ERCOFTAC Summerschool

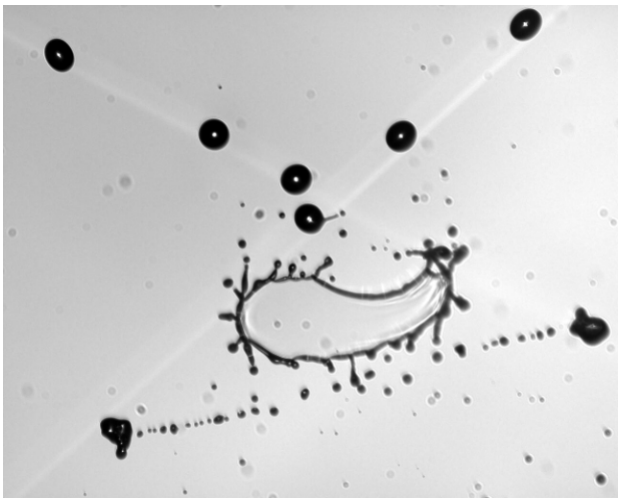
Modelling of Atomisation and Sprays for Technical and Industrial Applications

Prof. Dr.-Ing. Martin Sommerfeld

July 21 to 24, 2008

Halle (Saale), Germany

Mechanische Verfahrenstechnik
Zentrum für Ingenieurwissenschaften
Martin-Luther-Universität Halle-Wittenberg
D-06217 Merseburg, Germany



The art of droplet collisions

Aims of the Summerschool

The atomisation of liquids into small droplets and the resulting spray evolution is of great importance for a number of technical and industrial processes, as for example: spray combustion, spray coating, spray cooling, spray agglomeration, spray compaction and so on. Essential for producing a desired spray droplet size distribution is the atomisation of the liquid using different types of nozzles. The spray evolution is mainly governed by the nozzle geometry (initial condition) and aerodynamic transport. For analysing, optimising and designing spray processes increasingly numerical computations (CFD) are being used, also by industry. Industrial relevant processes are generally calculated based on the Reynolds-averaged conservation equations in connection with an appropriate turbulence model. For calculating two-phase flows extended approaches have to be used. The most known methods are the two-fluid (or Euler/Euler) approach and the Euler/Lagrange method. In the two-fluid approach to interpenetrating and interacting continua are considered resulting in two sets of conservation equations with similar structure, supplemented by the interaction terms. Multiple sets of conservation equations have to be used for resolving a spectrum of droplet sizes which is especially important for spray predictions.

The Euler/Lagrange method simulates the dispersed phase by tracking a large number of computational droplets. This approach is very attractive for predicting spray dispersion, however needs as an input the initial droplet size distribution. Both methods need to be extended appropriately for modelling all relevant elementary processes, such as liquid sheet or jet break-up, droplet interaction and collisions, droplet break-up and heat at mass transfer.

During the 4-day summerschool recent advances on the modelling and numerical prediction of sprays will be introduced. The areas to be covered in the summerschool are:

- Modelling of atomisation by different approaches
- Modelling of droplet break-up and collisions
- Modelling of droplet evaporation and combustion
- Numerical prediction and validation for spray processes
- Applications, such as sprays in engines, spray drying, spray cooling, spray coating

Additionally, lectures on recent advancements on single point spray measurements and imaging methods for spray analysis will be given.

Location

The summerschool will be held at the Martin-Luther-University Halle-Wittenberg, located on the Campus Heide in Halle/Saale, Von-Seckendorff-Platz 1 (building 38 on the map below). The lectures will be given in the lecture hall no. 5.09 and 5.10.

Registration

Early registration is strongly recommended (**no later than end of May 2008**). The full registration fee for the four-day course is 650 € and 500 € for ERCOFTAC members. The fee includes lecture notes, refreshments during the coffee breaks, Lunches and the summerschool banquet. No Mwst or VAT applies for the registration fee. After registration an invoice will be issued and send to the participant. Payment has to be made within 20 days by bank transfer. For cancellation of the registration before 30. May 2008 a handling charge of 50 € applies. Thereafter, the full fee needs to be paid.
Please send the attached registration form preferably by e-mail to:
carola.thomas@iw.uni-halle.de

ERCOFTAC fellowship

Young Ph.D. students (i.e. below 30 years) can apply for an ERCOFTAC fellowship by submitting their CV together with their Diploma certificate to the organiser by e-mail.

Office address, further information:

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e-mail: martin.sommerfeld@iw.uni-halle.de

Accomodation

It is suggested to select a hotel in the center of Halle (Saale). A list of hotels and the expected price range will be distributed upon registration.

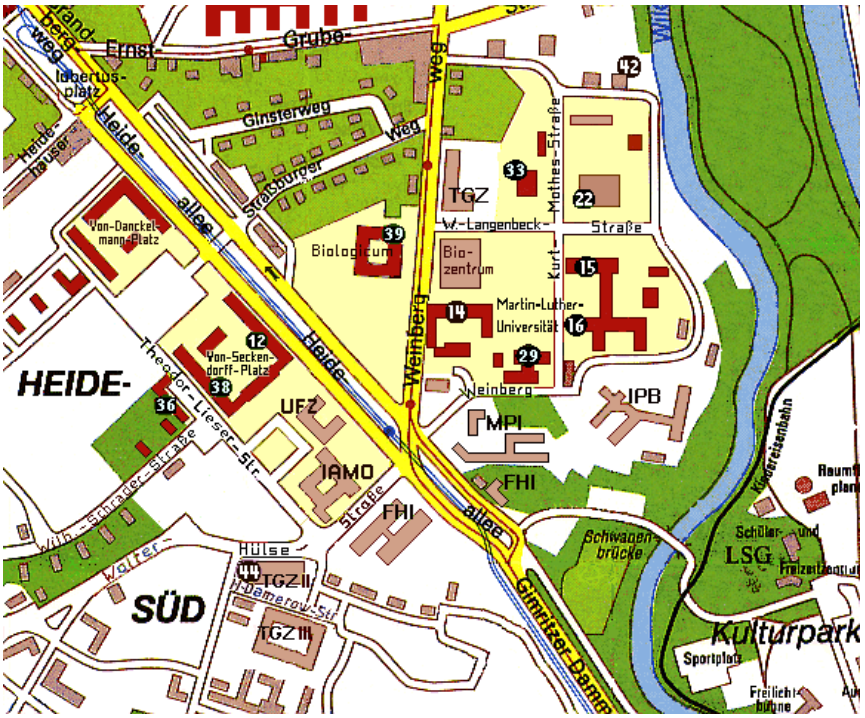
Travel information

By plane: The airport Leipzig-Halle is located about 40 km from Halle. Trains to Halle leave hourly and take about 15 minutes. From the station take a tram or taxi to your hotel.
By train: Halle Central Station can be reached by high-speed train from Frankfurt, Dresden, Nürnberg and Berlin. From the station take a tram or taxi to your hotel.
By car: Leave the motorway A14 at exit Halle-Trotha, and drive at the B6 direction Halle.

Travel to the meeting site

From Central Station take the tram number 4 or 5, direction Kröllwitz. You reach the campus in 10 – 15 minutes. Please leave the tram at tram stop Straßburger Weg.
From the city centre take the tram number 5, direction Kröllwitz, tram stop Markt or Hallmarkt. You reach the campus in 7 – 8 minutes. Please leave the tram at tram stop Straßburger Weg.

Map of the Campus Heide in Halle:



Legend:

Schedule of Lectures

Monday, 21. July 2008

8:30 – 9:00	Registration
9:00 – 9:30	M. Sommerfeld: Welcome, Introduction to the Summerschool
9:30 – 10:30	U. Fritsching: Spraying systems for different applications and empirical design
10:30 – 11:00	Coffee Break
11:00 – 12:00	A. Berlemont: Ghost Fluid methods: description and application on jet atomization (I)
12:00 – 13:00	A. Berlemont: Ghost Fluid methods: description and application on jet atomization (II)
13:00 – 14:00	Lunch Break
14:00 – 15:00	D. Bothe: VOF simulations of atomisation
15:00 – 16:00	M. Sommerfeld: Euler/Lagrange-approach for spray calculations
16:00 – 16:30	Coffee break
16:30 – 17:30	O. Simonin: Eulerian PDF-modelling of dispersion and evaporation of sprays

Tuesday, 22. July 2008

8:30 – 9:30	F.-X. Demoulin: Numerical simulation of the atomisation and primary break-up: The ELSA-model.

9:30 – 10:30	O. Soriano: Validation of a cavitation and turbulence induced model for primary break-up of diesel jets
10:30 – 11:00	Coffee Break
11:00 – 12:00	O. Simonin: Towards LES of Sprays
12:00 – 13:00	S. Horender: Modelling of droplet/spray evaporation
13:00 – 14:00	Lunch Break
14:00 – 15:00	P. Villedieu: Multi-component droplet evaporation
15:00 – 16:00	P. Villedieu: Modelling of droplet/spray impingement on cold and hot walls
16:00 – 16:30	Coffee break
16:30 – 17:30	M. Sommerfeld: Modelling of droplet collisions
19:00	Summerschool banquet

Wednesday, 23. July 2008

8:30 – 9:30	O. Simonin: Modelling of droplet collisions in the multi-fluid approach
9:30 – 10:30	S. Stübing: Collisions of highly viscous droplets and structure modelling
10:30 – 11:00	Coffee Break
11:00 – 12:00	M. Sommerfeld: Lagrangian modelling of droplet break-up

12:00 - 13:00	G. Lavergne: Spray ignition
13:00 – 14:00	Lunch Break
14:00 – 15:00	N. Damaschke: Single-point measurements in sprays
15:00 – 16:00	N. Damaschke: Imaging methods for droplet spray analysis
16:00 – 16:30	Coffee break
16:30 – 17:30	U. Fritsching: Modelling and simulation of the spray-forming process

Thursday, 24. July 2008

8:30 – 9:30	G. Lavergne: Prediction of sprays in combustion systems
9:30 – 10:30	S. Blei: Numerical prediction of spray drying processes
10:30 – 11:00	Coffee Break
11:00 – 12:00	J. Domnick: Use of CFD to estimate the film thickness in electrostatically supported spray painting
12:00 – 13:00	Summary and discussion
13:00 – 14:00	Lunch Break
14:00	End of Summerschool

Lecturers at the Summerschool

Prof. Dr. Alain Berlemont: His research activities have been developed in CORIA-UMR6614, where more than 150 people are involved in different topics, such as combustion, two phase flows, plasmas, turbulence, sprays, dynamical systems and instabilities, measurement techniques, all with experimental and simulation activities. His main topics of interest were:

- Lagrangian modeling of dispersed turbulent two phase flows
- Two way coupling between particles and turbulence
- Lagrangian modeling of droplet vaporization
- Two way coupling between vaporizing droplet and turbulence, momentum, energy and heat transfers between both phases
- Particle collisions in turbulent flows

Now developing level set method for interface tracking for coalescence/ break up of droplets and atomization of liquid jets. Set up of 3D computer code with Level Set / Ghost Fluid / VOF coupling under MPI parallelization

Dr. Stefan Blei is working as Senior Research Engineer at BASF AG Ludwigshafen since April 2005. Before this activity he finished his PhD in the field of spray drying and particle agglomeration at the Martin Luther Universität Halle Wittenberg, chair for Mechanical Process Engineering (Prof. Dr.-Ing. Martin Sommerfeld). His current activities are, among others, concentrated on the following topics:

- Design and Scale up of solids processes specificely in the field of drying technology.
- Process development work in the fields of superabsorbent polymers and catalysts.
- Design of drying related process steps for different polymer brands of BASF.
- Work in the fields of belt dryers, contact dryers, dryer towers, spray dryers.

Prof. Dr. Dieter Bothe is head of the chair „Mathematics (CCES)“ since 2006 at RWTH Aachen University. The chair is part of the recently founded “Center for Computational Engineering Science” of which Prof. Bothe is also the Vice-Director. Further, he is a founding member of the Jülich Aachen Research Alliance (JARA) which has been founded in 2007 in scope of the German Excellence Initiative. Prof. Bothe got his Ph.D. in Mathematics in 1993 at University of Paderborn and habilitated in Mathematics on *Nonlinear Evolution Equations and Reaction Diffusion Systems* in 2000 at the same University. He is an assigned member of the VDI-GVC committees

Multiphase Flows and *Mixing processes* and a member of the *German Mathematical Society* (DMS) and of the *American Mathematical Society* (DMS). His current research topics are

- Nonlinear Evolution Problems: Existence and Qualitative Theory
- Reaction-Diffusion Systems: Nonlinear Diffusion, Electromigration, Instantaneous Reaction Limits
- Two-Phase Flows: Modelling, Analysis and Volume of Fluid Simulation.
  - Hydrodynamics of Drops and Bubbles
  - Influence of Soluble Surfactants
  - Reactive Mass Transfer in Gas-Liquid Flows
- Passive / Reactive Flow Mixing in Microsystems

Prof. Dr.-Ing. Nils Damaschke is chair holder of „Optoelectronics an Photonic Systems“ at the Institute of General Electrical Engineering at the University of Rostock since April 2006. His research activities are in the field of optical and optoelectronic sensors, with a focus on spectroscopy, velocity measurement techniques and optical measurement techniques for fluid mechanics. The following topics are currently under investigation

- Development of spatial filtering technique for velocity measurement of surfaces, flows and fluxes and for surface structure characterisation by using array sensors with on-chip pre-processing
- Development of specialized systems for three dimensional determination of flow velocities by using concepts of laser Doppler technique, particle image velocimetry and defocused particle images
- Investigation of innovative in-situ optical sizing techniques of individual particles by using femtosecond pulses, imaging techniques and principles of phase Doppler, time-shift technique and laser induced incandescence.
- Spectroscopic absorption technique for characterisation of exhaust gases.

Dr. François-Xavier Demoulin is assistant professor at the University of Rouen, France. He passed his PHD under the direction of Pr. Borghi at the University of Marseille in 1999 on the subject: Contribution to the modeling of turbulent combustion in two-phase flows. Since, he has been working in collaboration with automotive industries to improve the accuracy of models used to simulate engines. His current research activities are on the following topics:

- Development of atomisation models dedicated to the primary break-up, the so-called ELSA model

- Detail numerical analysis of turbulent-spray interaction including evaporation and mixing
- Development of turbulent combustion models

Modelling of supercritical combustion for rocket engines application

Prof. Dr.-Ing. Joachim Domnick is Professor for Process and Application Systems in Organic Coating in the Faculty for Applied Sciences at the University of Applied Sciences Esslingen. Since more than 20 years he is involved in experimental and numerical investigations on the field of two-phase flows. His current activities include:

- Experimental and numerical investigations of process technologies related to coating systems, such as spray coating, drying and spray booth flows
- Modelling of atomization processes in coating, including rotary atomization and atomization of non-Newtonian liquids and suspensions
- Investigations of particulate two-phase flows (powder coating) related to dosing, conveying and application
- Health and safety issues in coating processes

Prof. Dr.-Ing. Udo Fritsching is head of the research group "Multiphase Flow with Heat and Mass Transfer" within the Institute for Materials Science IWT in Bremen and Professor in the Chemical Engineering Department of the University of Bremen. The research activities in the multiphase flow group are mainly focussed on processes for the producion, handling and conditioning of dispersed media like droplets, particles, and powders including:

- description of dispersed multiphase flow processes with heat and mass transfer
- analysis of particle - fluid interactions and particle - particle interactions
- phase change analysis in dispersed media (evaporation, solidification, boiling, ...)
- analysis of spray processes, description of liquid fragmentation processes, powder production by atomization of liquids, solutions, and melts
- investigation of fluid flow and heat transfer in materials processing and engineering.

The investigations are based on experimental and numerical modelling and simulation techniques. Process analysis is performed to obtain economical and ecological suitable process routes and set-up or optimize engineering processes with dispersed phases.

Dr. Stefan Hbrender joined the group of Prof. Sommerfeld in 2003. He received his PhD from Imperial College in 2003 and has been working on multiphase flow measurements and predictions since 1996. His current research activities are concentrated on the following topics:

- Experimental analysis of multi-phase flows using optical instrumentation, such as flow visualization, digital image analysis and phase-Doppler anemometry.
- Development of numerical methods for the prediction of dispersed turbulent multi-phase flows.
- Application of Computational Fluid Dynamics for design and optimisation of industrial processes involving multi-phase flows such as spraying systems, spray dryers and processes for or based on nano-particle production.

Prof. Gérard Lavergne teaches Propulsion and Energetics at SUPAERO/ISAE, the top graduate "Grande École" school of Aeronautics and Space (Science), in Toulouse, France. He is also a research director at ONERA Toulouse. His research is focused on the field of two-phase flows and combustion in propulsion systems such as ramjets, turbojets, rocket propellers and piston engines. His research team is well known for the modelling of the main physical processes in combustors, namely

- primary and secondary liquid-sheet breakup
- droplet / wall (cold and hot) interaction, including shear-driven liquid film modelling
- mono-component and multi-component droplet evaporation
- spray ignition under high-altitude conditions
- droplet interactions in dense sprays (evaporation, collision, etc.)

These theoretical and empirical models are first validated on fundamental experiments, then integrated in CEDRE-SPARTE, the ONERA Euler-Langrange numerical code, for further validation on more complex configurations in test facilities operating under real conditions.

Prof. Dr. Olivier Simonin is senior engineer at the research and development division of EDF in Paris and Professor at the Institut National Polytechnique de Toulouse (INPT). Prof. Simonin is well known for his research in the following topics:

- Utilization of gaseous turbulence Direct Numerical Simulation (DNS) and Large-Eddy Simulation (LES) approaches coupled with discrete particle simulation (DPS) to study particle-turbulence, particle-particle and particle-wall interactions in dilute dispersed particulate flows.

- Development of joint fluid-particle PDF approach for stochastic Lagrangian and n-fluid Eulerian modelling of reactive gas-particle turbulent flows
- Development of Euler-Euler LES approach for gas-particle turbulent reactive flows based on the mesoscopic particle velocity formalism
- Development of n-fluid Eulerian modelling of gas-solid fluidized beds with particle transport properties modified by turbulence influence and interstitial gas friction effects. 3D unsteady simulation of reactive circulating and dense fluidized beds at laboratory, pilot and industrial scales

Prof. Dr.-Ing. Martin Sommerfeld is head of the chair „Mechanical Process Engineering“ at the Martin-Luther-University Halle-Wittenberg since October 1993. He is known for his contributions to multiphase flow measurements, modelling and numerical prediction. His current research activities are, among others, concentrated on the following topics:

- analysis of fundamentals in dispersed multi-phase flows (using DNS and Lattice-Bolzmann methods, as well as high-resolution experiments) with the aim of developing physical models for describing relevant transport phenomena
- detailed experimental analysis of multi-phase flows using modern optical instrumentation, such as flow visualization combined with digital image analysis and phase-Doppler anemometry
- development of numerical methods for the prediction of dispersed multi-phase flows
- application of numerical methods for design and optimisation of industrial processes involving multi-phase flows, such as, stirred vessels, spraying systems and spray dryers, pneumatic conveying and cyclones, bubble columns and loop reactors and processes for nano-particle production.

Dipl. Ing. Oscar Soriano works as development engineer for VDO Automotive AG in the Continental Corporation. His main activity in the company is the three-dimensional simulation of multiphase flows both for Eulerian and Lagrangian frame of reference for several components of injection systems like injector and pump. The main area of interest of his work is the injection nozzle and the spray formation. He studied engineering science in Spain at the University of Cartagena with specialisation in the field of fluid mechanics. In 2003 he moved to Germany to write his master thesis on the development of the sac-hole pressure of Diesel injection nozzles. During the next four years he carried out research on Diesel spray atomization under engine conditions and its link to the flow inside the

injection nozzle. At the present time he is working on his Ph.D. focusing on the mentioned topic in collaboration with the University of Halle-Wittenberg.

Dipl.-Ing. Sebastian Stübing is PhD-student at the chair "Mechanical Process Engineering" at the Martin-Luther-University Halle-Wittenberg since March 2005. He studied Environmental-Process-Engineering at TU Clausthal from 1999 until 2005. In 2003 he was research student at the Department of Chemical and Nuclear Engineering at Polytecnical University of Valencia (Spain). Sebastian Stübing did his Diploma-thesis about the fluiddynamical behaviour of a new reactor packing at the institute "Separation and Process Technology" of the TU Clausthal.
His current research activities are:

- Lagrangian modelling of agglomerate structures
- Experimental investigation of the collision behaviour of highly viscous suspension droplets
- Investigation of adhesive forces in electrostatical precipitators
- Experimental investigation of particle-particle collisions in spray-dryers

Besides that he did some projects with industrial partners concerning:

- Optimization of the fluid-flow inside a spray-dryer
- Development of an electrostatic precipitator for the food industry.

Dr.-Ing. Philippe Villedieu is senior scientist in the Multiphase Flow Research Unit of ONERA and associate professor at the National Institute of Applied Science (INSA) of Toulouse. He is the author of numerous publications on multiphase flow modelling and is responsible for the development of the ONERA Lagrangian solver for sprays simulation. His current research activities are, among others, concentrated on the following topics:

- development of new Eulerian models based on the moment approach and quadrature methods,
- development of models and efficient numerical methods for multi-component droplet evaporation,
- development of Lagrangian models for hailstones (or droplet) / wall interactions,
- spray ignition,
- LES of reactive two-phase flows.