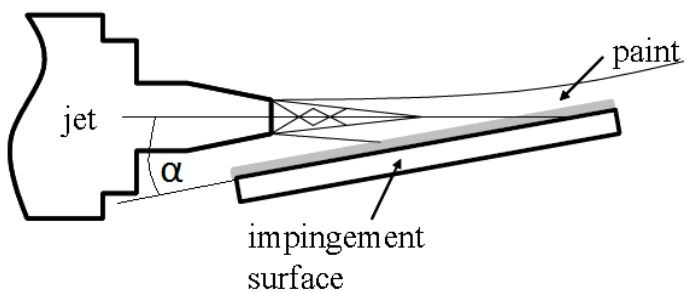
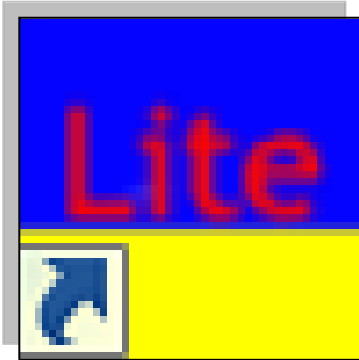


2009

Lab 1: Introduction to OMS Lite



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Lab 1: Introduction to OMS Lite

Introduction: This example is designed to introduce the most basic concepts of Pressure-Sensitive Paint (PSP) data reduction. The example files are located in the [Lab 1\Lab_1 data files] directory. First, we will introduce the experimental setup and data acquisition. Next, the data reduction procedure will be explained and the basic tools available in OMS Lite will be identified and their function explained.

Experimental Setup: A schematic of the experimental setup for the inclined impinging jet is shown in Figure 1. The physical parameters of interest are the geometric impingement distance (H) the impingement angle (α), and jet pressure ratio (Φ). The distance along the major axis of the jet from the center of the jet nozzle to the geometric impingement point (GIP) is the impingement distance (H). The GIP is defined as the intersection of the jet axis with the impingement surface. The impingement distance (H) is set at four jet diameters for this experiment. The impingement angle (α) is defined as the angle between the major axis of the jet and the surface of the impingement plate. The impingement angle (α) is set to fifteen degrees. Finally, the pressure ratio (Φ) is defined as the ratio of the jet plenum pressure to the ambient pressure (P_o/P_∞). The pressure ratio (Φ) is 3.03, this results in a sonic

under-expanded jet for the converging nozzle that we are using. Upon exit from the nozzle, the flow expands and accelerates to supersonic speeds. The resulting shocks and expansion fans will interact with the impingement surface and create a complex pressure distribution that will be investigated using the PSP.

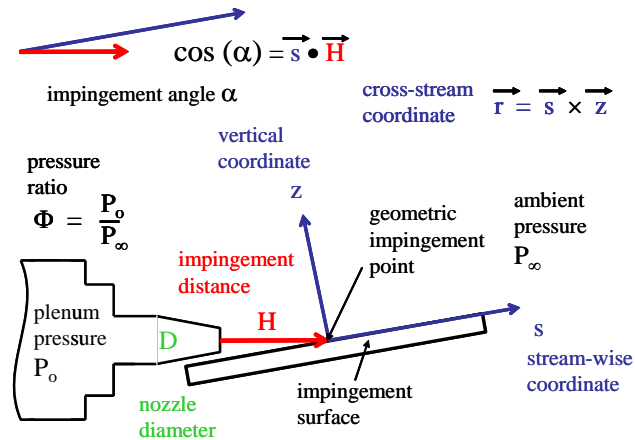


Figure 1: Geometry and nomenclature for the inclined impinging

Data Acquisition Procedure: A schematic of the PSP experimental setup is shown in Figure 3. The PSP (UF470) is applied to the surface of the impingement plate using a Badger Air Brush. The paint is excited using light from several LED arrays (ISSI LM2, 470 nm). The luminescent intensity from the paint on the model surface is optically filtered

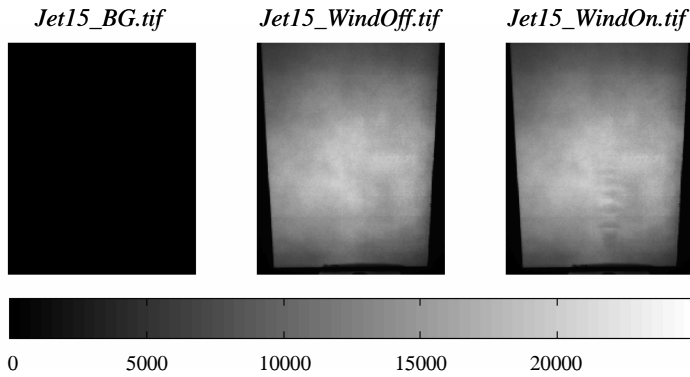


Figure 2: Raw images for impinging jet

determine the pressure distribution. Three images are taken during the data acquisition procedure (seen in Figure 2). The first image is a background image (*Jet15_BG.tif*). This is taken to compensate for any ambient light present. The background image is just that, the background or backdrop of the camera's view during data acquisition. The background image is subtracted from the wind-off and wind-on images. The next image taken is the wind-off image (*Jet15_WindOff.tif*). This image is taken with the test object (flat plate) in the picture but with the jet off. The final image taken is the wind-on image (*Jet15_WindOn.tif*). This image is taken of the test object with the jet turned on.

Data Reduction: The data reduction procedure for PSP involves taking the ratio of the wind-off / wind-on images and converting this image to pressure using a calibration that relates this ratio to pressure. For practical implementation of PSP, several other image processing steps are often required. These steps can include compensating for the background lighting, image alignment, filtering, in-situ calibration, temperature correction, and resection. We will first process the data using a simple ratio and introduce the Single Channel Basic GUI of OMS-Lite and the image display tools. Reducing the data into an image of pressure involves taking the ratio of the wind-off / wind-on images and then calibrating the image to relate the ratio to pressure.

using a 610 nm long-pass filter (Andover OG610) to eliminate the excitation light. Images of the painted impingement surface are captured using a thermo-electrically cooled CCD camera. These images are stored digitally and will be processed using OMS-Lite to

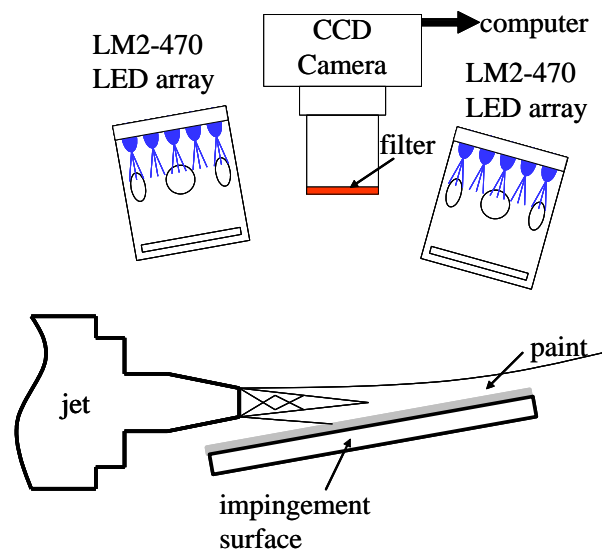



Figure 3: Impinging jet experimental setup


Creating a new project:

Open up the program OMS Lite

by double-clicking the  icon on the desktop.

The first step is to select or create a project file. The project file, stored in the *.xml* format, contains the source image file names and data processing parameters selected by the user for the

current data processing exercise. To create a new

project file, select New from the File menu or select the  (New Project) button from the

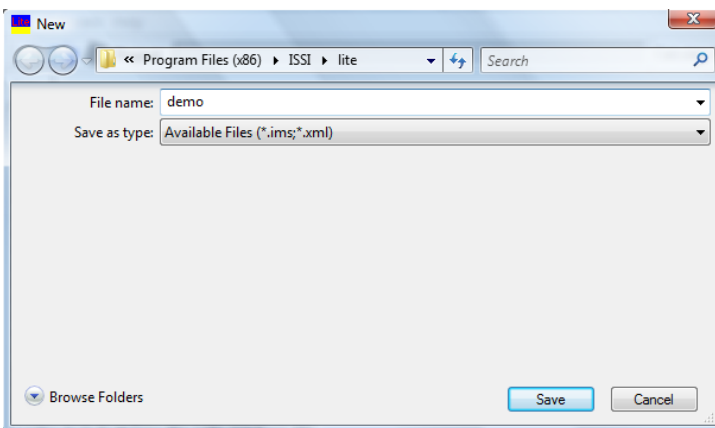


Figure 5: New project window

Select the PSP Single Channel. In the new project window (Figure 5), navigate to the [Lab 1\Lab_1 data files] directory, this directory should contain the *Jet15_***.tif* images. Type "Jet.xml" in the dialog window, then hit the Save button to create the project file. Once the new file has been saved the OMS Lite GUI window (Figure 6) will appear. This window will allow the user to import the wind-on, wind-off, and background images into OMS Lite.

The layout of the GUI is similar to a flow chart for PSP data reduction. Logical blocks for selecting, viewing, and performing preliminary processing of wind-off and wind-on images

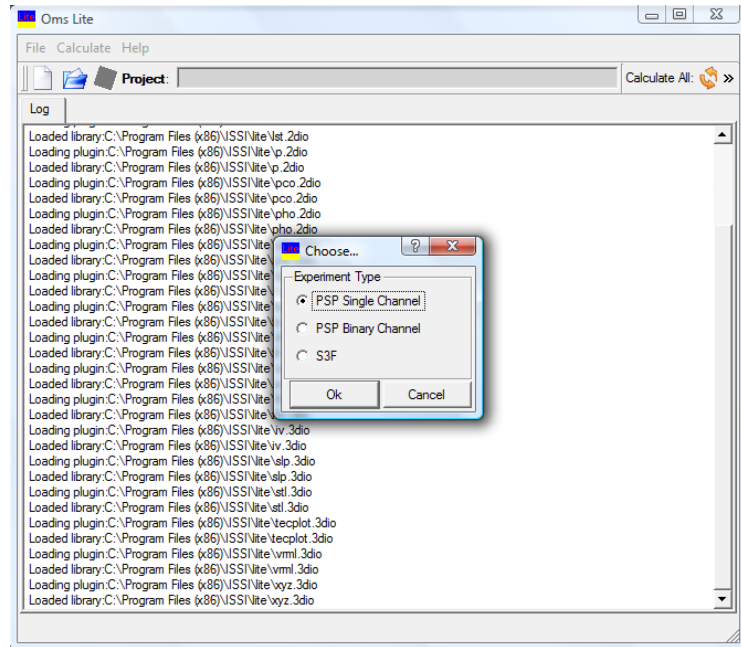



Figure 4: Select Experiment type

toolbar. To load an Existing Project select Open from the File menu or select the  button from the toolbar. We will create a new project and process the previously described inclined impinging jet data. A window (Figure 4) will open up asking the user to choose which experiment type they will run.

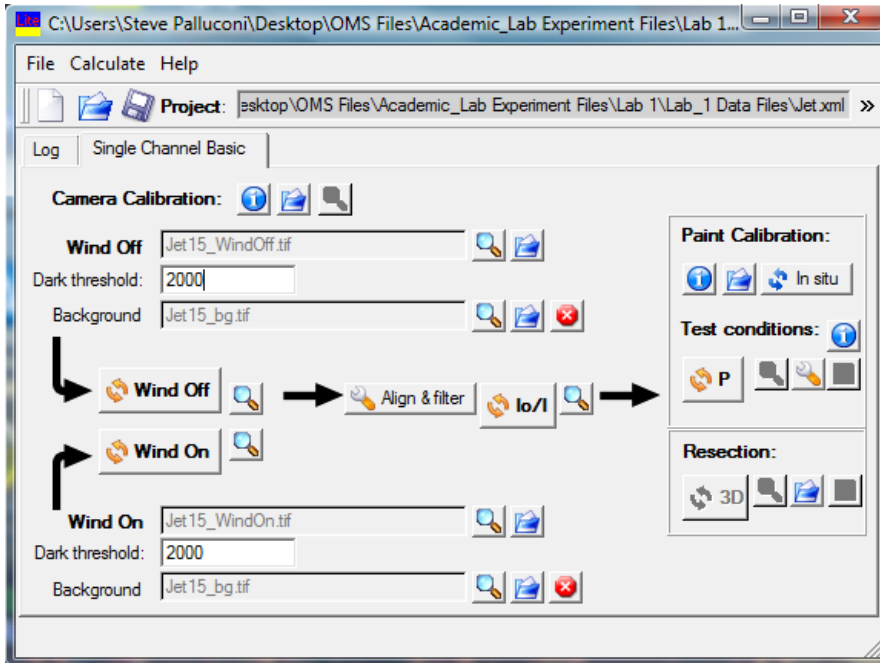


Figure 6: GUI for the Single Channel tab of OMS Lite

are located on the left side of the GUI. These are followed by a block for alignment of the images, computing the ratio, and filtering the ratio image. Next is a block for converting the ratio image to pressure. Finally, there is a block for performing a resection of the two-dimensional image onto a three dimensional geometry.

Select Source Images: Next we will select the wind-off and wind-on images. Start the file select dialog for the wind-off image by selecting the (File) button to the right of the Wind Off field. The file select dialog should default into the directory containing the project

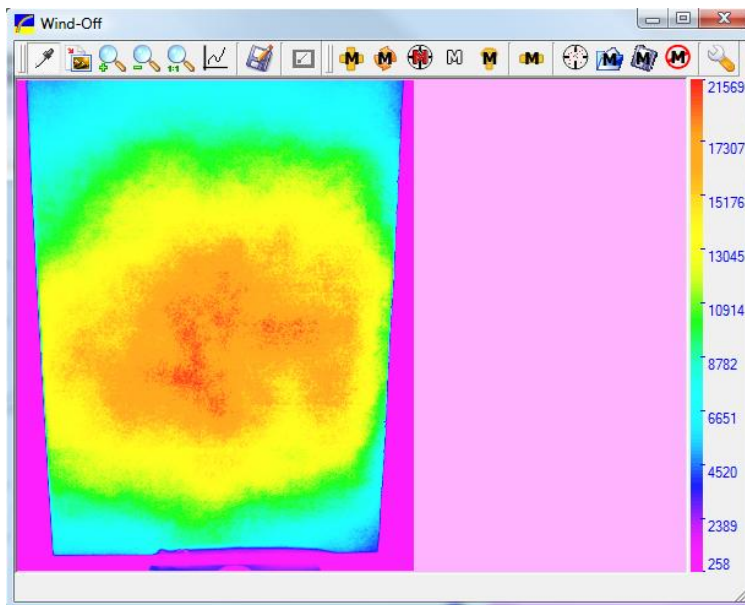









Figure 7: Wind-off uncorrected image

file. Select the image named "Jet15_WindOff.tif" as the wind-off image. This image name should now appear in the Wind Off field. To select the wind-on image, use the (File) button the right of the Wind On field. The file select dialog should again default into the directory with the project file. Select the image named Jet15_WindOn.tif" as

the wind-on image. This image name should now appear in the Wind On field.

Display and Interrogate an Image Using the Viewer: Select the  (View) button to the right of the Wind Off field to display and inspect the wind-off image. A window similar to Figure 7 should appear named Wind Off indicating that this is the wind-off image. Note that the toolbar at the top of image window includes tools for saving () , zooming () , and probing () the image as well as a set of tools for working with markers (Add, Move, Delete, Toggle). The subject of markers, which are used for image alignment, will be covered in a later example.

Select the Probe button to inspect the signal level of the image at a selected location. Determine the signal level of the image at a given location by moving the mouse to that location and left clicking the mouse. The location and signal level will appear at the bottom of the Wind Off window (Figure 7). The signal level, for example, at $x = 140, y = 150$ is close to 20,000 counts. A region of interest of the image may be magnified by selecting the  (Zoom in/out) tool and left clicking at the center of this region. The region may be demagnified by a right click of the mouse. The  (Modify) button may be used to change the upper and lower limits of the display as well as select the color map for the current display.

Selecting the  (Modify) button causes the Advanced Image Fashion (Figure 8) panel to appear. The Paint max is the signal level associated with the top of the color map and the Paint min is the signal level associated with the bottom of the color map. By default, these values are set to the maximum (Paint max) and minimum (Paint min) signal level of the displayed image. Occasionally, it is desirable to enhance features within a specified range. This is accomplished by manually entering the desired Paint

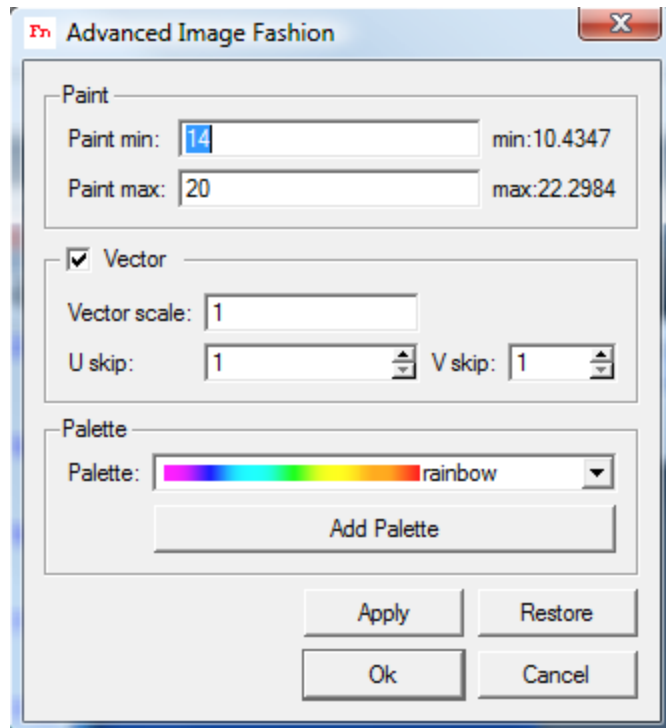






Figure 8: Advanced Image Fashion Window




max and Paint min into the appropriate fields and selecting the Apply button. To restore the default settings (image min and max), select the 'Restore' button.

The Advanced Image Fashion panel may also be used to change the color map that is used to display the image. There are several color maps available to the user including several variations of red-green-blue (red_green_blue, rainbow) and gray scale maps (the_gray). The color map control is a drop-down menu in the Palette on the Advanced Image Fashion panel. It is occasionally desirable to change the color map to visually enhance certain features in the image. It is also noted that the displayed image may be exported at any time by selecting the  (Export) button at the top left of the Wind Off window. Finally, the image window may be closed upon completion of image inspection by selecting the  (Close) button at the upper right corner of the image.

Background and Dark Level: Generally, a background image and a dark level are selected in the Wind Off and Wind On blocks. Even under the best experimental conditions, some ambient light is present. PSP is based on the measurement of the intensity from the painted surface. The ambient light is a source of noise in a PSP measurement. The background image is used to correct the wind-on and wind-off images for the effects of the ambient light. This is accomplished by taking an image of the painted surface with the illumination source turned off. This image, known as the background image, is subtracted from the wind-on and wind-off images. Generally the ambient lighting is constant and a single background image is sufficient for both the wind-off and wind-on conditions however, individual background images may be used if necessary. The background image is selected using the  (File) button to the right of the Background field in the Wind Off and Wind On blocks. Select the file "Jet15_bg.tif" for both the Wind On and Wind Off blocks. Again, each image may be inspected using the image viewer by selecting the  (View) button.

The dark level field has reference to a minimum signal level that yields meaningful data. Again, PSP measurements are based on the measurement of the luminescent signal intensity from the painted surface. It is not uncommon for some regions of the surface to produce substantially smaller signals than the bulk of the painted surface. This may be due to poor illumination, physical damage to the paint (chipping), or the presence of markers on the surface that are used for image alignment. If the signal level is too low in a given region, the signal to noise ratio is not sufficient to yield meaningful data. These regions should be

excluded from the remainder of the data processing as they will yield inaccurate data. This is accomplished using the dark level field. Regions of the image that have a signal level below the dark level are set inactive for the remainder of the data processing. For this example, the dark level is set to 2000 for both wind-on and wind-off images.

Process Source Images: The source images, background image, and dark level are processed to produce a corrected wind-off and wind-on image. First, the background image is subtracted from the source (wind-off or wind-on) image. Next, the resulting image is scanned and any pixel with a signal below the dark level is deactivated for the remainder of the data processing. The wind-off image is processed by selecting the Wind Off Process ( Wind Off) button and the wind-on image is processed by selecting the Wind On Process ( Wind On) button. Again, the processed images may be viewed and interrogated by selecting the  (View) button to the right of the Wind On Process and Wind Off Process fields. Display the processed Wind-Off image (Figure 9) and note that the signals from the unpainted portion of the impingement plate and the nozzle have been eliminated.

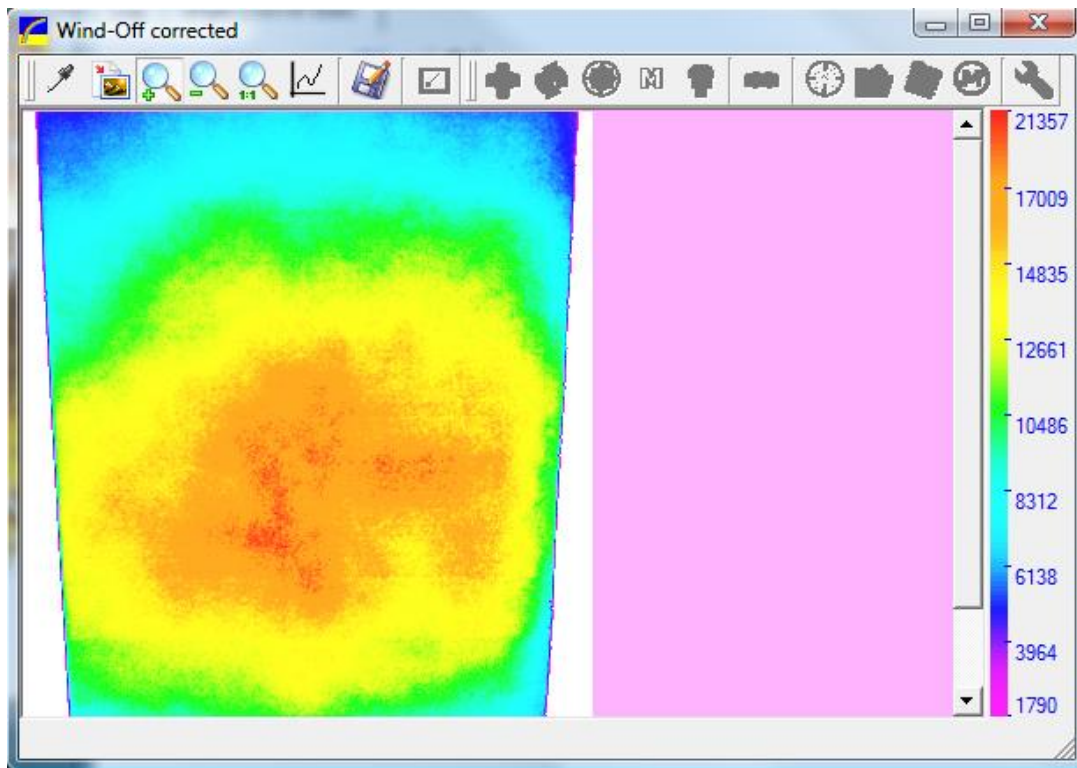


Figure 9: Wind-off corrected image

Align, Ratio, and Filter: The next step in the data reduction process is computing the ratio of the wind-off over the wind-on image. This ratio will then be converted to pressure using the calibration of the PSP. Under ideal conditions, one could simply divide the wind-off image by the wind-on image on a pixel by pixel basis. Unfortunately, there are several sources of noise that must be considered before proceeding. These sources include shot noise from the camera and misalignment of the images. The tools for minimizing this noise include image alignment and image filtering.

The noise level on the ratio image can be improved by applying a low-pass filter to the image after taking the ratio. In OMS Lite, this is accomplished by using the Filter option in the Alignment Options panel (Figure 10). The low-pass filter options include, Flat, Gauss, and Median filters. The size of the filter is set using the Dx: and Dy: boxes. Finally, minimum and maximum limits may be set that will exclude data that is out of the prescribed range. For this example, we will apply a (Dx:) 3 pixel by (Dy:) 3 pixel Flat filter to the image. It is important to remember that the spatial resolution of the final image will be reduced by the application of a low-pass filter. The size of the filter should be selected to smooth the data without compromising the spatial resolution unnecessarily. Finally, minimum and maximum limits (Threshold) may be set that will exclude data that is out of the prescribed range. Thinning will be discussed in a later lab. The values shown were used for this example.

It is not uncommon for some slight movement of the model or camera to occur between the acquisition of the wind-off and wind-on images. Every effort should be made to minimize this type of movement as it can be a major source of error in PSP measurements. Unfortunately, issues such as aerodynamic loading of a model or vibration of the mounting hardware are unavoidable. Movement of the model or camera usually results in a slight

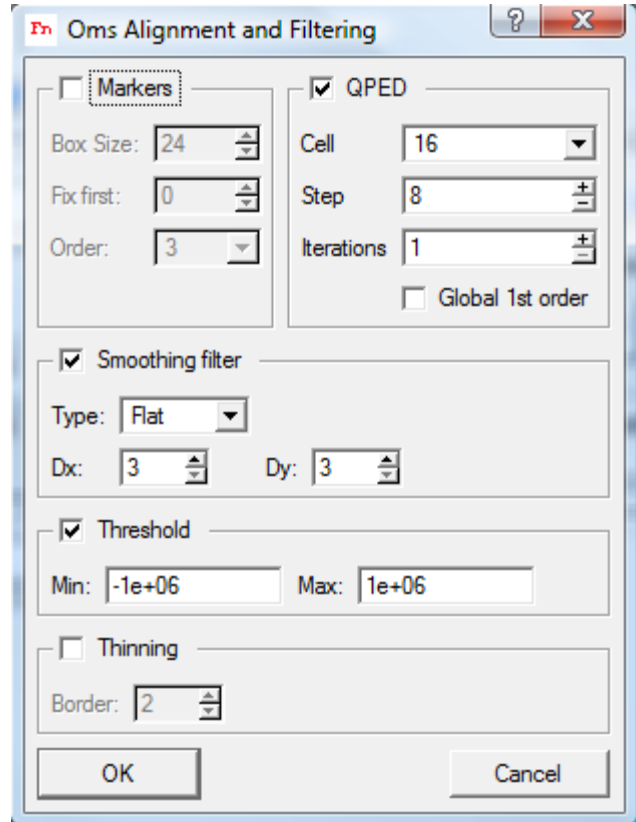




Figure 10: Alignment and Filtering window

misalignment of the wind-off and wind-on images. Computing a ratio of the wind-off over wind-on image when these images are misaligned will yield a ratio image that is noisy. This noise will be especially noticeable near any model edges or in other regions with strong gradients. Significant misalignment can result in data that is too noisy to be of any quantitative value. This noise can be minimized using image alignment tools.

OMS Lite includes two image alignment procedures, Markers and QPED. Both procedures attempt to determine the shift between the wind-off and wind-on image. The wind-on image is then shifted or mapped onto the wind-off image before the image ratio is computed. For this example the QPED algorithm is used. This procedure uses a cross-correlation procedure to detect and correct for slight movement between the wind-off and wind-on images. The QPED alignment procedure is activated by checking the QPED box in the Alignment Options Panel.

The default values shown for Cell, Step and Iterations were used in this example. Users can vary these settings to see the effect on the alignment procedure. With the filter and alignment options selected, the Alignment Options Panel is closed and the ratio image is computed by selecting the Ratio Process () button. The ratio image may be viewed by selecting the  (View) button to the right of the Ratio button, this image is displayed in Figure 11. Note the complex structure of the shocks and expansions on the impingement surface and the high spatial resolution that the PSP technique offers. If the vector field is displayed, press the on the top toolbar to deactivate it. The vector field appears as a dot matrix over top of the image.

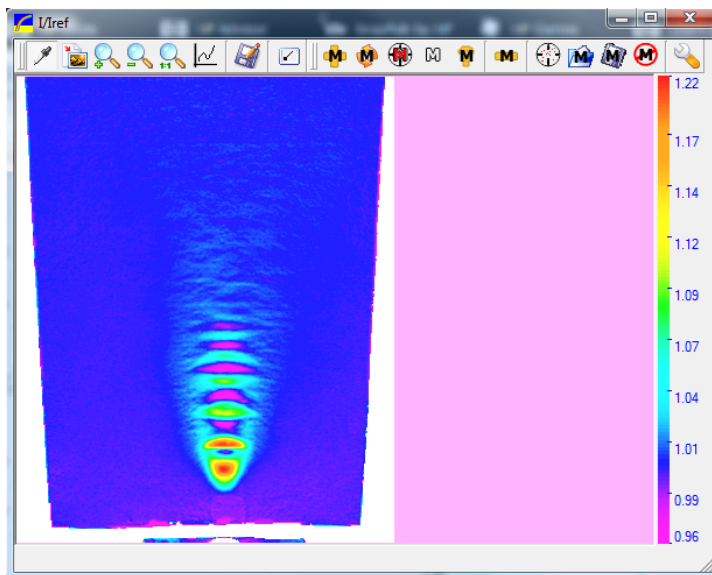


Figure 11: Ratio Image

Finally, the impact of the alignment and filter process may be demonstrated by computing the ratio image without using the filter and alignment tools. This is done by deactivating the filter and alignment option in the Alignment Options Panel. Note the *fuzzy* appearance of the image; this is indicative of high frequency noise.

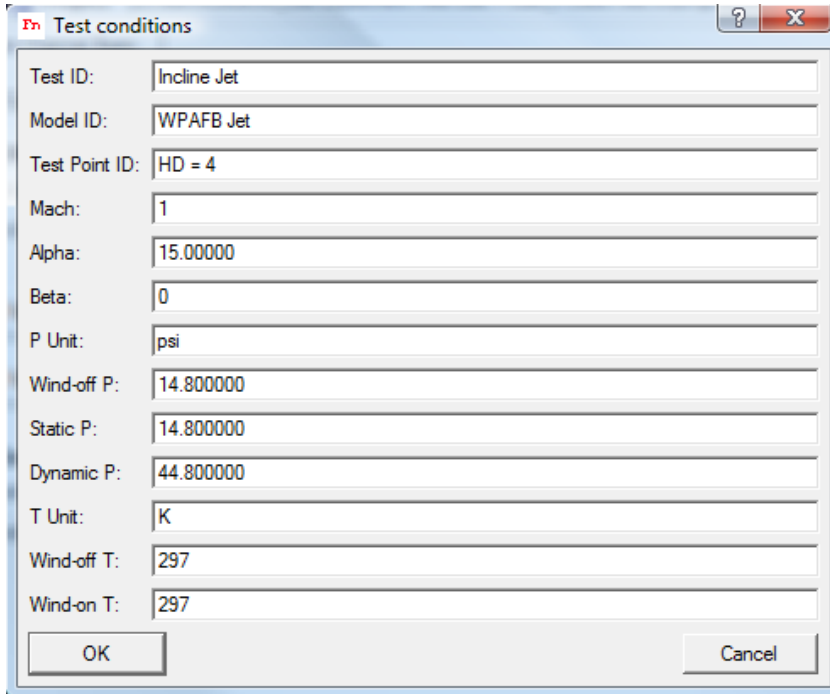


Figure 12: Test Conditions window

In this case the noise is the result of camera shot noise rather than image alignment. Noise from image misalignment would appear as strong gradients near the edge of the painted region.

Convert to

Pressure: The final step in the process is to convert the ratio image to pressure; this may be accomplished using

either an in-situ or a-priori calibration. The a-priori process will be demonstrated here. The first step is to load the paint calibration. This may be done by loading a paint calibration file or entering the paint calibration parameters.

The tools for doing either are in the Paint Calibration and Test Conditions block (Figure 13) on the right side of the Single Channel GUI (Figure 6). The paint calibration parameters are a 3 by 3 matrix of coefficients that relate the intensity ratio of the paint to temperature and pressure of the paint. A more detailed description of the paint calibration parameters is given in the document OMS Calibration. Select the Load Paint Calibration File (📁) button in the Paint Calibration block. Select the calibration for UniFIB (UniFIB.clb should be in the directory with the images). Again, the process of creating a calibration file is discussed in the OMS Calibration document.

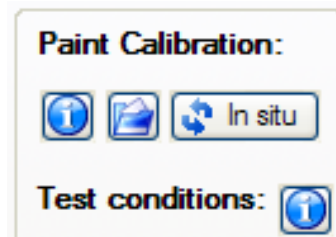


Figure 13: Paint Calibration and Test Conditions block

Data processing using PSP is based on the ratio of images. One image is at a known condition (reference or wind-off) and a second image is at an unknown condition (test or wind-on). To convert the ratio to pressure, it is necessary to enter the conditions that existed when the reference image was acquired. The panel for editing this information is displayed by selecting the Test Conditions button from the Paint Calibration and Test

Conditions block (Figure 13) and the Test Conditions Panel (Figure 12) is displayed. The Wind-off pressure (14.8 psia for this experiment) and Wind-off temperature (297 K for this experiment) are entered in the appropriate fields. It is also necessary to enter the units that will be used for pressure (psi, Pa) and temperature (K, C).

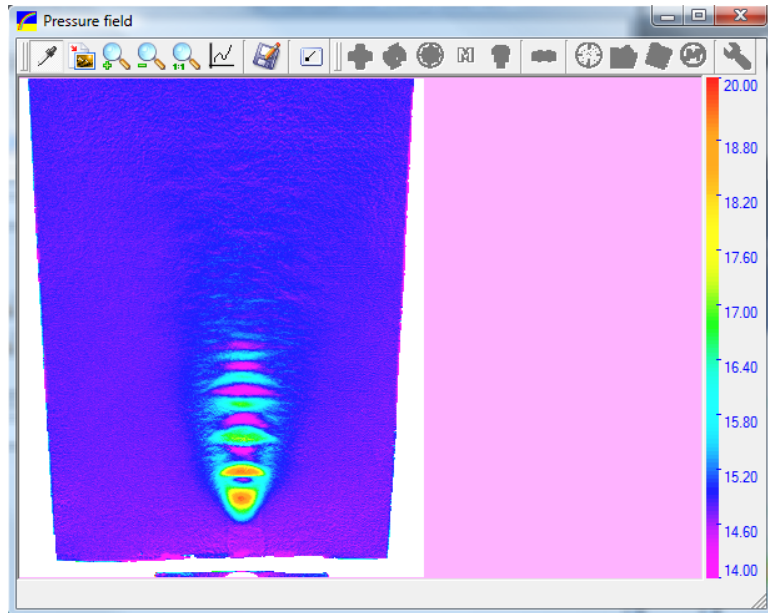




Figure 14: Pressure Field for inclined impinging jet

Finally, for a single component

PSP, it is necessary to enter the temperature of the model at the wind-on condition (297 K for this experiment). There is also space to add information such as the static and dynamic pressure; this information can be used to compute pressure coefficients. Information that is used to identify a specific test and test configuration may also be stored in the project file to facilitate analysis at a later date. Use all test conditions shown in Figure 12 for this experiment. With the calibration file loaded and the test conditions entered the conversion to pressure may be completed by selecting the Calculate Pressure field () button. The pressure field may be viewed by selecting the  (View) button to the right of the Calculate Pressure field button and the image may be interrogated, scaled, or the color map changed using the OMS Viewer. The final pressure field includes strong pressure gradients and alternating regions of high pressure and low pressure. Note that there are several regions where the surface pressure is below the ambient pressure, these are the result of the expansion fans in the super-sonic flow.

Exporting the Pressure Field: The pressure field may be exported into any of the following file formats: The native format for OMS is *.ims. Common programs used to display data such as TecPlot are also supported (TecPlot ASCII format, *.dat). Other formats include PCO (*.b16), TIFF (*.tif), and PI (*.spe) files. The PCO and TIF file formats do not support floating point numbers. Regardless of the format that is used to export the data, the file format for each of the supported files is available.