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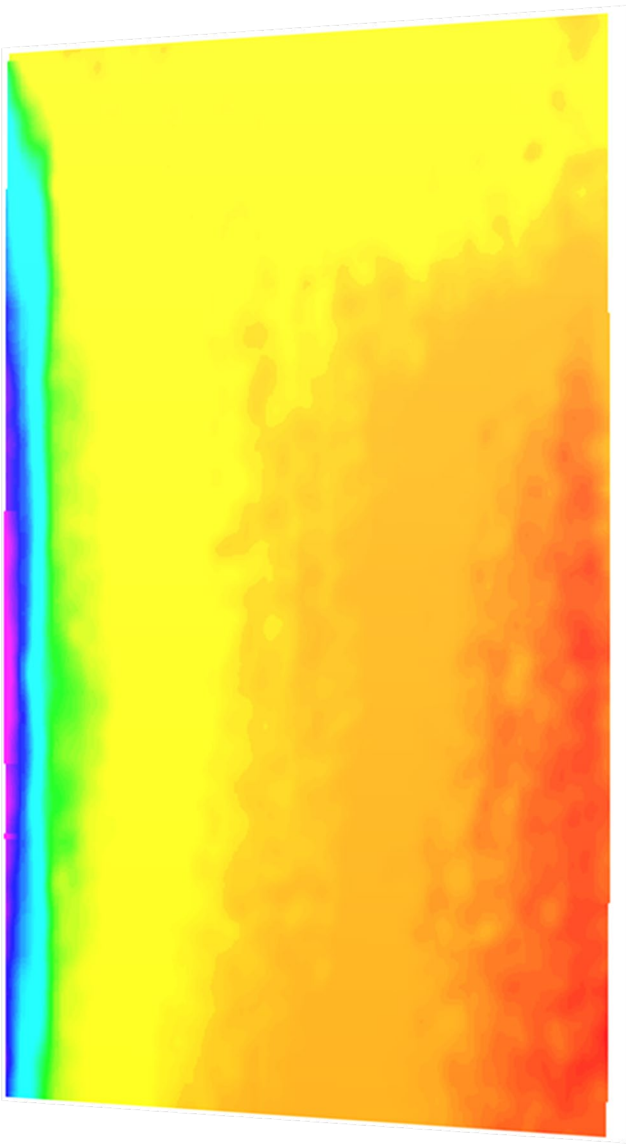
Lab 4: Pressure Gradients Over a Wing



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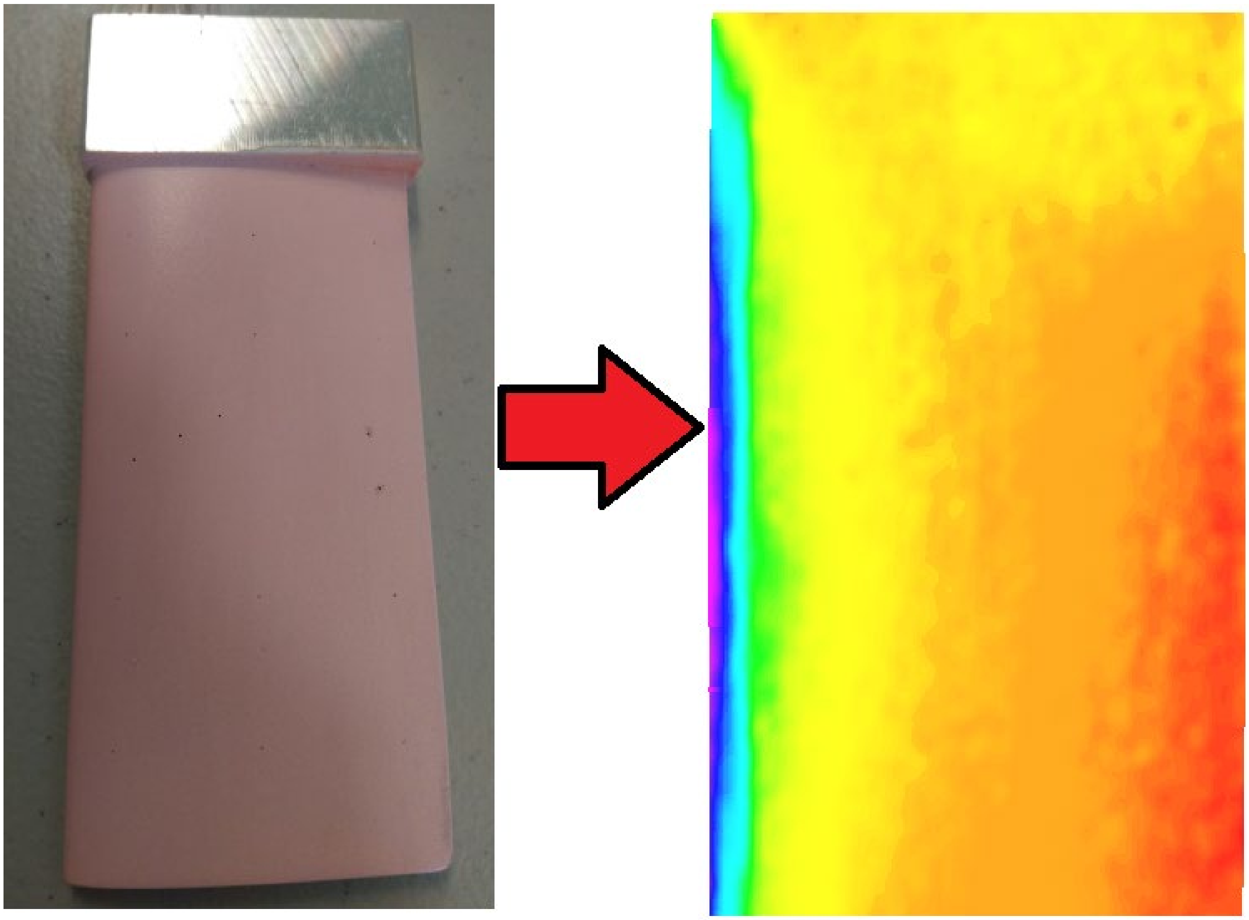
Introduction

Like the previous lab, this experiment is run in a low-speed wind tunnel to investigate the pressure gradients over a NACA 0012 airfoil using the PSP system. The NACA 0012 is a well-known and well-studied symmetrical airfoil.



Although the NACA 0012 wing model included with the system does not have pressure taps, the dataset used in this example does. For the dataset, a pressure scanning system was used to acquire pressure tap measurements in real time, synchronized with the PSP acquisition. This lab experiment will introduce pressure tap correction using these pressure taps in post-processing. The goal of this experiment is to utilize all of the tools found in OMS-Lite.

Begin by coating the NACA 0012 wing model with FIB Basecoat and then BinaryFIB® and then curing it according to the painting instructions.

Hardware

The PSP-CCD-C scientific CCD camera from is used in conjunction with an LM2X-DM-400 LED lamp. The LED lamp illuminates the test object, exciting the luminescent probe in the paint, and the emission from the probe is then captured by the camera through a 530-nm long-pass filter. As in the previous labs, the laptop connects to the camera to acquire data through ProAcquire and then reduces data in OMS-Lite. Refer to the ProAcquire user manual and hardware user manuals for detailed instruction on each.

Figure 1: PSP-CCD-C CCD Camera

Figure 2: LM2X-DM 400 nm LED Lamp

Figure 3: NACA 0012

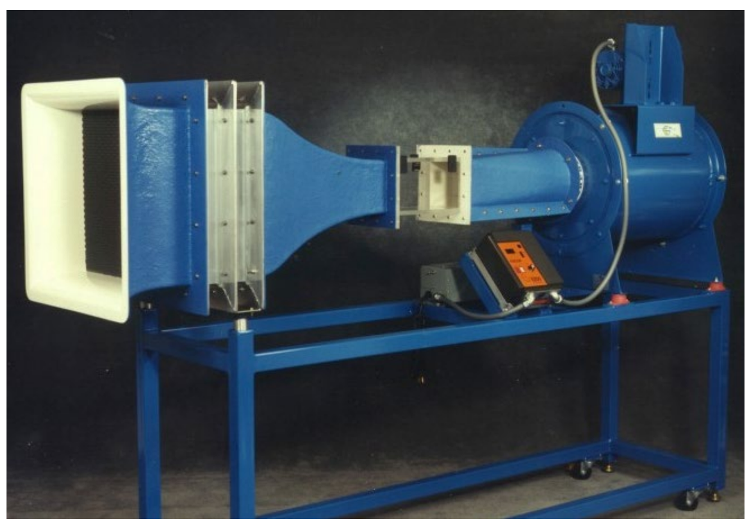


Figure 4: Wind Tunnel

A small NACA0012 wing is used inside the test window of a low-speed wind tunnel. This can be painted with either BinaryFIB® or Binary UniCoat pressure sensitive paint for this demonstration. Be sure to account for all power supplies and cables. Once all of the equipment is accounted for, it is time to set up the experiment. Users should complete Labs 1 and 2, which cover basic hardware and software setup and use, before beginning this exercise.

The P

SG-3 pulse delay generator can also be used as the master timer if one was purchased.

Experimental Setup

The camera and LED lamp should be mounted so that they are rigid and do not move when the wind tunnel is being run. This will help to eliminate inaccuracies in the data. The camera and LED lamp should be positioned near the test window so that the camera can focus on the test object and the LED lamp can uniformly illuminate the surface as shown in Figure 5. Attach all power supplies to the camera, LED lamp, and the computer. More details of experimental setup and data acquisition are explained in Labs 2 and 3.

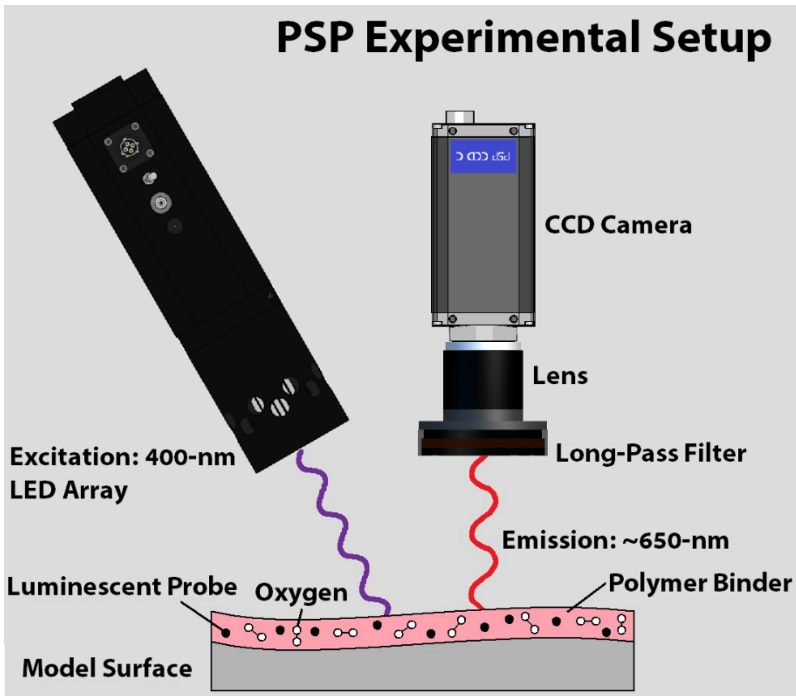
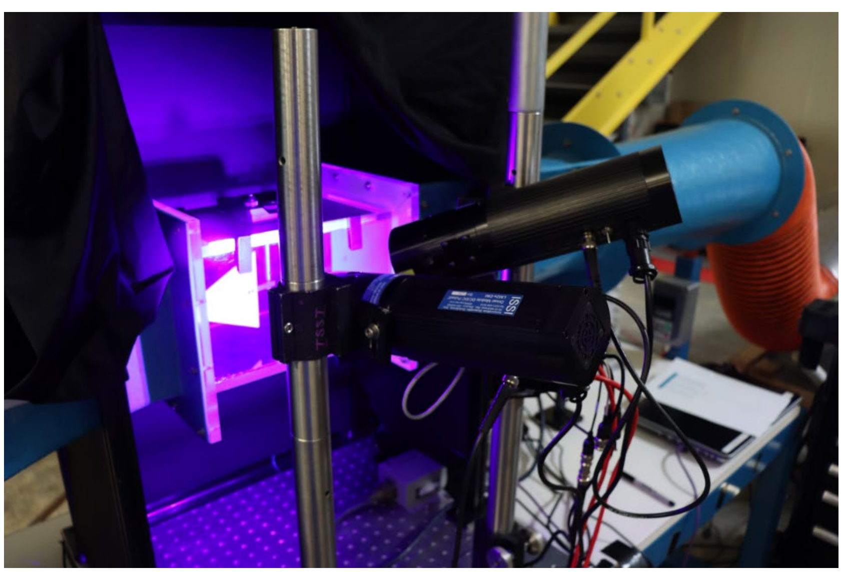


Figure 5: Experimental Setup



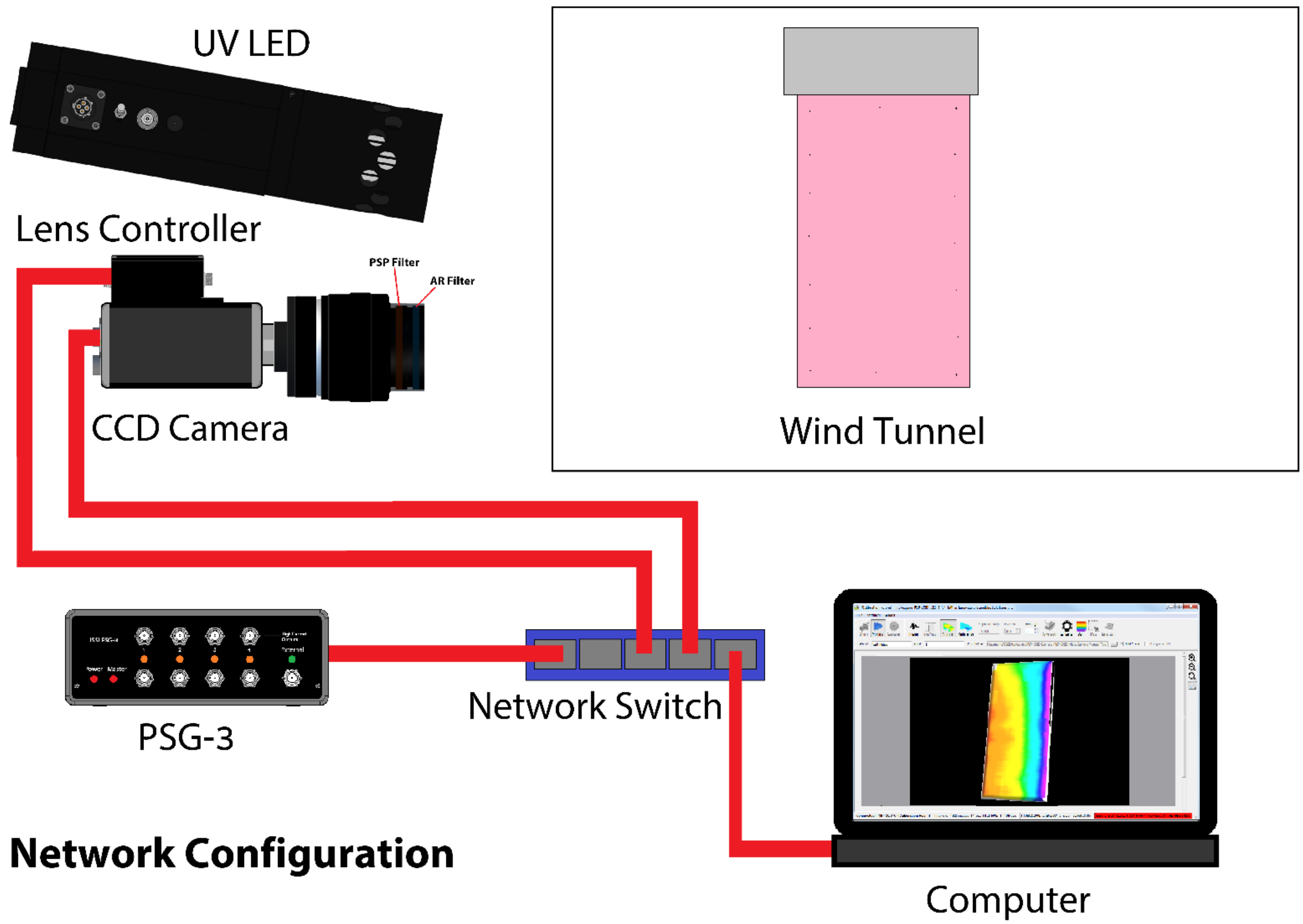


Figure 6: Hardware Network Setup

The wind tunnel has a 6-inch test section window where the test object is to be placed. Mount the wing with the winglet attached in the center of the test section. In wind tunnel tests where the test body is likely to bend or rotate during data acquisition, it is sometimes necessary to use markers for image alignment. Markers can be physically placed on the test object by simply marking the painted surface with a pen. This will show up on the wind-off and wind-on images as an area with little to no illumination since the paint is not visible.

Data Acquisition

In ProAcquire ( ), use the live preview ( ) to view the image seen by the camera and adjust the camera's focus so that the image in the preview is clear. Be sure to turn off or block any light sources to avoid noise in your data before data acquisition begins. Capture the background image with the room lighting and the LED lamp turned off. Save the background image (***background.tif***) in a new folder where all images for this experiment will be stored.

Create a new file each time a new image with different settings is captured by pressing the icon in the upper left area of OMS Acquire next to the file path description. Turn the LED lamp on and allow it to stabilize for about one minute before taking data. Capture the wind-off (***wind_off_XXXms_Xfr.tif***) images with the wind tunnel off. Set the frames to average to 128 and the exposure time to around 500ms. This is dependent on LED placement, paint quality and lens aperture. It is important not to saturate the image by over-exposing it. ProAcquire will allow you to probe the image to check the intensity level before acquiring any data.

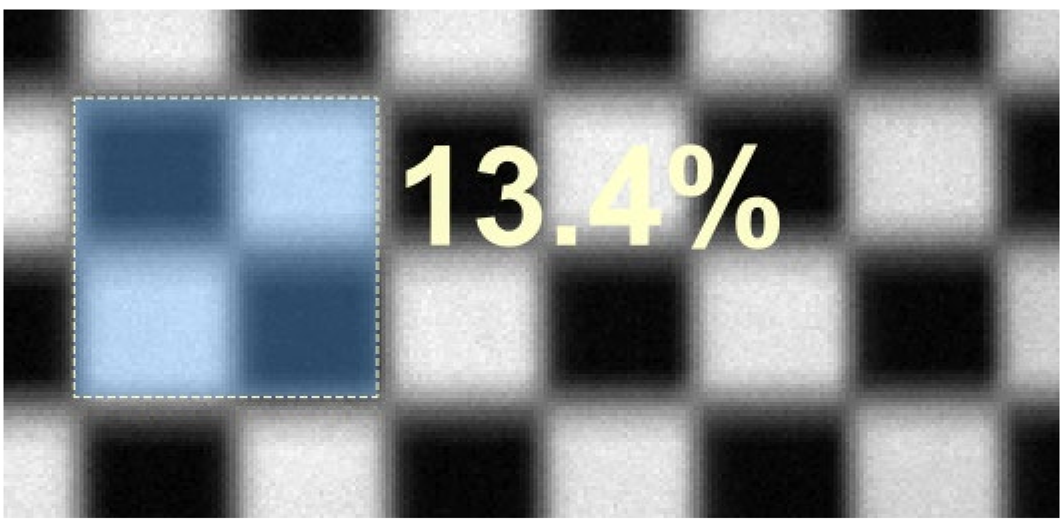


Figure 7: Average ROI Intensity from ProAcquire

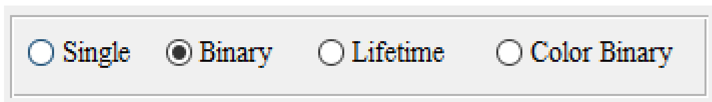
Ideally, you want the intensity level to be somewhere in the middle of the spectrum (0-4096 counts). The image is saturated if the dynamic range reaches 100%. Ideally, the wind-on signal levels are 80-90% of dynamic range. The response from the CCD sensor is linear between 10-90%. If you are seeing a factor of 2 jump in intensity when a force (wind-on condition) is applied to the surface, then you should have enough of the intensity spectrum available to accommodate that jump.

Turn on the wind tunnel and set it to the desired airspeed and allow it to stabilize. Once the tunnel is up to speed the data acquisition can begin. Capture a wind-on image averaging 128 frames and save it as a name that will reference these conditions (Example: ***wind_on_XXXms_Xmps_Xfr.tif***). If when processing the images in OMS Lite the images do not appear to have an acceptable resolution, it may be necessary to average more frames to capture the pressure distribution. This is only one factor since exposure time, lens aperture, shot noise, and wind tunnel speed also have an effect on your data.

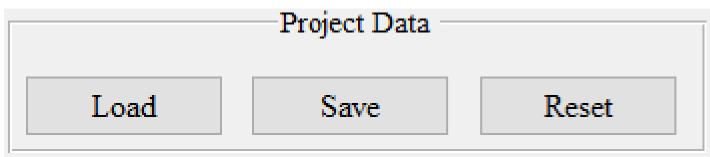
Once all images are captured, gradually slow down the airspeed of the wind tunnel and turn the power off. All images for data reduction should now be acquired and saved.

Data Reduction

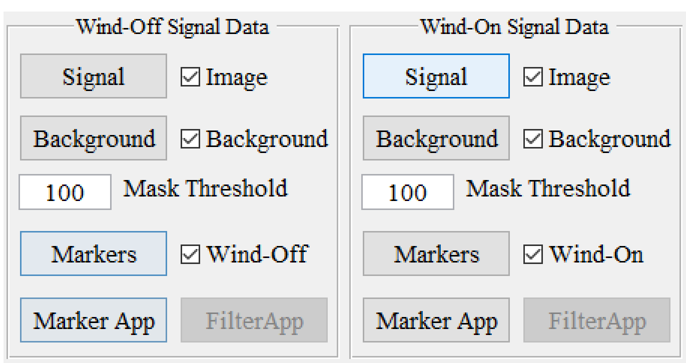
Reducing the data into an image of pressure involves taking the ratio of the wind-off / wind-on images and then calibrating the image to relate the ratio to pressure. Create a new project in OMS Lite using the ***Binary*** option.



Select the folder where the image files are saved to save the project. Save the project as ***NACA_0012.pspproj*** or something that will reference the experiment.



In the OMS-Lite interface, load the wind-off, wind-on, and background images. The mask threshold should be set to around 100 for the signal images and 50 for the reference images to remove the background level pixels from each image. Probe the image to verify the background level for the signal and reference images.



Split Colors should be checked in ProAcquire when using a color camera. For monochrome cameras, this option will not be available. This feature will split the image into the 4 color channels on the camera. The software will only save the two needed for data processing, the red (pressure) and green (reference).

Pressure sensitive (red) images will have the extension ***_p***, while reference (green) images have the extension ***_r***. Monochrome camera images will have no extension.

Note that the resolution of the color camera split images is one fourth of the total resolution of the camera due to this splitting.

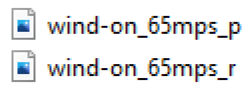


Figure 7: Saved Images

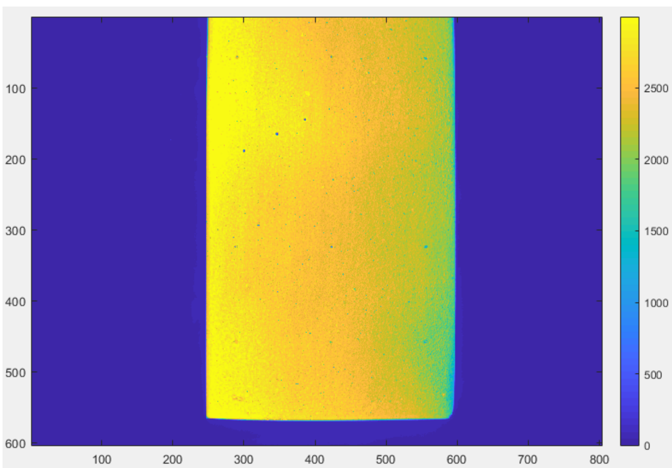


Figure 8: Signal Channel Uncorrected Image

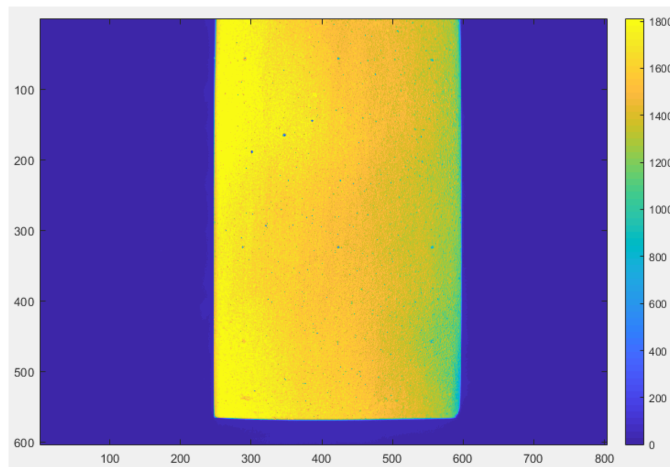


Figure 9: Reference Channel Uncorrected Image

The signal images have a maximum intensity around 3,000 counts while the reference image is around 1,600. In general the signal channel should be around twice the intensity of the reference image at atmospheric conditions. To test this in your setup, check the signal levels on the wind-off images using the histogram in the image viewer (shown in Figure 10).

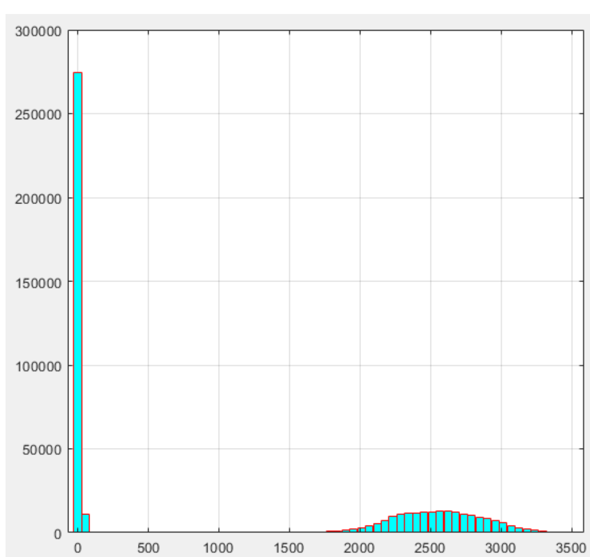


Figure 10: Histogram of Wind-off Signal Image

Registration Markers

Next registration marker files will need to be created for this dataset. The physical registration markers should be added with a small marker or pen so that they are clearly visible in the camera view of the painted model. These are to be added after applying and curing the PSP.

The marker application allows the user to add, move or remove registration markers on the bitmap image. Markers are used for image registration to correct for model movement that can occur between wind-off and wind-on conditions and for pressure tap correction where pressure taps are present.

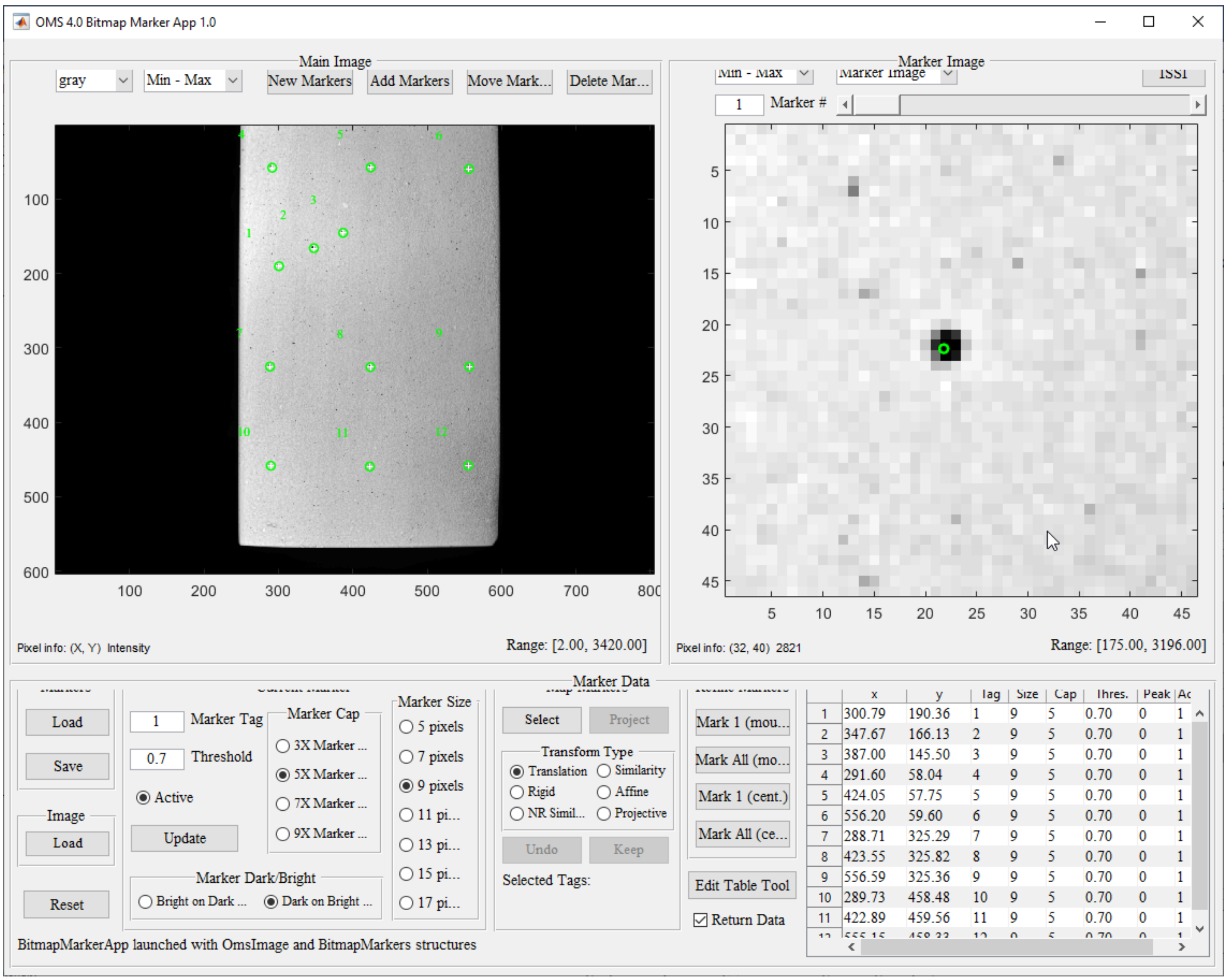


Figure 14: Marker Application

There are 12 registration markers including 3 pressure taps on this model used for this experiment. The pressure taps are the 3 diagonal markers.

<u>Markers</u>

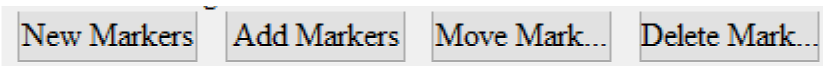
Save/Load – save and open existing markers or marker files

<u>Image</u>

Load – load an image into the Marker App

Reset – clear all images and markers from the Marker App

To add new markers to an image, select the **New Markers** button at the top of the screen.



Threshold - sets the threshold value of the current marker (0.1 to 0.9)

Marker Dark/Bright – select the marker type, dark marker on bright background or a bright marker on a dark background.

Marker Cap – selects the size of the marker selection tool window

Marker Size – size of the expectant physical marker on the bitmap

Clicking **New Markers** will pop up a green box. Drag this box to the first marker and double-left-click the mouse to set it as a marker. **Add Markers** will add additional markers to an existing marker set. Begin by selecting the 3 diagonal pressure taps and then marking the remainder of the registration marks. Use a 5X marker cap and 7-pixel marker size. **Dark on Bright** should be selected for these markers as they are a dark spot on a bright background.

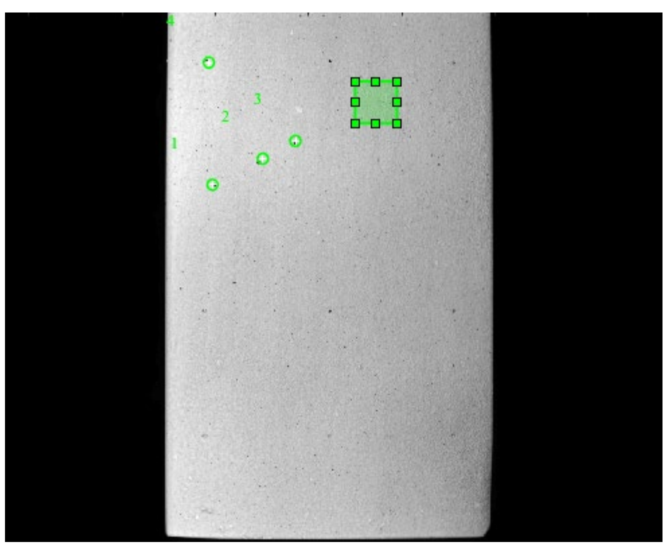


Figure 15: Adding markers to the uncorrected image

To move an existing marker, click the **Move Marker** button on the top toolbar of the main image screen. A blue box will appear. Drag the blue box over the marker to be moved. Double-click on the marker. Now a green box will appear. Drag the green box to the physical marker location where you want to place this bitmap marker. Double-click on the physical marker location. The marker will now move to the physical marker location.

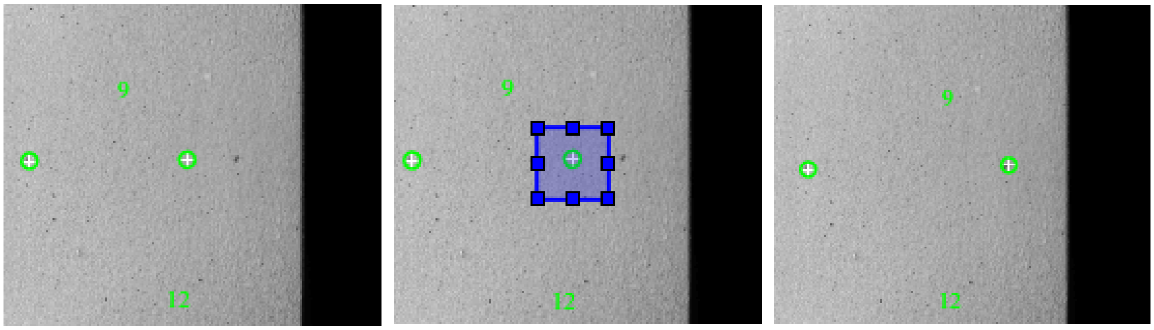
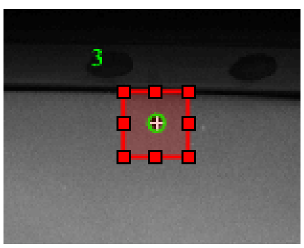


Figure 16: Moving a Marker

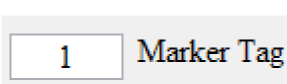
To delete an existing marker, click **Delete Marker**. A red box will appear on the image. Drag this box over to the marker and double-left-click on the marker to delete it. If you are having trouble viewing the markers, adjust the autoscale settings to more easily view them.



Current Marker

To change the current marker being viewed, use the slider or text window on the right side zoomed-in view called Marker Image.

This tool set allows for adjustment of each marker on the bitmap.



- sets the tag number of the current marker

Refine Markers

Marker positions may need refinement due to non-centered placement when they were manually positioned. Marker refinement tools find the center point (peak or pit) of each marker automatically using the existing marker position and a cross-correlation algorithm to center the marker in the same position on the marker in all images. This is necessary for proper image alignment due to model movement between wind-off and wind-on conditions.

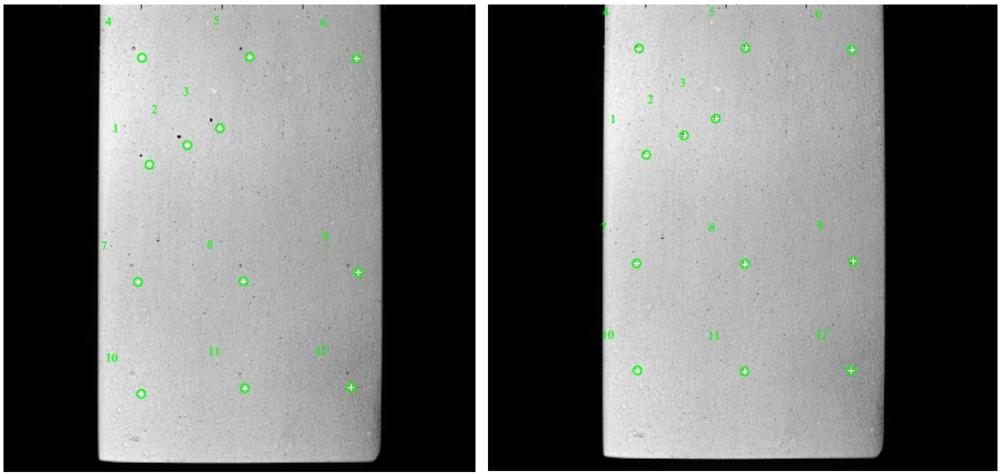


Figure 17: Markers Before (left) and After (Right) Refinement

Manual Refinement

Mark 1 (Mouse) – Refine current marker position manual using mouse. Double-left-click on the green box once it is centered around the physical marker location.

Mark All (Mouse) – refine all marker positions manually using mouse. Once selected the program will move to each marker automatically after the manual revision. Double-left-click on the green box once it is centered around the physical marker location.

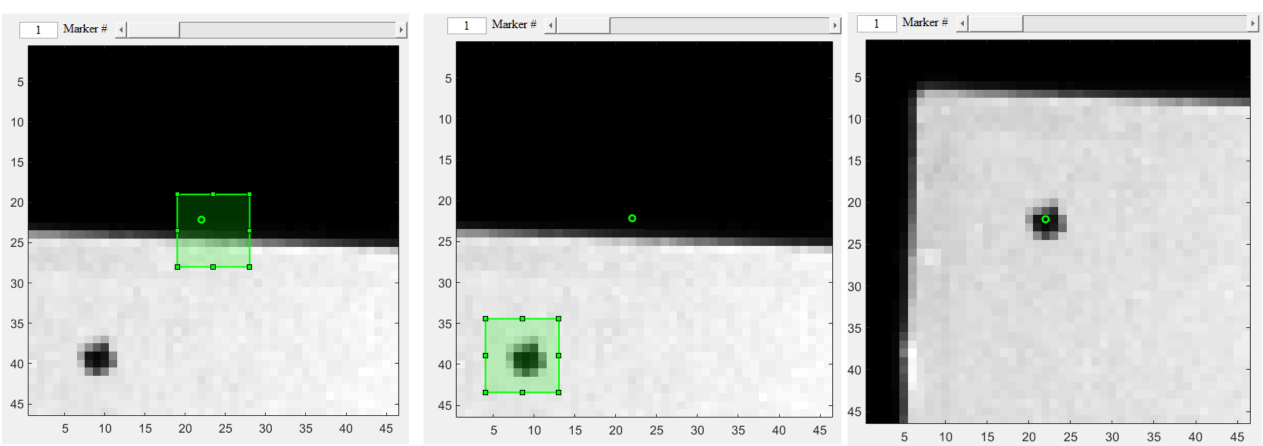


Figure 18: Marker Refinement

To exit, right click the mouse inside the green box.

Automatic Refinement

Mark 1 (Center) – refine marker position on current marker using centroid calculation.

Mark All (Center) – refine all marker positions to find the center point of each physical marker using centroid calculation. When manually marking images, it is not necessary to mark each individual image in a wind-off/wind-on set. For example, mark the wind-off image of a camera view and then save the markers corresponding to that image. Now open the wind-on image of that same camera view. Load the markers that were saved for the wind-off image. They will all be shifted from the center of the makers on the wind-on image because the model moves relative to the camera between wind-off and wind-on. Click the **Mark All (Center)** button and the marker tool will automatically revise each marker so that it is at the center point of each physical marker.

Marker Table – the marker table displays the XY location of each marker, the enumeration and the tag associated and the cap size used to select the marker. Active and inactive markers are indicated by a 1 or 0. 1 is active and 0 is inactive and will not be used for image alignment or pressure tap correction.

	x	y	Tag	Size	Cap	Thres.	Peak	Acti...
1	300.79	190.36	1	9	5	0.70	0	1
2	347.67	166.13	2	9	5	0.70	0	1
3	387.00	145.50	3	9	5	0.70	0	1
4	291.60	58.04	4	9	5	0.70	0	1
5	424.05	57.75	5	9	5	0.70	0	1
6	556.20	59.60	6	9	5	0.70	0	1
7	288.71	325.29	7	9	5	0.70	0	1
8	423.55	325.82	8	9	5	0.70	0	1
9	556.59	325.36	9	9	5	0.70	0	1
10	289.73	458.48	10	9	5	0.70	0	1
11	422.89	459.56	11	9	5	0.70	0	1
12	555.15	458.33	12	9	5	0.70	0	1

Figure 19: Marker Table

Edit Table Tool – will allow for indexing the markers to match tag enumeration to the index or allow for the tag to be changed to match existing drawings for pressure taps or markers on the model. Many times, markers are added manually using a pen and then these locations are manually or automatically selected using the marker application, paying no attention to the enumeration used by the model mesh or pressure tap map. Editing the tag number of each marker allows the user to match the tag to the physical marker it's matched with so that they have the same enumeration on the physical model and bitmap data during post-processing.

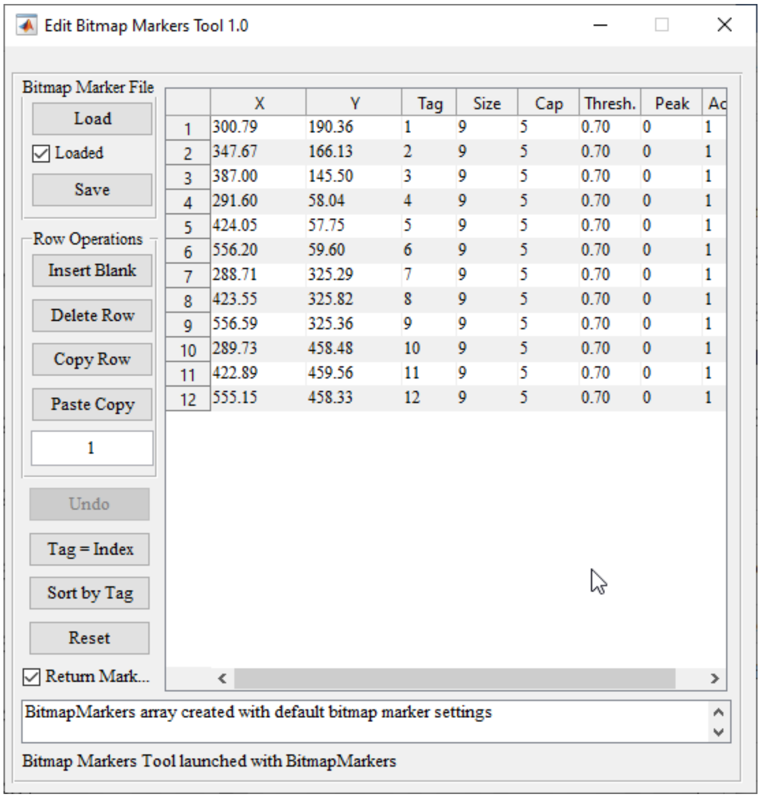
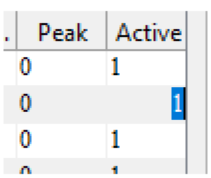


Figure 20: Edit Marker Tool Table

Markers can be saved or loaded from this window. Markers can be made active or inactive in this window. Active =1, Inactive =0.



Click on the number shown in the ***Active*** column for the marker you want to activate/deactivate and set type 1 or 0.

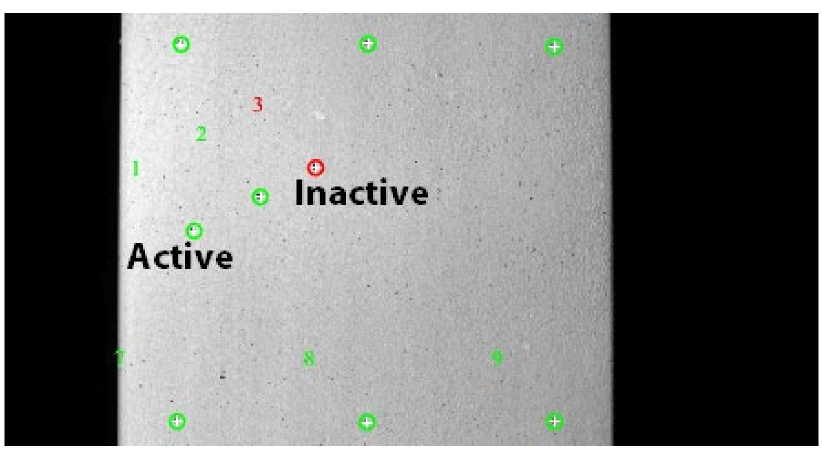


Figure 21: Active/Inactive Markers

Row Operations

Insert Blank – inserts a blank row into the marker list where values can be manually entered.

Delete Row – removes an existing row from the list

Copy Row – copies an existing row to the clipboard

Past Row – paste an existing row to the list

The text box shows which row the operation will be performed on

Undo – go back one operation

Tag=Index – sets the tag number to the index number

Sort by Tag – sort the rows based on tag number only (lowest to highest)

Reset – revert to original enumeration and arrangement

Image Alignment

The ***Registration Application*** allows you to test out different image alignment tools using the markers to optimize the alignment for the dataset. There are several options for mapping algorithms to choose from. These options correspond to the type of model movement between the fixed and moving images, anywhere from simple 2D translations to complex twisting and bending.

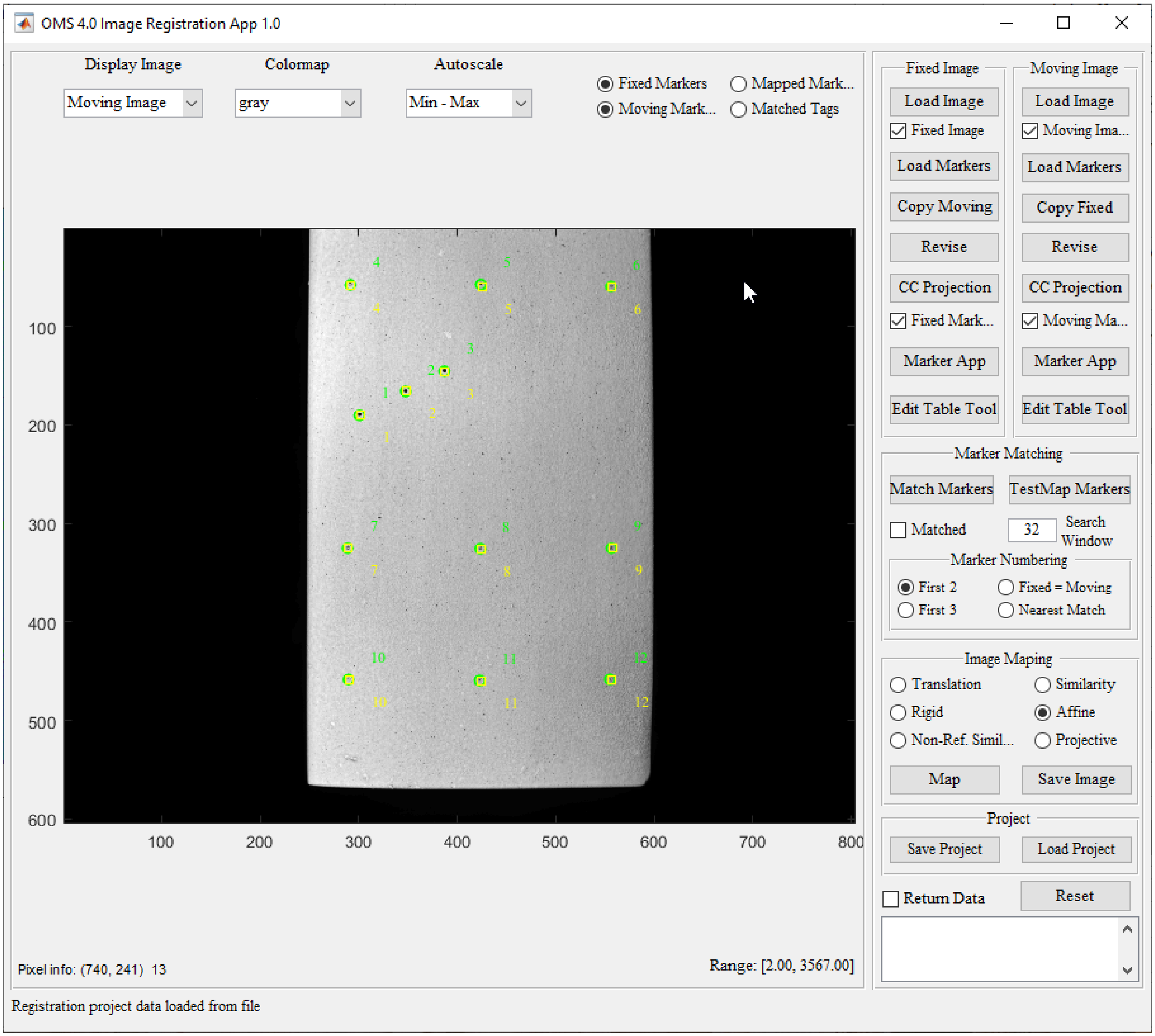


Figure 22: Registration Application

Translation: Warp moving image using translation transform based on control points. Used for 2D translational movements of the model between fixed and moving images.

Rigid: Warp moving image using rigid transform based on control points. For rigid 1D or small movements

Non-Ref Similarity: Warp moving image using non-reflective similarity transform based on control points.

Similarity: Warp moving image using similarity transform based on control points.

Affine: Warp moving image using affine transform based on control points.

Projective: Warp moving image using projective transform based on control points.

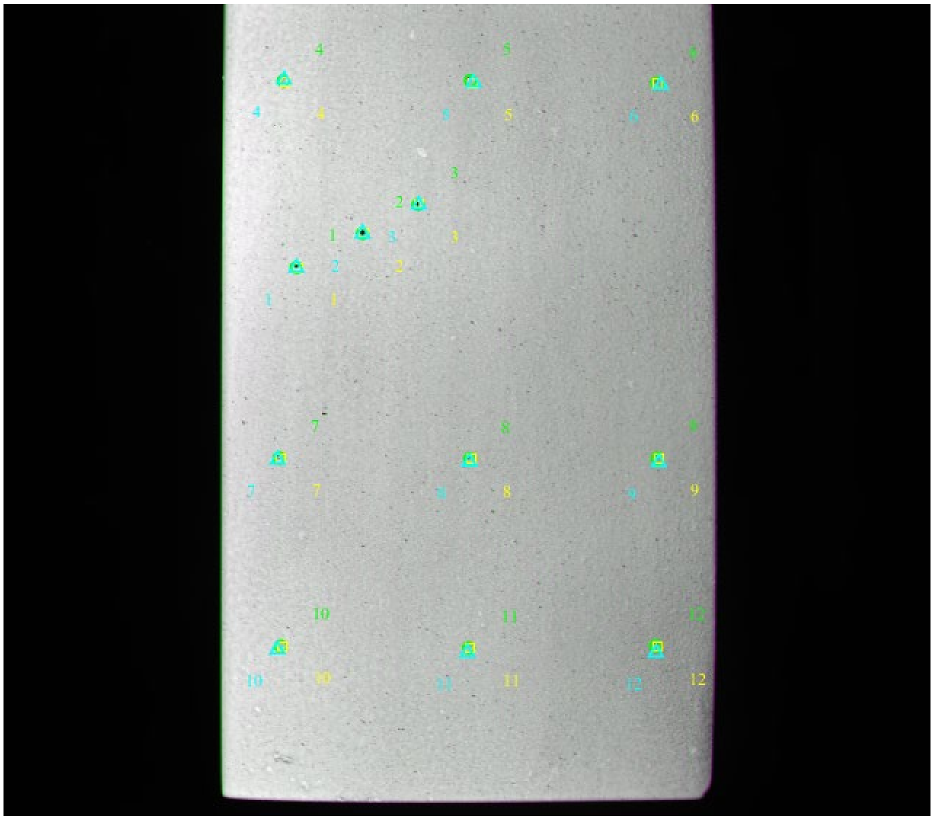


Figure 23: The Fixed-Mapped image showing the image alignment after mapping using the Registration App

For this example, an ***Affine*** image mapping was used. Marker Number of ***Fixed=Moving*** was used meaning fixed marker numbers are identical to the moving marker numbering. There is a slight shift of about 1-2 pixels between wind-off and wind-on conditions. Mapping the moving (wind-on) image to the fixed (wind-off) image will align the two, eliminating the shift shown in Figure 15. Once the image has been mapped, save the mapped image and save the project from the ***Registration Application*** in the same folder where the data is stored. To load a previously saved registration project file, click ***Load Project***.

Digital Image Filtering

Digital image filtering is used to reduce shot noise, remove paint imperfections and shrink the look-up table of the image to better visualize gradients in the image. This is often necessary in PSP data processing, especially for low-speed data like in this example where the dynamic pressure is very small and gradients are closer to the noise level of the image. Shot noise is a result of the digital image acquisition and can add a speckle pattern to the image. This problem gets worse the warmer the image sensor gets. Ways to reduce or remove shot noise are to keep the sensor cooler, take a longer record of images to compute the average and to apply smoothing filters to the image in post-processing. Each time a smoothing filter is applied, the pixel-to-pixel variation is being reduced to produce a smoother image. Each time one is applied, the minimum and maximum (look-up table) values change. There are 4 options available for image filtering. Filter types and sizes can be tested in the ***Image Viewer*** tool before applying them to the project data.

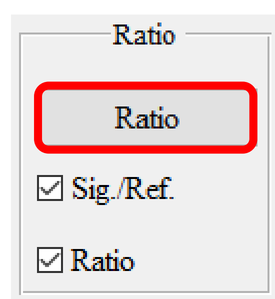
Flat Lowpass: This linear filter computes the average value of the pixels in the selected region in a square and assigns that average value to all pixels. This is also known as a box filter.

Round Lowpass: This linear filter computes the average value of the pixels in the selected region in a circle and assigns that average value to all pixels.

Gauss Lowpass: This is a non-uniform lowpass image-blurring filter which convolves the image with a 2D Gaussian function. Gaussian filters are used to blur and remove noise from images. The Gaussian filter is not effective at remove salt and pepper noise from images.

Median: A median filter is a non-linear digital filter which is used to remove noise from an image. The median filter goes through the image pixel by pixel and replaces each pixel value with the median value of the neighboring pixels. Median filters force pixels with distinct intensities to be more like their neighbors, getting rid of intensity spikes (salt and pepper noise) which distinguish them. The median filter preserves the edges of the image while removing noise.

Filter Pre-Ratio will apply the selected filter to the PSP images before any image alignment or ratio is calculated. This is used to clean up data with higher shot noise. Select the X-Y pixel size (3-21) for the filter and the filter type and make sure to click the ***Active*** box to enable this filter.



The **Post-Ratio Filter** applies one of the low pass filters to the ratio image once computed. Select from one of the lowpass filter options, select pixel size (X-Y) and check the box for **Active** to enable this filter.

Click ***Ratio*** again to recompute the ratio if you change post ratio filter or thinning filter.

For this dataset, a pre-ratio flat lowpass filter of 12 pixels was used. This dataset was taken at 65 m/s which is relatively low speed with a dynamic pressure around 2,500 Pa. This filter size was mildly sufficient to smooth the shot noise from the raw images but additional filtering will be needed for the ratio image once it has been computed.

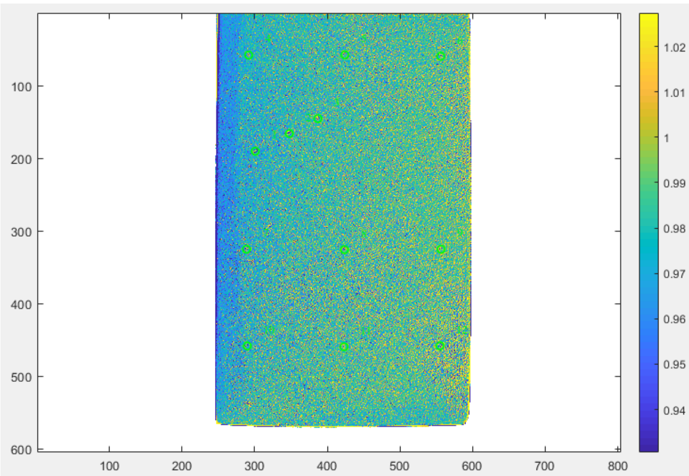


Figure 24: Ratio Image without Lowpass Filter

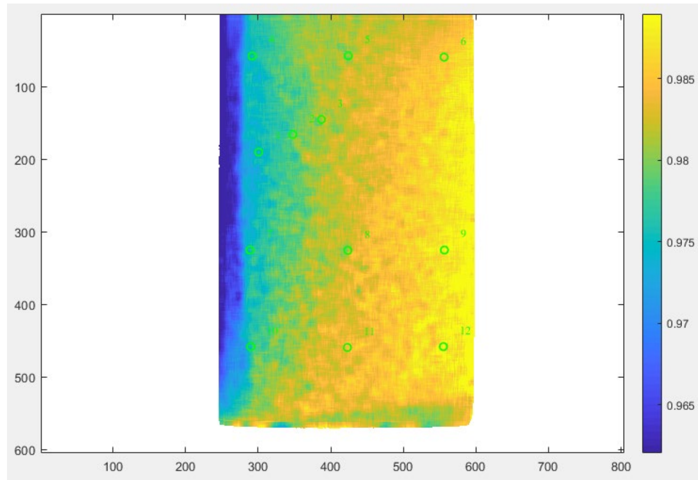


Figure 25: Ratio Image with Flat Lowpass Pre-Filter (12-px)

To further smooth the ratio image, a 21-pixel post-ratio filter was applied. We want to avoid over-filtering the image so that flow features are not removed but also filter sufficiently that we can visualize these features.

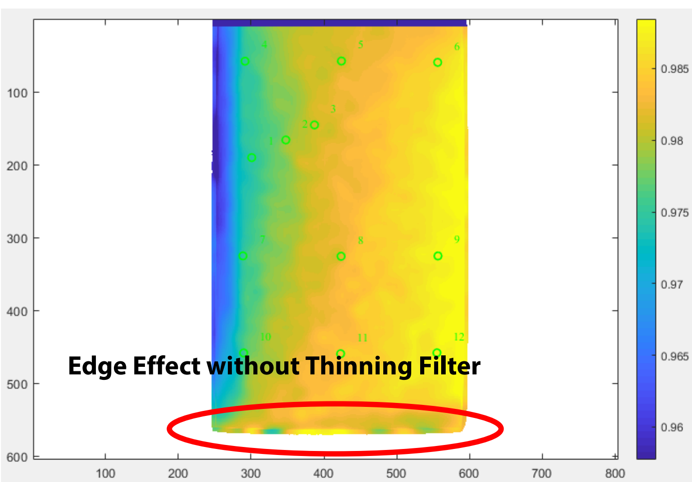


Figure 26: Ratio Image with Flat Lowpass Filter (21-px)

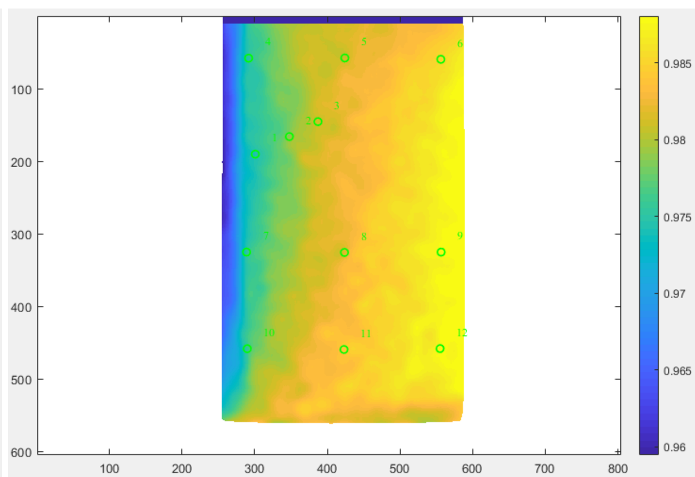


Figure 27: Ratio Image with Thinning Filter (10-px) Applied

You will notice that the edge of the image needs to be trimmed if you look at the bottom portion of the filtered image in Figure 26. A 10-pixel thinning filter was applied to the ratio image to remove this edge effect, the result shown in Figure 27.

Converting to Pressure

To convert to pressure, we need to input the test conditions for this particular experiment and load the paint calibration into OMS-Lite. The test conditions for this experiment are shown below in Figure 28.

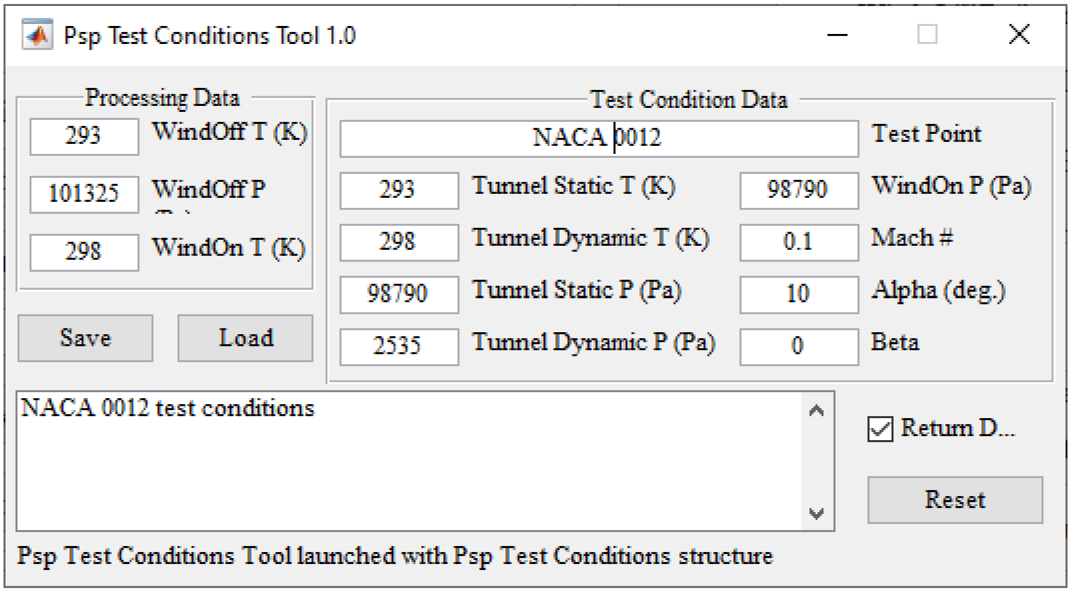
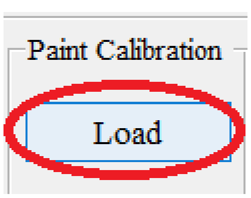


Figure 28: Test Conditions for NACA 0012 Experiment

This test was conducted at 65 m/s which corresponds to a dynamic pressure of 2,535 Pa. The temperature was taken from the pressure scanning system which was active during data acquisition.

The paint calibration tool within OMS 4.0 is used to load a previously saved calibration file into the project file. This calibration file is used to convert the intensity ratio to pressure, Cp or temperature values. This tool also features all the calibration post-processing tools used to create and edit a calibration from a dataset.

Use the ***BinaryFIB-B.pspcal*** file for this dataset.



Once the paint calibration has been loaded into the project file and the test conditions entered, the ratio image can be converted to pressure or temperature values. Prior to conversion to pressure, a digital image filter can be applied to the pressure image. In the ***Pressure Filter*** section, choose the filter type (same as outlined above in the ***Image Processing*** section) and size. Check the ***Active*** box to enable the filter upon conversion to pressure.

In this case, the final pressure image is applied a final 3-pixel Gauss lowpass filter.

Now we have a statistical image of the pressure gradient across the lifting surface of the NACA 0012 wing. The correspondence to a CFD model of this airfoil shape is shown in Figure 30.

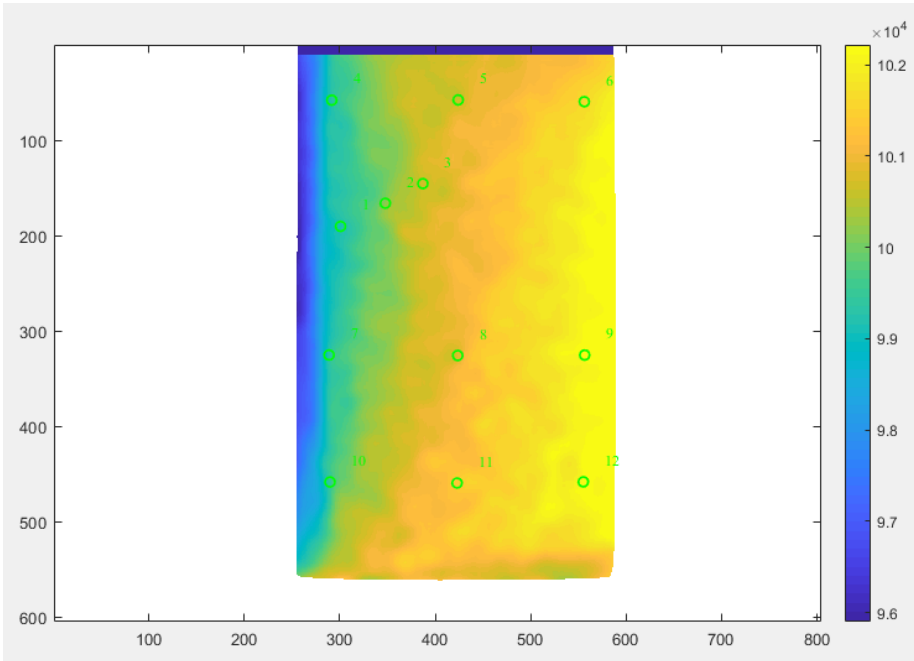


Figure 29: PSP Image of NACA 0012 Converted to Pressure (Pa)

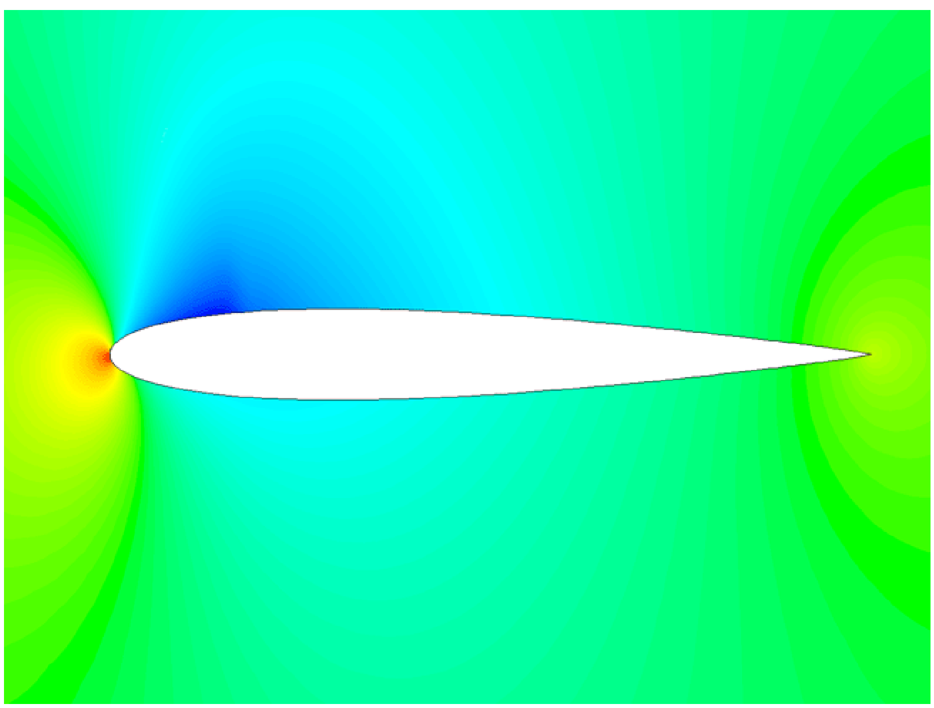
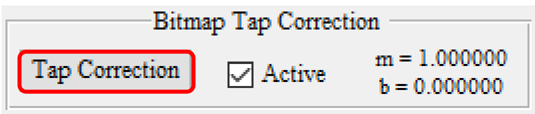


Figure 30: Computational Fluid Dynamics Model Of NACA 0012 Wing (Courtesy: Fluent Online)

The leading-edge pressure peak is difficult to see here (Figure 29) because the wing was placed at a slight angle of attack (10 degrees) and the camera is positioned normal to the upper surface. The airflow is traveling from the left to right of the page and the figure shows the lifting surface of the wing.

Bitmap Tap Correction Tool

The ***Bitmap Tap Correction Tool*** is used to apply a pressure tap or transducer correction to the processed PSP data. Two different corrections can be applied (bias or slope) to the PSP data using the pressure taps or transducers. Open the tool by clicking the ***Tap Correction*** button shown below:



The ***Bitmap Tap Correction Tool*** can import physical pressure tap or transducer data and location into the OMS project file. There are three datasets that need to be imported into this tool for pressure tap correction.

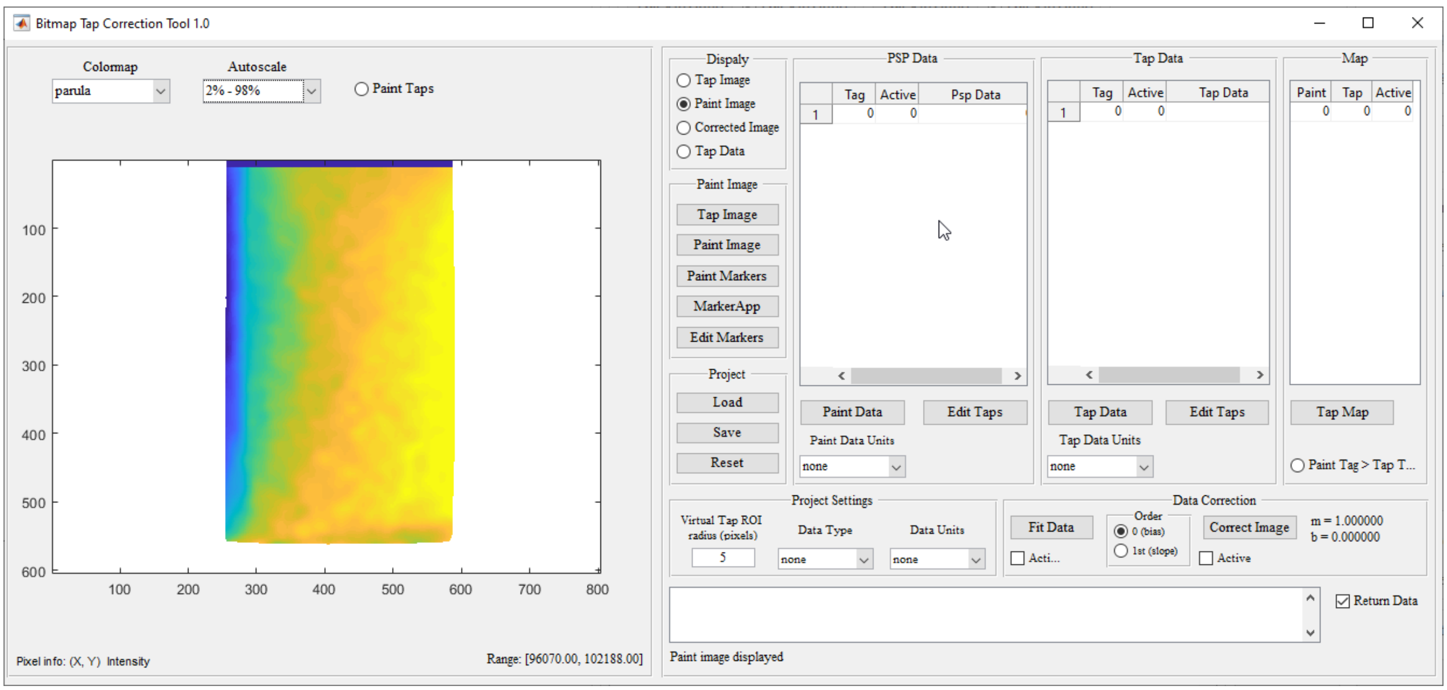


Figure 31: Bitmap Tap Correction Tool Main Window

Display

Tap Image – displays the tap image showing the tap locations on the bitmap overlayed on the processed image.

Paint Image – displays the computed pressure or temperature image from the processing.

Corrected Image – displays the corrected pressure or temperature image after applying the correction.

Tap Data – displays the tap data compared to the PSP data.

Paint Image

This section allows you to load images into the tap correction tool. The marker application can also be loaded from here to add or edit existing markers from the tap correction tool.

PSP Data is use to display the computed pressure value from the PSP data at the XY location of the pressure tap. To load PSP data into the ***Bitmap Tap Correction Tool***, first open the markers file for the pressure taps. This marker file will need to be separately created and saved. To create the pressure tap marker file, open the marker application and load the wind-off image with wind-off markers. Delete all 9 markers which are not pressure tap locations and save this as a new marker file called ***pressure.bmpmrk***.

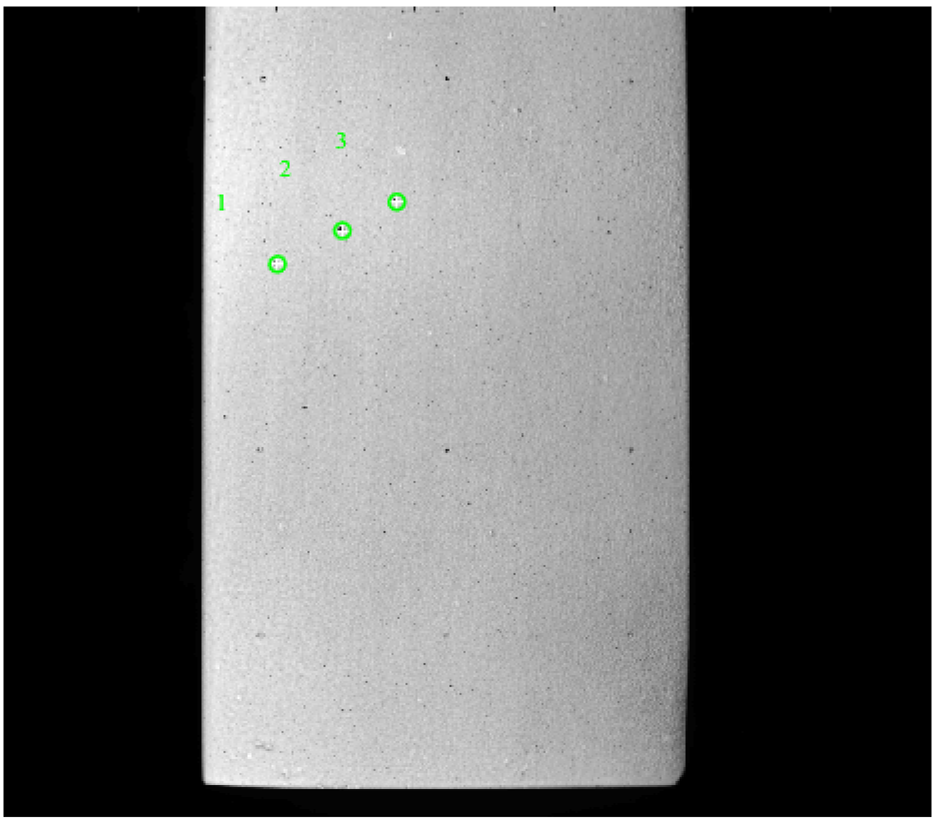
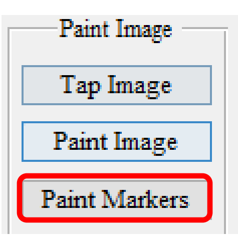


Figure 32: Markers on the Pressure Tap Locations

This marker file can then be loaded by clicking the ***Paint Markers*** button in the ***Paint Image*** section. With this marker file loaded, the tap locations will be shown and numbered on the pressure image.



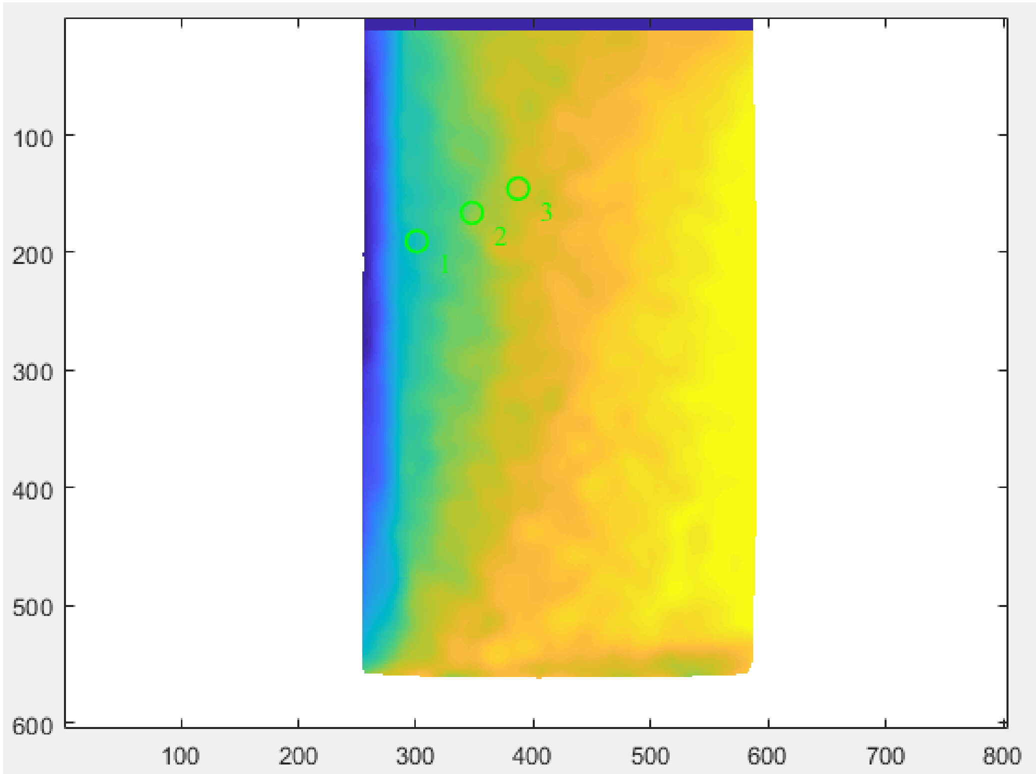


Figure 33: Pressure Tap Marker File Loaded in Bitmap Tap Correction Tool

To load PSP data into the ***PSP Data*** table using the Paint Markers file previously loaded, click ***Paint Data***. This will automatically pull the XY location and the PSP value (in chosen pressure units) and display it.

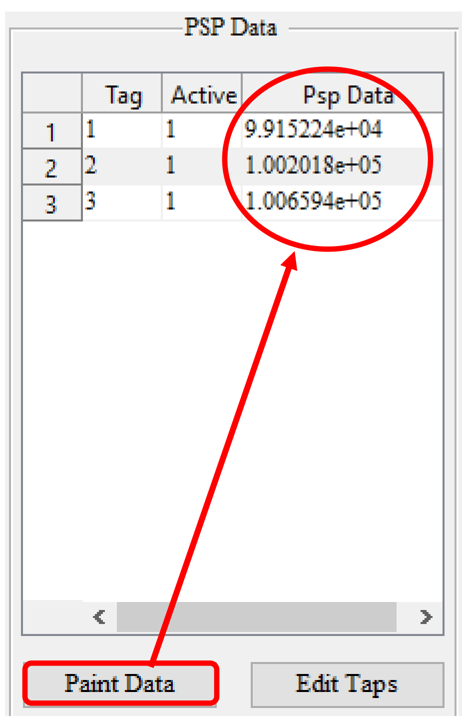


Figure 34: Importing PSP Information at Pressure Tap Locations

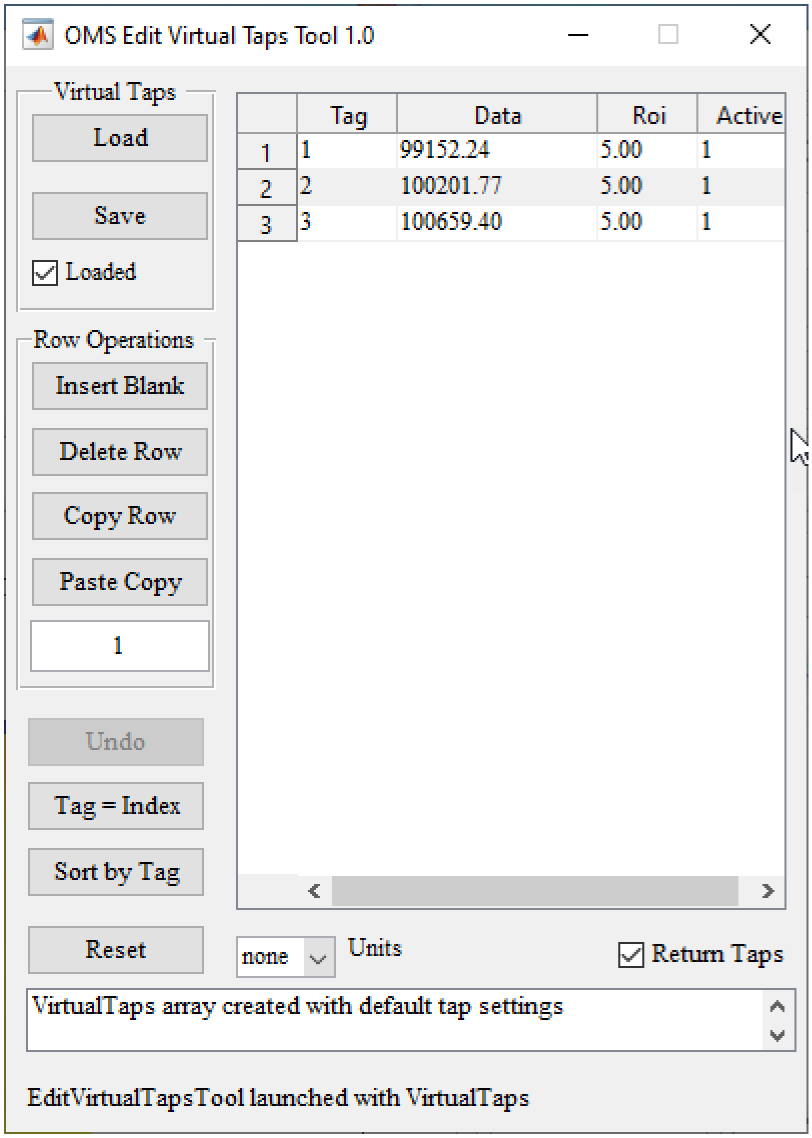


Figure 35: Edit PSP Tap Location Data

Tap Data is the measured value from the physical tap or transducer. This data can be imported from a CSV file with the tap locations and values. To load from a CSV file, click the ***Tap Data*** button underneath the ***Tap Data*** window. Select the CSV file where the tap data is saved. In order to properly read the CSV file, it must have the following headings for each column: *tapTag, tapData, Active*. For this dataset, load the file ***NACA_0012_Tap_Data.csv***.

Once this data has been imported via the CSV file, it can be saved as a virtual tap file (***.virtap*** format) native to OMS 4.0. To create a virtual tap file from a CSV file, click the ***Edit Taps*** button. This will open up a new window called ***OMS Edit Virtual Taps Tool 1.0***.

Within the ***OMS Edit Virtual Taps Tool 1.0*** tool, rows can be added/deleted and values changed. Row Operations will add blank rows, delete rows and copy and past rows. ***Tag = Index*** will match the tag number to the indexed value in the table. If a tag value is greater than the highest index number, it will be changed to match the index. ***Sort by Tag*** will sort the tap tags in numerical order.

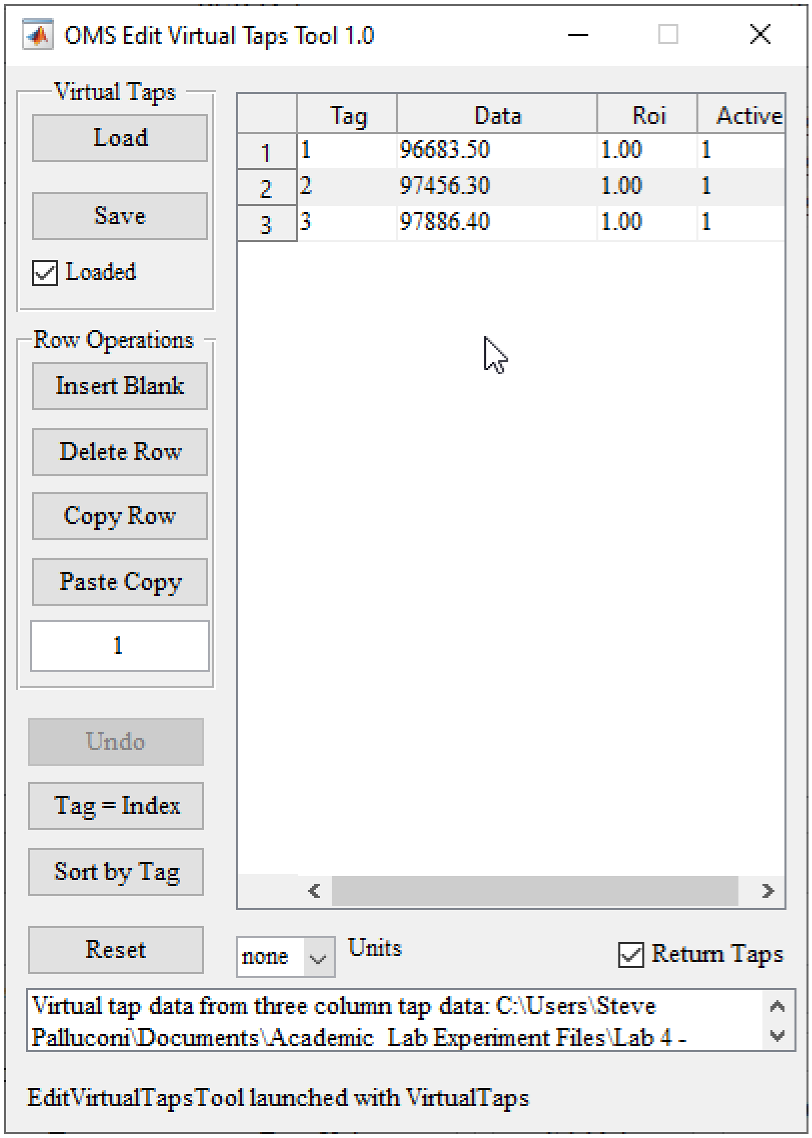


Figure 36: Edit Physical Tap Data from Pressure Scanner

Click ***Save*** to save the data as a virtual tap file that can be used in the OMS 4.0 package. Save the virtual tap file in the same location as the rest of the data from this particular project file.

Map refers to the correlation between the paint tap marker and physical tap location. In some cases, the marker locations selected in OMS for the taps or transducers may not match up with the pressure tap enumeration. This is a way of linking the two so the comparison is done to the correct tap or transducer. This data can be loaded from a CSV file. In order to properly read the CSV file, it must have the following headings for each column: *paintTag, tapTag, Active*. Load the file ***NACA 0012 TapMap.csv*** to load the tap map.

paintTag	tapTag	Active
1	1	1
2	2	1
3	3	1

CSV File

Paint	Tap	Active
1	1	1
2	2	1
3	3	1

Imported Tap Map

Once the tap map is imported, it may be edited within the ***Bitmap Tap Correction Tool*** by clicking on the value and changing it. Active taps = 1, Inactive taps = 0.

Paint Tag > Tap Tag will show the paint marker tag and tap tag on screen so the user can verify they match up correctly.

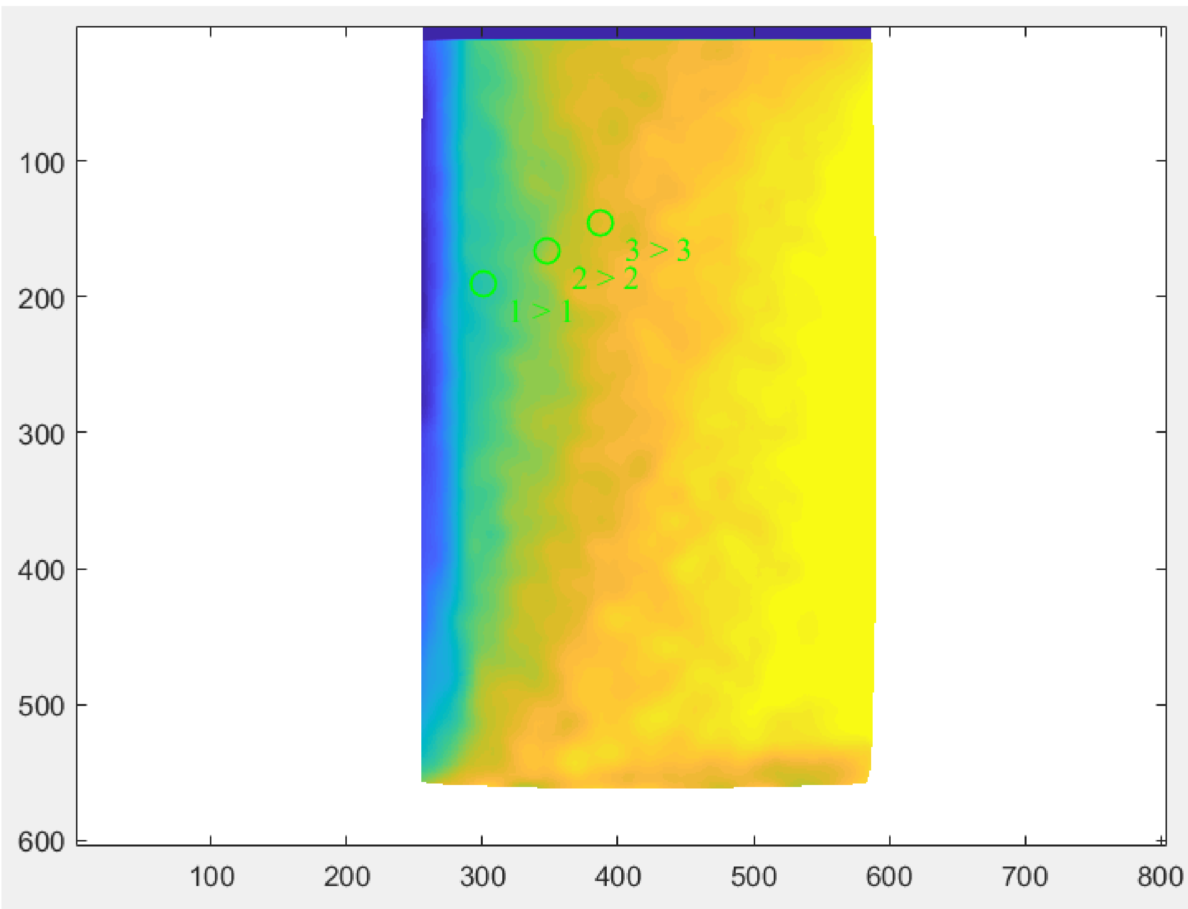


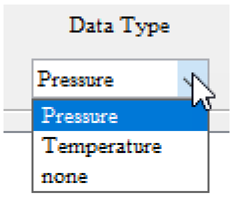
Figure 37: Paint Tag and Tap Tag Matching

When the PSP data, tap data and map have all been loaded and the units set, the tap data can be fit with the PSP data for evaluation.

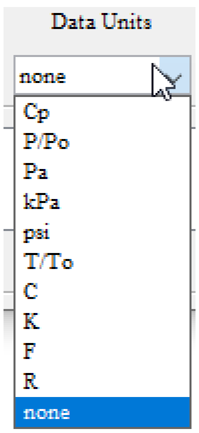
Project Settings

Virtual Tap ROI radius (pixels) is the radius around the marker representing the physical tap the tap correction will use to compute the comparison between taps and PSP/TSP.

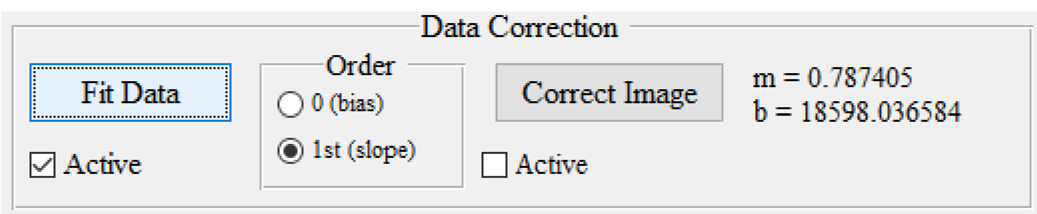
The ***Data Type*** should be selected for either PSP or TSP.



The ***Data Units*** can be chosen from the drop-down menu.

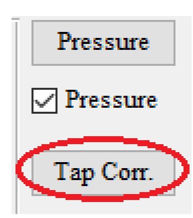


With the project settings complete, click the ***Fit Data*** button to preview the pressure tap bitmap correction.



Choose the order of the fit for the tap correction. The slope and offset will be displayed at right in the Data Correction section. If the correction is acceptable, click ***Correct Image***.

Ensure the ***Return Data*** box is checked then exit the ***Bitmap Tap Correction Tool*** and the data will be automatically loaded into the project file.



Once the pressure tap data has been imported, into the project file, apply the tap correction by the ***Tap Corr.*** Button.

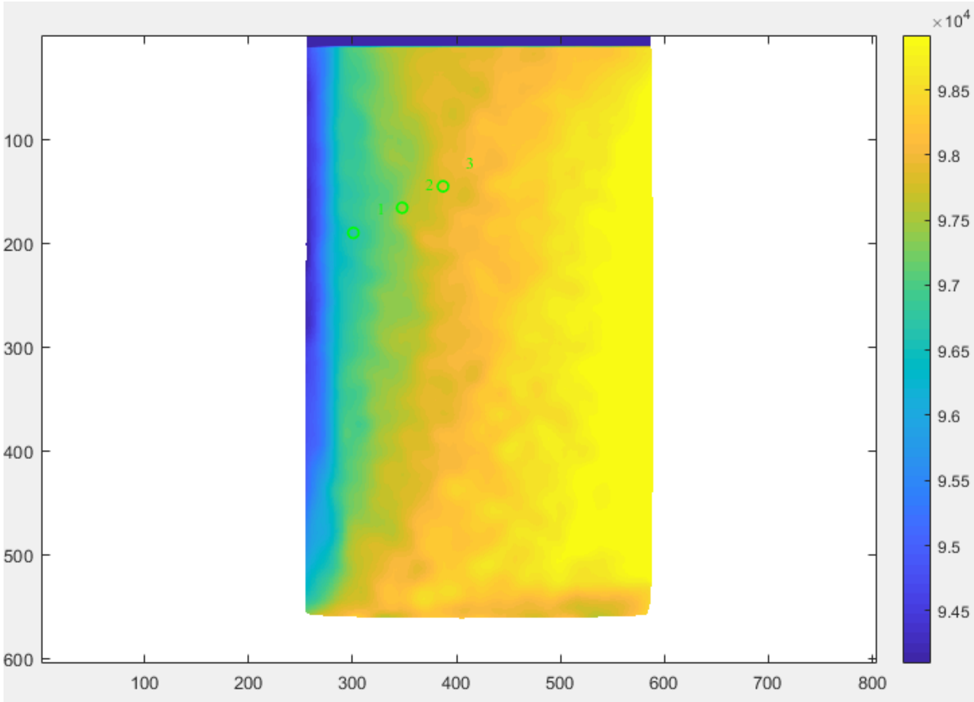


Figure 38: Final Corrected Image After Tap Correction

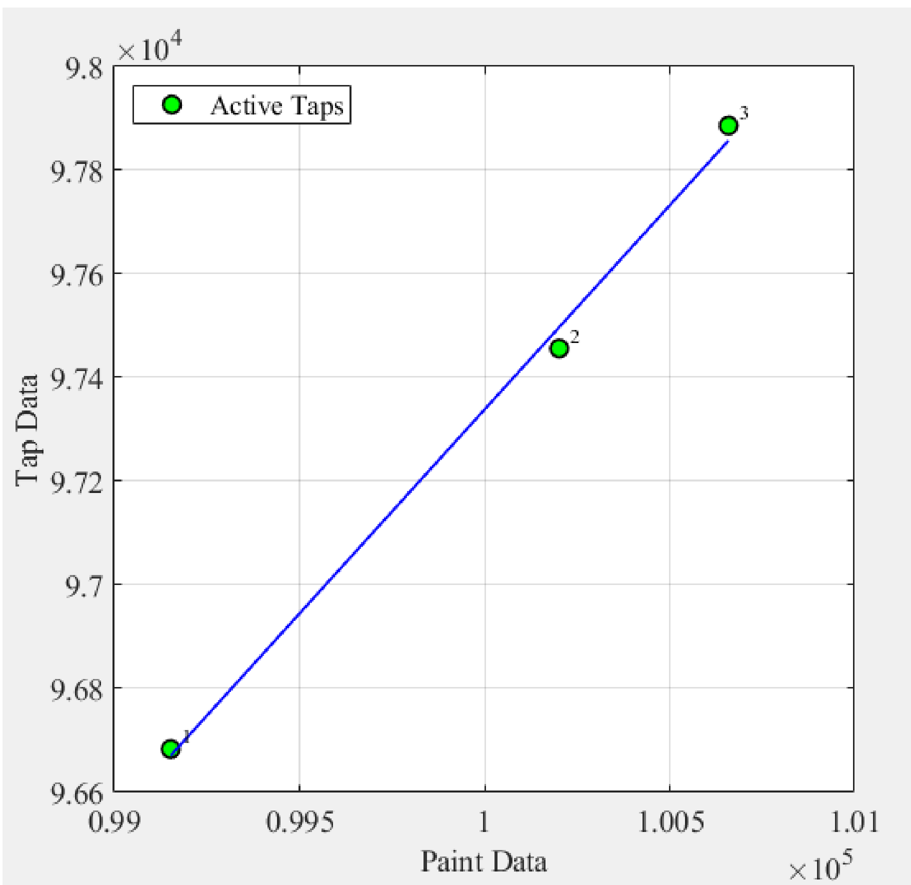


Figure 39: Tap vs. PSP Comparison

Processing Script

The processing script condenses all image processing functions into one window so that they can be saved and used on additional datasets. If you are processing a batch of single images individually, this script can be loaded into each project file rather than re-entering all parameters each time. The script for this dataset is shown in Figure 40.

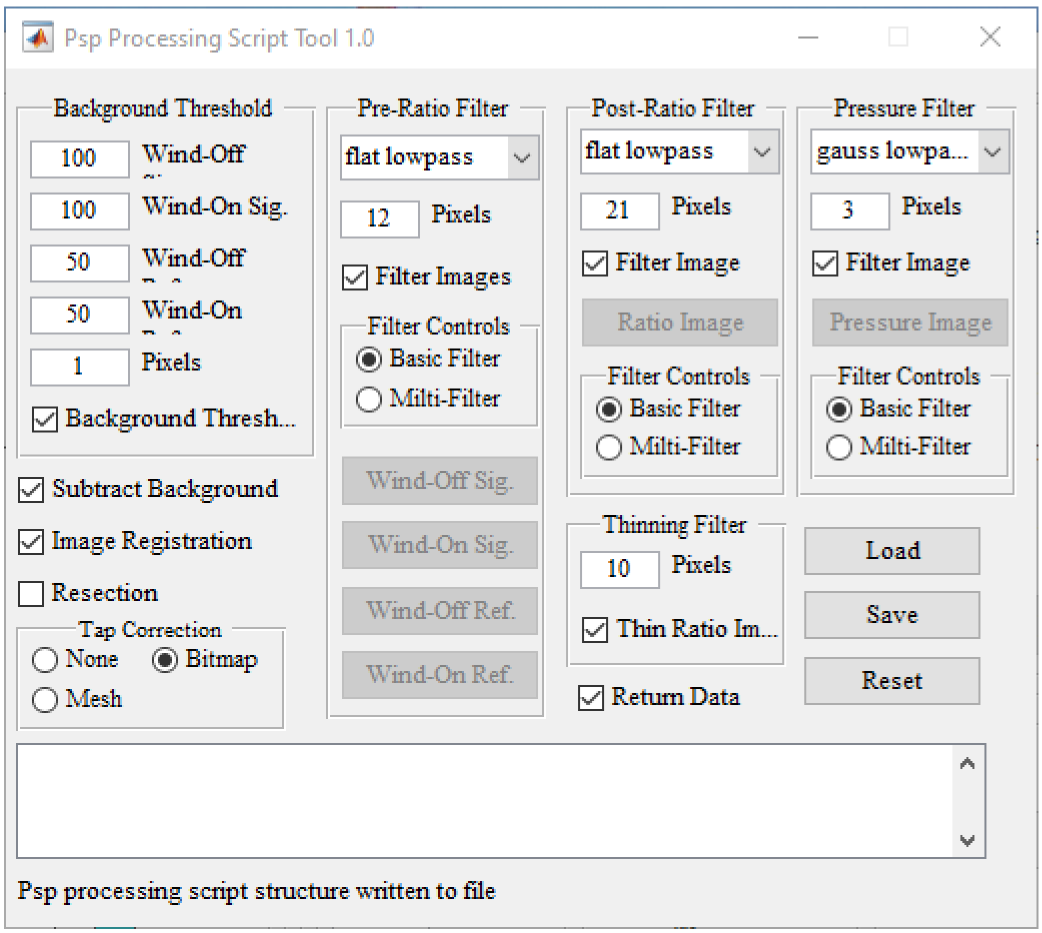


Figure 40: Processing Script for Delta Wing Project

Save this script with your project so it can be used to process additional PSP images from this dataset. To save the script to use for other datasets, click ***Save***. The script will be saved with the file format **.pspscript**.

Conclusions

Figure 41: Effects of a Winglet

The PSP results show good agreement with the pressure tap data which was simultaneously acquired as shown in Figure 38 and 39. Comparing the results to Figure 41, notice the low pressure/suction area near the front of the wing which produces lift. This compares well to CFD calculations of the same NACA 0012 wing. We can also see evidence of a tip vortex on the end of the wing. This vortex, like in the delta wing example, will produce a low-pressure region on the surface. A winglet will minimize the effects of wingtip vortices which disrupt the laminar flow over the wing surface and reduce the efficiency of the wing. The winglet moves the vortex up away from the wing's surface and reduces the lift-induced drag caused by that vortex. As you can see in Figure 41, the vortex on conventional wingtip is much larger than one where a winglet is present. Which is also present in Figure 42 on our PSP experiment.

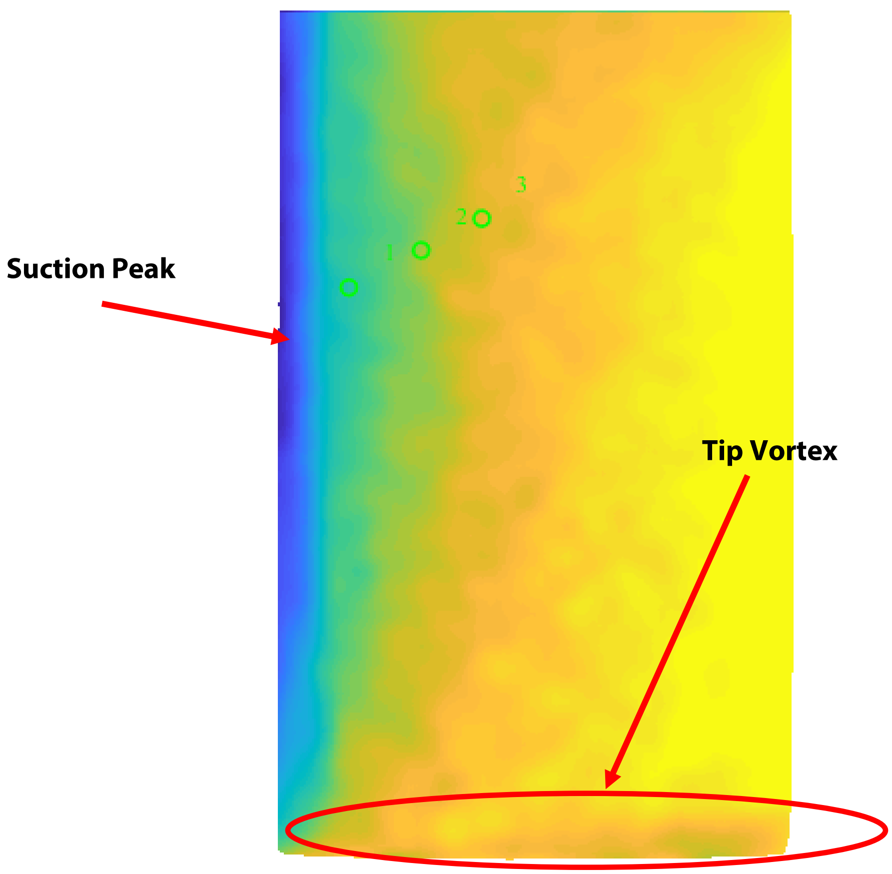


Figure 42: Flow Features over NACA 0012