30TH ANNUAL CONFERENCE

ILASS-Americas

Institute for Liquid Atomization and Spray Systems

2019 BOOK OF ABSTRACTS

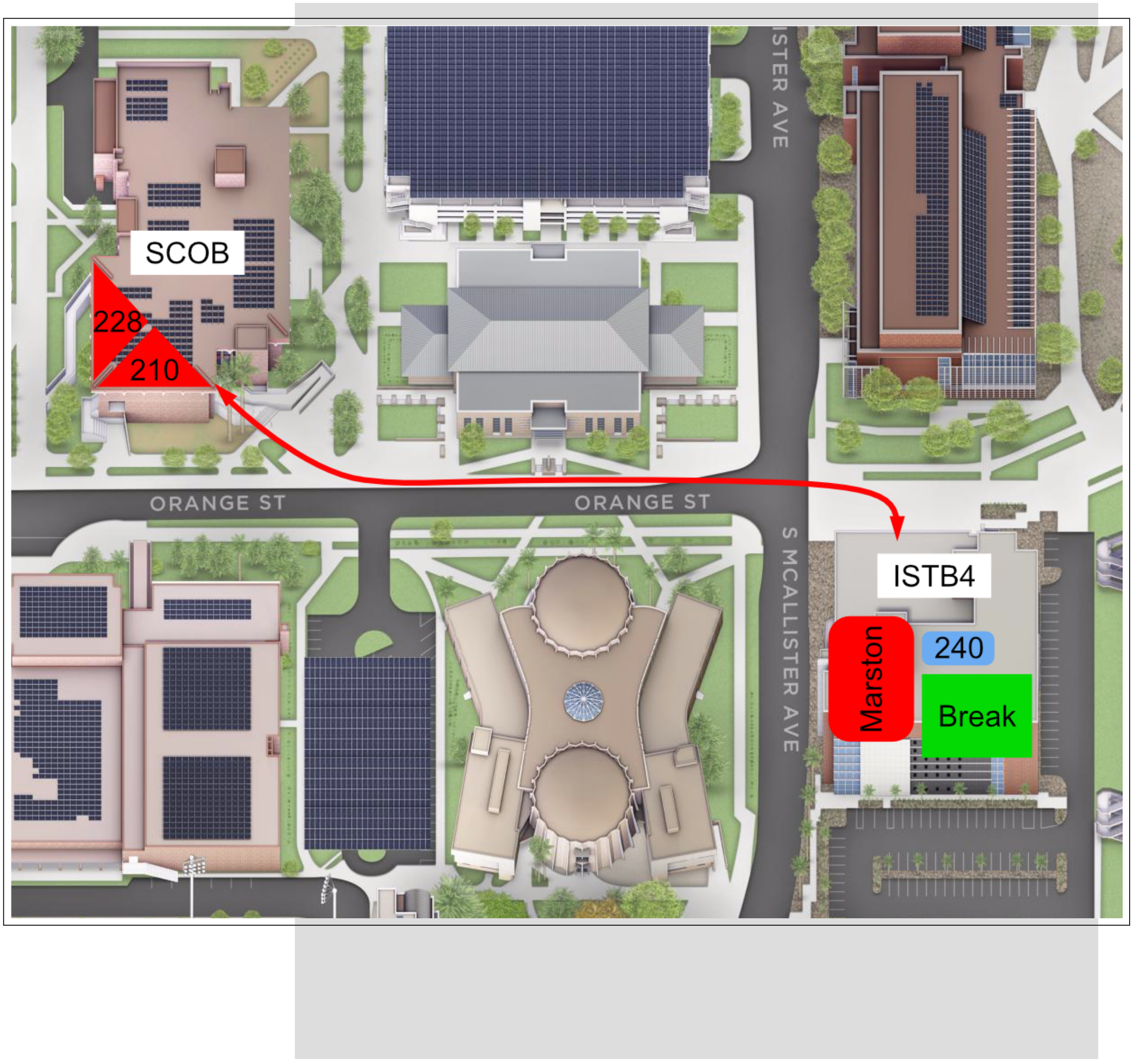
12-15 May 2019, Arizona State University, Tempe, AZ

TABLE OF CONTENTS

ILASS-Americas is a non-profit organization committed to providing state-of-the-art spray information to our annual conference attendees and especially to our student visitors. Thanks to our sponsors, we are able to significantly reduce conference registration fees for students each year.

CONFERENCE MAP

Two building will be used during the ILASS conference this year, SCOB and ISTB4. Please see the map below highlighting the buildings and rooms.



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Dow Chemical

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CONFERENCE ROOMS

Registration	ISTB4 Ground Floor
Welcome Reception with Exhibitors (Sunday Evening)	ISTB4 3rd Floor
Breakfast	ISTB4 3rd Floor
Lunch	ISTB4 3rd Floor
Breaks	ISTB4 3rd Floor
Keynote Presentation Room	SCOB 210
Plenary Session with Exhibitors	SCOB 210
Exhibitors Room	ISTB4 3rd Floor
Posters	ISTB4 3rd Floor
Presentation Rooms	See Detailed Program for session rooms
	SCOB 210
	SCOB 228
	ISTB4 Marston Theatre
	ISTB4 240
Technical Committee Meetings	See below for specific Meeting Rooms
Physics of Atomization (Monday)	ISTB4 3rd Floor
Computation and Modeling (Monday)	ISTB4 240
Diesel & Automotive (Monday)	ISTB4 Marston Theatre
Industrial & Agricultural Sprays (Tuesday)	ISTB4 3rd Floor
Aerospace Propulsion (Tuesday	ISTB4 Marston Theatre
Spray Measurements (Tuesday)	ISTB4 240

PROGRAM NOTES

These are some helpful notes for your time during ILASS-Americas 2019.

Registration takes place on Sunday, May 12 from 5-7pm in ISTB4 building on the Ground Floor.

A Welcome Reception will take place on Sunday, May 12 from 5:30-7:30pm in ISTB4 building on the 3rd Floor.

Breakfast (Continental) will be served every morning from approximately 7:00- 7:45am in the ISTB4 building on the 3rd Floor. Exhibitor booths will be open during this time, as well.

The ILASS-Americas Annual Business Meeting will be held during lunch on Tuesday, May 14. All conference attendees are welcome to attend.

Technical Committee Meetings will be held on Monday and Tuesday immediately following lunch. Conference attendees are strongly encouraged to join the technical committee discussions that match their interests. The meeting are open to all participants.

Exhibitor's Displays are shown each day from the start to the end of each day in the ISTB4 building on the 3rd Floor.

Poster Session will be held on Wednesday, May 15 from 9:20-10:00am in the ISTB4 building on the 3rd Floor with poster authors.

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

The Conference Reception will be held at the Heard Museum (2301 N. Central Ave., Phoenix, Arizona), on Tuesday May 14. Transportation to the museum will leave the ISTB4 building entrance at 5pm. Dinner will be served from 7:30-9:30pm. Return shuttles will depart starting at 9:30pm, with the last shuttle leaving at 10:45pm.

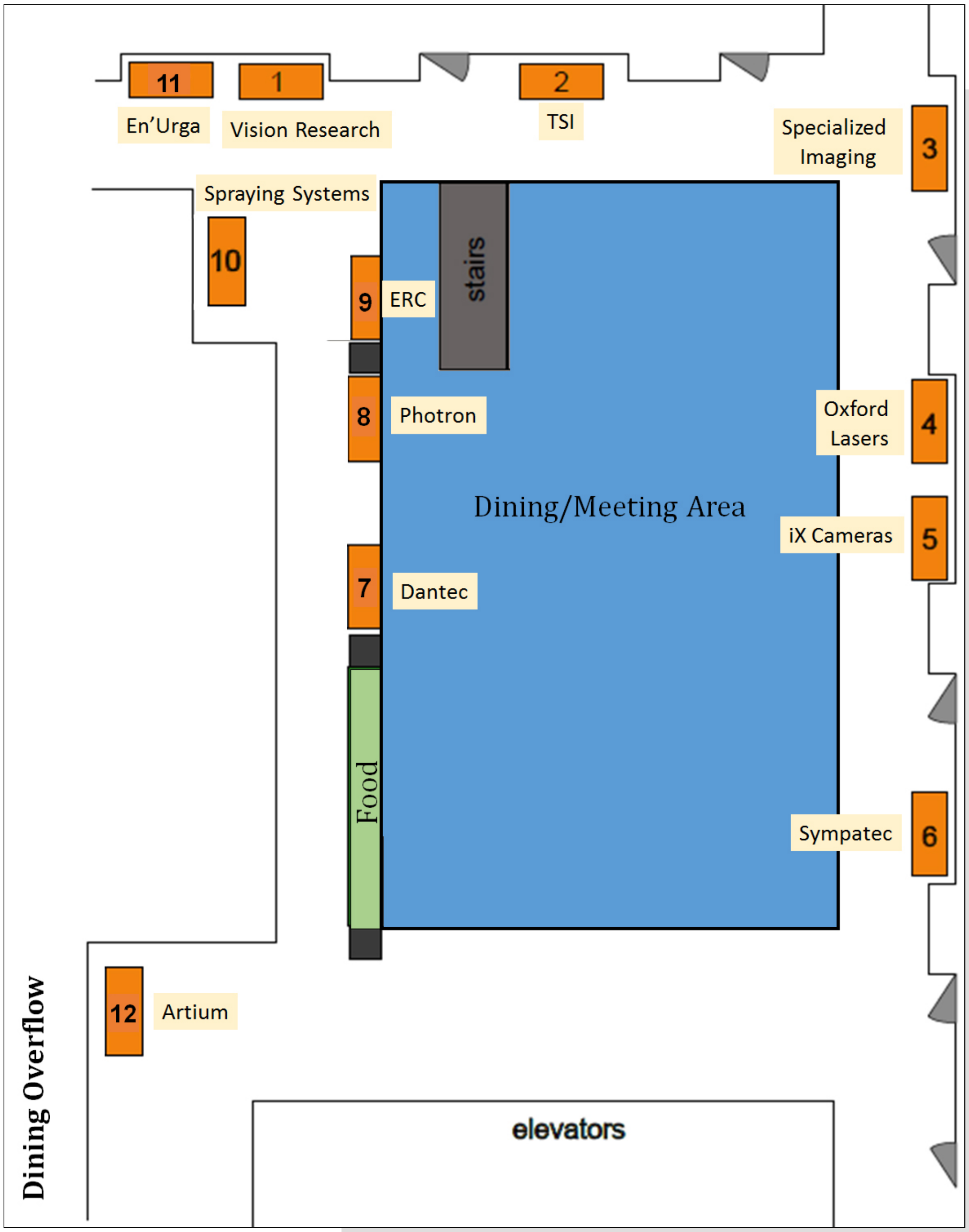
Paper numbers & links are provided on each abstract page of the ILASS-Americas 2019 Book. When the link is selected from the PDF located on the media drive, these links will auto-open the respective paper from the media drive.

EXHIBITOR INFORMATION

There are twelve exhibitors at this year's conference. They offer an array of diagnostic instrumentation, services, and equipment which are on display in the ISTB4 building on the 3rd floor. Specific details are outlined on the following pages with statements from each exhibitor.

The exhibitors at this year's conference are:

EXHIBITOR LAYOUT



About Vision Research

Vision Research, an AMETEK Inc. business unit, is a leading manufacturer of high-speed digital imaging systems that are indispensable across a wide variety of applications including defense, automotive, engineering, science, medical research, industrial, machine vision, and broadcast media. 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 highspeed 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.
100 Dey Road
Wayne, New Jersey 07470
phantom@ametek.com

TSI, Inc.

TSI Inc. 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 next generation of the PDPA system: the Powersight is compact, simple to use, and flexible with more laser power. For real-time instant velocity or simultaneous velocity and size measurements, the Powersight provides a higher laser power up to 500 mW per channel, increasing the capability of making measurements in challenging environments, like for GDI dense spray and large facilities with long focal standoff of several meters. The new FSA3800 processor combines signal analysis and photo-detection together for simple operation. The Powersight and FSA processor give you the powerful system arrangement of LDV and PDPA measurements.

TSI's Fluid Mechanic Systems can be easily configured to meet your current application and also be expanded for future applications. Contact TSI by phone at 800.680.1220, online at www.tsi.com, or stop by TSI's booth to learn more about our systems and how our measurement systems can meet your challenging research today.

Specialised Imaging manufactures and distributes Ultra High Speed Imaging Systems. We've been a leading manufacturer in the field for over 15 years made up of 20 or so seasoned scientists, engineers, and technicians devoted to ultra high speed imaging in concept design and manufacture. Our US office is a US veteran owned small business with offices in Temecula, California; Detroit, Michigan; and the Baltimore area. We offer sale, applications support and full line service of all products.

The Kirana Ultra High Speed Video Camera is capable of capturing 180 frames at 924 x 768 pixels per frame at all frame rates from 1,000 to 5 Million fps and exposure times down to 100 ns.

Our SIM Framing Cameras can capture up to 32 frames of 1360 x 1040 pixels @12 bits, at up to 1 Billion frames per second, with exposure times down to 3 ns.

We also offer a full line of single and double frame intensified cameras and standalone Image Intensifiers. We are also the North American representative for Optronis GmbH manufacturer of the OptoScope Streak Camera line.

We offer streak cameras with time resolution down to < 2 picoseconds, we also offer some of the largest format photocathodes at up to 35 mm long and time windows up to 40 mm long.

We are also the North American representative for Image Systems AB the developer of TEMA and TrackEye Motion Analysis Software which is the worlds most used automated motion tracking and analysis of video data for 2D, 3D, 6D and now DIC applications.

Specialised Imaging Inc,
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Temecula, CA 92591, USA
+1-951-296-6406

www.specialised-imaging.com

Oxford lasers Inc.

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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F: 01235 810060
E: Oxford.ltd@oxfordlasers.com

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Shirley MA 01464
USA
T: (978) 425-0755
F: (978)425 4487
E: oxford.inc@oxfordlasers.com

Revolutionizing high-speed camera technology

iX Cameras is a world-leading technology and product company specializing in the field of high-speed (slow motion) imaging. Based on proprietary innovative technologies, we design, build and sell cutting-edge ultra-fast cameras and software for a wide range of advanced scientific research applications. Our commitment to innovate and push the boundaries of high-speed video science is the reason we develop technically superior and easy-to-use products that our customers need to attain the highest scientific achievements and creativity. The innovation of our i-SPEED brand of cameras is backed by our world-class service and support teams, ensuring our customers' success.

Innovation built on our legacy

For over a decade, thousands of i-SPEED brand cameras were developed and sold by Olympus until the spinoff of the product development group in 2014. Today, the same heralded development team from Olympus, combined with new camera and software industry veterans, continues to design innovative state-of-the-art i-SPEED cameras under the iX Cameras name, always upholding the Olympus legacy of quality.

Products

i-SPEED 7 Series Cameras: Designed for engineering and research, i-SPEED 7 cameras provide the perfect balance of ultra-high resolution -- with higher pixel density for accuracy and the ability to zoom in to magnify detail -- with recording speeds that capture even the fastest transient events without any blur.

i-SPEED 5 Series Cameras: Designed with performance and environmental constraints in mind, the cameras are a new range of models from iX Cameras. The compact form factor of the 5 series contains plenty of power and memory for exceptional performance in both laboratory and field applications, all in a convenient package for ultimate functionality and portability. With an innovative sealed internal cooling system and sealed sensor, these are the first cameras in this class designed for use in harsh and demanding environments.

i-SPEED 2 Series Cameras: Bring portability and power to your application without exhausting your budget. The i-SPEED 2 features a beautiful 2.6 megapixel image sensor, optional extended battery and expandable video storage options.

Markets

Ballistics, Automotive testing, R&D testing, Production line monitoring and auditing, Biomechanics, Sports performance, Media and Cinematography

Offices

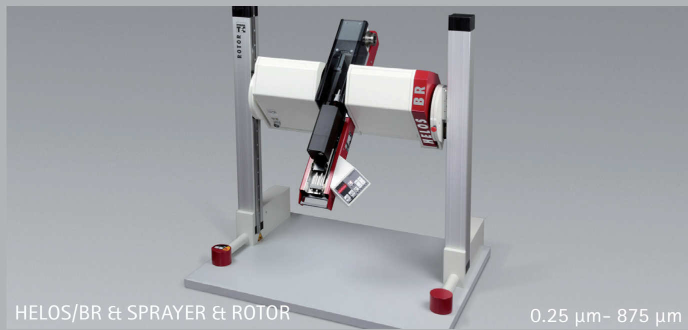
United States: 8 Cabot Road, Suite 1800, Woburn MA, 01801
United Kingdom: Bradley House, Locks Hill, Rochford, Essex SS4 1BB
China: No 399 Hangting Road, Oriental Hong Jing Garden ZhuQiao Town, Shanghai
India: J2-101, Swiss County, Thergaon, Pune-411033

ix-cameras.com

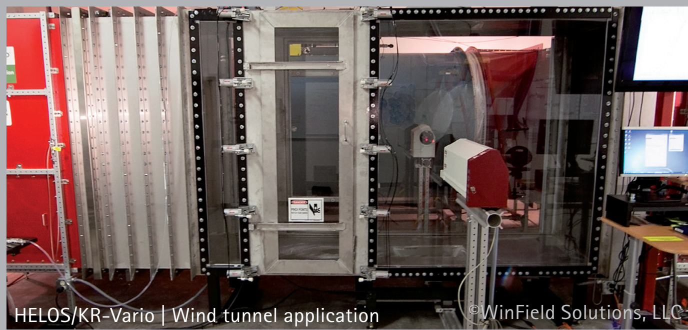
Particle Measurement | Laser Diffraction
Particle Size and Droplet Size Distribution
0.1 Microns to 8,750 Microns

Sympatec Technology for Spray Particle Size and Droplet Distribution


HELOS/BR & SPRAYER 0.25 µm- 875 µm


HELOS/BR & SPRAYER & ROTOR 0.25 µm- 875 µm


HELOS/KR-Vario 0,1 µm - 8,750 µm


HELOS/KR-Vario | Wind tunnel application ©WinField Solutions, LLC

Sympatec develops, manufactures, sells, services and supports an innovative range of modular instruments for particle size and shape analysis in laboratory and process applications for customers worldwide. Typical applications comprise dry powders, granules, fibres, suspensions, emulsions, gels, sprays and inhalants – spanning a size range from 0.5 nm up to 34,000 µm.

Our instruments reliably supply highly precise and reproducible results in very short measuring times and with excellent system-to-system comparability. The open measuring zone of our laser sensors is most suitable for the analysis of extended sprays provide a wide variety from technical spray applications like agricultural sprays to pharmaceutical applications like nasal sprays.

FDA conforming characterization of spray dynamic due to description of formation phase, stable phase and dissipation phase methods guarantees conformity with the pharmaceutical product approval. A team of highly-qualified service employees provides support for Sympatec instruments worldwide, and can also perform preventive maintenance and assist in system qualification.

Laser diffraction
The modular system concept of our proven HELOS laser diffraction sensors covers a wide range of dry and wet applications. Configurations for spray applications allow measurement of spray particle and spray droplet size distributions for more efficient product development of sprays and aerosols. It delivers valid and reproducible droplet size data from finest to coarse droplets.

Particle and droplet size characterisation within spray cones
Particles to be analysed as nebulae clouds of droplets or spray cones remain assigned to dry dispersion as long as air or gas is the continuous phase around the disperse systems. Together with the flexible SPRAYER adapter, the compact laser diffraction sensor HELOS/BR offers meaningful and reproducible analysis of the size distribution of droplets or solid particles in pump sprays, metered dose inhalers (MDI) and other pressurised sprays in the range from 0.25 µm to 875 µm. The adapter can be flexibly used for a wide range of different atomizer types and simulates the manual application of the relevant spray with a force or trajectory actuator.

HELOS/KR-Vario is the preferred model for application with extended particle clouds ranging from 0,1 µm to 8,750 µm. The open measuring zone, which can be varied in its width, supports the flexible adaptation of the optical measurement system to individual customer requirements in challenging technical applications in laboratories or pilot plants such as wind tunnels.

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www.sympatec.com

Dantec Dynamics specializes in the development, manufacture and application support of measurement systems that acquire and analyze data of physical properties in fluids (velocity, temperature, concentration, species) and in solid structures (strain, vibration, defects), as well as spray diagnostics (particle sizing and velocity). We deliver turnkey and customized solutions built on high-end laser optics, imaging, and sensor technologies.

Our measurement technologies for fluid and combustion dynamics include Particle Image Velocimetry (PIV), Hotwire/Constant Temperature Anemometry (CTA), Laser Doppler Velocimetry (LDV), Phase Doppler Particle Sizing (PDA), Laser Induced Fluorescence (LIF), Laser Induced Incandescence (LII) and Laser Grating Spectroscopy (LGS). For solid dynamics, we offer Digital Image Correlation (DIC) and Laser Shearography.

Turn Measurements into Knowledge

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www.dantecdynamics.com

Photron

Photron high-speed cameras have been designed to meet the requirements of specialized imaging techniques employed in fluid dynamics including Particle Image Velocimetry (PIV), Laser Induced Fluorescence (LIF) and others. We have been an industry leader in high-end, high-speed camera systems for over fifty years. Photron's continuing development of new state-of-the-art products shows our commitment to furthering research and development in the areas of digital imaging and motion analysis solutions.

Photron's comprehensive product range and ability to record video at up to 2.1 million fps with unmatched light sensitivity make us the first choice of engineers, scientists, technicians and other camera~~s~~ users around the world. Through high-speed video capture and slow-motion analysis, we can greatly slow down or stop any action, thereby enabling our customers to see precisely what occurred no matter how fast the event.

Photron offers a wide range of cameras with powerful features:
Megapixel resolution to 21,000fps
Reduced resolution to 2.1Mfps
Unparalleled light sensitivity at ISO 64,000
Minimum exposure to 159ns
Internal memory to 128GB
Fast download to PC or SSD
Extremely rugged design
Standard 2-year warranty

Applications and Imaging Examples
Liquid~~e~~ Spray (fuels, water, paint)
Spray Break-up and Atomization
Bubbles & Cavitation
Jet Nozzle Flow
Reactive Flows
Mixing Flows
Spray Formation
Flows in Pumping and Rotating Machinery
Flows in Devices for Life Sciences and Biomedical Work

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E: image@Photron.com
W: www.photron.com

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

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 spray and gas fired gas turbine combustion systems and industrial processes. The expertise ranges from the basic science of liquid injection and sprays associated with a wide array of applications to study of complex practical configurations for atomization and spray formation, fuel/air mixing and combustion, swirl generation, and associated pollutant formation and operability performance and control.

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 a specialized imaging system for inspection inside high temperature environments and a turn-key reference burner for calibration of laser diagnostics. Gaseous and liquid fired burners are also available.

Contact Information:

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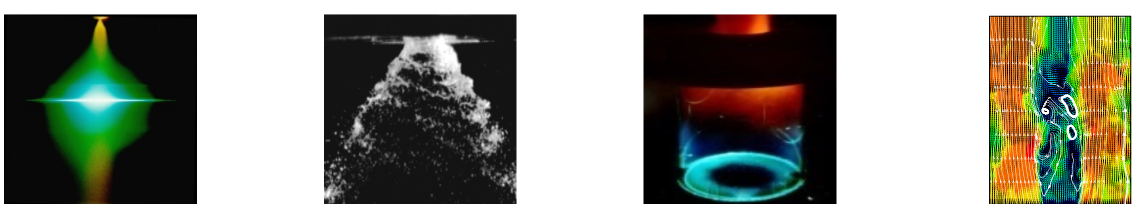

Phase Doppler Interferometry | High Speed Video | Reacting Spray Visualization | Particle Image Velocimetry

Figure 1 – Sample Data Sets (Many Other Measurements Are Available, Please Enquire).

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. With over 80 years of experience, our world-wide presence and highly skilled sales staff make us uniquely qualified to help with specific spray applications. We are experts in spray technology and our products are used in almost every manufacturing industry.

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 with Local Attention

With 10 manufacturing facilities located in North and South America, Europe and Asia and 85 sales engineering offices around the world - we can provide local service and quick delivery.

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Website: www.Spray.com

En'Urga Inc. is the industry leader in customized optical diagnostic equipment for the most challenging factory floor application. En'Urga Inc. has 25 years experience in optical diagnostics research, serving many Fortune 50 companies and Federal Government agencies. Our expertise in emission and absorption tomography in hostile environments enables measurement and control of varied processes in a wide array of industries. We specialize in research, design, development, calibration, and installation of instruments suitable for the measurement of temperatures, gas concentrations, emissivity, and particulate (liquid and powder) characteristics.

En'Urga Inc. has several products in its portfolio. The **SETScan** optical patternator obtains the 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. Custom units at 200 KHz are also available for studying transient sprays.

The **SPECTRALINE** series of spectrometers provides visible spectra from 0.3 to 1.1 microns at 100 KHz, and infrared spectra from 1.3 to 4.8 microns at 1.32 KHz. These are the highest speed 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.

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

The **PODScan** tomography system provides the tomographic mapping of drop sizes in sprays. In combination with the SPIvel velocimeter, the **PODScan** system can provide spatially resolved mass flux in spray in a matter of seconds.

All of En'Urga products can be leased or purchased from En'Urga Inc. 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 is used in these applications conform to the highest standards possible. At En'Urga Inc., customer service and innovation are our primary goals.

Contact info: 1201 Cumberland Avenue, Suite R, W. Lafayette, IN 47906
Ph. (765) 497-3269; Email: info@enurga.com

470 Lakeside Drive, Unit C
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 35 years and is acknowledged as the most reliable and accurate means for characterizing spray and aerosol droplet dynamics. Our goal over the past 20 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. Other applications include spray drying particle characterizations wherein particulate in liquid and solid irregular-shaped particles exist.

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 multi-beam imaging (patents pending) have been designed for atmospheric cloud monitoring and aircraft icing research.** These instruments are also used for a broad range of spray applications. They have undergone significant testing in the field. 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 **U.S. Army SBIR Ph II and NASA SBIR Phase I, II and III programs**, we have developed PDI and high speed imaging (**HSI**) systems for 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, ice crystals, and mixed phase conditions). We have also developed a line of **TurnKey (TK)** systems, an integrated PDI probe suitable for in-spray use. Our instruments are also used for quality control for inkjet printing of large OLED displays. 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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Email: info@artium.com
Website www.artium.com

Detailed Program

ILASS Americas 30th Annual Conference 2019

Sunday, May 12

S 5:00-7:00 PM — **Registration** — ISTB4 Ground Floor

S 5:30-7:30 PM — **Welcome Reception with Exhibitors** — ISTB4 3rd Floor

Monday, May 13

M 7:00-7:45 AM — **Breakfast with Exhibitors** — ISTB4 3rd Floor

M 7:45-8 AM — **Welcome and Opening Remarks** — SCOB 210

M 8-8:50 AM — **Keynote Lecture** — SCOB 210

Driving Innovation in Fire Sprinkler Sprays

Andre W. Marshall, University of Maryland & NSF Program Director

M 8:50-9:45 AM — **Plenary Session with Exhibitors** — SCOB 210

Chair: Mike Cloeter

Time	3D Imaging of Atomization (Special Session) Chairs: B. Halls & K. Bade SCOB 210	Automotive Sprays I Chairs: S. Parrish & L. Pickett SCOB 228
M 10:00 AM	**33: High-speed four-dimensional liquid mass distribution measurements in impinging jet sprays** N. Rahman, B. Halls, T. Meyer, J. Gord, M. Slipchenko, M. Lightfoot Purdue University, Aerospace Systems Directorate WPAFB, Aerospace Systems Directorate Edwards AFB	**106: Characterization of a Gasoline Multi-hole Spray Under Closely-Spaced Multiple Injection Operating Conditions** R. Grover, S. Parrish General Motors
M 10:20 AM	**41: Blood atomization from blunt impact on a liquid film using high-speed digital in-line holography** R. Das, R. Faflak, D. Attinger, J. Michael Iowa State University	**71: A Stochastic Kelvin-Helmholtz/Rayleigh-Taylor Breakup Model and a Synthetic Eddy Injection Model for Large-Eddy Simulations of Diesel Sprays** C-W. Tsang, C. Rutland The Dow Chemical Company, University of Wisconsin-Madison
M 10:40 AM	**56: Development of an atomization system for testing spraying variables using optical instruments** J. Giraldo, A. Colorado, A. Amell GASURE, University of Antioquia	**40: An Experimental and Computational Study of Fuel Properties Effect on Inert Spray Characteristics under Compression Ignition Engine Conditions** L. Zhao, M. Ameen, Y. Pei, M. Tang, Y. Zhang, M. Traver Argonne National Laboratory, Aramco Research Center

M 11:00-11:30 AM — **Break** — ISTB4 3rd floor

	Spray Characterization & Measurement I Chairs: A. Thistle & M. Cloeter SCOB 210	Compressible Multiphase Atomization (Special Session) Chairs: O. Desjardins & M. Herrmann SCOB 228
M 11:30 AM	**25: Measurement of Liquid Core Length of a Coaxial Two-fluid Spray** D. Li, J. Bothell, T. Morgan, T. Heindel, A. Aliseda, N. Machicoane, A. Kastengren Iowa State University, University of Washington, Argonne National Laboratory	**85: Diffuse Interface Modeling of Compressible Multiphase Flows using an Adaptive Mesh Refinement Library** F. Fritz, K. Kannan, C. Ballesteros, N. Fleischmann, M. Herrmann Technical University Munich, Arizona State University
M 11:50 AM	**51: Model reduction of primary atomization using optical flow** P. Sashittal, D. Bodony University of Illinois at Urbana-Champaign	**59: A Robust All-Mach Multiphase Flow Algorithm for High-Fidelity Simulations of Compressible Atomization** M. Kuhn, O. Desjardins Cornell University
M 12:10 PM	**90: Complementary Characterization of Standard Simplex Atomizers using Phase Doppler Interferometry and X-ray Radiography** B. Sforzo, S. Leask, A. Li, A. Tekawade, C. Powell, V. McDonell, A. Kastengren Argonne National Laboratory, University of California Irvine	**46: An all-Mach multiphase flow solver using block-structured AMR** M. Natarajan, R. Chiodi, M. Kuhn and O. Desjardins Cornell University

M 12:30-1:30 PM — **Lunch** — ISTB4 3rd Floor

M 1:30-2:20 PM — **Technical Committee Meetings**

Physics of Atomization	ISTB4 3rd Floor
Computation and Modeling	ISTB4 240
Diesel & Automotive	ISTB4 Marston Theater

Sessions	Computational Methods for Atomization I Chairs: M. Trujillo & B. Turnquist ISTB4 Marston Theater	Sprays in Analytical Plasma Spectroscopy (Special Session) Chairs: A. Montaser & V. McDonell ISTB4 240
M 2:30 PM	**35: Adjoint-based interfacial control of axisymmetric viscous drops** A. Fikl, D.Bodony University of Illinois at Urbana-Champaign	**104: The Importance of Atomic Spectrometry in Life and the Significance of Spray Quality** A. Montaser The George Washington University
M 2:50 PM	**24: Euler-Lagrange Simulations With Fully-Resolved Physics of Dense Spray Control** K. Liu, S. Balachandar University of Florida	**103: A Piezoelectrically Driven Nebulizer for Inductively Coupled Plasma (ICP) Atomic Spectrometry** H. Badiei PerkinElmer Inc.
M 3:10 PM	**26: Effect of Interface Reconstruction Methods on Atomizing Liquid Jet Simulations** R. Chiodi, O. Desjardins Cornell University	**105: Element- and size- based characterization of nanomaterials by interfacing ICP-MS with Field-Flow Fractionation** S. Tadjiki, A. Montaser Postnova Analytics Inc., The George Washington University
M 3:30 PM	**36: An efficient pressure solver for stochastic gas-liquid multiphase flows** B. Turnquist, M. Owkes Montana State University	**101: Development of Droplet Injection ICP-AES/MS and Elemental Analysis of Single Human Cancer Cells** A. Okino, S. Kohno, T. Miyake, Y. Suenaga, M. Shimada, Y. Matsumoto, K. Chiba Tokyo Institute of Technology, Kwansei Gakuin University

M 3:50-4:20 PM

Break ISTB4 3rd Floor

Sessions	**Atomization Theory, Analysis, & Modeling** Chairs: J. Poblador-Ibanez & D. Bodony ISTB4 Marston Theater	**Internal and Near Nozzle Behavior** Chairs: D. Sedarski & Y. LIng ISTB4 240
M 4:20 PM	**58: Role of Density in Gas-Assist Counterflow Atomization** E. Johnson, V. Srinivasan, P. Strykowski, A. Hoxie University of Minnesota Duluth, University of Minnesota Twin Cities	**57: A Computational Study of Nozzle Internal Flow and Its Effect on Spray Atomization** A. Agarwal, M. Trujillo University of Wisconsin - Madison
M 4:40 PM	**99: Control-Informed Dynamic Mode Decomposition Applied to the Ginzburg-Landau Equation** M. Banks, D. Bodony University of Illinois at Urbana-Champaign	**52: Temperature Dependent In-Nozzle Flow Investigations of Marine Diesel Injectors** R. Balz, D. Sedarsky Chalmers University of Technology
M 5:00 PM	**93: Extraction of Droplet Genealogies from High-Fidelity Atomization Simulations** C. Rubel, M. Owkes Montana State university	**47: Numerical investigation of air bubbles formation and dynamics in flow-blurring atomizers and its impact on near nozzle liquid breakup** D. Jiang, L. Jiang, Y. Ling Baylor University, University of Louisiana at Lafayette
M 5:20 PM	**18: Improving the validation of turbulent jet breakup models** B. Trettel University of Texas at Austin	**49: Influence of K-factor on Cavitation Suppression for a Heavy-duty Diesel Injector Operating with Straight-run Gasoline** R. Torelli, G. Magnotti, S. Som, Y. Pei, M. Traver Argonne National Laboratory, Aramco Services Company: Aramco Research Center – Detroit

Tuesday, May 14

T 7-7:50 AM

Breakfast with Exhibitors — ISTB4 3rd Floor

T 7:50-8:00 AM

Opening Remarks — SCOB 210

T 8:00-8:50 AM

Keynote Lecture — SCOB 210

Physical Mechanisms of Droplet/Turbulence Interaction

Antonino Ferrante, University of Washington

	X-Ray Diagnostics of Sprays I (Special Session) Chairs: A. Kastengren & K.-C. Lin SCOB 210	Jet-in-Crossflow I (Special Session) Chairs: B. Bornhoft & A. Hoxie SCOB 228
T 9:00 AM	**07: Neutron Imaging for the Two-Phase Flows inside an Aluminum Aerated-Liquid Injector** K.-C. Lin, C. Carter, L. Santodonato, H. Bilheus, Z. Zhang, C. Smith, A. Kastengren Taitech Inc., Air Force Res. Lab., Oak Ridge Nat. Lab., U. Tennessee, Argonne Nat. Lab	**60: Analysis of a Liquid Jet in Supersonic Crossflow using Large-Eddy Simulation** M. Kuhn, O. Desjardins Cornell University
T 9:20 AM	**31: Optimization of High-Speed White Beam X-ray Imaging for Spray Characterization** T. Morgan, J. Bothell, T. Burtnett, D. Li, T. Heindel, A. Aliseda, N. Machicoane, K. Matusik, A. Kastengren Iowa State U., U. Washington, Argonne Nat. Lab	**28: Validation and Analysis of primary atomization of turbulent liquid jet in crossflow simulations** A. Asuri Mukundan, T. Ménard, A. Berlemont, J. Brändle de Motta, M. Herrmann CNRS UMR6614 CORIA, Arizona State University
T 9:40 AM	**95: Preliminary Investigation of Apparent Mass Loss in Objects Due to Image Blur using X-ray Radiography** B. Halls Sandia National Laboratories	**87: An Analysis of Proper Orthogonal Decomposition and Dynamic Mode Decomposition on Liquid Jets in Crossflow** S. Leask, V. McDonell, S. Samuelsen UCI Combustion Laboratory
T 10:00 AM	**81: X-ray scattering-based temperature measurements of liquid in multiphase flows** N. Rahman, B. Halls, T. Meyer, J. Gord, K. Matusik, A. Kastengren Purdue U., Aerospace Systems Directorate WPAFB, Argonne Nat. Lab., Innovative Scientific Solutions	**03: A hybrid approach applied to spray in liquid jet in crossflow** D. Fontes, L. Meira, F. De Souza Federal University of Uberlândia

T 10:20-10:50 AM

Break — ISTB4 3rd Floor

Time	Droplet Phenomena Chairs: D. Johnson & K. Feigl SCOB 210	Spray Wall Interaction (Special Session) Chairs: M. Trujillo & F. Wang SCOB 228
T 10:50 AM	**67: Oscillation dynamics of a sessile drop on hydrophobic and hybrid surfaces** Y. Ling, J. Sakakeeny, X. Li, S. Popinet, J. Alvarado Baylor University, Sorbonne Universite, CNRS, UMR 7190, Institut Jean Le Rond d'Alembert, Texas A&M University	**39: Spray wall interaction and the formation of fuel wall films** F. Schulz, F. Beyrau Otto-von-Guericke-Universität Magdeburg
T 11:10 AM	**74: Computational and Experimental Investigation of Drop Breakup in Antral Contraction Wave Flows in a Model Stomach** F. Tanner, K. Feigl, D. Dufour, E. Windhab Michigan Technological University, ETH Zurich	**82: Retraction of water droplets after impact on solid substrates with different wettabilities** F. Wang, T. Fang North Carolina State University
T 11:30 AM	**66: Filament Extension Atomization** D. Johnson, J. Unidad, R. Neelakantan, M. Benedict, J. Kalb, K. Murphy, E. Karatay, E. Weflen PARC, A Xerox Company	**48: A computational study of splashing drop trains: secondary droplet formation and characterization** D. Markt Jr, A. Pathak, M. Raessi, S. Lee, R. Torelli University of Massachusetts Dartmouth, Michigan Technological University, Argonne National Laboratory
T 11:50-1:10 PM	**Lunch and ILASS Americas Annual Business Meeting**	ISTB4 3rd Floor
T 1:10-2:00 PM	**Technical Committee Meetings** Industrial & Agricultural Sprays Aerospace Propulsion Spray Measurements	ISTB4 3rd Floor ISTB4 Marston Theater ISTB4 240
	Turbulence Phenomena in Spray (Special Session) Chairs: O. Kaario & F. Tanner ISTB4 240	**Jet-in-Crossflow II (Special Session)** Chairs: K.-C. Lin & M. Kamin ISTB4 Marston Theater
T 2:10 PM	**19: Turbulent theory of velocity-profile-induced jet breakup** B. Trettel University of Texas at Austin	**14: Secondary Droplet Breakup Effects in Aerated-Liquid Injection into Subsonic and Supersonic Crossflows** J. Talbot, A. Kulkarni, J. Edwards, K-C. Lin, B. Bornhoft North Carolina State University, Air Force Research Laboratory
T 2:30 PM	**37: A Sub-grid Scale Energy Dissipation Rate Model for Large-eddy Spray Simulations** H. Li, C. Rutland, H. Im, F. Hernandez Perez University of Wisconsin-Madison, King Abdullah University of Science and Technology	**69: Effect of Density Ratio on Flowfield and Spray dynamics of Vaporizing Liquid Jet in Crossflow** M. Kamin, P. Khare University of Cincinnati
T 2:50 PM	**83: The Effect of Fuel: Large-Eddy Simulation of Spray A with Various Fuels** O. Kaario, V. Vuorinen, H. Kahila, M. Larmi Aalto University	**09: Numerical Simulation of Aerated-Liquid Injection into a Supersonic Crossflow** B. Bornhoft, K-C. Lin Air Force Research Laboratory, Taitech, Inc.
T 3:10 PM-3:40 PM	**Break**	ISTB4 3rd Floor

	Atomization & Spray Simulations I Chairs: X. Li & D. Markt ISTB4 Marston Theater	Spray Characterization & Measurements II Chairs: K. Bade & C. Lipp ISTB4 240
T 3:40 PM	**75: Drop evaporation and scalar mixing in dilute acetone sprays using large eddy simulation** X. Wang, J. Oefelein Georgia Institute of Technology	**92: Spray Nozzle Implementation for a Gas-Liquid Feed Application** M. Cloeter, C. Davidson, L. Hable, N. Wallace The Dow Chemical Company, Tenengeer, Inc., BETE Fog Nozzle, Inc.
T 4:00 PM	**34: Numerical Investigation on a New Design Concept of the Auxiliary Inspiratory Flow Supply Device for Dry Powder Inhalers** Y. Wu, J. Deng Trinity Valley School, School of Automotive Studies, Tongji University	**38: Control of large-scale instabilities and of drop sizes in assisted atomization** M. Alonzo, Z. Huang, A. Cartellier Univ. Grenoble Alpes, CNRS, Grenoble INP, Laboratory of Geophysical and Industrial Flows
T 4:20 PM	**42: Best Practices in the numerical modelling of liquid atomization processes** M. Sami, J. Schuetze, P. Hutcheson, P. Aguado Ansys	**88: Advances in imaging diagnostics for icing research in aircraft engines** J. Manin, W. Bachalo Artium Technologies
T 5:00 PM	**Transport to Museum**	Entrance to ISTB4
T 6:00-7:30 PM	**Cocktail Reception, Museum Tours**	
T 7:30-9:30 PM	**Dinner**	
T 9:30 PM	**First Shuttle Departs**	
T 10:45 PM	**Last Shuttle Departs**	

Wednesday, May 15

Time	Event	Location
W 7-7:50 AM	**Breakfast with Exhibitors**	ISTB4 3rd Floor
W 7:50-8 AM	**Opening Remarks**	ISTB4 Marston Theater

Sessions	**Experimental Methods & Instrumentation** Chairs: M. Minniti & D. Talley ISTB4 Marston Theater	**Atomization & Spray Simulations II** Chairs: M. Sami & K. Olshefski ISTB4 240
W 8:00 AM	**01: Enhanced Methods to Analyze and Extract Additional Insights from Liquid Flux Distribution (Patternation) Spray Data** C. Lipp Lake Innovation LLC	**50: Adjoint-based optimal control of an air-blasted planar sheet** L. Vu, A. Fikl, D. Bodony, O. Desjardins Cornell University, University of Illinois at Urbana-Champaign
W 8:20 AM	**05: Overcoming Saturation: Eliminating Intensity-Related Size Dynamic Range Limitations to Phase-Doppler Interferometry** C. Sipperley, K. Bade, R. Schick Step 2 Consulting, Inc., Spraying Systems, Co.	**44: Impact of Operating Conditions on the Spray in a High-Shear Nozzle/Swirler Injector In-vestigated using High-Fidelity Simulations** X. Li United Technologies Research Center
W 8:40 AM	**72: Femtosecond Holography of a Dodecane Jet Spray at High-Pressure Conditions** M. Minniti, A. Ziaee, D. Curran, J. Porter, T. Parker, D. Dunn-Rankin University of California Irvine, Metrolaser Inc., Colorado Schools of Mines, Florida Polytechnic University	**64: Modeling and detailed numerical simulation of the primary breakup of the "Spray G" gasoline jet** B. Jiang, Y. Ling Baylor University
W 9:00 AM	**29: An extinction-based technique for high-pressure spray field quantification** F. Poursadegh, O. Bibik, B. Yraguen, C. Genzale Georgia Institute of Technology	**12: Analysis of an axisymmetric liquid jet at supercritical pressures** J. Poblador-Ibanez, W. Sirignano University of California Irvine

W 9:20-10:00 AM	**Break & Poster Session**	ISTB4 3rd Floor
	17: Sensitivity of the range of a water jet to the breakup length and air entrainment B. Trettel, O. Ezekoye University of Texas at Austin	**53: Impingement Injector Spray Characteristics - A Study Using POD Technique** R. Pereira, D. Frederick University of Alabama in Huntsville
	84: Can a chart based on millions of trajectory simulations provide a simple tool to estimate how far a blood drop can fly? D. Attinger Iowa State University	**94: Demonstration of a Spectral Microscopy Imaging System for High Resolution, High-Speed Imaging of Primary Breakup in Fuel Sprays** K. Maassen, F. Poursadegh, C. Genzale Georgia Institute of Technology
	96: Near-Field Spray Characteristics of Vegetable Oil Using Flow Blurring Injection I. Qavi, N. Nasim, O. Akinyemi, L. Jiang University of Louisiana at Lafayette	**97: Study of Spray Characteristics for Different Impingement Lengths of Each Jet of Like Doublet Impinging Injectors.** S. Kathalagiri Vasantha kumar, F. Robert. A. The University of Alabama in Huntsville
		102: High-Fidelity Simulation of a Rotary Bell Atomizer with Electrohydrodynamic Effects V. Krisshna, M. Owkes Montana State University

	X-Ray Diagnostics of Sprays II (Special Session) Chairs: T. Meyer & J. Bothell ISTB4 Marston Theater	Computational Methods for Atomization II Chairs: M. Owkes & O. Desjardins ISTB4 240
W 10:00 AM	**86: Characterization of Near-Field Structures of Diesel Containing Carbon Dioxide in a Quiescent Environment Using X-Ray Radiography** T. Tidball, K.-C. Lin, A. Kastengren, T. Ombrello Taitec, Argonne, Nat. Lab., Air Force Res. Lab.	**89: Modeling Drop Deformation Effects in the Euler-Lagrange Prediction of Liquid Jet in Cross Flow** P. Pakseresht, S. Apte Oregon State University
W 10:20 AM	**61: X-ray Characterization and Spray Measurements of ECN Spray G Using Alternative Fuels Under Flashing Conditions** B. Sforzo, A. Tekawade, K. Matusik, A. Kastengren, J. Ilavsky, K. Fezzaa, C. Powell Argonne National Laboratory	**73: Advancements to a Dual-Scale approach for Simulating Turbulent Phase Interface Interactions** D. Kedelty, M. Herrmann, T. Ziegenhein Arizona State University
W 10:40 AM	**08: Exploration of Near-Field Structures of Aerated-Liquid Jets in Quiescent and Crossflow Environments Using Confocal X-Ray Fluorescence** K.-C. Lin, A. Kastengren, C. Carter Taitech, Argonne National Laboratory	**54: Speedup Analysis of Adaptive Mesh Refinement in the Simulation of Spray Formation** C. Kuo, M. Trujillo University of Wisconsin - Madison
W 11:00 AM	**10: Statistical analysis of focused beam measurements taken from a coaxial airblast spray** J. Bothell, D. Li, T. Morgan, T. Heindel, A. Aliseda, N. Machicoane, A. Kastengren Iowa State University, University of Washington, Advanced Photon Source	**15: Conservative Simulations of Atomization - Combining the Height Function Method with Rudman Dual Grids** K. Olshefski, M. Owkes Montana State University
W 11:20 AM	**65: A comparison between CFD and 3D X-ray Diagnostics of Internal Flow in a Cavitating Diesel Injector Nozzle** A. Tekawade, P. Mitra, B. Sforzo, K. Matusik, A. Kastengren, D. Schmidt, C. Powell Argonne National Laboratory, University of Massachusetts at Amherst	**30: Validation and Analysis of 3D DNS of planar pre-filming airblast atomization simulations** A. Asuri Mukundan, T. Ménard, A. Berlemont, J. Brändle de Motta, R. Eggels CNRS UMR6614 CORIA, Rolls-Royce Deutschland
W 11:40-12:30 PM	**Lunch and Prize Drawings**	

	Spray Applications II Chairs: R. Grover & F. Schulz ISTB4 Marston Theater	Automotive Sprays II Chairs: C. Powell & F. Poursadegh ISTB4 240
W 12:30 PM	**45: Development of a screening tool to assess fuel property effects on cavitation and erosion propensity** G.M. Magnotti, S. Som Argonne National Laboratory	**63: 3D Imaging of Cavitating Flow in a Diesel Injector at Practical Conditions using micro-CT** A. Tekawade, B. Sforzo, K. Matusik, A. Kastengren, C. Powell Argonne National Laboratory
W 12:50 PM	**11: PRELIMINARY STUDY OF THE REACTING FLOW FROM MULTI-ELEMENT SHEAR COAXIAL FLOWS** M. Roa, D. Talley Sierra Lobo, Inc., AFRL/RQRC	**100: The influence of ambient conditions and fuel type on gasoline spray plume direction** J. Hwang, L. Weiss, L. Pickett, S. Skeen Sandia National Laboratories, FAU Erlangen-Nuremberg
W 1:10 PM	**27: Characterization of Aqueous Cellulose Nanocrystals Sprays for Strengthening 3D Printed Polymer Structures** S. Shariatnia, F. Poursadegh, A. Asadi, D. Jarrahbashi Texas A&M, Georgia Institute of Technology	**20: An improved non-equilibrium multi-component evaporation model for blended diesel/alcohol droplets and sprays** P. Yi, S. Yang, T. Li, Y. Li University of Minnesota-Twin Cities, Shanghai Jiao Tong University, Lund University
W 1:30 PM	**80: Easy flowing emulsion (o/w) based spray-dried powder produced using dietary fiber as a wall material** B. Dubey, P. Roncato, M. Howarth National Centre of Excellence for Food Engineering, Sheffield Hallam University	**79: Varying the Bell Speed of an Electrostatic Rotating Bell** K. Sidawi, P. Moroz, S. Chandra University of Toronto, Polycon Industries
W 1:50 PM	**Conference closes**	

Andre W. Marshall, Ph.D.

Associate Professor
Department of Fire Protection Engineering
University of Maryland

Biography

Andre Marshall joined NSF in 2017 as Program Director for the Industry-University Cooperative Research Centers Program (IUCRC) on assignment from the University of Maryland, College Park. He currently serves as Innovation Corps (I-Corps) Program Director in the Division of Industrial Innovation and Partnerships (IIP). Dr. Marshall's experience spans roles as a corporate R&D engineer, an academic, and an entrepreneur. He joined the faculty of University of Maryland after developing patented next-generation low-emission technology for Rolls-Royce as part of the NASA Advanced Subsonic Transport (AST) program. At University of Maryland, Dr. Marshall is an Associate Professor in the Department of Fire Protection Engineering and Director of the Fire Testing and Evaluation Center (FireTEC). His research interests include fire suppression sprays and fire induced turbulent transport. In 2007, Dr. Marshall received the prestigious NSF Presidential Early CAREER Award for Scientists and Engineers (PECASE) for his research on spray characterization. The PECASE award is the highest honor bestowed by the U.S. government on scientists and engineers in the early stages of their independent research careers. Prof. Marshall's research team has collaborated with Fortune 500 companies such as FM Global and United Technologies on a variety of fire suppression challenges. In 2012, Prof. Marshall established a technology start-up team through the NSF I-Corps Program focused on commercializing innovations in spray technology. His technology is currently being licensed in the fire protection industry to improve fire sprinkler system design, evaluation, and optimization.

Driving Innovation in Fire Sprinkler Sprays

Andre W. Marshall Affiliation
University of Maryland
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Abstract

While advancements abound in many spray technology verticals (e.g. propulsion, coatings, and medical applications), the fire sprinkler spray has received relatively little fundamental research attention. Yet fire sprinkler sprays present interesting engineering challenges. There is no doubt that meeting these challenges would have compelling impact on life safety. Further, the fire suppression system can drive building design and utility in unexpected ways potentially resulting in outsized impact on building economies. From a device design perspective, the essential fire sprinkler is certainly robust, and in some ways elegant. These devices create large-scale, three-dimensional, high stokes number sprays through mechanical impingement. Upon activation, fire sprinkler systems offer protection by wetting 'fuel' not yet involved in the fire limiting its spread. These sprays are designed for penetration, coverage, and uniformity even while the detailed spray features are poorly understood. This persistent knowledge gap has resulted in a highly empirical design process that remains largely a matter of 'cut and try'. The basic research investments that provide foundational insights and enable disruptive technologies lag behind other spray technology verticals. Nevertheless, a body of basic research is forming that honors this quintessential high-stakes engineering problem pitting water against fire. Highlights of recent measurement and modeling advancements will be presented along with their novel tightly integrated analytical frameworks. These advancements have created new opportunities for the research, development, and design of fire sprinkler systems.

Prof. Antonino Ferrante

Associate Professor
William E. Boeing Department of Aeronautics and Astronautics
University of Washington

Biography

Antonino Ferrante is an Associate Professor of the William E. Boeing Department of Aeronautics & Astronautics at the University of Washington (UW), Seattle, where he leads the Computational Fluid Mechanics Lab. In 1996, he received the B.S. in Aeronautical Engineering from Universita' di Napoli, Federico II (Italy). In 1997, he received the M.S. in Aeronautics & Astronautics and the Belgian Government Prize from the von Karman Institute. In 2004, he received the Ph.D. in Mechanical and Aerospace Engineering from the University of California, Irvine, where he continued his research as Postdoctoral Scholar until 2007. From 2007 to 2009, he was Postdoctoral Scholar at the Graduate Aeronautical Laboratories of the California Institute of Technology (GALCIT). In 2009, he joined the UW as Assistant Professor where was tenured in 2015. Ferrante is recipient of the NSF CAREER Award (2011). Ferrante's research is mainly focused on understanding the physical mechanisms and modeling of complex flows, e.g. multiphase and wall-bounded turbulent flows, by developing new computational methodologies for DNS and LES apt to performing simulations on high-performance supercomputers.

Physical mechanisms of droplet/turbulence interaction

Antonino Ferrante
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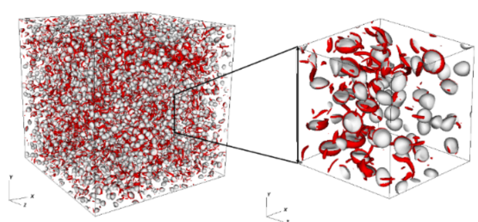
Abstract

The interaction of liquid droplets with turbulence are relevant to both environmental flows and engineering applications, e.g., rain formation and spray combustion. The physical mechanisms of droplet-turbulence interaction are largely unknown. The main goal of this research has been to investigate the physical mechanisms of droplet/turbulence interaction for non-evaporating and evaporating droplets.

Droplets in turbulent flows behave differently from solid particles, e.g., droplets deform, break up, coalesce and have internal fluid circulation. In order to simulate such behavior, we have developed a new pressure-correction method, *FastP**, for simulating incompressible two-fluid flows with large density and viscosity ratios between the two phases. The method's main advantage is that, for example, on a 10243 mesh, *FastP**, using the FFT-based parallel Poisson solver, is forty times faster than the method using multigrid. In general, *FastP** could be coupled with other interface advection methods such as level-set, phase-field, or front-tracking. We have coupled the pressure-correction method with a volume-of-fluid (VoF) method for its properties of being mass conserving and sharp-capturing of the interface.

We performed direct numerical simulation (DNS) of finite-size, non-evaporating droplets of diameter approximately equal to the Taylor lengthscale in decaying isotropic turbulence. We studied the effects of Weber number, viscosity ratio and density ratio. We derived the turbulence kinetic energy (TKE) equations for the two-fluid, carrier-fluid and droplet-fluid flow. This allows us to explain the pathways for TKE exchange between the carrier turbulent flow and the flow inside the droplet. The role of the interfacial surface energy is explained through the power of surface tension term of the two-fluid TKE equation. Also, we derive the relationship between the power of surface tension and the rate of change of total droplet surface area. This allows us to explain how droplet deformation, breakup and coalescence plays a role on the temporal evolution of TKE. Our DNS results show that increasing Weber number, the droplet to fluid density or viscosity ratios increases the decay rate of the two-fluid TKE relative to that of single-phase flow. Furthermore, we have developed a new methodology for the spectral analysis of multiphase flows. Via analysis of the DNS results both in physical and spectral space, the revealed physical mechanisms and opportunities for modeling will be presented. Recently, we have developed a new VoF-based method to simulate evaporating droplets. The verification and validation of the method, and the DNS results of droplet vaporization in isotropic turbulence will be presented in comparison to theory and experiments.



Paper Abstracts

High-speed Four-dimensional Liquid Mass Distribution Measurements in Impinging Jet Sprays

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Abstract

High-speed four-dimensional measurements are performed in an optically dense impinging jet spray using an x-ray radiographic technique. Three portable x-ray tube sources and high-speed imaging systems are used to obtain simultaneous radiographs of the impinging jet spray along three lines of sight. The imaging systems each consisted of a cesium iodide (CsI) phosphor plate, an f/2 objective, and a high-speed visible-light intensifier lens-coupled to a high-speed CMOS camera operating at 20 kHz. The radiographs were converted into a quantitative equivalent path length (EPL) of liquid water through the Beer-Lambert law, using a model to account for beam hardening as the x-rays are preferentially absorbed by the spray at the lower x-ray energies. The radiographs were converted into 3D structures through a multiplicative algebraic reconstruction technique (MART) using commercial software (LaVision DaVis 10). A quantitative analysis of the near-field region of the injector is shown, exploring the formation of a liquid rim at lower liquid flow rates as well as sheet break-up at higher flow rates. A qualitative mixing study with unlike liquid jets, one that is nearly fully transmissive and the other strongly absorbing, is also carried out to visualize pure and mixed regions as a function of time during jet impingement.

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Characterization of a Gasoline Multi-hole Spray Under Closely-Spaced Multiple Injection Operating Conditions

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Abstract

A combined experimental and modeling characterization of a multi-hole injector has been undertaken to understand the interplay of liquid and gas phase fluid dynamics under closely-spaced multiple injection operation. Indolene is injected at 30 MPa into an ambient environment at 6 bar and 300 C within a spray chamber from a 10-hole injector. Single injection events of 1, 2, 3, and 4 mg serve as a baseline for comparison against spit injection cases totaling 4 mg having 1, 2, and 3 mg fuel mass in the second pulse. Additionally, dwell time between pulses of 500, 1000, and 2000 μs is tested. These conditions are representative of a late injection strategy to improve robustness in a gasoline direct-injected engine. The liquid and vapor phases of the spray are visualized using a combination of an elastic scattering and schlieren technique. Transient probability envelopes of the variance of the fuel distribution are quantified over 25 injection events. The corresponding CFD computations are conducted using a Lagrangian particle tracking technique for the liquid spray and a Reynolds Averaged Navier Stokes (RANS) approach for the Eulerian gas phase. A post-processing methodology is outlined to scale the CFD images appropriately to compare against experimental images. The modeling results show good comparison with measured fuel distributions, especially at longer dwell times. CFD predictions also illustrate potential benefits of multiple injection in a spark-ignited engine application through local turbulence enhancement to support flame growth.

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Blood atomization from blunt impact on a liquid film using high-speed digital in-line holography

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Abstract

Bloodstain pattern analysis (BPA) is a potential tool for crime scene reconstruction, but efforts to connect the ultimate pattern left by blood droplets and the fluid dynamic origin of these droplets remain uncertain. The mechanism of blood-letting, the resulting size and velocity distributions, and the flight of these droplets to a surface and the wetting and drying on the surface can lead to a variety of blood patterns which may be analyzed. We present a study of the atomization mechanisms in the immediate moments after impact of a blunt cylinder on a film of liquid blood. High-speed imaging shows that secondary droplets originating from ligament break-up have different characteristics than the mist of droplets formed due to high velocity impact. Here, high speed imaging and digital in-line holography (DIH) at kHz-rates are used to quantify droplet diameters and velocities of blood droplets from 1-30 ms after impact. The Sandia HoloSand code was utilized to process holograms and identify droplet trajectories over multiple frames, improving the overall out-of-plane position and velocity estimates. The merits of DIH are compared with that of traditional backlit imaging and accuracy of out of plane velocity is discussed. The temporal evolution of diameters and velocities of blood droplets in a blunt impact (flat-to-flat surface) at up to 4 m/s is reported, and comparisons are made with water. This quantitative dataset will allow comparison with drag-based fluid dynamic models in order to connect the ultimate blood stain patterns generated in an experimental configuration.

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A Stochastic Kelvin-Helmholtz/Rayleigh-Taylor Breakup Model and a Synthetic Eddy Injection Model for Large-Eddy Simulations of Diesel Sprays

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Abstract

The goal of this study is to develop and improve physical models for large-eddy simulations of Diesel sprays. Particularly, the synthetic eddy injection model and the stochastic Kelvin-Helmholtz/Rayleigh-Taylor (KH-RT) atomization and breakup model were developed and tested. The synthetic eddy injection model determines fluctuations of velocities of liquid fuel at the spray nozzle exit. The model attempts to simulate turbulence at the nozzle exit without the need of internal nozzle flow simulations by superimposing a number of virtual coherent structures. The idea of the stochastic KH-RT model is to stochastically and dynamically determine several model parameters, specifically the KH and RT length and time scales. This is an attempt to reduce the sensitivity of the model parameters in the standard KH-RT model (Beale, J. and Reitz, R.D., 1999)). The performance of these two newly developed models was compared to the classical models, namely the standard KH-RT and the cone angle injection models (Reitz, R., 1987). Two experimental databases, the Engine Combustion Network constant-volume sprays (Pickett, L. M. et al., 2010) and the Engine Research Center optical engine sprays (Neal, N. & Rothamer, D., 2016) with a range of operating conditions were used to validate the models. The stochastic KH-RT model improved the prediction of the spatial distribution of liquid fuel in the region where secondary breakup occurs. The stochastic KH-RT model was able to better predict liquid penetrations in a wider range of operating conditions (errors within 5 %). The synthetic eddy injection model improved the predictions of the spatial distribution of liquid mass in the near-nozzle region and vapor penetrations at early stage of injection. The results suggest that development of instability modes and turbulent transport in the near-nozzle region were better represented by the synthetic eddy injection model. The model also showed less computational grid sensitivity. Overall, using these two new models overcomes several limitations in the original models and makes large eddy simulations (LES) as a more predictive tool for Diesel sprays.

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Development of an Atomization System for Testing Spraying Variables Using Optical Instruments

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Abstract

This paper addresses the design and construction of a variable pressure atomization system for testing spraying variables using optical instruments. The project goal is to develop local capabilities for characterizing spraying phenomena using optical techniques such as laser diagnostics, fluorescence, shadowgraph and Schlieren. The study reviews the state of the art of spraying rigs used elsewhere; the paper elaborates on the instruments required to build a state of the art test stand. The paper also reviews the existing optical techniques for studying sprays. The paper presents a detail design of the testing rig, including optics; cameras; pipelines; pressure, temperature and flow meters; Finally, the paper shows various pictures of experimental results of a liquid spray using optical techniques: Schlieren and shadowgraph.

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The Effect of Fuel Properties on Inert Spray Characteristics under Compression Ignition Engine Conditions

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Abstract

This paper is a contribution summarizing and analyzing existing experimental work on inert spray based on the Engine Combustion Network's (ECN) "Spray A" configuration from different research institutions. The experimental work was conducted under the same nominal conditions across different combustion vessels using various fuels and parametric variations. A number of fuels and their physical properties are summarized in this paper. These fuels are classified into four categories: Primary Reference Fuels (PRF), jet fuels, gasoline fuels, and diesel fuels. The effect of fuel properties on spray evolution and characteristics is investigated and analyzed in terms of spray liquid length. Global sensitivity analysis (GSA) is also conducted to quantify the relative importance of different physical properties towards specific targets. The results show that higher ambient temperature causes shorter liquid length, while higher density, boiling temperature, and viscosity generally lead to longer liquid length. GSA shows that ambient temperature and fuel density are the most dominant factor that affects liquid length, while viscosity and boiling temperature show only mild effects. PRF blends are then analyzed in further detail using a computational fluid dynamics (CFD) study. A Lagrangian-Eulerian modeling approach was used to characterize the inert spray behaviors in CONVERGE™ by means of a Reynolds-Averaged Navier-Stokes (RANS) formulation. Due to the similar liquid behaviors, liquid and vapor penetrations for PRF blends show insignificant difference.

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Measurement of Liquid Core Length of a Coaxial Two-fluid Spray

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Abstract

Shadowgraphs, tube-source X-ray radiographs, and synchrotron X-ray radiographs from a coaxial two-fluid spray are analyzed to measure the liquid core length of the spray. Two flow conditions: Re_l = 1,100, Re_g = 21,300, We = 40, and Re_l = 1,100, Re_g = 46,700, We = 196 are investigated. The standard deviations of the fluctuating intensity values are calculated and analyzed to estimate the liquid core length. Additionally, the largest connected domain is used to find an instantaneous breakup position of the spray. The results show that the high standard deviation region is related to the ligament development region, and the instantaneous position identifies ligament formation in the spray.

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Diffuse Interface Modeling of Compressible Multiphase Flows using an Adaptive Mesh Refinement Library

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Abstract

In this work, a diffuse interface method is developed using an unstructured adaptive mesh refinement (AMR) library for orthogonal Cartesian grids. The compressible multicomponent Euler equations, i.e. the quasi-conservative five-equation model including capillary effects, is discretized by the finite-volume method, which utilizes a fifth-order weighted essentially non-oscillatory (WENO) reconstruction procedure. The finite-volume method is complemented by a modified Harten-Lax-Van Leer Contact (HLLC) approximate Riemann solver which is used to upwind the fluxes on cell faces. Surface tension effects are integrated into the governing equations by virtue of the continuum surface force (CSF) model, whereas local interface curvature is calculated by utilizing second-order accurate height functions. The excessive numerical smearing of the material interface is limited to a narrow band of cells by employing the THINC reconstruction. The temporal integration is carried out by a three stage, third-order strong stability-preserving (SSP) Runge-Kutta scheme. Several one and two-dimensional benchmark problems are performed to verify the implementation and robustness of the method. The efficient utilization of AMR increases the resolution of small-scale flow features while keeping the computational cost feasible.

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Model Reduction of Primary Atomization using Optical Flow

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Abstract

Non-invasive flow visualization techniques for multiphase flows are critical to understanding primary atomization and sprays. Visual light shadowgraphy and X-Ray imaging are two techniques that can distinguish the liquid-as interface at high temporal and spatial resolutions. Multiple frames of the flow can be used to estimate temporally coherent flow trajectories. In this study, we propose a variational method that produces spatially and temporally coherent velocity field using physics-based constraints on the trajectories. A two-step method of flow estimation and model order reduction is employed. We apply the proposed method on synthetic data as well as simulation data from primary atomization of a liquid jet. Perspectives on applying the method for model reduction and hardware-in-the-loop flow control will also be given.

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A Robust All-Mach Multiphase Flow Algorithm for High-Fidelity Simulations of Compressible Atomization

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Abstract

High-fidelity simulations can accelerate understanding and illuminate important aspects of liquid atomization in highly compressible environments. For example, simulations can provide invaluable insights on the physics of scramjet engine cold-start, thereby helping design successful injection strategies. For simulating compressible liquid-gas flows with topology changes, we have developed an all-Mach, compressible multiphase flow solver that utilizes a low dissipation transport scheme to accurately represent turbulence in smooth, single-phase regions and applies a robust semi-Lagrangian scheme to handle discontinuous transport at interfaces and shocks. We employ a pressure projection scheme to avoid acoustic limitations on the time-step size. Within this framework, we focus on specific treatments of the volume fraction, pressure, and energy equations to improve stability.

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Complementary Characterization of Standard Simplex Atomizers using Phase Doppler Interferometry and X-ray Radiography

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Abstract

Several experimental diagnostic tools have been applied to the sprays generated by a set of standardized simplex atomizers operating with water. The near-nozzle spray was measured with X-ray radiography to quantify the liquid distribution. Furthermore, complementary phase doppler interferometry was performed under the same operating conditions to characterize the spray droplet sizing distributions in an overlapping spatial domain. Time-averaged X-ray radiography projections collected over a two-dimensional field of locations across the spray indicate subtle differences between atomizers and a broadening of the spray for lower supply pressures. Projections were collected for transverse scans just outside of the nozzle at a collection of rotation angles to allow for tomographic reconstruction of the spray immediately downstream of the nozzle exit. This cross-sectional slice of the spray reveals azimuthal variations in the liquid sheet which vary between injectors, indicating their geometric origins. Time-resolved measurements of the projected mass were collected for one axial and one transverse scan, which highlight the location of sheet breakup and the sensitivity of the sheet dynamics to the injection pressure. Phase doppler interferometry measurements were collected at centerline locations and an entire downstream plane for each spray condition and revealed the average particle sizes and droplet distributions. It was observed that the average droplet size increased and the distribution broadened for the lower supply pressures. Together, these quantities form a baseline set of characterizations for the standard simplex atomizers. This expanding set of measurements can be used to validate predictive models for future needs of the spray community.

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An all-Mach multiphase flow solver using block-structured AMR

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Abstract

Predictive simulations of multiphase flows require high fidelity numerical schemes and well resolved flow features. In this paper, we integrate the all-Mach multiphase flow algorithm that has been developed in [1] into AMReX – a framework for massively parallel, block-structured adaptive mesh refinement applications [2]. The compressible multiphase flow equations are solved, and the multiphase treatment uses an unsplit volume-of-fluid (VOF) approach with a piecewise linear interface calculation (PLIC) for the interface reconstruction. Test cases of Zalesak's disk and three dimensional deformation are performed to illustrate the ability of the solver to capture the liquid-gas interface, and compressible multiphase flow test cases involving a water-air interface – underwater explosion, and collapse of an air cavity in water, are done to validate the flow solver in the adaptive framework.

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Adjoint-based Interfacial Control of Axisymmetric Viscous Drops

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Abstract

We develop a continuous adjoint theory for the control of the deformation of a clean, neutrally buoyant droplet in Stokes flow. The problem reduces to the dynamics of the free drop surface, but this introduces significant complexity in the optimization process and, in particular, the formulation of the necessary optimality conditions and efficient numerical handling. We make use of well-known results from the field of topology optimization to derive rigorous adjoint equations and optimality conditions for this class of problems. Boundary integral methods are used to provide efficient and high-order approximations for each quantity of interest. Finally, our methodology is then tested on axisymmetric droplets controlled by the non-dimensional capillary number and several tracking-type cost functionals.

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The Importance of Atomic Spectrometry in Life and the Significance of Spray Quality

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Abstract

No one investigating atomic spectrometry one century ago could have conceived the amazing future journeys that are being traveled now in plasma spectrometry, expressly with inductively coupled plasmas (ICPs). It was G.E.F. Lundell in 1933 who settled how elemental analysis must be performed.[1] He asserted that certain methods of chemical analysis "are about as helpful to the analyst as the method for catching a bird which the old folks used to recommend to children-namely, to sprinkle salt on its tail. To do that, one obviously must have the bird in hand, and in that case, there is no need for the salt."

To highlight the absence of reliable and straightforward methods of chemical analysis, Lundell further advanced: "There is no dearth of methods that are entirely satisfactory for the determination of elements when they occur alone. The rub comes in because elements never occur alone, for nature and man both frown on celibacy. Methods of determination must, therefore, be judged by their selectiveness. It is in this respect that most methods are weak, and improvement must come".

One wonders what to cherish most in Lundell, the psychological understanding for the advancement of ideas, the sureness of scientific argumentation, the deep-felt real intelligence, the capacity for precise, orderly display, the full treatment of the undertaking the subject, or the sureness of definitive assessment.

It was an article by Lundell that guided me to the late Professor Velmer Fassel (Iowa State University and Ames Laboratory) who ultimately became my postdoctoral mentor. He had a profound impact on driving to the essential target. For this reason, he was nominated for Nobel Prize just before he passed away.

At a major conference, Velmer spoke in recognition of Professor James Winefordner who had won a notable award. As was his standard practice, he critically appraised Professor Wineforder's publications and asserted that Jim's most influential article was a review article that he penned with his postdoc, Linda Cline. His deciding tone irritated the audience to the degree that only one person stayed in the hall to compliment Velmer, for what I defined as "an outstanding lecture." Perplexed, he stated: "No one liked my speech other than you!"

Being thrilled by his lecture, I told him, "I would like to join your group for the sole purpose of investigating the ICP as an atomization source for atomic fluorescence spectrometry (AFS).[2]This was an unexpected proposal recognizing that Velmer had vigorously argued against the use of AFS! In puzzlement, he bought the idea! After publishing a single article, ICP-AFS was marketed by the Baird Corporation. This was before the first exploration on ICP-MS by Professor Sam Houk and coworkers, then and now at the Iowa States University and Ames Laboratory. Indeed, ICP-AFS is far more selective than ICP-atomic emission spectrometry and allows excellent detection limits for some, but not all elements. With the arrival of ICP-MS, Baird Corporation closed the destiny of ICP-AFS, my royalties, and consulting fees in relation to ICP-AFS.

After the postdoctoral studies, I joined the faculty at the Sharif University of Technology, the so-called MIT of Iran, in Tehran Iran and worked there during 1975-79. Since 1975, our research has been centered on plasma spectrometry for trace, ultratrace, isotopic, and speciation analysis of materials, such as nuclear wastes and semiconductor materials. Here is the most vital subject: The quality of aerosol or spray controls sensitivity, selectivity, accuracy, precision, the amount of sample used for chemical analysis, the ease of conducting the measurements, the simplicity of the entire

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A physics-based advanced Euler-Lagrange framework for droplet-droplet interaction in dense spray systems

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Euler-Lagrange (EL) methodology is the common approach used to simulate the collective dynamics of a very large number of dispersed droplets in the mid region of a spray. Traditional point-particle models used in these EL simulations assume the force on a droplets to depend only on mean Reynolds number and the mean volume fraction. This approximation ignores interactions among the droplets at the microscale and therefore significantly under-predicts fluctuations in droplet velocity and feed-back forces, resulting in incorrect mesoscale structures and macroscale dispersion. Furthermore, often the larger droplets under consideration are as large as the underlying Eulerian grid and this caused substantial error in the estimation of the undisturbed flow velocity for the drag force calculation. In this study we employ (i) the extended point-particle force (PIEP) model and rigorously account for the hydrodynamic influence of the neighboring droplets and (ii) the self-induced velocity correction (SIC) model for obtaining the true undisturbed fluid velocity which can then be used in the inter-phase coupling models. Both these models have been tested extensively for the cases of a random array of stationary and freely sedimenting particles. The overall objective of our project is to demonstrate multiphysics control of liquid sprays. The talk will also present the on-going simulation effort of a spray in the mid-field region, where the dispersed droplets in a turbulent flow is considered with the PIEP and SIC models. Mid-field control of spray using electrostatic and acoustic forcing will be systematically explored. This study is part of a multi-disciplinary university research initiative (MURI) funded by the Office of Naval Research to experimentally and computationally explore multi-physics spray control.

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A Piezoelectrically Driven Nebulizer for Inductively Coupled Plasma (ICP) Atomic Spectrometry

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Abstract

Pneumatic nebulization of liquid samples is the most commonly used method of sample introduction in ICP atomic emission and mass spectrometry. The performance of pneumatic nebulizers, however, is plagued by many drawbacks such as poor sample transport efficiency due to the wide droplet size distribution of primary aerosol and the need for a spray chamber to remove large size droplets. In addition, the nebulizer gas used to generate the primary aerosol is used to transport the droplets to the plasma, which dictates a compromise between the nebulization efficiency and droplet residence time in the plasma. Unlike a pneumatic nebulizer, a meshed piezoelectrically actuated nebulizer generates the sample aerosol by the vibrating action of a meshed membrane situated behind a typical injector tube of an ICP torch assembly. The nebulizer generates a narrow distribution of droplets that are typically around 6-10 μm in diameter and, therefore, the sample transport efficiency is significantly improved (typically >90%) without the need for a spray chamber. In addition to transport efficiency, the characteristics of the piezo-based nebulizer approach those of an ideal sample introduction system in many aspects, including: a) the use of an active mechanism of aerosol generation that yields a narrow size distribution of droplets with a low initial velocity (<5 m/s), b) unlinking the parameters that affect both the aerosol generation and transport processes, and therefore, allowing independent optimization of nebulizer and plasma parameters to achieve the best analytical performance, c) eliminating sources of noise such as those originating from perturbations caused by peristaltic pump pulsations, d) improved long-term signal stability and short term precision, e) providing a dynamic adjustment of the amount of aerosol generated and allowing multipoint calibration curves to be constructed from a single standard solution, and f) high tolerance to matrices with high dissolved solids in a variety of acidic solutions. This work discusses the design and development of the piezoelectric nebulizer, its analytical performance characteristics, and outlines challenges encountered with the piezo-nebulizer device for routine analysis of real samples.

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Effect of Interface Reconstruction Methods on Atomizing Liquid Jet Simulations

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Abstract

Often times, due to their superior mass conservation properties, geometric Volume of Fluid methods are used to simulate complex multiphase flows. In these methods, the interface separating the phases in mixed-phase cells is typically represented by one or more planes. Many different techniques exist to reconstruct and place this interface, however, these are often only compared to one another through simple, canonical test cases. This work studies the effect the choice of interface reconstruction method has on the droplet distribution resulting from a temporally evolving atomizing liquid jet. Specifically, the ELVIRA and MoF methods for piecewise-linear interface calculation reconstructions are compared, with special attention paid towards their relative levels of "numerical surface tension". From the results, we highlight the strengths and weaknesses of each reconstruction method and the relative importance that the choice of reconstruction method has on an actual atomization simulation.

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Element- and size- based characterization of nanomaterials by interfacing ICP-MS with Field-Flow Fractionation

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Abstract

Field-flow fractionation (FFF) was introduced to the scientific world in 1966 and was subsequently developed as a method for separating and sizing small particles and macromolecules. This presentation outlines and describes the way in which FFF instruments can be coupled to inductively couples plasma mass spectrometers (ICP-MS}. The significant information that can be derived from FFF-ICP-MS is a multi-element distribution across the size range of the sample particles. The element ratio spectrum versus size can be computed which gives valuable information about changes in sample composition as a function of particle size. Some important studies that have been undertaken in the past 25 years using FFF-ICP-MS, are summarized. This includes applications in the fields of clay mineralogy, soil science, aquatic particles and engineered nanoparticles. And finally, some problems with regard to nebulization will be discussed.

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An efficient pressure solver for stochastic gas-liquid multiphase flows

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Abstract

Application of intrusive uncertainty quantification (UQ) to multiphase flow simulations is a developing field. Interest stems from the potential for computational cost improvements over traditional non-intrusive UQ methods. UQ of atomizing flows would allow the effect of input variability on outputs to be predicted, such as how liquid viscosity affects drop size distributions. Recently, a computational framework for intrusive UQ of gas-liquid multiphase flows was created as a proof of concept. For this method, the most expensive aspect is the pressure calculation, making up approximately 80% of simulation run time. To reduce computational cost and the rate at which it grows with added uncertainty, a density decoupled pressure solution method suggested by Dodd and Ferrante [1] is extended into the stochastic framework. Previously, the dependence of pressure on density required solving N coupled Poisson equations, where N is the number of basis functions used for a polynomial chaos expansion of a stochastic variable. The proposed method decouples the Poisson equations for each basis weight, which increases the efficiency for the stochastic model as more basis functions are added. Here we provide a general overview for the novel pressure solver, with results from an atomizing jet showing improved computational time without a change in simulation accuracy. For deterministic simulations of a 256^2 mesh, results show the proposed method has a speed up factor of up to 75, while for stochastic simulations it is up to 290.

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Development of Droplet Injection ICP-AES/MS and Elemental Analysis of Single Human Cancer Cells

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Abstract

To analyze a small amount of sample, we developed a droplet injection ICP-AES/MS system. In this device, solution sample is not sprayed but injected as a small single droplet. When analyzing nanoparticles and cells, they are enclosed in the droplets and injected and introduced into a high temperature plasma then ions or emission was measured. As a result of analyzing single plant and human cells using this device, it was revealed that elemental analysis of fg order could be realized.

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Role of Density in Gas-Assist Counterflow Atomization

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Abstract

This study investigates the effect of gas density on the performance of counterflow atomization, using a novel internal mixing design. At fixed water flow rates and gas-to-liquid momentum ratios, the counterflow injection gas was systematically varied using air, argon, and helium. To evaluate spray quality, a combination of laser shadowgraphy and particle/droplet image analysis was used to measure the droplet Sauter mean diameter (SMD) and relative span factor (RSF). A gas mass flowmeter established gas-to-liquid mass ratio (GLR) and gas compression power as metrics of nozzle efficiency. In contrast with previous findings for other twin-fluid nozzle types, counterflow atomization was found to significantly benefit from a decrease in gas density, in terms of energy efficiency and spray quality. Potential mechanisms for this influence in the counterflow atomization process are proposed.

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A Computational Study of Nozzle Internal Flow and its Effect on Spray Atomization

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Abstract

In the present computational work, the effect of nozzle surface features on the atomization behavior of a liquid jet is analyzed through a comparison of internal and external flow from three representative injector configurations. The first two nozzle geometries consist of surface data generated by X-ray tomography scans of the ECN Spray A nozzle. The first geometry is based on a single such scan and the second geometry is a spline reconstruction of surface data generated by multiple scans. Both of these geometries are obtained from the ECN database. Boundary fitted grids are employed to capture the surface features accurately. The third geometry is a canonical one based on purely external flow from a circular orifice, i.e., no internal flow resolution. For the simulations, the two-phase flow is solved based on algebraic VoF methodology utilizing the OpenFoam solver, `interFoam`. The solver has recently been validated against X-Ray projected-mass-density data for Spray A at engine-like conditions. Across these three configurations, we find that the breakup length of the topologically connected liquid varies appreciably, with the first geometry yielding the shortest breakup length. While the liquid turbulent kinetic energy plays an important role in the accelerated breakup of the first configuration, it is by far not the only contributing factor. An analysis of the temporally-averaged velocity near the orifice openings reveals that the flow field orthogonal to the streamwise direction contains key features that have a significant effect on the breakup. The mean radial velocity near the injector walls directly affects the morphology of the emanating liquid jet. It not only leads to a quick growth of surface disturbances but is also responsible for producing secondary features on the liquid surface. The third configuration is characterized by milder surface disturbances in the near field and consequently longer breakup lengths.

Keywords: ECN Spray A; Injector Nozzle; Surface Roughness; Spray Atomization; Primary Breakup; High Fidelity Simulation.

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Control-Informed Dynamic Mode Decomposition Applied to the Ginzburg-Landau Equation

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Abstract

Constructing robust data-driven reduced order models for atomization is difficult because of the rich variety of possible behaviors observed. Moreover, a reduced order model constructed from data acquired at a single operating point will not be robust to changes in control inputs or boundary conditions, thereby limiting the model's utility in control. We propose an optimization problem which, when solved, specifies an input designed to drive the dynamical system such that the data-informed reduced order model is sensitive to changes in input. This method is system agnostic and is based on the idea of persistence of excitation (PE). When a data sample satisfies the PE property, it guarantees that the data represents the dynamics well and that the hidden model parameters of the system can be approximated. The resulting richness of the data set improves the quality of data-driven model reduction schemes. To demonstrate our method, we apply PE-informed Dynamic Mode Decomposition (DMD) to the simulation and closed loop control of the linear Ginzburg-Landau equation. The application of these methods to the atomization of a liquid spray is also investigated, but our choice of model reduction does not turn out to be powerful enough to be applied to this system.

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Temperature Dependent In-Nozzle Flow Investigations of Marine Diesel Injectors

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Abstract

The completely asymmetrically and eccentrically arranged orifices in large marine two-stroke Diesel engine fuel injector nozzles lead to significant spray axis deviations and unusual flow interaction effects. These undesired aberrations lead to reduced engine performance and are only limitedly researched and comparable, as injector nozzles from small- and mid-sized Diesel engines have extensively different geometries. Experimental work and CFD simulations have shown that the in-nozzle flow and especially cavitation significantly influences the spray deviations.

To further investigate the in-nozzle flow of large marine two-stroke Diesel engine injectors, a transparent nozzle holder made of PMMA has been used to provide optical access. The lower fuel pressure of two-stroke compared to small and mid-sized Diesel engines allows the acquisition of in-nozzle flow images under real conditions regarding fuel pressures of 50 MPa. However, as the transparent nozzle body is made of a thermoplastic, the operating temperatures are limited. So far, the in-nozzle flow visualizations acquired have been performed under ambient temperature conditions. As increased fuel temperature decreases viscosity and strongly increases vapor pressure, the intensity of in-nozzle flow cavitation is significantly linked to the fuel temperature.

To further approach realistic fuel injection conditions, the fuel injector and fuel were heated up to a set of different temperatures. This allowed the investigation of the cavitation behavior of the in-nozzle flow under different and realistic temperature conditions of the fuel.

The experiments were performed using Diesel fuel and the nozzle used was a 75° arranged, 0.75 mm diameter, one-orifice setup that matches large marine two-stroke Diesel engine injector nozzles. Hydro-erosive grinding was used to generate radii between the main bore and the orifice in the nozzle to produce realistic injector nozzle geometries.

The optical measurement technique Shadowgraphy was used to visualize the in-nozzle flow in the orifice during the complete injection process using a far-field microscope, a high-speed camera and a diode laser.

The evaluation of cavitation regions in the nozzle delivers valued validation data for cavitation CFD models and helps further modeling the flow accurately.

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Extraction of Droplet Genealogies from High-Fidelity Atomization Simulations

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Abstract

Many research groups are capable of performing impressive high-fidelity simulations of atomizing jets due to advances in numerical methods and ever increasing computational resources. These simulations produce very large data-sets describing the flow and interface location giving the potential to advance our understanding of atomization. The challenge to making the results useful is extracting relevant physics from these large data-sets. In this work, we propose a physics extraction technique that provides the ancestry of droplets created as the coherent liquid core breaks into droplets and ligaments which may continue to break into smaller droplets. This information is stored in a graphical database to be easily queried. To improve low-fidelity atomization models and help gain a better understanding of the atomization process in general.

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Numerical investigation of air bubbles formation and internal flows in flow-blurring atomizers and its impact on liquid breakup

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Abstract

Flow-blurring atomization is a novel fuel injection technique and has been shown to generate finer sprays than conventional airblast atomizers with the same air-to-liquid mass flux ratio. In flow-blurring atomizers, high speed air impinge on the liquid stream through an orifice gap. Under certain geometric and flow conditions, the air stream cuts through the bulk liquid and portion of the air stream penetrate back into the liquid stream, forming a back-flow region inside the nozzle. Air bubbles formed in the back-flow region has been shown to significantly enhance the breakup of bulk liquids downstream of the nozzle exit. The underlying mechanisms are not fully understood, since the internal flow inside the nozzle is difficult to measure in experiments. In this paper, we aim to use direct numerical simulation to investigate the internal flow structure inside the FB atomizer and to explore its effect on the liquid breakup. We simulate half of the FB nozzle in a 2D domain, assuming symmetric boundary condition. The volume-of-fluid method is used to resolve the gas-liquid interface, and the multiphase flow solver, *Basilisk*, is used for simulation.

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Improving the validation of turbulent jet breakup models

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Abstract

Understanding the physics of the breakup of turbulent liquid jets is important for a variety of applications including engine sprays, fire suppression systems, and water jet cutting. Models of turbulent jet breakup allow predictions of quantities of interest like the droplet size distribution and breakup length of the jet. These models are compared against experimental data in a process called validation. If the model predictions are within the experimental uncertainty, then the model is "validated" and believed to be accurate, and possibly can explain the physics. Uncertainty quantification is necessary for model validation. While unfortunately relatively few experimental studies quantify uncertainty, that is not the most pressing validation issue in turbulent jet breakup. I detail 3 additional problems that can make the apparent validation of a model actually an illusion, regardless of how well the model appears to match the data. These problems include: 1. important variables being omitted or guessed in experiments and models, 2. confounding between independent variables, that is, two variables changing simultaneously, making determining cause and effect impossible, and 3. testing only combinations of submodels and not each submodel in isolation. To avoid these problems and others, I developed validation guidelines that are detailed in this work. Following these guidelines, I compiled a large experimental database. Only 28 out of 47 experimental studies considered met my data quality guidelines. Only 18 studies had quantified uncertainty, and only 3 studies had substantial variation in the turbulence intensity.

*https://trettelresearch.com/contact.html

Influence of K-factor on Cavitation Suppression for a Heavy-duty Diesel Injector Operating with Straight-run Gasoline

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Abstract

The occurrence of cavitation inside injectors is generally undesirable since it can cause material erosion and result in deviations from the expected operating conditions and performance. Previous numerical work employing an injector geometry measured with x-ray diagnostics and operating with a high-volatility straight-run gasoline has shown that: (1) most of the cavitation is generally observed at low needle lifts, (2) needle motion is responsible for asymmetric structures in the internal flow as well as large pressure and velocity gradients that trigger phase transition at the orifice inlets, and (3) cavitation affects the injector discharge coefficient and distribution of injected fuel. To explore the potential for material damage within the injector orifices due to cavitation cloud collapse, the cavitation-induced erosion risk assessment (CIERA) tool has been applied for the first time to the realistic geometry of a heavy-duty injector using the CONVERGE software. Critical locations with high erosive potential matched qualitatively well with x-ray scans of an eroded injector sample that underwent a durability test with straight-run gasoline. This motivated a CFD exploration of orifice design modifications, using a nominal reconstruction of the realistic geometry and an automated procedure for fast generation of modified surface files. In this work, the influence of the orifice K-factor on the intensity and duration of cavitation structures was investigated. Quantitative and qualitative analyses highlighted the importance of this parameter in limiting or suppressing cavitation inside the injector orifices and provided useful insights and design guidelines for injectors operating with high-volatility fuels.

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Neutron Imaging for the Two-Phase Flows inside an Aluminum Aerated-Liquid Injector

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Abstract

Aerated-liquid (or effervescent, or barbotage) injection has been shown to be a capable liquid atomization scheme. The objective of the present study is to characterize the two-phase flow structures in aerated liquid within an aluminum nozzle, using the neutron imaging technique available at the Oak Ridge National Laboratory. Long-exposure neutron images of two-phase flows at different injection conditions, including variations in liquid flow rate, aeration level, and aerating tube configuration, were obtained. Water and nitrogen were used as the working fluid and aerating gas, respectively. For the purposes of direct comparison, high-speed x-ray images with aluminum and beryllium nozzles were obtained at the Argonne National Laboratory, using the same injector assembly and injection conditions. It was found that time-averaged two-phase flow structures inside an aluminum nozzle can be successfully visualized by the present neutron imaging setup, without the use of any dopant in the injection fluid. Effects of liquid flow rate, aeration level, and aerating tube configuration on internal two-phase flow structures were subsequently explored, based on the neutron images. Comparisons between neutron imaging and the companion x-ray imaging clearly demonstrate the advantages and challenges in applying each *in-situ* imaging technique for the present imaging setup configurations. Neutron imaging at Oak Ridge National Laboratory provides time-averaged qualitative line-of-sight liquid distribution patterns inside a more practical metal nozzle. X-ray imaging at Argonne National Laboratory provides time-resolved qualitative line-of-sight distributions or evolution (in compiled movie clips) of the doped two-phase flow with a satisfactory quality for the beryllium nozzle and with somewhat degraded quality for the aluminum nozzle. Comparison between neutron imaging and quantitative x-ray radiography and fluorescence measurements highlights the needs to improve the spatial resolution and to extract quantitative liquid mass distributions from neutron images in the future.

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Analysis of a Liquid Jet in Supersonic Crossflow using Large-Eddy Simulation

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Abstract

In understanding the detailed physics of scramjet engine cold-start, simulations can provide useful insights for design. To better grasp the complexity of this design problem, we perform large-eddy simulations of a liquid jet in a supersonic gas crossflow and compare our findings with experiments. These simulations employ a fractional-step method that includes a hybrid advection step, which couples semi-Lagrangian transport with an implicit low-dissipation scheme, and an implicit pressure projection step based on a Helmholtz equation. We explore this relevant flow from qualitative and quantitative perspectives, analyzing liquid plume trajectory, droplet size distribution, and frequency of instabilities. From this analysis, we draw preliminary conclusions about the effects of inflow conditions, evaluating the significance of turbulence in the liquid jet. Additionally, we characterize the spray by measuring spatial distributions of droplet statistics.

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Optimization of High-Speed White Beam X-ray Imaging for Spray Characterization

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Abstract

The near-field region of a spray has a significant impact on the downstream dynamics. However, the near-field region remains one of the most difficult areas to characterize due to its optical density to visible light. One of the methods used to probe the near-field region is high-speed white beam (broad-spectrum) X-ray radiography, which generates path integrated, time sequenced images of the spray. While white beam imaging is effective at probing the near-field region, high intensity synchrotron sources are required to acquire high-speed time-resolved image sequences. The drawback to a synchrotron source is it emits a significant portion of its X-ray spectrum at energies that are minimally attenuated by most sprays. This paper will examine the various parameters that can be tuned to improve the characterization of sprays with white beam X-rays, and will assess their effects on the X-ray image quality. A representative spray conditions will be shown using a canonical coaxial gas-liquid atomizer imaged at the 7-BM beamline of the Advanced Photon Source at Argonne National Laboratory.

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Validation and Analysis of primary atomization of turbulent liquid jet in crossflow simulations

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Abstract

This paper presents the results from direct numerical simulations of the primary atomization of a turbulent liquid jet injected into liquid crossflow. The simulations are performed for an experimentally analyzed configuration of Brown and McDonell (2006, "*Near Field Behavior of a Liquid Jet in a Crossflow*", ILASS Americas, 19th Annual Conference on Liquid Atomization and Spray Systems). The turbulent liquid jet ($q = 6.6$, $\mathrm{Re} = 14\,000$, $\mathrm{We} = 2178$) is injected into a subsonic gaseous crossflow ($\mathrm{Re} = 570\,000$, $\mathrm{We} = 330$). The liquid/gas interface is captured using a coupled level set volume of fluid (CLSVOF) method. The jet penetration obtained from the simulations show good agreement with the experimental correlations and also to the findings from the literature. Two breakup mechanisms are observed: column breakup mode in which waves on the windward side of the jet propagate, roll up and form bag-like structures until they breakup; and ligament breakup mode caused by the corrugations of the liquid core surface forming thin ligaments on the liquid jet sides that subsequently breakup into droplets. Analysis of the crossflow velocity component of the liquid packets from the simulation shows that a number of liquid packets exist in the domain whose velocities are same as that of the gaseous crossflow.

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Preliminary Investigation of Apparent Mass Loss in Objects Due to Image Blur using X-ray Radiography

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Abstract

The apparent mass loss of an object is examined as a function of image blur in x-ray radiographs. Apparent mass loss arises from the nonlinear conversion from x-ray transmission to path length, where blur in the transmission image biases the shorter path lengths. Several image characteristics affect the measured mass including: the severity of blur, the size and shape of the object, the transmission level, and the variance of transmission. This preliminary discussion investigates the severity of blur, the size and shape of the object using experimental and simulated images, and the investigation of the transmission level using simulated images. Understanding the effect image blur has on the measured mass when the image characteristics are known may lead to a methodology for correcting the error.

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An Analysis of Proper Orthogonal Decomposition and Dynamic Mode Decomposition on Liquid Jets in Crossflow

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Abstract

The analysis of turbulent flows has long been of interest, particularly within liquid atomization studies, in an effort to understand the underlying phenomena which govern the fluid flow processes. Recently, the data decomposition techniques of proper orthogonal decomposition (POD) and dynamic mode decomposition (DMD) have had demonstrable utility in the analysis of dynamic systems from video data. These methods attempt to extract independent coherent modes which represent spatio-temporal structures in order to describe oscillatory phenomena. Although numerous works investigating flow processes have implemented POD and DMD, the results are often highly interpretive and there is limited link between the decomposition theory and the interpreted physical meaning of the extracted modes. This work aims to develop the understanding of the interpretation of these modes when applied to liquid jet in crossflow video data. Initially, simple canonical flows, such as a dilational jet and consequent jet breakup, were analyzed to highlight fundamental differences between POD and DMD and to provide intuition to modal information. A number of jet in crossflow flow conditions were then analyzed of increasing complexity. As the complexity of the flow changes, as does the interpretability of the extracted modes, likely due to a change in the mechanisms affecting the flow behavior. This can be accounted for with knowledge of the modal energy distribution and an understanding of the extracted DMD spectrum. Additionally, an understanding of simpler systems can help guide the understanding of more complex systems in a hierarchical manner. While there can be utility in implementing POD and DMD for jet in crossflow analysis, care must be taken to distinguish true underlying flow processes from decomposition artifacts present in the modal information.

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X-ray Scattering-Based Temperature Measurements of Liquid in Multiphase Flows

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Abstract

X-ray diffraction based time averaged liquid temperature measurements were demonstrated in a spray. Experiments were conducted at the Sector 7 Bending Magnet beamline at the Advanced Photon Source within Argonne National Laboratory. The high flux available at the Advanced Photon Source was utilized to obtain an x-ray beam of 15 keV energy at a focused size of 5×6 μm^2 to probe the spray. The measurements captured the interference patterns of coherent, nearest-neighbor x-ray scattering from liquid molecules, and was collected by a photodiode array. The shape of the interference patterns, as described by its peak intensity, location, and statistical moments such as variance and kurtosis, shifted predictably with molecular spacing. The molecular spacing was correlated to the liquid-phase temperature, and was independent of the gas-phase temperature or spray geometry. Temperature measurements were done on three different liquids tested in a simple jet—water, ethanol, and dodecane. The liquid jets tested were varied in temperature through the use of hot and iced water baths for heating and cooling the jets, and compared against thermocouple-measured temperatures before the jet exit. This technique establishes a method to probe the liquid-phase temperature in reacting and non-reacting multiphase flows.

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A hybrid approach applied to spray in liquid jet in crossflow

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Abstract

The main goal of this work is to present a proper low computational cost methodology for numerical solution of spray formation in a liquid jet in crossflow configuration, by means of a hybrid approach. The hybrid approach is composed by the VOF method and a discrete particle solver implemented on an unstructured grid code, termed UNSCYFL3D. Two secondary breakup models and two $k - \epsilon$ turbulence closure models were systematically evaluated, in order to establish a suitable methodology to solve liquid jet in crossflow at low computational cost. Numerical results display good agreement with the experimental ones, particularly regarding the liquid jet topology, spray formation, mean diameter of droplets, droplet size distribution, and droplet velocity.

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Oscillation of a Sessile Drop on Hydrophobic/Superhydrophobic Surfaces

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Abstract

Oscillation of sessile drops on hydrophobic surfaces is important to many applications. In the present study, we investigate the oscillation of a sessile drop on hydrophobic or superhydrophobic surfaces through direct numerical simulation. The simulation is performed by the adaptive multiphase flow solver, Basilisk. The volume-of-fluid method is used to resolve the gas-liquid interface. A parametric study has been performed to systematically study the effects of the contact angle on the natural oscillation frequencies for different modes. Both the limiting cases for freely-moving and pinned contact lines are considered to investigate the contact line mobility on drop oscillation frequencies. The results show that the first spherical harmonic mode (the translation mode for a free drop) is dominant. This observation is consistent with former experimental and theoretical studies. It is also observed that the oscillation frequency decreases with increasing contact angles, approaching the Lamb's frequency values.

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Spray/wall-interaction and the formation of wall films

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Abstract

Newer European Emission Standards limit the particulate number emissions under real driving conditions. For direct injection spark ignition (DISI) gasoline engines it is still difficult to meet these limits. Since wall wetting resulting from spray impingement is the main reason for particulate emissions, the exhaust emissions can only efficiently be reduced by minimizing the fuel deposition on the combustion chamber walls. As basis for a further reduction of particulate emissions This study presents the results of different fuel wall film investigations.

In order to measure the fuel film mass and area the method of laser-induced fluorescence was applied, while the investigations have been carried out using the spray of a modern six-hole injector, injecting an iso-octane/3-pentanone mixture. In the experiments the effect of impingement angle, nozzle/wall distance, ambient pressure and temperature, rail pressure as well as the fuel temperature were determined. One the one hand, empirical models were derived using DOE analysis. On the other hand, the results can help engine development to optimize geometries and injection strategies. For example, the deposited fuel film mass will decrease, with flatter impingement angles, increasing initial fuel temperature or nozzle/wall distance, while the impact of the rail pressure is dependent on turbo-charging.

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Computational and Experimental Investigation of Drop Breakup in Antral Contraction Wave Flows in a Model Stomach

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Abstract

The breakup of drops in a model stomach is investigated numerically and experimentally. A simplified artificial stomach was constructed, consisting of a tube which was closed at one end to represent the antrum and the closed pylorus. Antral contraction waves were modeled by a moving hollow piston. The computational domain used in the simulations mirrored this setup. Experiments and simulations were first performed for different single-phase fluids, relative occlusions and wave speeds. Velocity profiles, measured along the centerline using ultrasound Doppler, were used to validate the stomach model and numerical simulations. The retropulsive jet and velocity were similar to those from simulations in complex 3D geometries of the stomach and with in-vivo measurements. Liquid drops of different sizes and initial locations were then tracked through the flows and their breakup behavior was recorded. The drops were highly viscous with low interfacial tension to represent the conditions in the stomach. The strain rates and stresses along the various particle paths were determined from single-phase flow simulations. Combining this particle tracking information with drop breakup behavior from the experiments and two-phase simulations, different breakup conditions and regimes were identified. It was found that the experiments and simulations agreed well in terms of drop behavior and breakup. After this validation, a detailed parameter study was performed using two-phase flow simulations in order to determine more precise breakup conditions in terms of viscosity ratio. On a graph of critical capillary number versus viscosity ratio, the breakup regime was found to be bounded above and below by two critical capillary number curves. For capillary numbers below the lower curve, breakup did not occur due to the drop not being sufficiently stretched as it passed under the wave, while for capillary numbers above the upper curve, breakup did not occur due to decreasing viscous stresses and low interfacial tension preventing Rayleigh-Plateau instabilities from sufficiently forming on the drop. Moreover, breakup occurred only for viscosity ratios less than four.

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Retraction of water droplets after impact on solid substrates with different wettabilities

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Abstract

Studying retraction dynamics can facilitate the understanding of droplet rebounding on solid substrates and improve the design of superhydrophobic surfaces. Most efforts have been focused on the retraction of aqueous drops on hydrophobic surfaces. In this study, we extend the scope of research to include more hydrophilic surfaces with different receding contact angles from 21° to 85°. A wide range of impacting Weber numbers ($1<We<1000$) are investigated. The Ohnesorge number (Oh) is kept at 0.002, indicating that the investigated conditions fall within the inertia-capillary (IC) regime. For the same We, the droplet is found to retract faster on the surface with higher receding contact angle. During this IC regime, the retraction curves ($[D(t)/D_m]$ vs $[t]$) cannot simply collapse into a universal shape as in viscous regime due to the difference in t_m marking the time instance at maximum spread and in t_r marking the start of retraction. Moreover, for small We, a certain relaxation period (t_r-t_m) exists, in which the dynamic contact angle decreases from the advancing to the receding contact angle before the three-phase contact line can retract. With a further normalization by t_r, the retraction curves ($[D(t)/D_m]$ vs $[t/t_r]$) demonstrates that the modified retraction rate ($2V_{ret}/(D_m/t_r)$) decreases with the increasing We. Finally, effects of the receding contact angle and the impacting We on the modified retraction rate are compared with classical Taylor-Culick retracting theory for thin films.

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Filament Extension Atomization (FEA)

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Abstract

PARC has developed the Filament Extension Atomizer (FEA) to address the inability of conventional spray-production systems to create high-quality aerosols of non-Newtonian fluids. FEA allows spraying of a wider range of fluids, including those that are strain hardening due to presence of macromolecular components or simply high viscosity. The technology is capable of spraying a wide range of strain-hardening, non-Newtonian, and high-viscosity (>1000 Pa-s) fluids with tight particle size distributions, tunable droplet sizes (from 100s of microns down to 3 microns), and at a large range of scales depending on the application. At the core of FEA, a fluid enters the nip, or contact area, between two high-speed counter-rotating rollers. As the fluid exits the nip, multiple filaments are formed. These filaments are stretched and thinned until eventually they break into droplets. These droplets are harvested and the resulting entrained flow can be shaped and directed to accommodate a wide range of applications. We will present our work on spraying of Newtonian solutions, non-Newtonian dilute solutions of polymers, polymer melts, and high viscosity fluids to demonstrate the range and depth of this technology.

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A computational study of splashing drop trains: secondary droplet formation and characterization

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Abstract

We present 3D numerical simulations of the impingement of a train of ethanol drops, originally conducted experimentally by Yarin and Weiss (Journal of Fluid Mechanics, 1995), to characterize the secondary droplets. Our numerical results have been previously validated, demonstrating the ability to accurately capture the splashing dynamics. In this work, the focus is on gaining insight into formation and distribution of secondary droplets. A robust post-processing algorithm is used, which quantifies the number, volume and velocity of secondary droplets. The secondary droplets are characterized within close proximity to the impingement point at small length and temporal scales, which is extremely challenging to achieve experimentally. By studying the temporal evolution of secondary droplet formation, distinct phases of secondary droplet formation are identified, providing detailed insights into the instability-driven breakup process of lamellae. Time-averaged secondary droplet characteristics are presented, describing the global distribution of secondary droplets. Such analyses are vital to understanding fuel drop impingement, facilitating the development of highly accurate spray-wall interaction models for improved predictability in Lagrangian solvers.

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Turbulent theory of velocity-profile-induced jet breakup

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Abstract

Velocity profile relaxation is commonly believed to be a cause of jet breakup. This claim is critically reevaluated in this work. Contrary to common belief, laminar liquid jets with parabolic velocity profiles are actually more stable than laminar jets with flatter velocity profiles. This is shown using prior theory and experiments. For turbulent jets, the influence of the velocity profile is more difficult to determine. Previous experimentalists claimed to show that the velocity profile has an effect by varying the nozzle length. The claim is that the boundary layer thickness grows with nozzle length, and that the larger the boundary layer, the less stable the jet. In this work, nozzle length is shown to be a poor proxy for velocity profile effects because the turbulence intensity also increases as the nozzle length increases. Studies with this confounding were ignored in this work. Thinner boundary layers have greater shear, yet experiments have shown that if the boundary layer were made thinner (all else constant), the jet often is more stable. This is termed the "shear paradox". A potential resolution to the shear paradox is developed by considering that the area with shear also decreases as the boundary layer thickness is decreased, and by non-dimensionalizing the turbulent production rate by the dissipation. This theory shows an interaction between the integral scale and velocity profile relaxation which has not been previously discussed. The theoretical prediction that a smaller integral scale leads to more stable jets (due to increased turbulent dissipation) is shown to be somewhat consistent with the limited experimental and DNS data available.

*https://trettelresearch.com/contact.html

Secondary Droplet Breakup Effects in Aerated-Liquid Injection into Subsonic and Supersonic Crossflows

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Abstract

Aerated-liquid or 'barbotage' atomization initiates primary breakup by injecting a small amount of gas into a co-flowing liquid and then expanding the mixture through a small-orifice nozzle. At high gas-to-liquid mass ratios and relatively large nozzle diameters, the result is a highly-turbulent two-phase flow that can be characterized as having a core-annular structure. The injection of the two-phase flow into a crossflow environment results in the breakup of the annular liquid sheet followed possibly by secondary droplet breakup mechanisms. This work implements a secondary droplet breakup model based on a modified form of the Cascade Atomization Breakup strategy of Tanner. The model uses two different estimates of a breakup time, one associated with the prediction of droplet breakup itself and another used in the estimation of 'child' droplet sizes. The Lagrangian droplet-tracking model is coupled with an Eulerian homogeneous mixture model, evolved as a large-eddy simulation, to simulate the evolution of the initially dense spray. Results are presented for two cases: one involving 'out-in' aerated liquid injection into a Mach 0.3 subsonic crossflow and the other involving aerated-liquid injection into a Mach 2.3 supersonic crossflow. Predictions are compared with phase Doppler particle anemometry (PDPA) measurements for the subsonic and supersonic crossflow experiments and also with shadowgraph imagery for the supersonic crossflow experiments. The inclusion of secondary breakup effects does not improve agreement with PDPA measurements for either case, as high Weber numbers experienced during the initial injection of the spray lead to a very rapid sequence of breakup events and the removal of most droplets larger than 10 microns. Agreement with shadowgraph imagery does improve when breakup is included for injection into a supersonic crossflow, as the smaller droplets generated follow the axial flow more closely.

A Sub-grid Scale Energy Dissipation Rate Model for Large-eddy Spray Simulations

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Abstract

In high Reynolds number turbulent flows, energy dissipation refers to the process of energy transfer from kinetic energy to internal energy due to molecular viscosity. In large eddy simulation (LES) with one-equation turbulence models, the energy dissipation process is modeled by a rate term in the transport equation of the subgrid-scale (SGS) kinetic energy, k_{sgs}. Despite its important role in maintaining a proper energy balance between the resolved and SGS scales, modeling of the energy dissipation rate has received scarce attention. In this paper, a SGS model belonging to the dynamic structure family is developed based on findings from direct numerical simulation (DNS) studies of decaying isotropic turbulence. The model utilizes a Leonard-type term, a SGS viscosity, and a characteristic scaling term to predict the energy dissipation rate in LES. *A posteriori* tests of the model have been carried out under direct-injection gasoline and diesel engine-like conditions. Spray characteristics such as penetration rates and mixture fractions have been examined. It is found that the current SGS model accurately predicts vapor-phase penetrations across different mesh resolutions under both gasoline and diesel spray conditions, due to its correct scaling of SGS energy dissipation rate with the SGS kinetic energy and LES fitter width. In contrast, the classic model that is widely used in the literature predicts a scaling of energy dissipation rate upon mesh resolution, exhibiting a noticeable mesh dependence.

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Effect of Gas Density on Flowfield and Spray Dynamics of Vaporizing Liquid jet in Crossflow

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Abstract

This study focuses on enhancing the understanding of effects of air density on spray and flowfield characteristics of a vaporizing water jet injected in air crossflow using high-fidelity numerical simulations in an Eulerian-Lagrangian framework.. The gas phase is treated in an Eulerian frame, with turbulence closure achieved through large eddy simulation (LES) technique. The liquid phase is modeled in the Lagrangian reference frame using the blob approach. Primary atomization of the liquid jet is modeled using the K-H wave breakup model, with Taylor Analogy breakup (TAB) model implemented to account for secondary breakup. Three-way coupling accounts for the interactions between the liquid and gaseous fields (including the effect of finite-size of the dispersed phase on the continuous flowfield) by accounting for the exchange of mass, momentum and energy between the two phases. The formulation is validated against experimental measurements of liquid jet penetration and droplet size distributions for a liquid jet in crossflow at weber number of 68 and momentum flux ratio of 9 at two temperatures – 298 K and 573 K. Results show a very good agreement for the prediction of both the penetration of the liquid jet as well as Sauter Mean Diameter (SMD) distribution. Systematic studies are then conducted to identify the effect of air density on the characteristics of vaporizing liquid jet in crossflow at two chamber pressures of 2.1 bar and 3.8 bar, at a temperature of 573 K. Spray characteristics, namely the liquid jet penetration and droplet size distribution, and the flowfield associated with the two cases are analyzed in detail. Increase in inflow air pressure, and therefore an increase in air density, was found to have a significant effect in enhancing the atomization process, which led to smaller droplet sizes.

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Large-Eddy Simulation of Spray A with Various Fuels

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Abstract

Lagrangian Particle Tracking (LPT) and Large-Eddy Simulation (LES) were used to assess the effect of different fuels on spray characteristics. In such a two-way coupled modeling scenario spray momentum is transferred to the gaseous phase near the nozzle at small scales. The momentum transfer leads to intense gas phase acceleration, formation of a multiphase gas-liquid jet, transition into turbulence, and eventual liquid evaporation. To assess fuel property effects on liquid spray formation, the non-reacting Engine Combustion Network (ECN) Spray A target condition was chosen as the baseline case. In the Spray A, n-dodecane is injected at injection pressure of 150 MPa into engine relevant conditions (P = 6 MPa, T = 900 K). The validated Spray A case was modified by replacing n-dodecane with diesel, methanol, dimethyl ether (DME), or propane assuming 150 MPa injection pressure. The model features and performance for various fuels in the under-resolved near-nozzle region are discussed. The main findings of the paper are as follows: 1) We show that, in addition to the well-known liquid penetration (L_{liq}), and vapor penetration (L_{vap}), for all the investigated fuels, the modeled multiphase jets exhibit also a third length scale L_{core}, with discussed correspondence to a potential core part common to single phase jets. 2) As a characteristic feature of the present model, L_{core} is noted to correlate linearly with L_{liq} and L_{vap} for all the fuels. 3) A separate sensitivity test on density variation indicated that the liquid density had a relatively minor role on L_{liq}. In the absence of experimental and fully resolved numerical near-nozzle velocity data, the exact details of L_{core} remain as an open question. In contrast, fuel property effects on spray development have been consistently explained herein.

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Numerical Simulation of Aerated-Liquid Injection into a Supersonic Crossflow

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ABSTRACT

Numerical simulations of an aerated-liquid jet in a Mach 1.94 crossflow are presented. The numerical method includes solving the Reynold's averaged Navier-Stokes (RANS) equations with the shear stress transport (SST) turbulence model coupled to a Lagrangian droplet tracker to simulate the structures of the discharged plumes. Effects of turbulent dispersion and secondary break-up are considered. A simplified injection model is proposed where a spherical cone is used to specify the injection region given user specified spray angle, mean droplet diameter, and droplet size distribution. To compare with available experimental data, water is chosen as the liquid for each case. A grid refinement study was conducted to determine appropriate resolutions. Comparisons are made to phase Doppler particle analyzer (PDPA), shadowgraph, and laser-sheet imaging. Results suggest reasonable agreement between the chosen model conditions and the experimental data available. Particular attention is made to consider the biases within each experimental technique and how to best evaluate the simulated results with these considerations in mind.

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Investigation of droplet evaporation and scalar mixing in turbulent dilute acetone sprays using large eddy simulation

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Abstract

There are a variety of characteristic time scales associated with dilute sprays in turbulent flows. The drop time scales can be orders of magnitude smaller than the numerical time marching scale in the gaseous phase, rendering the gas-liquid coupling challenging. In this paper, large eddy simulations of turbulent non-reacting dilute spray jets are performed to explore the effect of subfilter time integration using a Lagrangian-Eulerian approach with two-way coupling. The subfilter closure for gas-phase velocity and scalar-mixing is achieved using the mixed dynamic Smagorinsky model. The dynamics of liquid drops are tracked using a system of Lagrangian particle equations. Different time scales for integrating drop equations are systematically evaluated to examine the influence on the overall spray dynamics and resultant interfacial exchange between the gas and liquid phases. Simulation results are compared with measurements from the Sydney spray experiment using acetone as the fuel. Profiles of mean and rms velocity for the gas and liquid phases and the drop size distribution are analyzed at different axial locations for three different drop loadings and inlet turbulence intensities. Conclusions are drawn accordingly.

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Spray Nozzle Implementation for a Gas-Liquid Feed Application

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Abstract

In a process at The Dow Chemical Company (Dow), a feed pipe flow contains both gas and liquid phases. It was desired to use a spray nozzle to distribute this multiphase flow. Although a small fraction on a mass basis, the amount of gas is 99+% on a volumetric basis, making efficient liquid phase distribution very difficult through other technology that was in use. Besides flow maldistribution, there was an undesirably large volume of mist generated.

A hydraulic spray nozzle approach was desired due to its inherent mechanical simplicity. However, the large vapor fraction in the feed fluid makes this unlike traditional spray applications. Due to this unusual nature, a test rig was utilized at BETE Fog Nozzle, Inc., to evaluate potential nozzle models and designs with external feed piping mimicking the Dow application. The piping configuration was important so that the multiphase flow regime feeding the spray nozzle was mimicked as well. Air and water were used as substitute fluids to the Dow process using suitable scaling laws.

After testing some traditional nozzles such as the BETE MaxiPass® series, it was quickly concluded that a custom nozzle would need to be designed to achieve adequate performance, including a suitable spray angle to adequately distribute the flow. A new nozzle design utilizing an internal whirl vane and multiple orifice array was subsequently shown to meet the project coverage requirements while maintaining mist generation levels within reasonable limits. The spray nozzle was implemented and found to give improved performance.

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Numerical Investigation on a New Design Concept of the Auxiliary Inspiratory Flow Supply Device for Dry Powder Inhalers

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Abstract

Dry powder inhaler (DPI) is one of the preferred drug delivery devices for patients with lung diseases such as asthma and chronic obstructive pulmonary disease (COPD). Unlike the pressurized metered dose inhalers (pMDIs), DPIs are breath-actuated and therefore do not require good actuation–inhalation coordination for optimal lung deposition. However, the aerosol quality of DPIs exhibits strong dependency on the inspiratory flow rates. Failure to exhale to functional residual capacity before inhaling and insufficient inspiration resulting in a flow rate below a minimum of 30 L/min were two of the most common problems with DPIs. In this work, a new design concept that adding a manually-compressed bladder as the auxiliary air supply device to the DPIs is introduced to help the age-specific patients with insufficient lung capacity or users with respiratory obstructions to attain the effective inhaling flow rate. The Turbohaler® as one of the typical DPIs is used as a sample to determine the appropriate bladder volume and corresponding compression frequency. Furthermore, a numerical investigation about the inhaler internal flow condition is conducted to validate that the necessary flow rate and flow acceleration are achievable to generate sufficient turbulent energy inside the DPI for the deagglomeration of the drug particles during inhalation.

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Control of the frequency of the large-scale instability in assisted atomization

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Abstract

Topic areas: Atomization theory, Analysis & Modelling
Spray Characterization & Measurements (Special Session)
Experimental Methods & Instrumentation
Keywords: flapping instability, gas assisted injection, gas turbulence

Destabilization and dispersion of liquid jets by air-assisted atomization are widely used in various industrial processes. Close to the injector, the liquid breakup was found to result from successive instabilities, including a shear instability [1, 2, 3] that forms axial waves which are then destabilized into ligaments by a transverse Rayleigh-Taylor instability [1, 4, 5] and finally leads to drops [1, 2, 3]. For cylindrical jets, an additional instability is observed: indeed, the liquid jet oscillates and it breaks into large liquid fragments of the order of the local jet radius. Recent progresses have been achieved on the origin of that "flapping" instability [6]. In particular, two regimes have been identified. One regime happens to be controlled by the asymmetrical shear instability and the corresponding flapping frequency increases with the gas velocity. In the second regime, incoming perturbations are amplified and the corresponding frequency does not change with the gas velocity: instead, it is set by the velocity and the diameter of the liquid jet. Scaling laws have been proposed for these two regimes [6]. This "flapping" instability leads to the formation of large drops compared to those due to stripping: such large drop should be minimized in applications related to combustion in order to reduce pollutants emission and/or to improve engine efficiency. In the present study, we present some attempts to control that flapping frequency and, possibly, the resulting drop size. In particular, strategies grounded on the modulation of turbulence in the gas proved successful for shear instabilities [7]. The same strategy was tested for the flapping. Experiments have been performed on a cylindrical vertical liquid jet (5 mm in diameter) driven by a fast coaxial annular gas stream (5 mm in width). First, arrays of obstacles were patterned inside the annular gas nozzle to enhance turbulence in the gas phase. Gas velocity profiles measured with hot wire anemometry showed that the turbulence intensity increases by 3 to 4% depending on the arrangement of obstacles. Measurements were carried out with fast imaging for gas velocities U_g from 15 to $90 m/s$ at fixed liquid velocity $U_l = 0.28 m/s$.The shear instability frequency is shown to increase with the turbulence in the gas, in agreement with the observations of Matas et al. (2015) for a planar air-water mixing layer [6]. Yet, the flapping instability remains unaffected, although it is known that the flapping can originate from the asymmetrical shear instability [6]. A possible reason for that difference is that the flapping mechanism involves pressure modulations and the latter are weakly sensitive to turbulence while the symmetrical shear instability is directly affected by viscous momentum exchanges at the interface that are strongly modified by the turbulence intensity [7]. We therefore sought another route to control the flapping instability. We know from [6] that the flapping instability can also grow from interface disturbances provided that they are large enough. Thus, disturbances were forced using a small obstacle in the gas stream that accelerates and produces a local deformation of the interface close to the injector exit. In practice, a steel rod was located at the nozzle exit perpendicularly to gas stream. Different rod diameters and radial positions were tested. For a rod sufficiently close to the liquid jet, a neat (up to 25%) increase in the flapping frequency is observed. Besides, increasing the rod diameter leads to higher flapping frequencies. Thus, the proposed technique is able to significantly change the flapping frequency. However, the origin of the frequency change is still unclear. In particular, it is not governed by the shedding frequency behind a rod.

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Best Practices in the numerical modelling of liquid atomization processes

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Abstract

Liquid atomization processes are used in several industries. The simulation of these processes requires understanding of complex physical phenomena and overcoming various modelling challenges, including resolution of multiple flow scales, cavitation, liquid/gas interface instabilities and liquid and gas compressibility. The modelling of these processes has been an active area of research among a number of groups and organizations. The approaches developed thus far are very computationally intensive, and thus require new techniques to handle the simulation in an optimized fashion. However,, with continued advancements in mathematical models and high-performance computing, simulating primary atomization is becoming more main-stream, which is evident by the increasing number of researchers in academics and engineers in industry running these detailed simulations.

This paper summarises our experience with such detailed simulation of liquid atomization. ANSYS, Inc. has developed a hybrid model that combines the volume-of-fluid (VOF) model with the discrete-phase model (DPM) to provide an efficient and robust tool that can provide some primary atomization prediction capability. ANSYS Fluent version 2019R1 is used to model several applications such as Simplex Nozzle, jet in cross flow and impinging jets. There are several physical models and solver settings that make an impact on the fidelity and efficiency of the simulation. We describe the components of the integrated VOF-to-DPM model transition setup and will present results from several simulations. Such simulations require robust modelling of turbulence, interface tracking, mesh adaption, model transition and parallel scalability. Care must be taken in preparing a computational grid that provides a basis for further mesh refinement to capture interfaces and high gradients, while also detecting liquid lumps for transition from an Eulerian to a Lagrangian description. The purpose of this paper is to highlight key steps in the simulation and lessons learned from these simulations to provide guidance to others in this area of research.

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Advances in imaging diagnostics for icing research in aircraft engines

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Abstract

High-altitude ice crystals and supercooled large drops have been recognized as an important threat to aviation safety because they can lead to engine damage and failure. Concerns with engine icing have increased with the advent of new, high-efficiency engines that appear to be more susceptible to icing. These threats have generated interest in investigating the particle field encountered by the aircraft, as well as the effects over engine behavior and performance. Measurements under test conditions consisting of mixed phase particle field containing liquid drops and ice crystals has been very challenging for the existing instrumentation.

We developed advanced imaging diagnostics and methods to investigate the particle field in simulated flight conditions, prone to icing. Experiments were performed at the propulsion system laboratory of NASA Glenn Research Center, a facility enabling the simulation of altitude conditions in a wind tunnel with liquid and ice particle generation. An uncertified turbofan jet engine was mounted in the measurement section, and a series of tests was carried out to cover the wide range of liquid drop and ice crystal conditions encountered during flight. High-resolution imaging was performed simultaneously at two locations both upstream and downstream of the fan in the bypass region of the jet engine. This document provides a detailed description of the diagnostics, as well as the image processing methods to obtain reliable and near-real time particle size distributions and concentration measurements.

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Methods to Analyze Liquid Flux Distribution (Patternation) Spray Data for Industrial and Agricultural Applications

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Abstract

The spatial distribution of liquid in a spray is an important characteristic that impacts the performance of many applications. Fuel spray applications have considered this factor for the design of various types of internal combustion engines for many years. Agricultural and industrial sprays are making greater use of Liquid Flux Distribution, LFD, to optimize spray performance. However, the methods of analysis are very application specific.

This paper describes several methods of LFD measurements including intrusive physical patternators. Physical patternators are more common for large flow number nozzles, high capacity, and large cross-sectional area industrial and agricultural sprays. The main focus of this paper is the description of methods of analysis. Statistical measures are used to compare the uniformity of LFD with overlapped spray patterns. Other measures yield additional insight to maximize the performance and make unbiased comparisons.

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Adjoint-based optimal control of an air-blasted planar sheet

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Abstract

Sprays are utilized in a variety of engineering applications from additive manufacturing to fuel injection. The capability to control sprays has potential to significantly improve spray performance. However, spray control has been limited and improvements to spraying technology have relied heavily on intuition-guided trial and error. Adjoint-based control methods provide sensitivity information to determine the best path to drive a system from one state to another, more desirable state. As such, an adjoint formulation provides a mathematical framework whereby control can be approached systematically. In this work, we present the adjoint equations for liquid-gas flows and validate them against an analytical solution for a one-dimensional advecting interface. Additionally, we solve the adjoint equations using a pressure-projection method and verify our multiphase adjoint solver against the same model problem. Finally, we demonstrate the calculation of multiphase adjoints in the case of an air-blasted liquid sheet, paving the way towards optimal control of sprays.

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Overcoming Saturation: Eliminating Intensity-Related Size Dynamic Range Limitations to Phase-Doppler Interferometry

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Abstract

In common with many other optical methods for droplet characterization, size dynamic range has been a limitation of phase-Doppler interferometry since its invention. The photodetectors used in these instruments have a finite dynamic range and light scatters from droplets essentially as the square of the droplet diameter. The traditional view is that this combination of physical effects leads to a limited dynamic range in droplet diameter where the largest droplet should be between thirty and fifty times larger than the minimum detectable droplet. However, not all droplet trajectories pass through the centers of the laser beams where the intensity is the highest. Even a very large drop may not saturate the detectors if it passes through the measurement volume sufficiently far from centerline. As such, there is no theoretical upper limit in droplet diameter due to intensity.

To build an unbiased diameter distribution or calculate spray flux from phase-Doppler data, one must take into account the variation of the measurement volume as a function of droplet size. This must account for the lack of valid measurements for large drops that saturate the detectors as they pass through the center of the volume. In their previous work[†], the authors presented a methodology for establishing the effective cross-sectional area of the measurement volume as a function of droplet size and trajectory. In addition, the authors demonstrated how such a model could be used to rigorously account for data validation criteria that might eliminate valid measurements along with invalid data. In this work, the authors demonstrate how this correction methodology can be applied to rigorously account for saturation effects as well as to eliminate spurious signals that may be generated by a phase-Doppler system as a result of saturation conditions.

[†] Sipperley, C.M., Bade, K.M., Schick, R.J., "Advanced Processing for Spray Flux Measurements Using Phase-Doppler Interferometry," *proceedings of the 14th Triennial International Conference on Liquid Atomization and Spray Systems*, Chicago, IL, USA, July 22-26, 2018.

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Impact of Operating Conditions on the Spray in a High-Shear Nozzle/Swirler Injector Investigated using High-Fidelity Simulations

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Abstract

Practical aero-engine fuel injection systems are highly complicated, combining complex fuel atomizing nozzle and air swirling elements to achieve good fuel-air mixing as well as long residence time in order to enhance both combustion efficiency and stability. Detailed understanding of the multiscale, multiphase flow processes (liquid jet atomization, swirling liquid transport, film formation/atomization) occurring in a realistic injector has been limited due to the complex geometries and the challenges encountered in experimental measurements, especially under the high temperature-pressure operating environment in aero-engine combustors. Recent advances in numerical methods and increases in computational power have enabled the first-principle high-fidelity simulation of such processes to achieve a comprehensive physics-based understanding by probing into the near-field two-phase details. In the past, we have conducted a detailed simulation of a high-shear nozzle/swirler injector at ambient conditions and validated the results against experimental measurements. In this work, we extend the same computational approach to study the impact of operating conditions on the spray physics in such a complex device. Numerical algorithms to handle liquid evaporation at elevated temperature have been developed. The previously validated ambient condition case was used as the baseline for comparison with other cases with higher temperature, pressure, and liquid fuel flow rate. The high fuel loading cases are compared with low fuel loading ones to help understanding the impact of filming on injector performance. The spray details regarding jet trajectory, atomization degree, film thickness, and jet-to-film volume flux ratio were analyzed under the ambient as well as the elevated conditions. It was observed that high temperature/pressure condition has little impact on the gaseous flow upstream of fuel injection, but significantly modifies in the near-field liquid spray inside the swirler in various aspects. The condition-induced changes also depend on the dominant liquid atomization mechanisms (jet-in-swirling-flow atomization or film-edge breakup), which are determined by the fuel loading conditions.

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Exploration of Near-Field Structures of Aerated-Liquid Jets in Quiescent and Crossflow Environments Using Confocal X-Ray Fluorescence

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Abstract

Quantitative time-averaged spatially-resolved liquid and gas mass distributions within the near field of aerated-liquid jets in both quiescent and subsonic crossflow environments were measured with the confocal x-ray fluorescence technique available at Argonne National Laboratory. Mass distribution patterns and interactions between liquid and gas plumes were then explored from these measurements. In a quiescent environment, the expansion processes of the aerating gas plume are fairly independent of the liquid plume and exhibit features similar to those of a typical gaseous jet. The initial expansion of the liquid plume is greatly assisted by that of the companion gas plume. The aerating gas plume exhibits a width smaller than that of the liquid plume, with limited interactions with the ambient air. In a subsonic crossflow environment, a unique plume crossing phenomenon can be observed within the near field of the discharged plume. During plume crossing, liquid on the leeward side of the plume can be stripped by the suppressed gas plume, with the remaining liquid merged with the liquid on the windward side of the plume. The aerating gas plume is mainly located at the lower center of the overall plume and also exhibits limited interactions with the freestream air.

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High-Fidelity Modeling and Simulation of Primary Breakup fo a Gasoline Surrogate Jet

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Abstract

In the present work, we model and simulate the injection and atomization of a gasoline surrogate jet by detailed numerical simulation. The surrogate fuel has a low volatility and thus no phase change occurs in the process. The nozzle geometry and operation conditions are similar to the Engine Combustion Network (ECN) "Spray G". We focus the present study on the near field where inter-jet interaction is of secondary importance. Therefore, we have considered only one of the eight jets in the original Spray G injectors. The liquid is injected from the inlet into a chamber with stagnant gas. A tangential component of velocity is introduced at the inlet to mimic the complex internal flow in the original spray G injector, which leads to the jet deflection. A parametric study on the inlet tangential velocity is carried out to identify the proper value to be used. Simulations are performed with the multiphase flow solver, *Basilisk*, on an adaptive mesh. The gas-liquid interface is captured by the volume-of-fluid method. The numerical results are compared to the X-ray experimental data for the jet deflection angle and the temporal variation of penetration length. The vortex dynamics in the near field are also presented by the assistance of the vortex-identification criterion.

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An extinction-based technique for high-pressure spray field quantification

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Abstract

Diesel sprays present a challenging environment for detailed quantitative measurement of the liquid field. Even though drop-sizing diagnostics, such as optical microscopy and Ultra-Small Angle X-ray Scattering (USAXS), have been recently demonstrated, little quantitative data exists to validate these results and further improve our understanding of high-pressure fuel spray formation. This work presents the development of a two-wavelength, line-of-sight extinction measurement to examine liquid volume fraction and the corresponding droplet field in high-pressure fuel sprays. Here, extinction of lasers emitting at 10.6µm and 0.633µm are used for the measurement. To enable quantification of the liquid field in optically dense regions of the spray, a custom transfer function is developed to account for the undesirable influence of multiple-scattering. The developed diagnostic is then applied to n-dodecane sprays from the Engine Combustion Network Spray D injector at a rail pressures of 500bar and an atmospheric chamber condition. The results are then compared against available droplet sizes measured using USAXS, as well as from more recent measurements using a Scattering-Absorption Measurement Ratio (SAMR) technique also developed in our group. The findings highlight the accuracy of the developed diagnostic and its superiority over X-ray based spray measurements in terms of complexity and required resources. Moreover, the presented diagnostic shows an improved capability in the dilute regions of the spray, i.e. near the periphery, where X-ray based diagnostics are generally subject to high noise and low signal sensitivity.

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Analysis of an axisymmetric liquid jet at supercritical pressures

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Abstract

A numerical methodology to solve the high-pressure liquid injection problem is presented. The governing equations of fluid dynamics are coupled with an interface tracking and matching algorithm allowing for heat and mass transfer to occur between the liquid and gas phases. Then, a two-dimensional temporal axisymmetric case is analyzed where a cool liquid decane jet is perturbed in contact with a hotter gas (e.g., oxygen) moving with a relative velocity of 30 m/s. Three supercritical chamber pressures for the pure hydrocarbon (i.e., 50, 100 and 150 bar) are studied. Phase equilibrium laws allow the coexistence of two phases in this pressure regime as the mixture critical properties change within the diffuse region near the interface. Results show that sufficiently thick diffusion layers evolve on both sides of the liquid-gas interface before substantial wave amplitude growth. As pressure increases and the mixture critical point is approached, the most unstable wavelengths are reduced while the instability growth rate increases. A comparison with previous subcritical works shows a clear difference with results obtained in the supercritical pressure regime. The pressure effect on the instability wavelength and growth rate is also corroborated by the linear theory application to the Kelvin-Helmholtz instability. Although heat is conducted from the hotter gas to the cooler liquid, condensation can occur when the gas internal energy is lower than the liquid internal energy.

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Characterization of Near-Field Structures of Diesel Containing Carbon Dioxide in a Quiescent Environment Using X-Ray Radiography

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Abstract

Liquid atomization plays an important role in automobile, propulsion, power, and chemical industries, where a liquid injection scheme capable of rapidly generating fine droplets for faster evaporation is sometimes preferred. Injection of fuel containing dissolved gas (IFCDG), that is, fuel in which gas has been fully dissolved prior to injection, is a promising injection scheme. During the injection process, the gas precipitates and rapidly expands, shattering the liquid column. IFCDG has been shown to have a positive effect on droplet size, flame temperature, and emissions. For this study, a flow control system for the on-demand and in-line generation of hydrocarbon fluid with dissolved gaseous carbon dioxide at a given concentration, was designed and assessed using the x-ray radiography technique available at the 7-BM beamline of the Advanced Photon Source at Argonne National Laboratory. The use of a synchrotron x-ray source with a monochromatic beam allowed for a conversion of x-ray intensity attenuation to line-of-sight liquid path length. An axisymmetric injector with a nozzle diameter of 0.76 mm and length of 7.6 mm was utilized to deliver the single-phase solution into a quiescent environment. The present study shows that the flow control and injection system is capable of creating a single-phase solution of fuel containing dissolved gas on-demand and in-line, and delivering a stable atomized spray. Through x-ray radiography, quantitative two-dimensional and axial time-averaged line-of-sight mass distributions show that the discharged spray can be well dispersed for an injection condition with a sufficiently high concentration of dissolved carbon dioxide.

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Modeling Drop Deformation Effects in the Euler-Lagrange Prediction of Liquid Jet in Cross Flow

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Abstract

Accurate prediction of spray atomization process using an Euler-Lagrange (EL) approach is challenging because of high volume fraction of the liquid phase in dense regimes. This would in reality displace a remarkable portion of the gaseous phase which is commonly ignored in the standard EL approaches. In addition, deformation of droplet due to the interaction of aerodynamic force, surface tension and viscous forces is typically neglected in modeling dense sprays. In this work, to capture the volumetric displacement effects using an EL approach, the spatio-temporal changes in the volume fraction of the gaseous phase are taken into account. This leads to zero-Mach number, variable density equations that give rise to a source term in both momentum and continuity equations. It is shown that the continuity source term increases the velocity and dynamics of the carrier phase close to the nozzle. However, owing to the jet spread and dispersion of droplets, these effects decrease further downstream. In order to quantify the droplet deformation effects, different models are compared together with an experimental data. Different breakup regimes are studied in order to identify the best model for each regime. The shape deformation effect is isolated by performing a single droplet injected into the cross flow with flow conditions similar to the bag-type breakup. A significant deviation in the motion of droplet is observed compared to a case where deformation is neglected.

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X-ray Characterization and Spray Measurements of ECN Spray G Using Alternative Fuels Under Flashing Conditions

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Abstract

A suite of detailed measurements both inside and outside the injection nozzle for the Engine Combustion Network "Spray G" have been collected. The dynamic pintle motion has been measured with high-speed X-ray phase contrast imaging while operating at flashing conditions. Furthermore, time-resolved fuel density was measured through tomographic x-ray radiography for neat iso-octane and a blend of 80% iso-octane with either 20% butanol or 20% ethanol by volume under a flash-boiling condition. Lastly, these same fuels were used during the collection of Ultra Small Angle X-ray Scattering (USAXS) measurements to quantify the specific surface area of the spray in the near-nozzle region. Time-resolved imaging through the injector body provide the pintle motion profile during heated operation. Orthogonal views consistently show full lift height of 53 microns, with transverse motions on the order of 5 microns, which represent a non-negligible portion of the gap between the pintle and seat, a potentially influential blockage to the uniform flow and distribution of fuel to the orifices. Spray density profiles generated through tomographic reconstruction of projected radiography measurements reveal the high dispersion of the fuel under the flashing condition. This injection behavior also causes the individual plumes to collapse and interact with each other, which can lead to additional flow field perturbations. These maps also show density discrepancies between the fuel blends, caused by their differing vaporization profiles. The spray differences between these fuels are further highlighted through the specific surface area profiles of droplets in the plumes. The pintle motion information serves as influential factors in the performance of the injector, while the combination of radiography and USAXS measurements provide a valuable quantification of the resulting spray morphology.

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Advancements to a Dual-Scale approach for Simulating Turbulent Phase Interface Interactions

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Abstract

Direct Numerical Simulation remains an expensive task for atomization simulations. To decrease the burden of DNS, a Dual-Scale modeling approach (Gorokhovski and Herrmann, 2008) to describe turbulent phase interface dynamics in a Large Eddy Simulation spatial filtering context is proposed. Spatial filtering of the governing equations of fluid motion introduce several sub-filter terms that require modeling. Instead of developing individual closure models for the interface associated terms, the Dual-Scale approach uses an exact closure by explicitly filtering a fully resolved realization of the phase interface. This resolved realization is maintained using a Refined Local Surface Grid approach (Herrmann, 2008) employing an unsplit geometric Volume-of-Fluid method (Owkes and Desjardins, 2014). Advection of the phase interface on this DNS scale requires a reconstruction of the fully resolved interface velocity. This velocity is the sum of the LES filter velocities, sub-filter turbulent eddies, and velocities induced by sub-filter interface dynamics. In this work, results from the Dual-Scale LES model employing sub-filter turbulent eddy reconstruction by combined approximate deconvolution and non-linear spectral enrichment (Bassenne et al. 2017) and sub-filter surface tension model (Herrmann 2013) are compared to DNS results for a phase interface in a homogeneous isotropic turbulent flow for various Weber numbers.

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Exploration of Near-Field Structures of Aerated-Liquid Jets in Quiescent and Crossflow Environments Using Confocal X-Ray Fluorescence

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Abstract

Quantitative time-averaged spatially-resolved liquid and gas mass distributions within the near field of aerated-liquid jets in both quiescent and subsonic crossflow environments were measured with the confocal x-ray fluorescence technique available at Argonne National Laboratory. Mass distribution patterns and interactions between liquid and gas plumes were then explored from these measurements. In a quiescent environment, the expansion processes of the aerating gas plume are fairly independent of the liquid plume and exhibit features similar to those of a typical gaseous jet. The initial expansion of the liquid plume is greatly assisted by that of the companion gas plume. The aerating gas plume exhibits a width smaller than that of the liquid plume, with limited interactions with the ambient air. In a subsonic crossflow environment, a unique plume crossing phenomenon can be observed within the near field of the discharged plume. During plume crossing, liquid on the leeward side of the plume can be stripped by the suppressed gas plume, with the remaining liquid merged with the liquid on the windward side of the plume. The aerating gas plume is mainly located at the lower center of the overall plume and also exhibits limited interactions with the freestream air.

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Speedup Analysis of Adaptive Mesh Refinement in the Simulation of Spray Formation

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Abstract

The Adaptive Mesh Refinement (AMR) technique is commonly regarded as an attractive means of improving the computational speed for two-phase flow problems. In this work, we investigate the speedup benefits of AMR for the simulations of spray atomization. The evaluation consists of a systematic analysis of results from the solvers `interDyMFoam` (AMR octree) and `interFoam` (static octree) codes, both forming the family of the algebraic Volume-of-Fluid solvers distributed within the open source OpenFOAM C++ Toolbox. As a preliminary test, we examine the standard problems including pure advection, stationary wave dynamics and Rayleigh-Plateau breakup of a liquid ligament. The results from this examination confirm the benchmark advantage of AMR in speed as demonstrated in the literature. For more realistic problems of liquid jet atomization, however, the test results are not as favorable. We find that the AMR speedup value, which is measured by a set of performance metrics, drops significantly as a function of time, from an initial value of $\mathscr{O}(10^2)$ to a value near or well below one. Besides, this decrease pertains to the increasing atomization severity characterized by the liquid based Weber numbers. The primary source of AMR performance deterioration is isolated and is found to be the increasing demands for the computational effort of obtaining the Pressure-Poisson solution, dismissing other potential problematic contributors such as mesh adaptation operation, interface advection or momentum solution transport.

Keywords: Adaptive mesh refinement, Speedup analysis, Spray atomization, Pressure Poisson Equation.

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Statistical analysis of focused beam radiographs taken from a coaxial airblast spray

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Abstract

Studying the near-field region of sprays is particularly challenging because it is optically dense. However, energy in the X-ray range is capable of penetrating this dense region and obtaining information that would otherwise be unavailable. Through time-resolved X-ray radiography, a better understanding of the near-field region is currently being developed. The 7-BM beamline at the Advanced Photon Source at Argonne National Lab was focused down to a 5 x 6 μm cross-sectional area. The attenuation in the beam, which is used to calculate the effective path length of liquid, was then collected at an effective rate of 270 kHz for 10 seconds. Various statistical measures were applied to the X-ray focused beam radiographs including average, standard deviation, skewness, and kurtosis, to quantify the spray from a canonical coaxial airblast nozzle. Results show that the average effective path length is useful in determining the intact length and spray angle. The capabilities of additional statistical measures in determining important spray characteristics are also discussed.

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Conservative Simulations of Atomization - Combining the Height Function Method with Rudman Dual Grids

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Abstract

The atomization process is significantly affected by the surface tension force, which controls the size and distribution of droplets. The surface tension force is directly proportional to the interface curvature and an accurate calculation of curvature is essential for predictive simulations of atomization. Furthermore, methods that consistently and conservatively transport momentum, which is discontinuous at the gas-liquid interface, are necessary for robust and accurate simulations. The height function method is a common technique to compute an accurate curvature as it is straightforward to implement and provides a second-order calculation. Additionally, using a Rudman dual mesh (Int. J. Numer. Meth. Fluids, 1998), which discretizes density on a twice as fine mesh, provides consistent and conservative discretizations of mass and momentum.

This work extends the standard height function method to include information from the Rudman dual mesh. When a dual grid is used, the standard height function method fails to capture fine grid interface perturbations and these perturbations can grow. The proposed method leverages a fine-grid height function method to compute the fine-gird interface perturbations and uses a fine-grid velocity field to oppose the fine-grid perturbations. This approach maintains consistent mass and momentum transport while also providing accurate interface transport that avoids non-physical dynamics. The method is tested using an oscillating droplet test case and compared to a standard height function.

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A comparison between CFD and 3D X-ray Diagnostics of Internal Flow in a Cavitating Diesel Injector Nozzle

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Abstract

X-ray computed tomography is used to obtain high-fidelity data as inputs and validation for CFD simulation of the Engine Combustion Network's Spray C diesel injector. The three-dimensional morphology of cavitating internal nozzle flow has been measured using X-ray phase-contrast imaging combined with computed tomography at 2 micrometer resolution. The cavitation layer arises from known azimuthal variations in the inlet corner radius and extends, at some angles, the full length to the exit of the nozzle potentially causing hydraulic flip. A flow blockage of up to 30% is observed at the nozzle exit. A high resolution (< 2 um) realistic geometry that is also obtained by X-ray tomography is used as input to CFD simulations. This geometry provides accurate detail of micron-scale features in the internal flow passages that are critical to modeling the cavitating flow. CFD simulations of the internal and near-nozzle flow through the single-hole injector have been performed using the Homogenous Relaxation Model. The steady-state flow at full needle lift is simulated with high spatial resolution at 1500 bar injection pressure and atmospheric ambient pressure at the nozzle exit. The simulation results show the evolution of the cavitation layer in agreement with the experimental data. The predictions also show the persistent effect on the downstream spray. The fact that this agreement was achieved with no adjustment to the model or to the model constants indicate that geometric uncertainty is at least as significant a source of error as model fidelity.

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Validation and Analysis of 3D DNS of planar pre-filming airblast atomization simulations

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Abstract

In this paper, results from direct numerical simulations (DNS) of published experimental configuration of planar pre-filming airblast atomization are presented. The simulations have been performed using our in-house multiphase Navier-Stokes equations solver ARCHER. The coupled level set volume of fluid (CLSVOF) method has been used for capturing the liquid/gas interface within the context of multiphase flows. This numerical method has been proved to well capture the interface from many of our previous works. A kerosene based fuel at an operating point corresponding to aircraft altitude relight conditions have been used in DNS. The results are analyzed in two parts: analysis of liquid droplets and analysis of liquid ligaments at the trailing edge of the pre-filmer plate. The analyses of the liquid droplets diameter and velocity distributions revealed that the results from the simulations are agreeing with the experimental data very satisfactorily. Moreover, the observation from these distributions is that the sheet breakup mechanism is dominant over the ligament breakup mechanism of atomization. Ligament analysis has been carried out by reducing the 3D DNS data to 1D liquid/gas interface contour. The frequency distribution of the liquid ligaments shows the under-prediction on their lengths in comparison to experiments. Overall, a satisfactory agreement has been achieved between the DNS and experiments.

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Development of a screening tool to assess fuel property effects on cavitation and erosion propensity

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Abstract

To advance compression ignition combustion strategies, researchers have evaluated fuel property effects and their impact on achieving higher efficiencies and lower emissions levels relative to current capabilities. Within the Department of Energy's Co-Optima initiative, there has been a recent focus on understanding the influence of fuel properties on fuel injection performance. To help identify candidate fuels that can meet desired injector performance metrics, a computational fuel screening tool is under development that can link fuel properties with the propensity of a given fuel to cavitate and lead to cavitation-induced erosion. In the initial development of this tool, five liquid fuel properties were selected to represent candidate fuels, namely density, viscosity, vapor pressure, surface tension, and heat of vaporization. A design of experiments methodology was employed to generate a set of pseudo-fuel cases, which can represent the main effects and interactions among the fuel properties and be related to cavitation erosion predictions. Large eddy simulations were performed using a mixture modeling approach to predict the cavitation and erosion propensity of these pseudo-fuels in terms of the mean fuel vapor mole fraction and stored impact energy from repeated cloud collapse events. The low order regression models generated from this study revealed the importance of liquid fuel density on cavitation propensity, whereas liquid viscosity was found to have a strong negative correlation with the erosion predictions. The surrogate models were then used in the fuel screening tool to rank the cavitation and erosion tendency of four candidate single-component fuels: methyl decanoate, iso-octane, ethanol and n-dodecane. While the fuel screening tool was not able to quantitatively predict the cavitation and erosion response metrics, the tool was able to accurately rank the relative cavitation and erosion propensity of the four fuels. Overall, ethanol and iso-octane were observed to produce the highest levels of cavitation and erosion, respectively.

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3D Imaging of Cavitating Flow in a Diesel Injector at Practical Conditions using X-ray micro-CT

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Abstract

The geometry of the Engine Combustion Network "Spray C" diesel injector has been previously measured using X-ray computed tomography and reveals features such as a sharp inlet corner and micron-sized defects (micro-CT). In this paper, X-ray phase contrast imaging is used to obtain images of the internal flow in this nozzle from multiple viewing angles. A tomographic reconstruction procedure is then applied to obtain the three-dimensional morphology of the flow with 2 micron resolution. The data reveal a strongly cavitating flow that is influenced by geometric features in the nozzle body. The data processing and experimental workflow are discussed. Photon statistics were improved by averaging the data over 200 injection events. Translational and rotational image registration was performed to align projections obtained from different lines-of-sight. A Fourier transform method of tomographic reconstruction was then applied to these projections. Finally, the X-ray phase contrast in the data was exploited by applying a low-pass filter and a segmentation algorithm to track the location of the liquid-gas interface. This leads to quantitative data such as cavitation layer thickness and effective flow area. This technique provides unique measurements of internal flow in a round nozzle through approximately 2 millimeters of steel at typical diesel operating conditions.

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Preliminary Study of Reacting Three-Element Gas/Liquid Shear Coaxial Flows

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Abstract

The average behavior and the flow dynamics from a linear array of three shear coaxial injectors operating under sub-critical pressures was investigated. High speed images captured the unsteady behavior of the annular gaseous hydrogen and liquid oxygen shear coaxial flows, revelant for liquid rocket engine applications. High-speed shadowgraph images along with OH* chemiluminescence captured the hydrodynamic instabilities and their subsequent flame interactions. The behavior of the center injector's response relative to its neighbors' influences are compared to the flow from single injector studies operating under the same conditions. The high speed shadowgraph images show a dramatic difference of the break up length of the liquid oxygen jet from the three-element injector compared to the single element injector. The average of the high speed shadowgraph images show that the break up length is significantly shorter for the single element. Spectral analysis of the OH* chemiluminescence flucuations in the near field shows that the individual flames share a common frequency and the center flame's fluctuations are out of phase with its neighbors. This frequency and out of phase nature is also present in the dynamic mode decomposition of the shadowgraph and OH* chemiluminescence images used to investigate the modal structures for the liquid oxygen jets and the flames, respectively. Overlaying the OH* chemiluminescence images on top of the shadowgraph images showed that the locations of high OH*chemiluminescence lie on the same locations where surface waves are observed on the center liquid oxygen jet.

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The influence of ambient conditions and fuel type on gasoline spray plume direction

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Abstract

This study investigated the spray behavior of iso-octane, a multi-component surrogate with diisobutylene, and a multi-component fuel with olefin molecular structure. Fuel was injected using Engine Combustion Network (ECN) spray G injector into a continuous flow spray vessel under ECN G2 flash boiling, G3 early injection, and G3HT (G3 with 393 K ambient temperature) conditions. High-speed extinction and Mie-scattering imaging were performed for many injections at different injector rotations, followed by optical property analysis and tomographic reconstruction to identify the 3-D liquid volume fraction distribution and plume direction evolution. Experimental results showed that the expected higher evaporation rate associated with the G3 elevated temperature condition resulted in a shorter liquid axial and radial penetration length compared to the G2 and G3 (baseline) conditions. Compared to the G3 condition, the G2 condition had a narrower liquid plume width but a longer axial liquid penetration despite flash boiling operation. Planar slices, available from the tomographically reconstructed extinction data, confirmed greater plume interaction for the flash boiling condition with an approximately 4° smaller plume direction angle relative to the nozzle drill angle. In terms of fuel, the olefinic fuel, which has a broader distillation curve exhibited the strongest spray plume collapse, but also the longest time for evaporation.

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Characterization of Aqueous Cellulose Nanocrystals Sprays for Strengthening 3D Printed Polymer Structures

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Abstract

This work presents a novel technique to enhance the strength of additively manufactured polymer parts. This is achieved by spraying aqueous suspensions of cellulose nanocrystals (CNC) between adjacent polymer layers during printing using fused filament fabrication method. CNC act as nano-stitches between the layers to improve the interlayer adhesion that ultimately strengthens the printed parts. An internal-mix, air-atomizing nozzle is used to create a CNC-career spray to deposit the CNC particles on the printed samples after evaporation. Controlling the spray system parameters such as the distance between the nozzle and the print bed and liquid/air flow rates ensures complete evaporation of the mixture to achieve the desired performance in the printed part. In this work, we focus on resolving the spray field at varying injection conditions. High-speed diffuse back illumination (DBI) technique is used to capture the spray field in both macro- and microscopic levels. The average diameter of droplets and the spreading angle are measured 40 μm and 20º, respectively. The results indicate that spraying aqueous suspensions with 0.5-1 wt% CNC increases the interlayer shear strength by 44%, tensile strength by 33%, tensile modulus by 20% and the toughness by 33% in both longitudinal and transverse printing directions.

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An improved non-equilibrium multi-component evaporation model for blended diesel/alcohol droplets and sprays

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Abstract

A non-equilibrium Langmuir-Knudsen model for multi-component pure diesel and blended diesel/alcohol sprays is developed and evaluated through comparisons with experimental measurements. This model takes into account most of the key processes during the droplet lifetime, including the finite heat conduction and limited mass diffusion inside the droplet, the differential diffusion in gas phase, as well as the non-equilibrium Langmuir-Knudsen evaporation law for multi-component droplets. Twenty discrete components are selected to represent the fuel. The present model shows good agreements with experimental measurements for pure ethanol, diesel, and blended diesel/ethanol droplets. Both equilibrium and non-equilibrium models perform nearly identically for low evaporation rate conditions. The non-equilibrium effects become significant when the initial droplet diameter is smaller than 20 μm, and these effects are enhanced with increasing ambient temperature and forced convection intensity. It is additionally observed that the non-equilibrium effects are more significant for the blended diesel/alcohol droplets than pure diesel, especially during the evaporation period of ethanol. The present evaporation model has been implemented into a multi-dimensional CFD code and applied to calculate the evaporation processes of single- and multi-component fuel droplets and sprays under various ambient conditions. The non-equilibrium effects for the blended diesel/alcohol sprays are also evaluated and proved to be significant for the fuel vapor component concentrations.

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Easy flowing emulsion (o/w) based spray-dried powder produced using dietary fiber as a wall material

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Abstract

The production of emulsion (o/w) based microstructured food powder through spray drying is a common practice in the food industry due to better shelf-life and easy transportation of the structured material. In general, the emulsion based powder flow behavior is poor due to lipid phase diffusion into the surface. The microstructure transform during spray-drying and the reconstitution of the emulsion powder are also a challenge by preserving the desired physiochemical properties such as emulsion size, stability, the control release kinetics of actives etc. The main objective of this study is to encapsulate the lipid phase using a wall material composed of protein (whey protein) and apple fiber. The stable submicron emulsions (o/w) were prepared using a rotor-stator at room temperature. Different fiber concentrations and different spray drying conditions were tested by varying the air to liquid mass ratio (ALR). The easy flowing of the emulsion powder was achieved when a relatively small amount (max. 5%) of fiber was used; however, the flowing performance declines with higher fiber content. The excellent reconstitution of the emulsion was also found by dissolving the particles at room temperature.

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Varying the Bell Speed of an Electrostatic Rotating Bell

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Abstract

Electrostatic Rotating Bell (ESRB) atomizers have excellent transfer efficiency and deposit a highly uniform film thickness, even while atomizing multicomponent viscous liquids such as paints. However, the operational parameters of ESRB atomizers have a large impact on the resultant spread of the spray and the droplet size. As such, this paper details the effects on the droplet size and substrate coverage when varying the rotational speed of an RB-1000 serrated bell-cup while keeping all other operational parameters constant. A 20 wt% aqueous glycerin solution was chosen to model paint as it has a similar viscosity at room temperature. The droplet size distribution for each bell speed was measured by capturing images of droplets in-flight, measuring their diameters and tallying their relative frequency. Increasing the rotational speed of the bell resulted in a decrease in the average droplet diameter. The rate of area coverage was captured using a high-speed camera positioned behind a vertical glass substrate. A probabilistic model of the rate of area coverage, which incorporated the droplet size and droplet flux, showed good agreement with values measured experimentally.

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POSTERS

The Poster Session will be held on Wednesday, May 15 from 9:20-10:00am in the ISTB4 building on the 3rd Floor with poster authors.

Sensitivity of the range of a water jet to the breakup length and air entrainment
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Impingement Injector Spray Characteristics - A Study Using POD Technique
Pereira, R. and Frederick Jr., R.A.

Can a chart based on millions of trajectory simulations provide a simple tool to estimate how far a blood drop can fly?
Attinger, D.

Demonstration of a Spectral Microscopy Imaging System for High Resolution, High-Speed Imaging of Primary Breakup in Fuel Sprays
Maassen, K.F., Poursadegh, F., and Genzale, C.L.

Near-Field Spray Characteristics of Vegetable Oil Using Flow Blurring Injection
Qavi, I., Nasim, N., Akinyemi, O., and Jiang, L.

Study of Spray Characteristics for Different Impingement Lengths of Each Jet of Like Doublet Impinging Injectors
Swarnalatha, K.V.k. and Frederick Jr., R.A.

High-Fidelity Simulation of a Rotary Bell Atomizer with Electrohydrodynamic Effects
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