



Challenges to Laser-Based Imaging Techniques in Gas Turbine Combustor Systems for Aerospace Applications

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CHALLENGES TO LASER-BASED IMAGING TECHNIQUES IN GAS TURBINE COMBUSTOR SYSTEMS FOR AEROSPACE APPLICATIONS

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Abstract

Increasingly severe constraints on emissions, noise and fuel efficiency must be met by the next generation of commercial aircraft powerplants. At NASA Lewis Research Center (LeRC) a cooperative research effort with industry is underway to design and test combustors that will meet these requirements. To accomplish these tasks, it is necessary to gain both a detailed understanding of the combustion processes and a precise knowledge of combustor and combustor subcomponent performance at close to actual conditions. To that end, researchers at LeRC are engaged in a comprehensive diagnostic investigation of high pressure reacting flowfields that duplicate conditions expected within the actual engine combustors. Unique, optically accessible flametubes and sector rig combustors, designed especially for these tests, afford the opportunity to probe these flowfields with the most advanced, laser-based optical diagnostic techniques. However, these same techniques, tested and proven on comparatively simple bench-top gaseous flame burners, encounter numerous restrictions and challenges when applied in these facilities. These include high pressures and temperatures, large flow rates, liquid fuels, remote testing, and carbon or other material deposits on combustor windows. Results are shown that document the success and versatility of these nonintrusive optical diagnostics despite the challenges to their implementation in realistic systems.

Introduction

The next generation of aircraft powerplants will operate at conditions resulting in much higher overall

combustor inlet temperatures and pressures compared with current designs.¹ A thorough understanding of combustion phenomena and combustor subcomponent performance at actual operating conditions is critical to the successful design and construction of these powerplants. Advances in non-intrusive optical diagnostic methods and test rig designs have now made it possible to acquire two-dimensional optical data from within combustors and flame tubes which closely simulate actual engine conditions. Performing experiments of this type, however, requires circumventing or otherwise overcoming inherent problems not typical of bench-top experiments. These problems, both logistical and technical, involve not only the diagnostic techniques, laser beam delivery, and data acquisition, but the test rigs themselves. Frequent combustor configuration changes place an additional burden on the diagnostic techniques requiring a robust design and the ability to adapt to multiple test rigs and frequent component modifications. The techniques must also accommodate other standard, less flexible measurement techniques such as gas sampling by probe extraction. Foremost, these techniques must be able to successfully translate from the bench-top to the powerplant; in other words, they must be capable of remote operation and of performing dependably in a frequently hostile environment.

Many mature optical diagnostic techniques have been used successfully on bench-top or laboratory scale setups and have had a significant impact on combustion studies.²⁻⁴ Raman techniques, such as coherent anti-Stokes Raman spectroscopy (CARS), have been used for years to study combustion phenomenon and to elucidate information concerning species and temperature.⁵ However, the point-wise and alignment-critical nature of CARS places severe limitations upon its application in an environment where there is a high degree of vibration, large temperature fluctuations, and the test cell is inaccessible during operation. Only recently have advances in the development of spatially resolved Raman spectroscopy been applied to

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combusting flowfields,⁶ although it has yet to be demonstrated in an actual aero-combustor. Similarly, degenerate four-wave mixing⁷ (DFWM) and transient grating spectroscopy⁸ (TGS) have shown great promise as diagnostic tools for high pressure combusting flowfields. However, with problems similar to those experienced by the CARS method, these too have yet to be successfully used in an actual combustor environment.

Laser-induced fluorescence (LIF), planar laser-induced fluorescence (PLIF), and recently, analog predissociative techniques have been used successfully to examine a wide range of combustion processes. The two-dimensional nature of PLIF has made it the more promising and useful of the two for aerospace gas turbine combustor applications. Additionally, its multi-species selectivity, flow field imaging capabilities, and potential quantitative nature make it a favorable candidate for flame studies.

PLIF has been used previously to probe laboratory scale low pressure and atmospheric pressure gaseous flames for species concentration and distribution,^{9, 10} velocity¹¹, and temperature¹² measurement. Shock tube studies by PLIF methods¹³ have also enjoyed significant success including temperature and species measurement. Recently, laboratory scale high pressure gaseous flames near 1.0 - 4.0 MPa,^{14, 15} and spray flames approaching 1.0 MPa¹⁶ have been successfully examined via PLIF imaging. PLIF Measurements made using optically accessible ground based power systems¹⁷, diesel¹⁸ and spark ignition¹⁹ (SI) engines have been critical to understanding the combustion processes in these systems. Recent two-dimensional fluorescence imaging measurements which simulate proposed gas turbine concepts but at atmospheric pressures have also been successfully performed²⁰.

While these investigations have produced significant results and have added greatly to our understanding of combustion processes, these experiments have only simulated certain aspects of the combustor and its operating conditions. What was needed was a means to nonintrusively examine the combusting flowfield, and to observe the performance of combustor subcomponents, such as the fuel injector and swirlers, operating at anticipated conditions of pressure and temperature, using jet fuels. The test rigs necessary to allow this type of testing present many challenges to successful application of optical diagnostics. Conditions approaching 6.1 - 10.1 MPa in pressure, 2255 K in temperature, and mass flows approaching 17 kg/s are under consideration for future tests. Furthermore, the very nature of this type of testing requires remote operation of all aspects of

the diagnostics procedures. This includes laser operation, data/image acquisition, and test rig operation. Optical accessibility to the combustion and fuel injection zones is also required, necessitating the application of complex window cooling technologies to prevent degradation and potential melting of window materials.

At NASA LeRC, efforts have been underway to adapt and implement existing nonintrusive optical diagnostics methods to examine the realistic, reacting flow fields generated by advanced fuel injector designs. Two optically accessible flametubes capable of operation up to 2.0 MPa in pressure and 2033 K in temperature with flow rates up to 3.68 kg/s are presently in use. A third, much larger housing designed for 6.7 MPa operation, has been delivered and installed but has not yet undergone optical testing. For these tests, optical accessibility is the key. Window materials must be fully capable of withstanding the above conditions while remaining optically clear for the acquisition of meaningful data and images.

Due to testing costs and strict scheduling constraints which precluded more time consuming individual testing, each diagnostic had to be integrated with the test rig in such a way as to allow simultaneous data acquisition. The optically accessible rigs at LeRC were designed to allow implementation of a large number of optical diagnostic methods. PLIF and Planar Mie scattering were chosen as the primary methods since adequate laser energy exists to make an acceptable laser sheet and the same UV excitation wavelength can be used for both. Furthermore, these techniques, in addition to having high temporal and spatial resolution and high sensitivity, allow an opportunity to examine both intermediate and stable species.

Hardware

The test facility at NASA LeRC delivers nonvitiated air to the two unique, optically accessible combustor test rigs utilized for this series of experiments and described in detail elsewhere.²¹⁻²² The first, pictured in Figure 1a, is a 21.6 cm x 21.6 cm radially-staged gas turbine combustor. This rig, called a sector rig, is designed to test larger, multi-component injector systems. The second test rig, shown in Figure 1b, measuring 7.6 cm x 7.6 cm, is a flame tube designed to test single component injectors or small, multi-component systems. Typical rig operating conditions range from inlet temperatures of 533 K - 866 K, inlet pressures of 0.55 MPa - 2.03 MPa, and mass flows of 0.16 kg/s to 0.77 kg/s for the flame tube, and 1.13 kg/s - 3.63 kg/s for the sector rig. Equivalence ratios (ϕ) range from

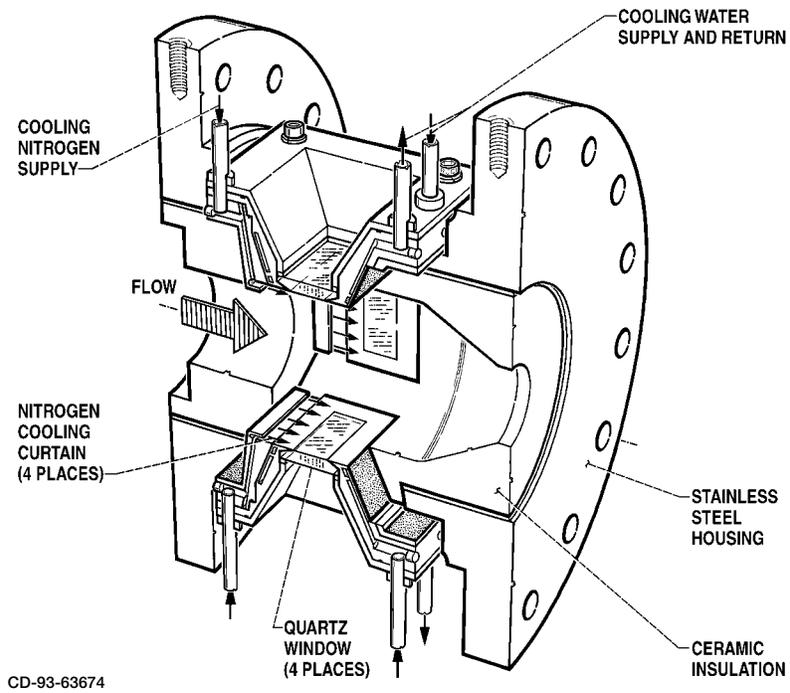


Figure 1a. Optically accessible radially-staged gas turbine sector housing.

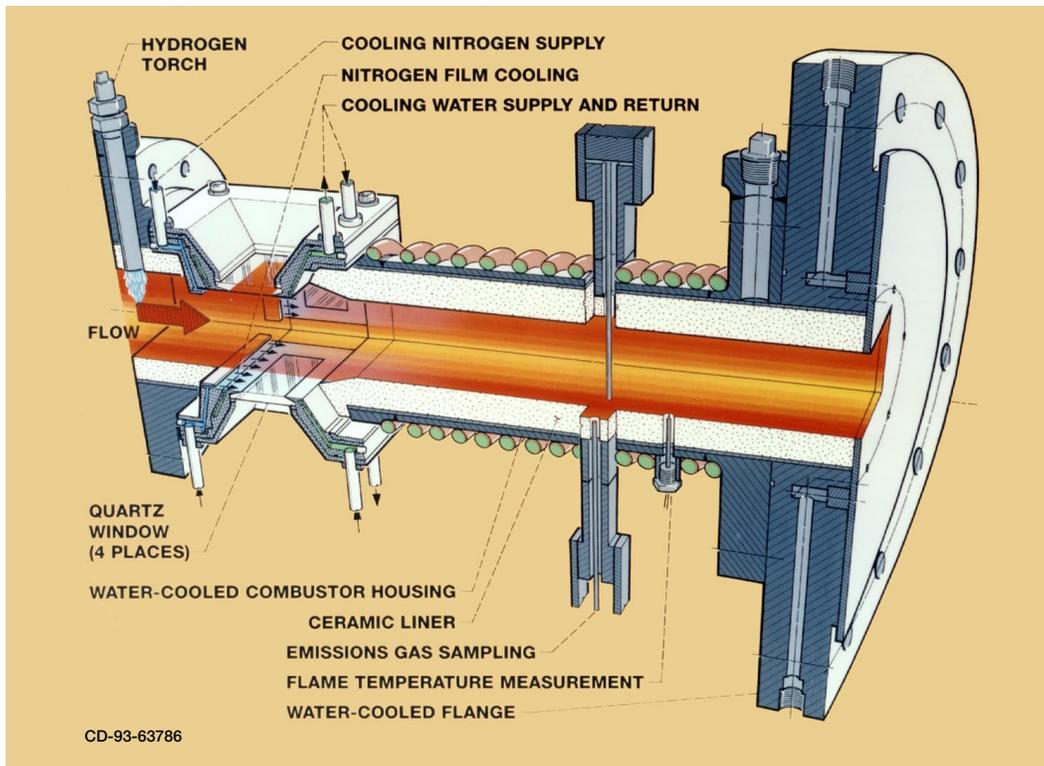


Figure 1b. Optically accessible flametube housing.

0.30 to 0.60. Initially JP-5 or JP-8 jet fuel was used for testing but Jet-A is now used for all tests.

The window housings, which are identical for each test rig, are equipped with UV grade fused silica windows measuring 38 mm axially, 51 mm radially, and 13 mm thick. To counter the heat generated in the combustor flow stream, the inner surface of the windows are cooled with a thin film of nitrogen. The nitrogen flow comprises less than 10% of the aggregate combustor mass flow and maintains a typical window inner surface temperature less than 977 K.

Window breakage has not been a major problem. Breakage, which typically occurs in the form of shear cracks, has been experienced only on the larger sector rig. Cracks have not occurred during a test run but only after the shutdown procedure has been completed and the rig is cooling down. Since breakage does not happen often and not always at the same location, it cannot be directly attributed to any one cause. However, it is assumed that the breakage occurs as a result of uneven cooling of the window mounts and the combustor thereby causing uneven stresses.

Window deposits are a recurring problem at certain test conditions. While testing specific fuel injector designs, it became necessary to periodically remove deposits that accumulated on the windows. This is accomplished by first retracting the ICCD cameras out of the way, then remotely sweeping a 50 mJ sheet of focused, 532 nm output provided by a Continuum "Surelite" Nd:YAG laser over both detector windows. In this manner, the deposits are ablated from the interior window surfaces. Cleaning the laser beam insertion window was found to be unnecessary since the continued panning of the incident 281 nm laser sheet effectively keeps this window clear.

A direct result of test rig heating is axial growth. Each rig demonstrates this characteristic to a varying degree. This growth is always in the upstream direction since the downstream segment of the rig is anchored to the test bed. Growth of up to 7-8 mm has been observed. Tracking and correcting for this growth with the incident lasers and cameras under remote control was an additional challenge during these experiments. This is achieved by scribing the combustor housing just below one of the imaging windows in millimeter increments. The output beam from a helium neon laser was then spotted at the origin of this ruling and monitored with a video camera throughout the test run. As the rig grows or shrinks with changing conditions, this beam spot is observed to drift along the scaled ruling. The camera

and laser sheet delivery system are then shifted an equal amount in the same direction, thereby maintaining the original, pre-lightoff alignment.

Various fuel injector designs have been fitted into each test rig. These injectors are positioned such that the injector exit plane projects approximately 5 mm into window viewing area, thereby providing a reference point for the resultant images and rig coordinate system. The rig coordinate system defines x as the azimuthal or horizontal direction with positive x to the right when looking upstream. Z is the axial coordinate, with $z = 0$ defined as the injector exit plane and positive z in the downstream direction. Y is the radial or vertical coordinate with positive values above the rig center line.

Optical Setup

Figure 2 presents a cutaway of the test facility and the experimental layout which is described in detail elsewhere.²³ The 10 Hz, 532 nm output from a Continuum model ND-81C, Nd:YAG laser pumps a ND 60 dye laser, the output of which is doubled by a UVX ultra-violet wavelength extension system. The resulting 281 nm output, maintained at approximately 20 mJ for the experiments described herein, is delivered through 90 mm acrylic tubes to the test cell by a series of remotely controlled high damage threshold mirrors. Since this laser provided a divergence of only 5 mrad, the laser output is allowed to freely expand over the beam path which ranges from 12 meters for the flame tube to 25 meters to the sector rig. The laser beam, prior to entering the test section, is formed into a sheet by a $f = 3000$ mm cylindrical lens. The resultant sheet size at the laser focal volume is approximately 22 mm by 0.3 mm. A second beam path, not shown in the figure, has recently been added to allow simultaneous two color experiments or the use of a second YAG laser for window cleaning operations.

Due to the distances involved, and to safety considerations demanding that the test cell be inaccessible to personnel during all test runs, positioning of the laser sheet and cameras by remote computer control is necessary. For the nearer flame tube rig, this requires controlling, effected by a Parker Hannifin Compumotor model 3000, up to four axes on the laser sheet positioning table suspended immediately above the windowed test section (see figure 2). Control of two Aerotech 3-axis positioners, each holding an ICCD camera, is accomplished via two Unidex model 11 controllers. For the more distant sector rig, a Compumotor model 4000 provides control for an additional 4 axes which are required for laser sheet delivery into that test section.

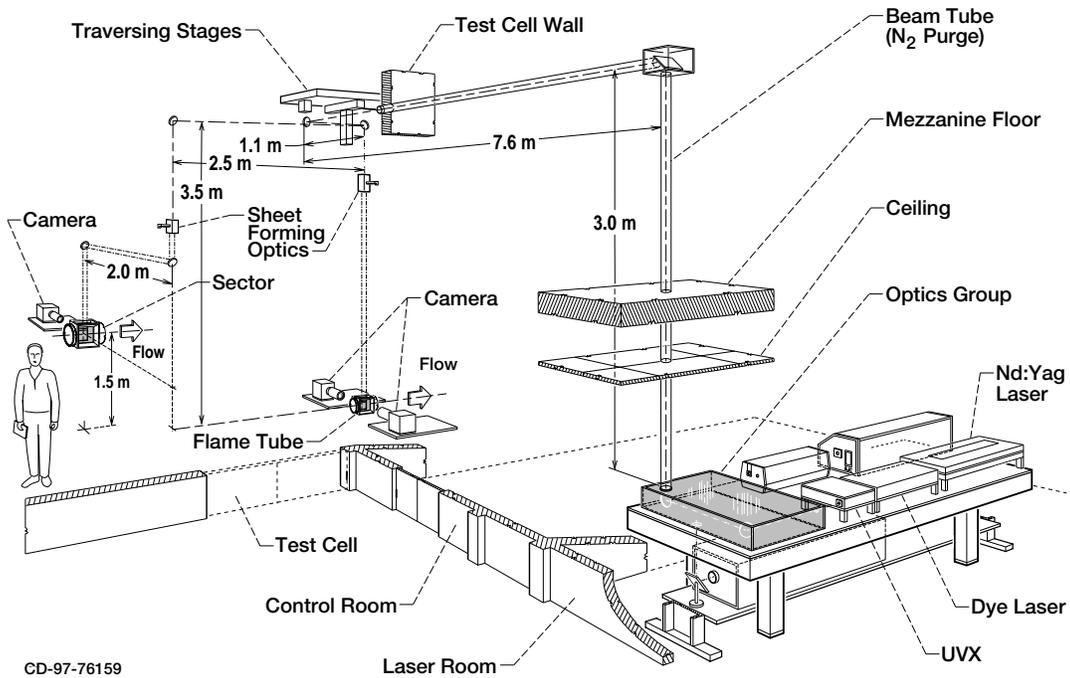


Figure 2. Optically diagnostic gas turbine test rig facility.

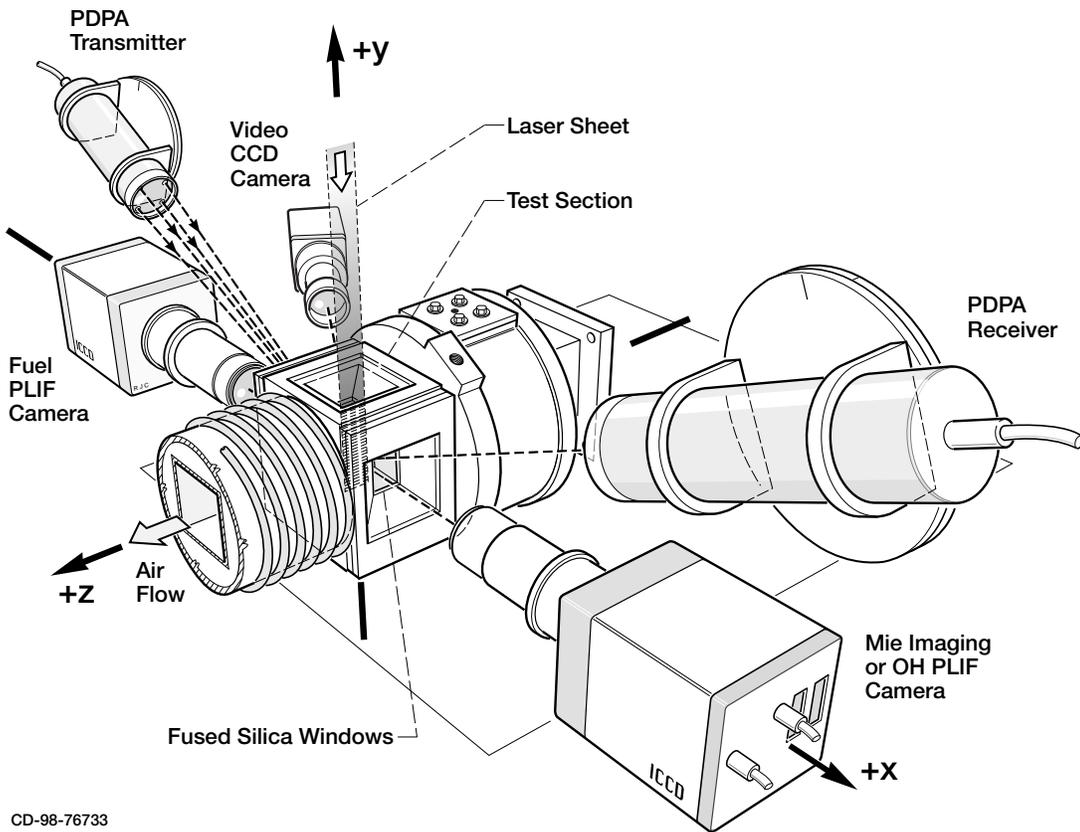


Figure 3. Optical diagnostic experimental configuration.

The complexity of this motion control system was reduced by writing a computer program to coordinate the simultaneous positioning of both the laser sheet and camera detection systems. The LabWindows/CVI software development tool from National Instruments was used to accomplish this task. The final program allows the user to select which laser beam and detector configuration is to be utilized for each test run from a possible ten combinations. The program also provides a high degree of flexibility by allowing the user to specify the type and orientation of each stage mounted in the test cell and how these stages are to be connected to the motion controllers. The program controls the distance and direction that each designated stage moves and allows the user to define an origin. The program, through keyboard command, positions the laser sheet anywhere within the insertion window with respect to the defined origin in terms of a rectangular coordinate system. The program records the user's coordinates, test conditions, as well as origin for future test runs or in case of a power failure.

Figure 3 illustrates the typical diagnostic setup used for this series of experiments. Fuel or OH PLIF and planar Mie scattering signals are collected normal to the incident laser sheet by gated and intensified 16 bit ICCD cameras from Princeton Instruments, each with a 384 x 576 pixel array. The intensifiers, adjusted to provide a 75 ns gate, are synchronously triggered with the laser pulse. Each camera uses a Nikon 105 mm f/4.5 UV Nikor lens focused on a plane coincident with the incident laser sheet. The PLIF camera is equipped with both a Schott WG-305 filter and a narrow band interference filter centered at 315 nm with a FWHM of 10.6 nm yielding a transmission efficiency of 16%. The Mie scattering camera is equipped with a narrow band interference filter centered at 283 nm with a FWHM of 2 nm and a transmission efficiency of 6%. Both single shots and on chip-averaging of successive images may be obtained using this detection system.

Figure 3 also shows the placement of a two-component Aerometrics Phase/Doppler particle analyzer (PDPA). This instrument is used to measure the light refractively scattered by fuel droplets (30° forward scatter). The PDPA system is mounted onto a large 3-axis Accudex positioner from Aerotech. The two-line 488 nm and 514 nm output is supplied by an argon ion laser from Coherent and delivered by fiber optic to the transmitter unit. The transmitter and receiver are aligned 15° from the horizontal plane to maximize the number of measurement sites within the test section. The focal lengths for both receiving and transmitting optics are 500 mm. The transmitter beam separations are 40 mm. Droplet size, velocity and number density

distributions may be obtained by shifting the data acquisition site along the propagation direction of the transmitter. Since the PDPA device makes point measurements within a small region, the probe volume must be traversed under remote control throughout the accessible flowfield to characterize the spray.

Originally each of these diagnostics were aligned separately, which led to difficulties in spatially correlating the data acquired from each method. Subsequently a single, universal alignment tool is used for each method. This constitutes a flat plate measuring 19 mm x 96 mm which is scribed on both sides with a metric ruling, and arrows indicating both the flow direction and the laser sheet path. The plate is inserted through the lower window location which was fitted with a spark plug for these experiments, and extends through the flow path a measured distance from the fuel injector exit plane. For reference, the center line of the combustor is also scribed into the plate. Holes measuring 3 mm in diameter are located along this center line for the purposes of aligning the PDPA instrument. Following alignment, the plate is withdrawn and the spark plug replaced.

Image Acquisition and Processing

Image collection is accomplished using Princeton Instrument's Winview software. The collected images are transferred to an SGI Indigo workstation for processing. Processing and image analysis on the SGI is accomplished using PV-WAVE from Visual Numerics, Inc. The gray scale images from the cameras are converted for display using a pseudocolor scale consisting of 25 color plus black (low intensity) and white (high intensity) where each color represents a span of 10 counts in a linear span of 255. The colors in the pseudocolor scale have been chosen to make it easier to see details in the less intense portions of the images. Image processing includes removal of noise spikes, background subtraction, and, in some cases, correction for laser sheet energy distribution.

We have also developed an additional, unique image processing capability that allows us to obtain views looking upstream into the fuel injectors. These views, called end-on or "cross flow" views, were developed to examine the fuel spray pattern or patterning of each fuel injector studied. In this process, forty-one side-view images are acquired at 1 mm increments across the flow field at each test condition. A computer program then configures these 41 images into an image stack. The program interpolates the region between each of the 41 individual images thereby filling in the gaps resulting in a smoothed 3-D image block. The image block

can then be sliced in any desired orientation. Figure 4 illustrates this process for a lean direct injector design installed in the sector rig. In this figure the flow exits the page to the right. The left side of the image shows, for the sake of simplicity, only a few selected side-view fuel fluorescence images in the z - y plane. The right side of the figure shows a few of the resultant cross flow views obtained in the manner described. The images in an image stack are scaled together so that the highest signal level represents the 99th percentile. The images are displayed in this manner in order to accentuate the lower light level structures that would otherwise be lost in the glare of the higher intensity features.

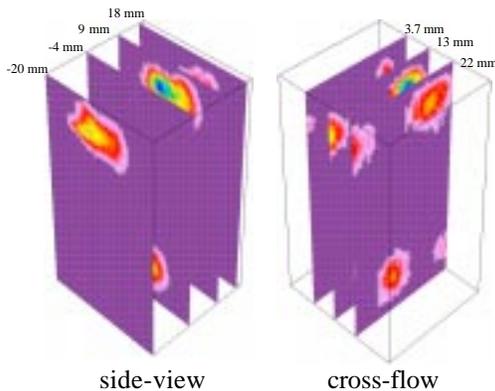


Figure 4. Sequential image stacking of side-view (z - y plane) fuel PLIF images acquired within the sector combustor yielding cross-flow (x - y) views. Test conditions: $\lambda_{exc} = 281.5$ nm, $T_{inlet} = 800$ K, $P_{inlet} = 1.46$ MPa, $\phi_{total} = 0.42$

Because the injectors are positioned with their injector exit planes projecting approximately 5 mm into the window viewing area, a large amount of incident laser light scatter from the injector face is encountered. This scatter is intense enough to allow passage of a small but significant portion through the selective filters of the detectors. This scatter is eliminated by placing an external beam block over the top of the laser sheet insertion window effectively blocking any light from hitting the face of the fuel injector.

Since direct measurement of the laser sheet intensity in the z direction is not practical, another technique has been developed to correct for the fall off in laser sheet power at the upstream and downstream edges. We assume that the average intensity in the cross-flow images over an area enclosing the jet should be constant as we move downstream over the relatively short axial range we can see. This is a reasonable assumption because the viewable distance is relatively short (approximately 40 mm). This assumption leads to the conclusion that any variation

in this average is due to laser sheet energy changes. In our recent work, we have chosen to correct the xy -images by a factor which causes the within-jet average to be a constant over a range of z values.

The left-hand image in figure 5 shows a typical side view, fuel fluorescence image obtained on the flame tube rig for a two-circuit fuel injector concept. The test conditions were: $P_{inlet} = 1.6$ MPa, $T_{inlet} = 680$ K, $\phi_{total} = 0.31$, and $\lambda_{exc} = 281.5$ nm. This image illustrates one of the challenges encountered in these experiments and brings out one of the many benefits. The problem illustrated here is the obscuration of the fluorescence signal by the buildup of soot on the detector windows. This deposition is seen here as a dark mass in the upstream (left) center position, just downstream of the injector location. The benefit illustrated is the ability to illuminate the detailed flowfield structure. This image, taken at the center line of the injector clearly shows the spray from both inner and outer fuel circuits. This imaging data has been used to calculate the full fuel spray angle at condition and subsequently found to agree quite well with the theoretical values at most test points. The soot buildup at low power condition, while problematic, was easily removed by the ablation method described earlier.

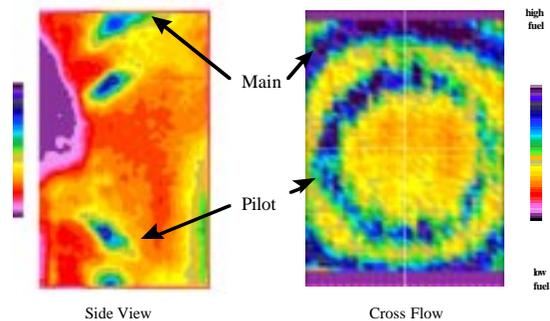


Figure 5. Comparison of side-view and cross-flow views acquired for a two-circuit injector installed in the flametube. Test conditions: $\lambda_{exc} = 281.5$ nm, $T_{inlet} = 682$ K, $P_{inlet} = 1.6$ MPa, $\phi_{total} = 0.304$

The right-hand image in figure 5 presents a cross flow image derived using the above described technique for a position 14 mm downstream from the fuel injector exit plane. The advantages of the cross flow display are quite obvious. Actual flow structure and fuel spray symmetry are clearly illuminated. In the fuel PLIF image, two concentric rings of fuel, either vapor and/or liquid, are seen to be coming out of the page and expanding away from the two-circuit injector with a high degree of uniformity.

Figure 6 shows the fuel PLIF cross flow image shown in figure 5 (right) compared with a planar Mie scattering cross flow image acquired simultaneously

at the same axial position. The fuel PLIF image again shows two concentric rings of fuel from the pair of injectors. In contrast, the planar Mie image shows only a single ring emanating from the inner fuel circuit, the outer ring is absent. The reason for this is due to the outer fuel circuit's apparent greater efficiency at vaporizing the fuel spray, which explains the lack of droplet scattering centers in this region. This comparison offers a means by which to address critical fuel vaporization issues which have been examined by other methods^{24,25} but with limited success.

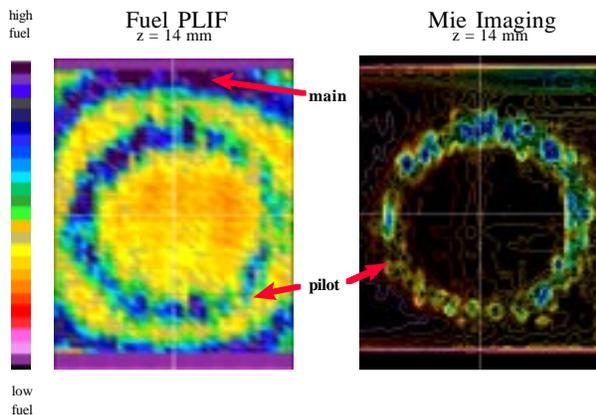


Figure 6. Comparison of fuel PLIF and Planar Mie scattering cross-flow images acquired at the same axial position for a two-circuit injector installed in the flametube. Test conditions: $\lambda_{exc} = 281.5 \text{ nm}$, $T_{inlet} = 682 \text{ K}$, $P_{inlet} = 1.6 \text{ MPa}$, $\phi_{total} = 0.304$

Another issue brought forward by considering figure 6 is the question of possible extinction effects. The right side in the PLIF image and the left side of the planar Mie scattering image, each being the side opposite their respective cameras, appear to show some decrease in signal intensity. This affect may be attributed to the extinction of the incident light sheet or to the extinction of the induced emission or scattering by the intervening flowfield. Since this phenomenon is not ubiquitous, but only appears thus far in test runs involving high pressures and large mass flows, we have as yet not investigated the extinction question thoroughly. Obviously, with tests scheduled to begin using the high pressure 6.08 MPa rig where extinction effects may be more severe, the investigation of these effects should be accomplished.

Tests were performed in which PLIF, Planar Mie scattering, and PDPA were each attempted. These tests were originally performed simultaneously with good results. However, due to the close tolerances in positioning the three different diagnostics (see figure 3), a few instances of unwelcome collisions between the various optical components occurred. In these collisions, optical alignment was invariably lost for

one or more of the detectors requiring shutdown of the rig in order to re-enter the test cell to realign the systems. Subsequently, the PDPA diagnostics were run only after moving the two ICCD cameras a safe distance downstream following their data acquisition run.

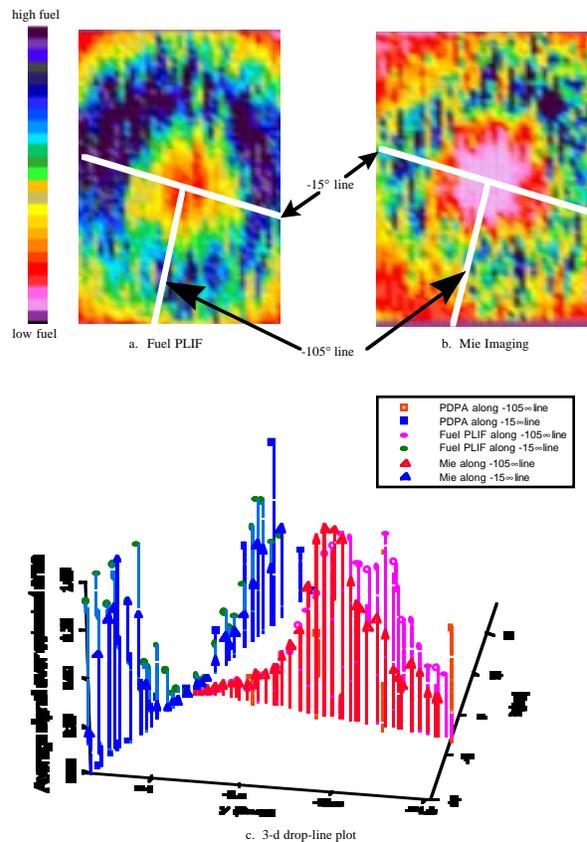


Figure 7. Comparison of fuel volume distribution as measured by PLIF, Mie Scattering and PDPA acquired at the same axial location. Lines in the images indicate the path along which PDPA measurements were made. Conditions: $\lambda_{exc} = 281.5 \text{ nm}$, $T_{inlet} = 616 \text{ K}$, $P_{inlet} = 558 \text{ kPa}$, $\phi_{total} = 0.445$

Figure 7 shows a comparison of the data acquired at the same axial location, 12.7 mm from the fuel injector exit plane, for each of the three techniques; PDPA, PLIF and planar Mie. For this series of experiments the flametube was equipped with a two-circuit fuel injector with only the pilot operating under the following flow conditions: $T_{inlet} = 616 \text{ K}$, $P_{inlet} = 558 \text{ kPa}$, $\phi = 0.445$, $\lambda_{exc} = 281.5 \text{ nm}$. The white lines labeled -105° and -15° on the PLIF and Mie images denote the path along which PDPA mass flux data was acquired. The graph at the bottom of the figure plots both the pixel intensity along the -105° (open symbols) and -15° (solid symbols) lines from the PLIF and Mie images and the mass flux data

acquired from PDPA measurements. From the plot, close agreement between the three different techniques is seen to exist along the -105° line. Along the -15° line, the agreement holds only for the data along the positive x axis. Along the minus x axis, the PDPA data falls off sharply. There are two possible causes for this observation; first may be the obscuration of the PDPA receiver due to the severe beam insertion angle involved. The second potential cause may be that of extinction of the scattered light from the far side of the flametube by the intervening flow. This data falloff has been observed prior to this on high pressure vaporizing sprays²⁶. The approximate 1-2 mm shift between the maxima for the three techniques on each of the plotted -105° and -15° lines is a vestige of using separate alignment methods. This has subsequently been eliminated by using the same alignment tool previously described for each of the diagnostics.

Conclusions and Future Considerations

We have demonstrated at NASA Lewis that various relatively mature laser diagnostic techniques can successfully be applied simultaneously to the realistic flowfields of high pressure and temperature aero-combustor test rigs. Images have been obtained through PLIF and planar Mie scattering measurements providing heretofore never before seen views of the combustion process and fuel injector operation at actual conditions. Our methods are evolving with experience and changes are continuously being made to improve or adapt diagnostic techniques to these large scale rigs. For example a remotely controlled motorized filter wheel is planned to be used on the ICCD cameras for all future imaging. The filter wheel, which holds up to five, two-inch diameter filters, will effectively increase our diagnostic capabilities by increasing the number of species and other flow parameters that can be examined in a single test run. Additionally, it will allow exact comparison between PLIF and Planar Mie scattering results thereby eliminating the need for corrections such as magnification, and pixel response variations, required when two different cameras are used.

Another example of continuous improvement is the advent of a new 1.0 nm FWHM narrowband interference filter making it possible to record OH PLIF by eliminating a majority of the interference of fluorescence signals in the region of the fuel injector exit plane. Until recently fuel fluorescence was examined rather than OH fluorescence because this interference precluded good OH PLIF measurements.

Further planned improvements include automating the process by which cross flow views are generated.

This will speed up one of the most time consuming aspects of the analysis. Additionally, topographical and three-dimensional plotting of image pixel intensity, which provides an easier means to examine the flow path, are also being automated.

The means to make corrections for laser sheet inhomogeneities such as those recently reported²⁷ are also being investigated. However, difficulties due to mandatory remote operation, and the fact that both the laser sheet and the resultant planar fluorescence and scattering must both pass through different windows of questionable transparency makes this a daunting task.

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13. ABSTRACT (<i>Maximum 200 words</i>) Increasingly severe constraints on emissions, noise and fuel efficiency must be met by the next generation of commercial aircraft powerplants. At NASA Lewis Research Center (LeRC) a cooperative research effort with industry is underway to design and test combustors that will meet these requirements. To accomplish these tasks, it is necessary to gain both a detailed understanding of the combustion processes and a precise knowledge of combustor and combustor subcomponent performance at close to actual conditions. To that end, researchers at LeRC are engaged in a comprehensive diagnostic investigation of high pressure reacting flowfields that duplicate conditions expected within the actual engine combustors. Unique, optically accessible flametubes and sector rig combustors, designed especially for these tests, afford the opportunity to probe these flowfields with the most advanced, laser-based optical diagnostic techniques. However, these same techniques, tested and proven on comparatively simple bench-top gaseous flame burners, encounter numerous restrictions and challenges when applied in these facilities. These include high pressures and temperatures, large flow rates, liquid fuels, remote testing, and carbon or other material deposits on combustor windows. Results are shown that document the success and versatility of these nonintrusive optical diagnostics despite the challenges to their implementation in realistic systems.				
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