dashed line represents the line x = 0.





Control of fluid mixing

Project Aim

The aims of the project are:

- to quantify and validate the efficiency of mixing;
- to explore the controllability of the flow through external excitation.

Progress

Based on the statistical correspondence between the global viscous dissipation *E* and the global entropy of the flow, we study stirring protocols such that $E \sim t^{B-1}$, where t denotes time and $0 < B < 1$ is the scaling exponent. In particular, we quantify mixing in a linear array of vortices and show that: (i) mixing is monotonically enhanced for increasing *B* and (ii) the mixing time *T* scales as $T \sim E^{-1/2}$. A publication on this work has been submitted to Phys. Rev. E.

Dissertations

-

Scientific Publications

-

Projectleaders
GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme
Complex dynamics of fluids

Participants
GJF van Heijst, H.Nijmeijer, F Fontenele Araujo, RR Trieling

Cooperations
-

Funded
TUE
1st 100% 2nd - 3rd -

Start of the project
2007

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Numerical simuations of 2D turbulence

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
K Schneider (Univ. Marseille, France) Prof CH Bruneau (Univ. of Bordeaux, France), W Kramer (TUe)
Funded
FOM
1st - 2nd 100% 3rd -
Start of the project
2003
Information

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Project Aim

It is the aim of these research projects to develop a better insight in the spectral and transport properties of quasi-two-dimensional flows, the dynamics of vortices in rotating and stratified fluids, and the effects of domain boundaries (solid walls) on (quasi-)2D turbulence.

Progress

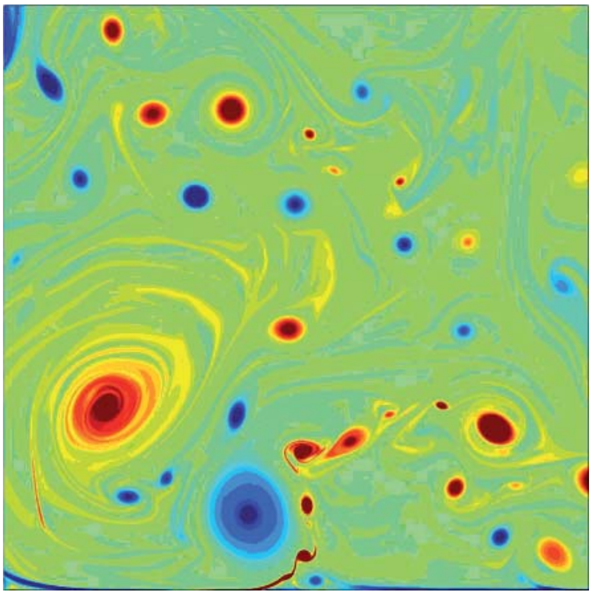
This project has been finished with the thesis by G.H. Keetels (June 2008).

Dissertations

-

Scientific Publications

1. Clercx, H.J.H. & G.J.F. van Heijst -Two-dimensional Navier-Stokes turbulence in bounded domains, Appl. Mech. Rev., 62, 020802-1/25 (2009).
2. Heijst, G.J.F. van & H.J.H. Clercx – Studies on quasi-2D turbulence – the effect of boundaries, Fluid Dyn. Res. 41, 064002-1/18 (2009).
3. Keetels, G.H., H.J.H. Clercx & G.J.F. van Heijst - Quasi-stationary states in a circular geometry, Phys. D, 238, 1129-1142 (2009).
4. Keetels, G.H., H.J.H. Clercx & G.J.F. van Heijst, The minimum-enstrophy principle for decaying 2D turbulence in circular domains, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 257-260, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).



Numerieke simulatie van twee-dimensionale turbulentie nabij een vlakke wand. Blauw: wervels met positieve vorticiteit. Rood: wervels met negatieve vorticiteit. De kleine wervels zijn het gevolg van de wisselwerking van de grote met de wand die als “wervelbron” fungeert.

2D turbulence: Simulation modules for anisotropic turbulence

Project Aim

It is the aim of this research project to develop a better insight in the spectral and transport properties of two-dimensional turbulence, the dynamics and interaction of vortices with no-slip walls, and the effects of domain boundaries (solid walls) on 2D turbulence and passive tracer transport.

Progress

This project has been concluded with the PhD thesis by W. Kramer (January 2007).

Dissertations

-

Scientific Publications

1. Kramer, W., R. Minero, H.J.H. Clercx & R.M.M. Mattheij - A finite volume local defect correction method for solving the transport equation, Comp. Fluids, 38, 533-543 (2009).

Projectleaders

GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme

Complex dynamics of fluids

Participants

HJH Clercx, GJF van Heijst, W Kramer

Cooperations

Prof CH Bruneau (Univ. of Bordeaux, France), Prof RMM Mattheij (Dept. Mathematics, TU/e), Dr AH Nielsen (Risø, Denmark), Prof JJ Rasmussen (Risø, Denmark), Prof K Schneider (Univ. Marseille, France).

Funded

NWO-CS

1st - 2nd 100% 3rd -

Start of the project

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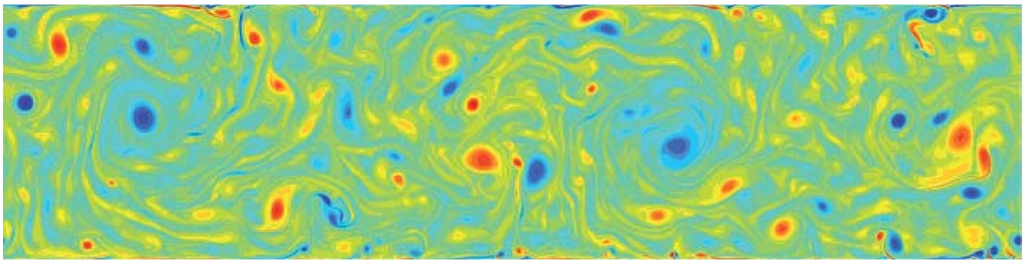
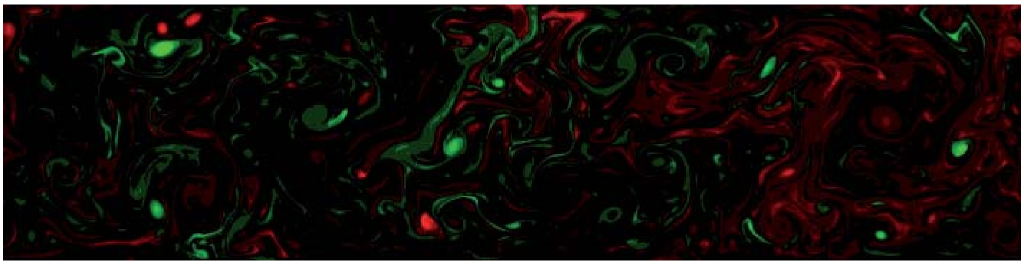
Aangedreven turbulentie in een twee-dimensionaal kanaal wordt gekenmerkt door het ontstaan van grote wervelstructuren.





Al naar gelang van de sterkte van deze wervels is het transport van materiaal inhomogeen.

Projectleaders
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts

Researchtheme
Complex dynamics of fluids

Participants
HJH Clercx, W Kramer, M van Aartrijk, A Dominguez-Guadarrama, E Aparicio-Medrano

Cooperations
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Prof E Meiburg (UCSB, USA),
Dr. KB Winters (Scripps,USA),
JGM Kuerten (Eindhoven Univ., Netherlands), Dr RE Uittenbogaard (Deltares), Prof M Scheffer (WUR)

Funded
NWO-VICI, Deltares
1st - 2nd 100% 3rd -

Start of the project
2006

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Project Aim

The aim of this project is twofold. In a first step the effects of rotating and or buoyancy on oscillating/pulsating channel flow subject to wind stress at the free surface will be studied. The second objective concerns the progress of dispersion, settling and aggregation of small (non-)spherical particles in homogeneous isotropic turbulence by 3D KS, the quantification of the vertical turbulent transport of phytoplankton by DNS and the associated process of scum formation at the free surface. This part concerns a combined study involving numerical simulations (TU/e), field observations (Deltares) and laboratory experiments (WUR).

Progress

The oscillating turbulent channel flow subjected to a wind stress is investigated by means of Direct Numerical Simulations and Large Eddy Simulations. This model serves as a simplified description of a fluid column in a tidal driven estuary. The generation of turbulence near the bottom wall and the free surface has been investigated and the vertical transport and mixing has been studied. The study is further extended by considering surface heating, which leads to a stable density stratification. The density stratification suppresses vertical fluctuations and, hence, limits the influence of the wind stress to the upper fluid layers. A parameter range study has been completed to map out the dispersion and settling velocities of non-spherical particles in homogeneous isotropic turbulence (mimicked by 3D-KS). The process of aggregate formation has been studied and the dynamics of porous aggregates have been investigated. In a separate study the vertical transport of phytoplankton in weak turbulence with and without stratification is considered. As a first step field studies have been conducted to obtain data on the physical and biological properties of a typical lake. First steps to conduct DNS of the vertical transport of phytoplankton in homogeneous isotropic turbulence have been made.

Dissertations

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Scientific Publications

1. Aparicio Medrano, E., Vlietland Lake 2009: Measurements, modeling, Summary, Delft, December 2009. (Internal report).
2. Kramer, W., V. Armenio & H.J.H. Clercx, The wind-driven turbulent oscillating channel flow subjected to a stable stratification, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 453-456, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).

Transport in Rayleigh-Bénard cells

Project Aim

The aim of this research project is threefold: 1) understanding of the effect of background rotation on Rayleigh-Bénard convection (RBC) and the role of Ekman boundary layers on the emergence of coherent structures in the flow, 2) heat transport measurements in (rotating) RBC in cylindrical convection cells, and 3) analysis of the dispersion of particles with (thermal) inertia and its subsequent feedback on the flow. For this purpose both laboratory experiments (SPIV measurements of the flow in a cylindrical convection cell) and direct numerical simulations have been performed (both cylindrical geometry and channel geometry).

Progress

The part on flow structuring in rotating Rayleigh-Bénard convection has been concluded with the thesis by Kunnen (2008). Currently, Nusselt measurements have been conducted for rotating RBC in cylinders with diameter over height aspect ratio equal to one. Larger aspect ratio cells have been built for new experiments. The currently available numerical codes for computation of turbulent RBC between two parallel plates have been restructured for HPC applications. The dynamics of particles with (thermal) inertia has been included and tested.

Dissertations

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Scientific Publications

1. Kunnen, R.P.J., B.J. Geurts & H.J.H. Clercx – Turbulence statistics and energy budget in rotating Rayleigh-Bénard convection, Eur. J. Mech. B/Fluids, 28, 578-589 (2009).
2. Kunnen, R.P.J., H.J.H. Clercx & B.J. Geurts, Anisotropy in turbulent rotating convection, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 413-414, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).
3. Stevens, R.J.A.M., Zhong, J.-Q., Clercx, H.J.H., Ahlers, G., Lohse, D. - Transitions between turbulent states in rotating Rayleigh-Bénard convection. Phys.Rev. Lett., 103, 024503 (2009).
4. Zhong, J.Q., R.J.A.M. Stevens, H.J.H. Clercx, R. Verzicco, D. Lohse & G. Ahlers – Prandtl-, Rayleigh-, and Rossby-number dependence of heat transport in turbulent, Phys. Rev. Lett., 102, 044502-1/4 (2009).
5. Stevens, R.J.A.M., J.-Q- Zhong, H.J.H. Clercx, R. Verzicco, D. Lohse & G. Ahlers -Prandtl-, Rayleigh-, and Rossby-number dependence of heat transport in turbulent rotating Rayleigh-Bénard convection, in: Advances in Turbulence XII, Proceedings of the 12th EUROMECH European Turbulence Conference, pp. 529-532, Editor: B. Eckhardt (Springer), 7-10 September Marburg, Germany (2009).

Projectleaders
GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme
Complex dynamics of fluids

Participants
HJH Clercx, BJ Geurts, GJF van Heijst, F Toschi, RJAM Stevens, V Lavezzo

Cooperations
Prof R Verzicco (Univ. Bari, Italy), D Lohse (Univ. Twente, Netherlands), Prof G Ahlers (UCSB, USA), Dr EMJ Komen (NRG-ECB).

Funded
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Dynamic behaviour of a High-Altitude Long-Endurance (HALE) wing

Projectleaders
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Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
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Funded
EU
1st - 2nd - 3rd 100%

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Project Aim

A new design High-Altitude Long-Endurance wing is currently under development in the EU project Vortexcell2050. For several reasons (structural and fuel load) it is desirable to have relatively thick wings. However, thick wings promote flow separation and/or massive vortex shedding, reducing flight performance significantly. The new design airfoil will be equipped with a cavity “vortex cell” in the wing in order to prevent flow separation. In this cavity a vortex will be trapped with active flow control. The goal of the current PhD project is to gain insight in the dynamic behavior of such a wing with a cavity and to explore which numerical CFD methods are suitable for estimating the unsteady forces on such an airfoil.

Progress

Two-dimensional Navier-Stokes simulations have been performed on an airfoil with and without cavity at a Reynolds number of 2*10^4, based on the chord length of the airfoil. The simulations indicate the presence of the first and second shear layer modes. These simulations are complemented by flow visualisations in a water channel and hot-wire measurements in the wind tunnel, at the same Reynolds number. The visualisations and hot-wire measurements confirm the oscillations of the shear layer at the first and second mode. The visualisations in the water channel also reveal the complex three-dimensional flow structure inside the cavity. At high Reynolds numbers in the wind tunnel the shear layer becomes turbulent.

Dissertations

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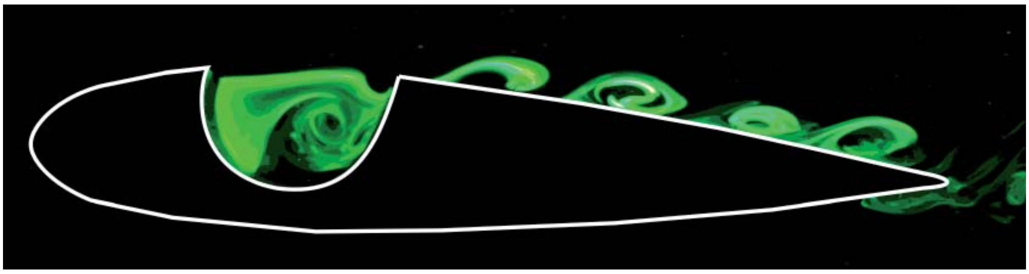
Scientific Publications

1. Olsman, W.F.J., M.M.E. van Osch, A. Hirschberg, R.R. Trieling & J.F.H. Willems, Local pressure difference over a NACA0018 Airfoil with cavity using acoustic forcing, in: Proceedings of the 47th AIAA Aerospace Sciences Meeting (publishers AIAA), 5 - 8 January, Orlando, Florida, USA (2009).



flow visualisation of the shear layer in the water channel

Tracers take the tube

Project Aim

Mass transport in laminar flows depends essentially on the topology of the Lagrangian fluid paths. Of great practical relevance are the fundamental mechanisms that cause such fluid paths to become chaotic; this implies efficient mass transport and is the desired state in typical laminar transport processes. Aim of the project is investigation of such fundamental "chaotization" mechanisms. The project specifically concentrates on the "chaotization" of the Lagrangian fluid paths of 3D Stokes flows by nonlinear perturbation via fluid inertia. This is investigated by theoretical, numerical and experimental methods.

Progress

Results of numerical simulations have been documented in a scientific paper that is currently under review for publication in Journal of Fluid Mechanics. Experimental validation of key aspects of these simulations by means of 3D-PTV measurements (using the 3DPTV code by ETH Zürich) in an existing laboratory set-up are currently underway. Furthermore, design and realisation of a new dedicated laboratory set-up for detailed experimental studies specifically on long-term tracer advection (which is beyond the capability of the current set-up) is in progress.

Dissertations

-

Scientific Publications

-

Projectleaders
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts

Researchtheme
Complex dynamics of fluids

Participants
HJH Clercx, GJF van Heijst,
MFM Speetjens, J Znaien

Cooperations
VV Meleshko (Kiev National Taras Shevchenko University, Ukraine),
W Kinzelbach (ETH Zürich, Switzerland)

Funded
FOM
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Start of the project
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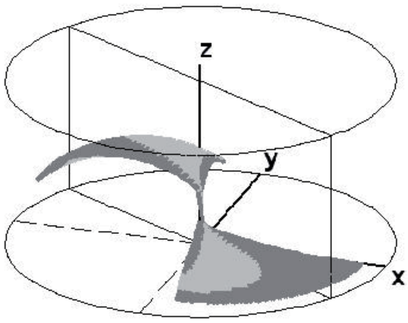
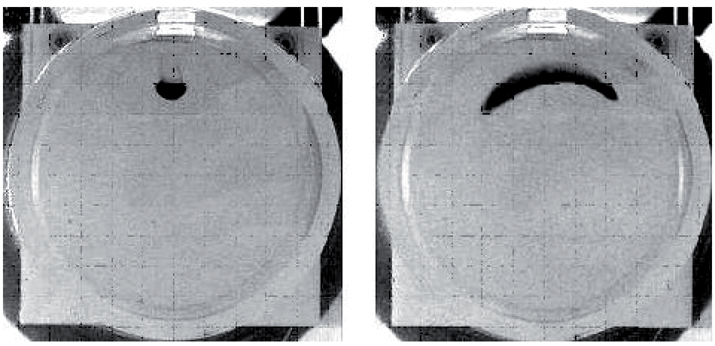


Series of period-1 lines of the entire family of 2-step forcing protocols, and hyperbolic segments of each line are distinguished



Dye visualization experiment: dye blob elliptic injected in a hyperbolic point, elongated in a specific direction and returned to the original position after one complete period of the forcing protocol, left: *time=0*, right: *time= T-period*

Turbulence at a free surface

Projectleaders
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts
Researchtheme
Complex dynamics of fluids
Participants
GJF van Heijst, W van de Water,
R Savelsberg
Cooperations
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Funded
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Project Aim

It is the aim of this research project to develop a better insight in the statistical properties of turbulence near a free surface by carrying out laboratory experiments in a water channel. Laser diagnostics and PIV will be used to measure free-surface wrinkling and the turbulent flow beneath the free surface.

Progress

This project has been concluded with the PhD thesis by R. Savelsberg (June 2006).

Dissertations

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Scientific Publications

1. Savelsberg, R. & W. van de Water - Experiments on free-surface turbulence, J. Fluid Mech. 619, 95-125 (2009).

Blowing in the wind: Aeolian patterns

Project Aim

Our aim is to shed more light on the aeolian sand transport mechanism and the way this leads to the formation and evolution of barchan dunes. Obviously, gravity plays a role which can be tuned in the experiment. Another point of interest is the dependence on and the role played by turbulence. These issues are addressed in wind tunnel experiments.

Progress

Barchan dunes can be found in sand barren regions under steady wind conditions. They translate in the direction of the wind while their shape remains unchanged. They have a minimal length in the order of ten metres, which renders laboratory experiments almost impossible. The length scale is set by the details of the sand-wind interaction. Smaller dunes do not evolve into the typical barchan dune shape. Our experimental approach produces dramatically scaled down barchan dunes. We produce small dunes that travel in the turbulent boundary layer of an open windtunnel. Particle image velocimetry on the surface of moving dunes reveals the flux of creeping sand, while measurement of sand grains flying through the air quantifies the key mechanism that moves sand by wind: saltation. The question is how much of the dune erosion is carried by the saltating grains, and how much by those crawling over the surface. This is a key question of aeolian transport models which can reach as far as the dunes on Mars.

Dissertations

-

Scientific Publications

1. Snouck, D., M.-T. Westra, & van de Water, W. - Turbulent parametric surface waves, Phys. Fluids 21, 025102 (2009).

Projectleaders

GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme

Complex structures of fluids

Participants

GJF van Heijst, W van de Water, D Snouck

Cooperations

-

Funded

FOM

1st - 2nd 100% 3rd -

Start of the project

2005

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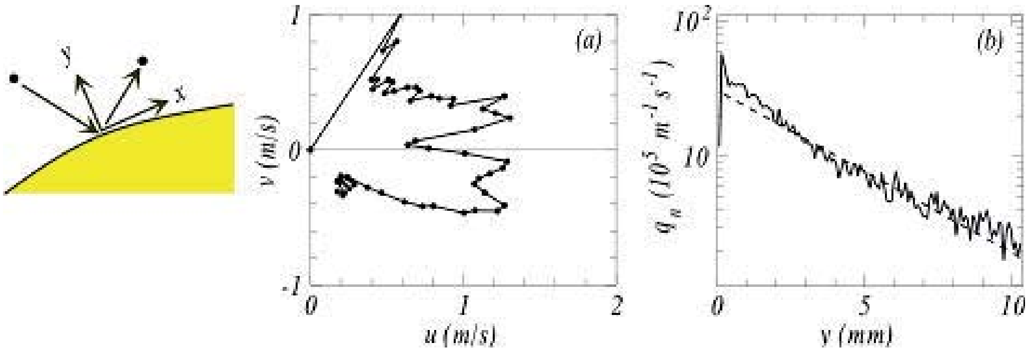
(a) Angular distribution of splash velocities when a grain collides with the dune face. (b) Vertical distribution of the the grain number flux over the dune crest. Due to the modulation of gravity in our experiment, the length scales have been reduced dramatically.



PROJECTLEADERS
GJF van Heijst, HJH Clercx,
H Kelder, BJ Geurts
RESEARCHTHEME
Complex structures of fluids
PARTICIPANTS
GJF van Heijst, PPJM Schram
COOPERATIONS
Prof SI Trigger (Moscow, Russia)
FUNDED
NWO
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PROJECT AIM

It is the aim of this project to reach a better understanding of stress distributions in static granular material, the dynamics of moving (excited) granular mixtures, the dynamical behaviour of particles in plasmas. and the mixing behaviour of 3D viscous flows.

PROGRESS

In direct collaboration with Prof.dr. S.A. Trigger (Moscow) research has been carried out on a number of different aspects of granular systems. The related work on dusty plasmas has also resulted in a few publications.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Trigger S.A., G.J.F. van Heijst, O.F. Petrov, P.P.J.M. Schram & Yu.P. Vlasov - Peculiarities of dusty plasma space distribution in traps, J. Phys. A, 42, 214028-214031 (2009).

Validation of tropospheric trace gas retrieval (focus on nitrogen dioxide) by satellites with ground based measurements

Project Aim

GROUND BASED NO2 OBSERVATIONS FOR SATELLITE VALIDATION

The aim of the project is to retrieve tropospheric nitrogen dioxide (NO2) concentrations from high resolution spectral observations of scattered sunlight. This NO2 product is used to validate retrievals from the OMI and SCIAMACHY satellite instruments.

Progress

A method has been developed to retrieve tropospheric columns of NO2 from ground based UV/VIS observations of scattered sunlight with a MAX-DOAS instrument. The essential step in the algorithm is a correction for the effect of aersols on the NO2 observations. A new method was developed to retrieve aerosol optical thickness (AOT) from observations of relative intensity. This method is applicable only to cloud free observations. The AOT retrieval was validated against a standardized technique to measure AOT from direct sun observations with a different type of instrument (fig 1). No significant bias was found, and a correlation of 0.85 which is relatively good considering the difference in observation techniques and the distance between the two sites of observation (22 km). Aerosol corrected tropospheric columns of NO2 were compared to satellite observations with the Ozone Monitoring Instrument (fig 2).

Dissertations

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Scientific Publications

1. Vlemmix, T., A.J.M.Piters, P.Stammes, P.Wang & P.F.Levelt - MAX-DOAS aerosol corrected tropospheric vertical columns of nitrogen dioxide, Proceedings of the 8th International Symposium on Tropospheric Profiling, Editors: A. Apituley, H.W.J. Russchenberg, W.A.A. Monna, (online)19–23 October, Delft, The Netherlands (2009).

Projectleaders

GJF van Heijst, HJH Clercx, H Kelder, BJ Geurts

Researchtheme

Complex dynamics of fluids

Participants

HM Kelder, PF Levelt, AJM Piters, T Vlemmix

Cooperations

KNMI

Funded

SRON

1st - 2nd 100% 3rd -

Start of the project

2007

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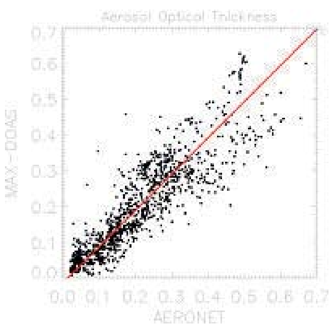
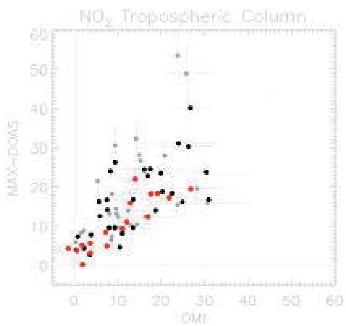
Selections of coincident observations were made with different criteria for errors in the ground based retrieval: 30%, 20%, 10%. This is shown in by the grey (30%), black (20%) and red (10%) data points in figure 2, which has units of [10^15 molecules/cm^2] along both axis. The average difference between ground based and satellite observation improved for more stringent selection of ground based observations, which gives confidence in both the ground based and satellite measurement.





Combustion Technology

Prof.dr. LPH de Goey

Prof.dr.ir. RSG Baert

Prof. LEM Aldén

The goal of the research programme of the ‘Combustion Technology Group’ is to gain insight in and knowledge on reacting flows in order to develop new and improve existing models of combustion systems. The models are used to guide new developments in the struggle to come to more efficient and clean conversion systems of fossil and sustainable fuels for a sustainable society. The knowledge and models developed are based on thorough physical and chemical understanding of the processes. This means that the gap between fundament and application has to be bridged continuously by transforming models describing physical/chemical behaviour on the smallest scales to models for the macroscopic scale of the full system. The knowledge is based on ‘generic’ theoretical and numerical insights for the propagation and structure of idealised flames and their interaction with acoustic waves, turbulent structures and inert/reacting surfaces. Most models for the combustion chemistry are based on a combination of the so-called laminar flamelet concept and chemical reduction methods leading to new techniques like FGM.

There is also a close entanglement of theoretical/numerical and experimental research. Available diagnostic techniques are e.g. flame visualisation, absorption techniques, LDV, PIV, LIF and Rayleigh scattering. Validation with the available laser-diagnostic measurement systems in the laboratory and real applications is carried out to disentangle the processes taking place on the various length and time scales. These measurements are carried out in flat (non-)adiabatic flames stabilised on the Heat Flux burner, laminar flames on Bunsen-type burners, flat turbulent flames on a weak-swirl burner, biomass grid, tube and bed reactors, optically-accessible combustion vessels and optically-accessible engines. Application areas are: small-scale laminar combustion systems, combustion of bio-fuels, engines and gas turbines. The application area of combustion engines is of particular interest.

Reduced chemistry models for Large Eddy simulations of partially-premixed combustion

Project Aim

Development, implementation and validation of the Flamelet Generated Manifold (FGM) reduction method (combustion chemistry tabulation) for simulation (LES and DNS) of complex combustion chemistry in partially-premixed turbulent flames. A method is to be defined which is able to combine premixed and non-premixed FGM tables for the simulation of partially-premixed combustion. This method will be implemented in an in-house Direct Numerical Simulation (DNS) code which is subsequently used to derive a subgrid combustion model for the non fully-resolved reaction layers in Large Eddy Simulations (LES).

Progress

An a-priori analysis for 4 different types of FGM tables has been performed for the Sandia Flames C-F. Results showed that the choice for the type of FGM table is used in CFD simulations greatly influences the accuracy of species mass fraction predictions, results for carbon-monoxide, hydrogen and hydroxyl have been published [2]. Currently a study how well partially-premixed laminar flames can be represented using a combination of a premixed and a non-premixed flamelet-based FGM table is in progress. Preliminary results have been presented [1]. In parallel, DNS simulations of turbulent jet flames (Sandia Flames D and F) and turbulent Bunsen flames are performed using a parallelized low-Mach DNS/LES code. Results will be used to derive a subgrid FGM combustion model for LES simulations.

Dissertations

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Scientific Publications

1. Flamelet Generated Manifolds for chemistry representation in partially-premixed flames. (Presentation, Model Reduction for Reacting Flows Workshop 2009, University of Notre Dame, USA.)
2. A priori analysis of Flamelet Generated Manifolds for simulation of turbulent partially-premixed methane-air flames. (W.J.S. Ramaekers, J.A. van Oijen and L.P.H. de Goey, Flow, Tubulence and Combustion, published online 26-05-2009.)

Projectleaders

LPH de Goey

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

WJS Ramaekers, JA van Oijen

Cooperations

TIMECOP-AE (EU) project
Rolls-Royce Deutschland

Funded

EU
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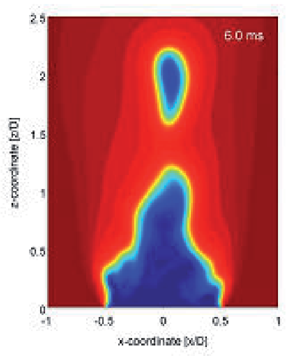

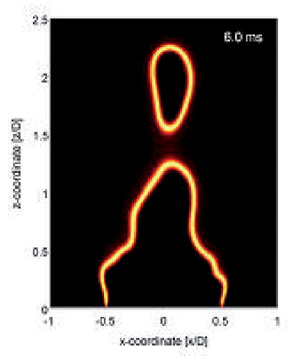

Instantaneous normalized progress variable (left) and progress variable source term (right) for a stoichiometric premixed, turbulent methane-air Bunsen flame. Dimensions have been normalized with respect to slot width.

Micro turbine combustor design analysis and optimization

Projectleaders
LPH de Goey, RJM Bastiaans, VN Kornilov
Researchtheme
Complex dynamics of fluids
Participants
VN Kornilov, LPH de Goey, RJM Bastiaans, RJM Heynens
Cooperations
Micro Turbine Technology BV
Funded
MTT, HTAS, OP Zuid
1st - 2nd - 3rd 100%
Start of the project
2007
Information
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Project Aim

Applying innovative ideas into the design of novel concepts of micro-CHP (combined heat and power) in small-scale applications (domestic boilers, CAP for trucks range extender in electrical vehicle). Fundamental research is involved as well. Some new conversion concepts are

- Combustion at high rotation rates
- Plasma assisted combustion
- Recuperative combustion
- Mild combustion
- Chemical transistor assisted combustion

Progress

Theoretical research has been carried out for a rotating combustor at very high RPM. This resulted in a patent application. For new designs with a non-rotating combustor, experimental research has been initiated. Challenge is the conversion of preheated ultra-lean fuel mixtures at elevated pressures. This is done to reduce flame temperatures to optimise emissions and to keep temperatures low to circumvent material degradation of the turbine. A high-pressure combustion chamber is built to test the new conversion methods. Many initial studies to new concepts are investigated in the laboraroty.

Dissertations

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Scientific Publications

1. A.I. van Berkel, G.J. Witteveen, R.J.M. Bastiaans, L.P.H. de Goey, Rotary Combustion Device, Patent: (pending) EP 1963640 (2009).

Flame stability and modeling of turbulent lean premixed gas-turbine combustors

Project Aim

The aim of the project is to develop credible physical models to simulate turbulent (partially) premixed combustion in gas turbines. This is conducted by starting with a reduction of the chemistry by application of Flamelet Generated Manifolds technique in combination with Direct Numerical Simulation. Turbulent closures are tested and appropriate LES and RANS models are developed. More and more physics is taken into account by including diffusion effects in the combustion and also extinction. In particular, the use of hydrogen as energy carrier is investigated.

Progress

Successful simulations FGM-DNS simulations are presented in the literature. It is found that the effect of flame stretch can be successfully taken into account in these simulations. Thus turbulent combustion by using LES and RANS is possible. These kind of calculations are carried out and presented in literature for several applications. It is also shown that the turbulent source term of the conversion can be modeled accurately based on the stretch theory of de Goey for methane combustion. Besides this several technical issues connected to the interaction of models and numerics are published. The influence of the highly diffusive effect of hydrogen addition to methane on a turbulent lean slot burner is investigated.

Dissertations

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Scientific Publications

1. A.W. Vreman, R.J.M. Bastiaans, B.J. Geurts, A similarity subgrid model for premixed turbulent combustion, Flow, Turbulence and Combustion, 82(2), 233-248, (2009).
2. R.J.M. Bastiaans, J.A. van Oijen, L.P.H. de Goey, Analysis of a strong mass based stretch model for turbulent premixed combustion, Phys. Fluids, 21, 015105, (2009).
3. A.W. Vreman, R.J.M. Bastiaans, B.J. Geurts, A similarity subgrid model for premixed turbulent combustion, Flow, Turbulence and Combustion, 82(2), 233-248, (2009).
4. R.J.M. Bastiaans, J.A. van Oijen, L.P.H. de Goey, Analysis of a strong mass based stretch model for turbulent premixed combustion, Phys. Fluids, 21, 015105, (2009),
5. H. Schmidt, M. Oevermann, R.J.M. Bastiaans, A.R. Kerstein, A priori tabulation of turbulent flame speeds via a combination of a stochastic mixing model and flamelet generated manifolds, extended to incorporate strain effects, ZIB Report, 09(09), Zuse Inst. Berlin, (2009).

Projectleaders
RJM Bastiaans

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
JA van Oijen, AW Vreman, LPH de Goey, JAM de Swart

Cooperations
BJ Geurts, H Schmidt, M Oevermann, AR Kerstein

Funded
University, STW, EU FP6
1st 50% 2nd 25% 3rd 25%

Start of the project
2006

Information

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Influence of bio-gas addition on the flame stability of lean premixed gas-turbine combustors

Projectleaders
RJM Bastiaans, LPH de Goey
LEM Aldén

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
JAM De Swart, JA van Oijen

Cooperations
Cambridge Univ. UK

Funded
STW, Electrabel
1st - 2nd 100% 3rd -

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2004

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Project Aim

Insight in the behaviour of flames where hydrogen is present is very valuable. When (highly diffusive) hydrogen is used as (part of) the fuel, preferential diffusion becomes important. In many practical applications, e.g. gas turbines, turbulent combustion takes place. This means that flame stretch influences the flame behaviour as well. Flame stretch is defined as the (density-weighted) rate of change of flame area and is a result of flame-flow interaction. Therefore, this study focuses on the influence of preferential diffusion and flame stretch on flame behaviour.

Progress

Using a three-dimensional numerical method, turbulent combustion is studied, using a DNS-FGM approach. First, Lewis numbers are chosen to be equal to one, which means that no preferential diffusion is present. Methane is used as a fuel and the influence of source term distribution on the flame behaviour is investigated. In a next step the method is adjusted in order to be able to capture preferential diffusion in a turbulent environment, where multi-dimensional FGMs are used. By knowing the local conditions, the proper values of thermo-chemical variables, e.g. chemical source term, are found. As a fuel, methane/hydrogen mixtures are used; the amount of hydrogen in the fuel is set to 0%, 20% and 40%.

Dissertations

1. J.A.M.de Swart, Modeling and analysis of flame stretch and preferential diffusion in premixed flames, PhD. Thesis, 2009, Eindhoven University of Technology. Advisors: L.P.H. de Goey, R.J.M. Bastiaans, Co-advisor: J.A. van Oijen.

Scientific Publications

1. A.W. Vreman, J.A. van Oijen, L.P.H. de Goey, R.J.M. Bastiaans, Direct numerical simulation of hydrogen addition in turbulent premixed Bunsen flames using flamelet generated manifold reduction, Int. J. Hydrog. Energy, 34, 2778-2788, (2009).
2. L.P.H. de Goey, J.A. van Oijen, R.J.M. Bastiaans, Premixed turbulent combustion modelling with FGM including preferential diffusion effects, VDI Berichte/VDI-TagungsbÃ¤nde, Sachgebiet Energie, 2056, 379-384, (2009).

Multi-scale modification of swirling combustion for optimized gas turbines combustion model

Project Aim

Multi-scale modification of swirling combustion for optimized gas turbines combustion model.

Progress

Literature survey has been carried out. Status modelling: At the moment we are implementing the FGM method for prediction of reactive flows. The FGM reduction technique defines that the number of progress variables can be increased straightforward in order to give a better description of the chemical phenomena related with the reactive flow. The present goal is to successfully simulate gas turbine burners by means of LES and application of a systematic reduction technique, such as FGM, to gas-turbine combustion. The purpose at this moment is to understand the physical aspects of reacting flows in high swirl flow conditions.

Dissertations

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Scientific Publications

-

Projectleaders

RJM Bastiaans, BJ Geurts, LPH de Goey

Researchtheme

Complex dynamics of fluids

Participants

Thiago Cardoso de Souza

Cooperations

UT ThH van der Meer

Funded

STW

1st - 2nd 100% 3rd -

Start of the project

2009

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Active model-based suppression of thermo-acoustic instabilities in gas-fired household boilers and heaters

Projectleaders
I Lopez, H Nijmeijer, LPH de Goey
Researchtheme
Complex dynamics of fluids
Participants
JDBJ van den Boom, VN Kornilov, I Lopez, H Nijmeijer, LPH de Goey
Cooperations
ATAG Verwarming Nederland B.V., Remeha B.V., AGPO Ferolli, Honeywell B.V., TNO Industrie en Techniek, Bekaert Combustion Technology. B.V., Eco Ceramics B.V.
Funded
STW
1st - 2nd 100% 3rd -
Start of the project
2004
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Project Aim

Applying active (feedback) control in order to suppress thermo-acoustic instabilities in gas-fired household boilers and heaters. A true model-based control mechanism, firmly rooted in combustion theory, based on our previous work concerning laminar flame dynamics will be used. Sensors and actuators are an explicit part of the research. In production type boiler equipment, an actual implementation will be tested.

Progress

Transfer functions of burner-stabilized flames are defined using a modal analysis technique. The correspondence of these transfer functions, without a dead time component, to measure transfer functions is near perfect. This means that linear control techiques are applicable to synthesize controllers to suppress thermo-acoustic instabilities. For the sensor and actuator research, studies to develop a cheap chemiluminescence sensor and to determine the actuator authority of an electric field on premixed flames are conducted. In order to quantify the influence of an electric field the change in laminar burning velocity (direct current) and change in OH* radical chemiluminescence (alternating current) are measured.

Dissertations

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Scientific Publications

1. van den Boom J.D.B.J., Konnov A.A., Verhasselt A.M.H.H., Kornilov V.N., de Goey L.P.H., Nijmeijer H. “The effect of a DC electric field on the laminar burning velocity of premixed methane/air flames”, Proc. Combust. Inst., 32 (2009) 1196-1203.

Acoustic response of multi-flame practical burner in different combustion regimes

Project Aim

The aim of this project is to experimentally characterize the acoustic behaviour of flames in different combustion regimes (flat flame, Bunsen type laminar flames and turbulent flames) and to propose a generalized solution for the acoustic response. This information will be then used for (in)stability prediction of the complete thermo-acoustic system.

Progress

- An experimental setup was build and measurement module/method is developed for identifying the thermo-acoustic behavior of transient/ turbulent flames.
- The acoustic response (i.e. Transfer function) of single Bunsen burner in different combustion regime (laminar, transient and weakly turbulent) was measured.
- The mean system time delay (τ0) and convective time (τc) is measured for different regime.
- The instability map was evaluated by experimental techniques and compared with numerical models.
- Dependence of the transfer function on the flame/perforation pattern was found.

Dissertations

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Scientific Publications

1. M. Manohar, V.N. Kornilov, K. Balachandran, L.P.H. de Goey, Thermo-acoustic instability of a simplified boiler: A comparative experimental Vs Modeling study, COMBURA2009 (STW) conference.
2. M. Manohar, V.N. Kornilov, L.P.H. de Goey, Evolution of thermo-acoustic transfer function of single Bunsen type flame: an experimental study, in Proceedings of the 16th International Congress on Sound and Vibration; Krakow, Poland, (2009).
3. M. Manohar, V.N. Kornilov, L.P.H. de Goey, Thermo-acoustic transfer function of a Bunsen flame: transition from laminar to turbulent regime, in Proceedings of the 4th European Combustion Meeting; Vienna , Austria, (2009).
4. V. Kornilov; M. Hoeijmakers; M. Mahohar; B. Karthik, I. L. Arteaga, H. Nijmeijer, L.P.H. de Goey, Criteria to evaluate thermo-acoustic (in)-stability of combustion, submitted in 33rd combustion symposium.

Projectleaders
LPH de Goey

Researchtheme
Complex dynamics of fluids

Participants
Manohar, VN Kornilov, LPH de Goey

Cooperations
LMS, Cambridge University, TU Munchen

Funded
AETHER (EU)
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2006

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Study of electric field influence on flat premixed flames

Projectleaders
LPH de Goey
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
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Cooperations
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Funded
AETHER (EU)
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Start of the project
2008
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Project Aim

The aim of the project is to study the mechanism of influence of electric field on flat premixed CH4/air flame and to improve our undestanding of this complex phenomena. Main empahsis will be placed on assessment of the applicability of electric fields (both constant and alternating) for damping thermoacoustic instabilities in the case of burner stabilized, laminar flames.

Progress

The influence of a DC EF on the thermoacoustic behavior of a flat CH4/air flame, which was characterized through a thermoacoustic transfer function (TF), is studied. It is shown that the application of the DC EF of positive polarity induces noticeable changes in the flat flame TF. In general, the TF of the flat flame shifts to higher frequencies, when the DC EF is applied. This shift relates to a decreased flame stand-off distance. For the experimental conditions studied the shift can comprise up to 50 Hz. For certain frequencies the change in phase due to the EF influence can reach 65°. Maximal electric power delivered to the flame was less than 0.5 % of flame thermal power. It is also possible to vary magnitude of shift by varying applied voltage and consequently electric power delivered to the flame. Moreover, for a given upstream gas velocity and given equivalence ratio a simple relation between EF and its influence on flat flame characteristics can be found. This opens an opportunity for control of thermoacoustic behaviour of the flat flame.

Dissertations

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Scientific Publications

1. E.N. Volkov, A. Konnov, M. Gula, K. Holtappels, A.A. Burluka, Chemistry of NOx decomposition at flame temperatures, in Proc. of the 4th European Combustion Meeting; Vienna, Austria, Article P810136, pp. 1-6, (2009).
2. E.N. Volkov, A. Sepman, V.N. Kornilov, A.A. Konnov, Y. Shoshyn, L.P.H. de Goey, Towards the mechanism of DC electric field effect on flat premixed flames, in Proc. of the 4th European Combustion Meeting; Vienna, Austria, Article P810337, pp. 1-6, (2009).
3. E.N. Volkov, V.N. Kornilov, L.P.H. de Goey, Influence of Electric Field on Thermoacoustic Transfer Function of Flat Premixed Flame, in Proc. of the 16th International Congress on Sound and Vibration; Kraków, Poland, Article 199, pp. 1-8, (2009).

Stretch effects on hydrogen/methane/air laminar flame propagation and extinction (STRELA)

Project Aim

The main scientific objective of the proposed research is to establish mechanisms through which flame stretch affects propagation and extinction of lean (limit) single-front methane/hydrogen/air flames. To meet this objective, it is proposed to carry out a detailed experimental investigation of upward propagation and extinction of lean/limit flames in vertical cylindrical channels of different diameters, closed at the upper end and opened at the bottom end.

Progress

The flame speeds measurements were performed for ultra-lean flames of hydrogen-methane-air mixtures propagating in a vertical tube. A transition from open-front regime to new flame-ball regime at decreasing fuel gas concentrations was studied in detail. Planar Laser Induced Fluorescence measurenments of OH radical were employed to characterise flame shapes and overall reaction rates. A setup was designed and built which allows for long-exposure filming of propagating flames with a moving video camera. A thin-filament pyrometry method is combined with the image registration by a moving camera was employed to measure detailed temperature distriobutions in these flames. It was established, that preferential diffusion effects are governed by flame stretch in open-front flames and by the flame curvature in uniform enclosed flameballs. The transition between these two regimes was studied for the first time.

Dissertations

-

Scientific Publications

1. Y.Shoshin, J.Jarosinski. On extinction mechanism of lean limit methane–air flame in a standard flammability tube. Proceedings of the Combustion Institute 32 (2009) 1043–1050.
2. Y.L. Shoshin, L.P.H. de Goey. On the Mean Stretch Rate over a Finite Flame Segment. 4th European Combustion Meeting, Vienna, Austria, 14-17 April, 2009.
3. E.N. Volkov, A. Sepman, V.N. Kornilov, A.A. Konnov, Y. Shoshyn, L.P.H. de Goey, Towards the mechanism of DC electric field effect on flat premixed flames, in Proc. of the 4th European Combustion Meeting, Vienna, Austria, 14-17 April, 2009.
4. Y. Shoshyn, A. Sepman, L.P.H. de Goey, Experimental study of ultra-lean flames in methane/hydrogen/air mixtures propagating in mesoscale vertical channel, in Combura; Nieuwegein, Netherlands, Conference Poster (2009).
5. Y. Shoshyn, L.P.H. de Goey, Experimental study of lean flammability limits of methane/hydrogen/air mixtures in tubes of different diameters, in Proceedings of the 6th Mediterranean Combustion Symposium; Ajaccio, Corsica, France, June 7-11, 2009.
6. Y. Shoshyn, L.P.H. de Goey, Experimental study of lean flammability limits of methane/hydrogen/air mixtures in tubes of different diameters, Experimental Thermal and Fluid Science 34 (2010) 373–380.

Projectleaders
LPH de Goey

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
Y Shoshin

Cooperations
-

Funded
European Commission, FP7 Marie Curie Program, IIF
1st - 2nd - 3rd 100%

Start of the project
2008

Information

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Towards a unified flamelet theory

Projectleaders
LPH de Goey
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
S Delhaye, LMT Somers, JA van Oijen
Cooperations
-
Funded
TUE
1^{st} 100% 2^{nd} - 3^{rd} -
Start of the project
2004
Information
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Project Aim

The aim of the project is to develop a unified Flamelet-Generated Manifolds method that captures premixed and non-premixed combustion as well as combustion regimes in between.

Progress

Finished PhD Thesis.

Dissertations

1. S. Delhaye, Incorporating unsteady flow-field effects in flamelet-generated manifolds, PhD. Thesis, 2009, Eindhoven University of Technology.

Scientific Publications

1. S. Delhaye, L.M.T. Somers, J.A. van Oijen, L.P.H. de Goey, Incorporating unsteady flow-effects beyond the extinction limit in flamelet-generated manifolds, Proc. Combust. Inst., 32(1), 1051-1058, (2009).

Engine efficiency: modeling fuel-air mixing and auto-ignition in a diesel engine-like environment

Project Aim

Study fuel-air mixing and its effect on auto-ignition and combustion in partially Premixed Charge Compression Ignition (PCCI) engine, using FGM method. CFD tools such as Star-CD (CD-adapco) and AVBP (LES code, Poinsot et al.) will be adopted. Simple fuel (n-heptane), and realistic fuel chemistry (mixtures of n-heptane/i-octane/toluene) will be explored in terms of their auto -ignition and combustion characteristics featuring PCCI combustion.

Progress

The following plan is adopted

1) Fulfill the hardware facility; Self-tutoring of Star-CD;
2) Literature study of previous Partially Premixed Combustion research, FGM approach; Design working plan and purposes.
3) Build FGM table using two methods: Calculating 1D flamelets using Chem1D; Performing Homogeneous Reactor computations using XPSR. Both Chem1D and XPSR are in-house codes from TU/e.
4) Study the built FGM table regarding to different conditions, i.e. pressure, temperature, species concentration etc. 5) Locate verification case (1D laminar configuration featuring stratified mixtures) and validation case (CRU experiment done at Shell Global Solutions); The built FGM table will be adopted into Star-CD to simulation these cases.

Dissertations

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Scientific Publications

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Projectleaders

B Somers

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

Z Hu

Cooperations

Eindhoven University of Technology (TU/e); Shell Global Solutions

Funded

EU Marie Curie ToK, Industry-Academia Partnership Scheme “engine efficiency”.
1st 67% 2nd 33% 3rd -

Start of the project

2009

Information

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Surrogate fuel concept for CFD of diesel engine combustion

Projectleaders
LPH de Goey, LMT Somers
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
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University of California, San Diego
Institut Français du Petrolé (IFP)
Funded
STW, DAF/PACCAR, Shell
1st - 2nd 90% 3rd 10%
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2008
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Project Aim

Development, implementation and validation of a surrogate fuel concept for diesel engine combustion. To be achieved by means of RaNS/LES and Flamelet Generated Manifold (FGM) based CFD in idealized and real engine conditions. Ultimately leading to an approach that can be applied to simulate fuel spray combustion and predict emission formation, accurately and efficiently.

Progress

In modern diesel engines, spray formation and combustion are the main processes that challenge engineers. Several ways to model fuel sprays (flow and turbulence) exist based on averaging (RaNS) approaches and LES approaches, that can be much more detailed in the sense that they resolve large eddies and therefore inherently introduce stronger inhomogeneity like observed in practice. Concerning ignition and combustion a tabulated chemistry approach (FGM) is to be adopted. In order to apply these models successfully in the design of engines, appropriate and accurate diesel fuel characteristics have to be captured. On one hand, the thermo-physical properties of the fluid are important due to vaporization and mixing processes that are involved. On the other hand, reaction kinetics play an important role as the gas phase combusts. Since diesel fuel consists of many different hydrocarbon components it is a very complex fuel to model. Therefore a surrogate fuel will be developed to use in realistic injection and combustion simulations.

Dissertations

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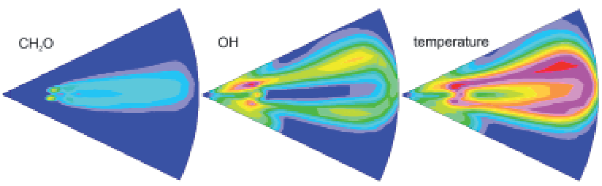
Scientific Publications

1. C. Bekdemir, L.M.T. Somers, L.P.H. de Goey, Numerical modeling of diesel spray formation and combustion, 4th European Combustion Meeting, Vienna, Austria, 2009.
2. C. Bekdemir, L.M.T. Somers, L.P.H. de Goey, First application of the Flamelet Generated Manifold (FGM) approach to the simulation of an igniting diesel spray, International Multidimensional Engine Modeling user's group meeting, Detroit, USA, 2009.
3. C. Bekdemir, L.M.T. Somers, L.P.H. de Goey, Flamelet Generated Manifold strategies in modeling of an igniting diesel spray, Towards Clean Diesel Engines, Aachen, Germany, 2009.
4. C. Bekdemir, L.M.T. Somers, L.P.H. de Goey, Modeling engine spray ignition with igniting flamelets, Workshop Turbulent Spray Combustion, Corsica, France, 2009.
5. L.M.T. Somers, C. Bekdemir, Modeling ignition in engine applications, 6th Mediterranean Combustion Symposium, Corsica, France, 2009.
6. E.P. Rijk, C. Bekdemir, L.M.T. Somers, L.P.H. de Goey, Numerical modeling of combustion in an engine cycle, COMBURA, Nieuwegein, The Netherlands, 2009.



Crossing the combustion modes in diesel engines

Project Aim

The development of a well established understanding of the processes occurring in the cylinder in different combustion regimes will be indispensable since new combustion concepts make diesel engines much more complex. It is aimed to develop a versatile model which is applicable for different combustion (current and future) modes. In addition to a 3D CDF tool, a multi-zone model is also going to be applied to simulate diesel combustion in a correct behavior. Besides, it is desired to explore the reduction of soot and NOx emissions by applying high EGR and enhanced mixing and altering fuel type in the project.

Progress

Numerical models are significant to minimize design time and expensive prototyping. Both a CFD model and a multi-zone model are used for diesel engine simulations. The multi-zone model has an advantage over CFD tools since more detailed chemical mechanisms can be included. However, the drawback is that stratification process due to this interaction between injection and in-cylinder flow cannot be modelled. Stratification estimation should be assumed or obtained from separate CFD simulations. First models are curently prepared and used.

Dissertations

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Scientific Publications

1. M.D. Boot, C.C.M. Luijten, L.M.T. Somers, U. Eguz, D.D.T.M. van Erp, B.A. Albrecht, R.S.G. Baert, Uncooled EGR as a Means of Limiting Wall-Wetting under Early DI Conditions, SAE Technical Papers, 2009-01-0665, (2009).

Projectleaders
LPH de Goey, LMT Somers

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
U Eguz

Cooperations
DAF

Funded
STW, DAF, Delphi, Shell, Avantium
1st - 2nd 70% 3rd 30%

Start of the project
2009

Information

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Developing a comprehensive diesel combustion model for HDDI to predict heat release rate and emissions (mainly soot)

Projectleaders
LMT Somers, LPH de Goey
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
S Ayyapureddi
Cooperations
DAF Trucks Eindhoven,
TNO Eindhoven
Funded
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Project Aim

The prime aim of the current project is :

- Using reduced chemical reaction models to model detailed chemistry of diesel combustion, in a way to reduce the cost and time involved in numerical simulation
- Modelling of diesel soot

This can be realised with an attempt by coupling FGM* with STARCD** for non-premixed or diffusion flames to model conventional diesel combustion. Extended mechanisms are introduced in addition for emissions formation.

*Flamelet Generated Manifold; ** CFD commercial tool

Progress

- As to understand the present scenario of combustion models particularly on soot modelling literature survey is being done. Various advanced models in STARCD for diesel combustion were studied. This has given some understanding on evolution of various combustion models in literature.
- A study on the present modelling status has been done with reading the thesis of few master students on FGM coupling with STARCD. It has given some basic understanding on FGM modelling approach and its implementation on diesel combustion. Also it helped to understand the gap that needs to be filled in terms of improving the accuracy and extending applicability like including EGR, pressure variations, etc.
- Presently, some exercises to generate basic FGM tables for n-heptane mechanism using chem1D models are in progress.

Dissertations

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Scientific Publications

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Real-time model of advanced compression ignition engine combustion

Project Aim

The development of a generic phenomenological real-time model, which can simulate the influence of injection rate (and valve timing) on energy conversion and engine out emissions for a compression ignition engine.

Progress

An extensive validation of the NOX and Soot models has been performed on single- (Cyclops) and multi-cylinder Heavy-Duty Diesel engines. Excellent results were obtained proving the concept. PhD thesis, finalized.

Dissertations

1. X.L.J. Seykens, Development and validation of a phenomenological diesel engine combustion model, PhD. Thesis, 2010, Faculty of Mechanical Engineering, Advisors: R.S.G. Baert.

Scientific Publications

1. R.J.H. Klein-Douwel, P.J.M. Frijters, X.L.J. Seykens, L.M.T. Somers, R.S.G. Baert, Gas density and rail pressure effects on diesel spray growth from a heavy-duty common rail injector, Energy and Fuels, -, -, (2009).
2. X.L.J. Seykens, R.S.G. Baert, L.M.T. Somers, F.P.T. Willems, Experimental Validation of Extended NO and Soot Model for Advanced HD Diesel, in SAE World Congress; Detroit, United States, SAE 2009-01-0683, (2009).

Projectleaders

RSG Baert

Researchtheme

Complex dynamics of fluids

Participants

XLJ Seykens, LMT Somers, RSG Baert, LPH de Goey

Cooperations

-

Funded

TNO

1st - 2nd - 3rd 100%

Start of the project

2004

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Fuel(s)(spray) characterization and optimization for new engine combustion concepts

Projectleaders
CCM Luijten
Researchtheme
Complex dynamics of fluids
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Cooperations
DAF Trucks NV, Lund University
Funded
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1st 100% 2nd - 3rd -
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www.combustion.tue.nl

Project Aim

This project aims at a cross-coupling between developments in fuels and engines. On the engine side, the most important (class of) new combustion concept is PCCI: premixed charge compression ignition. PCCI, however, puts different requirements to the fuel than conventional combustion (more specifically, a lower CN is required to enhance premixing). On the fuels side, important trends are the introduction of alternative fuels: biodiesel, ethanol and synthetic fuels, but also more dedicated fuels that were identified as promising with respect to (low) emissions in earlier research. By studying these "new" fuels in a variety of test setups (including a diffusion burner, a high pressure cell for spray studies and several engines), a broad spectrum of data is gathered on the combustion behaviour of these fuels. Besides providing a database, these data also enable verification of numerical simulations.

Progress

The new high pressure cell for detailed fuel studies has been further utilized to do extensive measurements on different fuels, and has been prepared to accommodate a heat flux burner as well (see project of M.H. de Andrade Oliveira). The other high pressure cell, used for spray studies as described in [3], was further optimized in order to enhance its operating range and improve control of operation. Besides, results of earlier work on the precombustion method were published [1,2] Furthermore, engine studies were done on early-injection diesel engine combustion with an emphasis on the prevention of so-called "wall wetting" [4]. Also the route to PCCI combustion via fuel composition has been studied [5,6] (see MD Boot). With the same objective of better fuel and air premixing, research was done on a new injector nozzle concept [7]. Finally, the influence of non-ideal gas effects on the evaporation behaviour of fuel sprays was investigated, and two papers on this subject have been submitted [8,9]. Previous work on a dual-fuel application was submitted and is being revised [10].

Dissertations

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Scientific Publications

1. C.C.M. Luijten, E. Doosje, L.P.H. de Goey, Accurate analytical models for fractional pressure rise in constant volume, Int. J. Thermal Sci., 48(6), 1213-1222.
2. C.C.M. Luijten, E. Doosje, J.A. van Oijen, L.P.H. de Goey, Impact of dissociation and end pressure on determination of laminar burning velocities in constant volume combustion, Int. J. Thermal Sci., 48(6), 1206-1212.
3. R.S.G. Baert, P.J.M. Frijters, L.M.T. Somers, C.C.M. Luijten, W.A. de Boer, Design and operation of a high pressure, high temperature cell for HD diesel spray diagnostics: guidelines and results, SAE Technical Paper 2009-01-0649.
4. M.D. Boot, C.C.M. Luijten, L.M.T. Somers, U. Eguz, D.D.T.M. van Erp, B.A. Albrecht, R.S.G. Baert, Uncooled EGR as a Means of Limiting Wall-Wetting under Early DI Conditions, SAE Technical Papers, 2009-01-0665, (2009).
5. M.D. Boot, P.J.M. Frijters, C.C.M. Luijten, L.M.T. Somers, R.S.G. Baert, A.J. Donkerbroek, R.J.H. Klein-Douwel, N.J. Dam, Cyclic oxygenates: A new class of second generation biofuels for Diesel engines?, Energy and Fuels, 23(4), 1808-1817.

6. M.D. Boot, C.C.M. Luijten, E.P. Rijk, B.A. Albrecht, R.S.G. Baert, Optimization of operating conditions in the early direct injection premixed charge compression ignition regime, SAE Technical Paper 2009-24-0048.
7. J.J.E. Reijnders, M.D. Boot, C.C.M. Luijten, P.J.M. Frijters, L.P.H. de Goey, Porous fuel air mixing enhancing nozzle (PFAMEN) , SAE Paper 2009-24-0028.
8. C. Kurvers and C.C.M. Luijten, Real gas effects in mixing-limited spray vaporization models, submitted to Atomization & Sprays (2010).
9. C. Kurvers and C.C.M. Luijten, Real Gas Effects in Siebers' Mixing-Limited Spray Vaporization Model, submitted to SAE (as Technical Paper), 2010.
10. C.C.M. Luijten and E. Kerkhof, Jatropha oil and biogas in a dual fuel CI engine for rural electrification, submitted to Energy Conversion and Management.

INVESTIGATION OF ALTERNATIVE COMBUSTION CONCEPTS (AND FUELS) IN HEAVY-DUTY DIESEL ENGINES

PROJECTLEADERS
LPH de Goey, RSG Baert
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
M Boot, C Luijten
COOPERATIONS
DAF Trucks (Eindhoven), OWI (Aachen, DE), RUN (Nijmegen)
FUNDED
DAF Trucks NV
1st - 2nd - 3rd 100%
START OF THE PROJECT
2005
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PROJECT AIM

In the past, new emission targets for heavy-duty diesel vehicles could be met by fine-tuning and upgrading a number of engine parameters (e.g. injection timing, turbo pressure…) and components (e.g. valve / piston head geometry, fuel injection equipment…) respectively. It is improbable, however, that these measures will suffice for future stringent emission legislation. Accordingly, engine manufacturers are seen to gradually shift their focus to more advanced emission reduction technologies, foremost of which are alternative combustion (e.g. HCCI) concepts and (bio) fuels (e.g. low cetane number oxygenates). The accompanying challenges (f.i. wall-wetting for HCCI and engine compatibility for fuels) are subject of research.

PROGRESS

The past year has been spent on writing papers and the PhD thesis. The PhD defence is scheduled for the 20th of April 2010.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. M.D. Boot, P.J.M. Frijters, C.C.M. Luijten, L.M.T. Somers, R.S.G. Baert, A.J. Donkerbroek, R.J.H. Klein-Douwel, N.J. Dam, Cyclic oxygenates: A new class of second generation biofuels for Diesel engines?, Energy and Fuels, 23(4), 1808-1817, (2009).
2. M.D. Boot, C.C.M. Luijten, E.P. Rijk, B.A. Albrecht, R.S.G. Baert, Optimization of operating conditions in the early direct injection premixed charge compression ignition regime, SAE Technical Papers, -, 2009-24-0048, (2009).
3. J.J.E. Reijnders, M.D. Boot, C.C.M. Luijten, P.J.M. Frijters, L.P.H. de Goey, Porous fuel air mixing enhancing nozzle (PFAMEN) , SAE Technical Papers, -, 2009-24-0028, (2009).
4. R.J.H. Klein-Douwel, A.J. Donkerbroek, A.P. van Vliet, M.D. Boot, L.M.T. Somers, R.S.G. Baert, N.J. Dam, J.J. ter Meulen, Soot and chemiluminescence in diesel combustion of bio-derived, oxygenated and reference fuels, Proc. Combust. Inst., 32, 2817 - 2825, (2009).
5. M.D. Boot, C.C.M. Luijten, L.M.T. Somers, U. Eguz, D.D.T.M. van Erp, B.A. Albrecht, R.S.G. Baert, Uncooled EGR as a Means of Limiting Wall-Wetting under Early DI Conditions, SAE Technical Papers, -, 2009-01-0665, (2009).
6. R.H.L. Eichhorn, M.D. Boot, C.C.M. Luijten, Waste energy driven air conditioning system (WEDACS) , SAE Technical Papers, -, 2009-24-0063, (2009).

Towards clean diesel engine combustion (Sub project: characterization of mixture stratification in an optically accessible engine)

Project Aim

Premixed charge compression ignition (PCCI) is one of the most promising combustion strategies for internal combustion engines, since PCCI combustion is able to realize very low soot and nitric oxide emissions while maintaining high fuel efficiency. To achieve PCCI combustion with limited heat release rates, the influence of charge stratification on combustion will be investigated. In this project methods are investigated to achieve and measure charge stratification. As a first attempt to investigate the mixing process we measure in-cylinder velocities using time resolved particle image velocimetry (TR-PIV). Also the spray injection will be investigated.

Progress

A time resolved PIV setup has been built, containing a high speed laser, high speed camera and high speed controller. Time resolved PIV measurements have been performed on an optically accessible engine as a function of crank angle position, position in cylinder, compression ratio and rotational speed. The setup is updated with a new cylinderhead and dedicated injection equipment. In the future a diagnostic technique developed at RUN, to measure 2D temperature fields quantitatively, will be introduced to the engine at the TU/e.

Dissertations

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Scientific Publications

1. R.P.C. Zegers, T.J. van der Meyden, C.C.M. Luijten, N.J. Dam, R.S.G. Baert, L.P.H. de Goey, Crank angle resolved flow field characterization of a Heavy-Duty (PCCI) Engine, , 4th European Combustion Meeting, Vienna, Austria, 2009.

Projectleaders
LPH de Goey

Researchtheme
Complex dynamics of fluids

Participants
RPC Zegers, M Yu, NJ Dam, CCM Luijten

Cooperations
Radbout University Nijmegen
TNO

Funded
STW, DAF, Shell global solutions, Wärtsilä
1st - 2nd 80% 3rd 20%

Start of the project
2007

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Towards clean diesel engine combustion (Sub project: PCCI spray combustion in high pressure cell)

Projectleaders
LPH de Goey, RSG Baert, LEM Aldén

Researchtheme
Complex dynamics of fluids

Participants
?

Cooperations
?

Funded
?
1st 45% 2nd 30% 3rd 25%

Start of the project
?

Information
?

Project Aim

Premixed charge compression ignition (PCCI) is one of the most promising combustion strategies for internal combustion engines, since PCCI combustion is able to realize very low soot and nitric oxide emissions while maintaining high fuel efficiency. To obtain a more detailed understanding of PCCI combustion process, we aim to investigate a limited set of fuel spray mixing/reacting events. The objects include:

- Characterize of flow/temperature field prior to fuel injection (thermo-phosphor, Rayleigh Scattering, Raman Scattering etc.)
- Image the spray behavior and mixing progress during/after injection (Schlieren, LIF etc.)
- Build a database for numerical models.

Progress

A setup for Rayleigh Scattering and Raman Scattering method has been build, the evaluation of both methods is in progress. Schlieren and laser light scattering measurements have been performed on an optically accessible constant volume high pressure cell. The survivability of thermal graphic phosphors in combustion environment has been tested. In the future the LIF technique developed at RUN, to measure 2D temperature fields quantitatively, will be introduced at the TU/e.

Dissertations

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Scientific Publications

1. R.J.M. Bastiaans, M. Yu, C.C.M. Luijten, Cooling process of pre-combustion residual gases in the Eindhoven high pressure cell, in Proc. of the 4th European Combustion Meeting; Vienna, Austria, -, (2009).
2. R.P.C. Zegers, M. Yu, C.C.M. Luijten, N.J. Dam, R.S.G. Baert, L.P.H. de Goey, Fuel formulation and mixing strategy for rate of heat release control with PCCI combustion, in Seventh International Symposium Towards Clean Diesel Engines 2009; Editors: C. Schulz, N. Peters, Aachen, Germany, CEUR-ws.org/Vol-452/, (2009).

Development and application of a laminar coflow burner to study combustion of modern automotive (bio-)fuels at high pressure, using advanced laser diagnostics

Project Aim

It is attempted to build a bridge between laminar flame burners (in which simple fuels are burnt at atmospheric pressure) and the much more complex and demanding environment found in practical combustion engines. This is accomplished by designing and constructing a high pressure vessel and diffusion burner and integrating these with an evaporation system. This setup will enable the study of realistic automotive (bio-) fuels, applying advanced optical diagnostics techniques that will be assessed in cooperation with the Lund Institute of Technology. This assessment will shed light on the applicability of these methods in sooty environments at high pressure.

Progress

Over the last year, the experimental setup sketched above (which was integrated and first used in the previous year, as reported in Ref. [2]) was applied for further measurements. Soot volume fraction measurements (using line-of-sight attenuation) were done for an extensive list of (oxygenated) fuels, at atmospheric pressure [1,3]. Besides, the setup was adjusted and completed to enable high pressure application. Much effort was put into stabilization of the resulting (high pressure) diffusion flames. For gaseous fuels this has been very successful; for liquid fuels some challenges still remain. Later in the year, preparations were made for an extensive laser diagnostic measurement campaign at Lund University (Sweden), which is among the primary objectives of this PhD project. At the moment of writing this, the campaign is in progress. Furthermore, the design of a heat flux burner for the same vessel was completed and realised; first measurements (using a “copy” of the pressure vessel) are in progress, which will enable detailed diagnostics of pressurized premixed flames as well, and allow for the – new! – possibility to measure burning velocities at elevated pressures using the heat flux method. Near future plans consist of: completing the present laser diagnostic measurement campaign, probably followed by 1 or 2 more, giving information not only on the flames of interest, but also on the applicability of several advanced laser diagnostic methods at elevated pressures; analyse some flames in more detail and compare with numerical simulation results; and extend the feasibility study of the heat flux burner method at elevated pressures.

Dissertations

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Scientific Publications

1. M.H. de Andrade Oliveira, C.C.M. Luijten, L.P.H. de Goey, Soot measurements in laminar flames of gaseous and (prevavporized) liquid fuels, in Proc. of the 4th European Combust. Meeting, Eds. P. Szentannai and F. Winter, Vienna, Austria.
2. M.H. de Andrade Oliveira, P.A.M. Bertrand, C.C.M. Luijten, L.P.H. de Goey, Soot formation of lignin-derived fuels in a laminar co-flow diffusion flame, Nieuwegein, Netherlands, Combura Conference Poster (2009).
3. M.H. de Andrade Oliveira, L. Zhou, C.C.M. Luijten, L.P.H. de Goey, Soot measurements in laminar flames of gaseous and (prevaporized) liquid fuels, Heeze, Netherlands, European Graduate School on Sustainable Energy Conference Poster (2009).

Projectleaders
CCM Luijten, LPH de Goey, LEM Aldén

Researchtheme
Complex dynamics of fluids

Participants
MH de Andrade Oliveira

Cooperations
Lund Institute of Technology (Sweden)

Funded
TU/e, EU (Large Scale Facility at Lund University, optical diagnostic measurements)
1st 100% 2nd - 3rd -

Start of the project
2007

Information

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Two-line atomic fluorescence for temperature measurement in flames

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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RJM Bastiaans
Cooperations
-
Funded
TUE
1st 100% 2nd - 3rd -
Start of the project
2009
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Project Aim

Developing two-line atomic fluorescence using Ga or In atoms to the measurement of temperature fields near auto-ignition of diesel-type fuels and under conditions typical for a diesel engine.

Progress

The project has started only recently. A literature survey has been completed; currently, methods to seed the required atom into the fuel stream are under study. As an independent temperature measurement technique we consider Coherent Rayleigh-Brillouin Scattering.

Dissertations

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Scientific Publications

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Process Technology

Prof.dr.ir. JJH Brouwers

The programme of the group covers theoretical, numerical and experimental research on selected subjects in process technology. The subjects range from fundamentals to applications. The aims are to contribute to scientific issues relevant to the field, to develop tools for applying scientific results on practical cases and to design machinery and apparatus using these results. Many research activities are carried out in co-operation with and with support of industry.

The subjects of research are:

1. Stochastic processes and turbulence

The stochastic process of turbulence is a key issue in process technology, since fluid flow in process apparatus is generally turbulent and predicting flow quantities is a central issue in their design. A theory is being developed for stochastic turbulence, which involves asymptotically exact solution methods and reveals the truncation errors. Concerning numerical research, faster and more efficient numerical methods for DNS and LES models for particle-laden turbulent flow are being developed. Experimental research into inhomogeneous turbulence at intermediate and high Reynolds number is carried out by means of 3D-PTV in turbulent pipe flow.

2. Phase-transitional flow

Fluid flow in which a phase change occurs is of considerable importance in process technology. The research is focused on boiling, (dropwise) condensation and sublimation. The research is generic, aiming at results that are applicable in numeric codes and for the design of unit operations. As examples, the dependencies of drag and lift force coefficients on acceleration of bubbles and particles have been studied and the effect of the velocity field caused by condensation directly downstream of the inlet of a confined steam jet on self-similarity has been investigated. Current research focuses on inertia-dominated interaction of flow and bubbles or particles and on basic mechanisms of condensation and sublimation. The approach followed is analytical, experimental and numerical.

3. Development of new process technology

The insights gained in the first two topics are applied to new concepts of process technology, mainly in the area of rotational equipment, separation apparatus and heat and mass exchangers. These projects are carried out in close cooperation with industry and comprise the design, manufacturing and testing of new equipment. Centrifugal phase separation offers excellent opportunities for innovation. The group has a strong position in this field by the patented concept of rotational particle separation. A new development is the design where rotation is generated by swirl of the flow itself, which is particularly suited at high fluid pressures and receives much interest from the oil industry. A new in-house born idea is the wall-de-sublimator, which avoids the formation of aerosols by de-sublimating vapors on cooled surfaces of narrow-channeled heat exchangers. A relatively new means of ship propulsion is based on waterjets driven by pumps. The group studies the effects of non-uniform intake flow on performance and forces of the pump. A project on the development of a numerical method for unsteady flow in rotating machinery just started.

Hydrodynamic forces in a mixed-flow pump

Project Aim

This experimental and numerical investigation focuses on the effect of non-uniform suction flow on dynamic forces on the shaft of an impeller. Since these forces originate from the hydrodynamics of the internal flow they are classified as hydrodynamic forces, in contrast to forces due to, for example, system unbalance and gravitation. Measuring the hydrodynamic forces is generally very complicated and their relation to a distorted entrance flow field has never been studied extensively.

Progress

A closed-loop test rig is equipped with a scale model of a mixed-flow pump which is used for ship propulsion. A newly designed dynamometer is mounted between the shaft of the pump and the impeller. Dynamic forces on the impeller are measured accurately using six full bridges of strain gauges. In the testrig the velocity profile of the flow field entering the pump is adapted using various pipe bundles of a specific shape. Hydrodynamic forces on the impeller, resulting from non-uniform entrance flow, are measured for different operating conditions. It has been observed that a skewed axial velocity profile can lead to a considerable steady radial loading. Furthermore, blade excitation forces cause the impeller to whirl in a direction opposite to shaft rotation. Recently published results focus on the effect of non-uniform suction flow on global pump characteristics. CFD simulations of the flow through the pump reveal the flow phenomena underlying the observed behavior.

Dissertations

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Scientific Publications

1. B.P.M. van Esch, Performance and Radial Loading of a Mixed-flow Pump Under Non-uniform Suction Flow, J. Fluids Eng., 131(5), pp. 1-7 (2009).
2. B.P.M. van Esch, L. Cheng, Blade Interaction Forces in a Mixed-Flow Pump With Vaned Diffuser, in Proceedings of the ASME 2009 Fluids 2009 ASME Fluids Engineering Division Summer Meeting; Vail, Colorado, United States, FEDSM2009-78114 (2009).

Projectleaders
BPM van Esch

Researchtheme
Complex dynamics of fluids

Participants
BPM van Esch, C Li, JJH Brouwers

Cooperations
Wärtsilä Propulsion Netherlands
Yangzhou University, China

Funded
TU/e, Yangzhou University, China
Wärtsilä Propulsion Netherlands
1st 75% 2nd -% 3rd 25%

Start of the project
2004

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Numerical simulation of unsteady flow in hydraulic turbomachines

Projectleaders
BPM van Esch

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
D de Kleine, BPM van Esch, JGM Kuerten, JJH Brouwers

Cooperations
Wärtsilä Propulsion Netherlands; Nijhuis Pompen; BuNova Development; DP Industries; Bosman Watermanagement; BELI Technics; Technische Universiteit Delft

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2005

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Project Aim

The internal flow in turbomachines is very complex with regard to geometry, rotation and unsteadiness. The wish to calculate this type of flow with CFD poses high demands on the numerical model. Commercially available CFD codes are less suited for unsteady incompressible flow. The aim of this investigation is to develop a computer code based on a staggered grid approach and apply it to flows in centrifugal pumps.

Progress

The multi-block staggered-grid based computer code DeFT, originally developed in the group of Wesseling (TUD), is used as a basis. As a first step the difference in accuracy between collocated and staggered-grid methods is assessed for several unsteady incompressible flows. It is concluded that a staggered-grid method has a higher accuracy for corresponding time steps. Furthermore, it is observed that rough grids (e.g. with high skewness, large aspect ratio, or local grid refinement) pose no difficulty to the so-called WesBeek discretisation, in contrast to the classical staggered-grid discretisation. The code is adapted for calculating flows in a rotating frame of reference. Centrifugal and Coriolis forces are implemented in conservative form. It is shown that this method is more accurate than schemes in which these forces are represented as source terms in the NaS equations. The method is extended to allow for non-matching grids at block interfaces and validated by calculating the incompressible, turbulent flow through a cascade and comparing results with measurements. The agreement is found to be good. For a simulation of the flow through a turbomachine, the possibility of a sliding interface between the grids in the rotor and stator was added. Calculations of the flow through a 2D radial pump with stator vanes were found to correspond well with measurements.

Dissertations

1. D. de Kleine, Numerical simulation of unsteady flow in hydraulic turbomachines, PhD. Thesis, Eindhoven university of Technology, Eindhoven, The Netherlands (2009).

Scientific Publications

1. D. de Kleine, B.P.M. van Esch, J.G.M. Kuerten, A.W. Vreman, Calculation of Unsteady Flow in a Centrifugal Pump With Vaned Diffuser Using Staggered and Collocated Grid Methods, in Proceedings of the ASME 2009 Fluids Engineering Division Summer Meeting; Vail, Colorado, United States, FEDSM2009-78113 (2009).

Rapid heating with steam injection

Project Aim

The aims of the project are the development and validation of a new physical model that can be used in the simulation of the heating process of fluids by direct steam injection at relatively high temperatures and short residence times. To this end a combination of the diffuse interface method and large-eddy simulation will be used and dedicated experiments will be carried out.

Progress

Experiments at various conditions have been performed. The steam plume topology of direct contact condensation with flowing liquids has been measured and analyzed. A simple model based on bubble detachment knowledge has been found to be reasonably successful for prediction purposes of intermittent flow regimes. Local temperatures have been measured with micro-thermocouples at various positions downstream of the injection point. A non-intruding measuring technique for local temperatures, based on phosphoric tracers, has been developed; reproducibility tests are running. Results have been presented at the International Boiling Conference. A simulation method which uses the diffuse interface method for the calculation of the deformation of a bubble in a fluid has been constructed and validated. This model has been combined with large-eddy simulations in order to reduce computation time or to increase the simulation volume. A start has been made with the modeling of the energy equation with the same method. Results have been presented at various European conferences as well as at the Turbulence Conference, June 2009 at Martinique.

Dissertations

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Scientific Publications

1. Three conference proceedings, see our website at www.wtb.tue.nl/woc/ptc.

Projectleaders
CWM van der Geld, JGM Kuerten

Researchtheme
Complex dynamics of fluids

Participants
N Clerx, A Pecenko, JGM Kuerten, CWM van der Geld

Cooperations
NIZO food research, Stork Food & Dairy Systems B.V

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2006

Information
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Study of dropwise condensation

Projectleaders
CWM van der Geld
Researchtheme
Complex dynamics of fluids
Participants
M Grooten, CWM van der Geld
Cooperations
Klima, Verhulst, fac. Wsk, Innovation Handling
Funded
Faculteit W
1st 100% 2nd - 3rd -
Start of the project
2007
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Project Aim

To increase our understanding of the basic mechanisms of dropwise condensation and of sublimation, and to apply the knowledge thus gained to the improvement of the design of compact condensers.

Progress

A new dedicated small-scale test section has become operational in which drainage can be artificially controlled. Measurement accuracy has been inferred from the energy equation and measured temperatures and humidities. Experiments at various sweeping rates of the artificial drainage mechanism have been performed. Infrared recordings have been made simultaneously with video-camera recordings. A sophisticated analyzing tool for photographs of drop patterns has been developed by the faculty of applied mathematics for application in our test rig. The results, drop size distributions and plate coverage percentages by drops, will be used to verify expectations based on maximum drop size dependencies of heat transfer and drainage rates. A sophisticated measuring technique for humidity, based on the ultrasonic Doppler technique, has been developed by a local company and has been made working in our test rig. Two new types of compact condenser plates have been developed in cooperation with the group MATE of our faculty. They comprise special patterns of alternatively hydrophilic and hydrophobic plate material to promote drainage. Another type of plate condenser has been developed to enable direct comparison of dropwise and filmwise condensation.

Dissertations

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Scientific Publications

1. One journal publication, one conference contribution, see our website www.wtb.tue.nl/woc/ptc

Experiments on bubble detachment with application to once-through boilers

Project Aim

The effect of flow on boiling bubble detachment from a heated plane wall at constant temperature is experimentally studied. Aim of the measurements: validation of the predictions of a model for inviscid flow and quantification of the vorticity-based lift force on a bubble footed at a wall.

Progress

In 2009, periodic bubble oscillations have been investigated both experimentally and with analytical and numerical tools. Experiments with a dedicated test rig have been performed in microgravity arranged by the parabolic flight of an airplane, in cooperation with IMFT in France. Experiments have been performed of intravenous boiling, for medical applications, in a special test section. A test rig has been designed to facilitate boiling studies at elevated viscosities. A STW grant has been obtained for continuation of this research with two Ph.D. students.

Dissertations

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Scientific Publications

1. Two journal publications and various conference contributions, see our website www.wtb.tue.nl/woc/ptc.

Projectleaders
CWM van der Geld

Researchtheme
Complex dynamics of fluids

Participants
CWM van der Geld

Cooperations
DAF, Spirotech B.V.

Funded
EC-project AD-700-2
1st - 2nd - 3rd 20%

Start of the project
2004

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Analytical prediction of virtual mass-dominated interaction of flow and a bubble growing at a plane wall

Projectleaders
CWM van der Geld
Researchtheme
Complex dynamics of fluids
Participants
CWM van der Geld
Cooperations
-
Funded
-
1st - 2nd - 3rd -
Start of the project
2004
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Project Aim

A model for arbitrary deformation of a boiling bubble has been used to analyze periodic deformation of a bubble adhering to a cavity in a wall. This project will henceforth be reported simultaneously with the project on boiling.

Progress

A model for arbitrary deformation of a boiling bubble has been used to analyze periodic deformation of a bubble adhering to a cavity in a wall. This project will henceforth be reported simultaneously with the project on boiling.

Dissertations

-

Scientific Publications

1. One article in J. of Fluid Mech., see our website www.wtb.tue.nl/woc/ptc.

Statistical analysis of turbulent two-phase pipe flow by means of experiments

Project Aim

The aim of this research is to determine the statistical properties of inhomogeneous turbulence at intermediate and high Reynolds numbers and the effect of particles with inertia on these properties.

Progress

Various improvements were implemented in the 3D PTV test set-up, amongst which three new cameras and an improved illumination system. In addition, the obsolete trajectory reconstruction software has been replaced with LaVision software. Lagrangian velocity correlation functions have been determined for flows affected by the presence of particles with inertia, by measuring simultaneously the fluid velocity field, with tracers, and the inertia particle trajectories. At present new measurements are in preparation while the new analysis software is taken into use.

Dissertations

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Scientific Publications

-

Projectleaders

CWM van der Geld, JGM Kuerten

Researchtheme

Complex dynamics of fluids

Participants

JL Goes Oliveira, JGM Kuerten, CWM van der Geld

Cooperations

-

Funded

Shell, TUE

1st 100% 2nd - 3rd -

Start of the project

2003

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Large-eddy simulation of particle-laden flows

Projectleaders
JGM Kuerten
Researchtheme
Complex dynamics of fluids
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Cooperations
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Prof. dr. A. Soldati, Dr. C. Marchioli, University of Udine, Italy
Funded
STW, TU/e, DEISA
1st 50% 2nd 50% 3rd -
Start of the project
2003
Information
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Project Aim

The aim of this project is the study of dispersion of non-passive particles in turbulent non-isothermal channel flow by means of DNS and LES. Especially models for subgrid contributions in case LES is used for the fluid flow are developed and tested, both for particle velocity and particle temperature.

Progress

Dispersion of non-passive particles in turbulent channel flow is studied by means of DNS and LES. A topic of research is the errors made when the filtered fluid velocity is used in the particles' equation of motion. For the case of turbophoresis, the errors appear to be large. A model for the subgrid contribution has been developed and shows a substantial improvement in the results. Real LES calculations have been performed for various subgrid models. The dynamic eddy-viscosity model and especially the approximate deconvolution model yield results which agree well with the a priori results for a range of particle relaxation times. The proposed defiltering method of the fluid velocity shows also in the real LES a substantial improvement of the results. In 2009 DNS at Re_τ590 has been performed and a start has been made with DNS at Re_τ=950. Moreover, an equation for temperature as a passive scalar has been added.

Dissertations

-

Scientific Publications

1. A.W. Vreman, B.J. Geurts, N.G. Deen, J.A.M. Kuipers, J.G.M. Kuerten, Two- and four-way coupled Euler-Lagrangian large-eddy simulation of turbulent particle-laden channel flow, Flow, Turbulence and Combustion, 82(1), 47-71, (2009).

Bio-STIPS

Project Aim

The aim of this research is to develop a model for the calculation of the thickness of deposition that results after evaporation of a solvent from a droplet and of the distribution of (bio)molecules on/in the substrate.

Progress

A start has been made with the development of simple models for individual processes of evaporation, spreading and sorption of a microscopic drop on a porous or non-porous substrate. The methods have been combined and validation with experimental results has been made.

Dissertations

-

Scientific Publications

-

Projectleaders
JGM Kuerten

Researchtheme
Complex dynamics of fluids

Participants
DP Siregar, CWM van der Geld, JGM Kuerten

Cooperations
WUR, Philips Research. Océ

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2008

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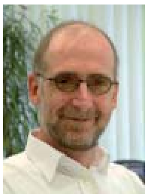
Energy Technology



Prof.dr.ir. AA van Steenhoven

Research in the field of Energy Technology at a Mechanical Engineering Department requires the combination of fundamental research together with the study of practical systems. Our group restricts its fundamental research to the field of Heat Transfer and the practical system study to Small-scale Energy Systems with a strong emphasis on Sustainability.

The approach is to combine advanced experimental, analytical and numerical techniques to investigate fundamental issues in heat transfer and to design, construct and test real energy conversion systems. In this way, the research also contributes to the engineering and research training of the mechanical engineering students. The research is concentrated on three topics:

a. Heat transfer and transitional flows

The research in this area is aimed at a better understanding of the fundamental characteristics of transitional flows in general. Flow cases that are studied are bypass transition along a flat plate (related to turbine blade cooling) and the mixed convection around a heated cylinder (related to electronics cooling). In these studies the attention is mainly focused on the physics of the 3D-transition of these types of flows and its influence on the heat transfer. Another research line concentrates on laminar (thermal) transport phenomena in compact fluid-dynamical systems.

b. Micro-scale heat transfer

The aim of this research line is to achieve a better understanding of the heat and mass transfer processes at the small scales. The focus is on evaporative cooling of electronic components, on multi-scale analyses to enhance the efficiency of compact heat storage and the dynamics of actuated super-paramagnetic particles as integrated fluid drivers in micro systems. On the smallest scales the physical processes on different scales are studied by coupling Molecular-Dynamics analyses with a Direct Simulation Monte Carlo model.

c. Heat-transfer engineering

The research activities in this area focus more on the system-level instead of the phenomenon-level. Two main research projects are fouling of heat exchangers as used in waste- incinerators and biomass-gasifiers, and heat transfer models for the human body under normal and surgical conditions.

More information about the research activities in these areas can be found on our website: www.energy.tue.nl

Control of transitional flow

Project Aim

Bypass transition of a boundary layer takes place at high mainstream turbulence levels. It is governed by the intrusion of non-linear disturbances into the viscous sublayer. This study aims at understanding the nature of the transition process and also the control of the transitional process.

Progress

The influence of passive control by means of travelling waves in boundary layer flows is studied, as well as the intrusion of small, heavy particles in a flow.

In 2008 a new direction in the study has developed: one-sided control of bypass transition. For this numerical study a grant of 400 kpcu-hours has been granted by DEISA. This showed that well-chosen modes of travelling surface waves are capable of delaying or even removing bypass transition (see figure).

Furthermore, stability analysis is initiated on flows containing small, heavy particles. In a water channel a combined visualization and PIV/PTV technique will be used to study both the onset and the development of the boundary layer instability with and without particles. These experimental results will then be combined with numerical simulations in which the development of single structures in the boundary layer can be studied.

Dissertations

-

Scientific Publications

1. P. Schlatter, E. Deusebio, L. Brandt, H.C. de Lange, Interaction of noise disturbances and streamwise streaks, in IUTAM Symposium on Laminar-Turbulent Transition, Stockholm, Sweden, (2009).
2. P. Dancova, H.C. de Lange, T. Vit, D. Sponiar, Z. Travnicek, Laminar channel flow effected by synthetic jets- experimental and numerical studies, in 7th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics; Editors: J.S. Szmyd, Krakow, Poland, (2009).

Projectleaders
HC de Lange, AA van Steenhoven

Researchtheme
Complex dynamics of fluids

Participants
PR Bloemen, J Klinkenberg

Cooperations
L Brandt, D Henningson and P Schlatter, KTH Stockholm, Sweden.

Funded
TUE
1st 100% 2nd - 3rd -

Start of the project
2000

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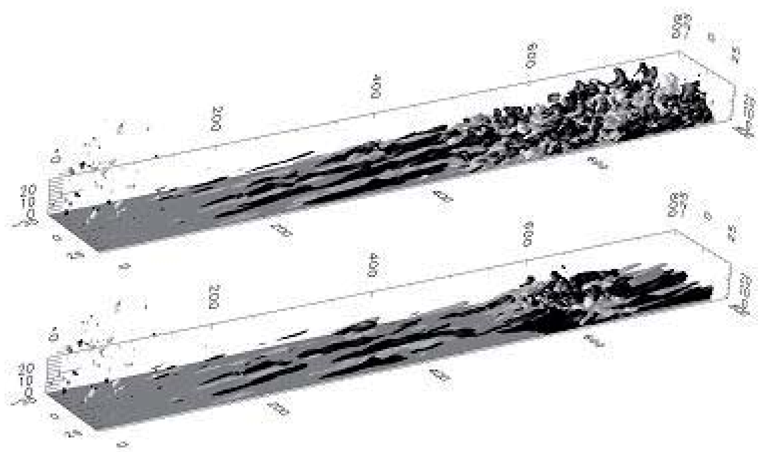

Top figure is the uncontrolled flow, lower figure is the controlled flow (control region $100<x<400$) with downstream travelling surface waves. One can observe that in the control region the streaks decay. After the control region, streaks are again generated.

Dynamics of transitional mixed-convection wake flows

Projectleaders
CCM Rindt, AA van Steenhoven
Researchtheme
Complex dynamics of fluids
Participants
I Yildirim, PR Bloemen
Cooperations
GJF van Heijst, Dept. Applied Physics, TU/e.
Funded
FOM
1st - 2nd 100% 3rd -
Start of the project
1996
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Project Aim

Transition to turbulence in a mixed convection wake flow behind a heated circular cylinder is investigated within this project. Both experiments and numerical simulations are executed in order to asses the effect of several disturbances and obtain a better understanding of the phenomena, which take place during transition to a turbulent flow.

Progress

The 3-D transition of the flow behind a circular cylinder with a near-wake wire disturbance has been investigated experimentally using PIV and flow visualization techniques and numerically using SEM simulations. The presence of the wire causes a forced mode of 3D wake transition to occur, namely Mode – C. This mode exhibits itself as streamwise vortices around the primary von Karman vortices and has approximately the same wavelength with the Mode-E in heated cylinders. However it also contains a period doubling character which has not been found in Mode-E transition. At this moment detailed experiments and numerical simulations are being performed in order to quantify the differences and similarities between the two forced modes of wake transition.

Dissertations

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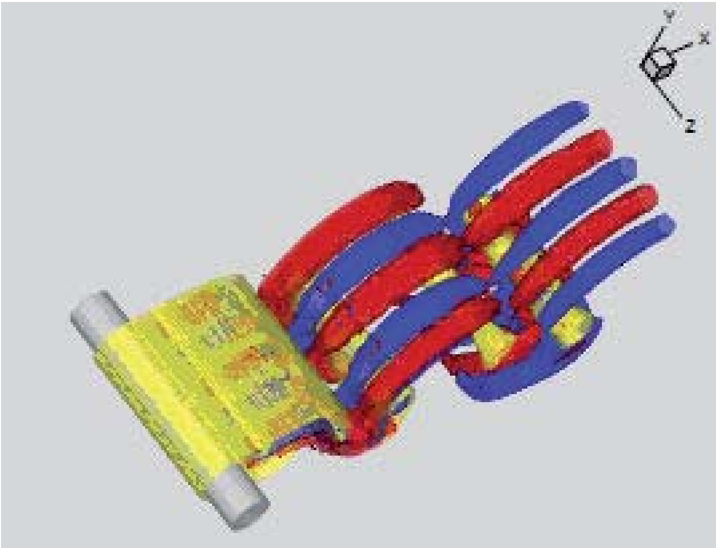
Scientific Publications

1. P.C.H. Aben, P.R. Bloemen, J.C.H. Zeegers, 2-D PIV measurements of oscillatory flow around parallel plates., Exp. Fluids, 46(4), 631-641, (2009).
2. I. Yildirim, C.C.M. Rindt, A.A. van Steenhoven, Flow field characteristics of circular-cylinder wake with a near-wake wire disturbance , 6th International Symposium on Turbulence and Shear Flow Phenomena; Seoul, Korea, (2009).
3. I. Yildirim, C.C.M. Rindt, A.A. van Steenhoven, Experimental investigation of shedding mode II behind a rotating cylinder, 7th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics; Krakow, Poland, (2009).



SEM simulation results showing the period doubling nature of the wire disturbed cylinder wake.Blue: positive streamwise vorticity, red: negative streamwise vorticity

Flow topology and heat transfer in microchannels

Project Aim

The heat transfer in (laminar) micro-flows depends essentially on the topology of the Lagrangian fluid paths. Aim of the study is to investigate the fundamental connection between heat transfer and flow topology and to explore its potential with regard to control and optimisation of heat transfer in micro-flows.

Progress

First numerical analyses for detailed investigation of the 3D flow topology in a micro-channel as a function of the different flow forcings and system parameters (Reynolds number, Peclet number) have been completed (left figure). The Lagrangian framework for heat-transfer visualisation and Lagrangian heat-transfer analyes in laminar flows has been extended and demonstrated for 3D steady systems (right figure). Furthermore, first exploratory experiments in micro-channels using micro-PIV have been carried out. Currently in progress are further extension of the above Lagrangian framework to 3D unsteady systems, its application to heat-transfer visualisation in micro-channels and continuation of the experimental studies.

Dissertations

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Scientific Publications

1. M.K. Singh, M.F.M. Speetjens, P.D. Anderson, Eigenmode analysis of scalar transport in distributive mixing, Phys. Fluids, 21, 093601, (2009).
2. M.K. Singh, P.D. Anderson, M.F.M. Speetjens, H.E.H. Meijer, Optimizing the Rotated Arc Mixer , AIChE Journal, 54(11), 2809-2822, (2008, appeared in 2009).
3. M.F.M. Speetjens, A.A. van Steenhoven, Visualisation of heat transfer in aminar flows, in Convective Heat and Mass Transfer in Sustainable Energy; Editors: Mourad Rebay, Hammamet, Tunisia, (2009).
4. M.F.M. Speetjens, A.A. van Steenhoven, A way to visualise heat transfer in 3D unsteady flows, in Proceedings HT2009 ASME Summer Heat Transfer Conference; San Francisco, United States, (2009).
5. M.F.M. Speetjens, A way to visualise heat transfer in 3D unsteady flows, in Proceedings 2nd Micro and Nanoflows Conference, West London, United Kingdom, (2009).

Projectleaders

MFM Speetjens, AA van Steenhoven

Researchtheme

Complex structures of fluids

Participants

Z Liu, PR Bloemen

Cooperations

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VV Meleshko, Kiev National Taras Shevchenko University, Ukraine,
G Metcalfe, CSIRO-MMT, Melbourne, Australia, A Reusken, Dept. Mathematics, RWTH, Aachen, Germany

Funded

TUE/W
1st 100% 2nd - 3rd -

Start of the project

2007

Information

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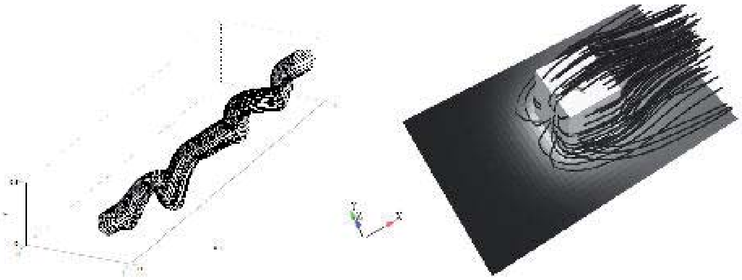

Visualisation of flow and thermal topologies. Panel a: toroidal transport barriers to fluid mixing in a 3D periodic micro-channel; panel b: thermal path emanating from a 3D hot object subject to a cold fluid flow in x-direction. Gray shades indicate temperature (dark: cold; bright: hot).

THERMAL MANAGEMENT BY CONTROLLED BOILING

PROJECTLEADERS
MFM Speetjens, H Nijmeijer, AA van Steenhoven

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
RW van Gils

COOPERATIONS
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FUNDED
TU/e-W (STW-application under review)
1st 100% 2nd - 3rd -

START OF THE PROJECT
2008

INFORMATION
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PROJECT AIM

Key issues in cutting-edge technologies (e.g. micro-electronics, lithographic systems) are massive heat removal and thermal homogenisation. Boiling heat transfer affords solutions to both issues and will play a central role in next-generation thermal-management schemes. However, to this end better control of the boiling process is essential. The study takes a first step towards this aim by the model-based development of control strategies for regu-lation of boiling under dynamic operating conditions in a representative 3D boiling system.

PROGRESS

Numerical and theoretical studies on the dynamics of the 2D closed-loop boiling system have been continued. A stronger link between the continuous and discrete models has been established so as to admit rigorous analyses using general nonlinear-systems methods. Moreover, first regulation and stabilisation of essentially heterogeneous 2D boiling states has been accomplished (left figure) and first exploratory experimental studies have been started in collaboration with ASML. Currently in progress is further analysis of the 2D closed-loop system and first steps towards implementation of the control strategy in the 3D system for stabilisation of 3D boiling states (right figure).

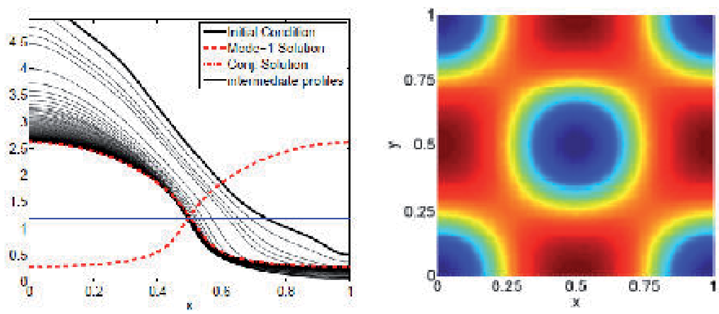
DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. R.W. van Gils, M.F.M. Speetjens, H. Nijmeijer, Feedback stabilisation of a one-dimensional nonlinear pool-boiling system, Int. J. Heat Mass Transfer, doi:10.1016/j.ijheatmasstransfer.2010.01.045, 2009.

Formation and stabilisation of heterogeneous steady states on the fluid-heater interface of heater elements. Panel a: regulation of an initial temperature profile towards an unstable heterogeneous boiling state (dashed) in 2D system. Ppanel b: typical unstable state in 3D system; bluish and redish regions are “low”' (wet) and “high” (dry) temperature zone.



Particle dynamics in magneto-fluidic microsystems

Project Aim

The dynamics of actuated superparamagnetic particles are studied as integrated fluid drivers in high surface area micro systems, which can find application in DNA / antibody screening devices. The magnetic and hydrodynamic interplay between particles, surrounding fluid and boundary walls is studied numerically. Experiments are carried out to evaluate the resulting particle configurations on their fluid driving performance and efficiency.

Progress

Experiments on single and ensembles of magnetic particles in open volumes; Development of computational fluid dynamics models for particles in confined volumes; Design and fabrication of a particle actuation device with an isodynamic force field; Optimization of excimer laser systems for micro channel fabrication; Numerical optimization of particle to channel dimensions for driving fluids; Investigations on the off-axis particle configuration to enhance convective streams; Integration of soft-magnetic micro-structures as magnetic flux guides.

Dissertations

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Scientific Publications

1. Derks RJS, Frijns AJH, Prins MWJ, Dietzel A. Multibody interactions of actuated magnetic particles used as fluid drivers in microchannels. Microfluidics and Nanofluidics, DOI 10.1007/s10404-009-0552, 2009.
2. Derks RJS, Frijns AJH, Prins MWJ, Dietzel A. Magnetic particles as multifunctional carriers and fluid drivers in microsystems, in MNE 2009; Ghent, Belgium, 2009.

Projectleaders
AJH Frijns, MWJ Prins, A Dietzel

Researchtheme
Complex dynamics of fluids

Participants
RJS Derks

Cooperations
Applied Physics, Eindhoven University of Technology

Funded
Eindhoven University of Technology
1st 100% 2nd - 3rd -

Start of the project
2006

Information

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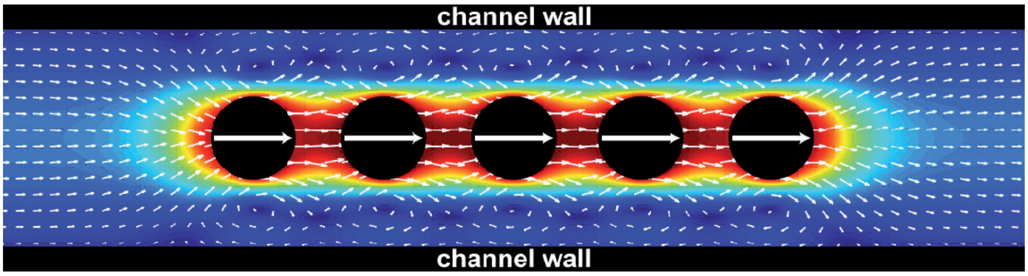

Free surface jetting

Projectleaders
Y Bellouard, AH Dietzel

Researchtheme
Complex dynamics of fluids

Participants
D Tiwari, Y Bellouard, AH Dietzel

Cooperations
TNO-Holst Eindhoven

Funded
TNO and Eindhoven University of Technology.
1st 50% 2nd 50% 3rd -

Start of the project
2008

Information
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Project Aim

The goal of this PhD project is to generate droplets from a free-standing fluid interface.

Progress

An experimental setup was built to study the interaction between ultrashort laser pulses with water. In preliminary experiments on laser-water surface interaction, we observed the formation of bubbles and possibly the formation of a jet or the ejection droplets. To understand the process better, an improved setup consisting of a pump / probe laser beam system has been implemented. The objective is to estimate the time scale of bubble creation and later to study the dynamics of this phenomena. Our current focus is to stroboscopically shadow-image the laser-liquid interaction region so to gain better knowledge about the shape, size and behavior of these laser-induced bubbles.

Dissertations

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Scientific Publications

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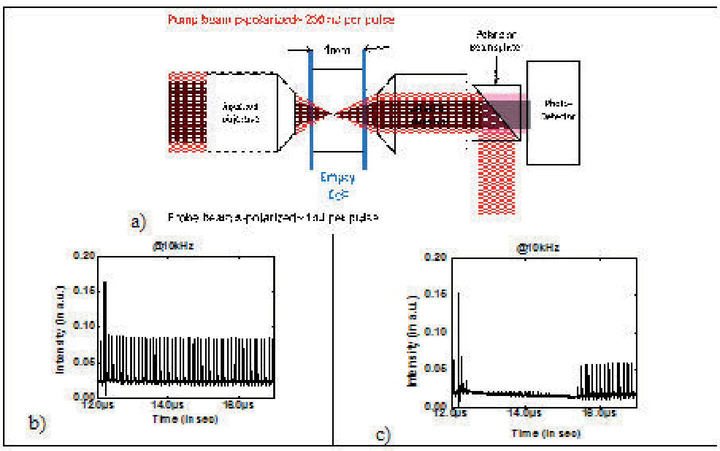
a) Schematic of the probe/pump setup. The two beams with different pulses-repetition rates pass through the same objective. The pump beam interact with the liquid while the low-energy probe beam is use to observe the dynamics of phenomena induced by the pump-beam.
b) Typical photo-detector signal for an emty water cell (c) for a filled water cell.



Microchannel-cooling

Project Aim

There is a tendency that mechanical and electrical components become smaller and smaller. Since most components produce heat when operating, it is essential to cool them in order to perform well and to ensure the life span of such a component. Macroscopic models for heat transfer are not sufficient to describe the cooling mechanisms on this scale anymore. Therefore particle-based models have to be used. The goal of this project is to study the convective heat transfer in micro-devices and evaporative cooling by Molecular Dynamics (MD) and Direct Simulation Monte Carlo (DSMC) techniques and the development of multi-scale simulation methods for gases.

Progress

The MD and DSMC models have been compared in three standard situations, to analyze where the methods are best suited. The evaporative cooling in microchannels is studied by MD simulations, and the thermodynamic effects of bonds in molecules such as O¬2 is studied. The microregion in a microchannel, where the evaporation interface is in contact with the wall, is modelled in full detail, and the enhanced heat transfer in this region studied. The local heat fluxes are well-predicted by the microregion continuum model, but local temperature profiles differ.

Dissertations

-

Scientific Publications

1. E.A.T. van den Akker, A.J.H. Frijns, A.A. van Steenhoven, P.A.J. Hilbers, Validation of Molecular Dynamics simulations of evaporation and condensation of more complex molecules, in Eurotherm Seminar Nr.84; Namur, Belgium, CD, (2009).

Projectleaders

AJH Frijn, AA van Steenhoven

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

EAT van den Akker, JH Kim

Cooperations

PAJ Hilbers, AJ Markvoort, Biomedical Engineering, TU/E
A Frezotti, Milan, ESAS, I
P Stephan, Technische Universität Darmstadt, D, Y Zhang, University of Strathclyde, Glasgow, UK

Funded

MicroNed, GASMEMS (Marie-Curie, FP7)
1st - 2nd - 3rd 100%

Start of the project

2002

Information

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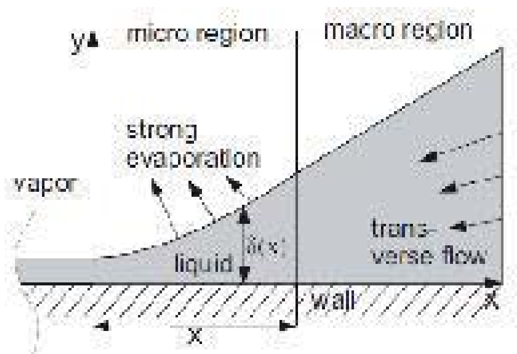
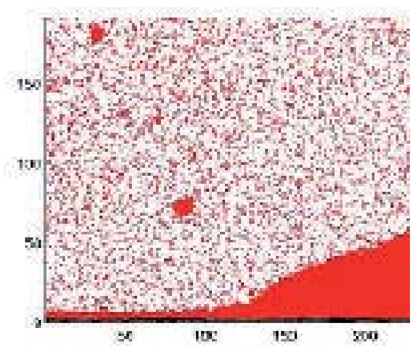
The micro region (left) and a snap-shot of the Molecular Dynamics simulation (right).





Molecular dynamics to enhance the efficiency of compact heat storage

Projectleaders
SV Nedea, CCM Rindt,
AA van Steenhoven

Researchtheme
Complex dynamics of fluids

Participants
E Iype

Cooperations
PAJ Hilbers, AJ Markvoort,
Biomedical Engineering, TU/E
HA Zondag, ECN, A van Duin,
Associate Professor, Mechanical and Nuclear Engineering, Penn State University.

Funded
European Graduate School
1st 25% 2nd 50% 3rd 25%

Start of the project
2009

Information
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Project Aim

To study the dynamics of hydration and dehydration reactions of salt hydrates (MgSO4.7H2O, MgCl2.xH2O etc) from a molecular point of view. The project aims to identify the molecular and structural parameters which limits the kinetics and usability of salt hydrates as thermochemical heat storage materials. This will help to classify such materials based on the storage efficiency, usability, kinetics, reusability etc. This information can be used to identify the best suitable material for thermochemical heat storage.

Progress

Preliminary studies are done on various thermochemical heat storage materials, especially on the molecular structure of hydrates like magnesium sulphate, magnesium chloride etc. A molecular dynamics approach coupled with a reactive force field method is being tried to model the hydration/dehydration reactions of magnesium sulphate. The reactive force field will have to be parameterized using density functional method.

Dissertations

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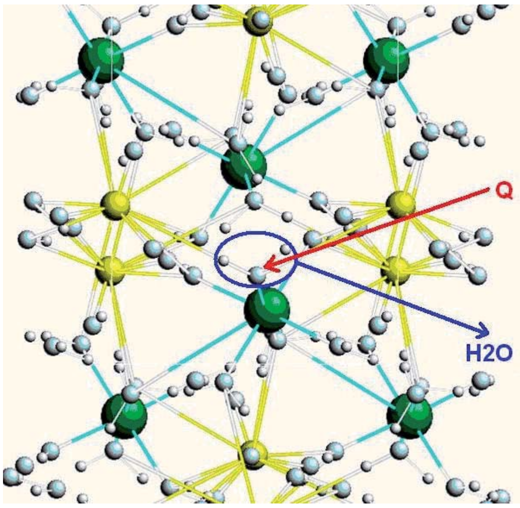
Scientific Publications

1. V.M. van Essen, H.A. Zondag, J. Cot Gores, L.P.J. Bleijendaal, M. Bakker, R. Schuitema, W.G.J. van Helden, Z. He, C.C.M. Rindt, Characterization of MgSO4 Hydrate for thermochemical Seasonal Heat Storage, J. Sol. Energy Engineering, 131(4), 041014, (2009).
2. S.V. Nedea, A.J. Markvoort, A.A. van Steenhoven, P.A.J. Hilbers, Heat Transfer Predictions for Micro-/Nanochannels at the Atomistic Level Using Combined Molecular Dynamics and Monte Carlo Techniques, J. Heat Transfer, 131(3), 33104, (2009).
3. A.J. Brouwer, C.C.M. Rindt, V.M. van Essen, W.G.J. van Helden, A.A. van Steenhoven, Hydration and dehydration of sorption materials: experiments in a small-scale reactor, in Int. Symp. on Convective Heat and Mass Transfer in Sustainable Energy; Editors: Mourad Rebay, Hammamet, Tunisia, paper 130, (2009).



Schematic of the crystalline molecular structure of MgSO4 containing coordinated water. By adding heat the water molecules will be expelled from the system.

Reduction of gas cooler fouling in biomass gasifiers

Project Aim

Fouling of heat exchange equipment used for the recovery of waste heat is an important constraint with respect to the use of such equipment. Because of fouling, the efficiency of such apparatus drops. In the worst case, fouling leads to total failure of the heat exchanger with enormous economical consequences. In this project, fouling in biomass gasifiers is investigated.

Progress

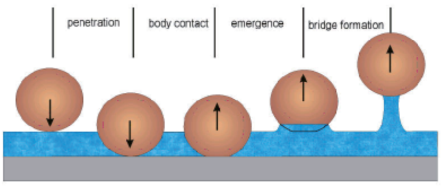
Fouling is defined as the accumulation of particles on a heat exchanger surface forming a layer of very low thermal conductivity which causes maintenance problems leading to economic losses. As observed in large-scale biomass gasifiers, the character of the fouling layer is related to the local gas temperature, velocity and condensable species present in the gas. Till now, most attention has been given to the development of models for the deposition and removal of dry particles from particulate fouling layers as a function of the impaction speed and fouling layer structure. At present, controlled fouling experiments are being carried out to investigate the factors that affect fouling like: gas phase velocity, particle type, particle size, concentration, condensation and gas phase temperature. The experiments are carried out in a specially designed high-temperature, up to 500 degrees Celsius, test-rig. Along with the controlled fouling, experiments for particle impaction over a liquid coated substrate are being carried out to determine the sticking and removal behavior in the presence of a thin liquid film.

Dissertations

-

Scientific Publications

1. M.S. Abd-Elhady, C.C.M. Rindt, A.A. van Steenhoven, Contact time of an incident particle hitting a 2D bed of particles, Powder Techn., 191(3), 315-326, (2009).
2. M.S. Abd-Elhady, C.C.M. Rindt, A.A. van Steenhoven, Optimization of flow direction to minimize particulate fouling of heat exchangers, Heat Transfer Engng., 30(10-11), 895-902, (2009).
3. M.S. Abd-Elhady, S. Abd-Elhady, C.C.M. Rindt, A.A. van Steenhoven, Removal of gas-side particulate fouling layers by foreign particles as a function of flow direction, Appl. Thermal Engng., 29(11-12), 2335-2343, (2009).
4. M.S. Abd-Elhady, C.C.M. Rindt, A.A. van Steenhoven, Infuence of the apex angle of coned shaped tubes on particulate fouling of heat exchangers, in 2009 ECI Conference on Heat Exchanger Fouling and Cleaning; Editors: H. Muller-Steinhagen et al., Schladming, Austria, (2009).
5. K.K Sathyanarayanarao Subbarao, C.C.M. Rindt, A.A. van Steenhoven, Preliminary study of particulate fouling in a high temperature controlled experimental facility, Proceedings of International Conference of Heat exchanger fouling and cleaning, Schladming, Austria



Schematic representation of particle impaction over a substrate coated with a thin liquid film

Projectleaders

CCM Rindt, AA van Steenhoven

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

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Cooperations

ECN Petten

Funded

SenterNovem

1st - 2nd - 3rd 100%

Start of the project

2007

Information

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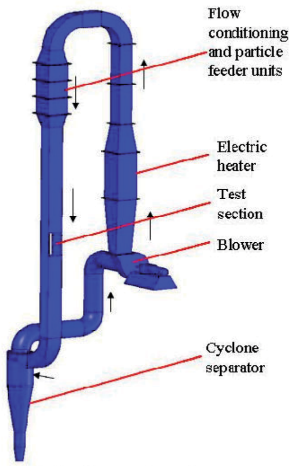

Controlled fouling experimental setup

PROJECTLEADERS
AJH Frijns, AA van Steenhoven
RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis
PARTICIPANTS
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COOPERATIONS
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FUNDED
AMC, TU/e-W, SenterNovem
1st 50% 2nd - 3rd 50%
START OF THE PROJECT
1999
INFORMATION
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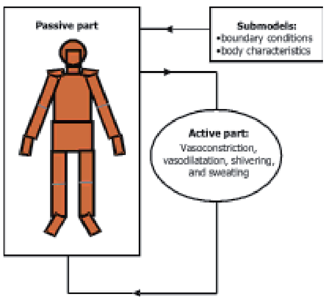
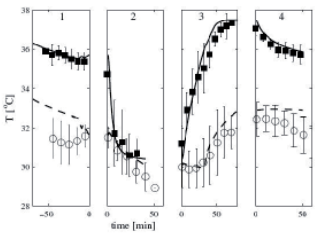


Above: thermo-physiological model; Below: Aortic valve surgery (symbols) and simulations (lines). Four stages are seen: (1) anesthesia stage, (2) cooling with heart lung machine, (3) warming with heart lung machine and (4) post-bypass stage. Upper and lower lines: core and skin temperatures, respectively.



PROJECT AIM

The goal of this project is to develop dynamic and human specific thermal models and to design new heat transfer equipment for rewarming of patients after anaesthetics and to predict thermal comfort in the build environment.

PROGRESS

A whole-body thermal model of a human is developed, including human thermoregulation under "normal conditions" and changes therein brought about by anaesthetics. This will help to predict the effect of possible thermal interventions. This thermo-physiological model will also be used to predict the thermal responses to (changes in) indoor climate. The model will be extended such that, from the skin temperatures and core temperatures, the thermal sensation can be predicted. This will be used to achieve energy savings in housings while ensuring thermal comfort for the occupants.

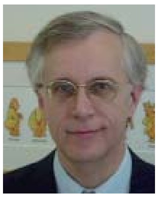
DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. A.J.H. Frijns, N.M.W. Severens, W.D. van Marken Lichtenbelt, B.R.M. Kingma, A.A. van Steenhoven, Measurement of the central vasoconstriction coefficient and local amplification coeffcients for a mathematical thermoregulation model, in PPTR2009, 3rd international symposium on physiology and pharmacology on temperature regulation; Matsue, Japan, CD, (2009).
2. F.E.M. Janssen, G.M.J. van Leeuwen, A.A. van Steenhoven, Heat transfer in patients under hypothermic conditions, in Proceedings ExHFT-7; Krakow, Poland, 71-80, (2009).
3. B.R.M. Kingma, W.D. van Marken Lichtenbelt, A.J.H. Frijns, W.H.M. Saris, A.A. van Steenhoven, Age related attenuation of cutaneous vasoconstrictor response depends on measurement site, in PPTR2009, 3rd international symposium on physiology and pharmacology on temperature regulation; Matsue, Japan, CD, (2009).
4. B.R.M. Kingma, W.D. van Marken Lichtenbelt, A.J.H. Frijns, W.H.M. Saris, A.A. van Steenhoven, Frequency analysis of skin perfusion during whole body cooling in glabrous and non-glabrous skin, in PPTR2009, 3rd international symposium on physiology and pharmacology on temperature regulation; Matsue, Japan, CD, (2009).
5. L. Schellen, W.D. van Marken Lichtenbelt, M.G.L.C. Loomans, A.J.H. Frijns, Jø. Toftum, M.H. de Wit, Thermal comfort, physiological responses and performance of elderly during exposure to a moderate temperature drift, in Proceedings of Healthy Buildings 2009; Syracuse, NY, United States, CD, (2009).
6. N.M.W. Severens, W.D. van Marken Lichtenbelt, A.J.H. Frijns, B.A.J.M. de Mol, A.A. van Steenhoven, Modelling thermoregulation in patients undergoing surgery, in PPTR2009, 3rd international symposium on physiology and pharmacology on temperature regulation; Matsue, Japan, CD, (2009).

Centre for Analysis, Scientific Computing and Applications (CASA)



Prof.dr. RMM Mattheij

The Centre for Analysis, Scientific Computing and Applications (CASA) combines all activities related to analysis at the Department of Mathematics and Computer Science of Eindhoven University of Technology. Its major research objective is to develop new and improve existing mathematical (both analytical and numerical) methods for a wide range of applications in science and engineering. More specifically, the research aims at developing and integrating methods and ideas from mathematical modelling, analysis of partial differential equations and scientific computing. This area of research is commonly known as Computational Science and Engineering (CSE). This is reflected by extensive collaboration with researchers in the technical sciences.

Also contact and cooperation with industrial partners is vital. The chairs participating in CASA are Applied Analysis, Variational Methods and Scientific Computing. Within CASA the research related to fluid dynamics deals with aero-acoustics, porous media, viscous and viscoelastic equations and CFD.

Stork Cryogenic Flow

Project Aim

Development of techniques for the construction of lower dimensional models (nodal, or 1D models) as an alternative of performing full 3D CFD methods, for simulating flow transport in components of the cryogenic industry. These lower dimensional models, should be adequate for their use in the simulation of a network of interconnected process components. The main effects to be captured are those generated by the flow wall shape, some other possible factors to study are: wall roughness, wall heat transfer, non-stationary wall, transitional flow and phase-transition.

Progress

We started with the case of laminar forced flow in axially symmetric pipes. Using the method of slow variations, we computed asymptotic solutions for the flow up to different orders. Based on these asymptotic solutions used, and in combination with an analytical formula for the friction factor derived after integrating the Navier-Stokes equations, we have been able to develop approximate expressions for the friction factor. The expressions so obtained, appear in terms of one dimensional integrals, which can be computed much faster than performing a CFD method. We also have started to validate the method, by making comparisons with the results obtained by CFD for a set of test examples featuring pipes with sinusoidal walls.

Dissertations

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Scientific Publications

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Projectleaders

RMM Mattheij, J Dam,
JHM ten Thije Boonkkamp

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

PI Rosen Esquivel

Cooperations

-

Funded

Stork Inoteq
1st - 2nd - 3rd 100%

Start of the project

2008

Information

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Acoustics of lined flow ducts

Projectleaders
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Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
West University of Timisoara, Romania

Funded
TUE
1st 100% 2nd 30% 3rd 25%

Start of the project
2008

Information
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Project Aim

- Hydro-acoustic instabilities in lined flow ducts.
- The role of the boundary condition for vanishing boundary layer thickness.
- Sound propagation in slowly varying ducts, including modal turning point interaction and exchange of acoustic energy.

Progress

Instability analysis of an incompressible flow with a linear velocity profile. Study of the boundary conditions for vanishing boundary layer thickness.

Instability analysis of an incompressible flow with a tanh velocity profile.

Dissertations

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Scientific Publications

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Stirling-type pulse-tube refrigerators for 4 K

Project Aim

The project concerns pulse-tube refrigerators (PTR) of the Stirling type for the important temperature region of 4 Kelvin. The system that we propose will operate at frequencies which are an order of magnitude higher and pressure amplitudes which are an order of magnitude lower than usual. A numerical model describing oscillating Helium flow in multi-stage coolers is to be developed. The main goals in this project include numerical analysis of the fluid flow in the system as well as employing an efficient method to increase the performance. To take into account the non-ideality of the gas inside the system.

Progress

The governing equations are low-Mach-number approximations of the conservation laws for mass, momentum and. A 2D model of the pulse-tube with domain decomposition and grid refinement close to the wall has been developed. The refinement was needed to accurately compute and detect wall-induced streaming effects. Finally, the 2D model of the pulse-tube was coupled to the 1D model of the regenerator. The single-stage PTR works now for a wide range of low temperatures. A one-dimensional model for a high-frequency three-stage PTR is done which is able to reach about 4 Kelvin. In the last stages of the regenerators at the three-stage PTR all temperature-pressure-dependent material properties are taken into account. The van der Waals equation was the equation of state.

Dissertations

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Scientific Publications

1. Etaati M A, Mattheij R M M, Tijsseling A S, de Waele A T A M, One-Dimensional Simulation of a Stirling Three-Stage Pulse-Tube Refrigerator, Proceedings of the ASME Heat Transfer Summer conference, HT2009-88087, San Francisco, USA, July 19-23, 2009.

Projectleaders
RMM Mattheij

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
MA Etaati, AS Tijsseling

Cooperations
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Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2005

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Numerical shape optimisation in industrial container forming

Projectleaders
RMM Mattheij
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
-
Cooperations
-
Funded
TUE
1st 100% 2nd - 3rd -
Start of the project
2007
Information
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Project Aim

The objective of the research is to develop and analyse numerical optimisation methods for inverse problems in industrial container forming processes. The area of application is temporarily mainly focused on glass blowing and may be extended to the forming of plastic containers in the future. Prior to the development of an optimisation method, well-posedness and sensitivity of the direct and inverse problem will be studied, which is crucial for the choice of the optimisation method.

Progress

A 2D axial-symmetrical glass container blow simulation model has been developed. This model simulates the blow stage of manufacturing glass containers, e.g. bottles or jars. In a blow stage a glass preform is brought into a mould and subsequently blown into a mould shape. The simulation model is based on level set methods. The inverse problem for glass blowing is to determine an optimal preform from the desired container shape. The beforementioned simulation model includes an optimisation method for this inverse problem. The method describes the glass-air interfaces of the preform by parametric curves, e.g. splines, Bezier curves, and finds the optimal positions of the control points of the curves.

Dissertations

-

Scientific Publications

1. Groot, J.A.W.M., Giannopapa, C.G., Mattheij, R.M.M. (2009). Numerical optimization of blowing glass parison shapes. Proceedings 2009 ASME Pressure Vessel and Piping Division Conference (Prague, Czech Republic, July 26-30, 2009).(pp. PVP2009 77946-1/22). ASME.

SPH simulation of transient flow and slug flow in pipelines

Project Aim

Smoothed Particle Hydrodynamics (SPH) numerical techniques are used to model the important problem of liquid slugs moving at high speeds in pipelines. The impact of such slugs at pipe bends, pumps and valves may cause great material damage. Fluid-structure interaction is taken into account to accurately estimate the impact forces. Slug flow, waterhammer and column separation are the phenomena dealt with. Experimental data obtained for the controlled filling and emptying of a large-scale pipe are used for validation.

Progress

A series of laboratory experiments on the controlled filling and emptying of pipelines, and on unsteady friction, has been carried out at Deltares, Delft, within the framework of the European Hydralab III project. The experimental data have been analysed and a test report written. The SPH method has been explored and applied to a set of one-dimensional test problems including waterhammer, column separation and thermal waves.

Dissertations

-

Scientific Publications

1. Vardy A., Bergant A., He S., Ariyaratne C., Koppel T., Annus I., Tijsseling A., Hou Q. 2009 Unsteady skin friction experimentation in a large diameter pipe. Proc. of the 3rd IAHR Int. Meeting of the Workgroup on Cavitation and Dynamic Problems in Hydraulic Machinery and Systems (Editor P. Rudolf), Brno, Czech Republic, October 2009, Paper P10, pp. 593-602.

Projectleaders
RMM Mattheij, AS Tijsseling

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
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Cooperations
University of Nottingham

Funded
The Chinese Ministry of Education
1st - 2nd - 3rd 100%

Start of the project
2008

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SOUND PROPAGATION IN A DUCT WITH SHEARED FLOW AND NON-LOCALLY REACTING LINERS

PROJECTLEADERS
RMM Mattheij, P Sijtsma, S Rienstra

RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis

PARTICIPANTS
P Sijtsma (supervisor NLR),
S Rienstra, B Mattheij, M Oppeneer

COOPERATIONS
Airbus

FUNDED
National Aerospace Laboratory NLR
1st - 2nd - 3rd 100%

START OF THE PROJECT
2009

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PROJECT AIM

The goal of the project is to further develop and make available a class of semi-analytical solutions for the propagation and attenuation of sound in flow ducts, aiming in particular to the reduction of noise from the auxiliary power unit (APU, a turbine engine) of aircraft. Here, the walls of the duct are covered with acoustically damping material, i.c. non-locally reacting liners (e.g. metallic foam). Furthermore, the mean flow exhibits strong shear and temperature gradients. Keywords: duct acoustics, aeroacoustics.

PROGRESS

A literature study has been performed to get acquainted with the physical principles of sound propagation in flow ducts and the modelling of acoustic material. Existing codes at the NLR and the TU/e have been studied. Furthermore, the development of a new code has been started (based on a more robust numerical method), which aims to combine the properties of the existing codes. Currently, the new code is only applicable to simple configurations for which analytical solutions exist, but it has been prepared for extensions for more complex physical behavior, like impedance walls, non-uniform flows. Finally, the development of surface waves in case of absorbing duct walls has been studied.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

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Applied Analysis

Prof.dr.ir. CJ van Duijn

Prof.dr. JJM Slot

The Eindhoven Applied Analysis group focuses on modeling, analysis of nonlinear differential equations and related computational methods. This diverse expertise is applied to a broad spectrum of problems arising in the engineering sciences, physics and industry. The philosophy is to contribute to the solution of relevant problems in these applied sciences as well as to participate in the development of the underlying mathematical framework. At the moment the main areas of applications are fluid mechanics, rheology, material science (including polymers) and porous media. For example:

Porous media

Porous media are (micro-) structures that appear in many disciplines of science and engineering, like ground water hydrology, soil mechanics, petroleum engineering, bioremediation, agricultural science, tissue engineering, or paper production. Typical for such problems is that different phenomena take place on different scales. One of the research topics is upscaling microstructures to macromodels. Examples are problems from hydrology, like groundwater flow, in particular seawater intrusion in coastal waters, contamination of aquifers, or subsurface storage of materials.

Thermo acoustics

Thermo acoustics, broadly speaking, deals with all kinds of acoustic effects in which heat conduction and entropy variations in the gaseous medium play a role. Although the study of these phenomena dates back to Lord Rayleigh, it has increasingly become an active area of research with lots of potential applications ranging from upgrading of industrial waste heat to environmentally friendly refrigeration. A focal area of interest is the development of mathematical models for the two main classes of thermo acoustic devices: prime movers that convert heat into sound and heat pumps that convert sound into heat.

Aero acoustics

One of the many measures taken to reduce the noise of aircraft engines is the application of acoustic lining in the inlet and bypass duct. In order to optimize the damping properties we need to model the sound propagation through the duct. By utilizing the inherent slow variation of a typical flow duct we found an analytic asymptotic solution of the problem that appeared to compare very favorably with proven numerical solutions. This solution was the starting point of a series of similar solutions for related cases, while it has been used to produce a superior matching procedure to connect CFD-type source data to the acoustic field, which is now being used throughout Europe to support CAA implementations.

Rheology

Rheology is the branch of science focusing on the flow and deformation behavior of complex materials. Complex materials often contain long molecules and/or particles that give them particular flow and deformation behavior in comparison with simple fluids like water or simple solids like pure metals. Examples can be found in industry, the environment, living systems and around the house: paints, polymer processing, production of tires, ink, glues, pharmaceutical -, agricultural - and cosmetic products, in oil production, production of photographic materials, displays and magnetic tapes, food products such as mayonnaise, cheese, margarine, domestic products like toothpaste and liquid detergents, mud, clay, blood and saliva. As in all branches of science also in rheology, in addition to experiment, mathematical modeling and numerical simulation play a very important role. From its inception in the beginning of the last century, when it involved almost exclusively continuum mechanics and constitutive modeling, rheology heavily relies on disciplines belonging to classical applied mathematics, such as differential equations, functional analysis, perturbation theory etc. However, with the increasing focus on the relationship between microscopic structure/processes and macroscopic properties of these complex materials nowadays, probability theory and in particular the theory of stochastic processes has become an essential discipline too. Currently, two focal areas of interest are the constitutive modeling of concentrated solutions of main chain liquid crystalline polymers and that of melts of entangled arbitrarily branched polymers.

Dynamic capillarity in porous media

Project Aim

This work will address mathematical and numerical analysis questions related to non-standard porous media flow models, and investigate the effect of different capillary pressure assumptions. In particular, we seek for non-standard entropy solutions to two-phase porous media flow problems, as limit cases when the capillary effects vanish.

Progress

In 2009 we continued investigating nonlinear and possibly degenerate models for two-phase flow problems involving a dynamic capillary pressure. We proved the existence of travelling wave solutions to such problems. In particular, for degenerate cases, we identify non-standard, sharp front travelling wave solutions. The numerical simulations agreed well with the theory.

Furthermore, we have analyzed numerical methods for pseudo-parabolic problems, paying a particular attention to the eventual occurrence of discontinuities. Also a semi-analytic approach was developed for a mathematical model based on the interfacial area concept.

Dissertations

-

Scientific Publications

1. I.S. Pop, J. Niessner, C.J. van Duijn, S.M. Hassanizadeh, Horizontal redistribution of fluids in a porous medium: the role of interfacial area in modeling hysteresis, Adv. Water Resour. 32 (2009), pp. 383-390.
2. C.M. Cuesta, I.S. Pop, Numerical schemes for a pseudo-parabolic Burgers equation: discontinuous data and long-time behaviour, J. Comput. Appl. Math. 224 (2009), pp. 269-283.

Projectleaders

CJ van Duijn

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

Y Fan, IS Pop, CJ van Duijn

Cooperations

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Funded

TUE

1st 100% 2nd - 3rd -

Start of the project

2008

Information

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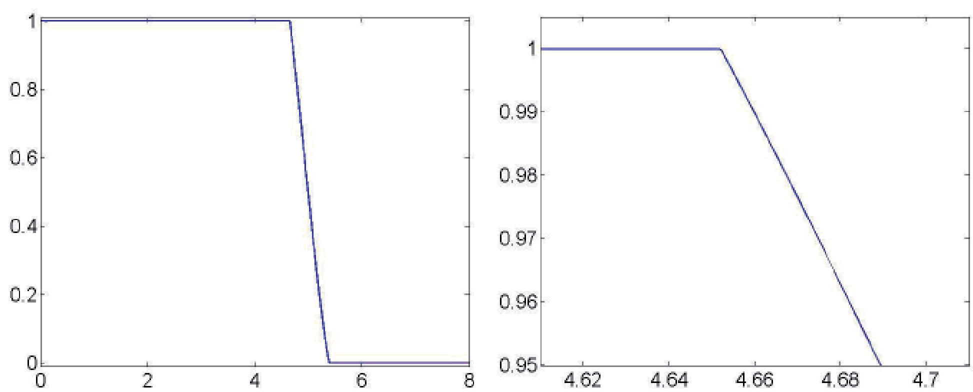

A sharp front TW solution (left); zoomed view in the discontinuity of the derivative (right)

Second generation of integrated batteries

Projectleaders
P Notten, MA Peletier, IS Pop
Researchtheme
Complex dynamics of fluids
Participants
K Kumar, TL van Noorden, P Notten, MA Peletier, IS Pop
Cooperations
Prof. R. Helmig (Stuttgart)
Prof. W. Jäger (Heidelberg)
Prof. A. Mikelić (Lyon)
Dr. M. Neuss-Radu (Heidelberg)
Funded
STW
1st 25% 2nd 50% 3rd 25%
Start of the project
2008
Information
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Project Aim

The project is related to the development of all-solid state rechargeable batteries having a high storage capacity. Such devices have a complex 3D geometry for the electrodes to enhance the surface area. The challenges are in the development of the appropriate technologies for the formation of these electrodes. In particular we focus on chemical vapor deposition processes (CVD), with the aim of getting a deeper understanding of the reactions taking place in a complex geometry.

Progress

Depending on the size of the reaction domain, the changes in the pore structure that are due to the deposition process may or may not be neglected. In mathematical terms, the models are defined in a fixed, respectively variable geometry, when the deposition layer generates a free boundary at the pore scale. So far we have developed mathematical models for both situations. For the fixed geometry model we have carried out numerical simulations showing a good agreement with the experimental results obtained for the deposition of Titanium dioxide inside trenches of different diameters, This work has implied determining the physical and chemical parameters. Furthermore, to understand the flow in a domain with variable geometry, we have considered a thin strip with reactions taking place at the lateral boundaries of the strip under dominant transport conditions. We have derived upscaled equations for the solute concentration, which are similar to the Taylor dispersion.

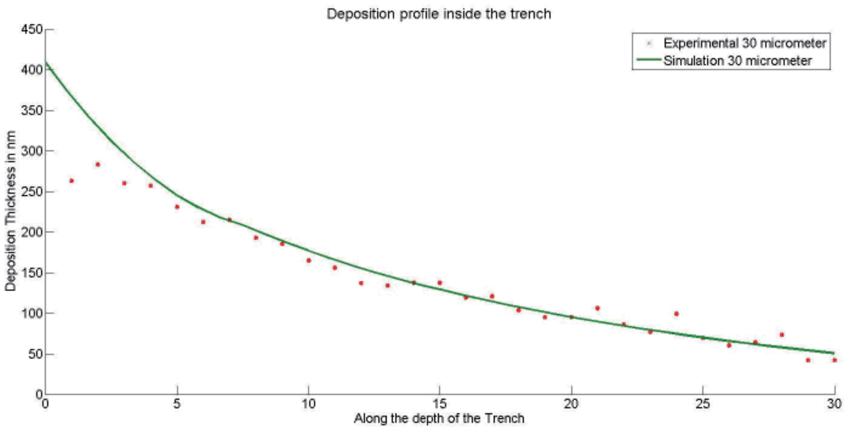
Dissertations

-

Scientific Publications

1. F. van Beckum, J.B. van den Berg, S. Boettcher, M. de Gee, K. Kumar, J. van Opheusden, Stiffening while Drying, Proceedings of the Sixty-Seventh European Study Group Mathematics with Industry, Wageningen, Netherland, 2009, 81-95.

Film thickness profile in trenches of 30 μm wide



Constitutive modeling of concentrated solutions of main-chain liquid crystalline polymers

Project Aim

The primary objective of this project is to develop a molecularly based constitutive model for the rheological behavior of concentrated solutions of main-chain liquid crystalline polymers (LCP) that may show nematic order. The model will be restricted to monodomain (single director) morphologies and the main focus will be on the role that chain flexibility plays in this behavior.

Progress

In 2009 a Rouse-like model for the description of highly-ordered concentrated solutions of LCP was developed and in the framework of this model the linear viscoelastic response in elongational flow was analysed. These results were presented in june on a TU/e-CASA-day and an internal CASA report about this work was written. A subsequent attempt to describe shear flow within this framework revealed the necessity to weaken the condition of high nematic ordering. We then derived an extended model that described the orientational degrees of freedom of the nematogen units more accurately, but involved some ad-hoc assumptions. In the last quarter of 2009 we started to rederive this model within the framework of the Curtiss-Bird-Hassager phase space kinetic theory in order to avoid these assumptions. This work is still in progress.

Dissertations

-

Scientific Publications

-

Projectleaders
JJM Slot

Researchtheme
Complex dynamics of fluids

Participants
O Matveichuk

Cooperations
Prof. dr. J. Molenaar (WUR),
Prof. dr. S. Picken (TUD),
Teijin Aramid R&D

Funded
Teijin-Aramid BV
1st - 2nd - 3rd 100%

Start of the project
2008

Information
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Mathematical models for chemical processes in porous media

Projectleaders
CJ van Duijn
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
CJ van Duijn, TL van Noorden, IS Pop
Cooperations
Prof. C Eck (Bielefeld University), Prof. R Helmig (University of Stuttgart), Prof. A Mikelić (University of Lyon 1, France), F Radu (University of Jena), M Röger (Max Planck Institute of Mathematics, Leipzig)
Funded
BSIK-BRICKS
1st 25% 2nd 50% 3rd 25%
Start of the project
2003
Information
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Project Aim

The project focuses on the derivation and the analysis of mathematical models for reactive flow in porous media. Specifically, we propose mathematical models for crystal dissolution and precipitation at the micro scale. These models are investigated analytically and numerically. Based on this knowledge, we seek for a rigorous mathematical derivation of macroscopic models.

Progress

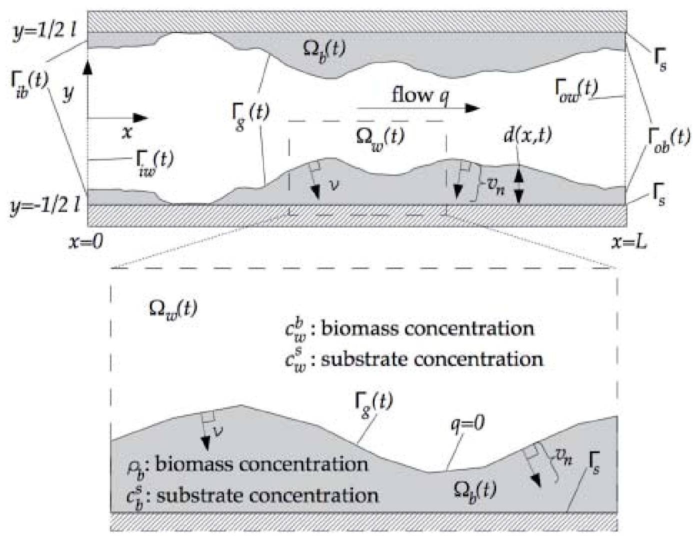
We are interested in chemically reacting flow in porous media. The analysis is carried out on the pore scale level, where dissolution and precipitation reactions are taking place on the boundary of the porous matrix. We assume that crystals have a size that cannot be neglected when compared to the pores, and propose a model that accounts for the changes in the flow domain. We have formulated a phase field model for the microscale dissolution-precipitation reaction. Furthermore, we have applied our formal upscaling results to a model describing biofilm growth in a thin strip. In addition we have considered different flow regimes and we have obtained formal upscaled models in the Taylor disspersion regime.

Dissertations

-

Scientific Publications

1. van Noorden, T. L. Crystal precipitation and dissolution in a thin strip. European J. Appl. Math. 20 (2009), no. 1, 69—91.
2. van Noorden, T. L. Crystal precipitation and dissolution in a porous medium: effective equations and numerical experiments. Multiscale Model. Simul. 7 (2009), no. 3, 1220--1236.
3. Mikelic, A., van Duijn, C.J, Rigorous derivation of a hyperbolic model for Taylor dispersion. CASA Report No. 09-36, Technische Universiteit Eindhoven (2009).



Schematic representation of a two-dimensional, thin strip with a biofilm attached to the strip boundary.

High-amplitude oscillatory gas flow in interaction with solid boundaries

Project Aim

The central theme of this research is the understanding of the energy balance in the aeroacoustic generation of sound and the thermoacoustic heat pumping mechanism at high sound amplitudes. The current state-of-the-art knowledge models use low sound amplitudes where linear models are sufficient. At high sound amplitudes the nonlinear phenomena are not well understood and holdback further progress and breakthroughs in this field. We propose several novel methods and techniques in order to get a grip on the nonlinear processess and to develop a nonlinear theoretical model. Validation of the theoretical predictions with experimental results will be a second focus of the project.

Progress

The article "Weakly nonlinear thermoacoustics for stacks with slowly varying pore cross-sections" was published in the Journal of Fluid Mechanics. A number of more publications are on the way. The part of the project under the charge of the Department of Mathematics and Computer Science was finalised by the defence of the dissertation by Peter in't panhuis at Eindhoven June 25, 2009.

Dissertations

1. Mathematical Aspects of Thermoacoustics" by Peter in't panhuis at Eindhoven June 25, 2009.

Scientific Publications

1. Weakly nonlinear thermoacoustics for stacks with slowly varying pore cross-sections" by P.H.M.W. in 't panhuis, S.W. Rienstra, J. Molenaar, J.J.M. Slot, Journal of Fluid Mechanics, Volume 618 (2009), pages 41-70.

Projectleaders

JCH Zegers, H Slot, SW Rienstra

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

PHWM in't panhuis, PCH Aben, SW Rienstra, JJM Slot, JCH Zeegers, A Hirschberg, ATAM de Waele

Cooperations

Prof. J. Molenaar, WUR, TU/e Physics Low Temperature Group (Prof.dr. ATAM de Waele, Dr.ir. JCH Zeegers, Prof.dr.ir. A. Hirschberg), ECN Petten, Shell Rijswijk, Aster Thermoacoustic

Funded

STW

1st - 2nd 100% 3rd -

Start of the project

2005

Information

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Constitutive modeling of arbitrary branched polymer melts

Projectleaders
JJM Slot

Researchtheme
Complex dynamics of fluids

Participants
V Shchetnikava

Cooperations
Prof. dr. P.D. Iedema, UvA

Funded
Dutch Polymer Institute (DPI)
1st - 2nd - 3rd 100%

Start of the project
2009

Information
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Project Aim

The primary objective of this project is to develop a molecularly based constitutive model for the rheological behavior of polymer melts consisting of arbitrary branched polymer molecules. An industrially relevant and prime example of such a system is provided by a melt of low-density polyethylene (ldPE). As such a system shows such an extreme variation in molecular composition, a description of this composition can only be given in statistical terms. Hence, the idea is to describe such a system by a finite set (ensemble) of representative molecular structures (topologies). Such an ensemble can be obtained via a combination of kinetic modeling and Monte Carlo simulation.

The work on kinetic modeling and Monte Carlo simulation will be done at the University of Amsterdam in a twin PhD project (not part of the JMBC).

Progress

The project started in September 2009. The remaining period in 2009 was mainly devoted to a study of relevant literature.

Dissertations

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Scientific Publications

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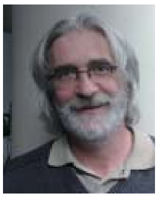
Cardiovascular Biomechanics



Prof.dr.ir. FN van de Vosse

The Cardiovascular Biomechanics group at the department of Biomedical Engineering aims to promote the use of experimentally validated predictive mathematical modeling, both in diagnosis and selection of therapy in clinical practice as well as in research and development in the medical device industry. The research in the group is divided in 4 areas of which the first is embedded in JMBC.

1. Hemodynamics

Hemodynamic factors such as like local pressure, velocity, wall shear stress and wall deformation are crucial for the proper functioning of the vascular system, the heart and its native valves. These factors play a key role in the genesis of vascular disease and, when measured properly, can also be predictive for the development of cardiovascular disease. Hemodynamics research in the group is focused on the development of mathematical models and the corresponding computational methods based on finite and spectral element approximations. These models are used to understand the functioning and response of the cardiovascular system. The models range from 0D lumped parameter and 1D wave propagation models of the entire cardiovascular system to 3D models of local fluid-structure interaction in specific arterial segments and heart valve dynamics. Both microscopic (blood as a suspension) as well as macroscopic (blood-wall interaction) scales are considered. In vitro laboratory experiments and measurement techniques are designed and used to validate the outcome of the computational simulations.

2. Mechanics and adaptation

Cardiovascular mechanics research is focused on the understanding of the mechanical response of vascular and cardiac tissue to mechanical loads, caused by the pulse wave propagation and cardiac contraction, as well as external forces caused by medical interventions.

3. Instrumentation and devices

Medical instrumentation and devices like ultrasound image modalities, pressure and flow sensors, particularly those used for advanced diagnostic measurements.

4. Clinical research

Through pilot or full clinical studies, in which patient data are gathered and used as input for patient specific modelling, evaluation of the predictive value of mathematical models to predict outcome of medical intervention can be performed.

Vascular remodeling after the creation of an arteriovenous fistula for hemodialysis

Project Aim

Hemodialysis dependent patients, need a well-functioning vascular access to connect them with the dialyzer. Usually, the vascular access is surgically created by making a connection between an artery and a vein in the arm. For the planning of the type of vascular access for each individual patient, it is very important to preoperatively predict the postoperative flow increase and vessel remodeling. A lumped patient-specific computer simulation model, based on preoperative MRA and duplex data, is developed to give insight in the postoperative blood flow increase and failure incidence for different fistula configurations.

Progress

We evaluated a lumped model for a vessel segment in which the element configuration is based on physical phenomena described by the boundary layer model and for which all parameters have a physically based quantitative value dependent on the Womersley number. The proposed electrical analog consists of a resistor and an inductor arranged in parallel, representing the flow impedance in respectively the vessel core and the boundary layer, in series with a second resistor. After incorporating a capacitor representing the vessel compliance in this rigid tube model, the element configuration resembles the configuration of the four-element windkessel model. In the limits for small and large Womersley numbers the relative impedances of the proposed lumped model corresponds to Womersley theory. Special elements for the pressure loss at the anastomosis have been developed.

Dissertations

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Scientific Publications

1. W. Huberts, E.M.H. Bosboom, F.N. van de Vosse, A lumped model for blood flow and pressure in the systemic arteries based on an approximate velocity profile function, Math. Biosc. Eng., 6(1), 27-40, (2009).

Projectleaders
FN van de Vosse, EMH Bosboom

Researchtheme
Complex dynamics of fluids

Participants
W Huberts

Cooperations
Maastricht University Medical Centre (MUMC).

Funded
MUMC, FP7 ARCH
1st 50% 2nd - 3rd 50%

Start of the project
2006

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Schematic representation of the 1D-0D equivalence for pulse wave propagation in elastic tubes (Huberts et al., 2009).

PROJECTLEADERS
FN van de Vosse, ACB Bogaerds
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
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COOPERATIONS
Philips Helthcare, University of Sheffield
FUNDED
Philips Healthcare.
1st - 2nd - 3rd 100%
START OF THE PROJECT
2006
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PROJECT AIM

Cerebral aneurysms are localized, thin walled dilatations of the arterial wall in the brain. The major risk is rupture, for which a parametric estimate is sought. A 1D wave propagation model and 3D computational fluid dynamics (CFD) model are combined in order to make full use of each model's strength. A biomechanical analysis of flow and stress based on patientspecific input is used to improve the diagnostics. The computational methods are validated using clinical measurements of pressure and flow and 3D PIV measurements in in-vitro set-ups.

PROGRESS

The 1D wave propagation model has been made patient specific by definition and implementation of proper in- and outflow conditions. An optimized formulation of the interface conditions at bifurcations has been derived and implemented. For different virtual patients the influence of the injection of contrast agent on local pressure and flow phenomena have been investigated. The analisis shows that the influence of contrast injection is nearly time independent but strongly depends on the location in the arterial tree at which pressure and flow are analysed.

DISSERTATIONS

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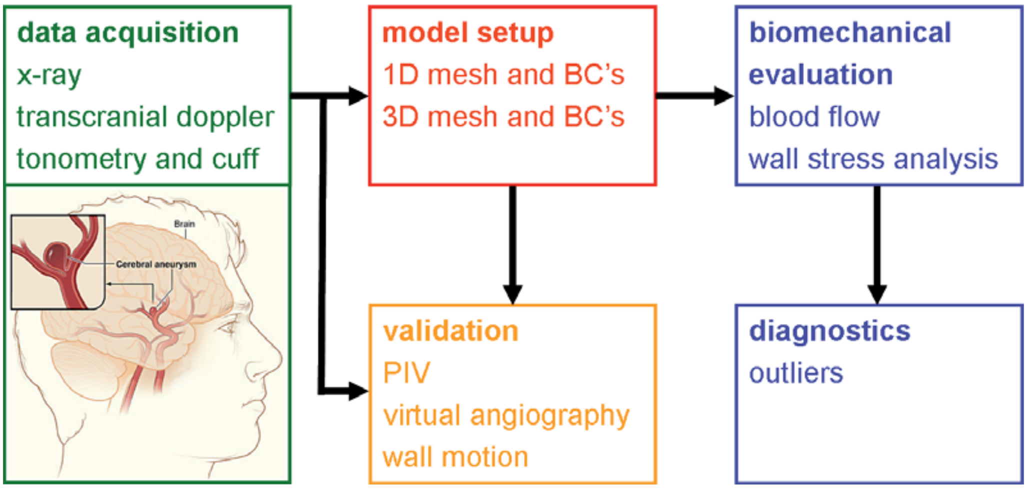
SCIENTIFIC PUBLICATIONS

1. G. Mulder, A.C.B. Bogaerds, P.M.J. Rongen, F.N. van de Vosse, On automated analysis of flow patterns in cerebral aneurysms based on vortex identification, J. Eng. Math., 64, 391-401, (2009).

Schematic outline of the fluid dynamics in cerebral arteries project (see also Mulder et al., 2009).



Transitional flow through mechanical heart valves

Project Aim

In healthy blood vessels, flow is in general laminar and standard computational methods like finite element or finite volume methods based on the linearized Navier-Stokes equations can be used. Distal to mechanical heart valves also transitional (transition to turbulence) flow with small scale local velocity fluctuations can be found. This study will focus on the implementation of spectral elements for fluid structure interaction. The simulations will be compared to flow experiments obtained with PIV, LDA or ultra sound measurements in an in-vitro set-up.

Progress

Methods to obtain flow from ultrasound velocity profiles in complex flow configurations (curved tubes) have been evaluated. Possibilities to apply different fluid structure strategies to high order spectral methods have been investigated from literature studies. Basic spectral element code has been inplemented in an in-house finite element libraray (TFEM) that allows for future fluid structure interaction analysis. First numerical test studies show the superior convergence properties of the spectral element approximations.

Dissertations

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Scientific Publications

1. A.C. Verkaik, B.W.A.M.M. Beulen, A.C.B. Bogaerds, M.C.M. Rutten, F.N. van de Vosse, Estimation of volume flow in curved tubes based on analytical and computational analysis of axial velocity profiles, Phys. Fluids, 21, 023602, (2009).

Projectleaders
FN van de Vosse, ACB Bogaerds

Researchtheme
Complex dynamics of fluids

Participants
AC Verkaik

Cooperations
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Funded
TUE
1st 100% 2nd - 3rd -

Start of the project
2008

Information

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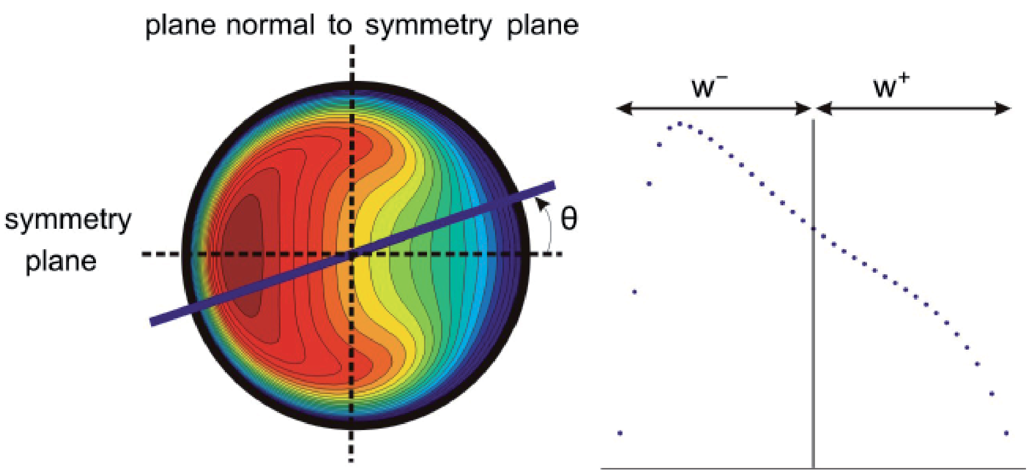
Simulated curved tube flow assessment from ultrasound velocity profiles along an arbitrary line (Verkaik et al., 2009).



Probing red blood cell mechanics

Projectleaders
FN van de Vosse, ACB Bogaerds
Researchtheme
Complex dynamics of fluids
Participants
RCH van der Burgt
Cooperations
TU/e Mechanical Engineering
TU/e Applied Physics
Funded
TU/e High Potential Research
Program: Blood in Motion
1st 100% 2nd - 3rd -
Start of the project
2009
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Project Aim

Because of the high volume contents of red blood cells (RBCs) in blood, mechanics of a single RBC plays a large role in plasma mixing and lateral transport of its components. Therefore, a characterization of the dynamical parameters of RBCs under different flow conditions is needed. Our strategy involves estimation of mechanical properties of the RBC using an inverse analysis which combines both numerical and experimental tools.

Progress

We designed a contactless experiment where a RBC is deformed in elongational flow. To this end, the RBC must be kept in the center at the stagnation point, which is an inherently unstable situation. Cell positioning is achieved by controlling the out flow ratio as a function of the cell position, which is tracked with a microscope. We numerically address the question whether the control system will be able to keep the cell at the preferred position. To estimate the necessary out flow ratio, 2D simulations are performed with fluid-structure interaction (FSI), which is modeled with a fictitious domain technique.

Dissertations

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Scientific Publications

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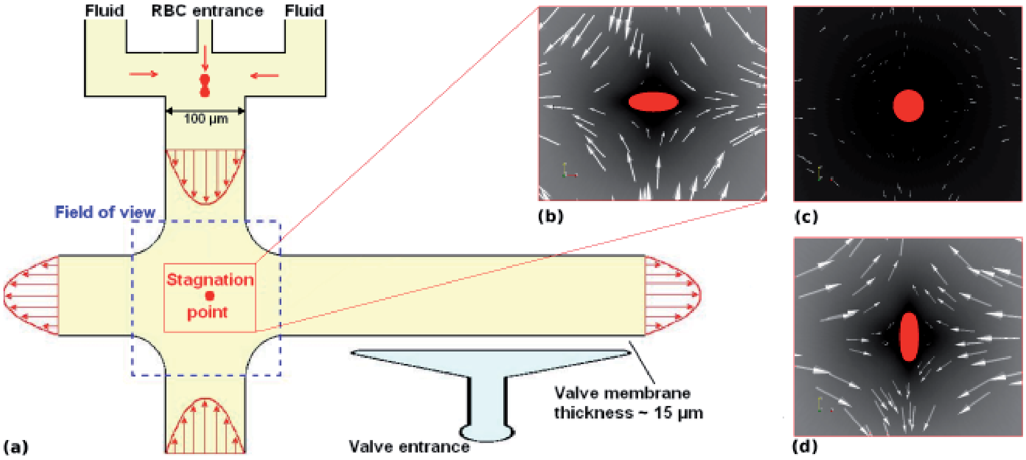
Cross slot configuration to probe the mechanical properties of red blood cells (unpublished).



Fundamentals of Chemical Reaction Engineering

Prof.dr.ir. JAM Kuipers

The research group FCRE participates amongst others in the OSPT and the JMBC for fluid mechanics and focuses on fundamentals of the discipline of chemical reaction engineering. Our main area of interest is the quantitative description of transport phenomena (including fluid flow) and the interplay with chemical transformations in multiphase chemical reactors. The generation of new knowledge and the development of new reactor models with improved predictive capability for this industrially important class of chemical reactors constitutes an important goal of our research activities. Through the intended co-operation with other (application oriented) research groups, both fundamental aspects and those closely related to applications will be studied through concerted action. The main research topics of the new group FCRE can be divided into the following three areas: Multiphase Reactors, Advanced Experimental Techniques and Novel Reactors, which will be discussed below in more detail.

An important area of attention is the development of advanced reactor models for multiphase reactors with industrial relevance. At present our research focuses on the hydrodynamics in these reactors because it is generally recognized that the lack of understanding of the flow phenomena is one of the central difficulties in the design and scale-up of multiphase reactors. In the near future the interplay of flow phenomena with chemical reactions will be studied in great detail. We use various types of CFD models (both commercial codes but mostly “in house” made codes) to study the relevant hydrodynamic phenomena at all relevant length and time scales (i.e. at the microscopic, mesocopic and macroscopic scale). In our group both multifluid models are being developed and models which treat the dispersed phase (particles, bubbles or droplets) in a discrete manner accounting for possible encounters between the dispersed elements.

The second important area of our research deals with the development of advanced experimental techniques to measure key quantities (i.e. local volume fractions and velocities of the dispersed and continuous phase). As an example we can mention the development of the digital particle image velocimetry technique to measure in a non-intrusive manner the velocity map of both the liquid phase and dispersed gas bubbles in (dense) gas-liquid dispersions. This type of flow very often arises in a variety of gas-liquid contactors/reactors. In this area we co-operate with specialists within the J.M. Burgerscentrum for fluid mechanics. Of course this research activity is intimately connected to the first research topic. Our third important area of research deals with the development of novel (multiphase) reactors with emphasis on integration and intensification of relevant process steps. As an example we can mention here the Rapid Reaction Cycling Reverse Flow (RRCRF) which integrates (in a thermal sense) endothermic and exothermic heterogeneously catalyzed chemical reactions where the endothermic reaction causes rapid (reversible) catalyst deactivation. These types of chemical reaction systems often arise in practice for instance in the production of lower alkenes form the corresponding alkanes via heterogeneously catalyzed dehydrogenation. The knowledge and tools developed within the other two areas of attention provide a sound basis to place this research activity on a firm footing.

Computational fluid dynamics and radio-active particle tracking of fluidized bed reactors

Project Aim

The main objective of this project is to develop a profound and fundamental understanding of particle mixing and circulation patterns in poly-dispersed gas-solid fluidized beds resulting in a predictive model for up-scaling of fluidized beds.

Progress

This project was finished in June 2009.

Dissertations

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Scientific Publications

1. J.A. Laverman, M.J. Ten Bulte, M. Van Sint Annaland, J.A.M. Kuipers (2009): Experimental and computational investigation on the macroscopic circulation patterns in a bubbling gas-solid fluidized bed, 8th World Congress of Chemical Engineering, Montreal, August 23-27, 2009.

Projectleaders

JAM Kuipers

Researchtheme

Complex dynamics of fluids

Participants

M van Sint Annaland, JA Laverman

Cooperations

Prof. J. Seville, (Un. of Birmingham)

Funded

DPI

1st - 2nd 100% 3rd -

Start of the project

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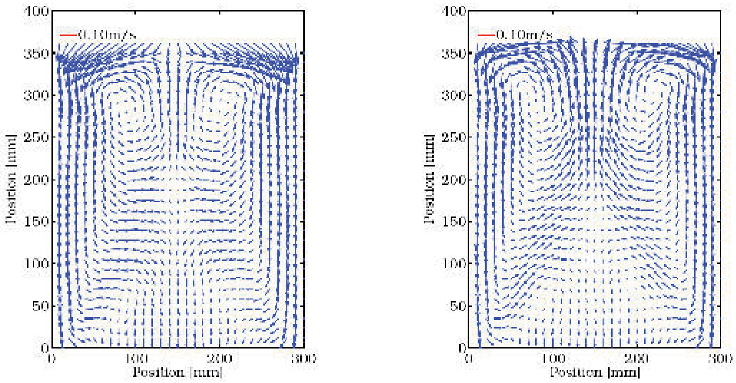
Time-averaged emulsion phase velocity profiles for 2.5 u/umf in a 030 m fluidized bed filled with glass beads, before filtering with DIA (left) and after filtering using DIA (right).



Experimental and computational study of high pressure fluidization of polymeric materials

Projectleaders
JAM Kuipers
Researchtheme
Complex dynamics of fluids
Participants
NG Deen, W Godlieb
Cooperations
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Funded
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Start of the project
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Project Aim

The goal of this project is to gain inside in the fluidization behaviour of the polyethylene particles at elevated pressure, using sophisticated state-of-the-art CFD models and non-intrusive electrical capacitance tomography measurement techniques.

Progress

This project was finished in May 2009.

Dissertations

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Scientific Publications

1. W. Godlieb, S. Gorter, N.G. Deen and J.A.M. Kuipers (2009): DEM and TFM simulations of solids mixing in a gas-solid fluidized bed, 7th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries, December 9-11, Melbourne, Australia.

Toward a reliable model for industrial gas-fluidized bed reactors with polydisperse particles

Project Aim

Fully resolved simulations of industrial sized fluidized beds are still far beyond the capabilities of current computers. Thus coarsened models have to be used, which do not resolve the flow on length scales comparable to the size of the fluidized particles. To account for physical effects on these small scales, such as momentum exchange between gas and solids, closures are required. Aim of this project is to obtain closures for the drag force in polydisperse particle gas system using results obtained from lattice Boltzmann and CFD–IBM simulations.

Progress

The lattice Boltzmann method was used for fully resolved simulation of the flow through random arrays of particles. The effect of changes in the local particle configuration on the drag force an individual particle feels was investigated. Initially a random array of particles was created and subsequently changed only at a distance greater than a radius R and the fluctuations of the drag with respect to the mean value was calculated from the simulation results(see figure). Furthermore an immersed boundary method (IBM) was implemented in an in-house CFD code and is currently validated.

Dissertations

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Scientific Publications

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Projectleaders
JAM Kuipers

Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
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Funded
NWO
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Start of the project
2006

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PROJECTLEADERS
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RESEARCHTHEME
Complex dynamics of fluids
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COOPERATIONS
Prof. Heinrich (TU Hamburg)
FUNDED
FOM, STW, EZ, Yara Sluiskil
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START OF THE PROJECT
2006
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PROJECT AIM

The aim of the project is to develop models that can be used to obtain the desired detailed, fundamental knowledge of granulation processes. In the project an existing discrete particle model will be used to also incorporate the presence of droplets. Thus a discrete element model (i.e. particles and droplets) model is obtained, incorporating the relevant processes at the level of individual elements. The discrete element model will be validated by comparing the simulation results with measurement results from Electrical Computed Tomography (ECT), Positron Emission Particle Tracking (PEPT) and combined Particle Image Velocimetry / Digital Image Analysis (PIV/DIA).

PROGRESS

Refinement of the existing discrete element model (DEM) has been continued by validating the incorporation of a droplet size distribution and implementation of the equation of motion of droplets and different drag relationships for the droplets. This validation has been successfully fulfilled and the DEM model is further developed. It was found that the collision properties, described by the restitution coefficient, have great influence on the bed dynamics. The restitution coefficient has therefore been changed into a moisture dependent variable, to define the effect of the droplets on the inter-particle interaction. Additionally, evaporation of moisture from the particles has been accounted for.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. M.S. van Buijtenen, N.G. Deen, S. Heinrich, S. Antonyuk, J.A.M. Kuipers (2009): A discrete particle simulation study on the influence of restitution coefficient on spout fluidized bed dynamics, Chemical Engineering & Technology, Volume 32, No. 3, Pages 454-462.
2. M.S. van Buijtenen, N.G. Deen, S. Heinrich, S. Antonyuk, J.A.M. Kuipers (2009): A discrete element study of wet particle-particle interaction during granulation in a spout fluidized bed, Canadian Journal of Chemical Engineering, Volume 87, Issue 2, Pages 308-317.
3. S. Antonyuk, S. Heinrich, M. Dosta, M.S. van Buijtenen, N.G. Deen and J.A.M. Kuipers (2009): Effect of the liquid layer on the impact behaviour of particles, 9th International Symposium on Agglomeration, 22 - 26 June 2009, Sheffield, UK.
4. M.S. van Buijtenen, M. Börner, N.G. Deen, S. Heinrich, S. Antonyuk and J.A.M. Kuipers (2009): An experimental study of the effect of collision properties on spout fluidized bed dynamics, 9th International Symposium on Agglomeration, 22 - 26 June 2009, Sheffield, UK..

PROJECT AIM

The aim of the project is to obtain a better understanding of gas-liquid bubbly flows in bubble columns in the heterogeneous regime by applying various measurement techniques and numerical models.

PROGRESS

A four-point optical fibre probe was used to study properties of bubbles, such as bubble velocity, bubble size, etc. The effect of bubble wobbling behaviour and physical properties of liquids on the accuracy of the velocity measurements were investigated through comparison with high speed camera recordings.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. W. Bai, N.G. Deen, and J.A.M. Kuipers (2009): Bubble properties of heterogeneous bubbly flows in a square bubble column, International Symposium of Multiphase Flows, July 11-15, 2009, Xi'an, China.

PROJECTLEADERS
JAM Kuipers

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
NG Deen, W Bai

COOPERATIONS
Prof. Mudde (TUD)

FUNDED
IMPACT (UT)
1st 100% 2nd - 3rd -

START OF THE PROJECT
2006

INFORMATION

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Fundamentals of Heterogeneous Bubbly Flow: mass- and heat transfer and chemical reaction in bubbly flow

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
Prof. Lohse (UT)
Funded
FOM, AkzoNobel, Corus, DSM Shell
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Start of the project
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Project Aim

The objective is to derive hydrodynamic and mass and heat transfer closures from the simulation results for the regime of high gas volume fractions (i.e. high superficial gas velocities). Swarm effects, i.e., the effects of the presence and behavior of neighboring bubbles, on the mass, momentum, and heat transfer rates will be quantified in the form of correlations, which will be used to study bubbly flows on a larger scale.

Progress

An adaptive mesh refinement code was developed for the description of species transport near gas-liquid interfaces. Furthermore, front tracking model simulations were performed to quantify the effect of the gas volume fraction on the drag on bubbles, as well as the bubble aspect ratio.

Dissertations

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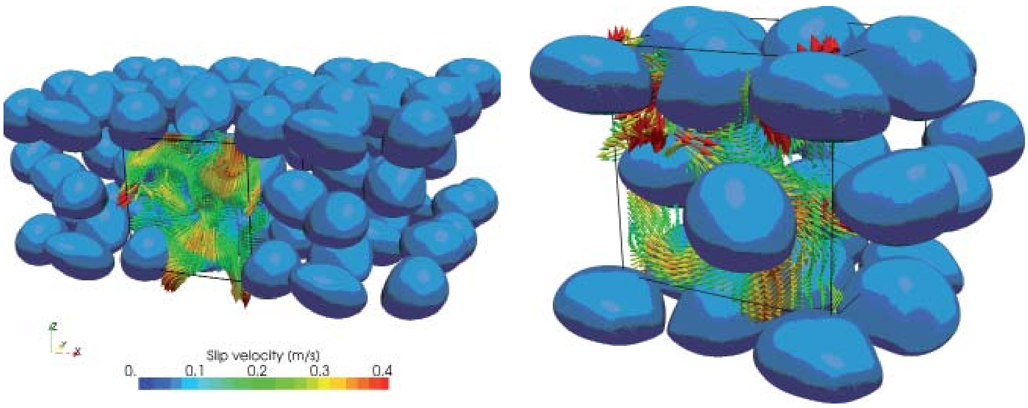
Scientific Publications

1. I. Roghair, M. van Sint Annaland and J.A.M. Kuipers (2009): Drag force on bubbles in bubble swarms, 7th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries, December 9-11, Melbourne, Australia.

Snapshots of a Front Tracking simulation of a swarm of eight bubbles in a periodic box.



Fundamentals of Heterogeneous Bubbly Flow: Coalescence, breakup and scale effects in bubbly flow

Project Aim

The objective is to derive investigate the combined effects of scale of operation (column diameter) and operating conditions on the hydrodynamics (flow structure, hold-up, large scale circulation patterns, coalescence and breakup).

Progress

A breakup model was incorporated in the discrete bubble model and an experimental setup was constructed.

Dissertations

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Scientific Publications

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Projectleaders
JAM Kuipers

Researchtheme
Complex dynamics of fluids

Participants
NG Deen, YM Lau

Cooperations
Prof. Lohse (UT)

Funded
FOM, AkzoNobel, Corus, DSM Shell
1st - 2nd 100% 3rd -

Start of the project
2008

Information
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Development of simulation models for polydispersed gas solid fluidized bed reactors

Projectleaders
JAM Kuipers
Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
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Funded
NWO
1st - 2nd 100% 3rd -
Start of the project
2008
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Project Aim

On the basis of the insights obtained from the activities described above, possible improvements of the KTGF will be considered; also the latest developments of further improving the KTGF for monodisperse systems (which is part of a parallel project) will be included. The main projection for subsequent years is the move to general polydisperse systems by developing a general multi-fluid code. All the steps which are taken in the first year for binary systems will be repeated for polydisperse systems.

Progress

Detailed comparison was made for monodispersed system between the newly developed MultiFluid Model (van Sint Annaland et al., 2009) and the more established Two Fluid Model. The sensitivity of the MFM to key parameters (like maximum particle fraction, restitution coefficient) was also investigated.

Dissertations

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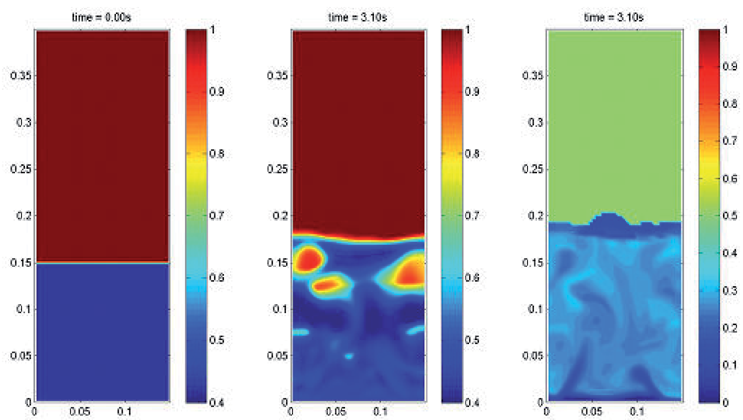
Scientific Publications

1. M. van Sint Annaland, G.A. Bokkers, M.J.V. Goldschmidt, O.O. Olaofe, M.A van der Hoef, J.A.M. Kuipers (2009): Development of a Multi-Fluid Model for poly-disperse dense gas-solid fluidised beds. Part I: Model derivation, Chemical Engineering Science, Volume 64, Issue 20, 15 October 2009, Pages 4222-4236.
2. M. van Sint Annaland, G.A. Bokkers, M.J.V. Goldschmidt, O.O. Olaofe, M.A van der Hoef, J.A.M. Kuipers (2009): Development of a Multi-Fluid Model for poly-disperse dense gas-solid fluidised beds. Part II: Segregation in binary particle mixtures, Chemical Engineering Science, Volume 64, Issue 20, 15 October 2009, Pages 4237-4246.

MultiFluid Model of idealized bidispersed fluidized bed (left and middle, pore distribution; right, particulate phase mass fraction)



Fluid particle slurry flows through constricted channel

Project Aim

We propose to study shallow fluid-particle flows or slurries in channels with complex geometries in general, and channels with constrictions in particular. Slurry flows are multiphase flows, common in industry and nature. The dense-conveying of molten metals and iron ore, mud flows in the building industry, and ice flows in rivers are typical examples.

Progress

This project was finished in February 2009.

Dissertations

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Scientific Publications

1. M. Abbas, M.A. van der Hoef, O. Bokhove, and J.A.M. Kuipers (2009): Discrete element study of liquid-solid slurry flows through constricted channels International Symposium of Multiphase Flows, July 11-15, 2009, Xi'an, China.

Projectleaders

JAM Kuipers

Researchtheme

Complex dynamics of fluids

Participants

MA van der Hoef, ME Abbas

Cooperations

Dr. O Bokhove (UT)

Funded

IMPACT (UT)

1st - 2nd 100% 3rd -

Start of the project

2008

Information

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Experimental and computational study of dense gas-fluidised beds with liquid injection

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
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Funded
DPI
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Project Aim

The main objective of this research project is to develop detailed understanding and quantitative descriptive tools for dense fluidized gas-solid suspensions, in which one of the reactants and/or a cooling liquid is injected into the bed as a liquid (through bottom or top spraying/atomization), taking into account the associated heat effects.

Progress

Alternatives for the experimental setup have been evaluated and the experimental setup is in a far developed stage. A custom made nozzle was developed. A proof of principle for the development of a new non-invasive measurement technique based on coupling Particle Image Velocimetry and Infrared Thermography, intended to overcome problems reported in prior research in similar fields was given and required equipment was selected and purchased.

Dissertations

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Scientific Publications

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MULTI-SCALE MODELING OF GELDART A PARTICLES IN GAS-FLUIDIZED BEDS

PROJECT AIM

The objective of this research is to explore the underlying mechanics of the failure of standard Eulerian model in simulation of Geldart A particles in gas-fluidized beds.

PROGRESS

The simulation methods used in this project are the two intermediate scale methods, i.e. standard Eulerian model and discrete particle model, in the multi-scale simulation framework of gas-solid flows (van der Hoef et al., 2008). Discrete particle model is able to capture the details of particle-particle and particle-wall interaction and is regarded as a reliable method to explore the nature of gas-fluidized beds. Standard Eulerian model treats both the fluid and solid phases as interpenetrating continua, the success or failure of such method is dominated by the constitutive laws used. Therefore, it is possible to study the nature of why standard Eulerian model fails to predict the hydrodynamics of Geldart A particles, through comparing the results obtained from the exactly same system using both methods.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

1. Junwu Wang, M.A. van der Hoef and J.A.M. Kuipers (2009): Why the two-fluid model fails to predict the bed expansion characteristics of Geldart a particles in gas-fluidized beds: A tentative answer, Chemical Engineering Science, Volume 64, Issue 3, February 2009, Pages 622-625.
2. Junwu Wang (2009): A review of Eulerian simulation of Geldart A particles in gasfluidized beds, Industrial & Engineering Chemistry Research 48 (12), pp 5567–5577.
3. J. Wang, M.A. van der Hoef, and J.A.M. Kuipers (2009): The role of particle-particle interactions in bubbling gas-fluidized beds of Geldart A particles: A discrete particle study, International Symposium of Multiphase Flows, July 11-15, 2009, Xi'an, China.

PROJECTLEADERS

JAM Kuipers

RESEARCHTHEME

Complex dynamics of fluids

PARTICIPANTS

MA van der Hoef, J Wang

COOPERATIONS

-

FUNDED

NWO

1st - 2nd 100% 3rd -

START OF THE PROJECT

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INFORMATION

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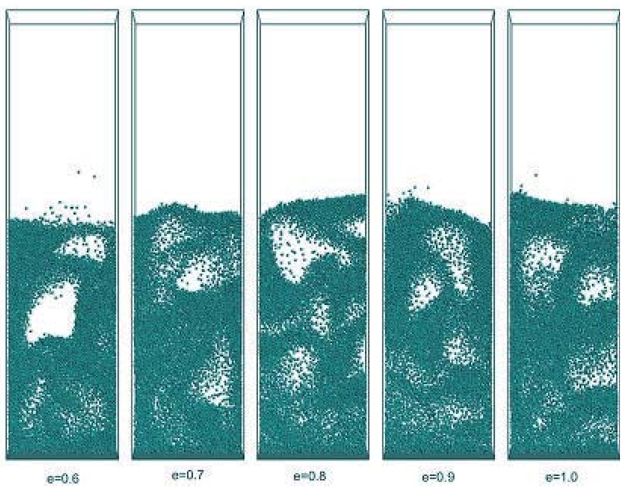

Snapshots of simulation results taken at a slit (the particles located at the dimensionless bed depth between 0.35 and 0.65 are shown), showing the effect of restitution coefficient, Ug=0.04m/s. The inter-particle friction and cohesive forces are not included.

Autothermal membrane reactor for the production of ultra-pure hydrogen with integrated CO_2 capture

Projectleaders
JAM Kuipers
Researchtheme
Complex dynamics of fluids
Participants
M van Sint Annaland, JF de Jong
Cooperations
Shell Global Solutions International
Funded
SenterNovem
1st - 2nd - 3rd 100%
Start of the project
2007
Information
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Project Aim

By means of fundamental research and an experimental demonstration unit, this project aims to provide proof-of-principle on the novel reactor concept with palladium membranes as well as perovskite membranes for oxygen separation. The effect of the presence of – and permeation through – membranes inside a fluidized bed hydrodynamics (in particular particle circulation patterns and bubble size distribution) will form the basis for a strong reactor design. This reactor will be built and tested.

Progress

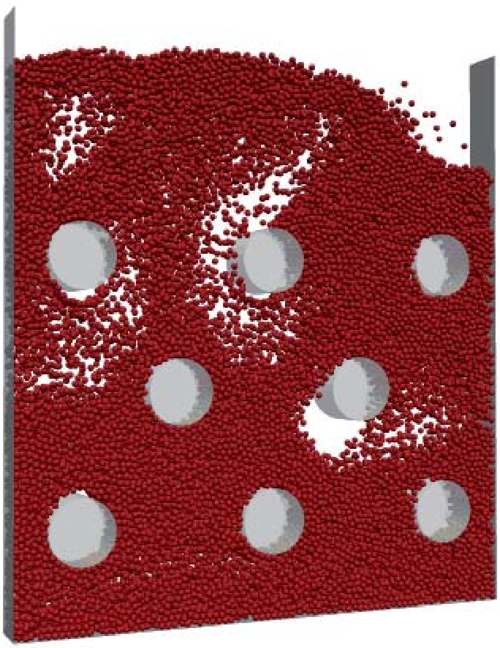
A pseudo-2D setup has been built to investigate the phenomena inside a fluidized bed using Particle Image Velocimetry (PIV). The focus lies in the beginning on permeation through vertical membranes for which gas addition as well as gas extraction is investigated. The experimental results are then compared to the Discrete Particle Model (DPM). In order to simulate membrane tubes, the Immersed Boundary Method (IBM) was implemented into the model and tested. In the beginning of 2010 the construction of the demonstration reactor will start.

Dissertations

-

Scientific Publications

1. J. de Jong, J.H. van Gerner, M. van Sint Annaland and J.A.M. Kuipers (2009): Development of a novel hybrid discrete particle-immersed boundary model for fluidized bed membrane reactors, 7th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries, December 9-11, Melbourne, Australia.



Snapshot of eight immersed membrane tubes in a DPM simulation

Next generation microreactors for ultra-pure H2 production

Project Aim

The objective of this research is to design a micro-fluidized bed membrane reactor for ultra-pure H2 production based on the studies in concerted action by detailed simulations using advanced fundamental models and well-defined experiments using advanced non-invasive experimental techniques.

Progress

Preliminary simulation work on the effect of gas velocity and bed aspect ratio on fluidization regime transition, i.e. the onset of turbulent fluidization and slugging has been carried out. Non-invasive experimental techniques such as ultrasound and PIV have been carried out for back mixing study.

Dissertations

-

Scientific Publications

-

Projectleaders

M van Sint Annaland

Researchtheme

Complex dynamics of fluids

Participants

M van Sint Annaland, N Dang, L Tan

Cooperations

-

Funded

NWO

1st - 2nd 100% 3rd -

Start of the project

2009

Information

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Vortex induced particle sorting

Projectleaders
JAM Kuipers
Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
R Hagmeijer
Funded
IMPACT
1st 100% 2nd - 3rd -
Start of the project
2009
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Project Aim

The objective of this project is to investigate the feasibility of a particle size sorting device based on the principle of preferential accumulation in vortex induced flow. Recent work on natural gas conditioners within the Engineering Fluid Dynamics group, aiming at separation of water from the gas by selective condensation and swirl, reveals that part of the droplets accumulate in the interior of the flow. The accumulation occurs on helical trajectories which are different for every droplet size. This mechanism could be potentially employed to design a particle sorting device.

Progress

The discrete particle model (DPM) and the immersed boundary method (IBM) are adopted for this project. Firstly the combination method was validated by pipe flow. Then in order to mimic a point vortex model, a rotating rod is assumed to rotate not only around its own axis, but also around the center of the circular domain. The steady streamlines of the carrier flow of this viscous vortex flow has been achieved, and the trajectory of a slipping particle in steady viscous vortex flow for different Stokes numbers was also investigated.

Dissertations

-

Scientific Publications

-

Effect of air on sand near the jamming point

Project Aim

The objective of the present proposal is to study in detail how the ambient and interstitial air influences the structure of loosely packed static granular matter close to the jamming point. In particular, we want to clarify the following questions: How does the sand bed respond to small disturbances and when does the ambient air pressure start to play a role? What causes the unexpectedly strong pressure dependence of the response of a granular bed to impacting objects? Are there structural changes in the sand bed as the pressure is reduced? Can air-fluidization facilitate the formation of extremely low granular packing densities, and if so, how? Is there any ageing in the pre-fluidized sand bed and if so, how does it depend on the ambient air pressure? Does air-fluidized sand close to the jamming point behave like an ordinary fluid? What happens to buoyancy and Archimedes' law close to the jamming point?

Progress

The project just got started; first results are in progress.

Dissertations

-

Scientific Publications

-

Projectleaders
JAM Kuipers

Researchtheme
Complex dynamics of fluids

Participants
MA van der Hoef, C Mesado Melia

Cooperations
D Lohse (UT)

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2009

Information
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Dispersed gas-liquid two-phase flows

Projectleaders
JAM Kuipers
Researchtheme
Complex dynamics of fluids
Participants
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W Bai, I Roghair, YM Lau
Cooperations
Prof. B.H. Hjertager (Aalborg),
Prof. G. Wild (Nancy),
Prof. D. Lohse (UT),
Prof. J.J.W. van der Vegt (UT)
Funded
FOM, STW, DSM, AkzoNobel, Shell,
Corus, Marin.
1st 10% 2nd 50% 3rd 40%
Start of the project
1996
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Project Aim

We use various types of CFD models (both commercial codes but mostly "in-house" made codes) to study the relevant hydrodynamic phenomena at all relevant length and time scales (i.e. at the microscopic, mesoscopic and macroscopic scale) in bubbly flows. Our main focus is on interface forces, mass-transfer, break-up and coalescence in bubble column reactors.

Progress

See the different sub-projects.

Dissertations

1. Dijkhuizen, W.: Deriving Closures for Bubbly Flows using Direct Numerical Simulations; PhD thesis University of Twente, Enschede, 2008.

Scientific Publications

1. D. Zhang, N.G. Deen, and J.A.M. Kuipers (2009): Euler-Euler Modeling of Flow, Mass Transfer, and Chemical Reaction in a Bubble Column, Industrial & Engineering Chemistry Research, 2009, 48 (1), 47-57.
2. N.G. Deen, M. van Sint Annaland, J.A.M. Kuipers (2009): Direct numerical simulation of complex multi-fluid flows using a combined front tracking and immersed boundary method, Chemical Engineering Science, Volume 64, Issue 9, Pages 2186-2201.
3. P. Willems, A.J.B. Kemperman, R.G.H. Lammertink, M. Wessling, M. van sint Annaland, N.G. Deen, J.A.M. Kuipers, W.G.J. van der Meer (2009): Bubbles in spacers: direct observation of bubble behavior in spacer filled membrane channels, Journal of Membrane Science, Volume 333, Issues 1-2, 1 May 2009, Pages 38-44.
4. D. Darmana, N.G. Deen, J.A.M. Kuipers, W. Harteveld and R.F. Mudde (2009): Numerical study of homogeneous bubbly flow: influence of the inlet conditions to the hydrodynamic behavior, International Journal of Multiphase Flow, 35 (2009) 1077–1099.
5. W. Bai, N.G. Deen, and J.A.M. Kuipers (2009): Bubble properties of heterogeneous bubbly flows in a square bubble column, International Symposium of Multiphase Flows, July 11-15, 2009, Xi'an, China.
6. I. Roghair, M. van Sint Annaland and J.A.M. Kuipers (2009): Drag force on bubbles in bubble swarms, 7th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries, December 9-11, Melbourne, Australia.

Dispersed gas-solid two-phase flows

Project Aim

We use various types of CFD models (both commercial codes but mostly "in house" made codes) to study the relevant hydrodynamic phenomena at all relevant length and time scales (i.e. at the microscopic, mesoscopic and macroscopic scale) in dense gas-particle flows. A very important area of attention is the set of gas-solid contactors that belong to the fluid bed family of reactors.

Progress

See the different sub-projects.

Dissertations

1. van Gerner, H.J.: Newton vs Stokes: Competing forces in Granular Matter; PhD thesis University of Twente, Enschede, 2009.

Scientific Publications

1. Heinrich, S., Deen, N.G., Adams, M., Seville, J.P.K., Kuipers, J.A.M., Peglow, M., Tsotsas, E. (2009): Chapter 5: Measuring techniques for particle formulation processes, (Eds.: Tsotsas, E., Mujumdar, A.S.), Modern Drying Technology, Volume 2: Experimental techniques (2009), Wiley-VCH, 187-278, ISBN 978-3-527-31557-4.
2. Junwu Wang, M.A. van der Hoef and J.A.M. Kuipers (2009): Why the two-fluid model fails to predict the bed expansion characteristics of Geldart a particles in gas-fluidized beds: A tentative answer, Chemical Engineering Science, Volume 64, Issue 3, February 2009, Pages 622-625.
3. B. Vreman, B.J. Geurts, N.G. Deen, J.A.M. Kuipers, J.G.M. Kuerten (2009): Two- and four-way coupled Euler-Lagrangian large-eddy simulation of turbulent particle-laden channel flow, Flow, Turbulence and Combustion (2009) 82:47–71.
4. J.M. Link, W. Godlieb, P. Tripp, N.G. Deen, S. Heinrich, J.A.M. Kuipers, M. Schönherr and M. Peglow (2009): Comparison of fibre optical measurements and discrete element simulations for the study of granulation in a spout fluidized bed, Powder Technology, Volume 189, Issue 2, 31 January 2009, Pages 202-217.
5. M.S. van Buijtenen, N.G. Deen, S. Heinrich, S. Antonyuk, J.A.M. Kuipers (2009): A discrete particle simulation study on the influence of restitution coefficient on spout fluidized bed dynamics, Chemical Engineering & Technology, Volume 32, No. 3, Pages 454-462.
6. O. Gryczka, S. Heinrich, N.G. Deen, J.A.M. Kuipers and L. Mörl (2009): Three-Dimensional Computational Fluid Dynamics Modeling of a Prismatic Spouted Bed, Chemical Engineering & Technology, Volume 32, No. 3, Pages 470-481.
7. M.S. van Buijtenen, N.G. Deen, S. Heinrich, S. Antonyuk, J.A.M. Kuipers (2009): A discrete element study of wet particle-particle interaction during granulation in a spout fluidized bed, Canadian Journal of Chemical Engineering, Volume 87, Issue 2, Pages 308-317.
8. O. Gryczka, S. Heinrich, N.G. Deen, M. van Sint Annaland, J.A.M. Kuipers and L. Mörl (2009): CFD modeling of a prismatic spouted bed with two adjustable gas inlets. Canadian Journal of Chemical Engineering, Volume 87 Issue 2, Pages 318-328.
9. S. Sarkar, M.A. van der Hoef and J.A.M. Kuipers (2009): Fluid-particle interaction from lattice Boltzmann simulations for flow through polydisperse random arrays of spheres. Chemical Engineering Science, Volume 64, Issue 11, 1 June 2009, Pages 2683-269.

Projectleaders
JAM Kuipers

Researchtheme
Complex dynamics of fluids

Participants
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W Godlieb, S Kriebitzsch,
MS van Buijtenen, OO Olaofe

Cooperations
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Prof. JJW van der Vegt (UT)
Prof. B Geurts (UT)
Dr. O Bokhove (UT)
Prof. J Seville (Birmingham)

Funded

AkzoNobel, DSM, FOM, NWO, Yara, Shell, Unilever
1st 10% 2nd 50% 3rd 40%

Start of the project
1996

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10. Y. He, N.G. Deen, M. van Sint Annaland, J.A.M. Kuipers (2009): Gas-solid turbulent flow in a circulating fluidized bed riser: experimental and numerical study of mono-disperse particle systems, Industrial & Engineering Chemistry Research, Vol. 48, pp. 8091–8097.
11. Y. He, N.G. Deen, M. van Sint Annaland, J.A.M. Kuipers (2009): Gas-solid turbulent flow in a circulating fluidized bed riser: numerical study of binary particle systems, Industrial & Engineering Chemistry Research, Vol. 48, pp. 8098–8108.
12. O. Gryczka, S. Heinrich, N.G. Deen, M. van Sint Annaland, J.A.M. Kuipers, M. Jacob and L. Mörl (2009): Characterization and CFD-modeling of the hydrodynamics of a prismatic spouted bed apparatus, Chemical Engineering Science, Volume 64, Issue 14, 15 July 2009, Pages 3352-3375.
13. Junwu Wang (2009): A review of Eulerian simulation of Geldart A particles in gasfluidized beds, Industrial & Engineering Chemistry Research 48 (12), pp 5567–5577.
14. M. van Sint Annaland, G.A. Bokkers, M.J.V. Goldschmidt, O.O. Olaofe, M.A van der Hoef, J.A.M. Kuipers (2009): Development of a Multi-Fluid Model for poly-disperse dense gas-solid fluidised beds. Part I: Model derivation, Chemical Engineering Science, Volume 64, Issue 20, 15 October 2009, Pages 4222-4236.
15. M. van Sint Annaland, G.A. Bokkers, M.J.V. Goldschmidt, O.O. Olaofe, M.A van der Hoef, J.A.M. Kuipers (2009): Development of a Multi-Fluid Model for poly-disperse dense gas-solid fluidised beds. Part II: Segregation in binary particle mixtures, Chemical Engineering Science, Volume 64, Issue 20, 15 October 2009, Pages 4237-4246.
16. H.J. van Gerner, G.A. Caballero-Robledo, D. van der Meer, K. van der Weele, and M.A van der Hoef (2009): Coarsening of Faraday heaps: Experiment, simulation and theory, Physical Review Letters, 103, 028001 (2009).
17. S. Sarkar, S.H.L. Kriebitzsch, M.A. van der Hoef and J.A.M. Kuipers (2009): Gas–solid interaction force from direct numerical simulation (DNS) of binary systems with extreme diameter ratios, Particuology, 7 (2009) 233–237.
18. Sergiy Antonyuk, Stefan Heinrich, Niels Deen, Hans Kuipers (2009): Influence of liquid layers on energy absorption during particle impact, Particuology, 7 (2009) 245–259.
19. S. Antonyuk, S. Heinrich, M. Dosta, M.S. van Buijtenen, N.G. Deen and J.A.M. Kuipers (2009): Effect of the liquid layer on the impact behaviour of particles, 9th International Symposium on Agglomeration, 22 - 26 June 2009, Sheffield, UK.
20. O. Gryczka, S. Heinrich, N.G. Deen, J.A.M. Kuipers and M. Jacob (2009): Analysis of the fluidization behaviour and application of a novel spouted bed apparatus for spray granulation and coating, 9th International Symposium on Agglomeration, 22 - 26 June 2009, Sheffield, UK.
21. M.S. van Buijtenen, M. Börner, N.G. Deen, S. Heinrich, S. Antonyuk and J.A.M. Kuipers (2009): An experimental study of the effect of collision properties on spout fluidized bed dynamics, 9th International Symposium on Agglomeration, 22 - 26 June 2009, Sheffield, UK.
22. M. Abbas, M.A. van der Hoef, O. Bokhove, and J.A.M. Kuipers (2009): Discrete element study of liquid-solid slurry flows through constricted channels, International Symposium of Multiphase Flows, July 11-15, 2009, Xi'an, China.
23. J. Wang, M.A. van der Hoef, and J.A.M. Kuipers (2009): The role of particle-particle interactions in bubbling gas-fluidized beds of Geldart A particles: A discrete particle study, International Symposium of Multiphase Flows, July 11-15, 2009, Xi'an, China.

24. J.A. Laverman, M.J. Ten Bulte, M. Van Sint Annaland, J.A.M. Kuipers (2009): Experimental and computational investigation on the macroscopic circulation patterns in a bubbling gas-solid fluidized bed, 8th World Congress of Chemical Engineering, Montreal, August 23-27, 2009.
25. J. de Jong, J.H. van Gerner, M. van Sint Annaland and J.A.M. Kuipers (2009): Development of a novel hybrid discrete particle-immersed boundary model for fluidized bed membrane reactors, 7th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries, December 9-11, Melbourne, Australia.
26. W. Godlieb, S. Gorter, N.G. Deen and J.A.M. Kuipers (2009): DEM and TFM simulations of solids mixing in a gas-solid fluidized bed, 7th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries, December 9-11, Melbourne, Australia.

Computational Biophysics

Prof.dr. WJ Briels

At Computational Biophysics we study the rheological properties of complex soft matter. Typical systems are multiphase systems consisting of hard particles, like the rod-like fd virus, dispersed in a Newtonian liquid or soft structures, like spherical or worm-like micelles or lipid bi-layers, resulting from self-assembling amphiphiles dissolved in water. Close to equilibrium the rheological properties are determined by the structural properties of the dispersed phase. Since these structures are usually stabilized by free energies in the order of several kT, they can easily be modified by applying flow gradients, which then give rise to a modification of the rheological properties as well. Well known phenomena resulting from this interplay between structure and flow are shear thinning, shear banding or temporal oscillations of optical and rheological properties in liquid crystalline polymer solutions.

The tools that we use belong to the field of particle based computer simulations. Since a full description of the observed phenomena requires a multi scale approach, our simulation methods range from simple molecular dynamics to Langevin dynamics and Brownian dynamics. Molecular dynamics simulations are mainly used to calculate free energies at small scales which govern the interactions at the mesoscopic scales. Our strength here is to a large extent in developing new methods. At the mesoscopic level we have developed a new model to describe polymer melt dynamics and are presently working on a new model to describe the rheology of living polymers and worm-like micelles. In the realm of Brownian dynamics, we have introduced event-driven algorithms.

Because the systems under study are mostly of biological relevance, last year the group adopted the name computational biophysics (CBP).

Structure formation in colloidal suspensions in flow and near walls

Project Aim

In this project we perform particle based simulations to study structure formation of colloids in various types of solvents and flow. The solvents to be simulated range from simple Newtonian to strongly shear thinning visco-elastic solvents. Flows being envisaged are stationary and oscillatory shear and elongational flows. Colloids will range from spheres to rods and plates. Besides flow, the influence of walls will be studied as well.

Progress

The responsive particle dynamics (RaPiD) simulation program for polymer melts, in which every particle represents a long entangled hydrocarbon chain, was extended to accommodate a free energy profile based on the Flory-Huggins theory. The model shows shear thinning, and the calculated storage and loss moduli, viscosity and Weissenberg number agree well with experimental results over a wide range of shear rates. Therefore, this model is well suited to efficiently simulate viscoelastic fluids. We are currently studying a dispersion of spherical colloidal particles in this fluid under shear.

Dissertations

-

Scientific Publications

1. W.J. Briels. Transient forces in flowing soft matter. Soft Matter 5, 4401 (2009).

Projectleaders
WJ Briels

Researchtheme
Complex dynamics of fluids

Participants
IS Santos de Oliveira, WK den Otter

Cooperations
JT Padding (UT & Leuven, B)
Prof.dr. J Vermant (Leuven, B)
Prof.dr. JKG Dhont (Jülich, D)

Funded
EU - nanodirect
1st - 2nd - 3rd 100%

Start of the project
2008

Information

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Rheology of branched polymers

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
JT Padding (UT & Leuven, B)
Funded
EU - dynacop
1st - 2nd - 3rd 100%
Start of the project
2009
Information
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Project Aim

Topologically complex polymers, such as star, comb or H-shaped branched polymers, exhibit complex dynamics and rheology and often show hierarchical relaxation over many different timescales. This in turn affects the processing and properties of their melts, which is a major issue in the industrial application of these polymers.

Progress

The newly started PhD student has familiarised herself with the responsive particle dynamics (RaPiD) program developed in our group for the simulation of polymers melts using one particle per linear chain. The code has being extended with bond-forces between the particles to create branched polymers, and the effects of these bonds and the topology on the rheological properties of the melt are being studied.

Dissertations

-

Scientific Publications

1. J.Sprakel, E. Spruijt, J. van der Gucht, J.T. Padding and W.J. Briels. Failure-mode transition in transient polymer networks with paticle-based simulations. Soft Matter 5, 4748 (2009).
2. A. AlSunaidi, W. K. den Otter and J.H.R. Clarke. Microphase separation and liquid-crystalline ordering of rod-coil copolymers. J. Chem. Phys. 130, 124910 (28 March 2009).

Structure formation in colloidal suspensions in flow and near walls

Project Aim

In this project we perform particle based simulations to study structure formation of colloids in various types of solvents and flow. The solvents to be simulated range from simple Newtonian to strongly shear thinning visco-elastic solvents. Flows being envisaged are stationary and oscillatory shear and elongational flows. Colloids will range from spheres to rods and plates. Besides flow, the influence of walls will be studied as well.

Progress

We have finished our work on kayaking rods in sheared suspensions and written a final paper on this subject. As a first exercise with confined colloidal fluids we have studied spherical particles in two dimensions with fully resolved hydrodynamic interactions. We have simulated a shish-kebab model of a colloidal rod with aspect ratio (length over diameter) L/D = 10 in the presence of a planar hard wall. Hydrodynamic interactions between rod and wall cause an overall enhancement of the friction tensor components. We find that the friction enhancements in reasonable approximation scale inversely linear with the closest distance d between the rod surface and the wall, for d in the range between D/8 and L. We have developed simulation techniques for two types of complex solvents, i.e. for worm-like micelles and gels of semi-flexible polymers.

Dissertations

-

Scientific Publications

1. J.T. Padding, W.J. Briels, M.R. Stukan and E.S. Boek. Review of multi-scale particulate simulation of the rheology of wormlike micellar fluids. Soft Matter 5, 4367 (2009).
2. Jimaan Sané, Johan T. Padding and Ard A. Louis. Hydrodynamics of confined colloidal fluids in two dimensions. Phys. Rev. E 79, 051402 (May 2009).
3. Y.G. Tao, W.K. den Otter and W.J. Briels. Kayaking and wagging of liquid crystals under shear: comparing director and mesogen motions. Europhys. Lett. 86, 56005 (June 2009).
4. J.T. Padding. Efficient simulation of non-crossing fibers and chains in a hydrodynamic solvent. J. Chem. Phys. 130, 144903 (14 April 2009).

Projectleaders
WJ Briels

Researchtheme
Complex dynamics of fluids

Participants
JT Padding, A Imperio

Cooperations
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Funded
EU - nanodirect

1st - 2nd - 3rd 100%

Start of the project
2008

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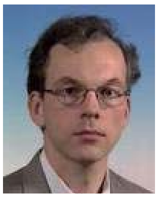
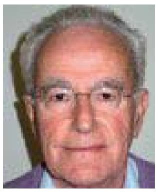
Physics of Fluids



Prof.dr. D Lohse

Prof.dr. A Prosperetti



Prof.dr.ir. L van Wijngaarden

The Physics of Fluids group in Twente works on a variety of aspects in fluid mechanics, in particular on those related to bubbles. The focus of our work is the fundamental understanding the phenomena of the physics of fluids, bubbles and jets, which we undertake by experimental, numerical and theoretical means. Besides in the J.M.Burgers Center, our research is embedded in the Research Institute of Mechanics, Processes and Control IMPACT, the MESA+ Institute, and the Research Institute for Biomedical Technology BMTi of the University of Twente. The group receives external research funds mainly from FOM, but also from STW, NWO, SenterNovem, EU and several companies. The focus research areas of the group are:

Turbulence and Two-Phase Flow

Fully developed turbulence is one of the big unsolved problems in fluid dynamics. The main question is the distribution of rare events, which has important implications for, e.g., flight safety. We approach this problem from a fundamental point of view, both experimentally, theoretically, and numerically. One particular important type of turbulence is turbulence (partly) driven by body forces, such as buoyancy. This can happen by either thermally driving the turbulence or also by driving the turbulence through bubbles or dispersed particles. Both will be advected by the flow but also act back on the surrounding liquid (two-way coupling). To be able to describe flow with many bubbles or particles efficiently, one needs an effective force description, on which and with which we work in several projects within our group. Finally, we are also interested in the radial dynamics of single bubbles in hydrodynamic or acoustic fields.

Granular Flow

Granular flows are fundamentally different from any other type of flow. In our research we focus on the clustering phenomenon that finds its origin in the inelastic collisions between the particles. There is much emphasis on the onset of clustering,which happens via a phase transition which is studied in both compartmentalized and continuous systems. Another line of our research deals with the impact of objects on very fine, decompactified sand, in which we explore the applicability of fluid models to granular systems. We uncovered links to distant phenomena like asteroid impact and a dry variety of quicksand.

Micro- and Nanofluidics

The physics of fluids at the microscale can be quite different from macrofluidic behavior. Here we study disturbing bubbles in microchannels found in ink jet printing. By patterning surfaces on sub-micron scales we try to identify individual ‘nanobubbles’ which may lead to a quantitative understanding of wall slip. These patterned surfaces may also serve as nucleation sites for cavitation bubbles generated through intense negative pressures.

Biomedical Flow

Bubbles have various applications in the biomedical field. Coated microbubbles are used in ultrasound imaging to enhace the contrast in cardiac or liver perfusion images. Bubbles can be targeted to specific cells for molecular imaging to non-invasively detect the presence and location of diseases such as cancer or atherosclerosis. Furthermore, the bubbles can be exploited to generate acoustic streaming and jetting near cell boundaries which leads to permeation, destruction or removal of target cells.

PROJECT AIM

The aim of the project is to understand the dynamics of an impact on liquids, including the resulting void collapse and jet formation. Both experimental and numerical methods are used.

PROGRESS

Using a combination of visualization techniques and numerical simulations we showed that the air inside the cavity reaches supersonic speeds just before pinch-off. The results have been published recently (Phys. Rev. Lett. 104, 024501 (2010).). By impacting disks with a harmonic disturbance we further investigated the collapse of non-axisymmetric cavities. An excellent agreement with a linear theory has been found, and non-linear behaviour is studied. The publication about the jet formation has drawn extra attention by a Physicsal Review Focus article.

DISSERTATIONS

1. S. Gekle Impact on Liquids: Void Collapse and Jet Formation (Nov. 13th, 2009). Cum Laude.

SCIENTIFIC PUBLICATIONS

1. S. Gekle, J. M. Gordillo, D. van der Meer and D. Lohse. High-speed jet formation after solid object impact. Phys. Rev. Lett. 102, 034502 (2009).
2. Bergmann, R.P.H.M., Andersen, A., Meer, D. van der & Bohr, T. Bubble Pinch-Off in a Rotating Flow. Phys. Rev. Lett. 102, 204501 (2009).
3. Bolaños-Jiménez, R., Sevilla, A., Martínez-Bazán, C., van der Meer, D., & Gordillo, J. M. The effect of liquid viscosity on bubble pinch-off. Phys. Fluids 21, 072103 (2009).
4. S. Gekle, J. H. Snoeijer, D. Lohse, and D. van der Meer. Approach to universality in axisymmetric bubble pinch-off. Phys. Rev. E. 80, 036305 (2009).
5. R. Bergmann, D. van der Meer, S. Gekle, A. van der Bos, and D. Lohse. Controlled impact of a disk on a water surface: cavity dynamics. J. Fluid Mech. 633, 381-409 (2009).

PROJECTLEADERS
D Lohse, D van der Meer

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
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COOPERATIONS
University of Sevilla, Spain

FUNDED
University of Twente, FOM
1st - 2nd 100% 3rd -

START OF THE PROJECT
2006

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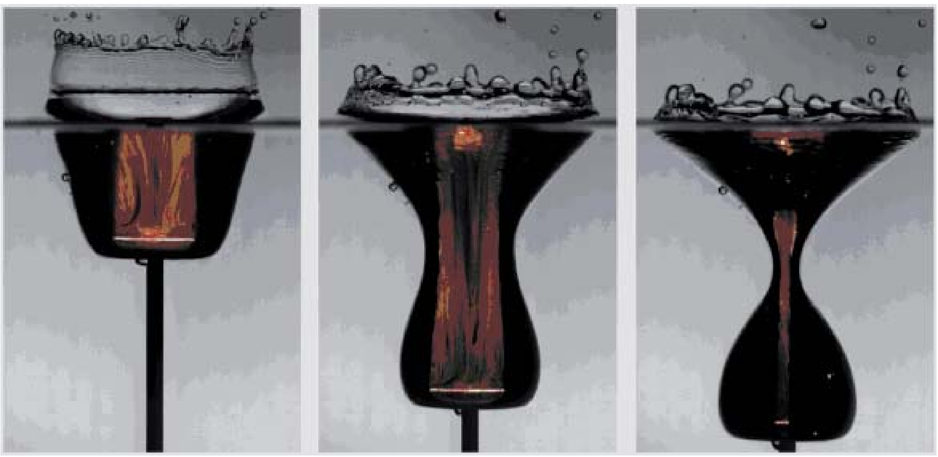

Ultra high-speed fluorescence imaging of encapsulated microbubbles for visualization of local drug delivery

Projectleaders
M Versluis
Researchtheme
Complex dynamics of fluids
Participants
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N de Jong, M Böhmer, D Lohse
Cooperations
Erasmus Medical Centre, Philips Research
Funded
EC
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Project Aim

Detailed knowledge on the complex dynamics of ultrasound contrast agents has been gained through the use of the Brandaris 128 high speed imaging facility. For visualization of drug release from loaded microbubbles fluorescence imaging is required. However, the nanoseconds timescales at which bubble oscillations, rupture and release take place makes time-resolved fluorescence imaging extremely challenging. The goal of this project is to do ultra high-speed fluorescence imaging of bubble oscillations and drug release at the timescales of bubble oscillations and rupture to gain insight in the mechanisms for local intravenous drug delivery.

Progress

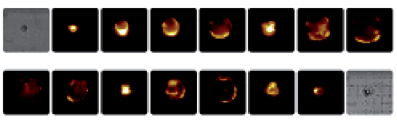
An ultra high-speed fluorescence imaging facility was constructed based on the Brandaris 128 high speed imaging system combined with a 5W CW laser (532nm). Oscillations of phospholipid coated microbubbles were recorded with frame rates up to 3 Mfps. These recordings showed phenomena such as dye shedding from the bubble wall and an inhomogeneous dye distribution, which are impossible to see in bright field. Ultra high-speed fluorescence recordings of up to 18 Mfps of oil-filled polymeric microcapsules (Philips Research) with a high dye concentration mixed in the hexadecane liquid core demonstrated a photo-acoustic effect.

Dissertations

-

Scientific Publications

1. Emmer, M., Vos, H.J., Goertz, D.E., Wamel, A. van, Versluis, M., & Jong, N. de. Pressure-Dependent Attenuation and Scattering of Phospholipid-Coated Microbubbles at Low Acoustic Pressures. Ultrasound in Med. and Biol. 35, 102-111 (2009).
2. Jong, N. de, Emmer, M., Wamel, A. van, & Versluis, M. Ultrasonic characterization of ultrasound contrast agents. Med Biol Eng Comput 47, 861–873 (2009).
3. Kooiman, K., Böhmer, M.R., Emmer, M., Vos, H.J., Chlon, C., Shi, W.T., Hall, C.S., Winter, S.H. de, Schroën, K., Versluis, M., Jong, N. de, & Wamel, A. van. Oil-filled polymer microcapsules for ultrasound-mediated delivery of lipophilic drugs.J. Controlled Release 133, 109-118 (2009).
4. Emmer, M., Vos, H., Versluis, M. & Jong, N. de. Radial modulation of single microbubbles. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 56, 2370-2379 (2009).
5. Borsboom, J.M.G., Bouakaz, A., & Jong, N. de. Pulse Subtraction Time Delay Imaging Method for Ultrasound Contrast Agent Detection. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 56, 1151-1158 (2009).
6. Novell, A., Meer, S. van der., Versluis, M., Jong, N. de, Bouakaz, A. Contrast Agent Response to Chirp Reversal: Simulations, Optical Observations, and Acoustical Verification. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 56, 1199-1206 (2009).
7. Zijlstra, A.G., Janssens, T., Wostyn, K., Versluis, M., Mertens, P.M., & Lohse, D. High speed imaging of 1 MHz driven microbubbles in contact with a rigid wall. Solid State Phenomena 145-146, 7-10 (2009).



Jamming of particles on a surface wave

Project Aim

Floating particles form clusters on a surface wave in various ways. It is known that the physical properties of the floaters and the wave regime have effects on the clustering. However, it is not fully understood how the particle distribution and their dynamics depend on the particle concentration:

* Do the clusters disappear in higher concentrations?

* Do the particles move purely at random or do they move cooperatively?

In this study, we would like to answer these questions both by performing experiments and by using statistical analysis borrowed from Lagrangian turbulence and colloidal physics. Our main interest is to understand the variations in the mobility and in the structral properties of the clusters by increasing the concentration and the relevant wave parameters, and in this way, to study physics near the jamming point.

Progress

In a first set of experiments we have varied the particle concentration for similar standing wave conditions. For low particle concentrations (left picture), we observe that hydrophobic light particles form very stable clusters at the antinodes. For higher concentrations (right picture), surprisingly, the same particles form clusters at the nodes. The explanation lies in the collective, attractive capillary interaction among particles which counteracts the tendency of the particles to move toward the antinodes. The transition between the two regimes has been studied as a function of the intermediate particle concentration and the transition interval has been determined experimentally.

When the clusters sit more at nodes in the intermediate concentration, the longer time dependent structures has been observed. Using a particle tracking method, the structural differences in the particle clustering have been analyzed by correlating the wave structure and the concentration, and by the pair correlation function. Currently we are analyzing the transition interval in more details, and analyzing longer time series to identify and to distinguish different time regimes.

Dissertations

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Scientific Publications

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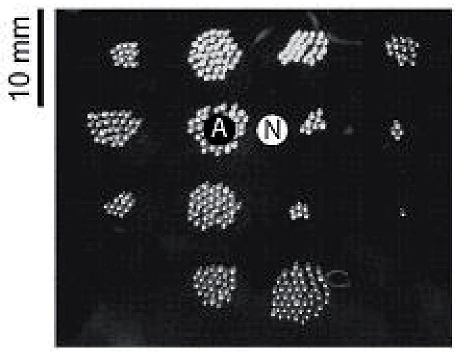

Figure 1: Antinode clusters at low particle concentration on a standing wave.

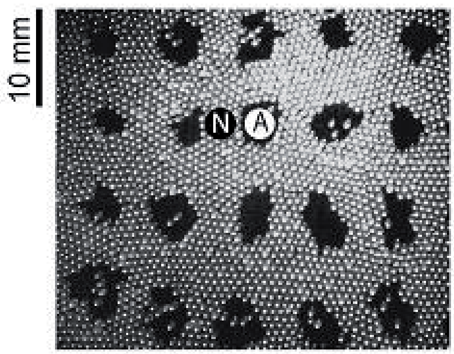

Figure 2: Node clusters at high particle concentration on a standing wave.

Projectleaders

D Lohse, D van der Meer

Researchtheme

Complex dynamics of fluids

Participants

C Sanli, D van der Meer, D Lohse

Cooperations

-

Funded

FOM-program Rheophysics: Connecting Jamming and Rheology

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Start of the project

2008

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Ship drag reduction by air lubrication – Turbulent Twente Taylor-Couette (T3C)

Projectleaders
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Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
TUD: Hydro- & Aerodynamics and Kramers Laboratorium, MARIN, Spaarnwater

Funded
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Project Aim

The overall aim is to find the mechanisms that are responsible for the ship's frictional drag reduction (DR) by air lubrication of the boundary layer flow. The focus lies on the efficiency, persistence, and scaling laws of these mechanisms. One major aim is to study DR in a stationary and stable flow and to this end, the UT has designed a turbulent Taylor-Couette setup (max. Re ~ 2•106) which is operational since July 2009. It will be used to study the behavior of two-phase flow in a boundary layer and the influence of wall characteristics such as roughness and hydrophobicity. This setup with two independently rotating cylinders and bubble injection has the advantage that it allows for statistically stationary flow and accurate resistance measurements by means of the applied torque on the inner rotating drum. Moreover, the bubble distribution in this stationary case will be measured and its effect on the overall torque will be theoretically analyzed. Utilizing a four-point optical fiber probe can give direct experimental proof on the bubble mechanism responsible for DR.

Progress

The T3C is taken into operation since July 2009 and the accuracy and stability of all the global parameters like rotation rate, fluid temperature and torque are examined and found to be well controlled. At this moment, an experiment in cooperation with Spaarnwater is in progress to investigate the effects of different foul-release and/or hydrophobic ship coatings to the skin drag in single and two-phase flows. Upcoming experiments will be 1) characterizing the flow profile inside the gap utilizing LDA in the case of co- and counter rotating cylinders, and 2) reproducing with larger accuracy the effect of bubbly induced drag reduction as described in Van den Berg et al., Bubbly Turbulent Drag Reduction Is a Boundary Layer Effect. Phys. Rev. Lett. 98, 084501 (2007). Next the flush mounted shear stress sensors will be worked out.

Dissertations

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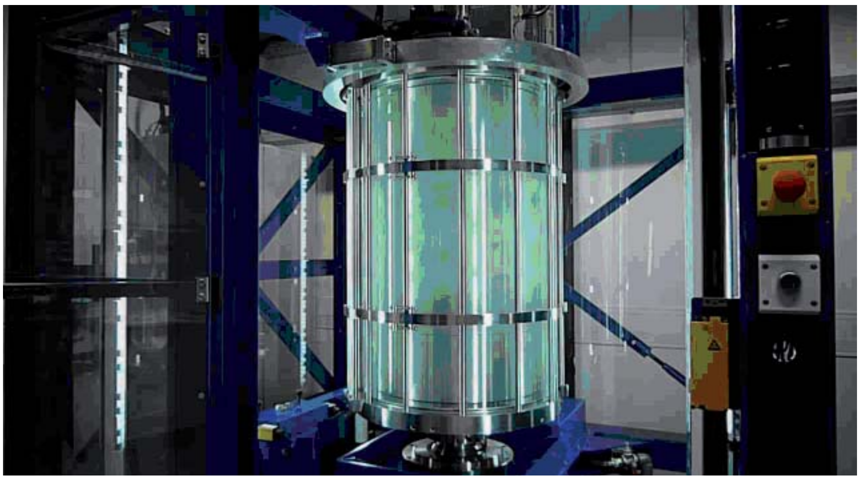
Scientific Publications

-



Micro bubble actuator

Project Aim

Typical actuators using the principle of thermodynamic phase change are slow because diffusion processes rule the dynamics. This project however aims to investigate the possibility to use an explosive thermo-¬dynamic phase change to generate a force by releasing heat at a large rate, which would make fast actuators possible.

Progress

The code developed for performing computations of two phase flow with phase change has been applied to study the dynamics of vapor bubbles in confined geometries. Specifically simulation of vapor bubbles in a cylindrical tube and vapor bubbles between two circular discs have been performed and compared to experiment. The simulation results for the tube geometry correspond well to experimental results and to the 1D model that we developed. For the disc case a model based on the cylindrical Rayleigh-Plesset equation was developed but satisfactory results were not achieved. The code however was more succesful in capturing the bubble dynamics. This is due to the bubble shape during its growth and collapse, which was not accounted for in the model but is of crucial importance.

Dissertations

-

Scientific Publications

1. Sun, C., Can, E., Dijkink, R., Lohse, D. & Prosperetti, A. Growth and collapse of a vapour bubble in a microtube: the role of thermal effects. J. Fluid Mech. 632, 5-16 (2009). See also: “Focus on Fluids” by M. Brenner, J. Fluid Mech. 632, 1-4 (2009).
2. Zhang, Q. & Prosperetti, A. Pressure-driven flow in a two-dimensional channel with porous walls. J. Fluid Mech. 631, 1 - 21 (2009).

Projectleaders

A Prosperetti, D Lohse

Researchtheme

Complex dynamics of fluids

Participants

E Can, C Sun, D Lohse,
A Prosperetti

Cooperations

Prof. Dr. M. Elwenspoek, University of Twente, Mesa+, University of Twente

Funded

STW
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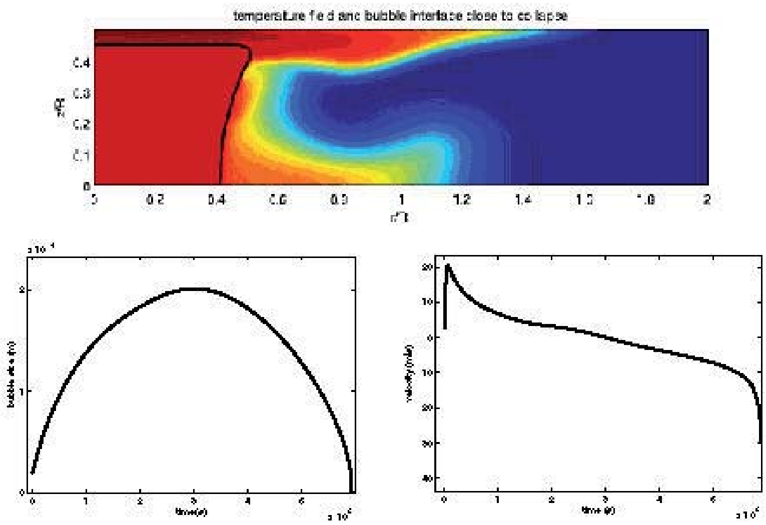

Surface nanobubbles

Projectleaders
D Lohse
Researchtheme
Complex dynamics of fluids
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University of Siegen (Dr. H. Schönherr), Institut de Physique de Rennes (G. Le Caër, B. Dollet)
Harvard University (Prof. Dr. M.P. Brenner)
Funded
FOM, STW-Nanoned, EU
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2009 (FOM, EU, university)
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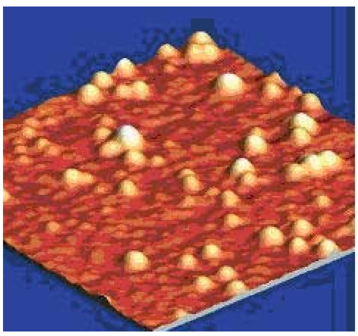

Project Aim

Immersing hydrophobic substrates in water leads to the surprising formation of nanoscopic bubbles adhered to the substrate. Several fundamental questions exist, for example: Why do surface nanobubbles not disappear through diffusion, how do they form, and how are they affected by substrate topography? To answer these questions, we employ experimental (including atomic force microscopy), numerical (including molecular dynamics), and theoretical methods. The ultimate aims of this research are to understand the behaviour of gas-liquid-substrate interactions at the nanoscale, as well as to control slip in nano/micro-fluidic devices.

Progress

AFM experiments revealed that the volume of the nanobubbles formed increases with gas concentration and liquid temperature. Contamination increases the contact angle of surface nanobubbles; in a relatively clean experiment the contact angle is closer to its macroscopic value. Nanobubbles form in a structured way, with a preferred radius and spacing between individual bubbles. An analytical model of diffusion in a potential field is used to investigate whether a potential gradient can lead to a gas influx at the contact line large enough to balance to the diffusive gas outflux, and stabilize the bubble. Preliminary MD simulations indicate that such a gas influx at the contact line can occur. Additionally, a theoretical study on the influence of surfactants on nanobubble stability is performed.

Dissertations

1. PhD thesis: Interfacial phenomena in micro- and nanofluidics: nanobubbles, cavitation, and wetting. B. M. Borkent, October 2, 2009. Cum Laude.
2. MSc thesis: Characterization of surface nanobubbles by means of atomic force microscopy. W.Walczyk, August 14, 2009.

Scientific Publications

1. Borkent, B.M., Schönherr, H., Le Caër G., Dollet, B. & Lohse, D. Preferred sizes and ordering in surface nanobubble populations. Phys. Rev. E 80, 036315 (2009).
2. Borkent, B.M., Gekle, S., Prosperetti, A., & Lohse, D. Nucleation threshold and deactivation mechanisms of nanoscopic cavitation nuclei. Phys. Fluids 21, 102003 (2009).
3. Heijnen, G.L., Quinto-Su, P.A., Zhao, X., & Ohl, C.D. Cavitation within a droplet. Phys. Fluids 21, 091102 (2009). Winning entry from the 26th Annual Gallery of Fluid Motion 2009.
4. Yang, S., Tsai, P., Kooij, E.S., Prosperetti, A., Zandvliet, H.J.W., & Lohse, D. Electrolytically Generated Nanobubbles on Highly Orientated Pyrolytic Graphite Surfaces Langmuir 25, (3) 1466–1474 (2009).

The effect of air on sand near the jamming point

Project Aim

Static granular matter is traditionally studied in terms of contact forces between the particles only. Recent experimental evidence shows that this framework is insufficient to describe loosely packed fine granular matter: The influence of the interstitial air needs to be taken into account. This influence becomes particularly strong where the contact forces between the grains become vanishingly small, i.e., close to the jamming point. The objective of this project is to study in detail how the ambient, interstitial air influences the structure of loosely packed, static granular matter close to the jamming point.

Progress

In one of the first experiments the pressure difference over and the air flow through the sand bed is measured during the events caused by an impacting ball: splash and penetration, jet formation, and granular eruption. The experiments are done at different container pressures and different release heights.

Dissertations

-

Scientific Publications

1. Lohse, D. & Meer, D. van der. Granular media: Structures in sand streams Nature 459, 1064-1065 (2009).

Projectleaders

D van der Meer, MA van der Hoef, JAM Kuipers, D Lohse

Researchtheme

Complex dynamics of fluids

Participants

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Cooperations

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Funded

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1st - 2nd 100% 3rd -

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PROJECTLEADERS
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RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
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FUNDED
FOM
1st - 2nd 100% 3rd -

START OF THE PROJECT
2008

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PROJECT AIM

Turbulent convection under rotation about a vertical axis is a simple model system for industrial and geophysical systems. Examples include flow in the atmosphere, oceans, the inner core of the earth, giant gas planets and the outer layer of the sun. The aim of this research project is to investigate the effect of background rotation on Rayleigh-Bénard convection. With a cylindrical Rayleigh-Bénard cell, which is placed on a rotating table, we can accurately measure the heat transport in the system. These measurements are supplemented by numerical studies which give full access to the full flow domain to study changes in the flow structure.

PROGRESS

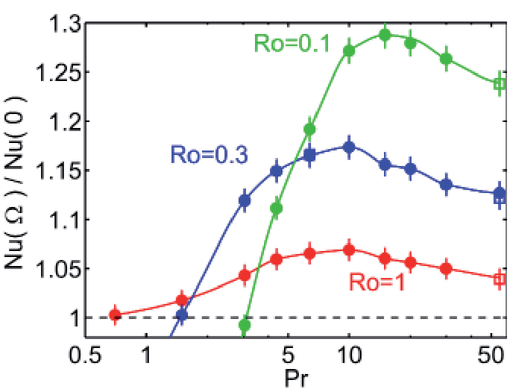
The experimental measurements and the results from direct numerical simulations (DNS) show that the heat transport in the system can increase up to 30 % due to rotation. This increased heat transfer is due to Ekman-pumping, i.e. rising and falling plumes of hot and cold fluid are stretched into vertical vortices that suck fluid out of the thermal boundary layers adjacent to the bottom and top plates. There is an optimal Pr number (with fixed Ra and Ro) for the heat transport enhancement, see figure 1, because the efficiency of Ekman pumping is limited for high and low Pr. For low Pr the efficiency is limited by the large thermal diffusivity, i.e. the heat that is sucked out of the thermal BL spreads out horizontally. For high Pr the efficiency is limited because the temperature of the fluid that is sucked out of the thermal BLs is relatively low.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Zhong, J.Q., Stevens. R.J.A.M., Clercx, H.J.H., Verzicco, R., Lohse, D., & Ahlers, G. Prandtl-, Rayleigh-, and Rossby-Number Dependence of Heat Transport in Turbulent Rotating Rayleigh-Bénard Convection. Phys. Rev. Lett. 102, 044502 (2009). See also the cover of that issue.
2. Stevens, R.J.A.M., Zhong, J.Q. Clercx, H.J.H., Ahlers, G., & Lohse, D. Transitions between turbulent states in rotating Rayleigh-Bénard convection. Phys. Rev. Lett. 103, 024503 (2009).
3. Stevens, R.J.A.M., Clercx, H.J.H., Lohse, D. Optimal Prandtl number for heat transfer in rotating Rayleigh-Bénard convection. Submitted to NJP, see arXiv:0912.0816 (2009).



Normalized heat transfer as function of Pr for Ra =10^8 and different Ro [3].

Vibration induced jamming and shear thickening

Project Aim

We develop model systems for shear thickening suspensions and probe their rheology and configurational changes close to the vibration-induced jamming point. The work is motivated by recent work describing the formation of persistent holes and finger like protrusions in thin layers of cornstarch that are shaken at high accelerations. These phenomena must be connected to the shear-thickening properties of the cornstarch and a change from a fluid to a more solid-like, jammed state, as it is unknown what mechanism causes these shapes. In a first series of experiments, a layer of cornstarch will be vibro-fluidized using a shaker. The experiment will be repeated in an index-matched suspension of micron-sized glass spheres (diameter 10-50μm) allowing us to also measure the microscopic properties of the fluid.

Progress

Experiments where mixtures of water and cornstarch/glass beads were done. For cornstarch we explored the effects of shaking strength, frequency, layer depth and concentration and the different kinds of distortions were mapped into a phase diagram. For glass beads preliminary experiments structures were found to be less stable. A 2nd direction was initiated in which we are studying the impact and sedimentation of a metal sphere into a shear thickening liquid bed. In these experiments we find that the sphere approaches the bottom in an oscillatory way which we believe to be caused by the shear thickening behavior of the liquid.

Dissertations

-

Scientific Publications

-

Projectleaders
D Lohse, D van der Meer

Researchtheme
Complex dynamics of fluids

Participants
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J Snoeijer

Cooperations
Part of FOM programme:
Rheophysics: Connecting jamming and rheology

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2008

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Formation of persistent holes and finger like protrusions in thin layers of cornstarch that are shaken at high accelerations.

Ultrasonic cleaning of root canals - Endodontic therapy through microstreaming and cavitation

Projectleaders
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Researchtheme
Complex dynamics of fluids
Participants
B Verhaagen, L Heijnen
Cooperations
L van der Sluis, L Jiang (Academic Center for Dentistry, Amsterdam, Netherlands), C Boutsioukis (Dental School, Aristotle University, Thessaloniki, Greece)
Funded
STW
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2007
Information
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Project Aim

Ultrasonic irrigation of the root canal is found to be much more efficient than conventional root canal irrigation using a syringe, in which bacteria often remain, leading to re-infection. Why ultrasonic irrigation is more effective is not known, however. Through experiments and numerical simulations we try to eludicate the cleaning mechanisms (streaming, cavitation, or other mechanisms) involved in root canal cleaning, with the final goal of improving root canal irrigation even more.

Progress

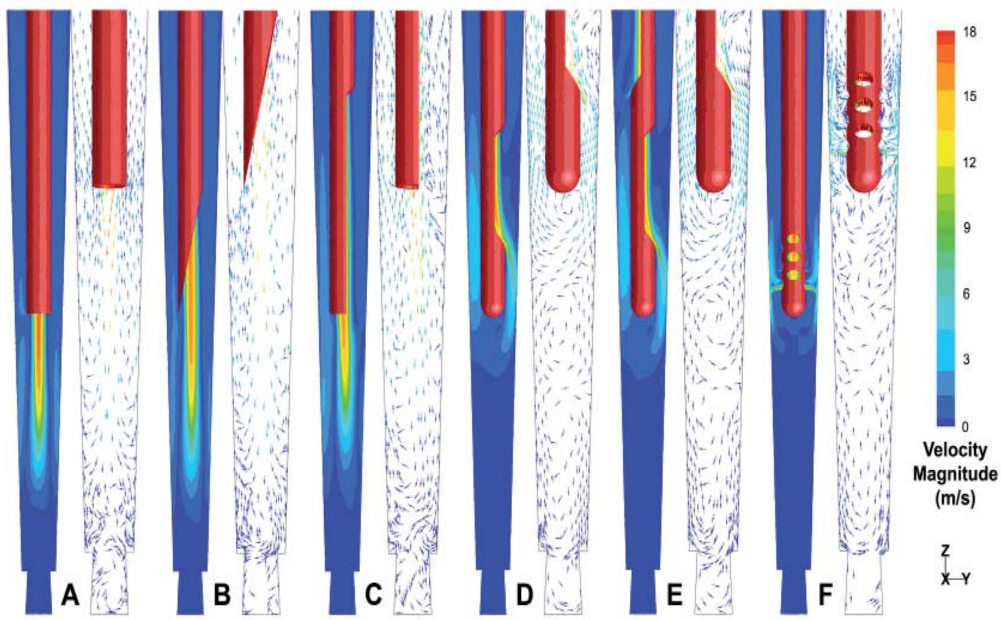
A computational model (developed by Christos Boutsioukis, Aristotle University of Thessaloniki, Greece) of flow from a needle in a root canal has been validated with high-speed PIV. The results from this study (flow velocity, replacement efficiency, shear stress, pressure) and other studies using the CFD model will be published soon. Meanwhile, work has been done on the measurement of the pressure developed during irrigation of the root canal. Also, studies on different aspects (e.g. different driving frequencies) of ultrasonic irrigation have been started and recently a master student has started his work on the influence of particles added to the ultrasonically activated fluid.

Dissertations

-

Scientific Publications

1. S.D. de Groot, B. Verhaagen, M. Versluis, M.-K. Wu, P.R. Wesselink, & L.W.M. van der Sluis. Laser-activated irrigation within root canals: cleaning efficacy and flow visualization. Int. Endod. J. 42, 1077-1083 (2009).



PROJECT AIM

The aim of the project is to gain understanding in the physical mechanism of ultrasonic cleaning with particular interest for the removal of nano sized particles from silicon wafers as is commonly applied in semiconductor industry.

PROGRESS

The previous set of experiments have revealed a particular type of cavitation bubble dynamics which results in the removal of nanoparticles due to strong focussing of fluid motion towards the boundary. Due to the notorious uncontrollability of cavitation these experiments are very difficult to reproduce which prompted the development of an improved setup to address this issue. This setup enables control over both gas content and the sound field. In addition, the controlled generation of bubbles needed for cleaning is required and investiged. Here, a new phenomenon where microbubbles are continuously generated from micropits was discovered (see image). A theoretical and experimental study is underway to quantify the hydrodynamic force required to dislodge a nano-particle from a substrate.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. S. Brems, M. Hauptmann, E. Camerotto, A. Pacco, S. Halder, A.G. Zijlstra, G. Doumen, T. Bearda, P.M. Mertens. Impact of Acoustical Reflections on Megasonic Cleaning Performance ECS Transactions, 25 (5) 287-294 (2009).
2. Zijlstra, A.G., Janssens, T., Wostyn, K., Versluis, M., Mertens, P.M., & Lohse, D. High speed imaging of 1 MHz driven microbubbles in contact with a rigid wall. Solid State Phenomena 145-146, 7-10 (2009).

PROJECTLEADERS
M Versluis, D Lohse, P Mertens

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
AG Zijlstra, M Versluis, PM Mertens, S Brems, D Fernandez Rivas

COOPERATIONS
IMEC, Leuven Belgium

FUNDED
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START OF THE PROJECT
2007

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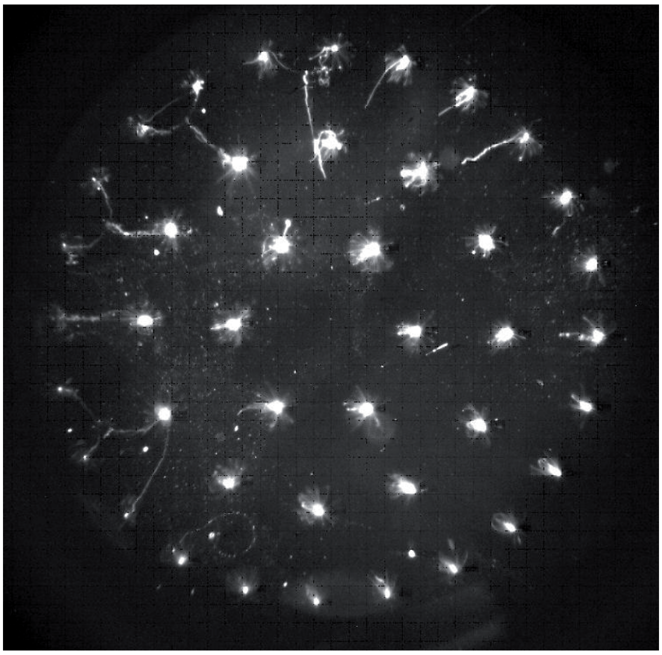

Generation of microbubbles by an array of micropits (r=10) in a 200 kHz acoustic field.

The dynamics of targeted microbubbles for molecular imaging with ultrasound

Projectleaders
M Versluis, N de Jong, D Lohse

Researchtheme
Complex dynamics of fluids

Participants
M Overvelde, V Garbin, T Hay, B Dollet, J Sijl, N de Jong, D Lohse, M Versluis

Cooperations
Bracco Research S.A., Biomedical Engineering Erasmus MC

Funded
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Start of the project
-

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Project Aim

Molecular imaging with ultrasound is a promising non-invasive technique for disease-specific imaging, enabling for instance the diagnosis of thrombus and inflammation. Selective imaging is performed by using ultrasound contrast agents containing ligands on their shell, which bind specifically to the target molecules. To improve molecular imaging diagnosis with ultrasound one would be able to distinguish adherent microbubbles from freely circulating ones. The simplest approach is to wash-out all the freely circulating microbubbles and image the remaining bubbles. The disadvantage is that it takes 5 to 10 minutes before all freely circulating bubbles are cleared by the liver and that there is no new supply of bubbles. Therefore it would be beneficial to distinguish acoustically between adherent and freely circulating microbubbles.

Progress

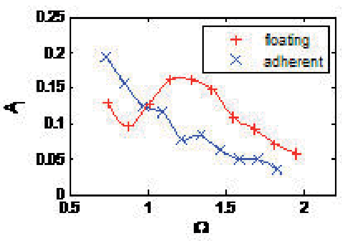
We investigated the influence of targeting on the dynamics of the microbubbles, in particular on the frequency of maximum response, by recording the radial response of individual microbubbles as a function of the applied acoustic pressure and frequency. The frequency of maximum response of adherent microbubbles was found to be over 50% lower than for bubbles in the unbounded fluid and over 30% lower than that of a bubble in contact with the wall. The change is caused by adhesion of the bubbles to the wall as no influence was found solely by the presence of the targeting ligands on the bubble dynamics. The shift in the frequency of maximum response may prove to be important for molecular imaging applications with ultrasound as these applications would benefit from an acoustic imaging method to distinguish adherent from freely circulating microbubbles.

Dissertations

1. Sijl, J. (2009, December, 16). "Ultrasound contrast agents - optical and acoustical characterization", University of Twente, (Enschede,The Netherlands: Physics of Fluids group). Promotoren: Prof. dr. D. Lohse and Prof. dr. ir. N. de Jong.

Scientific Publications

1. Valeria Garbin, Benjamin Dollet, Marlies Overvelde, Dan Cojoc, Enzo Di Fabrizio, Leen van Wijngaarden, Andrea Prosperetti, Nico de Jong, D Lohse, Michel Versluis. History force on coated microbubbles propelled by ultrasound. Physics of Fluids, 21(9) 092003. (2009).
2. Mie scattering distinguishes the topological charge of an optical vortex: a homage to Gustav Mie. Valeria Garbin, Giovanni Volpe, Enrico Ferrari, Michel Versluis, Dan Cojoc and Dmitri Petrov. New J. Phys 11, 013046 (2009).
3. Emmer, M., Vos, H., Versluis, M. & Jong, N. De. Radial modulation of single microbubbles. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 56, 2370-2379 (2009).



Resonance curves of a phospholipid-coated bubble floating against the wall (red) and adherent to the wall (blue) insonified with a pressure Pa = 100 kPa.

Rapid granular matter at its edge : Exploring critical phenomena and ratchets

Project Aim

One of the major goals in research on granular matter is to achieve some granular hydrodynamic description. In many situations such a description works, however, in others it breaks down. The origin of the breakdown of the granular hydrodynamic approach is the clustering. Therefore the aim of the project is to analyze the system properties at the phase transition towards clustering in detail.

Progress

We could first experimentally explore and then theoretically understand (by linear stability analysis) the phase diagram of shaken granular matter for large aspect rations. For this geometry the continuum approach works excellently. We moreover have experimentally realized a granular ratchet and described its characteristics.

Dissertations

-

Scientific Publications

1. Gerner, H.J. van, Caballero Robledo, G.A., Meer, D. van der, Weele, K. van der, & Hoef, M.A. van der. Coarsening of Faraday Heaps: Experiment, Simulation, and Theory. Phys. Rev. Lett. 103, 028001 (2009).
2. Weele, K. van der, Kanellopoulos, G., Tsiavos, C. & Meer, D. van der Transient granular shock waves and upstream motion on a staircase. Phys. Rev. E 80, 011305 (2009).
3. Eshuis, P., Weele, K. van der, Calzavarini, E., Lohse, D. & Meer, D. van der Exploring the limits of granular hydrodynamics: A horizontal array of inelastic particles. Phys. Rev. E 80, 011302 (2009).
4. Weele, K. van der, Kanellopoulos, G., Tsiavos, C. & Meer, D. van der. Transient granular shock waves and upstream motion on a staircase. Phys. Rev. E 80, 011305 (2009).
5. H.J. van Gerner, K. van der Weele, M.A. van der Hoef, and D. van der Meer, “Air-induced inverse Chladni patterns”, to be submitted to J. Fluid Mech. (2009).
6. H.J. van Gerner, M.A. van der Hoef, D. van der Meer, and K. van der Weele, “Gravity-induced inverse Chladni patterns”, to be submitted to Phys. Rev. E (2009).

Projectleaders
D Lohse, D van der Meer

Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
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Funded
FOM-program Physics of Granular Matter (03PGM02)
1st - 2nd 100% 3rd -

Start of the project
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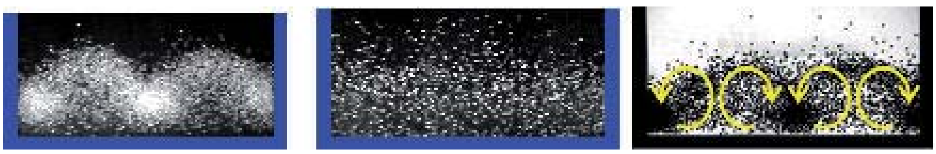

High Rayleigh number thermal convection

Projectleaders
D Lohse
Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
Prof. S. Grossmann, University of Marburg, Germany, Prof. G. Ahlers, University of California at Santa Barbara, United States, Prof. K.Q. Xia, The Chinese University of Hong Kong, Shatin
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FOM Programme on Turbulence
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Project Aim

The three aims of the project “High Rayleigh number thermal convection” are:

1. To investigate the irregular reversals of the large-scale circulation (the so called “wind” of turbulence).
2. To extend Grossmann-Lohse theory to non-Boussinesq effects on the heat flux, different geometries (aspect-ratio dependence), and boundary conditions (rough walls).
3. To check the theory against experimental and numerical data.

Progress

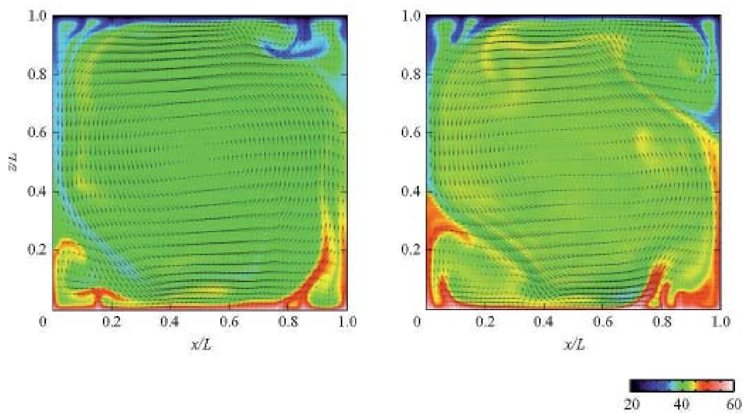
The main focus of the last year was on Non-Oberbeck-Boussinesq effects, which we explored both experimentally (in collaboration with G. Ahlers), theoretically, and numerically.

Dissertations

-

Scientific Publications

1. Ahlers, G., Grossmann, S., & Lohse. D. Heat transfer and large scale dynamics in turbulent Rayleigh-Bénard convection. Rev. of Mod. Phys. 81, 503-538 (2009).
2. Stevens. R.J.A.M., Zhong, J.Q., Clercx, H.J.H., Ahlers, G. & Lohse, D. Transitions between Turbulent States in Rotating Rayleigh-Bénard Convection. Phys. Rev. Lett. 103, 024503 (2009).
3. Zhong, J.Q., Stevens. R.J.A.M., Clercx, H.J.H., Verzicco, R., Lohse, D., & Ahlers, G. Prandtl-, Rayleigh-, and Rossby-Number Dependence of Heat Transport in Turbulent Rotating Rayleigh-Bénard Convection. Phys. Rev. Lett. 102, 044502 (2009). See also the cover of that issue.
4. Sugiyama, K., Calzavarini, E., Grossmann, S., & Lohse, D. Flow organization in two-dimensional non-Oberbeck–Boussinesq Rayleigh–Bénard convection in water. J. Fluid Mech. 637, 105-135 (2009).
5. Oresta, P., Verzicco, R., Lohse, D., & Prosperetti, A. Heat transfer mechanisms in bubbly Rayleigh-Bénard convection. Phys. Rev. E 80, 026304 (2009).



Snapshorts of the velocity (arrows) and temperature (colour) fields for $Ra = 10^8$ at T_m=40^{o}C, working fluid water, (a) corresponds to the OB case (all material properties are kept temperature independent, taken at T_m), (b) corresponds to the NOB case, both with the same Δ = 40K. The temperature colour scheme is in degrees C, same in both panels.

Efficient sonochemical microreactors

Project Aim

This project will emphasize on improvement of the energy efficiency sonochemical reactors by at least one order of magnitude by miniaturizing reactors to gain full control over the cavitation process and all its energetic aspects. Improvement of the energy efficiency by one order of magnitude will make the energy consumption of the process equivalent to the energy consumption of a conventional industrial stirred tank reactor, which will make sonochemical microreactors feasible. The major objective of the project is to design, develop and test energy efficient sonochemical microreactors.

Progress

We achieved stable hydrodynamic cavitation in a microchannel. No conversion of the oxidation of phenol and potassium iodide using a hydrodynamic cavitation microchip has been measured. Surface controlled cavitation experiments have been reproduced. No conversion of potassium iodide in controlled surface cavitation events has been measured. An ODE model simulating dynamics and radical production was developed and further extended by inclusion of heat and mass transport. Considering the crucial role of temperature in chemical production, a PDE model for the temperature field inside the bubble has been developed in order to investigate the limits of applicability of the ODE model.

Dissertations

-

Scientific Publications

-

Projectleaders

D Lohse

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

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Cooperations

TU Eindhoven Prof. Dr. J.T.F. Keurentjes, UT, Prof. Dr. J.G.E. Gardeniers, Ir. J. Rooze, D. Fernandez Rivas

Funded

STW

1st - 2nd 100% 3rd -

Start of the project

2009

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ZIPPING WETTING

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FUNDED
University Spearhead programme,
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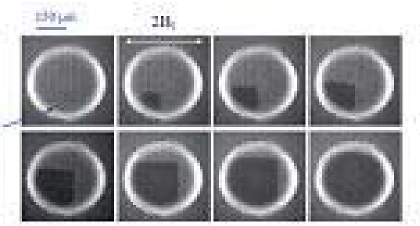
PROJECT AIM

Hydrophobic microstructures can exhibit superhydrophobic behavior with effective contact angles of 160o and even beyond. The Cassie's law describes such a state of composite wetting: an effective contact angle for the droplet is determined by surface heterogeneities, i.e. surface posts alternating with air pockets trapped below the droplet. In some cases, this superhydrophobicity can break down. After some initial infiltration the fluid can spread and the droplet impregnates through the microstructure, resulting into the smaller contact angle of the so-called "Wenzel state". In addition, a natural evaporating process can trigger this heterogenous to homogenous wetting transition. The project aims include 1) accurante measurements of the critical droplet size, 2) the water penetration dynamics, and 3) the physical mechanism of the Cassie-Baxter to Wenzel wetting transition triggered by evaporation.

PROGRESS

We have experimentally investigated the wetting transition from a Cassie-Baxter to a Wenzel state triggered by evaporation. An initially mm-sized water droplet can undergo the transition upon hydrophobic microstructures as the droplet evaporates down to a few hundred of microns in diameter. The transition point was determined by the bottom views using a high-speed camera (see Figure 1) when water starts to invade into the microstructures, marked by the dark areas in Figure 1. The long-time dynamics of the droplet shap was filmed at about 1 fps (Figure 2) to obtain the contact angle dynamics. The apprant contact angle was observed to be decreasing, with a slow (steep) decrease for the Cassie-Baxter (Wenzel) state, and the infiltration dynamics at this transition was studied. A theoretical model was established to estimate the surface energies for both a pure Cassie-Baxter and a pure Wenzel state. We found that a Cassie-Baxter droplet costs less surface enery initially and as evaporation goes on a Wenzel droplet is favored beased on the surface energy argument.



Snapshots of the bottom-view reveal the water infiltration dynamics at the transition from a Cassie-Baxter to a Wenzel wetting state triggered by evaporation. Here, the square lattice have the dimension with a = 5,w = 5, and h = 10 μm. The dark areas indicate the water imbibition, while the air pockets present in the bright areas enclosed by a rather bright circumference marked by the droplet base. These images are sequentially recorded at t = 0, 30, 58, 72, 116, 180, 236 and 310 ms from the transitional point, determined by the first frame where a small initial nfiltration point is observed (marked by an arrow). Figure 2: Snapshots of the side-views of an evaporating droplet with the time interval 15 s between the images, revealing the decrease of the contact angle. The dash lines, marking the drop base, separate the main droplet from its mirror image. The arrow shows the length scale of the critical diameter 2Bc at the wetting transition, determined from the bottom views.

Dissertations

-

Scientific Publications

1. Tsai, P., Peters, A.M., Pirat, C., Wessling, M., Lammertink, R.G.H., & Lohse, D. Quantifying effective slip length over micropatterned hydrophobic surfaces. Phys. Fluids 21, 112002 (2009).
2. Tsai, P., Pacheco, S., Pirat, C., Lefferts, L. & Lohse, D. Drop Impact upon Micro- and Nanostructured Superhydrophobic Surfaces. Langmuir 25, (20) 12293-12298 (2009). See also cover of that issue.
3. Yang, S., Tsai, P., Kooij, E.S., Prosperetti, A., Zandvliet, H.J.W., & Lohse, D. Electrolytically Generated Nanobubbles on Highly Orientated Pyrolytic Graphite Surfaces Langmuir 25, (3) 1466–1474 (2009).
4. Peters, A.M., Pirat, C., Sbragaglia, M., Borkent, B.M., Wessling, M., Lohse, D. & Lammertink, R.G.H. Cassie-Baxter to Wenzel state wetting transition: Scaling of the front velocity. Eur. Phys. J. E 29, 391–397 (2009).

Non Invasive Molecular Tumor Imaging and Killing (NIMTIK)

Projectleaders
M Versluis, T van Leeuwen
Researchtheme
Complex dynamics of fluids
Participants
J Sijl, S Manohar, M Versluis,
T van Leeuwen, N de Jong, D Lohse
Cooperations
Biophysical Engineering, University of Twente; Erasmus Medical Center
Funded
BMTI Portfolio, University of Twente
1st 50% 2nd - 3rd 50%
Start of the project
2004
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Project Aim

Here we focus on the development of a non-invasive method for early detection of tumors. By attaching specific bio-chemical target markers to microbubbles or by labeling antibodies to cancer cells the transport can be directed. Also the target site can be visualized using ultrasound imaging.
This may eventually lead to an increased detection rate of tumors or e.g. trombosis. We also work on the eradication of localized tumors. In addition to the ultrasound techniques aplied in our group the NIMTIK project also includes molecular imaging in the field of photo-acoustics and optical tomography. The synthesis of contrast particles for these techniques is under the guidance of the polymer chemists, while the optimization and signal analysis for each detection method is the task of the electrical engineers.

Progress

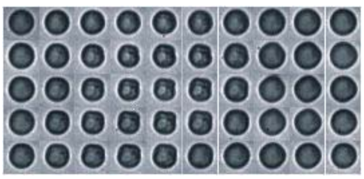
We have used the Brandaris ultrahigh-speed camera to investigate the radial dynamics of differently sized phospholipid coated microbubbles optically. In this experimental study we have varied both the driving pressure amplitude and frequency to investigate the dependence of the non-linear subharmonic and "compression-only" behavior of phospholipid coated microbubbles on the oscillation amplitude of the bubble wall. From the comparison between the experimental results and the numerical simulations we found that the initial surface tension of the bubble determines both its subharmonic and its "compression-only" behavior. These findings are valuable for the application of phospholipid coated microbubbles in medical ultrasound imaging. By controlling the initial conditions of the microbubbles, their non-linear/subharmonic behavior can be enhanced leading to an improved contrast to tissue ratio in contrast-enhanced ultrasound imaging.

Dissertations

1. Sijl, J. (2009, December, 16). "Ultrasound contrast agents - optical and acoustical characterization", University of Twente, (Enschede,The Netherlands: Physics of Fluids group). Promotoren: Prof. dr. D. Lohse and Prof. dr. ir. N. de Jong.

Scientific Publications

1. Marcia Emmer, Hendrik J. Vos, Michel Versluis, and Nico de Jong. Radial Modulation of Single Microbubbles. IEEE T. Ultrason. Ferr. 56, 2370 (2009).
2. Nico de Jong, Marcia Emmer, Annemieke van Wamel and Michel Versluis. Ultrasonic characterization of ultrasound contrast agents. Med. Biol. Eng. Comput. 47, 861¬873 (2009).
3. A. Novell, S.M. van der Meer, M. Versluis, N. de Jong, A. Bouakaz. Contrast agent response to chirp reversal: Simulations, optical observations and acoustical verification. IEEE T. Ultrason. Ferr. 56, 1199 (2009).
4. Marcia Emmer, Hendrik J. Vos, David E. Goertz, Annemieke van Wamel, Michel Versluis, and Nico de Jong. Pressure-dependent attenuation and scattering of phospholipid-coated microbubbles at low acoustic pressures Ultrasound Med. Biol. 35, 102 (2009).



An example of "compression-only'' behavior of a phospholipid coated microbubble, recorded with the Brandaris ultrahigh-speed camera. The optical images, show buckling of the phospholipid shell resulting from a high concentration of phopholipids on the bubble shell.

Bubble clustering in turbulent flows

Project Aim

The goal of the project is to characterize and quantify bubble accumulation (clustering) within the turbulent structures of the flow, and to study how bubbles affect the prevailing turbulence. Employment of novel experimental techniques is necessary, such as 3D Particle Tracking Velocimetry (PTV) and Phase Sensitive Constant Temperature Anemometry (CTA). The experimental results will provide useful information for the closures of front tracking simulations and point-like particle simulations as well.

Progress

First experiments to study Lagrangian statistics of microbubbles in isotropic turbulence with Re_τ> 200 have been performed. Experiments are performed at the Twente Water Tunnel using a 3D-Particle Tracking system to obtain the microbubbles' positions in a measurement volume of 5x5x5 cm^3. Microbubbles with size compared to Kolmogorov's lengthscale of the flow (≈ 100 μm) are generated using a porous ceramic plate. Using the positions we can construct the particles' trajectories and get velocities and accelerations along them. PDFs of velocity and acceleration can thus be calculated (see figure below). At the moment we want to obtain longer trajectories aiming at better long-time Lagrangian statistics. For this we need to implement an algorithm to connect interrupted segments of the trajectories.

Dissertations

-

Scientific Publications

-

Projectleaders

D Lohse

Researchtheme

Complex dynamics of fluids

Participants

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Y Tagawa, C Sun

Cooperations

AKZO-Nobel, Corus, DSM, Shell,
Prof. J.A.M. Kuipers, UT, Dr. M. van St. Annaland, UT, Dr. N. Deen, UT
Dr. E. Calzavarini, Dr. K. Sugiyama

Funded

FOM-IPP Programme: Fundamentals in heterogeneous bubbly flow.
1st - 2nd 100% 3rd -

Start of the project

2007

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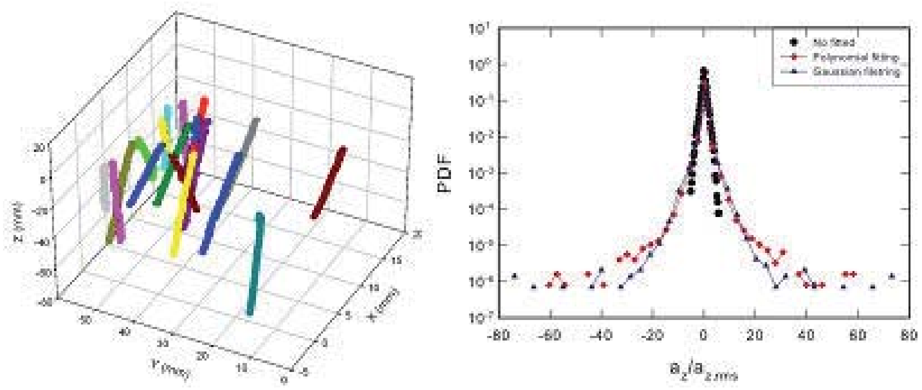

Contact line instabilities

Projectleaders
JH Snoeijer
Researchtheme
Complex dynamics of fluids
Participants
TS Chan, KG Winkels, D Lohse
Cooperations
ASML BV, Veldhoven
Funded
FOM, ASML and, EU
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Start of the project
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Project Aim

The aim of this project is to study the instabilities of advancing and receding contact lines, both theoretically and experimentally. Most work in the literature has focused on contact line dynamics in the viscosity dominated regime, neglecting outer flow effects or inertia. However in situations close to instabilities the latter two assumption might be violated. This occurs, for example, in the context of immersion lithography, and therefore the project is in close collaboration with ASML. The main issues to be addressed in this project are: stability of contact lines over a broad range of velocities, bubble entrapment, high Reynolds number motion, constant acceleration and oscillations.

Progress

For the theoretical approach, a numerical code based on a new two phase lubrication type model, is developed to study the critical speed for air entrainment near an advancing contact line. Results are verified with existing data from literature. With the used approach, new aspects of the air entrainment mechanism will be studied. For the experimental study, experiments are carried out on a turntable setup at ASML to investigate the effect of velocity on the dynamics of receding contact lines. Results are compared with theoretical models from literature that predict (i) a relation between the dynamic contact angle and the tip openings angle; and (ii) an exponential dependence of the tip curvature on the sliding velocity. Both predictions are in qualitative agreement with the experimental data. For further investigations, a similar turntable has been build at the University of Twente, which is capable of accurately rotating a glass wafer (Ø 30 mm) with controlled velocity and acceleration.

Dissertations

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Scientific Publications

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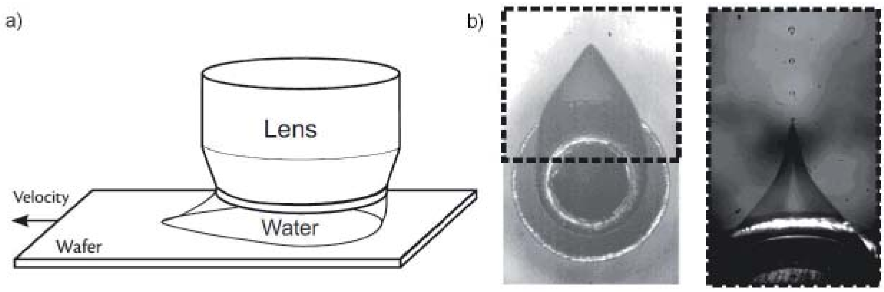
a) simplified sketch of the situation in immersion lithography systems, b) instabilities at the receding contact line.



AIR ENTRAPMENT IN PIEZO INKJET PRINTING

PROJECT AIM

A bubble that is entrained in the ink channel of a piezo-driven inkjet print head often leads to malfunction. This project works on an acoustic method to detect, prevent and understand the air entrapment. To complement the acoustic measurements, visual recordings of the droplet formation and air-entrapment are being done with high-speed cameras which verify the acoustic readings. In another part of the project the acoustics and the bubble-channel interaction inside the channel are modeled. In addition to the improvement of the stability of a print head, the dynamics of a bubble inside a confined space are studied in this project.

PROGRESS

The parameter space of bubble dynamics in an inkjet printhead has been investigated theoretically. A nonlinear model that describes the bubble dynamics in a confined space has been developed. With this model, theoretical predictions were confirmed. To find the relevant parameters for the droplet formation process, a second order accurate droplet formation model was developed, in which both droplet coalescence and separation can be simulated. Preliminary results from this model are shown in the figure below on the right hand side. Detailed experiments are conducted to verify the model and confirm the parameter study.

DISSERTATIONS

1. Roger Jeurissen. Bubbles in inkjet printheads: analytical and numerical models, October 23, 2009.

SCIENTIFIC PUBLICATIONS

1. R. Jeurissen, A. van der Bos, H. Reinten, M. van den Berg, H. Wijshoff, J. de Jong, M. Versluis, D. Lohse, Acoustic measurement of bubble size in an inkjet printhead, J. Acoust. Soc. Am. 126, (5) 2184-2190 (2009).

PROJECTLEADERS
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RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
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COOPERATIONS
H Reinten, H Wijshoff, M van den Berg, J de Jong (all Océ Technologies B.V.)

FUNDED
Océ Technologies, STW, MicroNed, HiPrins
1st - 2nd 100% 3rd -
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2006 - A van der Bos
2010 - T Driessen

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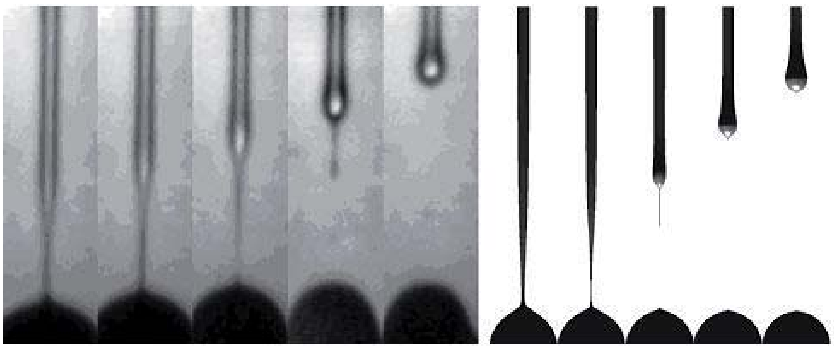

On the formation of monodisperse microsprays

Projectleaders
D Lohse, M Versluis

Researchtheme
Complex dynamics of fluids

Participants
W van Hoeve, M Versluis, D Lohse

Cooperations
MedSpray, Oce, Friesland-Campina, Prof. M. Brenner, Harvard

Funded
MicroNed
1st - 2nd - 3rd 100%

Start of the project
2007

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Project Aim

The aim of the project is to understand and control the formation of monodisperse droplets and bubbles. Bubbles and droplets with a well-controlled and narrow size distribution are important in several industrial and medical applications, e.g. in food industry the production of monodisperse powders through spray-drying results in a reduction of transportation and energy costs, in drug inhalation technology monodisperse droplets lead to an improved lung targeting, and in diagnostic ultrasound imaging monodisperse microbubbles can be used as ultrasound contrast agents.

Progress

In this project we study the formation of microdroplets through the spontaneous breakup of a microscopically thin liquid jets into droplets. A liquid that is forced to flow through a nozzle at sufficient large velocity forms a jet that is inherently unstable. A small disturbance introduced by mechanical vibrations or thermal fluctuations will grow when its wavelength exceeds the jet's circumference. The wave that grows fastest is the optimum wavelength for jet breakup and governs the droplet size. This phenomenon is known as "Rayleigh breakup". We study the formation of these microdroplets using ultra high-speed microscopic imaging and within a lubrication approximation model.

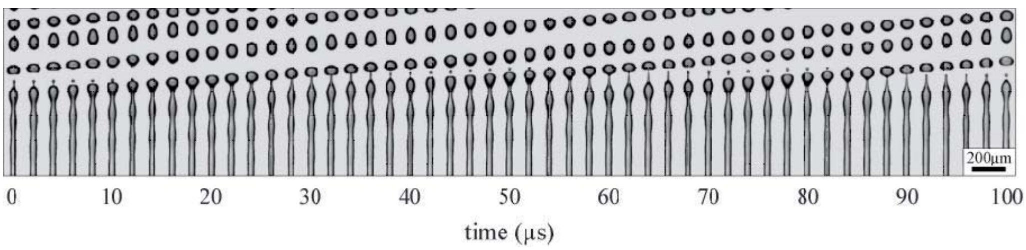
Dissertations

-

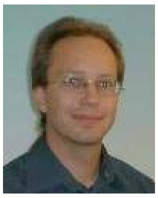
Scientific Publications

-

Time series of the spontaneous breakup of a liquid jet into a continuous stream of microdroplets.



Physics of Complex Fluids



Prof.dr. F Mugele

Mission

The goal of the PCF group is to understand and control the structure and the mechanical properties of liquids and interfaces on small scales ranging from a few nanometers to many micrometers. Our activities are subdivided in three categories: i) nanofluidics, ii) (electro)wetting & microfluidics, iii) soft matter mechanics. In nanofluidics we are interested in the range of validity of classical hydrodynamics and in its breakdown upon approaching molecular scales. In microfluidics we make use of the electrowetting effect to control the shape, the motion, and the generation of microdrops. These processes involve various challenging fundamental issues, such as contact angle hysteresis, the dynamics of contact lines, and hydrodynamic singularities. In soft matter mechanics, we are interested in the correlation between the internal structure of various types of complex fluids ranging from colloidal suspensions to living cells and their viscous and elastic properties. By improving the physical understanding of these physical phenomena we try to contribute to the improvement of various technological processes involving fluid motion on small scales, including oil recovery, immersion lithography, and inkjet printing.

Results & highlights 2009

In 2009 the group published 15 papers in refereed journals. Seven publications fall under the realm of the very successful Cell Stress strategic research program within the MESA+ institute under the coordination of Michel Duits (PCF). As a highlight, in November, the PhD thesis of Jane Li entitled “Linking Particle Dynamics to Intracellular Micromechanics in Living Cells” was completed.

2009 was also a year of the start of a major new research line in PCF related to enhanced oil recovery. In September, a 5-year research contract was signed between the PCF group and the oil multinational BP with a total volume of 4.25Mio€. The PCF research program “Rock-on-a-Chip: Micro- and Nanofluidics for Enhanced Oil Recovery” is part of the ExploRe program within BP, which comprises two other academic partners from Göttingen (Germany) and from Copenhagen (Denmark). The ExploRe program is part of a larger activity within BP aiming at an overall increase in efficiency of oil recovery by up to 10%. This efficiency is determined by combination of physical and physico-chemical processes ranging from the molecular scale to the – typically micrometric – pore scale all the way up to the macroscopic scale. The Rock-on-a-Chip program builds on the strengths is based on the scientific strengths of PCF group in micro- and nanofluidics and interfacial phenomena. The problems will be addressed by 4 PhD students and 6 postdoctoral researchers.

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Rheological study of structural aging in dense suspensions of soft particles

Project Aim

1. to study the rheological properties of aging colloidal suspensions.
2. to study the evolution of the typical relaxation time of the aging suspensions.

Progress

Using particle tracking microrheology, we studied the glass transition in dense suspensions of thermosensitive microgel particles. These suspensions can be tuned reversibly between the glass state at low temperature and the liquid state at high temperature. In the glass state, the ensemble averaged mean squared displacements (MSDs) of added fluorescent tracer particles depend on the age of the suspension. We also determine the local viscoelastic moduli, from the MSDs using the Generalized Stokes-Einstein Relation and compare them to the bulk moduli, measured using conventional rheometry. With particle tracking, one probes the viscoelastic moduli in a lower frequency range than with macrorheology, which makes it possible to determine the mean relaxation time that is inaccessible with macrorheology. In the glass state, the mean relaxation time increases linearly with the age of the sample.

Dissertations

-

Scientific Publications

-

Projectleaders

F Mugele, HTM van den Ende

Researchtheme

Complex structures of fluids

Participants

HTM van den Ende, Eko H Purnomo

Cooperations

-

Funded

FOM

1st - 2nd 100% 3rd -

Start of the project

2003

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Cell's response to mechanical stress

Projectleaders
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Researchtheme
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D. Wijnperle, A van den Berg (UT)
J. Schnekenburger (Uni Muenster)
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Funded
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1st 100% 2nd - 3rd -
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Project Aim

The purpose of this work is to study, using microrheological methods, the mechanical response of the cytoskeleton in living cells with respect to external mechanical actuation. The parameters of the actuation is focused on various deformation regimes, for example amplitude, time, speed, to obtain a viscoelastic mapping, which reflects real in vivo behavior of living cells and allows comparison with related experiments and modeling studies.

Progress

We studied the dynamics of two types of intracellular probe particles: ballistically injected latex spheres (BIPs) and endogenous granules (EGs), in tumor cell lines of differerent metastatic potential: breast tumor cells (MCF-7 malignant, MCF-10A benign) and pancreas adenocarcinoma (PaTu8988T malignant, PaTu8988S benign). For both tissue types and for both probes, the mean squared displacement (MSD) function measured in the malignant cells was substantially larger than in the benign cells. Only a few cells were needed to characterize the tissue as malignant or benign based on their MSD, since variations in MSD within the same cell line were relatively small. These findings suggest that intracellular particle tracking (IPT) can serve as a simple and reliable method for characterization of cell states obtained from a small amount of cell sample. Mechanical analysis of the same cell lines with Atomic Force Microscopy (AFM) in force-distance mode, revealed that AFM could distinguish between the benign and malignant breast cancer cells but not for the pancreatic tumor cell lines. This underlines the potential value of IPT as a complementary nanomechanical tool for studying cell state dependent mechanical properties.

Dissertations

1. Linking Particle Dynamics to Intracellular Micromechanics in Living Cells, Y.Li, 11-11-2009.

Scientific Publications

1. Mapping of spatiotemporal heterogeneous particle dynamics in living cells M.H.G. Duits, Y. Li, S.A. Vanapalli, F. Mugele, Phys. Rev. E 79, 051910, 2009.
2. Dynamics of ballistically injected latex particles in living human endothelial cells. Y. Li, S.A. Vanapalli, M.H.G. Duits, Biorheology, 46, 309, 2009.
3. On the origins of the universal dynamics of endogenous granules in mammalian cells. S.A. Vanapalli, Y. Li, F. Mugele, M.H.G. Duits, Molecular and Cellular Biomechanics, 150, 1-16, 2009.
4. Intracellular particle tracking as a tool for tumor cell characterization, Y. Li, J. Schnekenburger, M.H.G. Duits, J. Biomed. Optics 14, 6, 064005, 2009.
5. Microfluidics as a functional tool for cell mechanics, S.A. Vanapalli, M.H.G. Duits, F. Mugele, Biomicrofluidics, 3, 012006, 2009.
6. Hydrodynamic resistance of single confined moving drops in rectangular microchannels. S.A. Vanapalli, A.G. Banpurkar, D. van den Ende, M.H.G. Duits, F. Mugele. Lab Chip 9, 982, 2009.
7. Microfluidic valves with integrated structured elastomeric membranes for reversivle fluidic entrapment and in situ channel functionalization, S.A. Vanapalli, D. Wijnperle, A. v.d. Berg, F. Mugele, MHG Duits, Lab Chip, 2009.
8. Microfluidic technology in vascular research, A.D. van der Meer, A.A. Poot, M.H.G. Duits, J. Feijen, I. Vermes, J. Biomed. and Biotechn. ID, 823148, 2009.

Dynamic structure formation of colloids in confined geometries

Project Aim

We want to understand how confined colloidal fluids can change their structure and mechanical properties under the action of controlled external forces. This underexplored area in physical chemistry touches several fundamental issues and has potential for applications of colloids in microfluidic chips. The question: How does structure formation take place at high volume fractions under confinement and external forces? will be addressed via an approach where the dynamic forces and restructuring associated with the compression are (simultaneously) measured at microscopic scales (μm's and μN's).

Progress

We used video microscopy and particle tracking to study the dynamics of confined hard-sphere suspensions. Our fluids consisted of 1.1-μm-diameter silica spheres suspended at volume fractions of 0.33–0.42 in water-dimethyl sulfoxide. Suspensions were confined in a quasiparallel geometry between two glass surfaces: a millimeter-sized rough sphere and a smooth flat wall. First, as the separation distance (H) is decreased from 18 to 1 particle diameter, a transition takes place from a subdiffusive behavior (as in bulk) at large H, to completely caged particle dynamics at small H. These changes are accompanied by a strong decrease in the amplitude of the mean-square displacement (MSD) in the horizontal plane parallel to the confining surfaces. In contrast, the global volume fraction essentially remains constant when H is decreased. Second, measuring the MSD as a function of distance from the confining walls, we found that the MSD is not spatially uniform but smaller close to the walls. This effect is the strongest near the smooth wall where layering takes place. Although confinement also induces local variations in volume fraction, the spatial variations in MSD can be attributed only partially to this effect. The changes in MSD are predominantly a direct effect of the confining surfaces. Hence, both the wall roughness and the separation distance (H) influence the dynamics in confined geometries.

Dissertations

-

Scientific Publications

1. Influence of confinement by smooth and rough walls on particle dynamics in dense hard-sphere suspensions, H.B. Eral, H.T.M. van den Ende, F. Mugele, M.H.G. Duits. Phys. Rev. E., 80, 6, 2009.

Projectleaders
F Mugele

Researchtheme
Complex dynamics of fluids

Participants
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Cooperations
-

Funded
NWO-CW
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Start of the project
2006

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AFM spectroscpy of confined liquids

Projectleaders
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Researchtheme
Complex structures of fluids
Participants
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Cooperations
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Funded
FOM
1st - 2nd 100% 3rd -
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Project Aim

The goal is to get a quantitative understanding of the mechanical properties of liquids on small scales. To reach this goal we want to perform high resolution force measurements using atomic force microscopy. With a ultralow noise AFM system the molecular and surface forces in liquids will be determined. In particular we want to use Brownian force spectroscopy because it allows for the direct reconstructing interaction energies in thermal equilibrium with unprecedented resolution.

Progress

We set up an ultra-low noise AFM system. We examine the amplitude and phase of the AFM cantilever driven at very small amplitude upon approaching the tip towards the surface in a liquid medium. From the measured behavior of amplitude and phase we extracted both conservative interaction forces as well as dissipative forces of the nano-confined liquid films. Two different systems are studied: (i) Octamethyltetrasiloxane confined between the tip and a solid (HOPG) substrate. This model liquid is known to display liquid layering. At the moment MD simulations are performed to get a better understanding of the system. (ii) free liquid-vapor interfaces of nanobubbles on hydrophobic surfaces. The dynamic behavior of the cantilever is being modeled both analytically as numerically and the results are compared to the measurements. We have build an environmental control (to control temperature and humidity) for the AFM in order to study the behavior of the nano-confined liquids close to the freezing temperature.

Dissertations

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Scientific Publications

1. Small-amplitude AFM spectroscopy of confined liquid films. S. de Beer, F. Mugele, Microscopy and Analysis, 2009.
2. On the shape of surface nanobubbles. B.M. Borkent, S. de Beer, F. Mugele, D. Lohse, Langmuir, publ. web 16-09-2009.
3. Instability of confined water films between elastic surfaces. S. de Beer, D. ‘t Mannetje, S. Zantema, F. Mugele, Langmuir, publ. web 30-12-2009.

Electrowetting-based droplet generation and emulsification in microchannel

Project Aim

- To provide precise control of drop generation and potentially access to a wider range of drop sizes not attainable by pure flow focusing
- To achieve drop size as small as possible.

Progress

- We develop a simple, low-cost method to construct closed microchannels enclosed between two glass plates, each of which comprises electrodes and insulating layers.
- We demonstrate the new capabilities with two examples: EW-controlled drop generation in a flow focusing geometry, and EW-controlled imbibition pressure for oil displacement in a 2D device (low aspect ratio).
- The new chip design allows for a more precise and continuous control over the formation of monodisperse small drops with diameters from 1 to 15 µm in flow focusing devices.

Dissertations

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Scientific Publications

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Projectleaders
F Mugele, MHG Duits

Researchtheme
Complex structures of fluids

Participants
H Gu, MHG Duits, F Mugele

Cooperations
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Funded
Microned
1[st] - 2[nd] - 3[rd] 100%

Start of the project
2006

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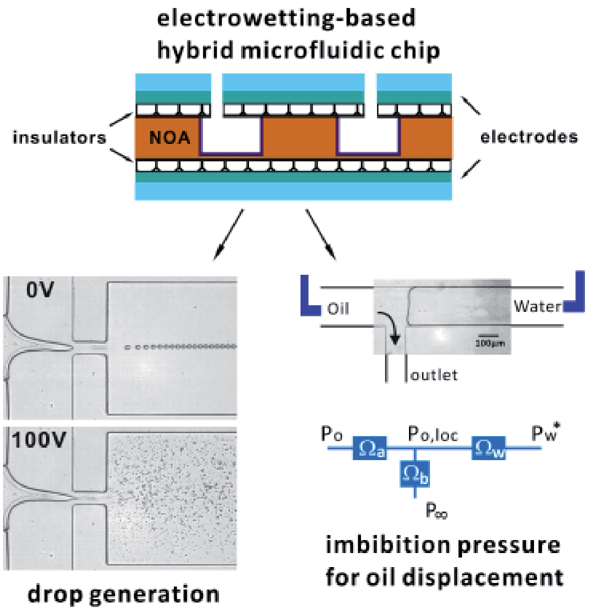
Phase diagram of drop generation



Electrorheology on Non-Newtonian fluids

Projectleaders
F Mugele, HTM van den Ende
Researchtheme
Complex structures of fluids
Participants
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Cooperations
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Funded
MicroNed Network
1st - 2nd - 3rd 100%
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2007
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Project Aim

Developement of a micro-rheometer driven by Electro-Osmotic Flow (EOF). By measuring the flow profile, for instance by optical techniques, one can determine the "stress"-"shear rate" relation of complex fluids in a micro channel. With this rheometer the behavior of emulsions and non-Newtonian fluids containing protein aggregates flowing through micro channels will be studied. Study of the behavior of small clusters flowing through a micro channel will be studied, especially the interaction of the droplets/clusters with a DC and low frequency AC electric field.

Progress

The electro osmotic flow (EOF) in microchallels is studied. A theoretical model was developed to determine the surface charge of the channel walls. A paper about this topic has been accepted by Electrophoresis. The surface charge of the microchannels is chemically modified and shear flow based on EOF was varified. In the current stage, the surface charge is controled using gate electrodes embedded in the channel wall, giving full controll over the surface charge and zeta potential.

Dissertations

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Scientific Publications

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Electrowetting controlled contact line dynamics

Project Aim

The goal of this project is to improve the understanding of both the physics of pinning and depinning of contact lines on structured surfaces and the dynamics of moving contact lines on such surfaces using electrowetting, with the ultimate goal of improving the performance of both immersion lithography and inkjet printing systems.

Progress

We have acquired a rotary-table system for the controlled study of steady-state dynamic contact lines, for which final adjustments are being made to begin measurements. We have studied the behaviour of moving microliter-scale water droplets (20-60µl) when an AC voltage of 1-10 kHz frequency is applied to it in an electrowetting set-up. We have seen that, as expected, a droplet can be made to move more easily over a surface, even ones with a hysteresis as small as 10o. However, the actual velocity of an already mobile droplet moving with a velocity on the order of 0.1-0.5 m/s under the influence of gravity shows no measurable change with applied voltage on many such surfaces. We are currently planning experiments on higher-hysteresis samples (20+o) to find out if these show an effect of AC electrowetting in both the threshold and velocity of sliding.

Dissertations

-

Scientific Publications

-

Projectleaders

F Mugele

Researchtheme

Complex dynamics of fluids

Participants

DJCM ‘t Mannetje, CU Murade,
HTM Van den Ende, F Mugele

Cooperations

FOM IPP

Funded

FOM

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Start of the project

2008

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Stability of confined water layers in hydrophobic nanochannels

Projectleaders
F Mugele

Researchtheme
Complex structures of fluids

Participants
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M van der Weide-Grevelink, JM Oh

Cooperations
-

Funded
NanoNed Network
1st - 2nd - 3rd 100%

Start of the project
2008

Information
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Project Aim

1. To study phase-transition in nanochannel.
2. To study stability of confined water layer in hydrophobic nanochannel.
3. To develop theoretical understanding for the effect of hydrophobic surface on phase-equilibria.

Progress

A nanochannel chip is designed to fabricate. The validity of Lucas-Washburn equation for water-ethanol mixture in nanochannel is examined. The results show that the filling of solvent mixture follows the-square-root-of-time dependence in the nanochannels with thickness larger than 6 nm. Smaller channels are filled before the front of the approaching liquid reaches the intrance of the nanochannel. This may be due to an evaporation-condensation proces or a precursor film.

Dissertations

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Scientific Publications

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Dynamics of spreading of model inks on complex surfaces for high-end printing applications

Project Aim

High-end printing of graphics and electronics requires a high degree of control of the spreading process of ink on the printing medium. The complex composition of both the surface and the ink makes the motion of the contact line and the spreading of the liquid a complex problem. The goal of the project is to understand the physical principles of spreading of model inks on model surfaces.

Progress

We examine the dynamics of droplet spreading on rough substrates (and compare this to spreading on a smooth glass substrate). Rough substrates are comprised of a smooth glass substrate covered with micron-sized silica particles deposited by a spin-coating technique. Spreading of millimeter-sized, highly-viscous silicon oil droplets is examined on various rough substrates that are characterized according to their roughness parameters. Spreading is in the capillary regime (spreading exponent of 1/10 on the smooth substrate), and the dynamics is modified by the roughness. On a rough substrate, the spreading droplet has a relatively fast imbibition front that wets the silica particles first, followed by a slower inner front. Next to the spreading dynamics, the roughness of the contact line is examined. In the near future, we want to examine smaller droplet (approx. 100 micron) using a microdispenser.

Dissertations

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Scientific Publications

-

Projectleaders
F Mugele

Researchtheme
Complex dynamics of fluids

Participants
J de Ruiter, HTM van den Ende, F Mugele

Cooperations
Industrial partners: Océ, TNO, OTB

Funded
HIPRINS
1st - 2nd - 3rd 100%

Start of the project
2009

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Imbibition of water into oil-filled microchannels with complex wall properties

Projectleaders
F Mugele
Researchtheme
Complex dynamics of fluids
Participants
R de Ruiter, MHG Duits, F Mugele
Cooperations
Max Planck Institute for Dynamics and Self-Organization, University of Copenhagen, BP
Funded
BP
1st - 2nd - 3rd 100%
Start of the project
2009
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Project Aim

At the level of individual pores, the efficiency of oil recovery is governed by the spontaneous and pressure driven imbibition of brine and the subsequent mobilization and flow of oil (and water) through the complex pore network. Chemical heterogeneity and topographic rougness control the initial distribution of oil and water in the pore space as well as the flow resistance experienced by mobilized oil. In this project, we will adress these issues by generating microfluidic channels with specifically designed and controllable wall patterns to elucidate the fundamental physical processes underlying the mobilization of oil in porous media.

Progress

We started the characterization of the system, which comprises artificial seawater and a model oil, consisting of n-decane with stearic acid as a polar component. The conditions under which an interfacial layer of stearic acid is formed at the oil-water interface, are studied. We performed initial experiments on the imbibition of water into an oil-filled channel, during which we ultimately want to determine the oil recovery from the channel through the thickness of the residual oil film, using dual-wavelength reflection interference contrast microscopy.

Dissertations

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Scientific Publications

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Electro-acoustic coupling in porous oil-water two-phase systems: the role of liquid micromenisci

Project Aim

Electro-seismic effect manifests itself as an electrical potential generated in the subsurface. However, various aspects of the experiment are not well described by the current standard theory electroseismic (ES) coupling. One shortcoming of this theory is the fact that it ignores the presence of liquid menisci at interfaces and within partially saturated porous media. The goal of this project is to analyze the role of liquid micromenisci in both the electro-seismic as well as in the inverse electro-seismic effect. We use model porous systems in which relevant parameters such as the pore geometry, surface chemistry are well controlled and defined.

Progress

One of the critical step in understand the Electro-acoustic coupling is to understand dynamics of micromenisci with applied pressure. So we started with performing the laboratory experiments to understand the change in the shape of micromenisci with the applied external pressure (hydrostatic). Simple porous system is used with well defined geometry and surface properties. The applied static pressure was varied over a wide range and corresponding curvature of the menisci is calculated. The shape of the micromenisci is calculated using inverse optical diffraction techinque which is well understood and developed in our group by ex-Phd student. Quantitative analysis was performed to understand the change in shape of menisci with applied external pressure. Some preliminary experiments has also been performed to understand the dynamics of micromenisci with external electrical pressure.

Dissertations

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Scientific Publications

-

Projectleaders
F Mugele

Researchtheme
Complex dynamics of fluids

Participants
T Kumar, HTM van den Ende

Cooperations
-

Funded
FOM
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2008

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Applied Analysis & Mathematical Physics (AAMP)

Prof.dr.ir. EWC van Groesen

In our group AAMP we study natural phenomena or help to design and improve technical apparatus or processes. We investigate the propagation of surface waves on a layer of fluid, the shock propagation caused by volcano eruptions through the earth, and the way how light gets reflected and transmitted through different materials.

We study these aspects with a set of suitable mathematical techniques that we extend and improve constantly. Our understanding of the phenomena is reflected in the mathematical models, which are updated and improved with increased understanding from theoretical investigations and simulations. Except for their mathematical structure with intrinsic beauty, our investigations are often 'useful': for hydrodynamic laboratories we advise how to generate the wave fields that they want to produce in their tanks to test ships in realistic situations, the calculations of seismic events may lead to an understanding which earth quakes give rise to large tsunamis, the design of optical devices with nano-scale structures helps to advance telecommunication, etc.

The topics mentioned above are very diverse in their appearance, and cover length scales ranging from 10^-9 till 10^7 meter. The beauty of the mathematical descriptions is that they are actually quite similar: the major physical process is the evolution of waves, or an abstraction of it. Special properties that depend on the application are reflected in the mathematical structure of the wave equations that are at the basis of the models. For instance, energy or momentum conservation corresponds to symmetries in the mathematical formulations. Specific methods that we use include variational methods, which exploit the remarkable fact that often a certain optimality property can be found in the phenomenon. Except for theoretical methods, often supported with computer algebraic calculations, regularly we design larger or smaller simulation tools of a numerical nature.

For the design of these numerical schemes we aim to keep the special properties of our theoretical models as well, leading to consistent finite dimensional version of the infinite dimensional models.

The research in water waves contains various topics. Characteristic is that for irrotational flows we approach the problems in a unified consistent modelling way. This is based on the fact that upon neglecting dissipation, the full free surface equations have a basic variational structure (Luke, 1967), with the free surface equations described by a Hamiltonian system (Zakharov 1968, Broer 1974). In our modelling of specific wave fields, we exploit this structure by finding approximations of the kinetic energy part of the Hamiltonian. This is used for approximate models described by pde's like the shallow water equations, Boussinesq-, KdV and NLS-type of equations.

For numerical simulations, this structure is exploited to find consistent discretizations by variational restriction: the functionals defined on infinite dimensional spaces are restricted to finite dimensional subspaces, which may be high dimensional but may also be much more restricted by including essential properties of the phenomenon in the description, depending on the specific cases.

Within the basic approach, we include various active or passive boundary conditions, depending on the application (to generate waves by wave flaps for hydrodynamic laboratories, or bottom motions for seismic applications), or to allow a reflection-free description for calculations on numerical artificial windows. Locally, the activities are grouped in the projects Math Modelling and consistent Numerical Simulations, Free flows and Extreme Waves, Coastal Waves, and Seismic generation of waves.

Wave dynamics in the coastal zone

Project Aim

Wave groups propagating in the coastal zone experience combined effects of wave non-linearity, bathymetry, wave-current interaction and wave breaking. Long wave generation is one effect which plays an important role in coastal morphodynamics and the motion of moored ships, just as the large spatial variability of high waves. The aim of this project is to come to improved modeling and understanding of waves in the coastal area, including aspects of tsunami waves.

Progress

With a Finite Element implementation of the Variational Bousinesq Model, tsunami simulations were continued for realistic cases in the Indonesian coastal waters. The same model has been used to perform accurate simulations for deterministic harbour waves, with specific investigations how much dispersive properties influence the resonant frequencies. In the project on effective boundary conditions we used the classical WKB-model to approximate the reflection from varying bottom; the explicit formulas will be used for EBC's in simple cases and for adjacent projects.

Dissertations

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Scientific Publications

1. D. Adytia & E. van Groesen, Variational Boussinesq model for simulations of coastal waves and tsunamis, Proceedings of the 5th International Conference on Asian Pacific Coasts, (APAC2009) 13-16 October 2009 Singapore 9ed: Soon Keat Tan, Zhenhua Huang]; World Scientific 2010, ISBN-13 978-981-4287-94-4, Volume 1 (ISBN-13 978-981-4287-96-8), pages: 122-128.

Projectleaders
EWC van Groesen

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
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Cooperations
LabMath-Indonesia, Bandung Indonesia, MARIN Wageningen.

Funded
UT, STW, NWO-ALW; MARIN
1st 20% 2nd 75% 3rd 5%

Start of the project
2003

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Generation of deterministic extreme waves in hydrodynamic laboratories

Projectleaders
EWC van Groesen
Researchtheme
Mathematical and computational methods for fluid flow analysis
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Cooperations
LabMath-Indonesia, Bandung Indonesia, MARIN Wageningen
Funded
UT, STW, MARIN
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2002
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Project Aim

The study of deformations of surface waves is focused on 'extreme waves'. The motivation comes from generating large amplitude waves in hydrodynamic laboratories. We investigate the maximal amplification factor that can be obtained from nonlinear effects in various wave groups (BF-instability, bi-harmonic deformations, soliton interactions), and properties of `extremal waves' for increasingly more complicated model equations.

Progress

For the Variational Boussinesq Model, the choice of the vertical potential profile has been directed form the parabolic to the hyperbolic cosine profile. This makes it possible to choose one parameter, a 'representative' wavenumber, to optimise the diespersion properties. With a new kinetic energy optimization principle, the dispersion can be optimized depending on information of the initial wave or the influxing signal. good results were obtained and submitted for publication. A generalization of the uni-directional AB-equation to 2 dimensions, the AB2-equation, an improvement of the KP-equation, was completed successfully. Numerical implementations were derived and will be used to design new measurements at MARIN and to use the results for benchmarking of the code. Theoretical results have been derived for the propagation of fully dispersive waves above varying bottom.

Dissertations

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Scientific Publications

1. E. van Groesen, Andonowati, L. She Liam & I. Lakhturov, Accurate modelling of uni-directional surface waves, Journal of Computational and Applied Mathematics 2009, doi:10.1016/j.cam.2009.08024 (online: 19 august 2009).
2. N. Karjanto & E. van Groesen, Qualitative comparisons of experimental results on deterministic freak wave generation based on modulational instability, Journal of Hydro-environment Research xx (2009) 1-7, doi:10.1016/j.jher.2009.10.008 (online 23 October 2009).

Numerical Analysis and Computational Mechanics

Prof.dr.ir. JWW van der Vegt

Prof.dr. HJH Clercx

Prof.dr.ir. BJ Geurts

The research in the Numerical Analysis and Computational Mechanics (NACM) group in the Department of Applied Mathematics of the University of Twente concentrates on two main topics:

- The development, analysis and application of numerical algorithms for the (adaptive) solution of partial differential equations for problems originating from the physical and technical sciences, in particular (discontinuous Galerkin) finite element methods.
- Mathematical modeling of complex physical problems to make them accessible for computation, in particular for turbulence and geophysical problems. In order to support these activities a significant research effort is directed towards the development of hpGEM, an object oriented toolkit for finite element methods, written in C++, and suitable for high performance parallel computers. Important applications are in the fields of gas dynamics, wet chemical etching of microstructures, fluid structure interaction, two phase flows both dispersed and with free surfaces, water waves, large eddy simulation of turbulent flows, geophysical flows and computational electromagnetics. Many of these projects are conducted in close collaboration with groups in physics and chemical technology, large technological research institutes (NLR, MARIN, WL Delft Hydraulics, KNMI), and industry (DSM, AKZO and Shell).

The research is conducted in the research institute IMPACT and the research in two-phase flows is part of the UT spearhead program “Dispersed multiphase flows”. The NACM group participates in the 3TU Center of Excellence for Multiscale Phenomena.

Space-time discontinuous Galerkin discretization for nonlinear free surface waves

Project Aim

Our aim is to develop a novel space-time discontinuous Galerkin (DG) method for nonlinear free surface waves based on variational principles. In this method, a space-time DG discretization stems from a discrete variational formulation as opposed to weak formulation. The advantage is that the resulting numerical discretization will be symmetric and sparse, and the numerical scheme shows no decay in the amplitude of free surface waves. Further, we aim to develop efficient nonlinear solvers for the present problem which are based on a pseudo-time integration methods. Both a 3D DG potential flow solver and a 3D DG wave and current models are in development. Comparison will be made with laboratory data of 3D inertial waves by The Royal Netherlands Institute of Sea Research (NIOZ) and with wave tank data of the Maritime Research Institute Netherlands (MARIN).

Progress

A variational space-time discontinuous Galerkin method has been developed for linear free surface waves based on Luke's variational principle. Numerical discretization gives in part rise to a symmetric and sparse linear algebraic equations which are solved using efficient sparse linear solvers like conjugate-gradient method. We have also developed the standard space-time DG method for free surface waves in which the numerical discretization emerges from weak formulation. Numerical schemes resulting from both methods are compared to find that the variational DG scheme shows no decay and the standard DG scheme shows a large decay in the amplitude of the waves. We are now extending both the variational and standard space-time DG methods for nonlinear free surface waves with corresponding efficient nonlinear solvers.

Dissertations

-

Scientific Publications

1. Onno Bokhove and Vijaya R. Ambati, 2009: Hybrid Rossby shelf modes in a laboratory ocean. J. Physical Oceanography 39(10), 2523—2542, 2009.

Projectleaders
O Bokhove, JJW van der Vegt

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
S Nurijanyan, VR Ambati

Cooperations
MARIN, NIOZ, Delft Hydraulics, Alkyon Hydraulic Consultancy & Research, and TU Delft Marine Technology

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2008

Information

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Control of aerosol migration with temperature gradients

Projectleaders
BJ Geurts

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
BS Deb, HJH Clercx

Cooperations
Dr. AK Kuczaj. NRG –ECN. NL, Dr. D Lakehal, ASCOMP GmbH. Switzerland, Dr. F Menter, ANSYS Germany. GmbH, Ir. J Kruithof. DAF Trucks. NL, Dr. JGM Kuerten. TU-Eindhoven

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2008

Information
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Project Aim

The main aim of the project is the computational study of the dynamics of aerosols in turbulent flows. Emphasis will be given on the detailed numerical simulation of the various physical phenomena associated with the aerosol. We focus on evaporation and condensation and, in a later stage, collisions and coalescence. We investigate how large numbers of these particles affect the turbulent flow field and vice versa, under conditions of a mean temperature gradient.

Progress

In the past period we concentrated on the mathematical modelling and the direct numerical simulation of the motion of the aerosols in homogeneous isotropic forced and decaying turbulent flow under the influence of a temperature gradient. We included thermophoresis on the particle motion and observed this effect to be small in strong turbulence. We have also developed the thermodynamic model of the particles undergoing evaporation and condensation in the turbulent flow and we are now working on simulating the combined model.

Dissertations

-

Scientific Publications

1. Contribution to the poster " Multiscale Modelling and Simulation " presented in the Woudschoten conference from October 7-9 2009 along with other co-authors.

Modeling of spatial and temporal variations in offshore sand waves: process oriented versus stochastic approach (STW - project TWO.5805)

Project Aim

Sand waves are patterns with a wavelength of around 500m length and 10m height in e.g. the North Sea where it is around 30m deep. The driving force of the development of sand waves is the vertical structure of the tidal current. In reality sand waves show temporal and spatial variations. The aim of this project is to obtain a better understanding of these variations. In this project we investigate the impact of both deterministic and stochastic variations. At the end of this project both approaches will be tested, to investigate to what extent they can describe reality.

Progress

This project finished in 2009 with the graduation of Sterlini in June 2009.

Dissertations

1. Modelling sandwave variation; Fenneke Sterlini. Graduation date: June 12, 2009.

Scientific Publications

-

Projectleaders

SJMH Hulsher, RMJ van Damme

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

FM Sterlini (van der Meer, PhD), J van den Berg, AA Németh, MAF Knaapen, RMJ van Damme, SJMH Hulscher

Cooperations

Dienst der Hydrografie – Koninklijke Marine; TNO-NITG; Argoss; RWS Directie Noordzee, RWS, Rijksinstituut voor Kust en Zee; Advanced Consultancy Romke Bijker; WL|Delft Hydraulics

Funded

STW

1st - 2nd 100% 3rd -

Start of the project

2003

Information

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PROJECTLEADERS
BJ Geurts
RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis
PARTICIPANTS
-
COOPERATIONS
Prof. HJH Clercx (TUE/UT)
Prof. DD Holm (Imperial College)
Prof. E Titi (UC Davis-Weizmann)
FUNDED
University of Twente
1st 100% 2nd - 3rd -
START OF THE PROJECT
-
INFORMATION
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PROJECT AIM

The goal of this project is the development of multiscale models for the simulation of complex flows under turbulent conditions. Consequences of rotation, buoyancy combustoin and interacting particles on flow-structuring are studied.

PROGRESS

Work was continued on the modulation of turbulence. Regularization models were extended to compressible flow and a comprehensive error-analysis was executed.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Kunnen, R.P.J., Geurts, B.J., Clercx, H.J.H.: 2010. Experimental and numerical investigation of turbulent convection in a rotating cylinder, J. Fluid Mech. 642 , 445 -476.
2. Kunnen, R.P.J., Geurts, B.J., Clercx, H.J.H.: 2009. Turbulence statistics and energy budget in rotating Rayleigh-B´enard convection, Eur. J. Mech. B, doi:10.1016/j.euromechflu.2009.01.003.
3. Geurts, B.J.: 2009. Analysis of errors occurring in large-eddy simulation, Phil. Trans. R. Soc. Lond. A-Math., Phys. and Eng. Sci., 367, 2885-2903, doi:10.1098/rsta.2009.0002.
4. Vreman, A.W., Geurts, B.J., Deen, N.G., Kuipers, J.A.M., Kuerten, J.G.M.: 2009.Two- and four-way coupled Euler-Lagrangian large-eddy simulation of turbulent particle-laden channel flow, Flow, Turbulence and Combustion, 82 47-71, DOI: 10.1007/s10494-008-9173-z.

Mathematical analysis and classification of flow topologies in cerebral aneurysms

Project Aim

Perform computational modeling, analysis and classification of flow topologies that occur in aneurysms in the human brain. Evaluation of the probability of rupture, and long-time stability are important factors.

Progress

Attention was given to work with a Fortran code which simulates the fluid flow inside complex domains. The main accent is on developing and using the Immersed Boundary Method, which provides a relatively simple 'masking function' technique for generating complex geometries. Validation of the method was done for the flow inside a cylindrical tube, where Poiseuille flow was assessed. Simulations of the flow give us the velocity and pressure fields for different basic geometrical vessel shapes such as a straight tube, smoothly curved tubes and tubes with model spheric aneurysms attached to. As a key component for the prediction of the risk of aneurysm rupture the shear stress was calculated at the vessel walls. The procedure was tested and reliable results were observed already at modest spatial resolution. This gives confidence in the application of the methodology to realistic aneurysms as developed in a family of human patients.

Dissertations

-

Scientific Publications

-

Projectleaders

BJ Geurts

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

J Mikhal

Cooperations

Prof.dr.ir. CH Slump
SAS Group, EEMCS Department, University of Twente.

Funded

University of Twente
1st 100% 2nd - 3rd -

Start of the project

2008

Information

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Aerosol particle motion in porous media

Projectleaders
BJ Geurts
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
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Cooperations
Philip Morris International – Dr. Steffen Stolz
Funded
Philip Morris International
1st - 2nd - 3rd 100%
Start of the project
2008
Information
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Project Aim

The target of the project is to understand aerosol particle dynamics in porous media. This is to be done by performing numerical simulations and analysis of aersol property evolution in complex geometry due to evaporation, condensation and (possible) collision.

Progress

Particle motion in a laminar flow through structured porous media was considered and simulated. The flow was obtained using a skew-symmetric finite volume discretization in combination with an immersed boundary method to represent the complex geometry of the flow domain. First results on aerosol filtration due to impaction for the chosen porous geometry were obtained. The dependence of filtration efficiency on particle size and flow condition was investigated.

Dissertations

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Scientific Publications

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Simulation of transport processes in a porous plug

Project Aim

Develop an efficient numerical method for accurately computing three-dimensional, time-dependent transport phenomena in moderate-Reynolds-number flows through geometrically complex domains. A method will be sought utilizing immersed boundary (IB) techniques. We apply this simulation strategy to understand aerosol transport through biomass.

Progress

A volume-penalizing IB method has been implemented to simulate the flow around arbitrarily shaped objects extracted from computer-tomography imagery. The method has been extended for coupled fluid-solid heat transfer predictions. Validation studies are being carried out and results are being processed for scientific publication.

Dissertations

-

Scientific Publications

-

Projectleaders
BJ Geurts

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
DJ Lopez Penha

Cooperations
dr. S Stolz (Philip Morris International)

Funded
Philip Morris International S.A.
1st - 2nd - 3rd 100%

Start of the project
2008.

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Compatible mathematical models for coastal hydrodynamics

Projectleaders
O Bokhove, JJW van der Vegt

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
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Cooperations
-

Funded
NWO
1st - 2nd 100% 3rd -

Start of the project
2009

Information
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Project Aim

Developing a unified discontinuous Galerkin finite element shallow water Boussinesq model to predict and analyze the hydrodynamics in the near-shore coastal zone. The project is divided into two tasks: the design of a conservative discontinuous finite element Boussinesq model, and the design and analysis of a shallow water finite element model with wave breaking, and flooding and drying. These elements then should be combined in a unified finite element coastal hydrodynamics model.

Progress

A literature study was done on variational principle and Hamiltonian formulation to get ready for driving a conservative model. The discontinuous Galerkin finite element discretization for shallow water equations was studied and investigated to include the flooding and drying event.

Dissertations

-

Scientific Publications

-

Hamiltonian-based numerical methods for forced-dissipative climate prediction

Project Aim

In this project we assess the behavior of (idealized) climate models which have a Hamiltonian discretization in the limit of no forcing and dissipation. We believe that such type of discretizations lead to better climate predictions. This objective is investigated in two ways:

- Difference in performance between Hamiltonian and conventional non-Hamiltonian based numerical discretizations for simplified low-order models.
- Construction of a hydrostatic stratified model on the sphere based on a symplectic Hamiltonian particle-mesh method.

Progress

Construction of Hamiltonian numerical scheme for hydrostatic flow in isentropic coordinates using a Hermite finite element discretization in the vertical and a Hamiltonian particle-mesh method in the horizontal. Implementation and validation of the model. Article in progress.

Dissertations

-

Scientific Publications

1. Bokhove, O. and Oliver, M. 2009, Hamiltonian N layer model for atmospheric dynamics. Geophys. Astrophys. Fluid Dyn. 103(6), 423-442.

Projectleaders
O Bokhove, J Frank

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
JJW van der Vegt, O Bokhove, J Frank, BWI Peeters

Cooperations
-

Funded
NWO
1st - 2nd 100% 3rd -

Start of the project
2006

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Discontinuous Galerkin finite element methods for (non) conservative partial differential equations

Projectleaders
JJW van der Vegt, O Bokhove
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
JJW van der Vegt, O Bokhove, S Rhebergen
Cooperations
-
Funded
IMPACT
1st 100% 2nd - 3rd -
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Project Aim

In this project we develop and test discontinuous Galerkin finite element methods for liquid-solid two-phase flows. We assume there are enough solid particles in the flow that the solid phase of the flow can also be modeled as a continuum. We qualitatively validate the numerical results with experimental data.

Progress

To improve the efficiency of solving the space-time discontinuous Galerkin discretization, we have developed, analyzed and tested optimized h-multigrid methods using explicit Runge-Kutta type smoothers for the 2D advection-diffusion equation. These methods have also been tested on solving inviscid flow over a NACA0012 airfoil, solving the Euler equations of gas dynamics.

The efficiency of h-multigrid methods has further been compared to p-multigrid methods.

Dissertations

-

Scientific Publications

1. S. Rhebergen, O. Bokhove and J.J.W. van der Vegt, Discontinuous Galerkin finite element method for shallow two-phase flows, Comput. Methods Appl. Mech. Engrg. , Vol. 198 pp 819-830, (2009).

MULTISCALE MODELING OF GRANULAR FLOWS

PROJECT AIM

The primary purpose of the project is to develop a new HMM model for granular flow, coupling a micro-scale discrete element model to the macro-scale continuum granular flow model. The new model will be verified through some test cases where closures are known experimentally or theoretically, such as for dry granular flows in a uniform channel with a rough bottom. Additionally, an investigation of segregation in granular flows will be undertaken. The main focus of the segregation work is on using an existing continuum model and particle simulation methods to explain phenomena caused by segregation.

PROGRESS

Both micro- and macroscale models for granular flow have been developed and implemented. The microscale model consists of a Discrete Element model (DEM) governed by Newtonian mechanics, whereas the macroscale model is a Discontinuous Galerkin finite element solver built on the in-house HPGEM package. Using the DEM, progress has been made in verifying the Pouliquen Jenkins chute flow rule and measure segregation rates in bi-dispersed flows. Comparison of the running speed of in-house code with other less generic (problem specific) codes has been undertaken. The particles based model is now being used to verify and, where necessary, improve the continuum description.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

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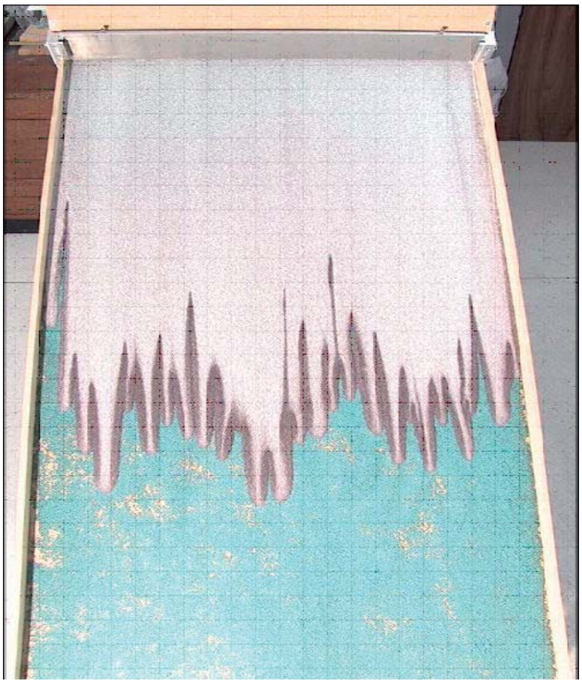

PROJECTLEADERS

O Bokhove, S Luding

RESEARCHTHEME

Mathematical and computational methods for fluid flow analysis

PARTICIPANTS

AR Thornton, T Weinhart

COOPERATIONS

-

FUNDED

Institute of Mechanics, Processes and Control, Twente (IMPACT)

1st 100% 2nd - 3rd -

START OF THE PROJECT

2009

INFORMATION

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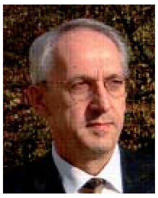
Engineering Fluid Dynamics

Prof.dr.ir. HWM Hoeijmakers

Prof.dr.ir. A Hirschberg



Prof.dr-Ing.habil GH Schnerr

Research within the group Engineering Fluid Dynamics deals with theoretical, numerical and ex¬peri¬men¬tal studies, aimed for applications in Mechanical Engineering. The reseach focusses on the following fields:

Fluid Mechanics of Rotating Flow Machinery

The flow in centrifugal pumps and around wind turbine blades is studied experimentally and numerically, with the objective of developing methods for predicting the performance of these machines. This relates to head, efficiency and cavitation characteristics for pumps and generated power for wind turbines. The meth¬ods are used as tools for improving the design of these rotating machines. Also methods for inverse design and optimalisation are considered. A new rotating test-rig has been developed for experimental studies of the flow in impeller channels.

Aero-acoustics

For Computational Aeroacoustics Discontinuous Galerkin finite-element methods for unstructured grids are developed for computing sound propagation in fluids. The capabilities of these methods are analysed ana¬lyt¬ically. Witin the field of Experimental Aeroacoustics the generation of sound by objects is studied. For this an aero-acoustic test facility has been developed that is based on a closed circuit wind tunnel. The (0.7x0.9 m2) free-jet test-section (maximum velocity 65 m/s) of the silent wind tunnel is enclosed by a 6x6x4m3 anechoic chamber.

Multi-phase flows and flows with phase transition

Models and unstructured-grid computational methods are developed for high-speed, swirling or non-swirl¬ing, condensing flows of mixtures of gases and liquids in complex geometries. Topics of interest are slip¬ping droplets in turbulent flow and the prediction of the evolution of droplet radius distribution. Models and unstructured-grid computational methods are developed for liquid flows with unsteady sheet cavitation.
Finally, phase transition is a driving mechanism in the study of ice accretion on aircraft wings in flight. Separation of oil/water mixtures is considered within a centrifugal force field generated in swirling pipe flows.

Fluid-structure interaction and Flow control

Research on fluid-structure interaction focuses on the flow-induced vibrations of compressor valves and on the unsteady motion of bluff bodies, in particular of gas bubbles and solid spheres induced by vortex shedding. Flow control is developed for application to wind turbine blades and diffusors. Both numerical and experimental investigations are conducted.

Thin-film flows

The flow in narrow domains between deforming surfaces under extreme conditions is studied theoretically as well as experimentally. An example is the lubricant film in roller bearings, i.e. Elasto-Hydrodynamic Lu¬bri¬cation. The theoretical research involves modelling, development of efficient numerical solution al¬go¬rithms and the use of these tools to derive general design rules for practical use. The experimental research employs a ball-on-disk apparatus and involves validation of predictions aa well as the study of grease lu¬bri¬cation phenomena.

Bio-physical flows

This research deals with the flow in lungs, in particular the flow-induced deformation of the elastic lung tubes and the deposition of aerosols in lungs. Research is aimed at developing new diagnostic and thera¬peutic tools.

Prediction of the hydraulic performance of centrifugal pumps

Projectleaders
NP Kruyt, HWM Hoeijmakers

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
RW Westra, NP Kruyt,
HWM Hoeijmakers

Cooperations
Flowserve BV

Funded
Senter, UT
1st 100% 2nd - 3rd -

Start of the project
1998

Information
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Project Aim

The hydraulic performance of pumps is studied both numerically and experimentally. For the numerical flow simulation a potential-flow method has been developed for the flow inside centrifugal and mixed-flow pumps. The method includes loss models and a cavitation inception model. The method has been extended to include a transpiration-type of model for the effect of sheet cavitation. The experimental work is carried out in the new Rotating. Flow facility.

Progress

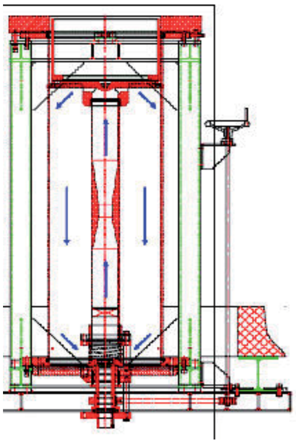
In 2009 some further work has been carried out and publication of results has been prepared.

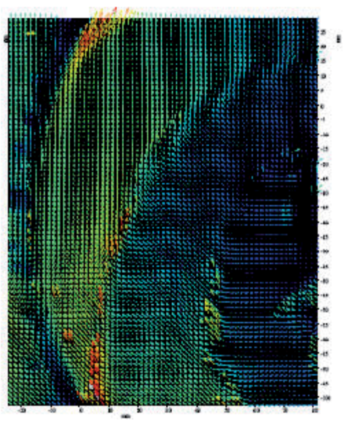
Dissertations

-

Scientific Publications

-





Inverse design and optimisation methods for centrifugal pumps and fans

Project Aim

Using the augmented potential-flow method developed for the prediction of the hydraulic performance of centrifugal and mixed flow pumps two types of design methods for three-dimensional configurations are nvestigated: (i) inverse-design methods and (ii) optimization methods. The validation of the computational methods has been carried out in the newly developed Rotating Flow facility, by PIV-measurements of the relative velocity field.

Progress

A three-dimensional inverse-design method for impellers of centrifugal pumps has been developed, by which an impeller geometry is obtained that meets the prescribed hydraulic characteristics (rotational speed, flow ate, head and loading). Optimisation methods have been developed in which the performance of centrifugal pump impellers is optimised with respect to required head, low losses and optimal cavitation characteristics. The relative velocity field has been measured at various operating conditions using PIV, in the newly developed Rotating Flow facility.

Dissertations

-

Scientific Publications

1. Westra, R.W. & Broersma, L. & van Andel, K. & Kruyt, N.P. (2009) Secondary flows in centrifugal pump impellers: PIV measurements and CFD computations. 2009 ASME 6th International Symposium on Pumping Machinery, Paper FEDSM2009-78275, Vail, CO, USA.

Projectleaders
NP Kruyt, HWM Hoeijmakers

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
RW Westra, NP Kruyt, HWM Hoeijmakers

Cooperations
Flowserve BV, Urenco Aerospace, Johnson Pump, IHC Parts & Services, NLR, Marin

Funded
STW,UT
1st - 2nd 100% 3rd -

Start of the project
2003

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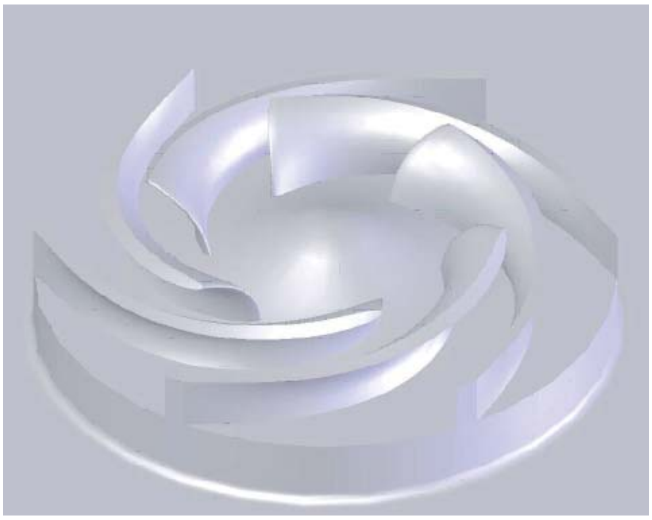

Aerodynamics of flexible windturbine blades

Projectleaders
HWM Hoeijmakers, A Hirschberg

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
H de Vries, E van Emden,
ETA van der Weide, A Hirschberg
HWM Hoeijmakers

Cooperations
ECN, TUD

Funded
ECN, UT
1st 30% 2nd - 3rd 70%

Start of the project
2000

Information
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Project Aim

CFD methods for unsteady flows are developed for the aero-elastic behavior of flexible windturbine blades. The methods considered range from inviscid flow methods coupled to boundary-layer methods to time-accurate RANS methods. The flow conditions to be considered include cases with dynamic stall. Means for flow control are explored, both experimentally and computationally.

Progress

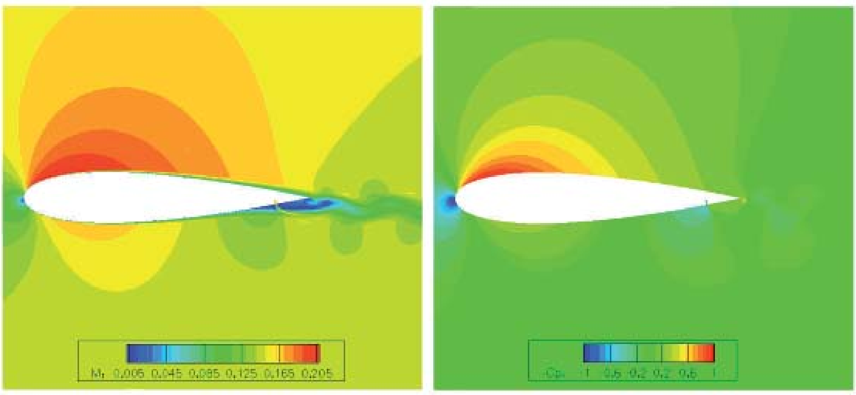
In 2009 the research into the application of flow control devices, such as synthetic jets, on wind turbine rotor blades has continued, both experimentally and computationally. On the computational side of the research, the development of an Unsteady Reynolds-averaged Navier-Stokes method has continued. The method solves the Navier-Stokes equations for time-dependent compressible flow, together with a one- or two-equation eddy-viscosity turbulence model in a loosely coupled manner. The discretization is an edge-based finite volume formulation on unstructured, hybrid, two- or three-dimensional grids. Implicit time integration is employed and 2nd order accuracy is obtained by the dual-time stepping method. Furthermore, algebraic agglomeration-based multigrid is used to solve the equations and the method is parallelized using Message Passing Interface routines and efficient partitioning of meshes (METIS). On the experimental side of the research, a number of airfoils with synthetic-jet actuation have been tested in the silent wind tunnel.

Dissertations

-

Scientific Publications

1. Boeije, de Vries, Cleine, van Emden, Zwart, Stobbe, Hirschberg, Hoeijmakers, “Fluidic Load Control for Wind Turbine Blades,” 47th AIAA Aerospace Sciences Meeting, AIAA paper 2009-684, Orlando, January 2009.
2. Smid, van Noort, Hirschberg, van Emden, de Vries, Stobbe, Zwart, Hoeijmakers, “Experimental Study of Fluidic Control of a Diffusor: influence of slit geometry,” 47th AIAA Aerospace Sciences Meeting, AIAA paper 2009-742, Orlando, January 2009.
3. Müller RAJ, Oyama A, Fujii K, Hoeijmakers HWM. Propulsion by an oscillating thin airfoil at low Reynolds number. In: Computational Fluid Dynamics, Springer Verlag, Berlin, 2009, pp. 241-246.



Advanced wind turbine blade optimization

Project Aim

Development of (aerodynamic) analysis tools and integration of these tools into a gradient based optimization framework such that the performance of wind turbine blades can be optimized according to a (user defined) cost function.

Progress

In the optimisation procedure the shape of the wind turbine blade will be modified during each design iteration. To accommodate the change in blade shape, the choice was made to employ multi-block overset grids for the discretization of the flow domain. For this purpose a hyperbolic field grid generation algorithm has been implemented. Subsequently, the implementation of the hole-cutting procedure for the overset grid method has commenced. Furthermore, the parametrization of the wind turbine blade shape has been investigated. It was found that non-uniform rational B-spline surfaces can be used to represent the shape of a typical wind turbine blade accurately and efficiently.

Dissertations

-

Scientific Publications

1. Nordström J, Gong, J, Van der Weide E, Svärd, M A stable and conservative high order multi-block method for the compressible Navier-Stokes equations. Journal of Computational Physics, Vol. 228, 2009.
2. Nordstrom J, Ham F, Shoeijbi M, Weide ETA van der, Svard M, Gianluca I, Gong J. A Hybrid Method for Unsteady Inviscid Flow. COMPUT FLUIDS,2009,38,4,875-882.
3. Abbas Q, Weide ETA van der, Nordstrom J. Accurate and Stable Calculations Involving Shocks Using a New Hybrid Scheme (online AIAA-paper 2009-3985).In: AIAA (ed). Proceedings39th AIAA Fluid Dynamics Conference. AIAA, Reston, VA, USA, 2009.

Projectleaders
HWM Hoeijmakers, ETA van der Weide

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
SH Jongsma, ETA van der Weide, AJJ Verhoeff HWM Hoeijmakers

Cooperations
AE-Rotor Techniek B.V.

Funded
Suzlon Blade Technology
1st - 2nd - 3rd 100%

Start of the project
2008

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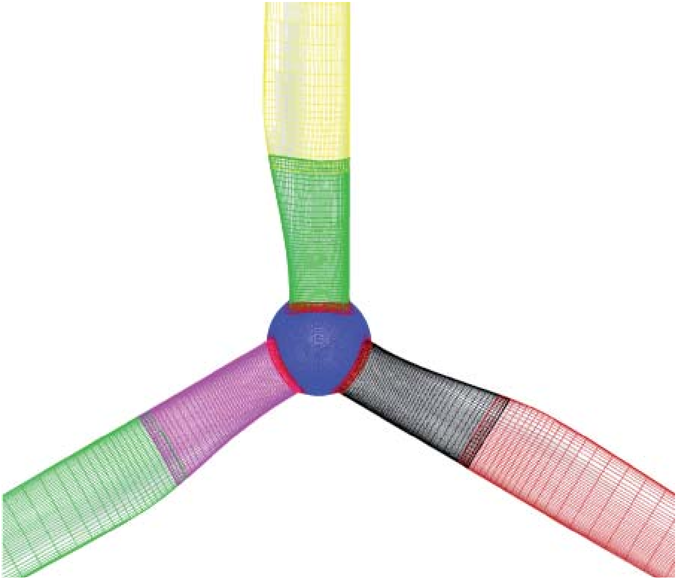

Overset surface grid on wind turbine nose cone and part of the rotor.

SMART FIXED WING AIRCRAFT, WP 1.1.4

PROJECTLEADERS
HWM Hoeijmakers, ETA van der Weide
RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis
PARTICIPANTS
ETA van der Weide, JM Tomas, HWM Hoeijmakers
COOPERATIONS
-
FUNDED
EU (CleanSky project)
1st - 2nd 100% 3rd -
START OF THE PROJECT
2009
INFORMATION
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PROJECT AIM

Investigate the possibility to apply synthetic jet flow control on the flaps of aircraft wings in order to increase the lift during take off and landing. The goal of this research is to determine the specifications of a synthetic jet flow control device in order to accomplish the desired effects.

PROGRESS

The NACA-0018 profile at an angle of attack of 15 degrees has been chosen as a testbed, because it shows a similar trailing edge separation as the flap of the DLR F15 configuration, the geometry investigated in WP 1.1.4 of the SFWA program. Initially 2D unsteady simulations were carried out, which indeed show a 10 percent increase in lift while the separation is (almost) removed. However, the required massflows to accomplish this goal are far beyond what can be realized in practice for synthetic jets. Consequently 3D simulations have been performed to investigate the performance of longitudinal slots and to explore the 3D effects of such slots. In order to reduce the computational times required these simulations have been carried out using steady blowing instead of synthetic jets. Preliminary results show that it is indeed possible to increase the lift while the required mass flow is significantly less than in the 2D case.

DISSERTATIONS

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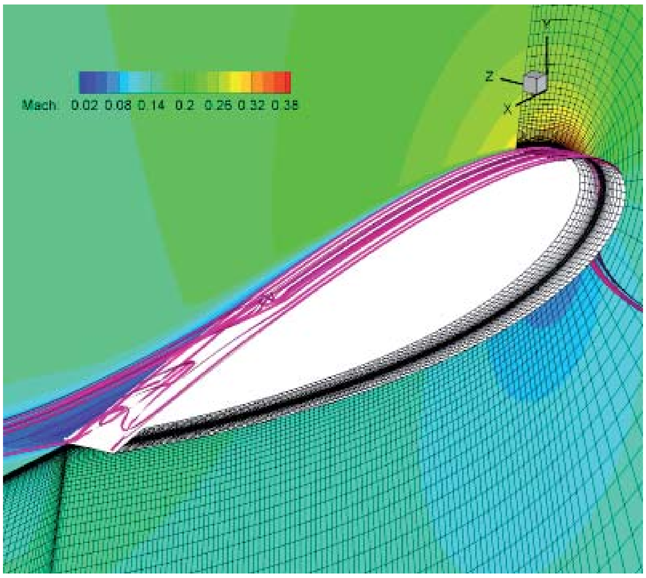
SCIENTIFIC PUBLICATIONS

-



Visualization of the vortices generated by continuous blowing .

Computational aero-acoustics

Project Aim

Computational Fluid Dynamics methods for unsteady flows are extended to numerically simulate flows including sound waves. Configurations aimed for are the flow over discontinuities, cavities, airfoils, blunt bodies, etc. Validation of computational results is pursued employing the Aero-Acoustic Test facility with a 0.9*0.7 m2 (65 m/s) open-jet test section within an anechoic room of 6x6x4 m3.

Progress

The linearized Euler equations in three spatial dimensions including source terms, as a physical-mathematical model for acoustic wave propagation in non-uniform background flow are considered. A Discontinuous-Galerkin (DG) Finite-Element method has been developed, employing tetrahedral or hexahedral elements and polynomial basis functions up to first degree for tetrahedral and up to third degree for hexahedral elements. The method has been verified extensively by comparison of numerically obtained data to exact solutions of selected test problems, e.g. acoustic wave propagation in a rectangular duct including forced vibration of part of the duct wall.

Dissertations

-

Scientific Publications

-

Projectleaders
HWM Hoeijmakers, A Hirschberg

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
CH Venner, A Hirschberg, HWM Hoeijmakers

Cooperations
UT, Tue, TNO

Funded
UT, TUE
1st 100% 2nd - 3rd -

Start of the project
1999

Information
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Experimental aero-acoustics

Projectleaders
A Hirschberg, HWM Hoeijmakers
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
A Hirschberg, HWM Hoeijmakers, G Guilloud, A Mueller
Cooperations
UT, Tue, TNO, VKI, LMS
Funded
UT, TUe
1st 100% 2nd - 3rd -
Start of the project
1999
Information
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Project Aim

Investigate experimentally the flow over discontinuities, cavities, airfoils, blunt bodies, etc. For this purpose the the existing 0.9*0.7 m2 (50 m/s) closed test section aerodymics windtunnel has been developed to an Aero-Acoustic Test facility (silent wind tunnel) with 0.9*0.7 m2 (65 m/s) open jet test section within a 6x6x4m3 anechoic chamber.

Progress

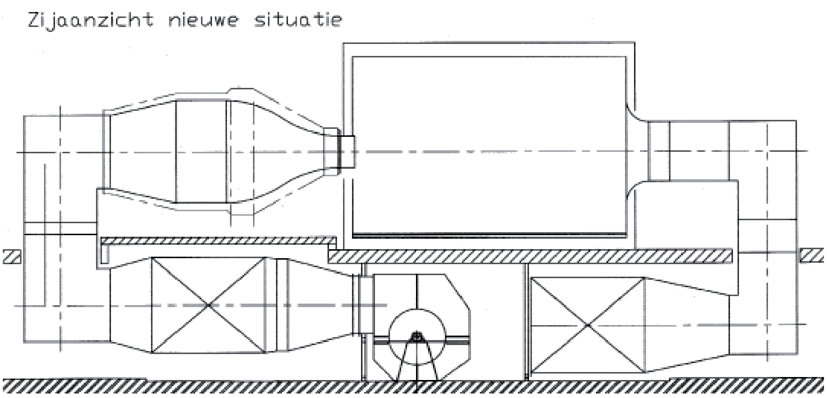
In 2008 the aero-acoustic test facility has been used for investigating the noise produced by blunt bodies, for testing a acoustic measurement technique for tyre-road interaction noise and for experiments on flow control employing fluidic actuators.

Dissertations

1. Oerlemans S Detection of aeroacoustic sound sources on aircraft and wind turbines. University of Twente. Enschede, the Netherlands, 2009.

Scientific Publications

1. Hirschberg A Introduction to aero-acoustics of internal flows. In: Antoine J, Cristophe J (eds). Aerodynamic noise from wall-bounded flows (VKI LS 2009-03, 1 Volume). Von Karman Institute, Waterloo, Belgium, 2009.
2. Nakiboglu G, Belfroid PCS, Tonon D, Willems FHJ, Hirschberg A A Parametric Study on the Whistling of Multiple Side Branch System as a Model for Corrugated Pipes (CD-rom paper PVP2009-77754). In: Giannopapa christi (ed). Proceedings of ASME-Pressure Vessels and Piping Division Conference. ASME, New York, USA, 2009.
3. Tonon D, Nakiboglu G, Belfroid PCS, Willems FHJ, Hirschberg A Whistling of corrugated pipes. In: Ambrosio J, Silva MT (eds). ESMC2009 7th EUROMECH Solid Mechanics Conference.Association for Theoretical, Applied and Computational Mechanics, Lissabon, Portugal, 2009, 519-520.
4. Tonon D, Nakiboglu G, Willems FHJ, Hirschberg A, Leandro R, Polifke W Self-sustained Aeroacoustic Oscillations in Multiple Side-Branch Pipe Systems (CD-ROM) AIAA paper 2009-3262. In:Proceedings of the 15th AIAA/CEAS Aeroacoustic Conference (on Disc Vol 14, No 6 (Aeroacoustics)). AIAA, Reston VA, USA, 2009.
5. Olsman WFJ, Osch MME van, Hirschberg A, Trieling RR, Willems FHJ Pressure difference over a NACA0018 airfoil with cavity using acoustic forcing. AIAA paper 2009-326.Proceedings 47th AIAA Aerospace Science Meeting (DVD). AIAA, Reston, VA, USA, 2009.



Analysis of droplet radius distribution in condensing flow

Project Aim

The objective of is to advance analysis of droplet size distributions in inviscid condensing flow. The background for this activity lies in the increasing demand from process industry for detailed and accurate data on condensing flows.

Progress

The General Dynamic Equation (GDE) that governs the droplet size distribution has been shown to be incomplete in the sense that for droplets smaller than the critical size higher order derivatives are required to obtain a more accurate mathematical-physical model. As a consequence, the investigation has been directed towards the so-called Kinetic Equation (KE), which consist of a balance equation for each discrete droplet size, measured in terms of the number of molecules included in the droplet. An extensive comparison of both models, the GDE and the KE, and an additional model consisting of the Fokker-Planck equation (FPE) has been conducted. The conclusion is that the KE is indeed the most complete model and that the GDE and the FPE are first and second order approximations, respectively. In addition, the sensitivities with respect to the equilibrium model used to formulate backward rates (evaporation), the sticking probability, and the surface tension are conducted. Furthermore, it has been shown that the quadrature method of moments (QMOM, DQMOM) suffers from a lack of the appropriate equilibrium distribution. Also, upon reformulation of the DQMOM equations to include the appropriate equilibrium distribution, it appears that it can not be guarranteed that the correct eigenvalues can be retained. This is ongoing research. Finally, in collaboration with Prof. M. Reeks and Dr. R. IJzermans from Newcastle University, a model was developed to simulate droplet condensation in atmospheric clouds. The model utilizes a Lagrangian approach, where individual droplets are tracked in a synthetic turbulent field, allowing for one-way and approximate two-way coupling. This investigation has confirmed the spectral broadening of the droplet size distribution observed in actual clouds, and sheds more light on the role played by turbulence during the condensation process.

Dissertations

1. Sidin RSR. Droplet size distribution in condensing flow. PhD thesisUniversity of Twente. Enschede, the Netherlands, 2009.

Scientific Publications

1. Sidin RSR, IJzermans RHA, Reeks MW. A Lagrangian approach to droplet condensation in atmospheric clouds. Phys. Fluids, 2009,21,10,1-16.
2. Putten DS van, Kalikmanov VI. Efficient approach to nucleation and growth dynamics Stationary diffusion flux model. (artikelnr 164508). J Chem. Phys. 2009,130,16,1,1-4.
3. Sidin RSR, Hagmeijer R, Sachs U. Evaluation of master equations for the droplet size distribution in condensing flow. Phys. Fluids, 2009, 21(7), 073303-1-0733303-16.

Projectleaders
R Hagmeijer, HWM Hoeijmakers

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
RSR Sidin, R Hagmeijer, HWM Hoeijmakers

Cooperations
Twister BV

Funded
UT
1st 100% 2nd - 3rd -

Start of the project
2005

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The structure of unsteady 3D sheet cavitation

Projectleaders
HWM Hoeijmakers, GH Schnerr
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
AH Koop, GH Schnerr, HWM Hoeijmakers
Cooperations
UT, TUD, TU Munchen, Marin, Wartsila, Flowserve, IHC, Holland Roer Propellers, RNN
Funded
STW, UT
1st 10% 2nd 90% 3rd -
Start of the project
2003
Information
HWM Hoeijmakers
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Project Aim

Three-dimensional flows with steady and unsteady sheet cavitation are considered such as occur on hydrofoils. Computational methods are developed based on an unstructured-grid finite-volume method coupled to a dispersed-bubble model for cavitation as developed in prof. Schnerr's group in München. The project is a cooperation between the group at the UT and the group of prof. van Terwisga at Delft University of Technology where experiments are designed and carried out for obtaining data for validation of the computational results.

Progress

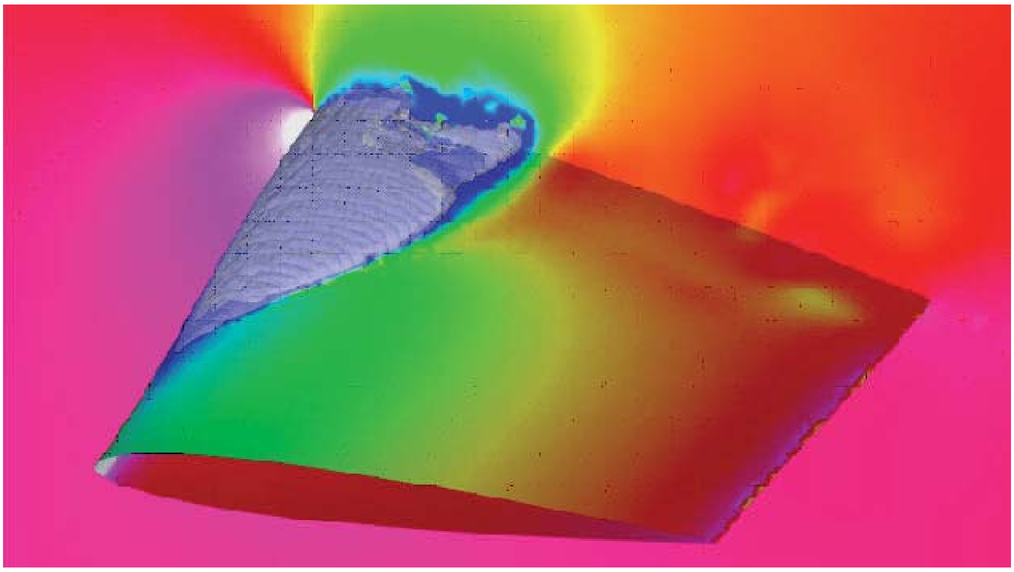
An unstructured-grid Euler method for compressible flow has developed for flows with cavitation. The method assumed the liquid and the vapor to be compressible and the liquid-vapor mixture to be in mechanical and thermal equilibrium. Various upwind schemes have been implemented. Results show that the method gives promising results for the flow around 2D and 3D hydrofoils. The latter results are compared with experimental results obtained by Foeth & Terwisga in the Delft Cavitation Tunnel.

Dissertations

-

Scientific Publications

1. Ton TA, Koop AH, Hoeijmakers HWM, Vries H de. Investigation of Vorticity Confinement in Compressible Flow AIAA 2009-3549. 19th AIAA Computational Fluid Dynamics Conference (DVD, Vol 14, No 7).
2. Koop AH , Hoeijmakers HWM. Numerical Simulation of Unsteady Three-Dimensional Sheet Cavitation. In: Ceccio Steve (ed). Proceedings 7th International Symposium on Cavitation University of Michigan, Ann Arbor, Mi, USA, 2009, Paper 52.



Ice accretion on aircraft wings

Project Aim

Numerical simulation of ice accretion on aircraft wings in flight at (extreme) icing conditions, including effects of splashing of large super-cooled droplets on impact, droplet breakup in high-shear regions of the flow, droplet coalescence.

Progress

Starting point has been a potential flow method coupled to a Lagrangian method to predict the water collection efficiency and to Messinger's model for the freezing thin layer of water along the surface. This method has been extended to poly-disperse droplet distributions and the capability to treat multi-element airfoil sections. Also a splashing-droplet model has been adapted and implemented. Furthermore an Eulerian method for predicting the water collection efficiency has been developed, which is more suitable for complex configurations. Furthermore an unstructured-grid Euler method for compressible flow has adapted for coupling to the ice-accretion models.

Dissertations

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Scientific Publications

-

Projectleaders
HWM Hoeijmakers

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
JM Hospers, HWM Hoeijmakers

Cooperations
TU Darmstadt, CIRA, INTA, ONERA,

Funded
EU, UT
1st 20% 2nd - 3rd 80%

Start of the project
2008

Information
HWM Hoeijmakers
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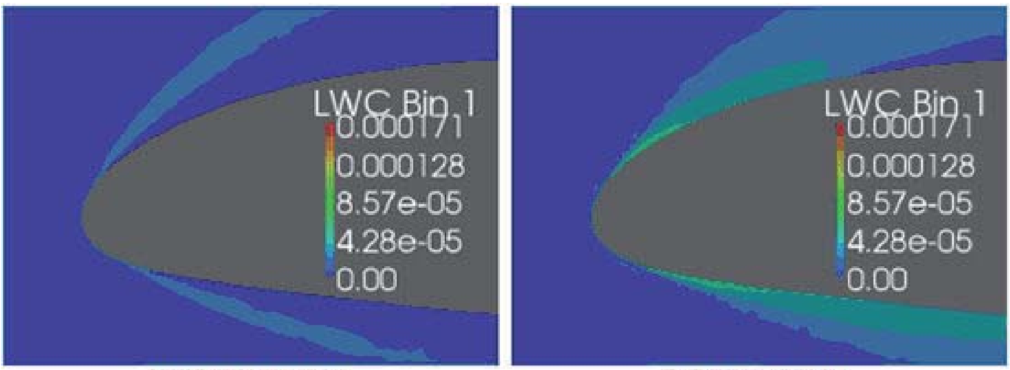
Calculated droplet distributions [kg/m3], region near the leading edge, 236 μm MVD, bin 1 (16 μm) University of Twente



(a) Without splashing model (b) With splashing model

Centrifugal separation of oil/water mixtures

Projectleaders
HWM Hoeijmakers
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
JJ Slot, HWM Hoeijmakers
Cooperations
TUD, Tue, Shell, FMC Technologies - CDS Engineering BV, Frames, Wintershall, WUR
Funded
DSTI, UT
1st 20% 2nd - 3rd 80%
Start of the project
2008
Information
HWM Hoeijmakers
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Project Aim

Modeling and numerical simulation of swirling flow of oil/water mixtures aimed at separation. At TU Delft an experimental set-up is developed for experimentally investigating these flows and providing data for validation. At Wageningen University the behavior of oil-water mixtures is studied at the micro-scale, including droplet colaescence and the effect of surfactants.

Progress

An inline bulk oil-water separator has been designed and it has been constructed at the TUD. Using CFD single-phase swirling water flow has been considered in detail and experimental measurements are being carried out. The results show a complex flow pattern with regions of reversed flow. Exploratory droplet tracking simulation have been carried out to study the behaviour of oil droplets in a dilute mixture. It was found that turbulence dispersion has a large effect and can hinder the separation. Currently, a start has been made with Eulerian-Eulerian two-phase calculations and the experimental rig is expected to be ready for multiphase experiments by mid 2010.

Dissertations

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Scientific Publications

-

Multiphase flow effects in compact produced-water treatment equipment

Project Aim

The physical phenomena occuring during produced-water treatment are studied numerically. Oil droplet, and gas bubble trajectories will be predicted for both swirling flow and settling conditions. Influence of effects such as a history term are required for prediction of trajectories. Collision and coelescence are important factors for advanced compact produced-water treatment. Occurrence of such effects is predicted making use of droplet and bubble trajectories.

Progress

Lagrangian particle tracking algorithm has been developed. The method includes drag effect, flow pressure and stress gradient effect, added mass effect, Saffmann and Magnus lift forces and a history term. The history term has been adapted to provide for non-Stokes effects in the history term. Publication has been prepared for ICMF 2010.

Dissertations

-

Scientific Publications

-

Projectleaders

HWM Hoeijmakers

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

DF van Eijkeren, HWM Hoeijmakers

Cooperations

FMC Technologies/CDS Separation Systems.

Funded

FMC Technologies/CDS Separation Systems

1st - 2nd - 3rd 100%

Start of the project

2009

Information

DF van Eijkeren
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Prediction of pumping effects on the performance of EHL contacts in tapered and spherical roller bearings

Projectleaders
HWM Hoeijmakers, CH Venner
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
MT van Zoelen, CH Venner, HWM Hoeijmakers, PM Lugt (SKF)
Cooperations
INSA-de Lyon, France
Funded
SKF ERC b.v.
1st - 2nd - 3rd 100%
Start of the project
2007
Information
CH Venner
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Project Aim

Development of accurate thin film flow models and numerical simulation algorithms to predict the long term lubricant film formation capacity in roller bearings accounting for the effects of starvation and the effects of centrifugal forces on lubricant redistribution.

Progress

The film thickness decay as predicted by the developed thin layer flow model has been compared with optical interferometry measurments for single EHL contacts showing excellent agreement for both circular as well as elliptic contacts. This work was awarded the 2008 Duncan Dowsan Tribolgy Award. In the past year the model has also been extended to multiple layer multiple contacts as they occur in rolling bearings and the effect of the bearing type on long term film thickness decay and distribution has been investigated.

Dissertations

1. Zoelen MT van. Thin layer flow in rolling element bearings. University of Twente. Enschede, The Netherlands, 2009.

Scientific Publications

1. Zoelen MT van , Venner CH, Lugt PM. Prediction of Film Thickness Decay in Starved EHL Contacts using a Thin Layer Flow Model', Proceedings of ImechE. part J,.P I MECH ENG J-J ENG,2009,223,0,541-552.
2. Lubrecht AA, Venner CH, Colin F. Film Thickness Calculation in Elasto-Hydrodynamic Line and Elliptical Contacts The Dowson, Higgingson, Hamrock contribution (Proc ImechE, part J). P I MECH ENG J-J ENG,2009,223,0,511-516.

Multiscale islands mixed lubrication modeling

Project Aim

Development of a mixed lubrication model based on first physical principles representing relevant aspects on different scales. In this mixed lubrication model the aim is to predict lubricated- and dry contact zones appearing for instance in starved lubricated bearings. Research consists of experimental and theoretical work.

Progress

Dry contact modeling including optimally efficient computational approach taking into account tangential stresses which appear for instance when friction and slip occur. Design and set up of experiments for modeling local film generation and break down mechanisms in EHL contact configurations.

Dissertations

-

Scientific Publications

-

Projectleaders

CH Venner, HWM Hoeijmakers

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

E van Emden, CH Venner, HWM Hoeijmakers, GE Morales-Espejel (SKF)

Cooperations

SKF

Funded

SKF

1st - 2nd - 3rd 100%

Start of the project

2009

Information

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Slow flows of granular materials

Projectleaders
NP Kruyt
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
NP Kruyt
Cooperations
University of Waterloo, Canada, UT-CT, University of Leeds, Université Joseph Fourier, Grenoble. France
Funded
UT
1st 100% 2nd - 3rd -
Start of the project
1998
Information
NP Kruyt
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Project Aim

The study of the (micro-mechanical) behavior of slowly flowing granular materials, in particular of the relation between microscopic behaviour and the macroscopic, continuum behaviour.

Progress

Force and relative displacement networks in slow granular flows have been investigated. Furthermore, using techniques developed for granular materials, the elastic properties of liquid foams have been investigated theoretically.

Dissertations

-

Scientific Publications

1. Antony, S.J. & Kruyt, N.P. (2009). Role of interparticle friction and particle-scale elasticity on shear-strength mechanism in three-dimensional granular media. Physical Review E 79 031308.
2. Rothenburg, L. & Kruyt, N.P. (2009). Micromechanical definition of an entropy for quasi-static deformation of granular materials. Journal of the Mechanics and Physics of Solids 57 634-655.
3. Kruyt, N.P. (2009). Micromechanical study of elastic behaviour of granular materials. Particles 2009, pp. 183-186, eds. E. Oñate & D.R.J. Owen, Barcelona, Spain.
4. Kruyt, N.P. (2009). Force fluctuations in quasi-static deformation of granular materials: deviations from mean-field behaviour. 7th European Solid Mechanics Conference, pp.201-202, eds. J. Ambrosio & M.T. Silva, Lisbon, Portugal.
5. Kruyt, N.P. & Rothenburg, L. (2009). Plasticity of granular materials: a structural-mechanics view. Powders & Grains 2009, AIP Conference Proceedings Vol. 1145, pp.1073-1076, eds. M. Nakagawa & S. Luding.

Flow and aerosol deposition in human lungs

Project Aim

Inhalation of therapeutic aerosols to treat lung diseases (e.g. asthma) is a problem since the upper airways (nose/mouth region) acts as a natural fiter (especially for small subjects (e.g. children). Results of in vitro measurements and CFD calculations show considerable differences. More over the difficult geometry and non stationair breathing patterns complicate the calculations. The ultimate aim is to predict how and which aerosols should be inhaled to maximize deposition in the required regions and avoid uper airway deposition in the individual patient .

Progress

In the last year a master student (T. Huijgen) worked on his master thesis on CFD calculations for the flow and spray in inhalers and comparison with experiments.

Dissertations

-

Scientific Publications

1. Zuur JK, Muller SH, Vincent A, Sinaasappel M, Jongh FHC de, Hilgers FJ. The influence of a heat and moisture exchanger on tracheal climate in a cold environment. MED ENG PHYS,2009,31,7,852-857.
2. Veenendaal MB van, Miedema M, Jongh FHC de , Lee JH van der, Frerichs I, Kaam AH van. Effect of closed endotracheal suction in high-frrequency ventilated premature infants measured with electrical impedance tomography. INTENS CARE MED,2009,35,12,2130-2134.

Projectleaders
HWM Hoeijmakers, FHC de Jongh

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
FHC de Jongh, HWM Hoeijmakers

Cooperations
MST, UVA-AMC, Medspray

Funded
UT
1st 100% 2nd - 3rd -

Start of the project
1998

Information

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Thermal Engineering

Prof.dr.ir. ThH van der Meer

The research activities of the Thermal Engineering Group mainly concentrate on thermal conversion processes for industrial applications from the disciplines thermodynamics, transport phenomena and fluid mechanics. The research aims at an increasing use of renewable fuels, and at a more efficient and clean utilization of fossil fuels. The projects are organized around three central themes: thermal conversion processes of fuels, turbulent gaseous combustion and thermo-acoustics, and instationary heat transfer.

The research theme thermal conversion processes of fuels is part of the research programme of the OSPT (research school on process technology)

The research theme Turbulent gaseous combustion and thermo-acoustics is related to questions on ignition, extinction, flame stability, pollutant formation, combustion noise and its interaction with the combustion chamber structure. Numerical models are developed (within CFX), and experimental research is done like flow visualisation, acoustic measurements and laser diagnostics like laser induced fluorescence and Ramen/Rayleigh spectroscopy for the in-flame measurements of temperature and species concentrations. the underlying physical-chemical processes. Currently a large EU-project, named LIMOUSINE, with three PhD’s and a post doc is ongoing on the topic of thermo-acoustics in gas turbines. Next there are several projects within the STW perspective program Clean Combustion Concepts.

The research theme “instationary heat transfer” is related to heat transfer in piston compressors, a pulsed compression reactor and new materials for enhanced heat transfer in regenerators and heat exchangers based on carbon nano-fibers attached to the heat transfer surface.

LIMOUSINE

PROJECT AIM

LIMOUSINE aims at the development of numerical tools to predict the chain of events leading to mechanical failure of gas turbine combustors due to limit cycles of low frequency pressure oscillations. Explored is the interaction and the feed back mechanisms between combustion dynamics, acoustics, aerodynamics and structural vibration. Essential is that not only the operating points with linear instability are identified, but also the nonlinear mechanisms leading to amplitude saturation.

PROGRESS

In the project European wide 17 PhD students are active, coordinated by the University of Twente. At the UT 3 PhD students and one Post Doc are employed in the area of fluid mechanics. Another PhD student is active in Limousine at the UT in the field of structural vibration and mechanical failure. Mehmet Kapucu is active in task 3.4 of LIMOUSINE: Experimental studies on DESIRE test rig. Literature review has been done. Data acquisition softwares have been learned like LabVIEW and Siglab. A one dimensional acoustic network model is under development. Few cold measurements are made in order to validate this model. A calibration tube has been designed to perform relative calibration between the pressure transducers.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

-

PROJECTLEADERS

JBW Kok

RESEARCHTHEME

Mathematical and computational methods for fluid flow analysis

PARTICIPANTS

M Kapucu, JBW Kok, R Alemela, ThH van der Meer

COOPERATIONS

Project in cooperation with DLR, CERFACS, Imperial College, Keele University, University of Zaragoza, University of Brno, Siemens Muelheim, Ifta Muenchen, Ansys Abingdon.

FUNDED

European Union: Marie Curie program

1st - 2nd - 3rd 100%

START OF THE PROJECT

2008

INFORMATION

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Close tolerance and lubricant free piston compressors

Projectleaders
JBW Kok
Researchtheme
Complex dynamics of fluids
Participants
U Lekic, JBW Kok, ThH van der Meer
Cooperations
Oxford University, Ansys, Stirling Cryogenics, Thales Cryogenics, Grasso
Funded
STW, Ansys, Stirling Cryogenics, Thales Cryogenics, Grasso
1st - 2nd 90% 3rd 10%
Start of the project
2005
Information
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Project Aim

The aim of the project is the formulation of design rules for unlubricated PCC's derived from experiments and numerical simulations. Numerical models are developed to provide a better understanding of matched materials in a PCC and their response under given circumstances. The numerical research combines Finite Element Methods (FEM) and Computational Fluid Dynamics (CFD) methods in an integrated approach for both the working fluid behaviour and the solid wall behaviour during compression and expansion in start-up and nominal operating conditions.

Progress

The thermo-mechanical loads of the interacting parts is predicted with a view to the performance and durability. The transient heat flux is predicted using thermodynamics and advanced CFD simulations. The CFD simulation incorporates specific features to account for the compression and expansion of the computational domain and for the near wall unsteady turbulent heat transfer. The temperature gradient between the in-cylinder gas and the piston-cylinder walls is high during compression and expansion. As a result there is an oscillating heat transfer between cylinder wall, piston surface and the working gas. The transient and oscillating thermal conditions cause expansion and stresses in the solid parts. In addition to that, a narrow tolerance between piston and cylinder must be realized for high performance of the piston cylinder device. Especially in cryogenic coolers the piston "blow by" must be minimized as the working fluid is Helium which has a very high diffusivity and hence tendency to "leak". Prediction of the transient thermal expansion and solid wall heat flux, with 10-100 nanometer accuracy is required. CFD computations of laminar and turbulent flow cycles have been performed, predicting flow and heat transfer. Good matches were found with experimental data from MIT in laminar conditions. In the turbulent case deviations occurred with experimental data. This is explored furtehr in detail. It appears the flow does not become turbulent but a thermal boundary layer does form. The time scales of thermal transport and piston displacement are explored. Experiments are performed at pressure ratio 2 and 8, and various charge pressures and piston speeds at the UT. Transient pressure can be measured accurately. To measure heat transfer directly at time scales of 10 ms proved to be extremely difficult. This also applied to the gas temperature, especially near piston dead centre. The transient wall temperature could however be measured accurately. The cylinder mass charge, taking into account blow by, could be determined by measuring pressure and temperature of the gas in both the cylinder and the crank house. For the high speed displacemnets now a DNS method is used in the CFD. This provided excellent comparison with pressure and temperature experimental data.

Dissertations

-

Scientific Publications

1. Lekic, U., Kok, J.B.W., Heat transfer in a gas spring, ExHFT-7 7th World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics Proceedings, 28th June- 3rd July 2009, Krakow, editors Janus S Szmyd and Tomasz A Kowalewski, ISBN 978-837464-235-4 (CD-ROM), Poland.

Numerical modelling of novel heat exchanger materials

Project Aim

A numerical study investigates a new heat exchanger material existing of a fine metallic structure, e.g. a metallic foam. The surface of this material carbon is covered with carbon nano fibers (CNF's). These fibers influence the fluid flow, and enlarge the heat exchanging surface. Preliminary experimental research has shown that the presence of these CNF's can enhance heat transfer by 50%. This depends very much on the CNF density and on the structure of the CNF itself. This numerical study gives directions in optimizing this new material.

Progress

A 3D hydrodynamic and thermal lattice Boltzmann code is developed.

To calculate the heat transfer coefficient through the CNF's layer a thermal lattice Boltzmann equation is solved. This problem includes the fluid-solid conjugate heat transfer problem. The fluid-solid conjugate heat transfer problem has to insure a temperature and heat flux at the interface. For validation of our code a micro-channel flow with a copper plate inside the channel is simulated. Results of our model have been compared with the results obtained by numerical solver which employs the Navier-Stokes equations (ANSYS CFX 11.0) and very high precision is found. 3D hydrodynamic and thermal simulations of the micro-channel flow with the CNF's have been preformed. Influence of the CNF's density deposited in a micro-channel is investigated. How this density influence the heat transfer is found.

Dissertations

-

Scientific Publications

-

Projectleaders
ThH van der Meer

Researchtheme
Complex dynamics of fluids

Participants
N Pelevic

Cooperations
-

Funded
SenterNovem, ATAG
1st - 2nd - 3rd 100%

Start of the project
2008

Information
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FLUISTCOM

PROJECTLEADERS
JBW Kok
RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis
PARTICIPANTS
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COOPERATIONS
Project in cooperation with DLR, CERFACS, CIMNE, Queen's College Belfast, Siemens
FUNDED
European Union: Marie Curie program
1st - 2nd - 3rd 100%
START OF THE PROJECT
2004
INFORMATION
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PROJECT AIM

FLUISTCOM investigates the fundamental scientific aspects in the field of fluid-structure interaction for turbulent combustion systems. The project is motivated by the recent push towards leaner combustion technologies and reduced emissions. Such lean premixed combustion systems are prone to thermo-acoustic instabilities that can induce intolerable vibrations of the chamber walls.

PROGRESS

Numerical investigation of the fluid structure interaction between reacting flow inside the combustion chamber, acoustics induced by the fluctuating flame and liner wall vibration has been performed. Two different fluid structure interaction models were used to predict amplitude of pressure and velocity fluctuations. The first model is called the one way interaction model and it is based on dynamical exchange data between two different numerical codes (CFX-Ansys). Second model is the acousto-elastic model that uses the data obtained during CFD calculations as an acoustic source. This source is later resolved inside the acoustic domain surrounded by flexible walls. The results were compared with the available experimental data. The modeling is now feasible to predict the effect of two way interaction between the combustion process and the vibrating liner wall. The simulations show that the fluid system and the structural system are coupled but only to some extent. Energy supplied by the flame at certain frequencies may be emitted by the structural system at different frequencies, thereby showing nonlinear behavior. The low frequency characteristics of the combustion system were measured accurately for validation purposes of the simulations.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. Pozarlik, A., Kok, J.B.W., Numerical prediction of combustion induced vibro-acoustical instabilities in a gas turbine combustor., Proceedings of the 16th International Congress on Sound and Vibration (ICSV16), (CD-ROM proceedings) (ISBN: 978-83-60716-71-7).

Pulsed compression technology: a breakthrough in high temperature processes

Project Aim

Production processes of base chemicals such as synthetic gas, ethylene or acetylene, take place at high temperatures and are currently very energy-intensive and inefficient. A new reactor type promises a breakthrough in the energy efficiency, capital costs and mobility of these production processes. The novel pulsed compression technology that is under investigation in this project has been proven in a "proof of principle reactor". However, run times of longer than approximately 30 sec were not attainable. This project aims to supply the required knowledge about the heating of both reactor and piston, to achieve run times in the order of one hour.

Progress

A new reactor, specifically designed for the investigation of thermo dynamical effects in the novel pulsed compression reactor, has been constructed. The new reactor incorporates various techniques for measuring temperature and pressure fluctuations at various positions in the reactor. In addition to facilitating the investigation of thermo dynamical effects, it will also make the investigation of gas flow through the gap between piston and reactor wall possible. The first measurements have been very insightfull and gave interesting results.

Dissertations

-

Scientific Publications

1. Oral presentation ExHFT 2009, Poland. Presentation title: "Determination of the instantaneous heat flux in a rapid compression machine".
2. Poster Combura 2009, NBC de blokhoeve, Nieuwegein, the Netherlands. Poster title: "pulsed compression technology, all you need is pressure".

Projectleaders
ThH van der Meer

Researchtheme
Complex dynamics of fluids

Participants
T Roestenberg

Cooperations
EnConTech BV
Shell Global Solutions

Funded
SenterNovem
1st - 2nd - 3rd 100%

Start of the project
2007

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LIMOUSINE

PROJECTLEADERS
JBW Kok

RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis

PARTICIPANTS
JC Roman Casado, JBW Kok, R Alemela, ThH van der Meer

COOPERATIONS
Project in cooperation with DLR, CERFACS, Imperial College, Keele University, University of Zaragoza, University of Brno, Siemens Muelheim, Ifta Muenchen, Ansys Abingdon.

FUNDED
European Union: Marie Curie program
1st - 2nd - 3rd 100%

START OF THE PROJECT
2008

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PROJECT AIM

LIMOUSINE aims at the development of numerical tools to predict the chain of events leading to mechanical failure of gas turbine combustors due to limit cycles of low frequency pressure oscillations. Explored is the interaction and the feed back mechanisms between combustion dynamics, acoustics, aerodynamics and structural vibration. Essential is that not only the operating points with linear instability are identified, but also the nonlinear mechanisms leading to amplitude saturation.

PROGRESS

In the project European wide 17 PhD students are active, coordinated by the University of Twente. At the UT 3 PhD students and one Post Doc are employed in the area of fluid mechanics. Another PhD student is active in Limousine at the UT in the field of structural vibration and mechanical failure. Key element in the project is a generic lab scale combustor that will operate in limit cycle pressure oscillation. It is designed at the UT, and will be operated in 5 identical copies in labs at UT, DLR, Imperial College, Ifta and University of Zaragoza. Each lab will use their specialism in diagnostics. Juan Carlos Roman Casado is active in task 3.1: Experiments on high-amplitude thermo-acoustic oscillations in model combustor. This task will focus on the measurement of acoustic and vibrational behaviour of the model combustor. These experiments will generate results for the growth rate and for limit cycle characteristics such as frequency and amplitude. The Green’s function and the end impedances will be measured (at room temperature). A characterization of the linear system is thus obtained. This will be used in the subsequent investigation of nonlinear effects. A prototype of the combustor has been built an tested. It showed limit cycle oscillation of a very interesting type: combustion dynamics to structural vibration, with acoustics as a passive carrier. A definitive design has been made, allowing more operational flexibility and optical access. Now it will be built in 6 copies.

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

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Limousine

Project Aim

LIMOUSINE aims at the development of numerical tools to predict the chain of events leading to mechanical failure of gas turbine combustors due to limit cycles of low frequency pressure oscillations. Explored is the interaction and the feed back mechanisms between combustion dynamics, acoustics, aerodynamics and structural vibration. Essential is that not only the operating points with linear instability are identified, but also the nonlinear mechanisms leading to amplitude saturation.

Progress

In the project European wide 17 PhD students are active, coordinated by the University of Twente. At the UT 3 PhD students and one Post Doc are employed in the area of fluid mechanics. Another PhD student is active in Limousine at the UT in the field of structural vibration and mechanical failure. Key element in the project is a generic lab scale combustor that will operate in limit cycle pressure oscillation. It is designed at the UT, and will be operated in 5 identical copies in labs at UT, DLR, Imperial College, Ifta and University of Zaragoza. Each lab will use their specialism in diagnostics. Santosh Kumar is active in task 2.1: Numerical studies (CFD) for transient turbulent combustion. Skills in CFD methods will be acquired. This will allow the ESR to calculate the rate of heat release distributed over the combustor domain. Reaction progress variable models are available, and the ESR will be taught how to predict unsteady turbulent combustion at high-amplitude oscillations in syngas and natural gas flames. This work will be performed with the CFD and combustion tools developed in the earlier projects DESIRE, HEGSA and FLUISTCOM. The calculated rate of heat release will be relevant to the use of numerical methods (FEM, lumped parameter) to calculate the propagation of pressure fluctuations in the combustor with variable end conditions. Specific attention will be given to: nonlinear thermo-acoustic behaviour of the system, compact or distributed heat release, vibrating walls, end conditions, turbulent damping and temperature gradients in the fluid. The past half year transient URANS simulations have been performed of the generic combustor at typical operating points. The combustion dynamics showed transient activity, correlating to the Strouhal number critical for vortex shedding by the wedge, that anchors the premixed flame.

Dissertations

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Scientific Publications

-

Projectleaders
JBW Kok

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
SK Tarband Veeraraghavan, JBW Kok, R Alemela, ThH van der Meer

Cooperations
Project in cooperation with DLR, CERFACS, Imperial College, Keele University, University of Zaragoza, University of Brno, Siemens Muelheim, Ifta Muenchen, Ansys Abingdon.

Funded
European Union: Marie Curie program
1st - 2nd - 3rd 100%

Start of the project
2008

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MoST: Multi-scale modification of swirling combustion for optimized gas turbines

Projectleaders
ThH van der Meer
Researchtheme
Complex dynamics of fluids
Participants
AA Verbeek
Cooperations
RJM Bastiaans, BJ Geurts
Funded
STW, Electrabel Nederland, Laborelec, Ansys Germany, TTS/Ansaldo
1st - 2nd 90% 3rd 10%
Start of the project
2010
Information
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Project Aim

The idea of this project is to optimize low swirl burners by adding resonant mixing perturbations. To that end both practical and fundamental research is needed. Physical experiments are crucial to find out a priori the resonant regimes in actual combustors under realistic conditions, in which the low swirl stabilization concept works with good specifications. The experiments will provide data for validation of the findings of the numerical simulations. Numerical simulation by means of DNS and LES, is an essential tool to understand the complex flame dynamics.

Progress

Started at Februari 2010.

Dissertations

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Scientific Publications

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ULRICO: Ultra Rich Combustion of Hydro Carbons

Project Aim

This project generates knowledge needed in the design and operation of ultra clean, efficient and reliable natural gas partial combustion systems to produce syngas, by the following means:

- Computational fluid dynamics modeling is applied to predict fuel rich turbulent combustion.
- The modeling will involve prediction of major and minor species,
- The modeling involves soot precursor and soot concentrations (particle size distribution).
- Multiple combustion regimes are explored, and their impact on soot formation, by changing burner design, type and time scales of mixing and combustor pressure.
- Measurements are made in a laboratory scale test rig, rendering data and model validation on major and minor species concentrations, soot particle size, nature and concentration, gas and wall temperatures.

Progress

Turbulent combustion models for fuel rich combustion and soot formation are developed, building. At the University of Twente the combustion model CFI is developed for turbulent combustion of gaseous hydrocarbons at elevated pressures. The CFI model has been demonstrated on lean natural gas and syngas flames. The CFI technique can be applied to very rich flames as well, if they are reacting at high temperature. This is the case in natural gas partial combustion systems, which will operate at 1400-1600 K. Of specific interest in the research will be that the chemical reactions occur at very fuel rich conditions and with oxygen or enriched air as an oxidizer. Models for the formation and destruction of soot are coupled to the gas phase chemistry models. It is taken into account that widely different flow and time scales prevail in the flame zone and post flame zone, where the products of the main flame are reformed to hydrogen and carbon monoxide. In contrast with a lean combustor, species that can oxidize the soot are nearly absent in the post flame zone and soot once formed is not oxidized but instead may still increase. Rich gaseous combustion models (like the CFI model) are embedded in the available commercial CFD code ANSYS-CFX in combination with the soot models. In 2009 specific attention is paid to the accurate modeling of the chemical reaction source term with a single progress variable. The behavior of ignition and flash back is studied at rich conditions in a backward facing step geometry.

Dissertations

-

Scientific Publications

-

Projectleaders
JBW Kok

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
M Woolderink, JBW Kok, ThH van der Meer

Cooperations
Shell Global Solutions Amsterdam, Aalborg Industries Nijmegen, Automotive Centre Eindhoven, Ansys Abingdon

Funded
STW, Shell Global Solutions Amsterdam , Ansys
1st - 2nd 85% 3rd 15%

Start of the project
2009

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Multi Scale Mechanics (MSM)

Prof.dr.rer.nat. S Luding

The group Multi Scale Mechanics (MSM) is part of the Mechanical Engineering department, and the Engineering Fluid Dynamics group, with MSM-research in the areas of multi-scale fluid- and solid mechanics, micro-macro approaches, particle and contact mechanics, micro-fluidics, and self-healing materials. Multi Scale Mechanics deals with fluids and solids, where various physical phenomena take place at different length-scales at the same time. Thus, Multi Scale Mechanics can involve very small and very large objects, very fast and very slow processes. Starting from atoms, the meso-scale with domains and particles is the next larger level and buildings, machines and constructions are the large structures involved. How does the mechanics on the small level affect the behavior at the larger levels? Micro-Macro theory is one way to predict and describe this, but also advanced numerical simulations help us to understand this. Thus, for application, Multi Scale Mechanics is needed to understand modern, advanced materials. Involving theory, numerical simulation and experiments for validation, these research results can then be used to optimize the design and the efficiency of buildings, machines, and materials.

Multiscale modeling of granular flows

Project Aim

The primary goal of the project is to develop a new Multi Scale Model for granular flows, coupling a micro-scale discrete element model to the macro-scale continuum granular flow model. The new model will be verified through test cases where closures are known experimentally or analytically, such as for dry granular flows in a uniform channel with a rough bottom. Additionally, an investigation of segregation in granular flows will be undertaken. The main focus of the segregation work is using an existing continuum model and particle simulation methods to explain phenomena caused by segregation.

Progress

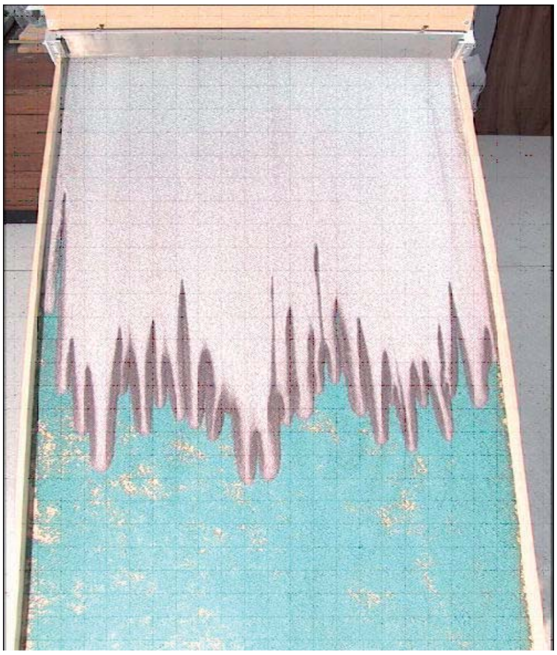
Both micro- and macro-scale models for granular flow have been developed and implemented. The micro-scale model consists of a Discrete Element model (DEM) governed by Newtonian mechanics, whereas the macro-scale model is a Discontinuous Galerkin finite element solver. Using the DEM, progress has been made in verifying the Pouliquen-Jenkins flow rule and measure segregation rates in bi-dispersed flows. The particles based model is now being used to verify and, where necessary, improve the continuum description. A variety of routines were developed to obtain statistical averages for problem-relevant parameters and are current being compared and contrasted.

Dissertations

-

Scientific Publications

1. Stefan Luding, Towards dense, realistic granular media in 2D. Nonlinearity 22, Number 12, December 2009 , pp. R101-R146(1).



Projectleaders

S Luding, O Bokhove

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

AR Thornton, T Weinhart

Cooperations

NACM – EWI - UTwente

Funded

CoE Fluid and Solid Mechanics, Faculty CTW UTwente, and Institute of Mechanics, Processes and Control, Twente (IMPACT)

1st 100% 2nd - 3rd -

Start of the project

2009

Information

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Jamming, shear banding and microstructures

Projectleaders
S Luding
Researchtheme
Complex dynamics of fluids
Participants
A Singh
Cooperations
-
Funded
FOM
1st - 2nd 100% 3rd -
Start of the project
2009
Information
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Project Aim

To probe the connections between jamming, shear banding and microstructures in numerical simulations of Brownian and non-Brownian systems with various interaction forces, shear rates, stress regimes.

Progress

DEM studies are being used and not defined to study the so-called "Split bottom ring shear cell" where a slow, quasi-static deformation leads to wide shear bands. The typical characteristic of these slow granular flows is rate independence. We simulated the system for different interaction forces and rotation of speeds. We validated the system properties (Energy, Yield Locus etc.) to be indpendent of (or scaling with) driving speed. Friction increases the yield stress and contact adhesion leads to a non-linear, pressure dependent yield locus. For higher driving speed the dynamic regime is entered as to be studied in the following period.

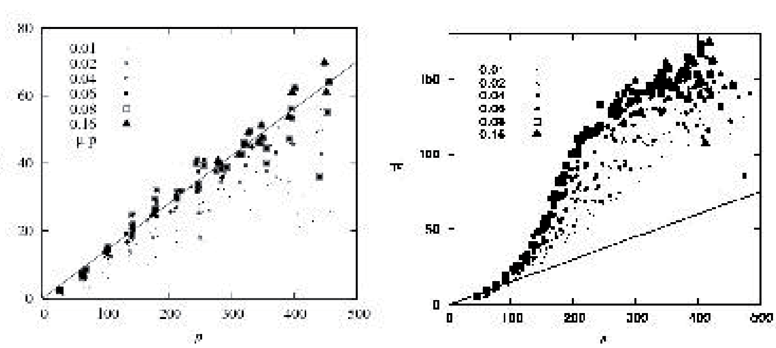
Dissertations

-

Scientific Publications

1. S. Luding & F. Alonso-Marroquin, How to get the Yield locus of an adhesive Powder from a Single numerical Experiment, in : 6th International Confrence for Conveying and Handling of Particulate Solid, P. Wypych (Eds.), Barton ACT Australia, CHOPS09 Proceedings, ISBN: 978-08528259065, pp. 522-527.
2. S. Luding, Constitutive relations of dense granulates with friction and adhesion from DEM, in: Confrence on Particle-Based methods Particles, E. Onate & D. R. J. Owen (Eds.), CIMNE, Barcelona, 2009, ISBN: 978-84-96736-82-5, pp. 159-162.
3. A. Singh, Jamming, Shear Banding and Microstructures (poster), in: Scale Transitions in Space and Time for Materials, Lorentz Center, Leiden.

Yield Locus for contact friction μ =0 with Kc=0 (Left) & Kc>0(Right)



Computational modeling of non-Newtonian flows in nano-channels

Project Aim

During the past few years molecular dynamics has been a widely applied tool to simulate fluid confined in micro/nano geometries. What makes interfacial fluids fundamentally different from the bulk fluid is the fact that their density varies considerably over microscopic distances. A class of such strongly inhomogeneous fluids are those confined in very narrow spaces by solid boundaries. In the present project the goal is to study the non-Newtonian transport properties of such fluids, investigate the effect of wall-fluid interaction, surface roughness and wall-morphology on the flow behavior.

Progress

In this project we simulate planar Poiseuille flow of a Lennard-Jones fluid in channels of various widths in the nanoscale regime. Furthermore, various boundary conditions, body forces and thermostats are applied and compared. We obtain average stress and strain profiles across the channel and the local viscosity can be estimated from stress-strain relations and as function of density. Anisotropic stress is found near the walls of the channel; the influence of various parameters on the anisotropy are studied. Understanding and quantifying the non-Newtonian behavior is a first step towards deriving a constitutive model that governs a strongly confined fluid.

Dissertations

-

Scientific Publications

1. S. Luding, Towards dense, realistic granular media in 2D, Nonlinearity 22, R101-R146, 2009.
2. S. Luding, From molecular dynamics and particle simulations towards constitutive relations for continuum theory, in: Advanced Computational Methods in Science and Engineering, B. Koren and K. Vuik (eds.), Springer Series Lecture Notes in Computational Science and Engineering #71, Springer, Berlin, ISBN: 978-3-642-03343-8, pp. 453-492, 2009.

Projectleaders
S Luding

Researchtheme
Complex dynamics of fluids

Participants
RM Hartkamp, A Ghosh, S Luding

Cooperations
J Westerweel (TUD), M. Sperl, DLR

Funded
MicroNed
1st 50% 2nd - 3rd 5-%

Start of the project
2006
since 2009 (RM Hartkamp)

Information
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Sound propagation in unconsolidated soils: discrete element simulations and theory

Projectleaders
S Luding
Researchtheme
Complex structures of fluids
Participants
O Mouraille
Cooperations
NP Kruyt, (UT), D Smeulders, (TUDelft), H Steeb (RUBochum, Germany)
Funded
FOM & Shell
1st - 2nd 50% 3rd 50%
Start of the project
2003
Information
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Project Aim

Based on discrete element simulations, the effect of interparticle forces like cohesion and friction on the sound propagation behaviour in dense packings of grains is studied. In addition, also the presence of rotations and possible rotational waves is to be examined. Numerical models, continuum theory, and experiments for complex dynamics of the granular fluids are being worked on.

Progress

The effect of disorder on wave propagation has been investigated by introducing a weak polydispersity in a regular structure of particles. Results reveal some interesting non-linear effects. In order to quantify some of theses effects we looked at the frequency content of P-wave signals by calculating the frequency-space diagrams for different polydisperse packings. Due to the irregularities present at the contact level, some frequencies are filtered. As the wave propagates away from the source, only low frequency waves are propagating. Experiments in sand and glass beads are done in Delft in the group of D. Smeulders and in Bochum, Germany in the group of H. Steeb. Most recently, ordered and disordered packings are examined concerning their eigenmodes and the corresponding translational and rotational degrees of freedom.

Dissertations

1. http://www2.msm.ctw.utwente.nl/sluding/THESIS/PhD_Mouraille.pdf

Scientific Publications

1. O. Mouraille, O. Herbst and S. Luding, Sound propagation in isotropically and uni-axially compressed cohesive, frictional granular solids, Engineering Fracture Mechanics 76, 786-791, 2009.
2. S. Luding, From molecular dynamics and particle simulations towards constitutive relations for continuum theory, in: Advanced Computational Methods in Science and Engineering, B. Koren and K. Vuik (eds.), Springer Series Lecture Notes in Computational Science and Engineering #71, Springer, Berlin, ISBN: 978-3-642-03343-8, pp. 453-492, 2009.

Hierarchical computational methods for scale bridging in composite materials

Project Aim

The project's broad goal is to understand the effect of microscopic particle properties on the macroscopic continuum behavior of granular materials. The long term objective is to devise a physically based constitutive model which depends explicitly on a limited set of these parameters.

Progress

The jamming behavior of frictionless packings of spheres under isotropic compression has been analyzed numerically using the Discrete Element Method. In particular, we have examined the evolution of the coordination number as function of the volume fraction which shows a discontinuity upon the transition from solid to fluid phase. Based on this, the effect of server-Al system parameters-r on the critical volume fraction has been studied; further extending the jamming behavior to higher volume fractions, we proposed a constitutive model relating isotropic deformation and pressure which depends on the coordination number as a state variable.

Dissertations

-

Scientific Publications

1. F. Göncü, O. Duran, and S. Luding, Jamming in frictionless packings of spheres: determination of the critical volume fraction, in: Powders and Grains 2009, M. Nakagawa and S. Luding (Eds.), AIP Conf. Procs. #1145, ISBN 978-0-7354-0682-7, pp. 531-534.
2. S. Luding, From molecular dynamics and particle simulations towards constitutive relations for continuum, Advanced Computational Methods in Science and Engineering, 2009 B. Koren and K. Vuik (Eds.), Springer, 978-3-642-03343-8, pp. 453-492.
3. A. Wouterse, S. Luding & A.P. Phillipse, On contact numbers in random rod packings, Granular Matter 2009, Volume 11(3) pp. 169-177.
4. O. Duran, V. Schwaemmle, P. Lind, H.J. Herrmann & L.P. Maia, The dune size distribution and scaling relations of barchan dunefields, Granular Matter 2009, Volume 11(1) pp. 7-11.

Projectleaders
S Luding

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
F Göncü, S Luding

Cooperations
O Duran

Funded
Delft Center for Computational Science an Engineering (DCSE)
1st 100% 2nd - 3rd -

Start of the project
2008

Information

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H-MSM Hierachical multi-scale modeling: a single data structure for micro-macro and multi phase/-field models

Projectleaders
S Luding
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
K Yazdchi, V Ogarko, S Srivastava
Cooperations
IMPACT, DEM Solutions, CSIRO
Funded
STW
1st - 2nd 75% 3rd 25%
Start of the project
2008
Information
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Project Aim

The goal of this project is to develop a multi-scale computational method that uses a single hierarchical data-structure as its basis – involving also multiple fields. Starting from meso-scopic structures (particles or domains) a grid is constructed on a hierarchical data structure. Algorithms and methods from various disciplines like computational fluid dynamics (CFD), molecular dynamics (MD), finite element method (FEM), etc., have to be combined. The scientific challenge is to understand systems with strongly different particle sizes with gas-, fluid-, and solid-like behavior at the same time. This involves multi-physics, micro-systems, (moving) interfaces and multi-field problems in general. More specific, such systems occur in grinding or comminution and transport of particulate systems – before and during processing of modern, high-performance materials.

Progress

The basic properties of Delaunay Triangulation (DT) data structures are reviewed. Besides several other tasks that can be performed by DT, it can also be used as a collision detection mechanism in discrete element method (DEM) and some potentials and challenging aspects of this data structures are studied. When the computational costs are compared with alternative, e.g., Linked Cell (LC) methods for different number of particles, the performance is similar and linear in the particle number. The major advantage of Delaunay edges/triangles/tetrahedra is that, they not only can be for contact detection but also for our FEM/CFD coupling as a mesh and for the micro-macro transition. In the next stage, a finite element (FE) based model for the viscous and incompressible fluid flow through a regular porous media composed of rigid (immobile) particles/fibers is considered, and an analytical-numerical approach is employed to calculate the associated transverse permeability. The effects of anisotropy, i.e., in particle shape or orientation, as well as porosity, i.e., volume fraction, on the overall permeability are studied in detail. The representation proposed is compared with the well known Carman-Kozeny (CK) equation. The results from this study can be used for verification and validation, i.e., as a closure relation, of more advanced coarse-grained models for particle-fluid interaction and for the coupling of DEM with FEM or CFD.

Dissertations

-

Scientific Publications

1. Yazdchi K., Salehi M., Shokrieh M.M., Analytical and numerical techniques for predicting the interfacial stresses of wavy carbon nanotube/polymer composites, Mechanics of Composite Materials, 2009, 45(2), 207-212.
2. Yazdchi K., Salehi M., Constitutive modeling of viscoelastic behavior of CNT/Polymer composites, CMS 2009, Enschede, The Netherlands.
3. Yazdchi K., Bertoldi K., and Luding S., Contact detection based on Delaunay Triangulation and its application in DEM, DEM Solutions, 2009, Edinburgh, UK.
4. Nakagawa M., Luding S., Powders and Grains 2009, AIP Conf. Proceedings #1145, CO, USA.
5. Yazdchi K. and Luding S., Continuous Hierarchical Multi-Scale Modeling, J.M. Burgers-Centrum, 2009, TU/e, The Netherlands.
6. Ogarko V. and Luding S., Data structures and algorithms for contact detection in numerical simulation of discrete particle systems, Engineering Mechanics Symposium, 2009, Lunteren, The Netherlands.

Modeling of long-range interaction forces and clustering phase diagram

Project Aim

The objective of this Ph.D. project is to develop a three-dimensional Molecular Dynamics (MD) environment and hydrodynamic theory for modeling long-range interaction forces based on hierarchical algorithms. The aim is both to model attractive/repulsive Coulomb interactions in homogeneous systems and compare the results with theoretical work.

Progress

In the last year, the consequences of using a modified equation of state in the stability properties of a 2D granular was studied. The theoretical predictions were confirmed by numerical experiments. The numerical view-point required the development of a new event-driven algorithm, that permits the simulation of cluster of particles, decreasing computational time. The method is useful when cohesive forces are taking into account.

Dissertations

-

Scientific Publications

1. Stefan Luding, Towards dense, realistic granular media in 2D. Nonlinearity 22, Number 12, December 2009 , pp. R101-R146(1).
2. M. K. Muller & S. Luding, Homogeneous cooling with repulsive and attractive long-range interactions, POWDERS AND GRAINS 2009. AIP Conference Proceedings, Volume 1145, pp. 42-47 (2009).
3. Gonzalez, S.; Risso, D.; Soto, R., Towards event-driven simulation of static sphere packings, POWDERS AND GRAINS 2009. AIP Conference Proceedings, Volume 1145, pp. 301-304 (2009).

Projectleaders
S Luding

Researchtheme
Complex dynamics of fluids

Participants
S Gonzalez, M-K Müller, S Luding

Cooperations
DE Wolf, Duisburg (Germany)

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2009

Information

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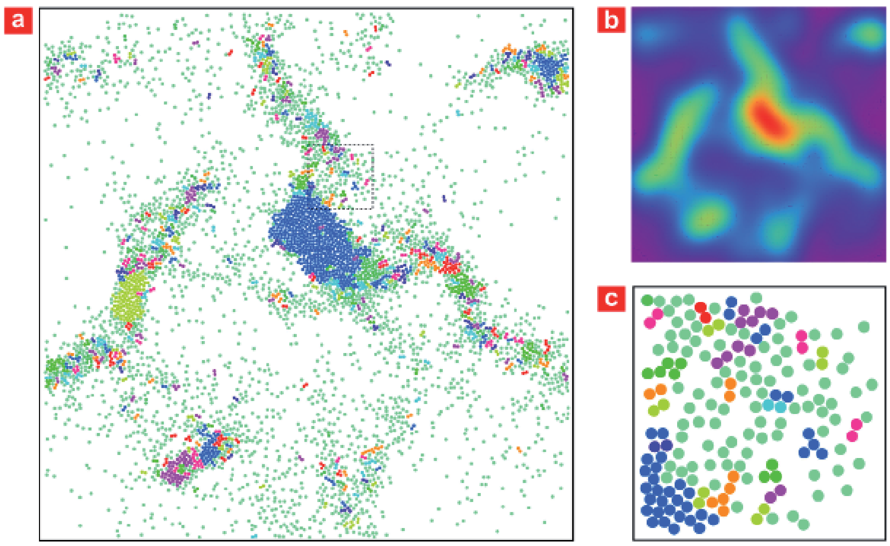
a) Snapshot of a system with N=5000 particles in a square box of size L=160d, with d the diameter of the particles, which are colored with different colors for different clusters, and with light green if they are alone. b) Coarse-grained description of the full system. Purple is low density and red is high density. c) Zoom of the dashed square- zone in a) The definition of cluster depends on the distance between the particles (<1.1d), and on the relative velocity of the particles.



PROJECTLEADERS
S Luding
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
K Yazdchi, V Ogarko, S Srivastava
COOPERATIONS
Prof. Dr. Hans Kuipers,
DEM solutions (Dr. John Favier),
CeParTec GmbH (Dr. Torsten Gröger), CSIRO (Dr. Paul Cleary).
FUNDED
STW, Industry
1st - 2nd 75% 3rd 25%
START OF THE PROJECT
2007
INFORMATION
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PROJECT AIM

Goal of the project is to develop a multi-scale computational method that uses a single hierarchical data-structure as basis – involving also multiple fields. Starting from meso-scopic structures (particles or domains) a grid is constructed on a hierarchical, tree-based data structure. The hierarchical approach allows for micro-macro transition, coupling of different fields, and coarsening or refinement – where possible or needed, respectively.

PROGRESS

During the last year several contact detection methods for polydisperse particle systems have been investigated. As a new method, Hierarchical Hashed Grid is proposed. For testing with realistic physical particle systems a procedure of creating these has been studied. Programs for molecular dynamics with soft (MD) and hard particles (ED) with growth are implemented and tested: the theoretical predictions were confirmed by numerical simulations. Behavior of Delaunay triangulation (simple and weighted) data structures for MD simulations have also been studied, this includes a study of the flipping algorithm in 2D.

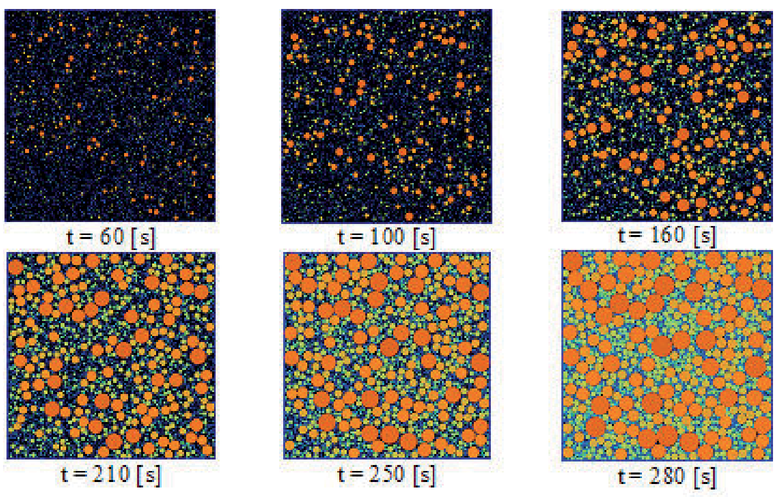
DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. S. Luding, From molecular dynamics and particle simulations towards constitutive relations for continuum theory, in: Advanced Computational Methods in Science and Engineering, B. Koren and K. Vuik (eds.), Springer Series Lecture Notes in Computational Science and Engineering #71, Springer, Berlin, ISBN: 978-3-642-03343-8, pp. 453-492, 2009.

The preparation of model systems with ED, 104 particles, polydispersity 100, final volume fraction 0.85, uniform mass distribution.



Water Engineering and Management

Prof.dr. SJMH Hulscher

The work of the “Water Engineering and Management (WEM) group was originally mainly devoted to the modelling of sand waves on the seabed. First it was shown, that the seabed patterns in the North Sea can be explained as free instabilities of the seabed. Subsequently, the modelling of sand waves was extended and refined. The group has worked on a scientific and practical tool for fully nonlinear modelling of sand waves. Over the last five years, the offshore morphodynamic work has broadened to rivers, coasts and blue-ice. Alternate bars in a flume were compared with (Ginzburg-)Landau-type models. The group was the first to explore data assimilation for morphodynamic predictions. Further work concentrated on using data assimilation to combine field data with sand wave amplitude models for maintenance dredging management of navigation channels and sand wave-related pipeline problems. Also, North Sea data were analysed and a new bed mode, called long bedwaves, was discovered. The origin of nearshore bars was addressed. A method was developed for modelling human interferences in a morphodynamic setting. This has opened perspectives for a new approach towards modelling large-scale sand mining in shallow seas. A project for developing tools for evaluation of human interference in the North Sea for optimal management of the seabed started recently and sediment transport concerning near-shore sand pits is being investigated. Since 2000 the group has studied the use of morphodynamical models in a societal context. Recently, a method for decision making based on quantitative information including uncertainties was developed in the multidisciplinary project Flyland, which opens the field of designing an assessment framework for appropriate modelling.

The issue of scale in applied coastal evolution modeling : part of a LOICZ-funded research entitled "Congruent Scales in Economics, Coastal Engineering and Morphology"

Project Aim

To assess safety of a dune-protected coastal area, dune erosion models are used. Dune erosion models are sensitive to cross-shore dune morphology. Therefore, to forecast long-term safety, on time periods of 50 up to 200 years, we need to have information on dune behavior on time periods of at least several decades. Along the central part of the Netherlands' coast, foredunes are highly managed. This research aims at investigating how different management measures have affected foredune morphodynamics on a timer period of decades. In addition, to examine whether the observed dynamics are large or not, we investigate foredune morphodynamics along a natural coast, which has comparable process controls. Also, the effects of management measures in a different environmental setting are examined to investigate whether management interventions leave similar imprints in different areas.

Progress

We used EOF analysis (Empirical Orthogonal Function analysis) to characterize foredune morphology on a somewhat spatially aggregated level. Results showed that most management interventions do not alter foredune morphodynamics significantly. Rather, the effects of natural processes are dominant in determining foredune morphodynamics. Nourishments do alter foredune morphodynamics considerably, since this measure alters the sediment budget of the system.

Dissertations

-

Scientific Publications

1. Brommer, M.B. and Bochev-van der Burgh, L.M., 2009, Sustainable coastal zone management: a concept for forecasting long-term and large-scale coastal evolution, Journal of Coastal Research 25(1), 181-188.
2. Bochev-van der Burgh, L.M., Wijnberg, K.M., Hulscher, S.J.M.H., 2009, Dune morphology along a nourished coastline, Journal of Coastal Research 56, 292-296.

Projectleaders

SJMH Hulscher

Researchtheme

Complex dynamics of fluids

Participants

LM Bochev-van der Burgh,
T Filatova, KM Wijnberg,
A van der Veen, JPM Mulder

Cooperations

-

Funded

ALW-NWO
1st - 2nd 100% 3rd -

Start of the project

2005

Information

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River bed form evolution modeling for flood management : Dune evolution and transition to plane beds

Projectleaders
SJMH Hulscher, CM Dohmen-Janssen

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
OJM van Duin, S Naqshband, FM Sterlini-van der Meer, JS Ribberink, AJ Paalberg

Cooperations
Deltares, HKV, Rijkswaterstaat, Waterdienst, University of Braunchweig

Funded
NWO/STW, University of Twente, Deltares/RWS, HKV
1st 45% 2nd 50% 3rd 5%

Start of the project
2010

Information
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Project Aim

The aim of the complete project is to develop knowledge and forecasting models on river bed form evolution in support of flood management; in particular for flood early warning systems (FEWS). The central interest of the current subproject will be the evolution (including initiation and decay) of different types of dunes, transition to upper stage plane beds and the translation of bed regime to roughness.

Progress

The research project started on February 1st of 2010 with the formal start of the two involved PhD-students. For the current subproject a literature study is carried out currently to get an idea of the issues regarding bed form modelling. Also, possible improvements to an existing model are identified in line of the subjects described above. Later on the knowledge gained by research, the model itself and the direction of improvements will be used to make a formal research proposal.

Dissertations

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Scientific Publications

-

Uncovering inherent dynamics in coupled bio-geomorphodynamic systems offshore

Project Aim

On the bed of the North Sea sand waves are present, which grow up to 25% of the water depth and migrate at a speed of tens of meters per year. These sand waves can pose a hazard to offshore constructions, navigation, pipelines and telecommunication cables. On the other hand, bed forms can protect the coastline against storms. The bottom of the North Sea is also covered by a great number of organisms live in and on the bottom of the sea. These organisms try to optimize their habitat, resulting in bio-geomorphological interactions. The precise interaction between the biological activity and geomorphodynamics is not known at this moment. Such knowledge is of great interest for reliable long-term geomorphodynamic predictions, especially in marine environments with large biological activities.

Progress

First model results are summarised in three journal papers. Focus upon flume experiments and field studies in coming years.

Dissertations

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Scientific Publications

1. Borsje, B.W., Buijsman, M.C., Besio, G., De Vries, M.B., Hulscher, S.J.M.H., Herman, P.M.J., Ridderinkhof, H., 2009. On the modelling of bio-physical influences on seasonal variation in sandwave characteristics. Journal of Coastal Research SI56, 698-702.
2. Borsje, B.W., De Vries, M.B., Hulscher, S.J.M.H., Herman, P.M.J., 2009. On the parameterization of biological activity on sandwave and sandbank dynamics. Ocean Dynamics 59, 659-670. doi: 10.1007/s10236-009-0199-0.
3. Borsje, B.W., De Vries, M.B., Bouma, T.J., Besio, G., Hulscher, S.J.M.H., Herman, P.M.J., 2009. Modeling bio-geomorphological influences for offshore sand waves. Continental Shelf Research 29, 1289-1301. doi: 10.1016 / j.csr.2009.02.008.
4. Borsje, B.W., Buijsman, M.B., Besio, G., De Vries, M.B., Hulscher, S.J.M.H.,Herman, P.M.J., Ridderinkhof, H., 2009. Modelling bio-physical influences on sandwave dynamics. In: Baptist, M.J. (Eds). Proceedings of the NCK-days 2009, Texel, The Netherlands, pp. 30.
5. Borsje, B.W., Buijsman, M.C., Besio, G., Hulscher, S.J.M.H., Herman, P.M.J., Ridderinkhof, H., 2009. Bio-geomorphological interactions in sandwave migration. In: Vionnet, C.A., Garcia, M.H., Latrubesse, E.M., Perillo, G.M.E. (Eds). Proceedings of the sixth IAHR Symposium on River, Coastal and Estuarine Morphodynamics (RCEM), Santa Fe, Argentina, pp 567-574.
6. Borsje, B.W., Bouma, T.J., De Vries, M.B., Hulscher, S.J.M.H., Herman, P.J., Besio, G., 2009. Bio-geomorphological interactions in offshore seabed patterns. In: McKee Smite, J. (Eds). Proceedings of the 31st International Conference on Coastal Engineering (ICCE), Hamburg, Germany, pp 4423-4435.

Projectleaders
SJMH Hulscher

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
BW Borsje, PMJ Herman, SJMH Hulscher, MB De Vries

Cooperations
Deltares

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2007

Information

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Predicting roughness due to bedform formation under partial transport conditions in large scale morphodynamic models

Projectleaders
SJMH Hulscher
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
-
Cooperations
-
Funded
1st 25% 2nd 50% 3rd 25%
Start of the project
2005
Information
A Tuijnder
053 489 4038

Project Aim

The project aim is to improve the use of morfodynamical river models under partial transport conditions. The focus is on the sub-models for bed roughness induced by bedforms and its link with the sediment transport process.

Progress

Morphodynamic model runs have been carried out for validation of the earlier developed model concepts for bedforms dimensions, roughness and sediment transport under partial transport conditions. Furthermore a thesis has been written on the research of the previous years. The project if now finished.

Dissertations

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Scientific Publications

1. Tuijnder, A.P., Ribberink, J.S. and Hulscher, S.J.M.H. (2009) An experimental study into the geometry of supply-limited dunes. Sedimentology, 56, pp. 1713-1727, doi: 10.1111/j.1365-3091.2009.01054.x
2. Tuijnder A.P., Ribberink, J.S. and Hulscher, S.J.M.H. (2009) Morphodynamic modelling of rivers under supply-limited conditions. In Vionnet, C., García, M. H., Latrubesse, E.M., Perillo, G.M.E. (Eds.) Proc. River, Coastal and Estuarine Morphodynamics, RCEM 2009, Publ. Taylor & Francis, London, ISBN 978-0-415-55426-8, Vol I, pp. 877 - 882.
3. Tuijnder, A.P. & Havinga, H. (2009). Onderzoek verfijnt modellen voor sedimenttransport. Land + water : magazine voor civiele- en milieutechniek 49(9), pp. 28 – 30.

Short-term biophysical interactions in coastal mangroves

Project Aim

To quantify the biophysical interactions that control the hydrodynamic energy attenuation and the local gross sediment transport fluxes in coastal mangroves.

Progress

A research proposal has been developed, describing how to quantify short-term biophysical interactions in coastal mangroves. The study will start with a field campaign in Matang, Malaysia. Subsequently flume experiments will be run to extend the range of hydrodynamic forcing (i.e. wave heights) in our database. This database will be applied to develop a process-based hydrodynamic and morphodynamic model to describe the attenuation of hydrodynamic energy by bio-physical interactions within coastal mangroves and the effects on the local morphology. The process-based model will finally be applied to determine the potential use of coastal mangroves to attenuate hydrodynamic energy and the effect on the local morphology.

Field measurements have been executed at the Zuidgors wetland in the Western Scheldt estuary in order to compare different field equipment for suitability of measuring hydrodynamics in intertidal vegetation. In these studies, vegetation is mimicked by different densities of bamboo sticks. The outcome of the study is that HR ADCP's are much more useful to our research than ADV's or ADCP's.

A field campaign planning has been setup for the field measurements that are planned for this year. Hydrodynamics will be measured along three contrasting cross-shore transects through the mangroves of Matang. Sediment transport will be studied over an entire creek basin, as this will facilitate comparison of creek input and sheet flow input of sediments into mangroves. Measurements along the transects and in the creek basin will be repeated three times, as there are three major season in the area (SW monsoon, inter-monsoon, NE monsoon).

Dissertations

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Scientific Publications

1. Horstman, E.M., Wijnberg, K.M., Hulscher, S.J.M.H. & Smale, A.J. (2009). On the consequences of a long-term perspective for coastal management. Ocean and Coastal Management, 52(12), 593-611.
2. Horstman, E.M., Wijnberg, K.M., Smale, A.J. & Hulscher, S.J.M.H. (2009). Long-term coastal management strategies: useful or useless? Journal of Coastal Research, 2009(56), 233-237.
3. Horstman, E.M., Wijnberg, K.M., Helder, A.J.P., Smale, A.J., Hulscher, S.J.M.H. & Dohmen-Janssen, C.M. (2009). Long-term coastal management strategies: useful or useless? In Book of abstracts NCK-Days 2009 (pp. 32-32). Delft: NCK.
4. Horstman, E.M., Mulder, J.P.M. & Hommes, S. (2009). Voorstel uitvoeringskader kustonderhoud. Civil Engineering and Management Research Report 2009R-003/WEM-003. Water Engineering & Management (WEM).

Projectleaders

SJMH Hulscher, CM Dohmen-Janssen

Researchtheme

Complex dynamics of fluids

Participants

EM Horstman, CM Dohmen-Janssen, SJMH Hulscher, PMJ Herman, TJ Bouma, EL Webb, DA Friess, D Galli, T Balke

Cooperations

Deltares, National University of Singapore, Netherlands Institute of Ecology, Forestry Department Malaysia, Universiti Putra Malaysia

Funded

Singapore-Delft Water Alliance (Deltares, National University of Singapore, Public Utilities Board Singapore)

1st 25% 2nd - 3rd 75%

Start of the project

2009

Information

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Uncertain hydraulic roughness in river models

Projectleaders
SJMH Hulscher
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
JJ Warmink, MJ Booij, H van der Klis (Deltares), SJMH Hulscher
Cooperations
Deltares
Funded
NWO/ STW
1st 25% 2nd 75% 3rd -
Start of the project
2007
Information
JJ Warmink
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Project Aim

To quantify the effects of uncertain hydraulic roughness on the results of hydrodynamic river models used for flood safety computations, and assess methods for communication of uncertainties in model results to decision makers.

Progress

Hydrodynamic river models are applied to design and evaluate measures for purposes such as safety against flooding. These numerical models are all based on a deterministic approach. However, the modeling of river processes involves numerous uncertainties, resulting in uncertain model results. Uncertainty is defined as any deviation from the unachievable ideal of complete determinism. Uncertainty in models comprises (1) the difference between a model outcome and a measurement and (2) the possible variation around the computed value or measurements. Knowledge of the type and magnitude of these uncertainties is crucial for a meaningful interpretation of the model results. The first step in the research was to determine the dominant model parts of 2D hydrodynamic river models. This research was carried out using expert opinion elicitation. 11 experts have been interviewed, for a specific case study and ranked the sources of uncertainty in the 2D river model WAQUA. Furthermore, they quantified the effect that the uncertainties had on the modelled water levels, based on their expertise. The results showed that the uncertainty in the upstream discharge and in the roughness equation for the main channel contributed most to the uncertainty in the water levels. The next step in this PhD research was to quantify the uncertainty in the main channel roughness predictor under design conditions. Therefore, we used statistical extrapolation of measured bed form characteristics to quantify the uncertainty between 10 different roughness predictors (e.g. Van Rijn, 1984; Vanoni-Hwang 1967). The results show that the uncertainty due to different predictors is large and has a significant effect on the computed water levels for design conditions.

Dissertations

-

Scientific Publications

1. Warmink, J.J., Van der Klis, H., Booij, M.J. and Hulscher, S.J.M.H. (2009) Quantification of uncertainty sources in a 2D hydraulic model for the river Rhine using expert opinions. In: Geophysical Research Abstracts, Vol. 11, EGU2009-8627. EGU General Assembly 2009, Vienna, Austria.
2. Warmink J.J., Van der Klis H., Booij, M.J. Hulscher S.J.M.H. (2009) Quantification of uncertainties in a 2D hydraulic model for the Dutch river Rhine using expert opinions. Extended abstract IWEH (workshop environmental hydraulics) October 2009, Valencia.

River bed form evolution modeling for flood management : on the influence of suspended sediment transport on dune modeling

Project Aim

The aim of the complete project is to develop knowledge and forecasting models on river bed form evolution in support of flood management; in particular for flood early warning systems (FEWS). The central interest will be the role of suspended sediment transport on evolution of dunes, interaction with superimposed dunes and transition to upper stage plane beds.

Progress

The kick off of this project was on February 2010. The first stage of this project involves a literature study with emphasis on the formulation of suspended sediment transport. The next step will be the implementation of suspended sediment transport formulation in the considered dune evolution model. Subsequently, numerical experiments will be carried out to investigate the effects of suspended sediment transport on dune evolution, interaction with superimposed dunes and transition to uppers stage plane beds.

Dissertations

-

Scientific Publications

-

Projectleaders
SJMH Hulscher, CM Dohmen-Janssen

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
S Naqshband, OJM van Duin, FM Sterlini-van der Meer, JS Ribberink, AJ Paalberg

Cooperations
Deltares, HKV, Rijkswaterstaat, Waterdienst, University of Braunchweig

Funded
NWO/STW, University of Twente, Deltares/RWS, HKV
1st 45% 2nd 50% 3rd 5%

Start of the project
2010

Information
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Combustion Science and Engineering

Prof.dr.ir. HB Levinsky

The mission of the Combustion Science and Engineering program is to:

- provide insight into the fundamental physical and chemical processes responsible for the behavior of high-temperature reacting systems, such as flames and low-temperature plasmas,
- conceive ways to control this behavior based on the insight gained,
- “translate” the results obtained into terms useful for engineering practice,
- disseminate the knowledge generated to both the scientific and practical communities,
- analyze the technical consequences of energy policy choices.

Combustion can be defined as a self-sustaining transition of a system from a non-equilibrium state, e.g., unreacted fuel and oxidizer, to equilibrium, accompanied by energy release. The combustion of even the simplest fossil fuel, methane, is exceptionally complex. Hundreds of elementary reactions involving many tens of chemical species are intimately coupled to energy and mass transport, yielding a spatial structure: the flame. The coupling of chemical reaction to transport renders the details of flame structure sensitive to external factors, and changes in fluid flow, heat transfer and identity of the fuel have major impacts on combustion properties (ignition, flame extinction, pollutant formation). The emphasis of the program is to formulate a microscopically correct and theoretically coherent description of the energy conversion process.

Since the only reliable source of information on this process is experiment, we develop and use non-invasive laser-spectroscopic methods (such as laser-induced fluorescence, spontaneous and coherent anti-stokes Raman scattering) to analyze stationary and instationary high-temperature reacting systems. Deeper insight is gained into system behavior by performing theoretical analyses of the phenomena under study, including the use of advanced numerical codes that solve the full conservation equations (i.e., including detailed transport and chemistry).

Current Activities

The majority of the current projects concern the effects of hydrogen addition on fossil fuel combustion. The results of these studies are used to point out the technical consequences of the future integration of hydrogen into the energy supply. Particularly, the limitations posed by the combustion behavior of hydrogen in existing equipment will have a major impact on any transition to a hydrogen economy.

- Flame structure: In two projects, laser diagnostics are developed and applied in flames at low pressure (to enlarge the size of the primary reaction zone) to study key intermediates responsible for pollutant formation, particularly NOx and soot. Analysis of the experimental results and comparison with those from numerical models help identify the shortcomings in the models, such as potentially incorrect boundary conditions, uncertainties in transport phenomena and failures in chemical mechanisms. Also, the possible effects of hydrogen addition to natural gas and other alkanes (suggested in energy policy for the transition to sustainable energy) on oxidation mechanism and pollutant formation are examined. Further, in a third project, the flame structure of pure hydrogen flames and hydrogen/alkane flames at atmospheric pressure are being studied. Here, the peculiar transport properties of hydrogen are particularly manifested.

- Ignition phenomena: A RCM is being built for a dual purpose: to assess the effects of sustainable fuels (hydrogen and biogas) on alkane ignition (related to engine knock) and to serve as an instrument with which, in combination with laser diagnostics currently being developed, elementary chemical processes in ignition are to be studied.
- Laser diagnostics: Raman, IR-absorption and laser-fluorescence methods are being developed for quantitative analysis of high-temperature reacting systems.

NOx formation in ultra-dilute, preheated combustion

Projectleaders
HB Levinsky, AV Mokhov
Researchtheme
Complex structures of fluids
Participants
AV Sepman
Cooperations
TU/e, Tata, Numeca
Funded
STW, Tata, Numeca
1st - 2nd 70% 3rd 30%
Start of the project
2009
Information
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Project Aim

Combustion using highly preheated air, together with diluted air and/or fuel, is a clean combustion concept that combines high efficiency and low pollutant emissions in industrial heating processes. To permit the optimization of NOx control, and to provide insight into the ultimate low-NOx potential of these methods, in this research we investigate the paths to NO formation in dilute, high temperature combustion. Towards this end, we perform quantitative laser-diagnostic measurements of flame structure, using LIF, Raman and TDLAS methods in the laminar coflow geometry, combined with detailed numerical simulations of the structure of the reaction zone.

Progress

This is a new project, started in July 2009. The progress to date has been in constructing the preheat coflow burner and shaking down the laser diagnostics. The new Raman diagnostic has been further examined, the LIF calibration method actualized, and attention to the TDLAS for HCN and NH3 has been paid.

Dissertations

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Scientific Publications

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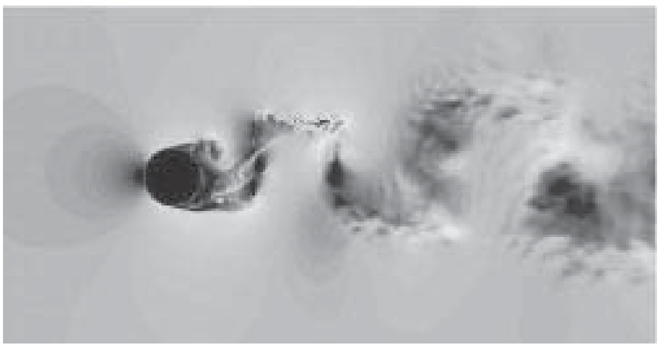
Computational mechanics and numerical mathematics

Prof.dr. AEP Veldman

The group Computational Mechanics and Numerical MathemThe group Computational Mechanics and Numerical Mathematics at the University of Groningen focuses on the development of numerical solution methods for partial differential equations in general, and for (aero- and hydrodynamic) flow simulation in particular (CFD). Keywords for our algorithmic developments are symmetry-preserving discretization, Cartesian cut-cell approach, sharp-interface methods, efficient sparse-matrix solvers and large-scale continuation methods. It is our strategy to combine all algorithmic innovations from the individual research projects into one coherent CFD concept, such that all projects can profit from each other.

Application areas are direct and large-eddy simulation of turbulent flow, free-surface flow in aerospace (sloshing onboard spacecraft) and maritime engineering (hydrodynamic wave loading), oceanography (stability of the global ocean circulation), bio-medical fluid dynamics (hemodynamics) and heat transport (Rayleigh-Bénard flow). We plan to extend our thus far mainly mono-disciplinary flow problems towards multi-physics: fluid-structure interaction, two-phase flow, atmospheric flow and turbulent combustion. In the process of knowledge transfer, the in-house developed computer codes ComFlo and MRILU play an important role. atics at the University of Groningen focuses on the development of numerical solution methods for partial differential equations in general, and for (aero- and hydrodynamic) flow simulation in particular (CFD). Keywords for our algorithmic developments are symmetry-preserving discretization, Cartesian cut-cell approach, sharp-interface methods, efficient sparse-matrix solvers and large-scale continuation methods. It is our strategy to combine all algorithmic innovations from the individual research projects into one coherent CFD concept, such that all projects can profit from each other.

Application areas are direct and large-eddy simulation of turbulent flow, free-surface flow in aerospace (sloshing onboard spacecraft) and maritime engineering (hydrodynamic wave loading), oceanography (stability of the global ocean circulation), bio-medical fluid dynamics (hemodynamics) and heat transport (Rayleigh-Bénard flow). We plan to extend our thus far mainly mono-disciplinary flow problems towards multi-physics: fluid-structure interaction, two-phase flow, atmospheric flow and turbulent combustion. In the process of knowledge transfer, the in-house developed computer codes ComFlo and MRILU play an important role.



Snapshot of a simulated turbulent flow at Re=3900

Direct and large-eddy simulation of turbulence

Project Aim

A main area of research concerns turbulent flow simulation. Turbulence modeling keeps computational effort within reasonable limits, but a price is paid in terms of accuracy. Thus research into direct numerical simulation (DNS) methods that resolve all length and time scales is envisaged. Our group concentrates on improving numerical techniques (space discretization and time integration) with which the price of DNS can be reduced significantly. Additionally, steps towards mathematical-based LES modeling are made.

Progress

The central theme of the project is to model and simulate turbulence in such a way that the symmetry and conservation properties of the Navier-Stokes equations are preserved. The extension of symmetry-preserving discretization method to unstructured grids has been continued in cooperation with prof. Soria and dr. Trias (UPC, Barcelona). The symmetry-preserving regularization models have been applied to turbulent flow with heat transfer. A procedure for determining the regularization parameter has been worked out for this case (in which a unique physical length scale is lacking). Spatial filters for unstructed meshes have been studied. A novel eddy-viscosity model has been developed (as spin-off from the regularization modelling). The parallellization of the simulation code is further improved; an evaluation of parallel methods for solving the Poisson problem for the pressure is started.

Dissertations

-

Scientific Publications

1. F.X Trias, M. Soria, A. Oliva and R.W.C.P. Verstappen. Modelling and discretizing a turbulent differentially heated cavity at Ra=1011. In: Proc. EUROMECH Colloquium 504: Large Eddy Simulation for Aerodynamics and Aeroacoustics, Munich, (eds. M. Manhart and C. Brun) CDROM, 3 pages, 2009.
2. F.X Trias, A. Gorobets, R.W.C.P. Verstappen, M. Soria, and A. Oliva. Turbulent flow around a wall-mounted cube: direct numerical simulation and regularization modelling. In: Proc. 21st Int. Conf. Parallel Computational Fluid Dynamics, Moffett Field, California, USA, Elsevier, 6 pages, 2009.
3. F. X. Trias, M. Soria, A. Gorobets, and R. W. C. P. Verstappen. Parameter-free modelling of a turbulent differentially heated cavity with Ra-number up to 1011. In: Turbulence Heat and Mass Transfer 6, (eds. K. Hanjalic et al.), Begell House Inc., 12 pages, 2009.
4. F. X. Trias, R. W. C. P. Verstappen, M. Soria, and A. Oliva. Parameter-free symmetry-preserving regularization modelling of turbulent natural convection flows. In: Proc. 2th Int. Conf. On Turbulence and Interactions, Martinique, (CD-ROM) 7 pages, 2009.
5. R. Verstappen. When does eddy viscosity damp subfilter scales sufficiently? In: Proc. Quality and Reliability of Large-Eddy Simulations (QLES2009), (eds. M. Vittoria Salvetti et al.) Pisa (CD-ROM) 10 pages, 2009.

Projectleaders
RWCP Verstappen

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
AJA Kort, JA Helder, M Younas, RWCP Verstappen, AEP Veldman and FW Wubs

Cooperations
NLR, TUD, UT, Politechnical University of Catalunya (Barcelona, E), Imperial College London (UK), TU Muenchen (D)

Funded
NWO-Computational Science, NWO-GBE
1st - 2nd 100% 3rd -

Start of the project
1996

Information

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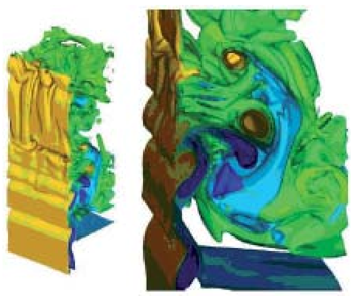
Iso-vorticity structures (color denotes pressure) in DNS of a thermal driven cavity at Rayleigh number 1011. The computations have been performed by dr. F.X. Trias (UPC, Barcelona) using a 4th-order symmetry-preserving discretization scheme



Simulation of hydrodynamic wave impact

Projectleaders
AEP Veldman
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
HJL van der Heiden, R Luppes, P van der Plas, AEP Veldman; B Duz (TUD), PR Wellens (TUD), RHM Huijsmans (TUD)
Cooperations
TU Delft, MARIN, Deltares, FORCE Technology (Norway), Hyundai Heavy Industries (Korea)
Funded
STW
1st - 2nd 100% 3rd -
Start of the project
1999
Information
AEP Veldman
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Project Aim

A fast-growing application area of our ComFlo simulation method is maritime technology. In close cooperation with MARIN and the offshore industry, focus is on hydrodynamic wave loading (green water, slamming) and sloshing in ship tanks.

Progress

The year 2009 marked the transition between the STW-funded free-surface projects ComFLOW-2 and ComFLOW-3 on hydrodynamic wave loading; main collaborators are TU Delft, MARIN, Deltares and FORCE Technology Norway. The new project started in autumn, with the appointment of a post-doc and the first PhD student; two more PhD students started early 2010. Emphasis in ComFLOW-3 is on modelling viscous effects (bilge keels, moonpools and side-by-side mooring), on improved generating and absorbing boundary conditions, and on improving numerical efficiency (local grid refinement, parallelization). For most of the year, dr. Moon from Hyundai Heavy Industries visited the group for further development of the ComFLOW functionality (hydroelasticity).

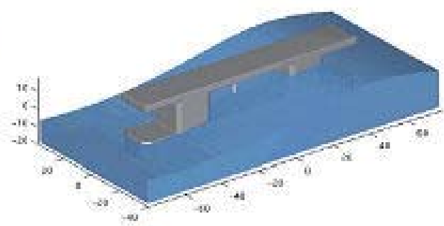
Dissertations

-

Scientific Publications

1. P.R. Wellens, R. Luppes, A.E.P. Veldman and M.J.A. Borsboom. CFD simulations of a semi-submersible with absorbing boundary conditions. In: Proc. 28th Conf. on Ocean, Offshore and Arctic Eng. OMAE2009, May 31-June 5, 2009, Honolulu, paper OMAE2009-79342.
2. R. Wemmenhove, B. Iwanowski, M. Lefranc, A.E.P. Veldman, R. Luppes and T. Bunnik. Simulation of sloshing dynamics in a tank by an improved Volume-of-Fluid method. In: Proc. ISOPE 2009, 1st Sloshing Dynamics and Design Symposium, Osaka, Japan, June 21-26 (2009) paper ISOPE2009-YHK-05, pp. 231-239.

The semi-submersible model in the experiment and the initial condition of a numerical simulation.



Numerical methods for the incompressible Navier-Stokes equations

Project Aim

The repeated solution of one or more systems of equations is part of any CFD method. Therefore the quest for improved matrix solvers is another major research area. A method (MRILU) is being developed that can cover a broad class of matrices: symmetric or non-symmetric, structured or unstructured.
A major application area is the modelling of flow patterns in global ocean circulation (with UU-IMAU). In particular, methods are sought to (artificially) accelerate the spin-up of ocean models, in order to bring the model in the state where the influence of the initial condition has vanished (equilibrium solutions).

Progress

In the research on sparse-matrix solvers a break through has been obtained. Based on the structure preserving direct method developed by de Niet and Wubs for Stokes flow problems, a two-level iterative structure preserving method has been constructed for Navier-Stokes flow problems (currently restricted to the Arakawa C-grid). The two-level method introduced has the following properties: (i) it is very robust, even close to the point where the solution becomes unstable; (ii) a single parameter controls fill and convergence; (iii) the convergence rate is grid independent; (iv) it can be parallelised in a natural way; (v) the matrix on the second level has the same structure as the original problem; (vi) the iteration takes place in the divergence-free space (`constraint preconditioner'); (vii) the approach can also be applied to Poisson problems. Wubs visited I.S. Duff (Rutherford Appleton Laboratory, Harwell), to incorporate our fill reducing orderings in the RAL codes.

Dissertations

-

Scientific Publications

1. E. Bernsen, H.A. Dijkstra and F.W. Wubs. Bifurcation analysis of wind-driven flows with MOM4. Ocean Modelling, 30 (2009) 95-105 (doi:10.1016/j.ocemod.2009.06.003).
2. A.C. de Niet and F.W. Wubs. Numerically stable {LDL^T}-factorization of {F}-type saddle point matrices. IMA J. Num. Anal. 29 (2009) 208-234 (doi:10.1093/imanum/drn005).
3. J. Thies, F. Wubs and H.A. Dijkstra. Bifurcation analysis of 3D ocean flows using a parallel fully implicit ocean model. Ocean Modelling 30 (2009) 287-297 (doi:10.1016/ j.ocemod.2009.07.005).
4. M. den Toom, F.W. Wubs and H.A. Dijkstra. Corrigendum to: A tailored solver for bifurcation studies of ocean-climate models. J. Comput. Phys. 228 (2009) 4962-4964 (doi:10.1016/j.jcp.2009.04.002).

Projectleaders
FW Wubs
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
J Thies, FW Wubs, HA Dijkstra (UU)
Cooperations
IMAU (UU), UL Bruxelles (B), TU Braunschweig (D), RAL (UK)
Funded
ALW
1st - 2nd 100% 3rd -
Start of the project
1994
Information

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Fluid-structure interaction in bio-fluidmechanics

Projectleaders
AEP Veldman
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
G Rozema, AEP Veldman,
NM Maurits (UMCG)
Cooperations
UMCG
Funded
RUG
1st 100% 2nd - 3rd -
Start of the project
1998
Information
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Project Aim

A special application of the RuG-developed ComFlo CFD method concerns the simulation of fluid-structure interaction. In particular, ComFlo is applied to solve problems in the field of hemodynamics (the flow of blood through distensible arteries) and artificial organs (in particular the design of voice prostheses).

Progress

This bio-medical fluid mechanics project studies cardio-vascular flow in elastic blood vessels and its relation with artherosclerosis (in cooperation with UMCG): an example of two-way fluid-structure interaction. An overall 0D model for the global blood circulation is being combined with a detailed 3D model of the flow in the arteria carotis. A highlight in the project is the numerical coupling approach, which is stable for all values of the physiological parameters.

Dissertations

-

Scientific Publications

-

Numerical bifurcation analysis

Project Aim

Research focuses on numerical methods to investigate stability and bifurcation behaviour of large-scale problems from our other research applications. Of particular interest are the stability of the global ocean circulation and of coherent structures in turbulent flow.

Progress

The numerical bifurcation analysis project, initiated by dr. Lust who has left the department in 2008, focuses on the computation of coherent self-sustained structures (unstable periodic solutions) in flow models in the turbulent regime. In this way a link with our turbulent flow research is established.

Dissertations

-

Scientific Publications

-

Projectleaders
FW Wubs

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
H Kırbaş, FW Wubs,
RWCP Verstappen, AEP Veldman

Cooperations
University of Leuven (B)

Funded
RUG
1st 100% 2nd - 3rd -

Start of the project
2004

Information
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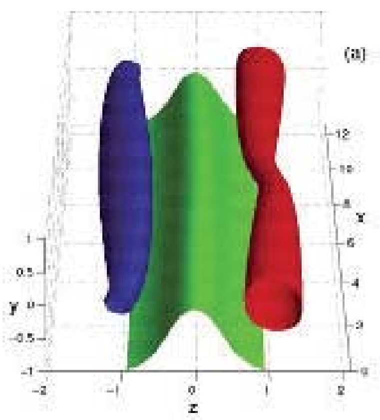
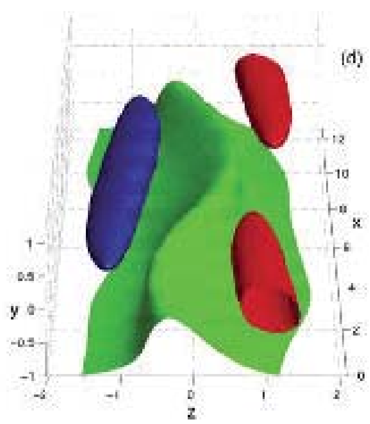
Bifurcation of streaky flow into self-sustained structures (computed by Frank Waleffe).





PROJECTLEADERS
AEP Veldman
RESEARCHTHEME
Mathematical and computational methods for fluid flow analysis
PARTICIPANTS
HA Bijleveld, AEP Veldman
COOPERATIONS
ECN
FUNDED
ECN
1st - 2nd - 3rd 100%
START OF THE PROJECT
2008
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PROJECT AIM

The project focuses on the aerodynamic optimization of turbine blades. The simulation approach builds on viscous-inviscid boundary-layer interaction. The numerical coupling between boundary layer and inviscid outer flow is similar to that used in the bio-medical project mentioned above.

PROGRESS

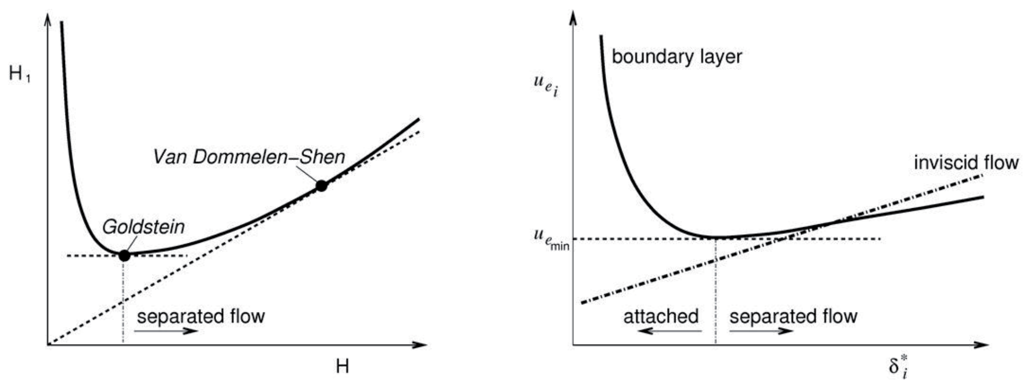
The project started in 2008. A detailed analysis has been made of steady and unsteady numerical descriptions for the interaction between boundary layer and outer flow. Hereto a model problem (indented plate) was defined, such that the analysis could focus on the singularities at the separation point (Goldstein) and deep inside the separated flow region (Van Dommelen-Shen).

DISSERTATIONS

-

SCIENTIFIC PUBLICATIONS

1. A.E.P. Veldman. A simple interaction law for viscous-inviscid interaction. J. Eng. Math. 65 (2009) 367-383 (doi:10.1007/s10665-009-9320-0).



Left: Relation between shape factors revealing singularities of Goldstein and Van Dommelen-Shen. Right: Schematic of boundary layer versus inviscid flow.

APPLIED MOLECULAR PHYSICS

Prof.dr. JJ ter Meulen

Prof.dr.ir. W van de Water

The Applied Molecular Physics group focuses on the development and application of sensitive laser diagnostics for the study of reactive and non-reactive processes. In addition, the group is involved in solid state and biophysics research.

The research program comprises the following projects:

(1) Laser diagnostics of the combustion process in a diesel engine

(2) Molecular distributions in flames

(3) Laser diagnostics of non-reactive flows

(4) Molecular dynamics in single collisions

(5) Chemical vapour deposition of diamond

(6) Laser diagnostics of neuronal processes in brain cells.

Of these the first three projects are most relevant for the JMBC research program.

(1) The aim of the diesel project is the development of laser based methods to measure local densities of nitric oxide (NO) and soot inside the combustion chamber of a realistic heavy duty truck diesel engine. The measurements, which should not disturb the combustion process, have to yield information about the spatial and temporal dependence of the produced nitric oxide and soot distributions in order to understand the complex chemical and physical processes that take place during the combustion. The final goal is to supply the engine manufacturers with relevant information in order to improve the diesel engine by a reduction of air polluting species, mainly NO and soot particles, in the exhaust gas. Various spectroscopic detection techniques are applied, such as Rayleigh and Raman scattering, Laser Induced Fluorescence (LIF) and Laser Induced Incandescence (LII), all in combination with 2D imaging techniques. The LII technique is applied to determine the size distribution of the soot particles. The results are used to validate the numerical models of the combustion process as developed by the TU/e group of Prof. R. Baert.

(2) In the flame research project non-intrusive laser diagnostic techniques are developed and applied to laminar flames in order to determine the local temperature and absolute molecular density distributions. Hereto the LIF technique is used in combination with Cavity Ring Down Spectroscopy (CRDS). In particular, the project focuses on the formation of NO and the effects on this by the addition of hydrogen to the fuel. The results are used to validate calculations by the group of Prof. L.P.H. de Goeij at the TU/e.

(3) Molecular Tagging Velocimetry is applied to write patterns of molecular tracers in air, and to follow their path in time, aiming for sufficient spatial and temporal resolution to resolve the smallest relevant scales in the flow. Photochemistry is used to create tracers in air, and spectroscopic methods, mainly Laser-Induced Fluorescence (LIF), are applied to visualize the tracer distribution after it has been modified by the flow. Turbulent flows are generated by air jets, either in a small free jet setup, or in a newly constructed pressure vessel. This project is a collaboration with the groups of Prof. W. van de Water (TU/e) and Prof. J. Westerweel (TUD).

Development and application of laser diagnostics for flame research

Project Aim

Laser-based detection techniques are developed and applied to study molecular density distributions in flames. The aim is to obtain quantitative information about spatial profiles of reactive intermediate species, in order to test numerical models using the Chem1D and Lamfla2D codes developed at the TU/e. Measurements are performed both in atmospheric and low-pressure flames, using Laser-Induced Fluorescence (LIF) and Cavity Ring-Down Spectroscopy (CRDS).

Progress

The experimental part of the work has focussed on the detection of NCN, as a hypothesized precursor for prompt NO. The molecule had been demonstrated earlier, but only in low-pressure flames. We succeeded to determine the NCN distribution in both CH4/NO2/N2 flames as well as in CH4/air flames, at up to atmospheric pressure. Also, we could show that Cavity Ring-Down measurements on NCN are 'polluted' by a significant contribution of formaldehyde. The distribution of NCN and related radicales was numerically modelled, by means of an extended version of the Konnov reaction mechanism. The qualitative agreement is good, quantitative experiments are in progress.

Dissertations

-

Scientific Publications

1. R.J.H. Klein-Douwel, N.J. Dam, J.J. ter Meulen, Detection of the NCN radical in low and atmospheric pressure flames, in Book of Abstracts 30th International Symposium on Free Radicals, Savonlinna, Finland, 25 - 30 July (2009).

Projectleaders
JJ ter Meulen

Researchtheme
Complex dynamics of fluids

Participants
NJ Dam, RJH Klein-Douwel

Cooperations
LPH de Goey, AA Konnov (TU/e)

Funded
STW
1st - 2nd 100% 3rd -

Start of the project
2006

Information

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Laser diagnostics of the combustion process inside a diesel engine

Projectleaders
JJ ter Meulen
Researchtheme
Complex dynamics of fluids
Participants
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Cooperations
RSG Baert, LMT Somers (TU/e)
Funded
STW
1st - 2nd 100% 3rd -
Start of the project
1991
Information
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Project Aim

Reliable, quantitative experimental data are a prerequisite for a better understanding of the combustion process in complex environments, like the combustion chamber of a heavy-duty truck Diesel engine. The aim of this project is to develop laser-diagnostics for the in-situ detection of chemical species concentrations and tempature fields. The emphasis has been on pollutant formation, mainly soot and nitric oxide (NO), combustion products that can be detected by means of Laser-Induced Incandescence (LII, for soot) and L-I Fluorescence (LIF, for NO). Attention recently shifted towards new, ultra-clean combustion concepts.

Progress

The main acitvities over the past year have been the completion of the thesis of Arjan Donkerbroek (defense in 2010), and the development of spectrally resolved toluene fluorescence thermometry for the determination of temperature inside a Diesel engine. The fluorescence spectrum of toluene is a function of local temperature. By simultaneously measuring the fluorescence in two wavelength bands, the temperature can be retrieved. An injection system has been designed and implemented, the method has been calibrated by means of motored engine runs, and measurements in the presence of fuel are in progress.

Dissertations

-

Scientific Publications

1. R.J.H. Klein-Douwel, A.J. Donkerbroek, A.P. van Vliet, M.D. Boot, L.M.T. Somers, R.S.G. Baert, N.J. Dam, and J.J. ter Meulen, Soot and chemiluminescence in diesel combustion of bio-derived, oxygenated and reference fuels, Proceedings of the Combustion Institute 32, 2817-2825 (2009). (doi:10.1016/j.proci.2008.06.140).
2. R.J.H. Klein-Douwel, P.J.M. Frijters, X.L.J. Seykens, L.M.T. Somers, R.S.G. Baert, Gas density and rail pressure effects on diesel spray growth from a heavy-duty common rail injector, Energy & Fuels, 23, 1832 - 1842 (2009). (doi: 10.1021/ef8003569).
3. M.D. Boot, P.J.M. Frijters, C.C.M. Luijten, L.M.T. Somers, R.S.G. Baert, A.J. Donkerbroek, R.J.H. Klein-Douwel, N.J. Dam, Cyclic oxygenates: a new class of second generation biofuels for diesel engines?, Energy & Fuels 23, 1808 - 1817 (2009). (doi: 10.1021/ef8003637).
4. A.J. Donkerbroek, A.P. van Vliet, L.M.T. Somers, P.J.M. Frijters, R.J.H. Klein-Douwel, N.J. Dam, W.L. Meerts, and J.J. ter Meulen, Time- and space-resolved quantitative LIF measurements of formaldehyde in a heavy-duty diesel engine, Combustion and flame 157, 155-166 (2009).
5. R.J.H. Klein-Douwel, N.J. Dam, J.J. ter Meulen, Unravelling NO formation in combustion: detection of NCN in flames, in Book of Abstracts Physics@FOM Veldhoven 2009, Veldhoven, The Netherlands, 20 - 21 January (2009).
6. A.J. Donkerbroek, A.P. van Vliet, R.J.H. Klein-Douwel, L.M.T. Somers, N.J. Dam, J.J. ter Meulen, Quantitative LIF measurements of formaldehyde in a heavy-duty diesel engine, in Book of Abstracts Physics@FOM Veldhoven 2009, Veldhoven, The Netherlands, 20 - 21 January (2009).

7. R.J.H. Klein-Douwel, A.J. Donkerbroek, A.P. van Vliet, M.D. Boot, L.M.T. Somers, R.S.G. Baert, N.J. Dam, J.J. ter Meulen, Biodiesel soot incandescence and NO emission studied in an optical engine, in: 7th International Symposium Towards Clean Diesel Engines TCDE 2009; Editor: C. Schulz, Aachen, Germany, 4 - 5 June (2009), pp. 65 - 67, CEUR Workshop Proceedings, ISSN 1613-0073, Vol-452 (http://ceur-ws.org/Vol-452/paper15.pdf).
8. R.J.H. Klein-Douwel, A.J. Donkerbroek, C.C.M. Luijten, M.D. Boot, L.M.T. Somers, N.J. Dam, J.J. ter Meulen, Spray growth of regular, synthetic, oxygenated and biodiesels in an optical engine, in 7th International Symposium Towards Clean Diesel Engines TCDE 2009; Editor: C. Schulz, Aachen, Germany, 4 - 5 June, pp. 91 – 93 (2009).

Writing in turbulent air

Projectleaders
JJ ter Meulen, W van de Water
Researchtheme
Complex dynamics of fluids
Participants
NJ Dam, M Mirzaei
Cooperations
-
Funded
STW, FOM
1st - 2nd 100% 3rd -
Start of the project
2002
Information
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Project Aim

Goal of this project is to study the velocity field in strong turbulence over the full relevant range of scales, that is, from the integral length scale down to the Kolmogorov scale. We use Molecular Tagging Velocimetry, writing a pattern into air by means of a strong laser beam. This pattern is followed in time by laser-induced fluorescence.

Progress

The measurements on the interplay between molecular and turbulent diffusion have been completed, and are in the process of being interpreted. Candidate phosphorescence molecules have one by one dropped out; it turns out that the phosphorescence lifetime under realistic experimental conditions is a limiting factor. Diffusion measurements have been performed using biacetyl as a phosphorescent tracer.

Dissertations

-

Scientific Publications

1. M. Mirzaei, Advances in Turbulence XII, in Proceedings of the 12th EuroMECH European Turbulence Conference, Marburg, Germany, 7-10 September (2009), Series Springer Proceedings in Physics, vol. 132 (2009).
2. M. Mirzaei, Advances in Turbulence XII, in Bulletin of American Physical Society, 62nd Annual Meeting of the APS - Division of Fluid Dynamics (APS-DFD), vol. 54, November (2009).

Granular and disordered media

Prof.dr.ir. ML van Hecke

The Granular and Disordered Media Group of Martin van Hecke investigates the slow flow and jamming of granulates, foams and macro emulsions. We focus on the interplay between mesoscopic organization and macroscopic flow features, and we combine video imaging with rheological measurements. We work closely together with the theory group of Vincenzo Vitelli. Topics we are currently woring on include the flow and yielding of agitated granular media, sound in sand and the fluctuating flow of foam.

Granular flow in split bottom geometries

Project Aim
Experimental work on granular flows in so-called split-bottom geometry.

Progress
There's a simple and general experimental protocol to generate slow granular flows that exhibit wide shear zones, qualitatively different from the narrow shear bands usually observed. The essence is to drive the granular medium not from the sidewalls, but to split the bottom of the container that supports the grains in two parts that slide pas each other. We have investigated the onset of rate dependence in dry grain flows, and in flows of particles submerged in fluids, where in the latter case a laser-sheet imaging technique gives access to the 3d organization of the grains. We have also investigated flows accompanied by weak vibrations.

Dissertations
1. J.A. Dijksman: Granular Media: Flow & Agitations. Leiden University December 1st 2009.

Scientific Publications

1. J.A. Dijksman and M. van Hecke: The role of tap duration for the steady state density of vibrated granular media. EPL 88, 44001 (2009).

Projectleaders
ML van Hecke

Researchtheme
Complex dynamics of fluids

Participants
JA Dijksman

Cooperations
-

Funded
FOM
1st - 2nd 100% 3rd -

Start of the project
2005

Information

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Flow of granular media

Projectleaders
ML van Hecke
Researchtheme
Complex dynamics of fluids
Participants
E Wandersman, K Nichol
Cooperations
-
Funded
FOM
1st - 2nd 100% 3rd -
Start of the project
2007
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Project Aim

These are two interconnected projects which probe the flow of weakly agitated granular media.

Progress

Granular media can mimic solids, as when a bowling ball rests on a sandy beach, but also easily made to flow, as in an hourglass. To capture both types of behavior, models for granular media assume that the internal stresses have to overcome a finite yielding threshold before the material flows – capturing the maximal slope of sand piles. However, obtaining a generally applicable relation between flow, applied stress and yield stress has remained elusive. Here we create a novel state of granular matter which combines a solid-like appearance with an absence of yield stress and a fluid-like response to external stresses, by locally shearing and stirring a layer of sand and probing its mechanical response in far-away regions where the material remains stationary.
Intruders placed into these far-away zones sink into the sand, and our results demonstrate that the yielding stress is zero here, just like in a simple fluid --- in complete disagreement with the classical view of granular media. We show that microscopic agitations of the grains caused by the far away flow drive strong fluctuations in the contact forces, thus effectively melting the network of contact forces and causing the material to yield. Both the far-away flow rate and properties of the probes determine their immersion rate. A paper will be published in PRL in 2010.

Dissertations

-

Scientific Publications

-

Critical scaling of foam slows: the dynamics of jamming

Project Aim

It has recently become clear that wet foams are one of the best experimental model systems to probe the dynamics of granular media near the so-called jamming point. It transpires from such studies that a suitable model system to probe the rheology of wet foams is in terms soft spheres with dynamic (viscous) friction. Motivated by these observations and recent insights in the area of jamming, the present project aims to answer three fundamental questions about model foams near jamming:

1. What are the scaling laws/functions that describe the dynamic jamming transitions.
2. What is the relation between these scaling laws and the non-affine flow of foam.
3. What are the diverging length and time scales near the jamming transition.

Progress

We have developed an analytical model for the scaling of stresses and fluctuations in flows near jamming. We probe flows of soft, vicious spheres near the jamming point, which acts as a critical point for static soft spheres. Starting from energy considerations, we find nontrivial scaling of velocity fluctuations with strain rate. Combining this scaling with insights from jamming, we arrive at an analytical model that predicts four distinct regimes of flow, each characterized by rational-valued scaling exponents. Both the number of regimes and values of the exponents depart from prior results. We validate predictions of the model with simulations.

Dissertations

-

Scientific Publications

-

Projectleaders

ML van Hecke

Researchtheme

Complex dynamics of fluids

Participants

E Woldhuis, BP Tighe, J Remmers, ML van Hecke, W van Saarloos

Cooperations

Joris Remmers, TU/e

Funded

FOM, UL

1st - 2nd 100% 3rd -

Start of the project

2008

Information

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PROJECTLEADERS
ML van Hecke
RESEARCHTHEME
Complex dynamics of fluids
PARTICIPANTS
Z Zeravcic, W van Saarloos, D Lohse
COOPERATIONS
This is a cooperation between the Leiden group and Lohse's group in Twente.
FUNDED
FOM
1st - 2nd 100% 3rd -
START OF THE PROJECT
2008
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PROJECT AIM

In the past few years intense experimental and theoretical studies of the dynamical oscillations of arrays of bubbles were done, since the understanding of how acoustic energy is propagating through these systems has many important applications in industry, medicine and oceanography. The dynamics of spherical bubbles, whose oscillations are driven by pressure waves is, governed by the Rayleigh-Plesset equation, expressed in terms of the dependency of the bubble radius on the conditions in the gas and liquid as well as the interaction with the surrounding bubbles. From this nonlinear equation we construct the so-called dynamical matrix for small amplitude excitations of the system and the study the localization behavior of the vibrations by introducing new methods which are motivated by earlier work on localization of vibrations in granular systems.

PROGRESS

Until now we have studied small hexagonal arrays of bubbles (~1500) with fixed boundaries. From the eigenvectors of the system we calculated the participation ratio P(w) which gives some insight into the localized character of the modes. We find that only the high-frequency modes show localized character. However, looking closely at these modes we found that they are modes localized on the boundary of the system and hence associated with the specific setup. We also looked at the excitability of the modes in the system. We found that ones that are excitable are the first few low-frequency and high-frequency boundary modes. This behaviour is also seen in the experiments done in Lohse's group – basically response of the bubble array to different kinds of excitations has strong signatures of the low and high frequency modes. The next step is to introduce disorder into the system; both spatial disorder as disorder in the interaction will be studied. A publication is in preparation.

DISSERTATIONS

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SCIENTIFIC PUBLICATIONS

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Mathematical Institute Leiden

Prof.dr.ir. B Koren

In Koren's Scientific Computing group (Leiden University and Centrum Wiskunde & Informatica, Amsterdam), advanced numerical techniques are developed. Applications are computational problems in fluid dynamics, magnetohydrodynamics and risk management. At present, emphasis lies on the development of:

- immersed boundary methods for flow computations around complex moving and/or deforming bodies,
- a computational method for wind-farm aerodynamics, and
- a numerical method for the Hamilton-Jacobi-Bellman equation, for the control of the heights of primary dikes in the Netherlands. Research has also been started on the investigation of:
- Edge Localized Modes in tokamak plasmas, by further development and application of computational tools.

Development of an immersed boundary method for the Euler equations

Project Aim

Development of an Euler-flow method, in which bodies of arbitrary shape and motion are immersed in a fixed, uniform, cartesian finite-volume grid, and in which the corresponding boundary conditions are embedded in the neighboring fixed-grid fluxes.

Progress

A new two-dimensional immersed-boundary algorithm for convection problems was proposed and analyzed. The computational domain is divided into equally sized, rectangular finite volumes that are fixed in space. The points of intersection of body boundaries, with cell faces, are detected. The boundaries are next approximated by straight line segments inside the cells, a single line segment per cell at a maximum. The cells that contain a boundary segment are identified and the boundary segment in it is aligned with the grid direction to which it is closest. The boundary conditions are embedded in the relevant fluxes in the immediate neighborhood. Test cases, such as, an infinitely thin model plate of arbitrary orientation, moving in a uniform 2D flow-field, and a unit model cylinder of arbitrary initial location, moving in a circular flow-field, have been studied. The work will be presented at the Institute for Computational Fluid Dynamics (ICFD) Conference, 2010, Reading, and at ECCOMAS CFD 2010, Lisbon.

Dissertations

-

Scientific Publications

1. Y. Hassen and B. Koren, A finite-volume method for convection problems with embedded moving boundaries, Proceedings Fifth International Conference on Computational Fluid Dynamics, Seoul, 2008, pp. 499-505 (H. Choi, H.G. Choi and J.Y. Yoo, eds.), Springer (2009).
2. Y. Hassen and B. Koren, Finite-volume discretizations and immersed boundaries, in: Advanced Computational Methods in Science and Engineering (B. Koren and C. Vuik, eds.), Lecture Notes in Computational Science and Engineering, 71, pp. 229-268, Springer (2009).

Projectleaders

B Koren

Researchtheme

Mathematical and computational methods for fluid flow analysis

Participants

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Cooperations

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Funded

TU Delft (DRC-CSE) and CWI

1st 50% 2nd - 3rd 50%

Start of the project

2006

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Development of a computational tool for the simulation of wind-farm aerodynamics

Projectleaders
B Koren
Researchtheme
Mathematical and computational methods for fluid flow analysis
Participants
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Cooperations
ECN and CWI
Funded
ECN and CWI
1st - 2nd - 3rd 100%
Start of the project
2008
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Project Aim

The Dutch government plans that a significant portion of the Dutch future energy need is to be produced by wind farms at the North Sea. A wind farm is a large set of wind turbines, often positioned in some matrix form. Various research questions still exist with respect to wind farms; economical, ecological and technological. A major technological question is how to position and design the separate wind turbines, such that the energy production of the wind farm as a whole is maximal. The goal of this project is to make a step towards answering this question.

Progress

After an initial investigation into vortex methods (2008), the focus has shifted to the use of finite- volume methods for the solution of the incompressible Navier-Stokes equations. Research has been performed on the use of so-called symmetry-preserving (or 'mimetic') methods for the accurate simulation of turbulence in wind-turbine wakes. Ongoing work is on high-order mimetic methods in combination with suitable boundary conditions. Another point of attention is the modelling of the turbine rotor, for which novel actuator-line methods are under development.

Dissertations

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Scientific Publications

-

Investigation of edge localized modes by further development and application of computational tools

Project Aim

Edge Localized Modes (ELMs) are disruptive magnetohydrodynamic (MHD) instabilities observed in torus-shaped fusion devices in which an extremely hot plasma is confined magnetically (tokamaks) for the eventual goal of energy production. The project aim is to develop and use a transient three-dimensional full MHD code to acquire a deeper understanding of the nonlinear development of ELMs. This is required to predict their impact on next-generation tokamaks, like ITER, and to find ways to control or trigger ELMs in an early stage of their development.

Progress

The project started in February 2010 with the investigation of ideal MHD equilibria and their stability. The main achievements are the extension of an analytical equilibrium solution including toroidal flow that already existed in literature, a systematic analysis of the stability of the continuous MHD spectrum in the presence of toroidal flow, and the discovery and analysis of low-frequency toroidal flow-induced Alfvén gap modes.

Dissertations

-

Scientific Publications

-

Projectleaders

B Koren, HJ de Blank

Researchtheme

Complex dynamics of fluids

Participants

JW Haverkort

Cooperations

FOM Institute for Plasma Physics "Rijnhuizen", CWI

Funded

FOM Institute for Plasma Physics "Rijnhuizen", CWI

1st 100% 2nd - 3rd -

Start of the project

2009

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Development and application of Immersed-Boundary Methods (IBM) and Induced Dimension Reduction (IDR) solution methods for convection-diffusion problems arising in engineering

Projectleaders
B Koren

Researchtheme
Mathematical and computational methods for fluid flow analysis

Participants
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Cooperations
Leiden University and CWI

Funded
Erasmus Mundus fellowship (50%)
CWI (50%)
1st - 2nd - 3rd 100%

Start of the project
2009

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Project Aim

Development of an immersed-boundary method to be applied to incompressible Navier-Stokes problems with moving and deforming boundaries. Bodies of arbitrary shape are immersed in a simple, fixed Cartesian grid, where the corresponding boundary conditions are embedded in the neighboring fluxes. A high quality and fast linear system solver is used: IDR(s), a member of the family of IDR methods.

Progress

Second-order accurate diffusive flux formulae with embedded boundary conditions were derived for one dimensional convection-diffusion problems. Using finite volumes, appropriate limiters and TVD restrictions for the convective term were taken into account. With implicit time integration, a system of equations is obtained. To efficiently solve this system, an IDR method, a new Krylov-projection-based solver, has been implemented and used. To guarantee convergence of the linear-system solvers, appropriate preconditioning and other linear-algebra techniques have been implemented and compared.

Dissertations

-

Scientific Publications

-

Experimental Zoology Group

Prof.dr.ir. JL van Leeuwen

The current main theme of the Experimental Zoology Group is the biomechanics and development of the locomotion and feeding system in fish and other vertebrates (such as amphibians, reptiles and horses), in an evolutionary perspective and in relation to animal welfare. Mechanisms of development, growth and adaptation are studied at several levels of structural organisation, from molecules to ecosystem. This integrates several research lines such as (1) architectural organisation and remodelling of muscle and skeletons in larval and juvenile fish and horses, (2) biofluid dynamics of swimming in larval fish, (3) effects of training on growth of the muscular system, signified by for instance molecular expression patterns, and (4) structural development and function of the equilibrium system. We have also an ecomorphology line of research that relates form and function at the organismal level to the actual niches and adaptive radiation in the natural enviroment.

The following research lines are carried out

1. Biomechanics of development in teleost fish
2. Biofluid dynamics of swimming and flight
3. Biomechanics of horses
4. Ecomorphology of cyprinid fish
5. Biomechanics of tongues and tentacles
6. Biomechanics of sensory systems and vocalisation
7. Biofluid dynamics of sponges

PROJECT AIM

We study vortex dynamic strategies of swimming and flying. In particular, we will determine whether animals tune their locomotory kinematics to exploit the dynamics of vortices to maximize performance and to simplify control. We will explore to what extent such strategies are adopted by zebrafish larvae and fruit flies, two established animal models that propel themselves in a similar fluid dynamic (Reynolds) regime. We aim to unravel the underlying vortex dynamic mechanisms to explore whether fish and insects exploit common vortex dynamic mechanisms.

PROGRESS

The first paper of 2009 explained how maple seed aerodynamics is very similar to that of insects and bats and was published as a Science report, featured on the cover. Two extended (tandem) papers on insect aerodynamics presented in a broad perspective with birds, bats, maple seeds and fish (and technical wings) appeared in the Journal of Experimental Biology (listed as one of the high-lights of the year). Finally a book chapter was published in a Springer book that explained how our work on insect aerodynamics has inspired the development of the DelFly micro air vehicle that flaps its wings like an insect. The PhD thesis was awarded with the Dutch Zoology Award and the Dutch Biophysics award. Finally the cover photo for the Science publication of Lentink became a finalist photography entry of the 2009 International Science and Engineering Visualization Challenge sponsored by NSF and Science.

DISSERTATIONS

1. D. Lentink (2008) Exploring the Biofluiddynamics of Swimming and Flight.

SCIENTIFIC PUBLICATIONS

1. Lentink, D.*, Dickson, W.B., van Leeuwen, J.L. and Dickinson, M.H. (2009). Leading-edge vortices elevate lift of autorotating plant seeds. Science 324, 1438 – 1440.
2. Lentink, D.* and Dickinson, M. H. (2009). Biofluiddynamic scaling of flapping, spinning and translating fins and wings. J. Exp. Biol. 212, 2691 – 2704.
3. Lentink, D.* and Dickinson, M. H. (2009). Rotational accelerations stabilize leading edge vortices on revolving fly wings. J. Exp. Biol. 212, 2705 – 2719.
4. Lentink, D.*, Jongerius, S.R. and Bradshaw, N.L. (2009). The scalable design of flapping micro air vehicles inspired by insect flight. In: Flying insects and robots. Eds: Floreano, D., Zufferey, J.-C.,Srinivasan, M.V. and Ellington, C., Springer.
5. Lentink, D.*, Dickson, W., van Leeuwen, J.L. and Dickinson, M.H. (2009) "A leading edge vortex slows down the descent of maple seeds" Annual Meeting of the Society for Integrative and Comparative Biology (SICB), Boston, USA.

PROJECTLEADERS
JL van Leeuwen, D Lentink

RESEARCHTHEME
Complex dynamics of fluids

PARTICIPANTS
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Prof.dr. H. Liu (Chiba)
Dr.ir. P Breedveld (TUD)

FUNDED
NWO ALW 817.02.012.
1st 5% 2nd 95% 3rd -

START OF THE PROJECT
Start PhD project: 2004
Start NWO ALW: 2007

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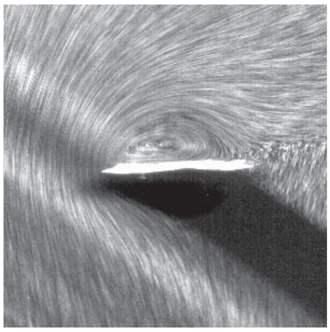

Institute for Marine and Atmospheric research Utrecht (IMAU)

Prof.dr. LRM Maas

Research in this theme focuses on the interactions between the water motion, sediment transport and bottom changes in coastal seas and estuaries. Both sandy and mud-dominated coastal systems are investigated. The following approaches are used to gain more understanding of hydrodynamic and morphodynamic processes: collection and analysis of field observations, simulations with complex numerical models and interpretation of these results, development and analysis of idealized mathematical models.

Internal wave patterns in 3D

Project Aim

Study of 3D internal wave patterns, both experimentally as well as theoretically. For this experiments have been carried out in tanks of different shapes, having simple and non-trivial stratification and by developing new tomographic observational tools.

Progress

The project has been virtually finished with the completion of a thesis (to be defended march 12, 2010 and the submission of a total of 6 papers.

Dissertations

-

Scientific Publications

-

Projectleaders
LRM Maas, A Doelman & S Dalziel

Researchtheme
Complex structures of fluids

Participants
J Hazewinkel, T Gerkema

Cooperations
CWI, Amsterdam,
DAMTP, Univ. Cambridge

Funded
NWO-Dynamics of Patterns program
1st 25% 2nd 50% 3rd 25%

Start of the project
2006

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Observational study of the equatorial boundary layer

Projectleaders
LRM Maas
Researchtheme
Complex structures of fluids
Participants
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Cooperations
-
Funded
NIOZ
1st 25% 2nd 50% 3rd 25%
Start of the project
2009
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Project Aim

The goal is to analyse existing data sets near the equator to bring understanding to the free boundary layer character. In particular the project aims at elucidating the role of internal gravity waves in driving (part of) the zonal equatorial current system and in establishing its impact on cross-equatorial transfer.

Progress

The project was started in September and the student has been reading literature on equatorial waves (both traditional and nontraditional theories).

Dissertations

-

Scientific Publications

-

List of Projects

COMPLEX DYNAMICS OF FLUIDS

Mathematical and Computational Methods for Fluid Flow Analysis

Complex Structures of Fluids

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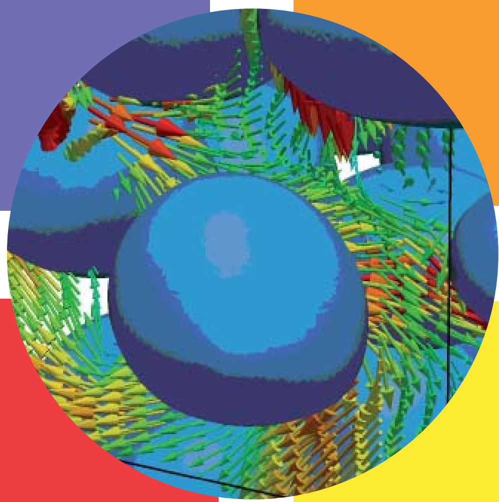

JMBC Annual Report & Research Programme
2009-2010