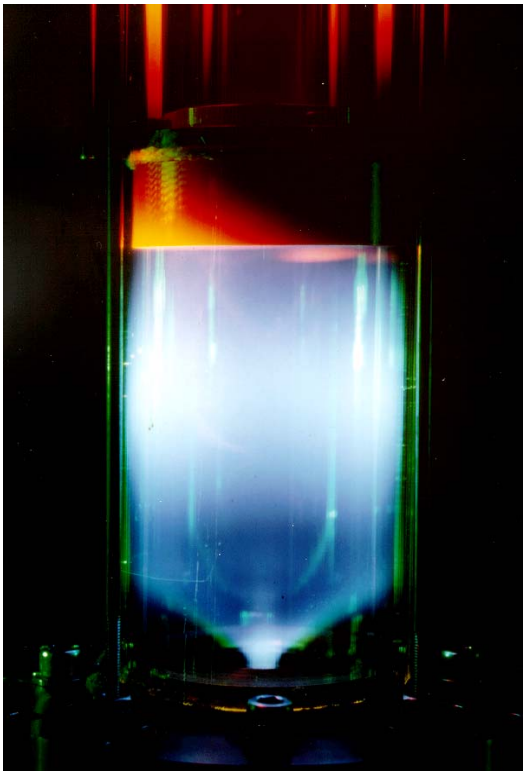
ENERGY RESEARCH CONSULTANTS

Research and Development Services



Contents

Since 1990, Energy Research Consultants (ERC) has been providing Research and Development Services for a wide range of commercial and government customers. ERC maintains a over 4,500 square feet of research facilities in Laguna Hills, California which house advanced test facilities and diagnostics that are applied to wide array of applications.

FACILITIES

ERC has six test stands, three of which are primarily utilized for study of gas and liquid fired combustion systems and/or components. Two are operated upfired and have exhausting capable of handling 6 lbs/sec of flow generated by devices fired with 1MW of fuel input. All facilities offer 3 axes of traversing with digital readouts for relative position. The fluid delivery systems are interchangeable between the three stands.

Air. ERC has four independent air generation sources producing the following flows:

0.05 lbs/s (40 SCFM) at pressures up to 150 psig
0.15 lbs/s (120 SCFM) at pressures up to 125 psig
1.00 lbs/s at pressures up to 1.2 psig
2.00 lbs/s at pressures up to 3 psig
2.25 lbs/s at pressures up to 4 psig
0.80 lbs/sec at pressures up to 10 psig
37.5 lbs/sec at pressures up to 0.2 psig
1.0 lbs/sec vitiated air at 1340 F at 200 m/s

In addition, 50 kW of non-vitiated preheating is available. Monitoring of air pressure, flow, temperature, and humidity is available via transducers and associated data acquisition interfaces.

Liquid. ERC has experience running the following distillate and non-distillate liquids:

Gasoline	heptane
Diesel	acetone
Calibration Fluid (MIL-PRF-7024D-Type II)	water
	water/glycerin
Jet-A/JP-8	Viscor

Five pumps are available:

1 gpm distillate fuel @ 300 psig
3 gpm water @3000 psig
10 gpm water @ 300 psig
100 gpm water @ 150 psig
1.4 gpm distillate fuel @ 600 psig

In addition, low pressure, low flow rates (to below 1 g/s) operation can be accomplished using an enclosed pressure container driving liquids with an inert gas pressure head up to 150 psig. In all cases, computer based monitoring of liquid flow rate, temperature and pressure is available via transducers and associated data acquisition interfaces. Multiple liquid circuits can be operated and monitored simultaneously (e.g., pilot and main stages).

Gaseous Fuel. ERC can flow up to 1MW of natural gas. In addition, additional fuel handling to provide higher hydrocarbons such as ethane, propane and butane is available. Also, hydrogen and diluents such as carbon dioxide and nitrogen can be accommodated.

Diagnostics. ERC maintains a wide array of conventional and advanced diagnostics including:

—Fuel/Air Mixing Probes
—Laser Anemometry
—Phase Doppler Interferometry
—Infrared Extinction/Scattering
—Emissions
—Temperature
—Planar Laser Induced Fluorescence
—Laser Induced Fluorescence
—Particle Image Velocimetry
—Planar Elastic Light Scattering
—Chemiluminescence Imaging
—Combustion Dynamics
—Laser Diffraction
—High Speed Visualization

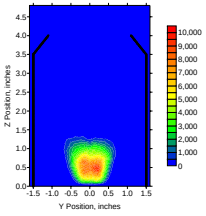
OTHER SERVICES

In addition to characterization of combustion systems and/or components, ERC can also provide assistance in development of test facilities, including design and fabrication of test stands, traverse systems, sampling systems, and specification, installation, and guidance on various diagnostics such as those outlined above. ERC can also put together data acquisition systems and do programming. ERC also has experience in the development, application, and interpretation of statistically designed evaluation methods which are being utilized in leading companies today for quality assurance. These methods, when applied to complex devices can provide an efficient cost effective means to identify the key factors that control performance of the devices. ERC can also provide analysis of results and provide interpretation of phenomena associated with combustion systems. We are happy to discuss your application and explore ways in which we can work with you.

DIAGNOSTICS

ERC personnel have considerable experience with a wide range of diagnostics as applied to a variety of applications.

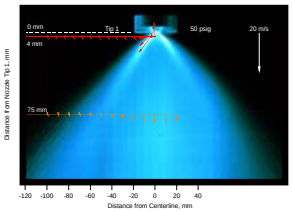
Fuel/Air Mixing Probes. For the characterization of fuel/air mixing in gaseous systems, ERC employs both intrusive and non-intrusive methods. Extractive probes can be used to pull a sample out of the flow and conveyed to the emissions analyzer package where a doped constituent (e.g., natural gas, carbon dioxide) can be monitored. This approach offers high accuracy and relatively high efficiency.



Laser Induced Fluorescence (LIF). If non-intrusive measurements are required of fuel or reaction species, either point or planar laser induced fluorescence (PLIF) can be utilized in both reacting and non-reacting flows. The specific species and methods employed will vary depending upon the type of information desired. Both continuous and pulsed lasers are available. For point measurements, a photomultiplier is used. For planar methods, scientific 16-bit intensified CCD cameras are available.

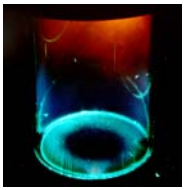
Laser Anemometry. To characterize the flowfield in reacting and non-reacting systems, a two-component laser anemometry system is available that features frequency domain processing. This method is used to provide a measure of a single component or of the total velocity at various points throughout the domain. This information is useful in defining the extent and strength of aerodynamic features such as recirculation zones, separation regions, and the like. Time resolved information can also be obtained and analyzed to search for periodic flow behavior that might be associated with shedding off a bluff body or some other instability in the system.

Particle Image Velocimetry (PIV). Measurements of particle velocity by tracking particle displacement with double pulsed laser and imaging.



Phase Doppler Interferometry (PDI). Phase Doppler interferometry systems with frequency domain processing (both TSI FSA3500 and Aerometrics DSA 3200) are available which can be applied in a variety of ways to reacting or non-reacting sprays. While primarily utilized to measure the joint distribution of particle size and two components of velocity at a point, it can also be utilized to measure flow field velocities in the absence of droplets or in the presence of droplets. Data

reduction programs have been developed at ERC to provide tabulated results in a wide variety of formats. PDI provides considerable information regarding the spray behavior and characteristics. In particular, it can provide the inlet conditions necessary for accurate computation fluid dynamics calculations. ERC personnel regularly apply PDI to reacting sprays and have extensive experience in reducing and tabulating data for model validation and/or further interpretation, including time resolved details and frequency analysis.



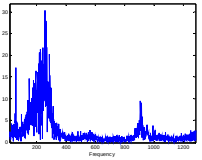
Planar Elastic Light Scattering Imaging (PELSI). ERC maintains a variety of optics to produce sheets or beams of laser light from either cw (e.g., Ar^+) or pulsed (e.g., Nd:YAG) lasers. Such lighting, when scattered by droplets or particles, can be imaged onto a digital camera. The camera can operate as both a video recorder or as a digital still camera with full user control over exposure (aperture and shutter speed). Close-up adapters are available to provide up to 30X magnification. In addition, ERC has the capability to extract frames from the video to conduct analysis (e.g., line profiles, comparison of images, etc.) as well as produce high quality video presentation of phenomena of interest. Various filters are utilized to isolate laser wavelengths and chemiluminescence from species of interest. The Nd:YAG laser can generate 4 ns pulses with energy levels sufficient to "freeze" the spray structure even with extreme magnification. This is useful in characterizing the highly complex breakup region.

Infrared Extinction/Scattering (IRES). ERC has the capability to measure the time-averaged concentration of vapor present within unconfined hydrocarbon sprays using a two-wavelength extinction technique. While a line-of-sight technique, spatially resolved information can be obtained for axisymmetric fields by deconvolving a series of parallel scans. This technique has been utilized to obtain time-resolved information as well, and can also be used in single phase situations to monitor fuel concentration.

Chemiluminescence Imaging. ERC has a variety of filters and cameras that can be used to image species such as OH, CH, or C2 which are helpful in determining the location of reaction zones. In addition to full field imaging, point measurements of radical species can also be useful in identifying dynamics associated with heat release and/or stability monitoring.

Emissions. ERC has the capability of measuring emissions including unburned hydrocarbons, oxygen, carbon monoxide, carbon dioxide, and oxides of nitrogen. In-situ samples are obtained using water-cooled extractive probes. ERC has implemented sophisticated data reduction tools for quality assurance, analysis, interpretation, and presentation of results. The spatial distribution of gaseous fuel can be determined through the use of microprobes and a flame ionization detector.

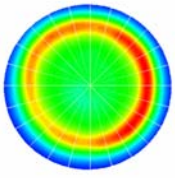
Combustion Dynamics. High sensitivity dynamic pressure probes are available with which to quantify the frequency and magnitude of combustion oscillations. Coupled with chemiluminescence, these probes can provide insight into the coupling between pressure and heat release.



Temperature. A variety of thermocouples are utilized to obtain in-situ temperature measurements.

Laser Diffraction (LD). A Malvern 2600C laser diffraction particle sizer is available to provide line-of-sight measurement of particle size distributions and particle concentration. This well established method of characterizing sprays provides a relatively rapid and consistent measurement with little user controls. ERC has optical arrangements to facilitate measurement of fine particles (1.2 microns) to those approaching 2 mm in diameter. ERC personnel have extensive experience in optimizing optical setups, dealing with potential issues such as beam steering, sample clipping, correction for laser extinction, and presentation and interpretation of results obtained using LD.

Planar Liquid Laser Induced Fluorescence (PLLIF). A technique related to PELSI is planar liquid laser induced fluorescence (PLLIF). In this case, rather than obtaining qualitative images, fluorescence is utilized to provide quantitative characterization of the spatial distribution of the liquid material.



Optical Patternation. Extending the PLIFF technique, ERC has develop a quantitative approach (under a Phase II SBIR) to the characterization of the spatial and temporal distribution of sprays ("optical patternation"). The technique corrects for both the attenuation of the incident light as it travels through the spray and the signal as it travels from the spray to the camera.

High Speed Visualization. High speed video up to 100,000 frames per sec with 1 microsecond exposure. Combined with various lighting techniques, high speed visualization can provide unique insight into the behavior of your system.

Calibration Devices. ERC has a wide variety of calibration devices, methods, and experience for quality control of all diagnostics and instrumentation.

Modeling

ERC applies commercial CFD codes (Fluent or CFD-ACE) to model reacting and non-reacting systems.

NEXT STEPS

Working with ERC is easy. With over 20 years of experience, a short phone conversation and answers to a few simple questions will generally be sufficient to let us give you a sense of what can be accomplished, how long it might take and what the cost will be. ERC maintains a number of example reports and project profiles that can be used to give you a clear idea of what you can expect.

Please direct inquiries to:

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EXAMPLE PAPERS

Characterization of a Superheated Fuel Jet in a Crossflow (2009). Paper GT2009-59358, TurboEXPO 2009, Orlando FL. (M. Corn, J. Cohen, D. Hautman, S. Thawley, C. Brown, and V. McDonell).

Dynamics of a Longitudinally Forced, Bluff Body Stabilized Flame (2009). Paper AIAA 2009-22, 47th AIAA Aerospace Sciences Meeting, Orlando FL (T. Lieuwen, D.V. Plaks, D.-H. Shin, U.M. Mondragon, C.T. Brown, V.G. McDonell, and B.V. Kiel)

Evaluation of Column Breakpoint and Trajectory for a Plain Liquid Jet Injected into a Crossflow (2008). ILASS-Americas 2008, Orlando, FL (S.M. Thawley, U.M. Mondragon, C.T. Brown, and V.G. McDonell)

Investigation of the Effect of Injector Discharge Coefficients on Penetration of a Plain Liquid Jet into a Subsonic Crossflow (2007). ILASS-Americas, Chicago, IL (C.T. Brown, U.M. Mondragon, and V.G. McDonell)

EXAMPLE PAPERs, count

Test Bed for Characterization of Liquid Jet Injection Phenomenon at Augmentor Conditions (2006). 42nd Joint Propulsion Conference, Sacramento, CA (C.T. Brown, V.G. McDonell, and B.V. Kiel)

Near Field Behavior of a Liquid Jet in a Crossflow (2006). ILASS-Americas, Toronto, Canada (C.T. Brown and V.G. McDonell)

Characteristics of High Capacity Cone Sprays Injected into a Crossflow (2004). ILASS Americas, Arlington, VA (C.T. Brown, V.G. McDonell, and S. Sherikar).

Accounting for Laser Extinction, Signal Attenuation, and Secondary Emission While Performing Optical Paternation in a Single Plane (2002). ILASS Americas, Madison, WI (C.T. Brown, V.G. McDonell, D.G. Talley).

KEY PERSONNEL

Christopher Brown, Vice President and Manager of Research

Christopher has been with ERC for more than 20 years and is a co-owner. He has a M.S. in Mechanical Engineering from U.C. Irvine .

Vincent McDonell, President and Senior Scientist

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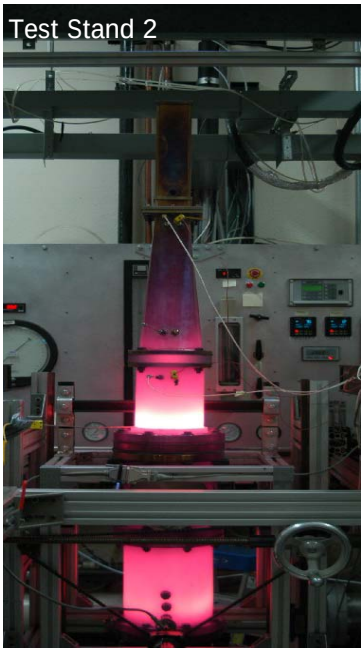
Qing Wang, Research Engineer



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