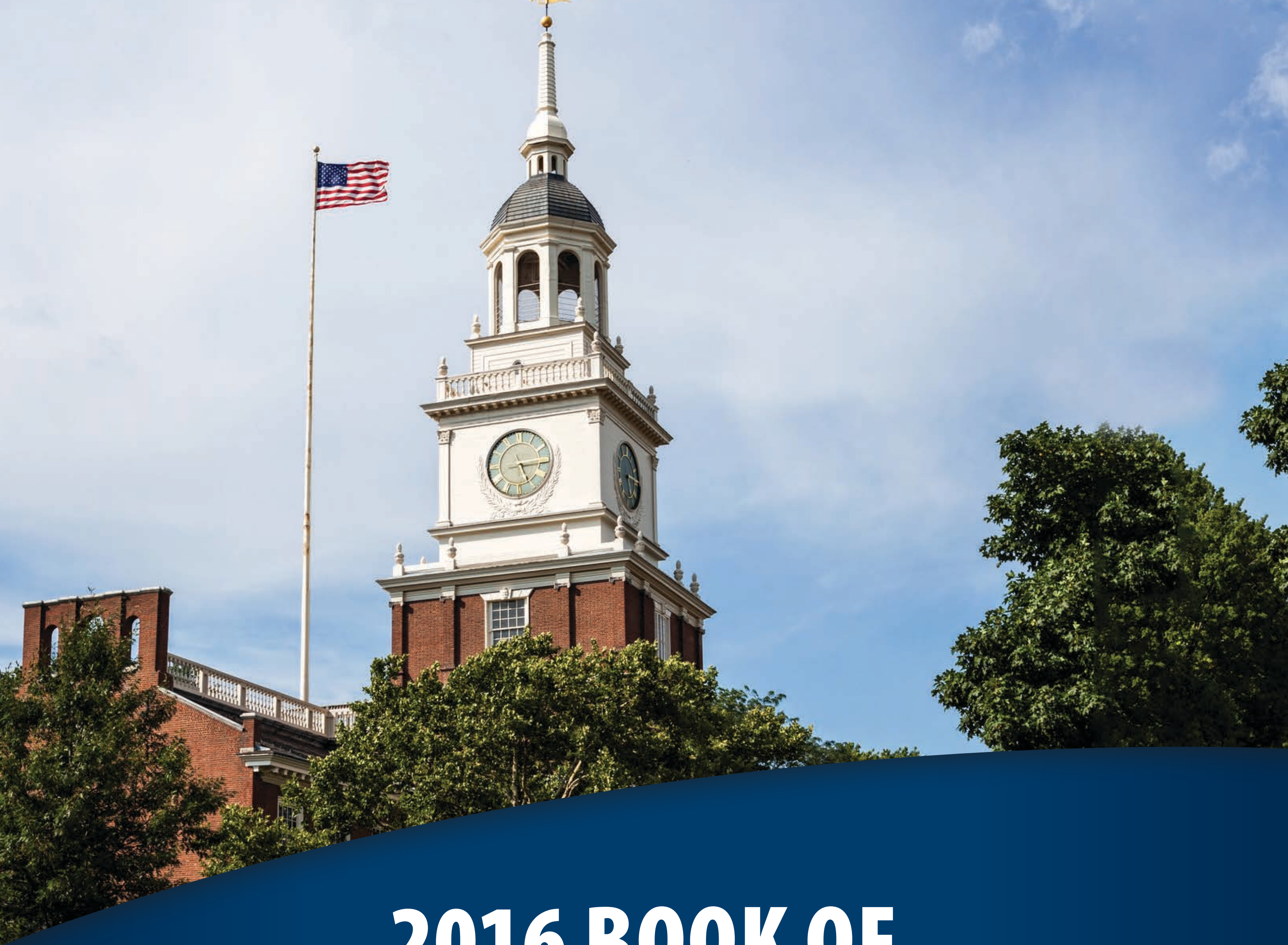
ILASS-Americas

Institute for Liquid Atomization and Spray Systems

28th Annual Conference



2016 BOOK OF ABSTRACTS

May 15 - 18, 2016 | Dearborn, MI

Henry Hotel

Table of Contents

ILASS-Americas

Institute for Liquid Atomization and Spray Systems

ILASS-Americas
Institute for Liquid Atomization and Spray Systems

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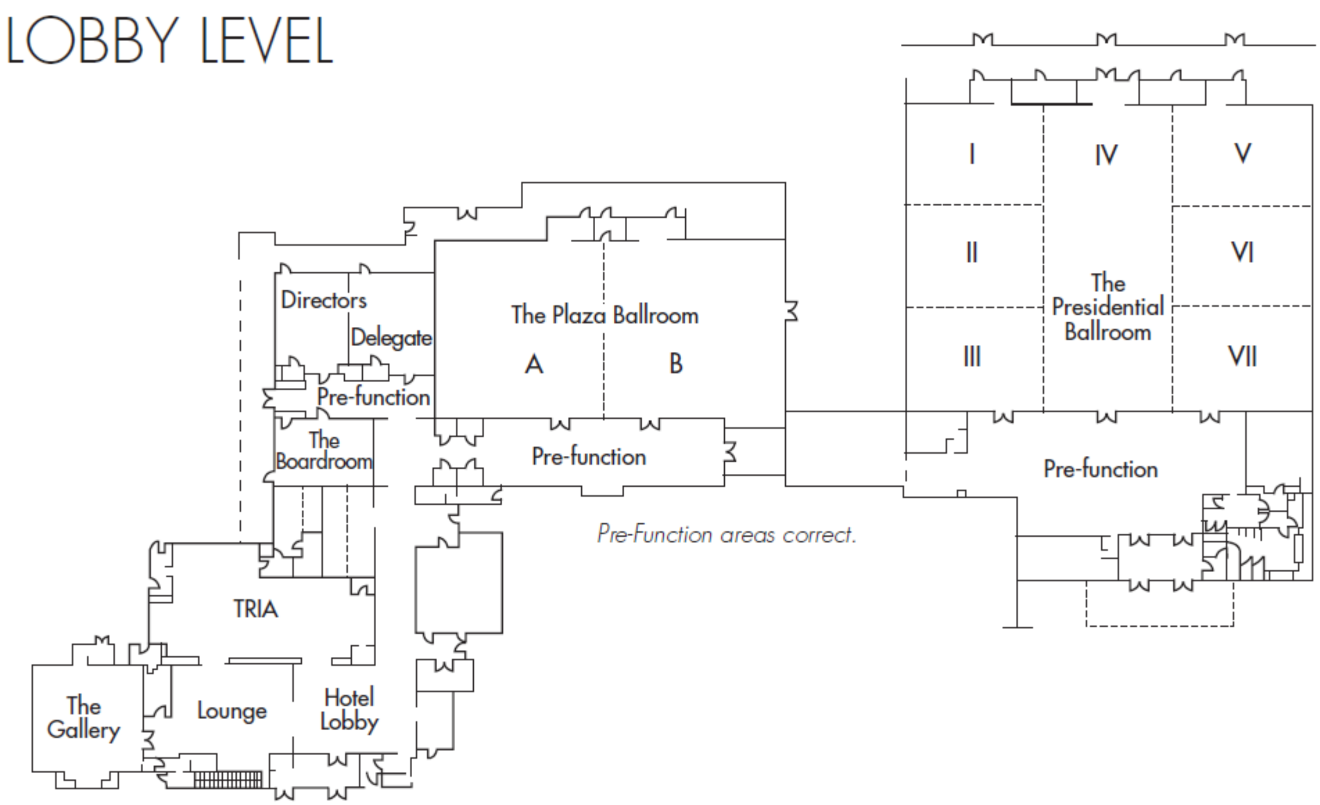
BEACON DYNAMICS
beacondynamics.com/injector-spray-visualization-and-analysis.html

FLUID AIR

Conference Map

Exhibitors Room	Plaza Ballroom
Welcome Reception	Plaza Ballroom
Breakfast	Plaza Ballroom
Keynote Presentation Room	Presidential Ballroom I-III
Presentation Rooms	Presidential Ballrooms I-III and VI-VII
Technical Committee Meetings	Presidential Ballrooms I-III, V, and VI-VII
Lunch	Presidential Ballroom IV



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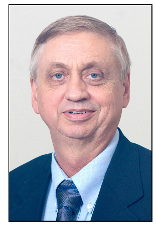

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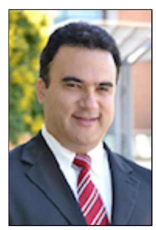

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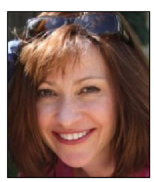


Meeting Planner
Laura Colderchant
Progress in Planning, Inc.

ILASS-Americas

Institute for Liquid Atomization and Spray Systems

28th Annual Conference on Liquid Atomization and Spray Systems

ILASS 2016 is the 28th Annual Conference for North and South America. This conference, like its predecessors, provides a venue to meet and share recent developments in the field of atomization. Industrialists, researchers, academics, and students meet to discuss a variety of topics in areas including: theory, modeling, applications, and spray diagnostics. This year's conferences will feature a number of special sessions on focused topics.

Invited Sessions

- Spray Image Analysis (Monday)
- Computational Methods for Atomization (Monday)
- Non-Newtonian Drop Breakup and Sprays (Monday)
- Liquid Jets & Sprays in Crossflow (Tuesday)
- Compressible Atomization (Wednesday)
- Atomization Technology Innovation Consortium (ATIC) (Wednesday)

General Topic Areas

- Instrumentation related to spray measurement including droplet size, velocity, impact, concentration, and patternation as well as film thickness, vapor concentration, and other parameters.
- Modeling of flow phenomena both inside and outside atomizers
- Design, operation, and performance of atomizers and spray systems
- Processes in which sprays are used such as spray reactors, spray dryers, humidifiers, spray coating, combustion, fire fighting, agricultural applications, medical applications, spray formations, and metal powder production.

Technical sessions at which state-of-the-art research, methods, and diagnostics are presented.

Manufacturer's exhibits showcasing the latest relevant instrumentation and hardware in the field.

Technical committees providing directed open discussions in areas of interest. All conference attendees are encouraged to attend.

Program Notes and Special Events

Registration will take place from 4-7 pm on Sunday in the Plaza Ballroom Foyer.

A Welcome Reception will take place from 5:30-7 pm on Sunday in the Plaza Ballroom.

A Panel Discussion on *Internal Flow of Automotive Injectors* will be held Sunday evening from 7-8:30 pm after the welcome reception, in the Gallery.

Exhibitors' Displays can be found from Sunday through Wednesday in the Plaza Ballroom.

Breakfast (Continental) will be served every morning from 7-7:55 am in the Plaza Ballroom.

Lunch will be served in Presidential Ballroom IV.

The ILASS-Americas Annual Business Meeting will be held during lunch on Tuesday in Presidential Ballroom IV.

Technical Committee Meetings will be held on Tuesday afternoon in Presidential Ballrooms I-III, V, and VI-VII. Conference attendees are strongly encouraged to join the technical committee discussions that match their interests. The meetings are open to all conference participants.

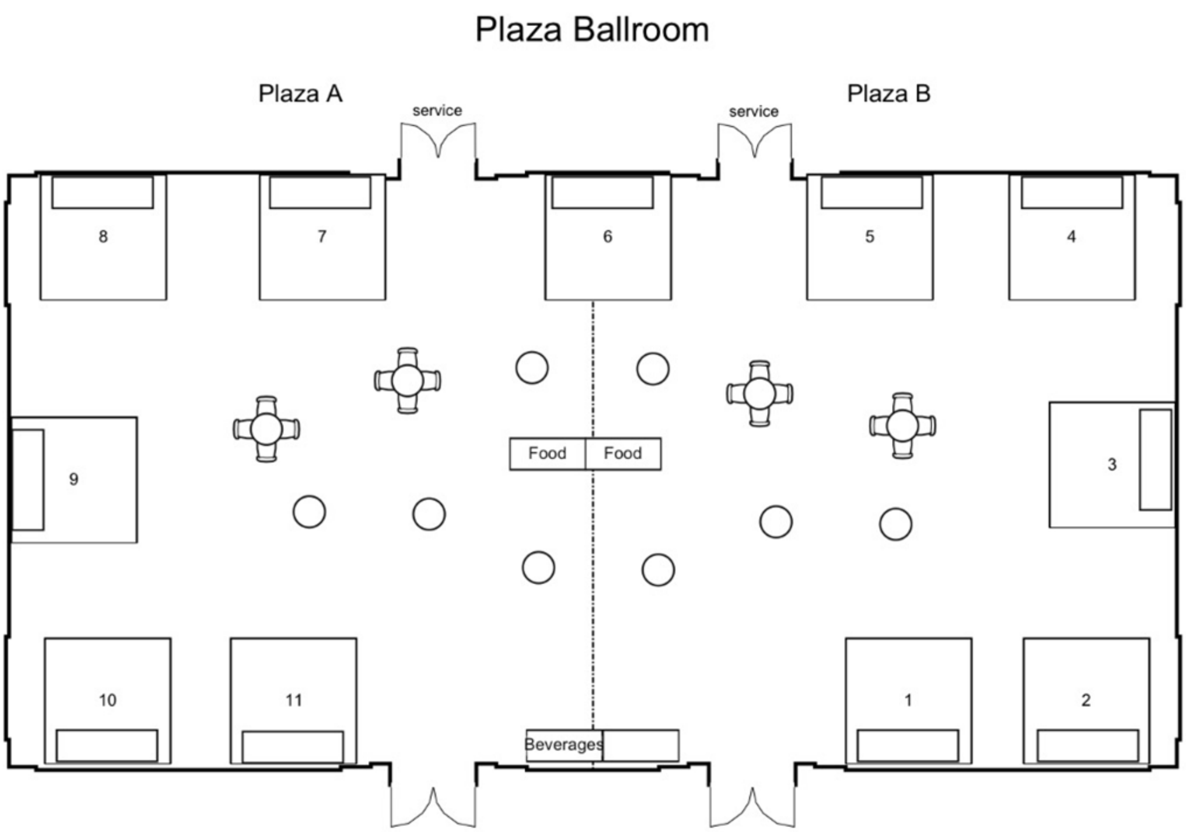
ILASS Service Awards will be presented at the reception dinner on Tuesday. The Simmons Award and the Marshall Award will be presented for the best paper and best student paper from the previous year's ILASS-Americas conference.

Program changes will be announced every morning, posted at the Registration Desk, and noted on the schedule poster outside each presentation room.

Paper numbers & links are provided on each abstract page of the ILASS 2016 Book. When the link is selected from the PDF located on the media drive, these links will auto-open the respective paper from the media drive.

Exhibitors

There are eleven exhibitors at this year's conference. They offer an array of diagnostic instrumentation, services, and equipment. Specific details are outlined on the following profiles from each exhibitor. The exhibitors at this year's conference are:



Oxford lasers Incorporated.

As one of the most successful spin offs from Oxford University in 1977, Oxford Lasers have been at the forefront of laser technology for almost 40 years.

Through huge shifts in the industrial applications and technological requirements; from uranium enrichment in the 1980's to high speed imaging for the pharmaceutical market in the 2000's, Oxford Lasers adapted and brought new laser technology solutions to market. Proving their ability to invent solutions applied not just to laser technology, but to the business too.

Oxford Lasers continue to develop new systems and solutions, the substantial R&D department is involved in numerous UK & European research projects which enables them to keep to the forefront of laser micromachining and high speed imaging techniques and technologies.

Today, Oxford Lasers operate two divisions of the business, Imaging and Industrial and have locations in America, France and the UK.

Imaging Division

Oxford Lasers Imaging Division offer laser systems, contract services, system rental, R&D and technical support for: High speed imaging, using high speed cameras, lasers and software to offer complete imaging solutions.

Oxford Lasers have significant experience within the field of spray characterisation, providing information on droplet size, droplet velocity and droplet shape. The VisiSize instrument range provides a range of capability to suit the different measurement challenges present in the field.

Industrial Division

Oxford Lasers Industrial Division offer the full spectrum of fully automated Laser Micro-Machining Tools from Compact Laser Micromachining Tools; perfect for R&D and Pilot Production, through to Ultrafast Laser Micromachining Tools; utilising the highest precision industrial laser technology.

In conjunction with providing a significant range of Laser Micromachining Tools, Oxford Lasers Industrial Division also offer Subcontract Laser Micromachining Services. With nine in-house Laser Micromachining systems, capabilities include micro-drilling, milling, patterning, scribing and cutting in a vast array of materials from Metals to Glass and have covered over 10,000 niche applications across a variety of sectors.

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En’Urga Inc.©
Innovations in Quality Control

En’Urga Inc.

Company Description

En’Urga Inc. is the industry leader in customized optical diagnostic equipment for the most challenging factory floor application. En'Urga Inc. has over 20 years experience in optical diagnostics research, serving many Fortune 50 companies and Federal Government agencies.

En’Urga Inc. provides testing and consulting services for combustors, spray nozzles, heat sinks, and other engine related components. We specialize in characterizing sprays (drop sizes, spray patterns, drop surface areas, velocities, mass fluxes, etc.) in ambient as well as high-pressure conditions. En’Urga Inc. has developed standardized test protocols for GDI injectors, urea dosers, consumer sprays, and paint sprays. These standardized test protocols ensure that the quality of the nozzle that are used in these applications confirm to the highest standards possible.

En’Urga Inc. has several products in their portfolio. Our latest product is the "***SETXvue Tomography System"***. The ***SETxvue Tomography System*** provides tomographic mapping using soft X-Rays for a wide range of applications including spray characterization and flame structure determination in the automotive and aerospace industry as well as mass flux determination of particulates in the food and pharmaceutical industry.

En'Urga also markets "***SETScan Optical Patternator***", "***SPIvel Velocimeter***" and "***Spectraline Imaging Spectrometer***".

The ***SETScan Optical Patternator"*** can obtain distribution of droplets in sprays or particles in particulate laden flows at a frequency of 10,000 Hz. The optical patternator is used for 100% quality of audit of nozzles in a wide variety of industries ranging from Aerospace to consumer products. Unlike laser sheet imaging patternators, the SETscan optical patternator provides quantitative information on various aspects of the spray such as spray angles, plume angles, % split in plumes, deviation, pitch, roll, and yaw angles. The SETscan patternator also provides the planar drop surface area density, the most useful quantity for ranking the performance of injectors for combustion and nozzles for spray drying.

The ***SPIvel Velocimeter*** provides full planar axial and radial velocities from high speed images obtained with any of the commercially available high speed cameras.

The ***Spectraline Imaging Spectrometers*** provides visible spectra from 0.3 to 1.1 microns at 40 KHz, and infrared spectra from 1.3 to 4.8 microns at 1.32 KHz. These are the fastest spectrometers available in the market. The Spectrometers are used to determine temperature and species concentration profiles in high frequency turbulent flames. These spectrometers are available with a range of accessories to enable hyper-spectral imaging and flame emission tomography.

All of En’Urga products can be leased or purchased from En’Urga Inc. More information can be obtained from our website at **www.enurga.com. E**mail us at **info@enurga.com**.

About Vision Research

Vision Research is a leading manufacturer of high-speed digital imaging systems that are indispensible across a wide variety of applications including defense, automotive, engineering, science, medical research, industrial manufacturing, packaging, sports broadcast, TV production and digital cinematography. The Wayne, N.J.-based company designs and manufactures the most comprehensive range of digital high-speed cameras available today, all of which deliver unsurpassed light-sensitivity, image resolution, acquisition speed and image quality. Over the course of its 60+ year history, Vision Research has earned numerous awards in recognition of its innovations in high-speed digital camera technology and sensor design, including a technical Emmy and an Academy Award®. Vision Research digital high-speed cameras add a new dimension to the sense of sight, allowing the user to see details of an event ***when it's too fast to see, and too important not to***™. For additional information regarding Vision Research, please visit www.phantomhighspeed.com.

Vision Research is a business unit of the Materials Analysis Division of AMETEK Inc., a leading global manufacturer of electronic instruments and electromechanical devices.

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Spraying Systems Co.®
Experts in Spray Technology

Spraying Systems Co. is the world's leading manufacturer of industrial spray products and produces high-quality spray nozzles, manifolds, systems and accessories. Our customers are located around the world and use our products in virtually every manufacturing industry. We work with our customers on a regular basis to help optimize spray performance and save many thousands of dollars each year.

Centers of Excellence

Spray Nozzles

Spray optimization begins with the best spray nozzle for the job. With nozzles available in thousands of sizes, hundreds of configurations and dozens of materials, we can meet your application needs.

Spray Control

AutoJet® Spray Control is our line of spray controllers and automated systems. Automated Spray Control can improve your operations by reducing overspray and chemical consumption, minimizing labor and improving product quality.

Spray Analysis

Our Spray Analysis and Research Services group conducts advanced spray testing and uses sophisticated modeling tools to determine spray performance. This work can be conducted in our spray laboratories — the industry's largest and most specialized or on location.

Spray Fabrication

Our custom headers, manifolds, injectors and lances help ensure application success with proper nozzle placement and positioning. Custom mounting systems and adapters simplify spray product installation and provide single-source supplier convenience.

Global representation, local attention

With 10 manufacturing facilities located in North and South America, Europe and Asia, we can quickly deliver our products to customers anywhere in the world. And with more than 85 sales engineering offices around the world, there is a local representative you can call on to provide hands-on assistance with your application.

Contact Information:

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Website: www.Spray.com, www.SprayAnalysis.com, www.AccuJet.com

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Sunnyvale, CA 94085

Artium specializes in developing and manufacturing advanced particle characterization instruments for the spray community. We offer a broad range of instruments for measuring sprays, clouds, and aerosol droplets. Our **Phase Doppler Interferometry (PDI)** instruments are based on the light scattering interferometry principle which was **invented and developed by our scientists**. This technology has been developed and evaluated over the past 30 years and is acknowledged as the most reliable and accurate means for characterizing spray and aerosol droplet dynamics. Our goal over the past 15 years has been to further refine the method and its implementation to insure greater measurement reliability and accuracy while making the instruments much easier to use. We have now introduced advanced particle imaging systems to allow easy and economic characterization of spray formation and drop size distributions. This method is also used for measuring aircraft icing sprays with mixed phase (liquid and ice) particles as well as large droplets that may be highly deformed.

System automation (US Patent 7,564,564) has been one of our key goals. We have introduced advanced methods and algorithms **(US Patent 7,788,067)** to minimize the possibility for user setup errors even for the most complex measurement tasks**.** Advanced modern electronics and computers coupled with **software utilizing innovative signal processing algorithms** and validation strategies have resulted in significantly improved instrument performance even under the most difficult measurement conditions.

Our **newly developed flight probes based on the phase Doppler method and imaging have been designed for atmospheric cloud monitoring and aircraft icing research.** They have undergone significant testing in the field. Our flight probes are being flown by the **U.S. Navy CIRPAS** for their cloud research program and have produced significant data on cloud properties. Testing at the **U.S. Air Force Eglin Air Force Base McKinley Climatic Laboratory**, General Electric's aircraft engine icing facility, and in the **NASA Glenn Research Center Icing Research Tunnel (IRT)** proved our instruments are capable of making reliable and accurate measurements in these challenging environments.

Under our **U.S. Army SBIR Ph II program**, we developed PDI and high speed imaging (**HSI**) systems for helicopter icing research. The probes have been successfully tested on a **UH60 Black Hawk Helicopter** under the U.S. Army's helicopter icing research program. The high speed imaging (HSI) probe characterizes non-spherical particles (deformed droplets and mixed phase conditions). We have also developed a line of **TurnKey (TK)** systems, an integrated PDI probe suitable for in-spray use. Artium's other products include the LDV and Laser Induced Incandescence (LII) which is used for measuring soot (black carbon) emission from engine exhaust and in ambient air.

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Dr. William Bachalo, President and CEO
Artium Technologies
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Email: info@artium.com Website www.artium.com

IMAGE TECHNOLOGY

nac Image Technology has a proven track record of developing high quality, reliable products that satisfy specific high-speed imaging requirements for a multitude of applications including: Spray Analysis and PIV, Aerospace, Range and Ballistics, Manufacturing, Test and Design, Automotive / Transportation, and many more! nac Image Technology is the only manufacturer of high-speed camera systems that has dedicated itself to producing complete, integrated systems that have the ***most light sensitivity, the best image quality, the largest memory capacities, the smallest camera heads, the fastest download times and the most inclusive software packages in the industry***.

Since 1958 nac has been a pioneer in developing new uses for image technology and has gained a reputation for quality, experience and reliability! All nac products go through rigorous environmental testing and certification so you can be confident that your nac Camera System will be a valuable and reliable tool for years to come.

When it comes to reliable, high-quality, high-speed camera systems, make the proven choice with nac and you'll ***see the visible difference****.*

Energy Research Consultants (ERC) was founded in 1990 to fulfill a need for application of state-of-the-art experimental and numerical modeling tools to problems associated with energy generation and use. Projects which require fast and confidential answers via advanced research tools which are not otherwise readily available are addressed through experienced personnel and a fully equipped research laboratory. In addition, on site work can be accommodated. Both experimental and numerical studies are conducted for clients that are addressing mission oriented, time critical projects.

ERC has extensive experience with a wide variety of fluid dynamic, combustion, and spray system applications. In particular, ERC maintains expertise in the characterization of non-reacting and reacting flows such as those found in automotive combustion chambers and exhaust after-treatment systems, as well as those found in gas and spray-fired gas turbine combustion systems and industrial processes. The expertise ranges from the basic science of sprays, combustion, turbulent transport, and diagnostics to practical configurations in the area of gaseous fuel injection, liquid-fuel atomization, swirl, pollutant formation and control, and fuel/air mixing.

Specialized measurement services are offered to both commercial and government clients. Available spray diagnostics include Phase Doppler Interferometry, Laser Diffraction, Planar Liquid Laser Induced Fluorescence (PLIF with continuous and pulsed lasers with intensified CCD cameras), planar and global OH* LIF, optical patternation, particle image velocity, tunable diode laser spectroscopy, liquid film thickness measurements, and high speed visualization. ERC has extensive experience applying these methods to wide array of customer systems. Other capabilities include CFD modeling, test facility development, and test plan development and execution using statistically designed experimental methods.

In addition to measurement services, ERC has also developed standalone design tools (for example, Advanced Spray Injection Phenomena Simulator--ASIPS; Flame Response Sensitivity Tool—FRST) and image analysis tools (for example, Automated Feature Extraction and Analysis Tool—AFEAT). ERC has also developed other products such as specialized imaging systems for inspection inside high temperature environments as well as coating system and particulate quality control. Gaseous and liquid fired burners are also available.

Contact Information:

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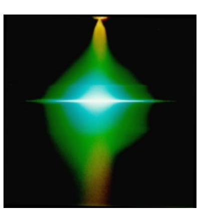

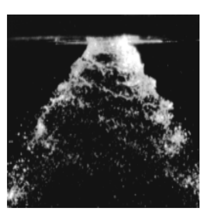

TSI Incorporated in Shoreview, Minnesota offers a complete line of products for spray diagnostics. Products include Phase Doppler Particle Analysis (PDPA) systems, Time-Resolved Particle Image Velocimetry (TR-PIV) systems, Global Patternation Systems, Global Sizing Velocimetry (GSV) systems and Quantitative Flow Visualization systems. These systems are used to characterize various aspects of a spray; from measuring droplet velocity and size at a specific location, to obtaining global information of the ligament formation, to identifying the breakup in a spray. Many of these systems are complementary to one other, helping the user to obtain the complete diagnostics of a spray.

The PDPA system is a single-point measurement technique which provides simultaneous, accurate droplet velocity and size of a spray, with a sampling rate up to 200,000 per second. Global imaging systems (TR-PIV, GSV and global patternation) offer planar measurements of a spray that is illuminated by a laser light sheet. PIV systems measure the velocity vector field of a spray with very high spatial resolution, so that the flow structure can be analyzed.

The GSV system simultaneously measures velocity and size of droplets, allowing users to calculate the volume flux. Meanwhile, global patternation allows researchers to observe the behavior of spray angles and the concentration distribution.

Quantitative flow visualization using shadowgraph can be performed using either high-resolution cameras or high-speed cameras. Results from the high-resolution cameras can provide a detailed structure of the size of the droplets and ligaments. Using high-speed cameras, the evolution of a spray structure can be observed with high-temporal resolution.

Product development and innovation are key elements to TSI’s Fluid Mechanics group. The team is continuously working on the state-of-the-art systems to obtain a better understanding of sprays. To learn more about TSI’s products, please visit the booth at the conference.

LaVision develops and sells integrated measurement systems for research and development in the areas of fluid mechanics, solid mechanics, microfluidics, liquid atomization, spray systems and combustion. Established over 25 years ago LaVision is the market leader in image based measurement systems and has sold systems and services into leading universities, companies and government labs worldwide. LaVision continues to strengthen its credibility in the field of fluid dynamics with its development of Tomographic PIV and Shake-The-Box Particle Tracking.

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Conference Schedule

ILASS-Americas 2016 Schedule

Sunday, May 15

S 4:00-7:00 PM	**Registration** *Plaza Ballroom Foyer*	
S 5:30-7:00 PM	**Welcome Reception with Exhibitors** *Plaza Ballroom*	
S 7:00-8:30 PM	**Panel Discussion** *The Gallery* **Internal Flow of Automotive Injectors** **Moderator:** R. Grover *GM* **Panelists:** L. Pickett, *Sandia National Laboratories*; D. Duke, Argonne National Laboratory; D. Schmidt, University of Massachussetts-Amherst; Bizhan Befrui, Delphi Luxembourg	

Monday, May 16

M 7:00-7:45 AM	**Breakfast with Exhibitors** *Plaza Ballroom*	
M 7:45-8:00 AM	**Welcome & Opening Remarks** *Presidential Ballroom I-III*	
M 8:00-9:00 AM	**Keynote Lecture** *Presidential Ballroom I-III* **Spray-Flow Interactions in Direct-Injected Engines** Volker Sick, University of Michigan	
M 9:00-10:00 AM	**Plenary Session with Exhibitors** *Presidential Ballroom I-III* *Chair: Lee Markle*	
	Spray Image Analysis (Invited Session) Chairs: B. Halls & D. Sedarsky *Presidential Ballroom I-III*	**Computational Methods for Atomization (Invited Session)** Chairs: M. Owkes & M. Trujillo *Presidential Ballroom VI-VII*
M 10:05-10:30 AM	**Segmentation and Thresholding Concerns** D. Sedarsky *Chalmers University*	**Framework for Uncertainty Quantification of Multiphase Flows Including Atomizing Jets** B. Turnquist, M. Owkes *Montana State University*
M 10:30-10:55 AM	**High-Speed Radiography and Visible Light Extinction of a Pressure-Swirl Atomizer** A. Kastengren *Argonne National Laboratory*	**Gradient Augmented Level Set Method for Two-Phase Flow Simulations with Phase Change** C. Anumolu, M. Trujillo, M. Aanjaneya, E. Sifakis *University of Wisconsin-Madison*
M 10:55-11:20 AM	**Toward Quantitative Spray Measurements using High-Performance High-Speed Video Cameras** J. Manin, L. Pickett, S. Skeen *Sandia National Laboratories*	**Underlying Errors in Level Set Methods** M. Trujillo, L. Anumolu, D. Ryddner *University of Wisconsin-Madison*
M 11:20-11:35 AM	**Break** *Plaza Ballroom*	
	Automotive Sprays I Chairs: M. Cloeter & N. Tamaki *Presidential Ballroom I-III*	**Atomization & Spray Simulations I** Chairs: S. Garrick & M. Owkes *Presidential Ballroom VI-VII*
M 11:35-12:00 PM	**Combined Visible and X-Ray Extinction Measurements in a Water Spray from a GDI Injector** Y. Sivathanu, J. Lim, M. Wolverton *En'Urga Inc.*	**Large Eddy Simulation of Turbulent Spray with a Filtered Density Function** E. Wenzel, S. Garrick *University of Minnesota*
M 12:00-12:25 PM	**Characterization of Diesel Spray Breakup Models Using Visible and X-Ray Extinction Measurements** G. Magnotti, C. Genzale *Georgia Institute of Technology*	**Least Square Curvature Calculation Method for VOF Scheme** E. Cauble, M. Owkes *Montana State University*
M 12:25-12:50 PM	**Improvement of Spray and Flow Characteristics of Injection Nozzle for Direct Injection Diesel Engine** N. Tamaki, T. Harada *Kindai University*	**High-Fidelity Simulations of Realistic Electrically-Charged Atomizing Diesel-Type Jets** M. Owkes, B. Van Poppel *Montana State University & U.S. Military Academy*
M 12:50-2:00 PM	**Lunch** *Presidential Ballroom IV*	

	Experimental Methods & Instrumentation Chairs: A. Kastengren & L. Pickett *Presidential Ballroom I-III*	Non-Newtonian Drop Breakup and Sprays (Invited Session) Chairs: P. Sojka & D. Schmidt *Presidential Ballroom VI-VII*
M 2:00-2:25 PM	**A New Monodisperse Droplet Generator and its Applications** H. Duan, B. Liu, A. Naqwi *MSP Corporation*	**Temporal Characteristics of Secondary Atomized Non-Newtonian Liquids in the Bag and Multimode Regimes** J. Rocha, P. Sojka *Purdue University*
M 2:25-2:50 PM	**Magnetic Resonance Imaging Measurements Inside and in the Near-Nozzle Regions** I. Mastikhin, A. Arbabi, S. Ahmadi, K. Bade *University of New Brunswick & Spraying Systems Co.*	**Breakup Morphology of Inelastic Drops at High Weber Numbers** V. Kulkarni, N. Rodrigues, P. Sojka *Purdue University*
M 2:50-3:15 PM	**High-Speed Two-Dimensional Synchrotron X-ray Radiography of Propulsion Sprays** B. Halls, J. Gord, B. Reuter, S. Roy, C. Radke, T. Meyer, A. Kastengren *AFRL & Spectral Energies, LLC & NASA JSC & Purdue University & Argonne National Laboratory*	**Spatially Resolved Characteristics of Elastic Non-Newtonian Secondary Breakup** S. Snyder, V. Kulkarni, P. Sojka *Purdue University*
M 3:15-3:40 PM	**Rapid Evaporation of Water Sprayed on Metallic Media Beds** D. Bouchard, S. Chandra *University of Toronto*	**Spray Characterization of Non-Newtonian Impinging Jets Using Digital In-Line Holography** N. Rodrigues, J. Gao, J. Chen, P. Sojka *Purdue University*
M 3:40-3:55 PM	**Break**	*Plaza Ballroom*
	Droplet Phenomena Chairs: E. Windhab & M. Trujillo *Presidential Ballroom I-III*	Atomization Theory & Modeling Chairs: J. Manin & M. Sami *Presidential Ballroom VI-VII*
M 3:55-4:20 PM	**An Experimental Study of the Influence of Particles on the Disintegration of the Rims of Fan Sheets Produced by Particulate Suspensions Formed during Atomization** F. Addo-Yobo *University of Trinidad and Tobago*	**Effect of Surface Wettability on Performance of Cooling Spray Process** S. Attarzadeh, A. Dolatabadi, H. Shetabivash *Concordia University*
M 4:20-4:45 PM	**Industrial Applications of Ultrasonically Stimulated Droplet Generation** J. Buckland *The Technology Partnership plc*	**Detailed Numerical Simulation in the Breakup Region of the Engine Combustion Network (ECN) Spray A** J. Manin *Sandia National Laboratories*
M 4:45-5:10 PM	**Deformation and Breakup of Drops in Three Dimensional Symmetric Flows and Comparisons with Experimental Observations** C. Liang, K. Feigl, F. Tanner *Michigan Technological University*	**Computing the Spray Characteristics of a Simplex Atomizer Using the ELSA Model** M. Sami, V. Kumar *ANSYS Inc.*
M 5:10-5:35 PM	**Continuum and Molecular Dynamics Simulations of Nanodroplet Collision** R. Bardia, Z. Liang, P. Keblinski, M. Trujillo *University of Wisconsin-Madison & Rensselaer Polytechnic Institute*	**Sampling of the Velocity Space: An Agenda for Liquid-Sheet Atomization Analysis** C. Bilger, R. Cant *University of Cambridge*
M 5:35-6:00 PM	**Evaporation of Falling Droplet using Sharp Interface Level Set Method** J. Shaikh, A. Sharma, R. Bhardwaj *IIT Bombay*	**Influence of Excluded Volumes of Particles and Menisci on Predicting Wave Growth and Stability Lengths of Sheets of Suspensions of Coarse Particles during the Atomization of Fan Sheets** F. Addo-Yobo, D. Boodlal *University of Trinidad and Tobago*
M 6:00-6:40 PM	**Technical Committee Meetings** Spray Measurements & Instrumentation *Presidential Ballroom I-III* Physics of Atomization *Presidential Ballroom VI-VII* Rocket & Airbreathing Power Fuel Atomization & Industrial Combustion *Presidential Ballroom V*	
M 6:40 PM	**Evening at Leisure**	

Tuesday, May 17

Time	Spray Characterization & Measurements	Internal and Near Nozzle Behavior
T 7:00-7:55 AM	**Breakfast with Exhibitors** *Plaza Ballroom*	
T 7:55-8:00 AM	**Opening Remarks** *Presidential Ballroom I-III*	
T 8:00-9:00 AM	**Keynote Lecture** *Presidential Ballroom I-III* **Functional Microstructure Generation in Food Powder Systems by Spray-Chilling and Spray Drying of Complex Multiphase Fluids** Erich J. Windhab, ETH Zurich	
	Spray Characterization & Measurements I Chairs: S. Amiri & F. Li *Presidential Ballroom I-III*	**Internal and Near Nozzle Behavior I** Chairs: D. Schmidt & C. Powell *Presidential Ballroom VI-VII*
T 9:05-9:30 AM	**Three-Dimensional Structure of Like-Doublet Impinging Jet Sprays Obtained Using Digital Inline Holography** C. White, W. Shang, J. Chen, P. Sojka, J. Mallory-O'Brien *Purdue University & Western New England University*	**X-ray Radiography Measurements and Numerical Simulations of Cavitation in a Metal Nozzle** D. Duke, A. Swantek, K. Matusik, A. Kastengren, J. P. Viera, R. Payri, C. Powell, D. Schmidt *Argonne National Laboratory & Universitat Politècnica de València & University of Massachusetts-Amherst*
T 9:30-9:55 AM	**Acoustically Forced Coaxial Hydrogen / Liquid Oxygen Jet Flames** M. Roa, D. Forliti, A. Badakhshan, D. Talley *Sierra Lobo, Inc. & ERC, Inc. & Air Force Research Laboratory*	**High Resolution X-Ray Tomography of Injection Nozzles** K. Matusik, D. Duke, C. Powell, A. Kastengren *Argonne National Laboratory*
T 9:55-10:20 AM	**Characterization of Glass Particle Suspension Droplets by Phase Doppler Particle Analyzer** S. Amiri, A. Akbarnozari, C. Moreau, A. Dolatabadi *Concordia University*	**Measurement of Flow Velocities in a to Scale Simplex Atomizer Using Particle Image Velocimetry** A. Thistle, S. Day *Advanced Atomization Technologies & Rochester Institute of Technology*
T 10:20-10:35 AM	**Break** *Plaza Ballroom*	
	Spray Characterization & Measurements II Chairs: K. Bade & S. Pack *Presidential Ballroom I-III*	**Internal and Near Nozzle Behavior II** Chairs: D. Duke & A. Thistle *Presidential Ballroom VI-VII*
T 10:35-11:00 AM	**Spray Diagnostics of Low NOx Air Blast Atomizers at Ambient and Elevated Pressure** S. Pack, J. Ryon, G. Zink *United Technologies Aerospace Systems*	**Near Nozzle Spray Characterization under Subcooled and Superheated Conditions of Various Direct-Injection Gasoline Injectors** S. Wu, M. Xu, D. Hung, H. Pan *Shanghai Jiao Tong University*
T 11:00-11:25 AM	**Comparison of Practical and Analytical Spray Performance in Defouling Process** F. Li, K. Brown, R. Schick *Spraying Systems Co.*	**New Estimation of Near Exit Streamwise Instabilities on High Speed Liquid Jets** G. Jaramillo, S. Collicott *Purdue University*
T 11:25-11:50 AM	**Local and General Spray Characteristics of Spray Dry Nozzles with Water** K. Bade, R. Schick, T. Oberg, C. Pagcatipunan *Spraying Systems Co.*	**Flash Boiling: A Parametric Study** S. Rachakonda, Y. Wang, D. Schmidt *University of Massachusetts-Amherst*
T 11:50-12:15 PM	**Review of Characteristics of Low Temperature Combustion (LTC)** A. Bhargava, G. Micklow *Florida Institute of Technology*	**String Flash-Boiling in Flashing and Non-Flashing Gasoline Direction Injection Simulations with Transient Needle Motion** E. Baldwin, D. Schmidt, R. Grover, S. Parrish, D. Duke, K. Matusik, A. Kastengren, C. Powell *University of Massachusetts-Amherst & General Motors & Argonne National Laboratory*
T 12:15-1:25 PM	**Lunch** *Presidential Ballroom IV* ILASS Americas Annual Business Meeting	

Time	Automotive Sprays II Chairs: T. Fang & S. Parrish *Presidential Ballroom I-III*	Atomization & Spray Simulations II Chairs: M. Arienti & J. Jog *Presidential Ballroom VI-VII*
T 1:25-1:50 PM	**Effect of Nozzle Configuration on Cycle-to-Cycle Variations of Spray Structure under Non-Flash Boiling and Flash Boiling Conditions via Proper Orthogonal Decomposition Technique** H. Pan, M. Xu, D. Hung, S. Wu, T. Li *Shanghai Jiao Tong University & University of Michigan–SJTU*	**Numerical Study of Annular Two-Phase Flow in Effervescent Atomizers** C. Mohapatra, M. Jog *University of Cincinnati*
T 1:50-2:15 PM	**Diesel Spray under High Injection Pressure** L. Wang, J. Lowrie, G. Ngaile, T. Fang *North Carolina State University*	**Numerical Study of Cavitation in High-Viscous Liquid Spray Systems** R. Ravendran, J. deClaville Christiansen , B. Endelt, P. Jensen *Aalborg University & Hans Jensen Lubricators*
T 2:15-2:40 PM	**Narrow Band Flame Emission of Dieseline and Diesel Spray Combustion in a Constant Volume Combustion Chamber** Z. Wu, W. Jing, W. Roberts, T. Fang *North Carolina State University*	**Validation and Analysis of Air-Blast Atomization Simulations** R. Chiodi, G. Agbaglah, O. Desjardins *Cornell University*
T 2:40-2:55 PM	**Break**	*Plaza Ballroom*
	Automotive Sprays III Chairs: B. Befrui & R. Grover *Presidential Ballroom I-III*	**Liquid Jets & Sprays in Crossflow (Invited Session)** Chairs: M. Herrmann & K.-C. Lin *Presidential Ballroom VI-VII*
T 2:55-3:20 PM	**The Effects of Parcel Count on Predictions of Spray Variability in Large-Eddy Simulations of Diesel Fuel Sprays** N. Van Dam, S. Som, A. Swantek, C. Powell *Argonne National Laboratory*	**Characterization of Liquid Jets in Subsonic Crossflows Using X-Ray Radiography** K.-C. Lin, C. Carter, S. Peltier, A. Kastengren, M.-C. Lai *Taitech, Inc. & Air Force Research Laboratory & Argonne National Laboratory & Wayne State University*
T 3:20-3:45 PM	**Parametric Study of HRM for Gasoline Sprays** K. Saha, S. Som, M. Battistoni *Argonne National Laboratory & University of Perugia*	**The Effect of Fuel Heating on the Penetration of a Liquid Jet in Crossflow** H. Wiest, S. Heister *Purdue University*
T 3:45-4:10 PM	**ECN GDi Spray G: Coupled LES Jet Primary Breakup - Lagrangian Spray Simulation and Comparison with Data** B. Befrui, A. Aye, A. Bossi, L. Markle, D. Varble *Delphi Automotive*	**High Fidelity Simulation of Impact of Pressure on Liquid Jet in Crossflow Atomization** X. Li, M. Soteriou *United Technologies Research Center*
T 4:10-4:50 PM	**Technical Committee Meetings** Diesel & Automotive Sprays Computation & Modeling Industrial & Agricultural Sprays	*Presidential Ballroom I-III* *Presidential Ballroom VI-VII* *Presidential Ballroom V*
T 5:00-5:05 PM	Bus Transport to Ford Rouge Factory	*Hotel Lobby*
T 5:15-6:30 PM	**Tour of the Ford Rouge Factory**	
T 6:30-6:45 PM	Bus Transport to the Henry Ford Museum	
T 6:45-7:45 PM	**Cocktail Reception**	*Henry Ford Museum*
T 7:45-9:40 PM	**Dinner** **Awards Presentation** Individual Museum Exploring	*Henry Ford Museum*
T 9:40 PM	Bus Transport back to Hotel	

Wednesday, May 18

Time		
W 7:00-7:55 AM	**Breakfast with Exhibitors** *Plaza Ballroom*	
W 7:55-8:00 AM	**Opening Remarks** *Presidential Ballroom I-III*	
W 8:00-9:00 AM	**Keynote Lecture** *Presidential Ballroom I-III* **Increased Control of Metal Powder Yields from Two-Fluid Close-Coupled Gas Atomization by Understanding of Gas and Melt Flow Manipulation** Iver Anderson, Ames Laboratory	
	Spray Applications Chairs: P. Sojka & K. Blakely *Presidential Ballroom I-III*	**Compressible Atomization I (Invited Session)** Chairs: J. Regele & D. Guildenbecher *Presidential Ballroom VI-VII*
W 9:05-9:30 AM	**Nozzle Selection During Process Development of a Pharmaceutical Spray Dried Solid Dispersion** K. Blakely, M. Hawk *Lilly Research Laboratories*	**Recent Developments in Experimental Methods for Quantification of High-Speed, Aerodynamically Driven Liquid Breakup** D. Guildenbecher *Sandia National Laboratories*
W 9:30-9:55 AM	**Investigation of an Electrohydrodynamic Atomization System for Use in Natural Gas Odorization** V. Ganesan, P. Citroen, O. Ondimu, R. Bahlmann, J. Marijnissen, L. Agostinho *NHL University of Applied Sciences & University of Florida & DNV GL Oil and Gas*	**Numerical Simulation of a Shock Wave Impacting a Droplet Using the Adaptive Wavelet-Collocation Method** Z. Hosseinzadeh-Nik, M. Aslani, J. Regele, *Iowa State University*
W 9:55-10:20 AM	**Spray Patternation for the USDA Drift Reduction Task Force (DRTF) Nozzles: The Influence of Liquid Formulation and Operating Conditions** S. Solaiman, B. Young, J. Snyder, P. Sojka *Purdue University*	**Direct Numerical Simulation of Aerated-Liquid Injection within an 'Inside-Out' Nozzle Design** J. Edwards, B. Bornhoft, K.-C. Lin, S. Cox-Stouffer *North Carolina State University & Taitech, Inc.*
W 10:20-10:45 AM	**Size and Velocity Measurements for Agricultural Sprays as a Function of Nozzle Operating Conditions, Nozzle to Plant Canopy Height and Liquid Formulation** P. Jiminez, J. Snyder, B. Young, P. Sojka *Purdue University*	**Toward Liquid Jet Atomization in Supersonic Crossflows** P. Ireland, O. Desjardins *Cornell University*
W 10:45-11:00 AM	**Break** *Plaza Ballroom*	
	Atomization Technology Innovation Consortium (ATIC) (Invited Session) Chairs: I. Anderson & V. McDonell *Presidential Ballroom I-III*	**Compressible Atomization II (Invited Session)** Chairs: J. Regele & D. Guildenbecher *Presidential Ballroom VI-VII*
W 11:00-11:25 AM	**Industrial Centrifugal Atomization Methods and Products** M. Hash, T. Pearson *Ervin Industries*	**An In-Cell-Reconstruction Volume Tracking Method for Simulating Atomization in Compressible Flows** C. Ballesteros, M. Herrmann, *Arizona State University*
W 11:25-11:50 AM	**Overview of the Atomization Technology Innovation Consortium** G. Hildeman, S. Henry *Nexight Group & ASM International*	**Computation of the Break-Up of a Molten Drop under Sudden Acceleration** M. Arienti, F. Doisneau, J. Oefelein *Sandia National Laboratories*
W 11:50-12:15 PM	**Discussion** Moderator: Iver Anderson, *Ames Laboratory*	**A Finite Volume Method for Simulating Droplet Breakup in a Supersonic Cross Flow** D. Garrick, J. Regele *Iowa State University*
W 12:15-1:25 PM	**Lunch and Drawing for Prizes** *Presidential Ballroom IV*	
W 1:25 PM	**Conference Closes**	

Keynote Abstracts

ILASS-Americas
Institute for Liquid Atomization and Spray Systems

ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Spray-Flow Interactions in Direct-Injected Engines

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Abstract

Over the past twenty years continuously improving fuel injector technology has enabled a flurry of developments for new gasoline direct-injected engines. Direct injection of fuel allows flexible and precise control of timing and amount of fuel delivered and thereby is an enabling technology for overall-lean combustion strategies that employ stratified fuel/air mixtures. Under such operating conditions an ignitable fuel cloud is prepared that is rich enough to be flammable but not too rich to produce soot. In addition, this fuel cloud is spatially positioned accurately to interact with the spark plasma for reliable ignition. The repeatability of fuel injector sprays under static environmental conditions is typically quite high. However, once the developing fuel spray interacts with the in-cylinder turbulent gas flow the fuel dispersion, evaporation, and mixture preparation are altered with potentially substantial cycle-to-cycle variations. In turn, combustion progress can be affected to lead to variations in power output all the way to partial burns and misfires.

Better understanding of the processes that govern the interaction of sprays and in-cylinder flow is therefore important and requires attention. This presentation will cover examples of optical imaging techniques, especially those employing short-pulsed laser illumination that have enabled studies to capture details of fuel sprays in engines such as their spatial extent, velocity, and the impact of spray-gas flow interaction, mixing, and combustion. Many imaging techniques are based on Mie scattering, others employ laser-induced fluorescence, or a combination of both to extract useful information. The availability of powerful high repetition rate lasers and high frame rate cameras supported studies of cycle-resolved measurements to understand how spray-gas flow interactions can lead to misfires. As powerful as planar imaging techniques are for internal combustion engine research, it is also clear that in-cylinder processes are highly three-dimensional. The presentation closes with newer developments that use plenoptic imaging to capture the three-dimensional structure of fuel sprays with a single camera and in single exposures.

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Functional Microstructure Generation in Food Powder Systems by Spray-Chilling and Spray Drying of Complex Multiphase Fluids

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Abstract

Recent studies showed the ability of cold spray processing (prilling) and spray drying to tailor the morphology of simple or double emulsion based fluid systems as investigated for two types of air assisted nozzle geometries under various processing conditions. The spray process parameters varied were (i) air to liquid flow ratio (GLR), (ii) spraying pressure, (iii) mass flow rate. The results depicted that the emulsion flow inside the nozzle (liquid-cap) as well as in the spray (liquid filament) have distinct impact on the resulting product structure due to the respective flow stresses acting. Increasing the flow stresses either lead to an additional dispersing impact or to separation and coalescence of the disperse fluid phase(s). Besides the process parameters, the material characteristics of the emulsion system such as viscosity ratio λ of dispersed to continuous phase and the interfacial tension were varied in a wider range. The results demonstrated a systematic increase in structure stability for higher λ values in a range of 0.32 to 30. As representative dimensionless numbers (a) a critical modified liquid Weber number $We_{\mathrm{l,Drop,cr}}/\lambda$ and (b) a critical modified gas Weber number $We_{\mathrm{g,Drop,cr}}/\lambda$ were defined to describe the effect of liquid cap-tip and air-assisted spraying respectively with regard to preserving the disperse microstructure of the treated emulsions. Above such critical We-numbers, the dispersed emulsion phase drops were broken up and drop mean sizes were exponentially decreased due to the flow stresses acting either in the liquid flow inside the nozzle or in the spray filament flow outside the nozzle. Dynamic viscosity and dynamic moduli (G', G'') of treated emulsions increased with decreasing droplet size of the dispersed phase(s) thus altering the spraying performance but as well the properties of the liquid product systems reconstituted from the resulting chilled or dried powders. A third critical Weber number $We_{\mathrm{g,Nozzle,cr}}$ was derived for the spray droplet (tertiary droplet) generation by spray filament break-up providing information of the smallest spray droplet that could be attained, while keeping the dispersed emulsion (secondary) droplet unchanged in size. The impact of $We_{\mathrm{g,Nozzle}}$ on the resulting spray (tertiary) mean drop size was systematically explored for internal (INMIX) and external (EXMIX) liquid-gas mixing air assist nozzles. High speed videography and laser shadowgraphy were applied to visualize liquid spray filament stretching and breakup, as well as velocity distributions in the sprays. Most gentle spray conditions for complete preservation of disperse emulsion structure were only achieve in the Rayleigh filament breakup regime. Accordingly a pressure controlled rotary "Rayleigh-atomizer" was developed to study emulsion spraying by filament stretching and gently spray drop formation preserving the emulsion (secondary) droplet structure but at the same time by pressure adjustment enable higher throughput rates than possible for conventional rotary spraying nozzles for which centrifugal forces determine filament stretch and throughput rate at the same time. Filament length and drop size decreased with increasing rotational speed at a given total pressure (sum of centrifugal pressure and static liquid pressure at nozzle inlet) or flow rate, and the filament length and drop size increased with increasing liquid pressures and related throughput rate at a given rotational speed. Chilling-solidification of the spray drops was superimposed in selected cases of interest. Prilling (spraying + chilling) was carried out for various emulsion systems in a prilling tower applying average air temperatures of ca. $-10°$ C for higher melting fat-continuous emulsions down to $-50°$ C for low melting oil- or water-continuous emulsions, in order to produce solid powder particles. The micro-structure of the solid particles was analyzed in further detail by cryo-scanning electron microscopy (Cryo-SEM). Concerning emulsion structure preservation in the products, the results clearly demonstrated that the disperse structure can differ significantly from the initial emulsion structure if critical flow stress conditions are exceeded. Respective process-structure functions were quantified. For emulsion based prilled powders, the applicability and adjustability as functional component carriers being of big interest in industries such as food, pharmaceutical and cosmetics, we designed an in vitro experimental test setup. With this the release kinetics of functional components encapsulated/embedded in dispersed emulsion secondary or tertiary drop phase(s) were quantified.

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Increased Control of Metal Powder Yields from Two-Fluid Close-Coupled Gas Atomization by Understanding of Gas and Melt Flow Manipulation

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Abstract

Improved particle size control and process efficiency are critical to minimize gas consumption and off-size powder production by two-fluid close-coupled gas atomization, particularly for high cost or reactive metals and alloys. Thus, knowledge of the operating physics of atomization is needed to improve melt feed tubes and gas nozzles and to select atomization parameters. Physical modeling and visualization with high-speed videography and schlieren imagining allowed exploration of proposed melt and gas flow models. Model predictions were tested with experimental atomization trials. Supported by U.S. DoE from OS-BES and FE-Cross-Cutting Research, by U.S. DoD-ARO, and by Work for Others sponsors at Ames Laboratory, through U.S. DoE contract no. DE-AC02-07CH11358.

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Abstracts

ILASS-Americas
Institute for Liquid Atomization and Spray Systems

Thresholding and segmentation concerns in spray imaging

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Abstract

Continuing advances in fast digital detection, high-resolution imaging hardware, and new diagnostic methods have provided a wealth of valuable experimental imaging data for the study of spray breakup and atomization. The availability of higher quality visualizations of spray phenomena is an undeniably positive, but taking full advantage of these data requires automated image processing methods. In general, these analysis tools implicitly filter and distort the image source data and care must be taken to ensure that the assumptions required to apply the processing methods are valid. In this work, we briefly discuss the basis of a spatially resolved intensity signals subject to sampling and Nyquist limits, and examine thresholding, clustering, and segmentation of image regions for identifying spray fluid structures. Image data compiled for the study of spray breakup under well-controlled conditions using the Chalmers steady spray are analyzed to provide context for discussing concerns for basic thresholding and more sophisticated segmentation of spray images.

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Framework for Uncertainty Quantification of Multiphase Flows Including Atomizing Jets

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Abstract

Uncertainty quantification (UQ) is a very necessary and often neglected component in producing useful results from fluid flow simulations, particularly when knowledge of initial and boundary conditions or fluid properties is not exact. Reliably estimating the impact of input uncertainty on design criteria can help to minimize unwanted variability in critical areas. A framework to couple UQ and multiphase flow numerical techniques is proposed. Useful for simulating gas-liquid flows, this framework will advance our understanding of atomizing fuel injectors, ram-jet engines, and a multitude of other flow scenarios. The proposed scheme leverages an intrusive polynomial chaos method which significantly reduces computational cost over non-intrusive collocation methods such as Monte-Carlo. Using the intrusive method requires transforming the governing equations into weak form through substitution of stochastic (random) variables. We extend the single-phase framework of Le Maître et al. [1] to multiphase flows, achieved by the addition of a random level set scheme to capture the (now random) phase interface. The proposed framework is then applied to canonical multiphase flow problems to assess the feasibility of the approach for providing useful information on gas-liquid flows.

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High-Speed Radiography and Visible Light Extinction of a Pressure-Swirl Atomizer

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Abstract

X-ray radiography, imaging, and fluorescence have been applied to optically dense sprays with great success. The majority of these studies have focused on fuel spray studies for combustion engines and rockets, which have often required demanding or unusual environments or flow configurations that are not easily replicated by other researchers. The x-ray results probe a different aspect of the spray (liquid density distribution) than visible light diagnostics (scattering from droplets), and as such it can be difficult to compare results from x-ray radiography measurements to results with more conventional diagnostics. Moreover, many previous studies of quasi-steady state sprays have focused exclusively on the time-averaged behavior of the spray. This study will focus on detailed, time-resolved measurements of a small-scale, commercially available pressure swirl atomizer with simultaneous x-ray radiography and visible light extinction. The data available from both the time-averaged and fluctuation measurements will be described, as well as the potential to correlate visible light extinction with x-ray radiography.

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Simulating Phase-Change Phenomena Using Gradient Augmented Level Set Approach

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Abstract

A sharp interface capturing approach is presented for two-phase flow simulations with phase change. The Gradient Augmented Level Set (GALS) method is coupled with the two-phase momentum and energy conservation equations to advect the liquid-gas interface and predict heat transfer with phase change. The Ghost Fluid Method (GFM) is adopted to discretize the advection and diffusion terms for velocity in computational cells located in the interfacial region. Furthermore, the GFM is also employed to treat the discontinuity in the stress tensor, velocity, and temperature gradient across the interface yielding a more accurate treatment in handling interfacial jump conditions. Thermal convection and diffusion terms are approximated by explicitly identifying the interface location, resulting in a sharp treatment for the energy solution. This sharp treatment is extended in estimating the interfacial mass transfer rate. At the computational cell, an n-cubic Hermite interpolation scheme is employed to describe the interface location, which is locally fourth-order accurate. This extent of subgrid level description provides an accurate methodology for treating the various interfacial processes with a high degree of sharpness. The ability to predict the interface and temperature evolutions accurately is illustrated by comparing numerical results with existing 1D to 3D analytical solutions.

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Toward quantitative spray measurements using high-performance high-speed video cameras

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Abstract

While performed by only a few fortunate researchers a decade ago, time-resolved measurements of spray atomization and mixing using high-speed digital video-cameras are now standard. The development of quantitatively robust spray measurements, imaging the time history of the event, requires dependable high-speed imaging equipment. This aspect becomes critical when the diagnostic relies on photonic quantification as needed for the measurement of optical extinction commonly used to measure the liquid extent of penetrating sprays. One potential issue is that the instrument (high-speed camera) used to quantify the extinction of light by the spray droplets must be linear and repeatable. Under certain circumstances, the weaknesses of commercially available high-speed cameras render the experiment complicated and uncertain.

This study evaluated two advanced CMOS-based continuous-recording high-speed cameras available at the moment. Various parameters potentially important toward accurate time-resolved measurements and photonic quantification have been measured under controlled conditions on the bench, using state-of-the-art instrumentation. We will detail the procedures and results of the tests laid out to measure sensor sensitivity, linearity, signal-to-noise ratio and image lag, defined as dependence/persistence of the previous frame. The performance of the camera electronics were evaluated through measurements of the pixel readout and electronic shutter accuracy. Results show that, with care and understanding of their performance, the cameras can be reasonable alternatives to scientific CCD cameras, while also delivering, time-resolved multi-frame data.

Underlying Errors in Level Set Methods

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Abstract

The practice of periodically reinitializing the level set function is well established in two-phase flow applications as a way of controlling the growth of anomalies and/or numerical errors. In the present work, the underlying roots of this anomalous growth are studied, where it is established that the augmentation of the magnitude of the level set gradient ($|\nabla\phi|$) is directly connected to the nature of the flow field; hence, it is not necessarily the result of some type of numerical error. More specifically, for a general flow field advecting the level set function, it is shown that the eigenpairs of the strain rate tensor are responsible for the rate of change of $|\nabla\phi|$ along a fluid particle trajectory. This straining action not only affects the magnitude of $|\nabla\phi|$, but other higher order derivatives as well. Adopting the Gradient Augmented Level Set method to produce tangible illustrative results, it is shown from numerical analysis that the error for ϕ is directly connected to the size of $|\nabla\phi|$ and to the magnitude of the second and fourth order derivatives of ϕ. These analytical findings are subsequently supported by various examples. The role of reinitialization is discussed, where it is shown that in cases where the zero level set contour has a local radius of curvature that is below the local grid resolution, reinitialization exacerbates rather than diminishes the degree of error. For other cases, where the interface is well resolved, reinitialization helps stabilize the error as intended.

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Combined Visible and X-Ray Extinction Measurements in a Water Spray from a GDI Injector

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Abstract

Characterization of GDI injectors in the near injector region using conventional optical techniques is difficult due to the high levels of obscuration present in these sprays. This paper describes the characterization of a GDI injector using combined X-Ray and laser extinction tomography. One of the advantages of using X-Rays is that the near injector region of dense sprays can be characterized reliably. A single axis X-Ray system was used to obtain laser extinction measurements in a water spray from a GDI injector. The injector was operated at several pressures representative of those used in the automotive industry. The injector was rotated to provide data a multiple view angles. The data was deconvoluted using a Maximum Likelihood Estimation method to provide the local mass concentrations in the spray. For validation purposes, additional measurements were obtained at several locations downstream of the injector where the path integrated extinction was less than 95%. At these locations, the GDI injector was also evaluated using a SETscan optical patternator. The SETscan optical patternator provided the planar local surface area densities in the spray. The Sauter Mean Diameter (SMD) of the spray was estimated from these combined X-Ray and laser extinction measurements. A diffraction based instrument was also used to obtain the SMD in the spray at the same location. The results obtained from the diffraction system and the combined visible and X-Ray extinction measurements agreed with each other within the uncertainty bands of the methods. Therefore, a combination of soft X-Ray and visible extinction tomography promises to provide a unique method for characterizing sprays from GDI injectors.

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Large eddy simulation of turbulent spray with a filtered density function

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Abstract

Liquid atomization is a fundamental process found in inhalation aerosols, fuel injectors, and agricultural sprays, yet our methods for predicting the process are underdeveloped. Current state-of-the-art computational methods either prescribe primary atomization or are prohibitively expensive. We present a novel filtered density function (FDF) method for the large eddy simulation (LES) of primary atomization. A single fluid formulation is considered, such that the Eulerian governing equations are solved throughout the domain for both phases, while a set of phase-identifying Lagrangian/stochastic particles define the local volume of fluid. A Lagrangian volume of fluid provides conservation and, when coupled to a FDF, sub-grid-scale phase resolution. We consider both smoothed particle hydrodynamics and the finite particle method for construction of the particle-based interface geometry, as well as the pairwise force and curvature-based methods for determination of the surface tension term. These different particle approaches are compared with respect to geometric convergence and dynamic performance. This serves as a significant step in the development of a LES methodology for simulating turbulent sprays.

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Characterization of Diesel Spray Breakup Models Using Visible and X-Ray Extinction Measurements

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Abstract

For direct-injection engines, fuel injection and atomization are known to influence combustion and emissions formation. In light of increasingly stringent emissions regulations, accurate modeling of these spray physics is therefore key to enable simulation-based design of high-efficiency clean combustion engines. However, the physical mechanisms governing the primary breakup of the liquid fuel spray into droplets are still unknown. The most widely employed models assume that breakup is dominated by aerodynamic shear-induced instabilities at the surface of the liquid fuel jet. However, recent experimental images have suggested that liquid turbulence dominates the spray breakup process for fuel injection into atmospheric conditions. While conventional injection conditions are characterized by dense ambient environments, many new combustion strategies utilize advanced fuel timing, which can result in injection conditions that approach atmospheric densities. These trends suggest that turbulence may play a more influential role than is assumed in the majority of models employed in today's engine simulation packages. Therefore, re-assessment of the physics underlying spray breakup models is needed to characterize expected droplet sizes from the primary breakup process and identify current modeling inaccuracies.

Towards this goal, aerodynamic spray breakup is simulated in the computational fluid dynamics code CONVERGE over a range of ambient and injection conditions. The response of predicted droplet size to changes in operating condition is compared to predictions from turbulent spray breakup theory. The largest discrepancy between the predictions is seen at low ambient densities (less than 7.6 kg/m^3). To help address knowledge gaps in expected spray structure under these conditions, a new experimental methodology was developed using joint x-ray and laser extinction measurements to deconvolve the measured signal into SMD distributions. Initial results demonstrate success of the methodology in capturing expected trends of SMD with changes in injection pressure and indicate that current spray breakup models severely underpredict droplet size distributions.

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Least Square Curvature Calculation Method for VOF Schemes

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Abstract

A new method is proposed to compute the curvature of the gas-liquid interface present in a multiphase flow such as an atomizing jet. The curvature is proportional to the surface tension force thus an accurate evaluation of the curvature is necessary for predictive simulations of these flows. Particularly, the small scales present in the atomization of a coherent liquid structure into droplets will be controlled by surface tension forces.

The proposed scheme employs a least square method to fit an implicit polynomial function to a cloud of points created at the interface. The points are constructed from the volume of fluid (VOF) representation of the phase interface. The curvature is computed explicitly from this polynomial function. The purposed curvature method is tested extensively in order to determine the optimal stencil size and the degree of the polynomial function in order to reduce computational cost and increase numerical accuracy. The results are then compared against the standard height function method.

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Improvement of Spray and Flow Characteristics of Injection Nozzle for Direct Injection Diesel Engine

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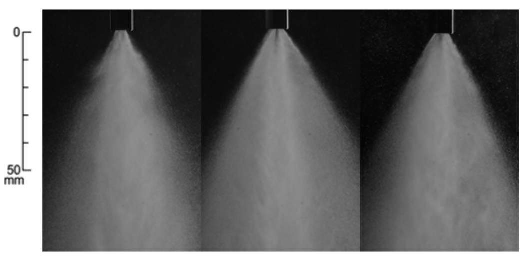
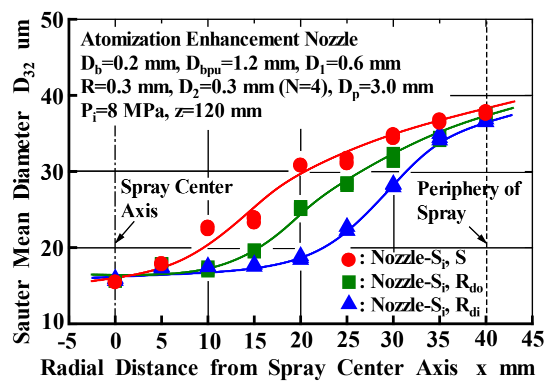
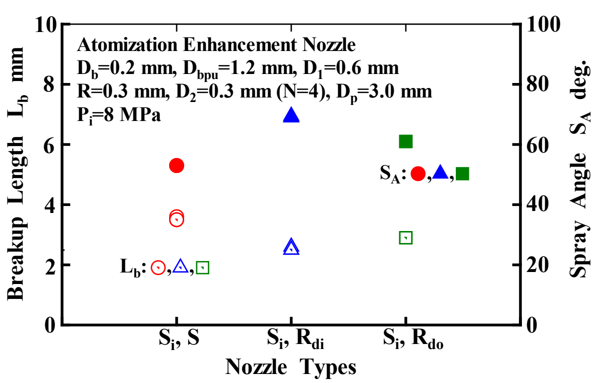
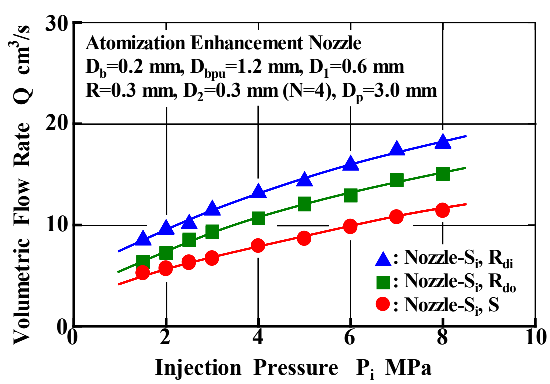
Abstract

The purpose of this study is to develop of a direct injection Diesel nozzle, which is obtained high-dispersion spray inside a combustion chamber by strong disturbance of liquid flow due to cavitation phenomena. Diesel injector is necessary to jet of fuel high-injection pressure over about 200 MPa. In spite of high-injection pressure, at best spray angle may take about from 10 to 20 degrees and droplet diameter; Sauter mean diameter may take about 10 microns. Moreover, since conventional Diesel injector cuts away an edge of inlet of nozzle holes in order to increase discharge coefficient and to improve flow characteristics, high-injection pressure is demanded to obtain spray suitable for combustion. The nozzle, which was designed and invented in this study, was obtained with considerably large spray angle of over 70 degrees, short breakup length; liquid core length of about 2 mm for hole diameter of 0.3 mm, Sauter mean diameter of 10 microns order; about 15 microns and homogeneous droplets of spray toward radial direction of spray at injection pressure of 8 MPa. Moreover, volumetric flow rate of nozzle with round cutting at inlet of the nozzle hole was obtained about two times one compared with sharp inlet shape nozzle at all injection pressure region. Both spray and flow characteristics were improved significantly.









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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

High-Fidelity Simulations of Realistic Electrically-Charged Atomizing Diesel-Type Jets

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Abstract

Electrohydrodyanmics (EHD) has the potential to significantly influence spray characteristics. In this work, the potential benefits for applying EHD to realistic Diesel-type jets is explored. We consider jets with Reynolds number of 10,000 and Weber number of 10,000. These jets are studied with high-fidelity numerical simulations performed using a state-of-the-art numerical framework that globally conserves mass, momentum, and the electric charge density even at the gas-liquid interface where discontinuities exist. We found that EHD effects are capable of enhancing atomization of realistic Diesel jets with reasonable electric charge loadings. The results demonstrate EHD is a viable methodology to improve performance of fuel injection systems.

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A New Monodisperse Droplet Generator and its Applications

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Abstract

Monodisperse droplet standards are valuable for calibrating spray diagnostics instrumentation and for investigating the effect of drop diameter on the spray phenomena, such as droplet combustion and droplet-film interaction. There is a growing interest in finer monodisperse droplets. To address this need, a new instrument for generating a wide range of monodisperse droplets is introduced, which is an advancement of the technology underlying Vibrating Orifice Aerosol Generator or VOAG. In a VOAG, monodisperse droplets are generated by using uniform ultrasonic perturbations for breaking a liquid jet, which is created by forcing the liquid out of a small orifice. This approach is suitable for generating relatively large drops (e.g. greater than 50 micron), but difficult for producing finer droplets, as smaller orifices are easily clogged or damaged. This problem is solved in a newly-developed instrument, referred to as Flow-focusing Aerosol Generator (FMAG), in which liquid is released from a nozzle with a large internal diameter (100 micron in the present realization). Liquid jet is subsequently attenuated using acceleration of the surrounding co-flowing air. A final jet diameter as small as 8 micron is realized. As in VOAG, ultrasonic perturbations are used in FMAG to break up the attenuated liquid jet into uniformly-sized droplets. In order to demonstrate the use of FMAG as a calibration standard, response curves of a phase Doppler interferometer using 15 to 65 micron monodisperse droplets are presented. Also, results of our preliminary experiments on spraying biological material are included. Activity of lipase enzyme after nebulization with FMAG and a conventional nebulizer was measured. Activity of the sample sprayed by FMAG was about twice that of the conventional nebulizer. Enzyme activity of FMAG-sprayed sample dropped only by 6% when ultrasonic perturbation was turned on. FMAG is shown to be promising for spraying liquids containing large and fragile biological molecules.

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Temporal Characteristics of Secondary Atomized Non-Newtonian Liquids in the Bag and Multimode Regimes

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Abstract

Six non-Newtonian shear thinning solutions, with Ostwald-de Waele (power-law) model consistency indices of $0.046 \leq K \leq 0.30$ and flow behavior indices of $0.71 \leq n \leq 0.93$, were formulated and used to form single drops that were subject to aerodynamic loading via a continuous jet. Conditions were adjusted so that breakup occurred in the bag and multimode regimes with Weber (We=20 and 30) and Ohnesorge ($0.002 \leq Oh \leq 0.38$). High speed shadowgraphy was used to measure the instantaneous drop centroid positions with these data then used to calculate the corresponding velocities, accelerations and drag coefficients. Temporally resolved drop bag/axial length and rim diameter/transverse dimension were also determined as functions of time. Increased viscous forces caused the rate of drop deformation to decrease in both the axial and transverse directions, which lead to a reduction in drop velocity and the concomitant decrease in C_d peak near initiation time and increases the time to reach each liquids end of bag breakup minimum C_d. Besides viscosity, increasing We increases the rate of deformation in the axial and transverse directions, leads to more rapid drop velocity growth, and to larger peaks in C_d near the initiation time.

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Magnetic Resonance Imaging measurements inside and in the near-nozzle regions

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Abstract

Magnetic Resonance Imaging (MRI) is a non-invasive, three-dimensional imaging technique capable of measuring optically opaque media. Its signal can be sensitized to many parameters (velocity, diffusion/mechanical dispersion, air-liquid boundaries, etc). It is most sensitive where the sample's density is the highest, i.e., inside the spray nozzle and in the near-nozzle regions; these are also regions which represent a significant challenge for the most common methods used in spray characterization [1].

In this study, results are presented using MRI 1H measurements of near-nozzle and inside the nozzle regions of a water spray generated by a ceramic flat-fan hydraulic atomization nozzle. High flow speeds and the medium heterogeneity required the use of short encoding times (0.1-0.5 ms) and the use of MRI techniques originally developed for materials science applications. Water flow inside the nozzle was well-characterized by proton density and velocity maps which demonstrated the flow acceleration, with rotation developing towards the orifice. The signal from the near-nozzle region showed the expected flat-fan pattern up to 4 mm away from the orifice, with steady signal loss with distance, as the liquid atomized into droplets. The results demonstrate the potential of MRI for measuring spray characteristics in these regions, and measurement challenges are discussed.

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Breakup morphology of inelastic drops at high Weber numbers

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Abstract

We report breakup morphology of inelastic non-Newtonian drops exposed to a co-flowing air stream at high air jet velocities. Power-law solutions were prepared by mixing one of two grades of CMC (sodium carboxymethyl-cellulose) with DI-water. Breakup morphology is reported in terms of Weber number, *We* based on the air density, ρ_a, and Ohnesorge number, *Oh*, based on the zero shear rate viscosity. We present results for the sheet thinning and catastrophic breakup regimes, which correspond to *We* beyond those at which bag-and-stamen breakup is seen. For the sheet thinning case the morphology is very similar to its Newtonian counterpart. For the catastrophic case, however, we observed the formation of a thin sheet which rolls up from it edges before collapsing onto itself and eventually disintegrating into smaller fragments. These topological changes are strongly dependent on the ratio $Oh/\sqrt{We}$. In contrast, the dependence on power law index, *n*, however, was not found to be strong for the range of *n* tested.

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High-Speed Two-Dimensional Synchrotron X-ray Radiography of Propulsion Sprays

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Abstract

High-speed (120 kHz), two-dimensional x-ray imaging is demonstrated to observe dynamics and quantify the path-integrated liquid distributions in propulsion sprays. The high spatial resolution (65 μm), high temporal resolution (350 ns) measurements are made at the 7-BM beamline of the Advanced Photon Source at Argonne National Laboratory using broadband white beam x-rays. Potassium iodide is added to the liquid at 10% by mass to increase x-ray attenuation and image contrast. A set of two imaging experiments was pursued: interrogation of a swirl coaxial spray and an impinging jet spray. The accuracy and precision of the measurements are quantified, and limitations of the technique and future strategies are discussed.

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Spatially Resolved Characteristics of Elastic Non-Newtonian Secondary Breakup

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Abstract

The present work consists of a study of spatially resolved secondary atomization characterization (fragment size and velocity distributions). This is especially important, as non-Newtonian liquids lack the depth of research of Newtonian liquids, and fragment size and velocity distributions are mostly unknown. The spatial characterization of a viscoelastic xanthan gum solution undergoing breakup in the bag regime were obtained using both dual- and fiber-mode PDA systems. The xanthan gum solutions were characterized using the Carreau rheological model and Zimm relaxation time model, as these were the best fit to the experimental data. Data were obtained at multiple air mass flow rates (Weber number) and at both fixed and varying radial distances for a set downstream location (location was selected such that the liquid bag had undergone breakup, and the rim had almost completed breakup). Initially, a bi-modal distribution was expected to be seen in the PDA data, as the rim and bag fragments are two distinct sizes; instead, a bimodal distribution was only seen for a few cases, and in those cases, it was attributed to large bag fragments instead of rim fragments after observing corresponding high-speed video of the breakup process. These videos also showed that small fragments from the bag occurred closer to the drop entry into the air stream (early in the breakup process); these small fragments then had time to accelerate to the air jet velocity. The larger fragments, with a larger surface area to volume ratio, took longer to accelerate. Measurements taken at different axially locations showed that the bag breakup process is not symmetric. After again analyzing high speed video, it was seen that the fragments formed from the bag breakup process tend to disperse radially instead of traveling directly downstream with the air flow; this asymmetry was indeed reflected in both the fragment and velocity distribution data.

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Rapid Evaporation of Water Sprayed on Metallic Media Beds

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Abstract

Rapid evaporation of water for steam generation can be achieved by spraying liquid droplets on a heated metallic surface. This paper describes an experimental study to measure the rate at which water sprayed on the surface of a metallic media bed evaporates. The experimental test apparatus consists of a balance, one pan of which is filled with the metallic media while the other pan acts as a counterweight. The metal is heated electrically to the desired initial temperature, after which the heater is switched off and a water spray is directed on the hot surface. A digital force gauge is used to measure the displacement of the balance arm as a function of time, from which the mass of water in the pan is determined. This change in mass is used to quantify the rate that the water evaporates, and to study the influence that different parameters have on the evaporation rate of water. The parameters studied in this paper include the thermal mass of the media bed and the total surface area. Increasing the surface area does not necessarily increase the rate of water evaporation. The impact and evaporation of water droplets on the hot surface is captured using high-speed photography.

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Spray Characterization of non-Newtonian Impinging Jets Using Digital In-Line Holography.

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Abstract

Impinging jets are a common method for atomizing propellants in liquid rocket engines. Recent work has investigated improving rocket engine safety while also improving the performance by using non-Newtonian liquids. Since viscosity hinders the atomization process, liquids that exhibit strong shear-thinning behavior are required. The two non-Newtonian liquids considered in this work were solutions of carboxymethylcellulose (CMC) and DI-water having 0.8 wt.-% CMC-7MF and 1.4 wt.-% CMC-7MF. The Bird-Carreau rheological model was adopted to describe the shear-shinning behavior. A generalized Bird-Carreau jet Reynolds number was used as the primary independent variable. To that end, spatially resolved, three-dimensional (3D) spray characteristics are acquired to evaluate the efficacy of non-Newtonian liquid atomization. A double-exposure digital in-line holography (DIH) system and a hybrid method image analysis program is used in this work to extract 3-D distributions of droplet size and drop velocity. Spray characteristics using DI water are also considered to serve as a reference for the non-Newtonian spray cases.

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The Influence of Particles on the Disintegration of the rims of fan sheets of Particulate Suspensions formed during Atomization

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Abstract

The effects of particles on the break-up of rims of freely moving sheets of aqueous suspensions formed by hydraulic pressure nozzles have been studied using high speed photography. The rims of suspensions and of water show fingers – micro-jets at uneven spacing along rim trajectory. Under identical atomizing conditions, the presence of coarse particles in the sheets reduces the stability of the rims, leading to shorter break-up lengths compared to sheets free of particles. This effect is intensified by increasing the size and volume fraction of particles. The wavelengths of the surface disturbances that break up the rim are much larger than the particle diameter and do not vary much with size of particles used in the formulation of the suspension, when a large orifice nozzle is used. The amplitudes of the waves that break up the rims of the sheets of suspensions are the same order of magnitude as those that break up the rims of sheets of water free of particles. Drop sizes produced by unstable rims of sheets of high volume fraction of coarse particles are same magnitude as those produced by the sheets themselves in sharp contrast to drop sizes produced by unstable rims of sheets containing low volume fraction solids, which are much larger than those produced by the sheets. Rims of sheets of suspensions are subject to radial and axial disturbances, in much the same way as the rims of sheets free of particles, however the former are more unstable.

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Numerical Study of the Effect of Surface Wettability on Performance of Spray Cooling Process

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Abstract

A three dimensional CFD model including coupling between multiphase flow and conjugated heat transfer modules is developed to simulate the impact, spreading and transient heat transfer between a cold water droplet onto heated surfaces. The impingement results in terms of total heat transfer is compared for Superhydrophobic and hydrophilic surfaces. The simulations are based on a primitive approach toward optimization of spray cooling process efficiency, and determining the total dissipated energy from the surface. The Navier-stokes equation expressing flow distribution of the liquid and the gas, coupled with the Volume of Fluid (VOF) method for tracking the interface between the liquid and gas are solved numerically using finite volume methodology. The mesh dependency and the domain sensitivity are examined using three dimensional models. It is demonstrated that the spray cooling effort onto the superhydrophobic substrate was capable of improving the efficiency of the cooling process for nearly 5 % comparing with that onto a hydrophilic surface.

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Industrial applications of ultrasonically stimulated droplet generation

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Abstract

Droplet generation by Plateau-Rayleigh jet breakup, observed by Savart in 1833, can produce extremely precise and regular droplet streams. The technique is the basis of continuous inkjet printing, in which drop size, direction, velocity and jet breakup length must be uniformly controlled across hundreds of nozzles. It has been commercialized in a diverse range of other applications, including high precision surface coating and cleaning, cell sorting, microfluidic emulsion generation, microparticle generation and encapsulation, and even production of laser targets for extreme ultraviolet lithography.

Operation of large numbers of jets in parallel allows scalable throughput with unchanged hydrodynamic conditions and predictable output, taking advantage of nozzle array micromachining techniques used to produce modern inkjet print heads. However the need for microscopic nozzles is a key challenge when small droplets of particle-containing liquids are needed, with nozzle blockage limiting applications where the ratio of droplet diameter to maximum particle diameter is less than approximately 10. We present droplet generator designs to minimise blockage using ultrasonic nozzle plate motion to provide jet breakup stimulation and nozzle cleaning, combined with cross-flow or flow-focussing liquid feeds. These new designs enable a wide range of applications requiring high throughput, high precision spray generation, bridging the gap between the capabilities of random spray breakup processes and inkjet technologies.

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Detailed numerical simulation in the breakup region of the Engine Combustion Network (ECN) Spray A

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Abstract

The Spray A case of the Engine Combustion Network has been widely studied since the inception of this widespread research effort. Detailed visual observations of the breakup processes and droplet formation have been reported, x-ray radiography has also been applied to the near nozzle of Spray A to quantitatively obtain the fuel mass distribution in the dense spray region. Because of the experimental limitations of the current diagnostics in this region, high-fidelity simulation seems like an obvious alternative to look into the problem and deliver paramount information of the breakup processes to improve the global understanding as well as engineering models. Yet, only a few publications have reported high-resolution large eddy simulation (LES) or direct numerical simulation (DNS) of the breakup processes in the Spray A injection case.

Detailed simulations of the near-nozzle region of Spray A have been conducted and the results are reported and analyzed. An open source code solving the incompressible Navier-Stokes equations was used to investigate the stages of the atomization processes under the challenging conditions of Spray A. The predictions demonstrated once again that injection mass flow rate is paramount to predict the development of such sprays in the near-field. Comparisons between x-ray radiography measurements and numerical predictions showed that an unperturbed liquid region is observed in both cases, extending over 10 orifice diameters from the nozzle exit. The simulations also showed that highly detailed computations are needed to understand these processes and that the conditions of a typical diesel injection event represent a highly challenging problem to modelers.

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Deformation and Breakup Computations of Drops in Three Dimensional Symmetric Flows and Comparisons with Experimental Observations

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Abstract

Numerical simulations are performed to study the deformation and breakup of a water drop in a three dimensional symmetric airflow at different Weber numbers. The breakup regimes considered include the bag breakup, the stamen breakup and the sheet-thinning/stripping breakup. The simulations are performed using a modified version of the interFoam solver in OpenFOAM®. The numerical results reflect the behavior of the different breakup regimes observed in experiments. Furthermore, the drop size distributions of each breakup regime obtained in the simulations are quantified by lognormal distribution and volume-weighted chi-squared distribution. These product drop size distributions are consistent with the experimental observations.

Key Words: drop deformation, drop breakup, bag breakup, stamen breakup, sheet-thinning breakup, stripping breakup, product drop distributions

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Computing the spray characteristics of a Simplex atomizer using the Ω-Y model

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Abstract

Modeling the near nozzle flow dynamics is a pretty challenging task. Accurate detailed predictions require transient LES and VOF models which are expensive computational models. A relatively simpler, low cost Ω-Y model is used in this study to predict spray angle and droplet size distribution for a commercial nozzle. The model solves a scalar transport equation for interface surface area density and is implemented in a computational fluid dynamics code, ANSYS FLUENT. Steady state solver is used along with a user de-fined scalar to compute the interfacial area density transport equation. The liquid fraction is tracked via a species transport equation. The spray pattern and droplet size distribution is compared with laboratory data and a VOF study for the same nozzle flow condition.

Keywords: CFD, Sprays, Modeling, Atomization

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A Continuum and Molecular Dynamics Simulation of Nano-droplets Collision

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Abstract

The extent to which the continuum treatment holds in binary droplet collisions is examined in the present work by using a continuum-based implicit surface capturing strategy (Volume-of-Fluid coupled to Navier-Stokes) and a molecular dynamics methodology. The droplet pairs are arranged in a head-on-collision configuration with an initial separation distance of 5.3 nm and a velocity of 3 ms^{-1}. The size of droplets ranges from 10 to 50 nm. Inspecting the results, the collision process can be described as consisting of two periods: a pre-impact phase that ends with the initial contact of both droplets, and a post-impact phase characterized by the merging, deformation, and coalescence of the droplets. The largest difference between the continuum and MD predictions is observed in the pre-impact period, where the continuum-based viscous and pressure drag forces significantly overestimate the MD predictions. Due to large value of Knudsen number in the gas (Kn_{gas} =1.972), this behavior is expected. During the post-impact period, both MD and continuum-based simulations are strikingly similar, with only a moderate difference in the peak kinetic energy recorded during the collision process. With values for the Knudsen number in the liquid (Kn_{liquid} = 0.01 for D = 36nm) much closer to the continuum regime, this behavior is expected. The 50 nm droplet case is sufficiently large to be predicted reasonably well with the continuum treatment. However, for droplets smaller than approximately 36 nm, the departure from continuum behavior becomes noticeably pronounced, and becomes drastically different for the 10 nm droplets.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Sampling of the Velocity Space: An Agenda for Liquid-Sheet Atomization Analysis

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Abstract

A novel state-of-the-art numerical capability for efficient modelling of multiphase flows has been developed and applied to primary breakup of liquid sprays. The Robust Conservative Level Set (RCLS) method uses high-order WENO schemes on mixed-element unstructured meshes to solve the transport equation for the level-set variable. The method is implemented within the framework of OpenFOAM, and is fully parallelized. The present study uses the new capability to understand the phenomenology observed during prefilming air-blast atomisation of a planar liquid sheet. In commercial aircraft application, this is essential for effective control of fuel atomization and cleaner, more efficient combustion processes. We performed a parametric study to make an informed qualitative assessment on the impact of various liquid and air velocities for a fixed prefilmer geometry. The computations reproduced the transient nature of the fluid dynamics of the phase interface behavior. The study has revealed the importance of the interaction between the two fluids at the prefilmer lip. The behavior and development of the liquid sheet is found to be influenced mainly by the relative inertia of the gas and the liquid. Results also show the influence of vortex action and shearing effects on the breakup mechanism at the atomizer edge by varying the operating conditions to map a wide range of gas and liquid velocities.

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A Sharp Interface Level Set Method for Evaporation of a Falling Droplet

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Abstract

In gas turbine engines, the burning rate of the fuels are governed by the evaporation of liquid fuels in the surrounding ambient at higher temperature. In this work, an in-house sharp interface Level Set code based on the Ghost Fluid Method (GFM) is used. Energy, species and momentum equations are solved in axi-symmetric coordinates for studying the droplet evaporation phenomenon, falling under gravity. The energy and vapor mass fraction species equations are coupled - using Clausius–Clapeyron relation; and validated with d^2 law for Stefan flow condition. The energy and species equations are further coupled with sharp interface based flow solver for capturing the internal circulation - Marangoni currents developed in the liquid droplet due to temperature gradient at the interface. The effect of atomized droplet size, ambient temperature, and droplet temperature on the deforming droplet are studied. Parametric study is done to understand the near-vicinity flow physics on evaporation dynamics of the droplet. The evaporation data of the droplet in the hot surrounding medium can be used to predict the ignition delay and combustion characteristics in the fuel droplets.
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The Influence of Excluded Volumes of Particles and Menisci on predicting Wave Growth and Stability Lengths of Sheets of Suspensions of Coarse Particles during the Atomization of fan sheets

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Abstract

A high speed photographic technique has been used to demonstrate the effect of coarse particles in destabilizing sheets of suspensions produced by single fluid hydraulic spray nozzle. Increasing the volume fraction of wetted coarse particles, increases growth rates of waves and reduces the sheet break-up lengths. Furthermore, the amplitude ratios of the waves required to break up sheets of suspensions closer to the nozzle are much lower than those required to break up sheets of the liquid medium free of particles further away from the nozzle. To account for these observations, a semi-empirical model is presented which predicts the growth rates of waves on sheets of suspensions produced by hydraulic spray nozzles during atomization. It takes into account, the volume of particles and the associated liquid held around them which are not thinned by the radial flow of liquid within a sheet in calculating the effective thickness of the sheet in the inter-particles space. The model has been validated by using it to predict the growth rate of waves on sheets during the atomization of suspensions under standardized conditions. The model predicts faster growth rate of waves on sheets of suspended wetting particles compared to growth rates on sheets free of particles produced under identical conditions. The predictions are consistent with the above observations and pertinent results reported in the literature. It predicts that non-wetting particles have a smaller effect on growth rates of waves on sheets compared to the effect of wetted particles. In predicting the break-up of sheets of suspended particles by wave action, it is important to estimate the effect of wetting particles in thinning regions of sheets in the inter-particles space below that predicted by the commonly used hyperbolic law.

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Three-dimensional Structure of Like-doublet Impinging Jet Sprays Obtained Using Digital Inline Holography

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Abstract

Digital inline holography (DIH) is used to measure bow ligament geometry, bow ligament velocity and bow ligament shedding frequency for like doublet impinging jet sprays. The influence of jet Re on each of these quantities is presented with preliminary physical explanations provided for each.

X-ray radiography measurements and numerical simulations of cavitation in a metal nozzle

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Abstract

Making quantitative measurements of the vapor distribution in a cavitating nozzle is difficult, owing to the scattering of light at the phase interfaces and walls, as well as the small scales involved. In this paper, we present the results of new x-ray radiography experiments performed at the 7-BM beamline of the Advanced Photon Source at Argonne National Laboratory. X-ray radiography enables quantitative measurement of the fluid density in multi-phase flows that are optically opaque. Cavitation in a submerged beryllium nozzle 500 microns in diameter with L/D ratio of 6 was studied. Beryllium was used as it is highly transparent to x-rays. It can withstand higher pressures than plastic models and has a surface roughness similar to a metal fuel injector. We present quantitative, time-resolved measurements of cavitation vapor distribution with a spatial resolution of 5um and a temporal bandwidth of 6.5MHz. The measurements are compared to RANS and LES predictions of the flow made using a homogeneous relaxation model. The properties of the gasoline surrogate used in the experiments have been replicated in a pressure-enthalpy lookup table that avoids the need for a simplified equation of state. Comparisons are made at cavitation and Reynolds numbers typical of diesel injectors, and variations between the quantitative experimental vapor fraction data and the simulations are discussed. In addition to quantitative comparisons of the time-average vapor fraction distribution in the nozzle, the time-resolved radiography data enable quantitative comparison of the power spectrum of the vapor volume fraction between experiments and simulations. The data highlight the need for validation of both time-average and transient phenomena in cavitation simulations.

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Acoustically Forced Coaxial Hydrogen / Liquid Oxygen Jet Flames

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Abstract

Combustion instabilities can pose serious problems in the development of liquid rocket engines. In order to understand and predict them, it is necessary to understand how representative liquid rocket injector flames react to acoustic waves. In this study, a representative coaxial gaseous hydrogen / liquid oxygen (LOX) jet flame is visualized for both reacting and nonreacting cases. The jet flame was studied unforced, without acoustics, and forced, with transverse acoustic waves in a pressure node and a pressure antinode configuration. For unforced flames, reactions are found to cause a significantly more expanded plume due to the vaporization and expansion of the LOX. Flame holding is established at the lip with a particularly dominant LOX recirculation zone. Nonreacting convective structures propagate downstream at relatively constant velocity, while reacting structures start at a slow speed and gradually accelerate with downstream distance. These structures never reach the velocity of the nonreacting structures. Reactions shift the spectral content to lower frequencies, consistent with trends observed in the linear stability literature. For forced flames, acoustics do not appear to affect the flame holding. Dynamic mode decomposition detects jet response not only at the fundamental frequency but at higher harmonics as well. Reactions produce inconsistent trends in the harmonics: reactions promote harmonics at a pressure antinode while they damp harmonics at a pressure node.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

High Resolution X-Ray Tomography of Injection Nozzles

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Abstract

Tomographic imaging of gasoline and diesel injection nozzles has important applications in industry and research. At high spatial resolution, tomography provides dimensional metrology capable of exposing machining tolerances as well as the effect of nozzle geometry on observed fuel spray behavior. Tracking the three dimensional (3D) structure of the nozzle throughout its lifetime can also reveal any changes to the fuel's flow path caused by deposit formation and cavitation erosion. Additionally, isosurface visualization of tomographic reconstructions provides true 3D nozzle geometry for mesh generation in computational simulations. In order to make tomography a viable tool for such applications, the technique must produce images at high spatial resolution with relatively low computational demand. Recent upgrades to the 7–BM beamline at the Advanced Photon Source at Argonne National Laboratory now allow us to perform x–ray tomography of fuel injectors with 3 micron spatial resolution. The large energy and flux of synchrotron radiation permits high contrast imaging of the nozzle interior with minimal reconstruction artifacts. Additionally, TomoPy, a parallelizable high performance Python toolbox developed for use at synchrotron facilities, maintains practical computational time for data processing. We present a brief overview of the tomography process and its capabilities, complemented by a sample of reconstruction results of an eight–hole direct gasoline injection nozzle. The 3D nozzle reconstruction exposes micron–scale features with high fidelity and requires minimal manual post–processing to create a 3D isosurface rendering fit for use in CFD meshing.

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Characterization of Glass Particle Suspension Droplets by Phase Doppler Particle Analyzer

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Abstract

In Suspension Plasma Spray (SPS), the submicron coating particles are injected to the plasma gas through the suspension droplets. The size, velocity, and momentum of these droplets have a strong effect on the interplay between the suspension and the plasma jet and can consequently affect the properties of a coating product. In this study, an aqueous suspension of fine glass particles was atomized by utilizing a twin-fluid (effervescent) atomizer which can create small-size droplets with a low gas pressure and flow rate. For a better understanding of the suspension atomization, the influence of suspension properties such as concentration and surface tension were investigated on the size, velocity, and momentum of the atomized droplets. These characteristics were concurrently measured by using a non-intrusive optical technique, Phase Doppler Particle Anemometry (PDPA). In this method, the droplet velocity is computed from the Doppler shift frequency of the captured scattering signal. Also, the droplet size is calculated from the phase change in the signal received by three detectors. It was found that the suspension surface tension is reduced by increasing the mass concentration of the glass particles. This leads to a stronger droplet break-up which consequently creates a smaller size distribution and an improved suspension atomization. However, a noticeable momentum decrement was observed due to the droplet size reduction which finally yields a shorter suspension penetration into the plasma jet.

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Measurement of Flow Velocities in a To-Scale Simplex Atomizer Using Particle Image Velocimetry.

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Abstract

To better understand atomization in a commercial aviation gas turbine combustion environment, we present experimental measurements of the internal fuel flow of a simplex atomizer. Particle Image Velocimetry was used to measure velocity in a plane axial of a standard aerospace fuel atomizer. The geometry studied used a 0.74mm orifice and is typical of a commercial aircraft engine. MIL PRF-7024 was employed as the working fluid and two mass flow rates were studied. Particle Image Velocimetry data on a small simplex atomizer was collected and methods are detailed including the machining of the optically clear spin chamber, properly replicating the geometry, and challenges associated with seeding MIL PRF-7024. The method of data collection is discussed for future application to other geometries. Flow fields showed the majority of mass flowrate around the air core. In addition to increased understanding of this complex flow, this data may be used to support and validate computational analyses of gas turbine fuel injection.

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Spray Diagnostics of Low NOx Air Blast Atomizers at Ambient and Elevated Pressure

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Abstract

Spray diagnostics measurements of 5 different air blast atomizers at ambient pressure conditions are presented. These atomizers were derived from an atomizer originally developed as part of a combustor design for NASA's Environmentally Responsible Aviation (ERA) N+2 advanced, low NOx combustor technologies program. The main objective of the presented research is to probe the performance of the air blast atomizer designs that could be utilized in this combustion system. The atomizer designs were developed extensively by utilizing CFD with the intent of rapidly and thoroughly mixing fuel and air to minimize NOx emissions. This paper provides comparisons of the air flow field predicted by CFD to that measured by Particle Image Velocimetry (PIV) at ambient air-only test conditions. Additionally, the atomizer's behavior with both air and fuel was investigated using Laser Induced Fluorescence (LIF). In these tests, a laser dye (Pyromethene 597) was added to MIL-PRF-7024 Type II test fluid and excited by a laser sheet to produce the LIF results. These air and liquid PIV/LIF results are presented and compared to air-only PIV results as well as a comparison made with multiphase CFD simulations. These 5 concepts were finally tested in a medium pressure combustion rig at UTRC to obtain emission measurements. This emission data is presented and compared to CFD predictions in this paper.

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Near Nozzle Spray Characteristics of Spark-Ignition Direct-Injection Fuel Injectors under Sub-cooled and Superheated Conditions

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Abstract

More attention has been paid to fuel spray research due to the widely adoption of spark-ignition direct-injection (SIDI) engines in today's passenger vehicles. However, the fuel residue and carbon deposit at injector nozzle exit reduces the hydraulic diameter and hence the hydraulic flow in the nozzle, which results in higher fuel consumption and deteriorated engine combustion. Extensive studies have been performed to investigate the effects of fuel additives on injector deposit formation for injector deposit reduction. In this study, near nozzle fuel spray of various direct-injection gasoline injectors is studied under a wide range of sub-cooled and superheated conditions. Injectors with different length to diameter ratio were investigated. A high pressure constant volume chamber was used to produce various ambient conditions. High speed backlit imaging technique was applied to record the near nozzle spray structure, including the start of injection and end of injection. Dense liquid core of the near nozzle spray was identified clearly under sub-cooled condition with weak atomization. However, fuel atomized quickly soon after fuel was discharged from the nozzles, and liquid core was hardly visualized. Results show that large ligaments and droplets are generated at the end of injection of liquid fuel spray which adhere to the nozzle hole and result in deposit formation of injector holes. However, as to the flash boiling spray, no liquid ligament exists at the end of injection, which indicates considerable improvement of end of injection performance and provides a new method to resolve the injector deposit issues.

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Comparison of Practical and Analytical Spray Performance in Defouling Process

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Abstract

Heat exchangers are widely used in heating, air conditioning, refrigeration, industrial plants and refineries, gas processing and water treatment. Fouling is a chronic operating and design problem for retaining highly effective heat exchangers. This leads to countless chemical and mechanical attempts for reducing fouling. Mitigation of fouling and removal of deposits can be addressed efficiently with proper design and gas conditioning modification. All previous mentioned factors and uncertainties can be examined, evaluated and optimized by using computational fluid dynamics (CFD) simulation.

Typical defouling and cleaning process involves chemical solvent sprayed on the heat exchanger surfaces. Manufacturers and operators are facing increasing difficulty to preserve heat exchanger efficiency due to complex structures. Spray behavior and performance cannot be simply predicted due to the many variables involved such as nozzle characteristics, geometry, orientation, gas flow of heat exchanger and pressure resistance. There are tremendous challenges associated with fouling of heat exchangers, where CFD is known as a common tool to predict and resolve those problems. In this work, we will compare the performance of CFD simulation of spray with practical droplet test data in a scaled heat exchanger built and tested in Spraying Systems Co. spray laboratory for a pilot anti-fouling imitation. The spray characteristics based CFD will be used to validate the importance of reasonable and precise spray input simulation in a solvent based defouling process.

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New estimation of near exit streamwise instabilities on high speed liquid jets

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Abstract

Linear stability analysis (LSA) of liquid jets has traditionally been performed with hyperbolic secant or Gaussian velocity profiles. A different approach is presented here, in which a shear flow profile, near the jet exit ($0.2 < x/D < 1.0$) is used to analyze streamwise instabilities in high speed liquid jets at $150 < Re_{\delta_2} < 670$. Here x is the streamwise location, D is the exit jet diameter, and Re_{δ_2} is the Reynolds number based on the momentum thickness of the boundary layer. The Rayleigh equation is solved using a hyperbolic tangent velocity profile to perform a temporal and a spatial stability analysis (TSA and SSA respectively). Results show agreement with respect to experimental results, by Portillo et al. [1], of better than 15 % for the near-exit streamwise instabilities wavelength at the jet surface. The momentum thickness is the chosen reference length to scale estimated instabilities wavelength values. A discussion about the benefits of the Blasius equation versus CFD to determine the former is offered. Among some of the advantages of the hyperbolic tangent profile is that the integration of the respective ODE is made on a real path instead of the complex path which is typical of LSA solutions for the other profiles. Also, in this work is discussed the impact of the change of variables and a mathematical transformation known as the Riccati transformation to simplify numerically the derivation and the solution of the Rayleigh equation to perform respective LSA's.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Local and general spray characteristics of spray dry nozzles with water

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Abstract

Spray dry nozzles represent a notable portion of industrial nozzles, and are typically used to generate a dried powder from a liquid or slurry. From a spray technology perspective, these nozzles are identified as hydraulic atomization nozzles that operate at high pressures in order to generate relatively small droplets with controlled distributions. In this study, nozzles which are used for spray drying in areas such as the Dairy, Food, Pharmaceutical, and Chemical industries, are characterized and analyzed over a range of operating conditions. Parameters of interest include nozzle type (Swirlchamber, Slotted Core, and Whirlchamber), nozzle capacity (size), and operating pressure. For this study, water is used as the primary spray fluid, and all data are acquired using a Phase Doppler Analyzer instrument. Traditionally difficult measurements, due to high spray density, detailed results of drop size and velocity across each spray plume provide insight on the spray characteristics as the operating conditions are altered. Shifts in localized max/min characteristics lead to general characteristic trends which are investigated in detail; such as, a decrease in drop size and an increase in velocity with increasing operating pressure. The combination of point measurements with overall characteristics, using the methods outlined in Bade and Schick [4], provides new perspective on the generation and development of these sprays.

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Flash Boiling: A Parametric Study

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Abstract

CFD simulations with thermal non-equilibrium, an Eulerian-Eulerian primary atomization model and a four component gasoline surrogate were carried out on 2D axisymmetric straight and stepped nozzles to study the effect of the geometric factors and the operating conditions on the spray. The effects of the inlet corner radius, nozzle diameter, counter-bore diameter and the inner nozzle length were assessed along with the effects of varying injection and ambient pressures and the fuel temperature. The influence of these parameters on the coefficient of discharge, the spray-cone angle and the Sauter mean diameter (SMD) were analyzed both qualitatively and quantitatively. Non-dimensional groups were identified and correlations were established. Results indicate that the inlet corner radius dominates the coefficient of discharge; the time available for the fuel to vaporize determines the spray cone angle. Whereas, the SMD is dominated by the extent of fuel superheat, defined as a ratio of the ambient to saturation pressure of the fuel.

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Study of Characteristics of Low Temperature Combustion (LTC)

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Abstract

Through an extensive literature survey the important characteristics of Low Temperature Combustion (LTC) Engine operation were investigated. Previous research indicates that low temperature combustion is capable of producing ultra-low nitrogen oxides (NOx) and soot emissions. The principle of LTC is based on enhancing the air fuel mixing and reducing the combustion temperature, which results in the reduction of NOx and particle emissions. LTC is typically achieved through high dilution rates and low compression ratios, resulting in an increased auto–ignition delay that produces significant noise and deteriorates the combustion phasing and at the same time, the lower combustion temperature and reduced oxygen concentration increases hydrocarbon (HC) and carbon monoxide (CO) emissions, which can result in various problems at low load.

This paper summarizes studies and experiments that have been carried out on LTC Engine operation as a means of achieving low emissions and noise, with better fuel efficiency and stability of the combustion process. Improvements in the promptness and accuracy of the combustion control as well as the tightened control on the intake oxygen concentration can enhance the robustness and the efficiency of the LTC operation in diesel engines. A summary of the effects of the fuel injection pressure, exhaust gas recirculation (EGR), injection timing and swirl ratio on combustion and engine-out emissions are presented. The thermodynamic advantages LTC engines using Low Heat Rejection (LHR) concepts is also presented along with areas which will be addressed with future research programs.

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String Flash-Boiling in Flashing and Non-Flashing Gasoline Direction Injection Simulations with Transient Needle Motion

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Abstract

A computational study was performed to investigate the influence of transient needle motion on gasoline direct injection (GDI) internal nozzle flow and near-field sprays. Simulations were conducted with a compressible Eulerian flow solver modeling liquid, vapor, and non-condensable gas phases with a diffuse interface. Variable rate generation and condensation of fuel vapor were captured using the homogeneous relaxation model (HRM). The non-flashing (spray G) and flashing (spray G2) conditions specified by the Engine Combustion Network were modeled using the nominal spray G nozzle geometry and transient needle lift and wobble were based upon ensemble averaged x-ray imaging preformed at Argonne National Lab. The minimum needle lift simulated was 5 μm and dynamic mesh motion was achieved with Laplacian smoothing. The results were qualitatively validated against experimental imaging and the experimental rate of injection profile was captured accurately using pressure boundary conditions and needle motion to actuate the injection. Needle wobble was found to have no measurable effect on the flow. Low needle lift is shown to result in vapor generation as fuel rushes past the needle. And finally, the internal injector flow is shown to contain many transient and interacting vortices which cause perturbations in the spray angle, fluctuations in the mass flux, and frequently result in string flash-boiling.

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Effect of Nozzle Configuration on Cycle-to-Cycle Variations of Spray Structure under Non-Flash Boiling and Flash Boiling Conditions via Proper Orthogonal Decomposition

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Abstract

The cycle-to-cycle variations of fuel air mixing have significant effect on combustion efficiency and emission of IC engines. In a spark ignition direct injection (SIDI) engine, liquid fuel spray plays an important role in governing the mixture formation, and therefore a robust spray would contribute to improved combustion process and reduced emissions. In this paper, the spray characteristics of three different single-hole prototype injectors were investigated. These prototype injectors had the same internal design but with different L/D (length to diameter) ratio of 0.5, 1.0 and 2.5. N-Hexane with 9% diethyl-methyl-amine (DEMA) and 2% fluorobenzene (FB) added as the dopants was used as the fuel in the experiments. Fuel injection pressure was 10 MPa, and experimental conditions covered a wide range of non-flash boiling and flash boiling conditions by adjusting the ambient pressure and fuel temperature accordingly. Laser induced exciplex fluorescence technique was used to investigate the vapor and liquid phases of the spray behavior. Characteristics of spray variations were analyzed using the proper orthogonal decomposition technique. Experimental results show that for the same injector, flash boiling spray behaved more repeatable than that of non-flash boiling (liquid) spray due to different mechanisms of primary atomization, and variation of spray vapor phase was stronger than that of the spray liquid phase. The spray variations of injectors with L/D ratio of 0.5 and 2.5 were similar while a higher magnitude of variations was found with L/D ratio of 1.0. These results were caused by different in-nozzle flow characteristics and interaction between spray and ambient air.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Numerical Study of Laminar Annular Two-Phase Flow in Effervescent Atomizers

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Abstract

Computational simulations of two-phase laminar flow in effervescent atomizers have been carried out. The flow is considered in the annular flow regime. A non-uniform, structured computational grid of 48000 cells is used for an axisymmetric effervescent atomizer consisting of a mixing chamber, convergence section and an orifice section. Volume of Fluid (VOF) model is used to investigate the water-air two-phase flow. The flow is considered compressible and the formulation is axisymmetric. The Gas-to-Liquid Ratio or GLR is varied from 0.005 to 0.07, with a liquid flow rate variation from 0.14 l/min to 0.27 l/min. For each case, the liquid sheet thickness and velocity at the orifice exit are obtained from the numerical solutions. At a constant liquid flow rate, the liquid sheet thickness varies inversely with gas-to-liquid ratio (GLR). Moreover the decrease in the sheet thickness is sharper at lower values of GLR and the variation becomes more gradual as GLR increases. Furthermore, an increase in liquid flow rate results in an increase in the sheet thickness. With an increase in the orifice diameter, non-dimensionalized sheet thickness increases. Sheet thickness varies marginally with changes in orifice length, angle of the convergence section, and liquid surface tension. Based upon the computational study, an empirical correlation to predict the sheet thickness as a function of the exit Reynolds number and GLR is proposed.

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Characteristics of Diesel Spray Under High Injection Pressure

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Abstract

Increasing injection pressures can improve combustion efficiency in direct-injection diesel engines attributing to enhanced atomization. In this work, a high pressure experimental setup was established to generate ultra-high fuel pressures. An intensification system was used to magnify the pressure by about 10 times and provide an injection pressure of up to 10000 bar (1000MPa). Preliminary testing of the high pressure system produced a peak pressure of about 8700 bar (870MPa). Since there is no available commercial fuel injector that can handle such a high pressure, relatively low pressure levels were used to perform the preliminary test for a commercially available piezoelectric diesel fuel injector. High pressure diesel fuel was injected into atmospheric pressure (1 atm) and temperature (298 K). The injection activation pulse duration was 1 millisecond. The fuel injection event was synchronized with the instruments for high-speed imaging by using a pulse generator, and spray images were taken by a high speed camera for spray analysis. The penetration velocity of the spray increases with the increase of the injection pressure, while the spray starts to appear at the nozzle exit a little bit later for higher injection pressures due to the operation mechanism of the injector. The spray angle decreases by a small amount during the injection. Due to the design of the fuel injector, the maximum pressure used in the preliminary testing was 2500 bar (250MPa). In order to achieve fuel injection under even higher pressures, new injection devices or modifications on existing fuel injectors are needed for further studies.

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Numerical study of cavitation of high-viscous liquid spray systems

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Abstract

It is difficult to atomize high-viscous liquids using pressure spray systems unless high fluid pressure is applied. To enhance the degree of liquid atomization of high-viscous sprays, the internal nozzle geometry can be designed so that cavitation is promoted. Cavitation in the nozzle affects the subsequent atomization behavior, because it introduces a stochastic behavior of the liquid stream and destabilizes the jet. In the present work, a numerical simulation model of an injection nozzle is developed to predict cavitation of high-viscous liquids. The modelling is carried out in the open-source CFD software package OpenFOAM using a standard incompressible multiphase flow solver. The in-nozzle cavitation phenomenon is captured using the Schneer-Saur cavitation model. The numerical simulation model is validated using high-speed shadow graphic images of a transparent acrylic nozzle with an orifice diameter of 0.3 mm.

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Narrow Band Flame Emission of Dieseline and Diesel Spray Combustion in a Constant Volume Combustion Chamber

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Abstract

In this paper, spray combustion of diesel (No. 2) and diesel-gasoline blend (dieseline: 80% diesel and 20% gasoline by volume) were investigated in an optically accessible constant volume combustion chamber. Effects of ambient conditions on flame emissions were studied. Ambient oxygen concentration was set from 12% to 21% and three ambient temperatures were selected: 800K, 1000K and 1200K. An intensified CCD camera was employed coupled with two bandpass filters to capture 430nm and 470nm flame emissions. Under non-sooting conditions, the narrow-band flame emissions at 430 nm and 470 nm can be used as indicators of CH* (methylidyne) and HCHO* (formaldehyde). The lift-off length was measured by OH* chemiluminescence at 310 nm. Flame emission structure and intensity distribution were compared for both emissions between dieseline and diesel. Steady-state flame emission images show that both emissions become shorter, thinner and stronger with larger oxygen concentration and higher ambient temperature for both diesel and dieseline. Weak intensity areas locate at flame periphery and upstream for both fuels for all ambient conditions. Average flame emission intensity and area were calculated. For most conditions, diesel has stronger average flame emission intensity than dieseline for 430 nm emission, and similar phenomena could be observed for 470 nm emission with 800K and 1200K ambient temperatures. However, for 1000K ambient temperature 470 nm emission cases, dieseline has stronger average flame emission intensities than diesel for all oxygen concentrations. As for average flame emission area, both emissions have smaller average emission area with higher ambient oxygen concentration and temperature for both fuels, while dieseline has slightly larger average flame emission area than diesel for most cases.

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Validation and Analysis of Air-Blast Atomization Simulations

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Abstract

We have numerically simulated published experimental planar and cylindrical air-blast atomization configurations using our in-house multiphase Navier-Stokes solver, NGA. The liquid-gas interface was tracked using two different approaches: a semi-lagrangian geometric volume of fluid (VOF) scheme and an Accurate Conservative Level-Set (ACLS) scheme. The ability of our solver to predict primary wavelengths of instability and atomization is demonstrated for both planar and cylindrical liquid jets with coflowing air through the matching of results with experiments. Furthermore, using these simulations, we have demonstrated the cascade of instabilities that lead to atomization, from Kelvin-Helmholtz to Rayleigh-Taylor to Rayleigh-Plateau, without the addition of noise or a perturbation to the initial conditions. The advantages of each interface-tracking method for the simulation of atomizing planar jets, mainly the accuracy and computational cost, are also compared, where the accuracy is assessed as the ability to match the experimental primary instability frequency.

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The Effects of Parcel Count on Predictions of Spray Variability in Large-eddy Simulations of Diesel Fuel Sprays

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Abstract

Shot-to-shot variations in fuel injection events has been recognized as an important contributor to cycle-to-cycle variations of direct-injection engines. For engine simulations, Lagrangian spray simulations are typically used. This method does not directly resolve the sources of shot-to-shot variations and instead must rely on perturbing boundary conditions to simulate spray variability. Currently, the most-used method is to vary the random seed used within the spray models for each realization. The Lagrangian spray methodology, however, is based on a Monte-Carlo approximation of the full spray behavior, and thus the predicted spray variability will depend on the number of spray parcels introduced. Experimental measurements of projected mass density (PMD), including shot-to-shot variation in PMD, of a single-hole diesel injector under non-vaporizing conditions were acquired using fast radiography at the Advanced Photon Source at Argonne National Laboratory. 10 simulation realizations were performed varying the random seed of each realization for each of three different numbers of spray parcels, 200, 400, and 800 thousand. The computational fluid dynamics (CFD) grid resolution was kept constant at 62.5 μm to isolate the effect of parcel count from resolution of gas-phase turbulence. The predicted mean quantities of both global and local variables were all similar regardless of the number of parcels used in the spray simulation, but reducing the number of spray parcels used in the simulations greatly increased the predicted shot-to-shot variability of local quantities such as PMD. The parcel count had less of an effect on predicted variability of global quantities such as spray penetration.

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Characterization of Liquid Jets in Subsonic Crossflows Using X-Ray Radiography

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Abstract

Spray structures of liquid jets in subsonic crossflows were characterized using X-ray radiography at the 7-BM beamline of the Advanced Photon Source at Argonne National Laboratory. A small-scale wind tunnel with a test section of 51 mm (H) × 51 mm (W) × 152 mm (L) provided a freestream flow up to Mach 0.3. The wide windows of the test section are fitted with a thin polyimide film for high X-ray transmittance. An axisymmetric aerated-liquid injector fitted with an exchangeable adaptor was used to generate a pure- or aerated-liquid jet at the desired injection conditions. The transmitted X-ray intensities were processed to give quantitative liquid mass distributions within the spray at various injection conditions. The present results were also used to derive spray penetration heights for comparison with predictions from the existing correlations. Companion PDPA measurements were carried out to compare with the X-ray radiography measurements and to expand the understanding of the liquid jets in crossflows. The present study shows that the present techniques provide quantitative measurements of liquid mass distribution within both the near field, including the jet column, and the far field of liquid jets in subsonic crossflows. In the near field, deformation of the liquid column in the pure-liquid jets and the co-annular-like column structure in the aerated-liquid jets were also measured. In the far field, the present efforts to compare the measured penetration heights, based on various threshold values, with predictions from existing penetration height correlations offer new perspectives on characterizing spray penetration in crossflows. In general, the penetration heights predicted from shadowgraph-based correlations are in agreement with the time-averaged water mass contours and may ignore a significant amount of injected liquid mass in the far field. The penetration heights predicted from PDPA-based correlations are in agreement with the standard deviation water mass contours and are more indicative of the outer boundary of droplet presence. The approach to comparison of liquid mass distribution using spanwise-integrated liquid volumes from both X-ray radiography and PDPA measurements is relatively well illustrated in the present study. A discrepancy between X-radiography and PDPA measurements of liquid mass distribution near the tunnel floor was observed. The factors contributing to this discrepancy should be explored in the future.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Parametric Study of HRM for Gasoline Sprays

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Abstract

Flash boiling is known to be a common phenomenon for Gasoline Direct Injection (GDI) engine sprays. Homogeneous Relaxation Model has been adopted in many recent numerical studies for predicting cavitation and flash boiling. Assessment of the Homogeneous Relaxation Model has been presented in this study. Sensitivity analysis of the model parameters has been documented to infer the driving factors for the flash boiling predictions. The model parameters have been varied over a range and the differences in predictions for the extent of flashing have been studied. Apart from flashing in the near-nozzle regions, mild cavitation is also predicted inside the gasoline injectors. The variation in the predicted time-scales through the model parameters for predicting these two different thermodynamic phenomena (cavitation, flash) have been elaborated in this study.

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The Effect of Fuel Temperature on the Penetration of a Liquid Jet in Crossflow

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Abstract

The increased thermal demands of advanced aeroengines necessitates the use of fuel as a primary coolant. The resulting higher fuel temperatures cause a reduction in fuel density, viscosity, and surface tension, which can have an effect on the overall spray breakup, trajectory, and penetration of the liquid jet in crossflow. An experimental study was conducted to assess the effects of elevated fuel temperatures on the penetration of a heated liquid jet in crossflow. Experiments were run with a liquid jet of Jet-A fuel at injection temperatures from ambient to over 320°C in a steady air crossflow that could be adjusted to simulate gas turbine combustor conditions. Based on the vapor pressure curve of Jet-A, flashing conditions for the jet were assumed to be reached at the highest fuel temperatures. High speed backlit imaging as well as Mie scattering was used to capture the reduction in penetration caused by the large increase in fuel temperature. Image processing techniques were employed to extract the upper edge trajectory of the jet in an effort to develop a correlation for predicting penetration changes for the heated liquid jet in crossflow. Typically, trajectory correlations are based on the momentum flux ratio, aerodynamic Weber number, and axial distance downstream from the injection point. For a heated liquid jet in crossflow, the vaporization of a multi-component fuel as well as changes in fuel properties need to be incorporated into a correlation in order to effectively predict the trajectory.

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ECN GDi Spray G: Coupled LES Jet Primary Breakup - Lagrangian Spray Simulation and Comparison with Data

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Abstract

Computational fluid dynamic (CFD) simulation of in-cylinder mixture preparation is an important component of the gasoline direct injection (GDi) engine spray pattern (or targeting) optimization process. A major area of shortcoming in CFD Lagrangian stochastic simulation of GDi spray is the proper account of the jet primary breakup (with regards to the initial droplet size - velocity distribution function) due to the substantial influence of nozzle geometry on the primary atomization process. The objective of this study is to assess the predictive capability of the volume-of-fluid large-eddy-simulation (VOF-LES) method for quantitative analysis of the spray primary breakup, so to enable a fully predictive analysis of the complete GDi spray processes. The paper presents results from a VOF-LES analysis of the ECN spray G seat flow and the near-field primary atomization coupled to a Lagrangian stochastics simulation method adopting the discrete droplet model (DDM). The analysis is carried out for a vaporizing n-Heptane spray injection into the atmospheric ambient. The distinction of this case, compared with previous application of the method, is the notable interaction of spray with the counter-bore walls. Hence, the interest is whether the VOF-LES method properly captures the interaction effects on the spray plume primary atomization.

The injector internal flow and jet primary breakup simulation is performed with the Open-FOAM software suite. The simulation of the spray processes - propagation, secondary atomization, and the droplet-air exchanges - are carried out using the AVL-FIRE commercial CFD code. The accuracy of the VOF-LES primary atomization data is inferred from the predictive accuracy of the simulated far-field spray plume trajectory, cone angle, droplet-size distribution and the transient spray-tip penetration versus the experimental data. The comparison shows encouraging agreement.

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High Fidelity Simulation of the Impact of Density Ratio on Liquid Jet in Crossflow Atomization

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Abstract

Atomization of liquid fuel jets by cross-flowing air is critical to the performance of many aerospace combustors. Recent advances in numerical methods and increases in computational power have enabled the first principle, high fidelity simulation of this phenomenon. In the recent past we demonstrated for the first time such simulations that were comprehensively validated against experimental data obtained at ambient conditions. At combustor operating conditions, however, both temperature and pressure are significantly elevated. In this work we perform a computational study of the impact of reduced liquid-gas density ratio due to increased air density associated with operating pressure elevation on the atomization physics. A previously validated ambient condition case is used as the baseline for comparison with three cases with decreasing density ratios. The density ratio is independently varied by adjusting the gas density and velocity together so that the momentum flux ratio and Weber number are maintained constant. Results indicate a significant modification of the atomization process at lower density ratios. Although the global-scale jet penetration and trajectory are not significantly modified by the conditions, both the process of liquid breakup and the degree of atomization are altered. The trends in the degree of atomization represented by the liquid volume to area ratio extracted from in the simulation results agree with the observations from a recent experiment at elevated pressure conditions. Further effort is still required to understand the detailed physical mechanisms for atomization at different density ratios.

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Nozzle Selection During Process Development of a Pharmaceutical Spray Dried Solid Dispersion

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Abstract

Spray drying is a common unit operation across many industries due to the ability to control bulk powder properties and isolate dry product from a liquid feed in a single operation. For the pharmaceutical industry, spray drying offers the control of physical properties of crystalline or amorphous active pharmaceutical ingredients (APIs), as a neat or formulated drug product that can lead to improved bioavailability of the drug candidate. Drug candidate molecules are often formulated as a solid dispersion, incorporating both API and a polymer excipient for enhanced dissolution performance and improved physical stability. Bulk density and particle size of the spray dried dispersion can impact downstream manufacturability as well as performance of the dosage form. Robust ranges should be explored during development while minimizing the use of high-cost and limited supply API. For Compound A, formulated as a spray dried amorphous solid dispersion for oral delivery, atomization was decoupled from the drying process and a Phase Doppler Particle Analyzer was used to determine the appropriate nozzle for several different particle size targets. The selected nozzles were then used within a pilot scale spray dryer to produce product with the desired particle size and density combinations for downstream manufacturability testing.

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Recent Developments in Experimental Methods for Quantification of High-speed, Aerodynamically Driven Liquid Breakup

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Abstract

The breakup of liquids due to aerodynamic forces has been experimentally investigated for many decades. Despite the large body of work, few investigations have quantified secondary droplet sizes and velocities, especially near the site of breakup. This is mostly due to experimental challenges and the limited temporal resolution of historical diagnostics. This work summarizes our recent efforts to develop and apply new diagnostics for these challenging multiphase flows. We begin by reviewing previous work including our own using traditional imaging and phase Doppler anemometry of the breakup of liquid drops in a cross-flow. Next, we discuss the development and application of digital in-line holography (DIH) for these flows. This method provides 3D realization of secondary droplet positions and sizes in a large measurement volume. Finally, we discuss new work extending the DIH diagnostic to kHz repetition rates. This method has been applied to study the fragmentation of a 1 mm liquid column in cross flows of atmospheric air up to ~70 m/s. Measured quantities include secondary droplet 3D positions, in-plane morphologies, and three-component velocities all at 100 kHz. The data from these new diagnostics will be useful for development and validation of atomization models.

Application of Electrohydrodynamic Atomization in Natural Gas Odorization

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Abstract

Natural gas is a widely used domestic commodity. Given its odorless nature, artificial odorization is carried out to facilitate easy detection of leaks. Conventionally drip injection of odorant through orifices is used in the pipeline systems. Despite the widespread usage of this method by the natural gas industry, it allows poor control of droplet size and thus has limited effectiveness with respect to diffusion of the odorant in the gas. It has been observed that, given the large droplet size produced and a used flow velocity in such systems, only a part of the odorant diffuses in the gas flow leading to accumulation at the bottom of the pipeline.

In this work an Electrohydrodynamic Atomization (EHDA, or electrospray) system was investigated as an alternative to allow control and manipulation of the odorant's droplet size and dispersion with the intention to provide better diffusion and subsequently better odorization. Results of pilot scale experiments carried out in a 1200 cm long transparent natural gas pipeline section have shown a 66% increment in the diffusion of odorant, mainly due to reduction in droplet size and better dispersion, when compared to a drip injection situation. Experiments have shown that, despite the fact that the flow of natural gas is perpendicular to the spray and the confined environment operational conditions, a cone-jet mode was achieved with a narrow droplet size distribution (RSD ~0.26). If EHDA can be implemented, a substantial reduction of consumption of the odorant seems possible.

Numerical simulation of a shock wave impacting a droplet using the adaptive wavelet-collocation method

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Abstract

Under startup conditions, supersonic combustors must atomize and ignite liquid fuel at hypersonic speeds. Little is known about fluid atomization in a supersonic cross flow experimentally and few methods exist to investigate the behavior numerically. In order to simulate this behavior an approach must be used that naturally accounts for the multiscale nature of the atomization process. In this work, a five equation interface-capturing scheme is developed to solve the compressible multi-component Navier-Stokes equations. The gas phase is modeled as an ideal gas and the liquid phase is modeled using a stiffened-gas equation of state. In order to account for the truly multiscale nature of this fluid behavior, the governing equations are solved using the highly efficient Parallel Adaptive Wavelet-Collocation Method (PAWCM). The PAWCM uses wavelets to dynamically adapt the grid used to represent the solution, which minimizes the overall computational cost and allows larger simulations to be performed. Shocks and interfaces are captured using a modified version of the hyperbolic solver developed specifically for the PAWCM. Surface tension is modeled using a continuous surface approach. One and two-dimensional simulations are used to demonstrate the method's capabilities.

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Spray patternation for the USDA Drift Reduction Task Force (DRTF) Nozzles: The influence of liquid formulation and operating conditions

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Abstract

We report measured spray patternation (using an En'Urga OP-600) at two axial locations for sprays formed using each of five fan nozzles. Data were acquired for supply pressures of 240, 380 and 650 kPa (20, 40 and 80 psi) using liquids whose viscosities, surface tensions and densities are representative of typical agricultural products. Results showed how patternation, reported as the spatial distribution of drop area/unit spray volume, changes with downstream distance from the atomizer, with variations in supply pressure, and with changes in liquid surface tension, viscosity and density, for each type of nozzle. Findings discussed here contribute in two ways to our understanding of spray drift. First, they will provide the relative spray coverage across each row, thereby helping to maximize application efficiency. Second, they will provide additional input to modern ag spray computational codes for drift prediction.

Direct Numerical Simulation of Aerated-Liquid Injection within 'Out-In' and 'In-Out' Nozzle Designs

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Abstract

Direct numerical simulations of two-phase liquid water / gaseous nitrogen flow within prototype aerated-liquid injectors being considered for cold-start fueling are presented in this paper. The aerated liquid injectors each consist of a plenum chamber, a mixing chamber, and a nozzle but differ in how the aerating gas is introduced into the flow. In the 'out-in' design, gas is injected through small orifices oriented along the perimeter of the mixing tube; in the 'in-out' design, gas is injected through a centrally-located perforated tube. A homogeneous mixture formulation of the Navier-Stokes equations is solved using a sharp interface capturing method combined with a continuum surface tension model. The 'resolving power' of the interface-capturing scheme is limited by a CFL condition. As a result, the scheme cannot accurately capture structures smaller than about 50 μm for the present mesh sizes. For a gas-to-liquid mass ratio (GLR) of 0.04, the aeration gas forces the liquid toward the walls of the nozzle, producing a thin film that is deformed by aerodynamic shear forces in the highly-turbulent nozzle flow. Parcels of liquid are stripped from the annular liquid sheet, populating the interior of the nozzle with liquid material. The 'internal atomization' process is more rapid for the 'in-out' design, as the rapid acceleration of the two-phase flow into the nozzle produces a *vena contracta* that leads to very high velocities (< 250 m/s) in this region. The momentum flux of the exiting two-phase flow is higher for the 'out-in' design. Comparisons with experimental line-of-sight density measurements obtained using X-ray radiography for the in-out injectors show good agreement in the annular and mixing regions. The calculations predict a higher liquid content in the exiting nozzle flow than evidenced in the experimental measurements.

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Size and velocity measurements for agricultural sprays as a function of nozzle operating conditions, nozzle to plant canopy height and liquid formulation

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Abstract

Spray drift has been, and continues to be, a concern of the agricultural community. At this time its bio-impact is assessed by using a forward light scattering instrument to make planar-averaged drop size distribution measurements at a chosen distance from the nozzle exit plane. The resulting MMD is compared to EPA-accepted values and the spray categorized as: extremely fine (**XF**), very fine (**VF**), fine (**F**), medium (**M**), coarse (**C**), very coarse (**VC**), extremely-coarse (**XC**), and ultra-coarse (**UC**).

While drop size distribution data are important when evaluating spray drift, the sizes and velocities of individual drops are crucial as inputs to advanced drift prediction codes. Here we present PDA drop size and velocity distribution data acquired for sprays produced by commercially available nozzles that are often used for EPA drift evaluation tests. The separate influences of liquid supply pressure, nozzle height above the spray canopy, and liquid type are reported and discussed in terms of simple models for fan spray formation.

ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Toward liquid jet atomization in supersonic crossflows

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Abstract

Liquid jet atomization is commonly studied in incompressible flows, and a variety of simulation techniques have been developed for these flows. In this work, we extend and adapt several of these techniques to compressible flows. Past studies have highlighted two common challenges in simulating multiphase flows with high density ratios. The first challenge is that the simulated flow quantities experience unphysical oscillations and artificial diffusion near the interfaces due to the abrupt changes in thermodynamic quantities there. We alleviate this issue by employing a fast marching method ('FMM,' see [1]) to perform efficient, second-order, one-sided extrapolations across phase boundaries. In this way, the phase interfaces can be advanced using smoothly varying extrapolated values, and the overall multiphase field can be reconstructed by combining the different phases together. The second challenge for multiphase compressible flows, particularly those with atomization, is in handling the complex topological changes of the interfaces. We address this issue by using a level set formulation. The level set formulation is able to capture complex topological changes without additional effort, making it ideal for the study of liquid jet atomization. We present results from one-, two-, and three-dimensional studies of compressible liquid/gas flows to test our ability to address these two challenges in realistic, multiphase compressible flows.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Industrial Centrifugal Atomization Methods and Products

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Abstract

Centrifugal atomization is used by industry to make a variety of commercial powder products. An overview of industrial methods used to develop and produce these metallic and ceramic materials will be presented. Centrifugal atomization enables production of high-purity, dense, highly spherical shot or powders with minimal satellite particles and narrow particle size distributions. Our in-house atomizers are capable of making as-solidified particle size distributions with average particle diameters ranging roughly from 20 to 500 microns. Additionally, quench rates on the order of 10^6 ^{o}C/sec can be achieved when very fine-grained or even amorphous microstructures are desired. Melting can be done in air, within an inert atmosphere, or under vacuum. Current products include stainless steel blasting shot of all sizes and metal powders used for hot isostatic pressing, metal injection molding, and additive manufacturing.

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An in-cell-reconstruction volume tracking method for simulating atomization in compressible flows

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Abstract

Many applications of atomization occur in flows involving Mach numbers beyond the range that can be modeled using low-Mach number incompressible formulations. In this paper we present a hybrid tracking capturing scheme using an in-cell-reconstruction technique based on the method originally proposed by Smiljanovski et al. [1] for deflagration waves coupled to a volume-of-fluid volume tracking method. The resulting method is applicable to compressible flows that involve the interaction of shocks with phase interfaces. The new approach uses a second-order wave propagation algorithm by LeVeque [2] for finite volume methods and avoids the need for small time steps by using cell face aperture averaged wave updates of the volume averaged states of cells containing the phase interface. The method maintains the phase interface as a discontinuity in the continuum limit by reconstructing the liquid and gas states from cell average values using the jump conditions across the phase interface and the geometric information provided by the volume-of-fluid method. The performance of the method is demonstrated using standard one-dimensional test cases involving interactions of shocks with interfaces.

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ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

Overview of the Atomization Technology Innovation Consortium (ATIC)

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Abstract

An overview of the need and purpose for establishing an Atomization Technology Innovation Consortium (ATIC) will be presented in terms of the potential impact on overcoming barriers to developing advanced atomization and spraying technology. Atomization, or the controlled fragmentation of a liquid stream into particles, is a technology that is widely used in a range of cross-industry applications, including powder materials production, industrial and agricultural sprays, fuel atomization, and industrial combustion. Approximately 19,500 U.S. companies—94% of which are small and medium enterprises—manufacture or use atomized products. While these industries already make up a significant portion of U.S. manufacturing economy, the development and implementation of advanced manufacturing tools and capabilities has the potential to further improve the efficiency, productivity, and global competitiveness of these industries by overcoming key atomization and spraying challenges, such as the real-time control of atomization to produce smaller droplets and narrower size ranges.

ASM International, with guidance from a team of experts and representatives from key sectors of the atomization and spraying communities, is leading the way toward establishment of an Atomization Technology Innovation Consortium. The program is funded by the NIST Advanced Manufacturing Technology Consortia (AM Tech) Program. The goal of ATIC is to meet the national need for advanced atomization technology by development of an action-oriented roadmap that identifies activities that would address barriers & gaps and define areas of opportunity throughout the entire spectrum of industries that use atomization and spraying technologies. The roadmap will be a focal point that outlines high-priority areas for development that can be addressed by forming an industry-based consortium composed of stakeholders along the atomization technology supply and end-use value chain.

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Computation of the break-up of a molten metal drop under sudden acceleration

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Abstract

To shed more light into the breakup process of molten metal, the dynamics of a molten metal circular cross-section under sudden acceleration is simulated with focus on the mechanism of fragmentation under the passage of a Mach 1.2 shock. In this exploratory study, we have ignored parameters such as yield stress and fracture toughness of the metal to concentrate on the hydrodynamics effects due to surface tension and inertia. We show that this type of simulations is now feasible, albeit at considerable grid refinement that is necessary to resolve the thin ligament structure and the ensuing small droplets formation.

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A finite volume method for simulating droplet breakup in a supersonic cross flow

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Abstract

Shock waves are often used in experiments to create a shear flow across liquid droplets to study secondary atomization. Similar behavior occurs inside of supersonic combustors under startup conditions, but it is not as easy to study these conditions experimentally. In order to investigate this phenomenon further, a numerical approach is developed to simulate compressible multiphase flows under the effects of surface tension forces. The flow field is solved via the compressible multicomponent Euler equations discretized with the finite volume method on a uniform Cartesian grid. The solver utilizes a total variation diminishing (TVD) third-order Runge-Kutta method for time-marching and second order limited spatial reconstruction. The Harten-Lax-van Leer contact (HLLC) approximate Riemann solver is used to upwind the fluxes. The fluid interface is captured through an additional transport equation for the volume fraction. Smearing of the fluid interface via numerical diffusion is countered using an interface compression technique applied at the end of each physical timestep. The stiffened gas equation of state is used to close the system. Surface tension is incorporated using the Continuum Surface Force (CSF) model and the required interface curvature is computed using a smoothed interface function and central differences. The multicomponent flow solver is first validated using various one and two dimensional benchmark problems before the surface tension model is verified with comparisons to the analytical values of the pressure jump specified by the Young-Laplace equation and the oscillation period of an ellipse. Finally, a preliminary investigation is performed on the effects of surface tension in a dual droplet interaction with a Mach 6 shock in air and shows the tendency of capillary forces to resist droplet deformation.

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Index of Authors

All authors are listed here with the page number(s) of their respective abstract(s). Paper numbers are provided next to the page number on each abstract's page, and are linked to the respective papers on the media drive (to use this feature you must view the PDF on the media drive).

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