Droplet Dynamics under Extreme Boundary Conditions: The Collaborative Research Center SFB-TRR 75

B. Weigand *, C. Tropea**
* Institut für Thermodynamik der Luft- und Raumfahrt, University of Stuttgart, Germany, bernhard.weigand@itlr.uni-stuttgart.de
**Fachgebiet Strömungslehre und Aerodynamik, Center of Smart Interfaces, Technische Universität Darmstadt, Germany, ctropea@sla.tu-darmstadt.de

Abstract

Processes involving droplets play a central role in both nature and in engineering applications. While some of these examples and applications can be extremely complex, they can often be well understood in terms of very basic drop dynamic processes, which is also the first step to improvements and/or optimization. The Collaborative Research Center (CRC) SFB-TRR 75 was established in January 2010 to focus on research about such basic drop processes, but in particular on those processes involving extreme boundary conditions, for example, near thermodynamic critical conditions, very low temperatures, under strong electric fields or in situations involving extremely large gradients of boundary conditions.

Researchers from the University of Stuttgart, the Technische Universität Darmstadt and the DLR at Lampoldshausen participate in this CRC, coming from various departments, including Mathematics, Chemistry, Electrical Engineering, Mechanical Engineering and Computer Sciences. The goal is to gain a better physical understanding of the essential processes as a basis for new analytical and numerical descriptions, thereby leading to an improved prediction of large systems in nature or in technical applications. This contribution gives an overview of the projects being pursued at the SFB-TRR 75 and highlights scientific results from the first two years of operation. The main purpose of the paper is to familiarize colleagues with this extensive and dedicated research effort in the area of drop dynamics and to motivate and initiate future collaboration with others in the field.

Introduction

Drops and drop dynamics are ubiquitous, often even going unnoticed by observers. However, one must bear in mind that droplets are found not only in nature, e.g. in clouds, fog, rain, or spindrift, but also in many engineering systems e.g. in gasoline or Diesel engines, gas turbines, aero-engines, rocket engines, spray cooling processes, chemical reactors, or agricultural sprays. Being so common an occurrence, scientists have been interested in the description of droplets since long ago. The behaviour of fluids under the influence of surface tension has been studied in the 19th century for instance by Plateau [1] and Lord Rayleigh [2], who studied the formation of droplets from a liquid jet. For naturally occurring drop systems the book of Pruppacher and Klett [3] and for engineering systems the book of Lefebvre [4] can be considered seminal works. On the one hand publications in this field deal with more or less complex large natural or engineering systems; on the other hand with basic droplet phenomena and processes. However, in most cases the studies are under moderate ambient conditions. Being more difficult to perform, experimental and/or numerical studies for extreme boundary conditions are rare; hence processes under such extreme conditions are far less understood. Extreme boundary conditions include for instance an ambient electrical field or high temperatures or pressures. Nevertheless, systems under extreme ambient conditions often play an important role in many natural and engineering applications. As an example, droplets in high clouds are super-cooled or during thunderstorms droplets are under high electrical fields. In Diesel and rocket engines droplets are injected under supercritical conditions or during droplet impact on solid walls high gradients are found near the three phase contact line. Due to the lack of information about droplets under extreme ambient conditions the SFB-TRR75 has been established to study the basic physical processes involved, understanding that these studies are very difficult and complex and cannot be conducted by any one single research group.

Therefore, a network with research groups from different disciplines and which exchanges experience and knowledge on a regular basis is required, and this has led to the collaborative research center (CRC) SFB-TRR75. In this CRC basic studies of the physical processes lead to models for the description of droplet phenomena, which can then be used in numerical or analytical descriptions of complex natural or engineering systems. In the following sections the structure and some examples of the work within the SFB-TRR75 are presented.

The Collaborative Research Center (CRC) SFB-TRR75

The SFB-TRR75 consists of 15 sub-projects which are clustered into three main areas as shown below, together with the responsible researcher(s):

Research Area A: Methods and Fundamentals

- TP-A1: Interactive Visualization of Droplet Dynamics (T. Ertl, F. Sadlo)
- TP-A2: Development of Numerical Methods for the Simulation of Compressible Droplet Dynamics under Extreme Ambient Conditions (C.D. Munz)
- TP-A3: Analysis and Numerics of Front- and Phase Field Methods for Droplet Dynamics (C. Rohde)
- TP-A4: Molecular Dynamics Simulations of Droplet Evaporation in the Non-linear Response Regime (F. Müller-Plathe, N. van der Vegt)
- TP-A5: Simulation of the Mechanical Deformation and Movement of Droplets on Polymer Insulation Surfaces with Strong Electric Fields (T. Weiland, E. Gjonaj)
- TP-A6: Non-equilibrium Thermodynamics of Boundaries: Application of the Density Functional Theory to Mixtures of Polar Substances (J. Groß)

Research Area B: Free Droplets

- TP-B1: Investigation of the Behavior of Super-cooled Droplets Concerning Evaporation, Condensation and Solidification for Different Boundary Conditions (B. Weigand, N. Roth)
- TP-B2: Experimental Investigations of Droplet Evaporation under Extreme Conditions with high Resolution Laser Diagnostic Methods (G. Lamanna, A. Dreizler)
- TP-B3: Modelling and Simulation of Droplet Evaporation in Foreign-Gas Environment under Transcritical Conditions (A. Sadiki, J. Janicka)
- TP-BX (Associated Project): Experimental Investigation of Transient Injection Phenomena in Rocket Combustion Chambers under High Altitude Conditions with Special Focus on Flash-Evaporation (C. Manfletti, M. Oschwald)

Research Area C: Droplets with Wall-Interactions

- TP-C1: Numerical Simulation of the Transport Phenomena for Droplet-Wall Interaction on Hot Walls with special Focus on the Three-Phase Contact Line (T. Gambaryan-Roisman, P. Stephan)
- TP-C2: High Resolution Measurements for the Heat Transfer during Droplet-Wall-Interactions with special Focus on the Three-Phase Contact Line (P. Stephan, T. Gambaryan-Roisman)
- TP-C3: Droplet-Wall Interactions of Super-cooled Droplets on Cold Surfaces (S. Jakirlic, C. Tropea)
- TP-C4: Droplet-Wall Interactions for Hot Surfaces and High Ambient Pressures (I. Roisman, C. Tropea)
- TP-Z: Administration of the SFB-TRR 75 (B. Weigand)

In **Research Area A** numerical and analytical methods are developed which are pre-requisites for conducting the work in the other research areas. Methods for visualization are developed in TP-A1. TP-A2 and TP-A3 are concerned with the development of numerical methods. In TP-A4 basic droplet dynamic processes are investigated by molecular thermodynamics. In TP-A5 simulations of the mechanical deformation and movement of droplets on polymer insulation surfaces with strong electric fields are investigated. TP-A6 investigates the non-equilibrium thermodynamics of interfaces. Here the classical density functional theory is applied to mixtures of polar substances. All projects in **Research Area A** contribute fundamental results to **Research Area B** and **Research Area C**. In **Research Area B** droplets free of solid boundaries are investigated. In TP-B1 droplet dynamics problems involving sub-cooled droplets in clouds and the formation of ice crystals in clouds are investigated. TP-B2 investigates experimentally the evaporation of droplets under extreme thermodynamic conditions. The modelling and simulation of droplet evaporation in a foreign-gas environment under transcritical conditions is investigated in TP-B3, whereas the associated project TP-BX investigates flash evaporation for the transient injection of propellant in a rocket combustion chamber. In **Research Area C** droplet-wall interactions are investigated. In TP-C1 and TP-C2 special focus is set on the three-phase contact line during droplet-wall interaction. In TP-C3 droplet-wall interactions are investigated for sub-cooled droplets on cold surfaces and in TP-C4 droplet-wall interaction is investigated for hot surfaces under high ambient pressures. The administration of the CRC is embedded in TP-Z and within this project a vigorous guest scientist program involving a large number of invited speakers from all over the world is organized. For further information, the reader is referred to www.sfbtrr75.de.

Selected Results

Below, some selected results from the first two years of the CRC and from the three research areas are given.

Research Area A: Methods and Fundamentals

TP-A1: T. Ertl, F. Sadlo, G. Karch, Visualization Research Center, University of Stuttgart

Visualization is becoming omnipresent in science and engineering, supporting the data analysis process from the exploration of simulated or measured data, to the extraction of hidden structures therein, to validate and verify new models. Although visualization techniques have found their way into many commercial and academic software packages, these techniques are rather limited regarding visualization research and the demands in the respective fields. This impedes rapid exploration of data and validation and is one of the reasons why visualization research is such a rapidly growing branch of science, busy to catch up with the disciplines that produce the data together with the respective research questions.

This sub-project plays various roles within the CRC. Since the drop dynamics are addressed both experimentally and by simulation, one aspect is the integration of these two fields. This is provided by visual analysis methods that can be applied in each of the fields separately with subsequent comparison of the results, or directly by comparative visualization. Furthermore, visualization serves as a basis for communication within the projects as well as to the outside. A main focus is on the development of dedicated visualization methods for visualization of the physical drop specific mechanisms, such as advection-diffusion processes and the spatio-temporal structure of features. One focus of the work is therefore placed on the size and intricacy of the time-dependent data and their representation, necessitating appropriate approaches and the use of parallelization on multi-GPU-clusters. A further goal is the development of visualization techniques that directly visualize higher order p- and hp-adaptive simulation data. Due to their piecewise analytic representation, these data cannot be investigated with standard visualization techniques, and resampling would induce computational overhead and reduced visualization quality. Feature extraction is a prominent example where approaches based on resampling achieve poor results. The extraction of iso-surfaces, ridges, and vortex core lines has therefore been of core interest. Visualization of higher order (discontinuous Galerkin) data requires dedicated techniques with emphasis on accuracy and efficiency [5]. So far a technique for visualizing of iso-surfaces has been developed [6] and for extracting line-type features such as *vortex core lines* and *ridge lines* from higher order data [7]. Besides providing an accurate view of higher order data, these techniques can also be applied to traditional discretized data, where continuity is established by means of interpolation, providing an exact visualization of the resulting representation.

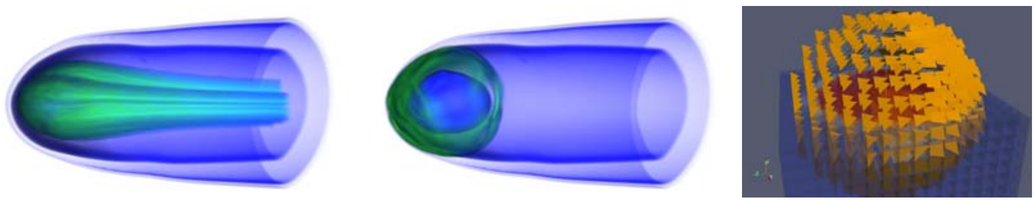


Figure 1 Evaporating drop with dye advection (green) visualizing advection-diffusion (left) and passive diffusion only (center). Preliminary visualization of PLIC interfaces in the simulation of a droplet (right).

This supports both development and detailed inspection of simulation techniques as well as visualization algorithms. Since droplets lack a clear interface under extreme ambient conditions, volume rendering, possibly combined with geometric features such as iso-surfaces and ridges, will become a central tool in the CRC. A GPU-based raycasting technique for time-dependent data that is able to integrate geometric representations has been developed. This was a primary building block for an extensive project on the visualization of advection-diffusion processes. The virtual dye model not only accounts for advection but also for diffusion with respect to both the concentration of simulated quantities such as vapor and the concentration of the virtual dye itself (see Figure 1 (left, center)). Advection-diffusion processes occur in multiple roles within the CRC. Currently a technique for visualizing Piecewise Linear Interface Calculation (PLIC) interfaces is being developed (Fig. 1 (right)). This work will shed light onto simulation modeling with PLIC.

TP-A5: T. Weiland, E. Gjonaj, H. Songoro, Institute of Theoretical Electromagnetic Fields, Technische Universität Darmstadt

An application example of particular interest for the power supply industry is the numerical modeling of water droplets on the surface of outdoor high voltage insulator systems based on polymeric materials. Such systems are exposed to permanent environmental stresses and are thus subject to damage and significant aging effects. Among the most important environmental factors, water droplets are deposited on the surface of the insulators by rain or dew. The high voltage field in the vicinity of these conductive droplets can be amplified by several orders of magnitude through their presence. Thus, local partial electrical discharges as well as electrical flashover may occur, which in the long term leads to the deterioration of the electrical insulation characteristics of the polymer-

ic surface and consequently to the insulation systems breakdown and electrical equipment's premature maintenance and/or replacement [8]. The computation of electric field stresses due to droplet-like wet pollution layers in high voltage insulators is therefore of paramount importance for the design and optimization of these devices.
The main challenge in the simulation process is the modeling of the time dependent motion and deformation of the droplet's shape under the influence of the high voltage field. These deformations strongly modify the electric field distribution in the vicinity of the droplet and especially along the contact line. It is necessary for the analysis to apply a coupled solution procedure including fluid dynamics as well as electric field simulations.
The electric field modeling is based on the numerical solution of the transient electro-quasi-static problem with a higher-order accurate finite element method [9]. For the discretization of the droplet geometry an unstructured curvilinear tetrahedral mesh is employed. The electric field distribution obtained in this simulation step provides the dielectric forces acting on the droplet and causes the time dependent deformation of the droplet geometry. For the solution of the Navier-Stokes equations, the well-established volume-of-fluid method for incompressible fluids is used. This simulation step provides the deformation of the droplet geometry, which in turn is responsible for the modification of the electric field distribution in the vicinity of the droplet. However, for coupled droplet simulations several additional modeling steps are necessary. These include the incorporation of electrical forces into the fluid dynamics solver, the dynamic adaption of the unstructured mesh to the time dependent droplet geometry, as well as a mesh correction procedure which is applied in every time step of the simulation. A detailed description of these approaches can be found in [9, 10]. Using the above procedure, first simulation results including the self-consistent computation of the droplet's deformation under the influence of high voltage fields were obtained [10]. The test problem consists of a 20µl water droplet mounted on a silicon rubber block. The driving electric field is generated by two planar electrodes which are operated with an alternating voltage at 50 Hz. The effective field strength corresponds to an electrical stress of 500 kV/m, which is typical for high voltage insulation systems. For this configuration, high frame rate video recordings obtained at the High Voltage Lab of the TU Darmstadt are available (http:// www.hst.tu-darmstadt.de). Figure 2 shows snapshots of the water droplet at three different time instants. In comparison, the droplet shape and hydrostatic pressure obtained in the simulation at the same time instants are shown. Obviously, the numerical simulation is fully capable of reproducing the correct oscillatory motion of the droplet under the influence of the high voltage field.

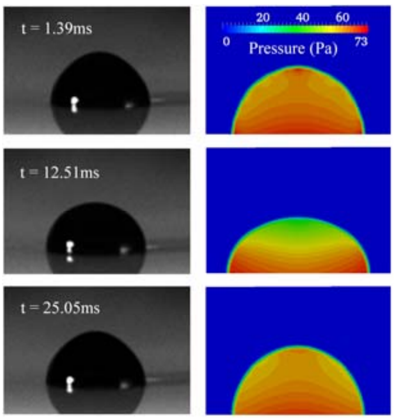


Figure 2 Comparison between measurement and simulation. Left: deformation of a water droplet under the influence of a high voltage field at three different time instants as recorded by a high-speed camera. Right: droplet shape and hydrostatic pressure resulting from a fully coupled electric field and fluid dynamics simulation.

Research Area B: Free Droplets

TP-B1: B. Weigand, N. Roth, D. Bonin, K. Eisenschmidt, P. Rauschenberger, Institute of Aerospace Thermodynamics, University of Stuttgart
The behavior of super-cooled droplets is studied experimentally and numerically. Super-cooled droplets refer to droplets which remain in the liquid state below the freezing temperature and such droplets are encountered for instance in clouds. The experimental study of the freezing process under realistic conditions is difficult. Indeed such studies are really only feasible using a plane, carrying instruments to measure data inside clouds. As such flights are expensive; a method to simulate the freezing process inside clouds has to be developed. The aim here is to characterize the freezing process experimentally, using light scattering techniques and developing an experiment to be able to detect the start of the freezing process, its speed, the size of the initial liquid droplet, its temperature and evaporation rate. To realize such measurements, a chamber has been developed, which is shown in Fig. 3. A droplet is injected into it and is optically levitated by a laser beam from below. Saturated air at ambient

temperature is injected at the top of the cooling chamber, the air is cooled when moving down into the chamber, reaching the lowest temperature close to the center. However, as the bottom of the chamber is open to the ambient, the temperature in the chamber exhibits a U-shaped profile (red curve in Fig. 3). Moving the droplet up or down by moving the levitating optical lens will result in a change of its temperature. In this way the freezing process inside the chamber can be controlled. The light scattered by the droplet is collected by CCD cameras at different angles and interpreted to yield size, temperature, freezing instant and all further required parameters.

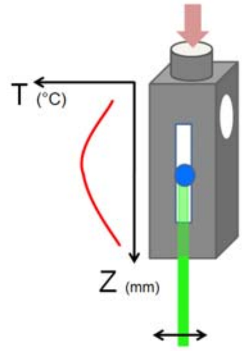


Figure 3 Experimental setup

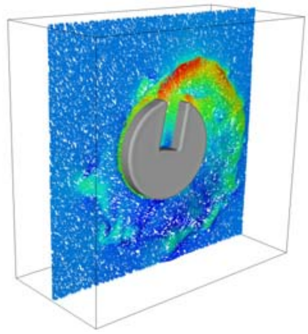


Figure 4 Disc rotating at constant angular speed in water.

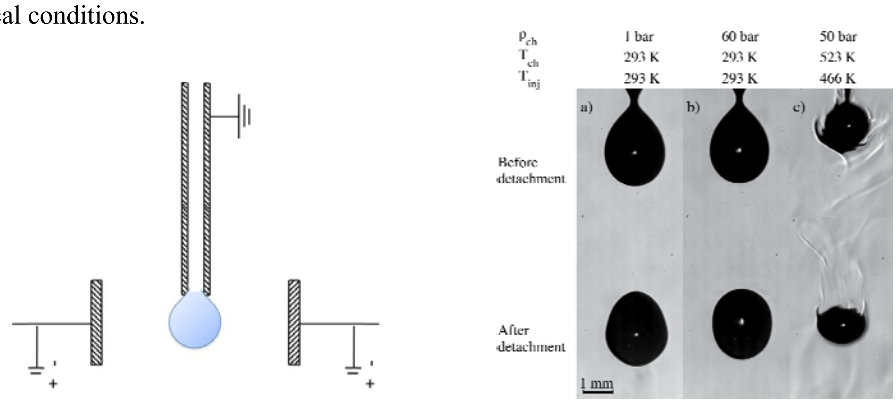
The code for the numerical investigations on freezing of super-cooled liquid droplets is the ITLR in-house code FS3D (Free Surface 3D), which is a code for direct numerical simulations (DNS) of incompressible multiphase flow. FS3D has been extended to the treatment of three phases [11] to simulate ice crystals, liquid water and air in the atmosphere. As another prerequisite for the numerical examination of freezing processes a module for rigid body motion was implemented into FS3D. The method differs from others in that it works completely within an Eulerian framework. The ability to preserve the shape of the rigid body was demonstrated on several test cases [12]. As an example, a disc with a cut-out and suspended in water, rotating at a constant angular velocity is presented in Fig. 4. The code is able to preserve its shape very well. The method was also validated against experimental values of the terminal velocity of free falling rigid spheres with very good accordance.

Now that the necessary numerical requirements are met, the simulation of the actual growth of ice particles is tackled. For this, the energy equation in temperature form can be used with only very few modifications. The phase change is currently being implemented. This comprises the computation of the enthalpy source due to solidification or melting and the mass source in the continuity equation. There are two major challenges. The first is the identification of cells in which a phase change must take place and the other is the distribution of solid (ice) in neighbor cells, if the production exceeds the remaining volume in the phase change cell. Both are crucial for the crystal morphology. A nucleation model will predict the rates of nucleation and the radius of the nuclei. So the number of nucleation events in each time step as well as the location inside the droplet can be determined.

TP-B2: G. Lamanna*, A. Dreizler, F. Weckenmann*, B. Bork**, *Institute of Aerospace Thermodynamics, University of Stuttgart, **Center of Smart Interfaces, Technische Universität Darmstadt**

Liquid droplet vaporization in supercritical environments and the tools for predicting its evolution are of significant interest in combustion science and technology. At these conditions, the drop may experience a thermodynamic transition to a supercritical state at its outer edge if the heat transfer from the surroundings prevails over the vaporization process. As a result, the process exhibits many characteristics distinct from subcritical vaporization, as typically observed at low-pressure conditions, thereby rendering conventional approaches and models invalid. In order to provide a database for model validation, this project follows a precise rationale. First, a novel drop-on-demand generator was developed to enable the reliable discharge of drops at near critical conditions. Second, two techniques are under development, capable of distinguishing between liquid and supercritical regions within the droplet. Third, different spectroscopic techniques will be analyzed to assess their applicability to the transcritical and supercritical regime. Hereafter the most relevant results attained so far are summarized.

The drop can be preheated up to 95% of its critical temperature and is anchored to a capillary by exploiting wettability effects. In order to control the detachment process and generate well-defined droplets, a technique has been developed whereby an external electric field is shortly imposed on the droplet to trigger the detachment process. The basic principle of the technique is that the charge distribution within the droplet is influenced by the external electric field, which decreases the effective surface tension and produces an external electric force. A schematic of the system is shown in Fig. 5 (a). During operation, particular care is taken to assure that the droplet is not charged upon detachment. A few examples of drop detachment are shown in Fig. 5 (b). The experiments exhibited very good reproducibility for droplet injections with identical test conditions. The droplet diameter and time of detachment have, in unheated chamber conditions and up to 60 bar, a reproducibility error of less than 1% and 0.5 ms, respectively. When the chamber is additionally heated, the shadowgraph images show dark regions around the droplet, presumably of gaseous or supercritical acetone. This prevents an accurate determination of the droplet size. Judging from the visual data, the droplet detachment process is still fairly reproducible under near-critical conditions.



(a) (b)

Figure 5 (a) Schematic of the droplet generator; (b) Droplets generated at different conditions, with two snapshots of each. The snapshots correspond for all three images to 0.5 ms before and 28 ms after droplet detachment

Two complementary techniques are considered for determining the presence of a gas/liquid interface within the liquid droplet, namely Planar Laser Induced Fluorescence and Phosphorescence (PLIFP) and light scattering in the framework of Fraunhofer and Rayleigh-Gans approximation. Hereafter the discussion will be limited to the PLIFP method. PLIFP working principle is based on the characteristic of acetone fluorescence and phosphorescence upon excitation with ultraviolet light. Both fluorescence and phosphorescence are found in the absence of oxygen; however, small concentrations of oxygen are sufficient to decrease the phosphorescence signal significantly, while leaving the fluorescence nearly unchanged. This characteristic of PLIFP will be exploited to differentiate between liquid and gaseous regions of the acetone droplet. Because diffusion of oxygen molecules within acetone is much faster if the acetone is gaseous or under supercritical conditions compared to the liquid phase, the liquid kernel of an acetone droplet will be characterized by the emission of phosphorescence and fluorescence whereas the acetone vapor shows fluorescence only. The potential of planar laser induced fluorescence and phosphorescence (PLIFP) of acetone were investigated in a calibration cell. A dye laser tuned to 320 nm was found to be a good compromise regarding absorption and penetration of the laser light in the droplet, as shown in Fig. 6 (a). Furthermore, a detailed study of the required oxygen concentration for a successful suppression of phosphorescence was performed. The results are shown in Fig. 6 (b). As can be seen, even small amounts of oxygen (≤ 2%) are sufficient for quenching phosphorescence effectively.

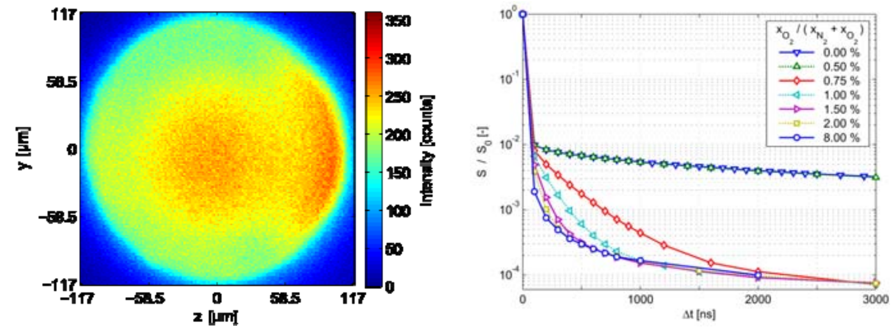


Figure 6 (a) Fluorescence of an acetone droplet excited 320 nm. Laser light enters the droplet from the left side.; (b) Fluorescence/Phosphorescence decay curves for different O_2-concentrations.

TP-BX (Associated Project): C. Manfletti, M. Oschwald, DLR, Institute of Rocket Propulsion, Lampoldshausen

Liquid rocket space propulsion applications cover a wide range of initial combustion chamber conditions varying from sea level pressures to near-vacuum pressures. In addition, propellants used vary from hypergolic propellants, which are liquid at sea-level ambient temperatures to propellants which are liquid at cryogenic temperatures. Upper stage liquid rocket engines as well as RCS (Reaction and Control System) and OMS (Orbital Manoeuvring System) engines are such engines which operate in extremely low pressure (high altitude) ambient conditions and pressures in the combustion chamber prior to the start-up of the engine (opening of the main propellant valves) are near vacuum. Depending on the engine cycle and propellant types and cycling of the engine, its start-up varies greatly. A phenomenon which is invariably encountered during this phase is flashing or flash-evaporation of the liquid propellant. This evaporation is due to the fact that the injection temperature of the liquid is above its ambient saturation temperature. The difference between these two temperatures is defined as the level of superheat [13]: $\Delta T_{\sup} = T_{inj} - T_{sat,a}$. The level of superheat defines the quality of flashing that will occur. It is important to note that flashing is not limited in occurrence to the combustion chamber but may occur as far upstream as the main propellant valves. In Figure 8 a series of Schlieren images depict the injection of liquid

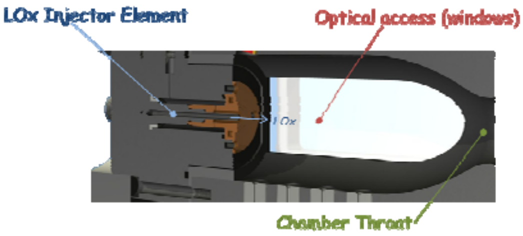


Figure 7 RCS Combustion Chamber

oxygen (LOx) as oxidiser, via a coaxial injector element, into a RCS combustion chamber (as shown in Figure 7) evacuated to approximately 30 mbar using the M3.1 test bench vacuum facility. The feed pressure and temperature are 3 bar and 90 K. The first image depicts a void chamber whereas the last image depicts a strongly flashing oxygen jet with an injection angle of >180°. The process shown is priming during which flashing, as a function of the valve opening sequence and downstream geometry, greatly varies.

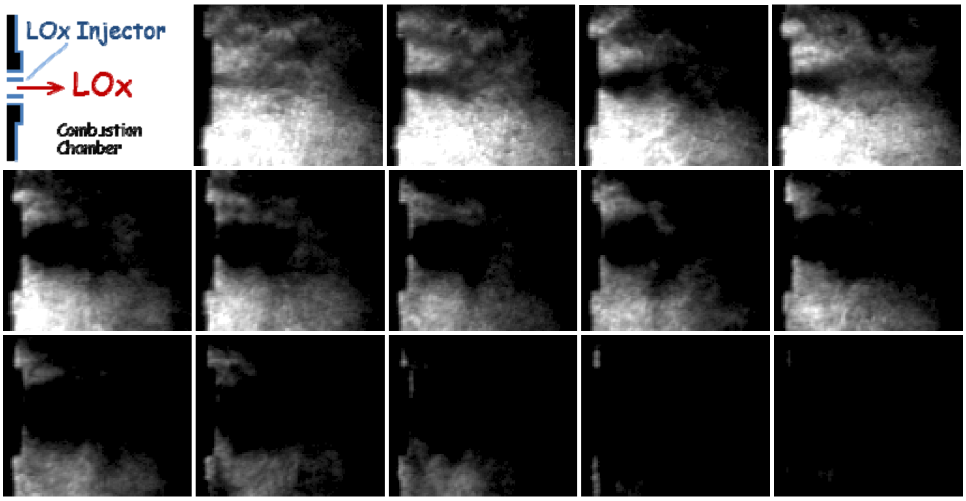


Figure 8 Schlieren image series of liquid oxygen flashing during the start-up/priming transient

Testing of LOx priming has been so far conducted using a standard coaxial injector element. Future studies aim at a study on the effect of $T_{\sup}$ and injector pressure drop on flashing using a dedicated injector head.

Research Area C: Droplets with Wall-Interactions

TP-C2: P. Stephan, T. Gambaryan-Roisman, S. Fischer, Technische Universität Darmstadt

Droplet impact on a hot surface is an important phenomenon for numerous applications. When the surface temperature is above the liquid saturation temperature but below the Leidenfrost temperature, the heat transfer to the droplet depends on the droplet hydrodynamics and on the heat and mass transfer in the vicinity of the three-phase contact line. In order to develop detailed models for droplet impact hydrodynamics and heat transfer, the three-phase contact line is studied experimentally using high-speed infrared thermography coupled with high-speed black and white imaging at a frame rate of 1000 Hz. Experiments have been performed investigating drop impact of the refrigerant FC-72 in a saturated vapor atmosphere onto a heated surface. The heater design consists of two sputtered layers on an infrared transparent calcium fluoride glass [14]. While the first layer increases the surface emissivity to achieve a better signal-to-noise ratio of the IR thermography, the second layer serves as heating layer. The thickness of both layers is approx. 400 nm each, allowing the measurement of highly resolved temperature fields (resolution of approx. 30 µm/pixel) very close to the heater/fluid interface. From the temperature fields, the heat flux distribution is calculated solving the differential equation of Fourier's law on a numerical grid within the heater substrate and patching in the temperature fields as transient boundary conditions. Prior to the experiments the test cell has been filled with vapor of the experimental fluid, which was kept at saturation temperature through a temperature controlled loop flowing through the test cell walls. Droplets were generated by re-condensation of the fluid at a slightly sub-cooled syringe positioned above the heater. By this method the droplet generation is purely Bond number controlled, resulting in highly reproducible droplet diameters (983 µm ± 18 µm) and impact Weber and Reynolds numbers. In Figure 9, the black and white image, the temperature field and the calculated heat flux distribution are shown exemplary 9 ms after drop impact, when the largest spreading of the droplet is reached. It can be seen, that high heat fluxes in close proximity of the 3-phase contact line lead to a local temperature drop of the substrate. These high heat fluxes are generated by evaporation and micro convection that transports cold liquid to the heater surface.

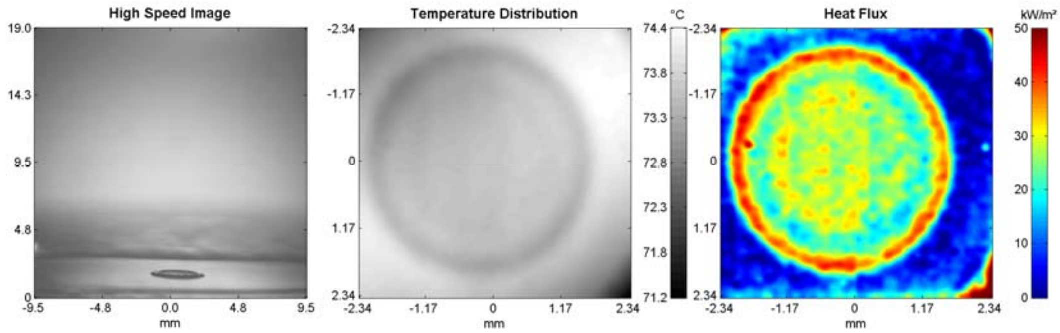


Figure 9 Image (left), temperature field (center) and heat flux distribution (right) 9ms after drop impact of an FC-72 droplet (t_{sat} = 56.14 °C, t_{vapor} = 56.29 °C, Re ≈ 2040, We ≈ 65)

Summary and Conclusions

In 2010, the Collaborative Research Center SFB-TRR75 was started, including 15 subprojects carried out at the University of Stuttgart, Technische Universität Darmstadt and DLR Lampoldshausen. The main goal of the CRC is the investigation of droplet dynamics under extreme ambient conditions. The nature of the investigated problems leads to strong interactions between the individual sub-projects. First sample results from this CRC demonstrate the progress achieved over the last two years.

Acknowledgements

The members of the SFB-TRR 75 would like to thank the Deutsche Forschungsgemeinschaft (DFG) for the funding of the SFB-TRR 75.

References

[1] J.A.F. Plateau. *Statique Expérimentale et Théorique des Liquides Soumis aux Seules Forces Moléculaires*.Gauthier & Villars, Paris (1873).
[2] Lord J.S.W. Rayleigh F.R.S. On the instability of jets. *Proc. London Math. Soc.*, Vol. 10, pp. 4-13 (1878).
[3] H.R. Pruppacher and J.D. Klett. *Microphysics of Clouds and Precipitation*. Reidel Publ. , Dordrecht (1978).
[4] A.H. Lefebvre. *Atomization and Sprays.* Combustion: An International Series. Hemisphere Publishing Corporation, New York (1989).
[5] F. Sadlo, M. Ueffinger, C. Pagot, D. Osmari, J. Comba, T. Ertl, C.-D. Munz and D. Weiskopf. *Computing in Science Engineering*, 13(3):84 –91 (2011).
[6] C. Pagot, J. Vollrath, F. Sadlo, D. Weiskopf, T. Ertl and J. Comba. Interactive isocontouring of high-order surfaces. In *Dagstuhl Follow-Ups* (2011).
[7] C. Pagot, D. Osmari, F. Sadlo, D. Weiskopf, T. Ertl and J. Comba, *Comp. Graphics Forum*, 30(3):751–760 (2011).
[8] T. Braunsberger, S. Iova, V. Hinrichsen and M. Kurrat. *XVI International Conference on Gas Discharges and their Applications*, Xi’an, China, September (2006).
[9] H. Songoro, E. Gjonaj and T. Weiland. *International Conference on Electromagnetics in Advanced Applications (ICEAA)*, September 2011: 1-4 (2011).
[10] T. Weiland, E. Gjonaj and S. Koc. ETG-Fachbericht, Vol. 131, *Feldsteuernde Isoliersysteme*, VDE Verlag, Berlin, Offenbach: 47-55 (2011).
[11] K. Eisenschmidt, P. Rauschenberger and B. Weigand. *ILASS - Europe*, Estoril (2011).
[12] P. Rauschenberger, J. Schlottke, K. Eisenschmidt and B. Weigand. *ILASS - Europe*, Estoril (2011).
[13] R.Lecourt, P. Barricau, J. Steelant. *Atomization and Sprays* 19(2):103-133 (2009).
[14] S. Fischer, S. Herbert, A. Sielaff, E. M. Slomski, P. Stephan and M. Oechsner, *Microgravity Sci. Technol.S.I. Gravitational Effects on Liquid:* DOI 10.1007/s12217-011-9273-6 (2011).