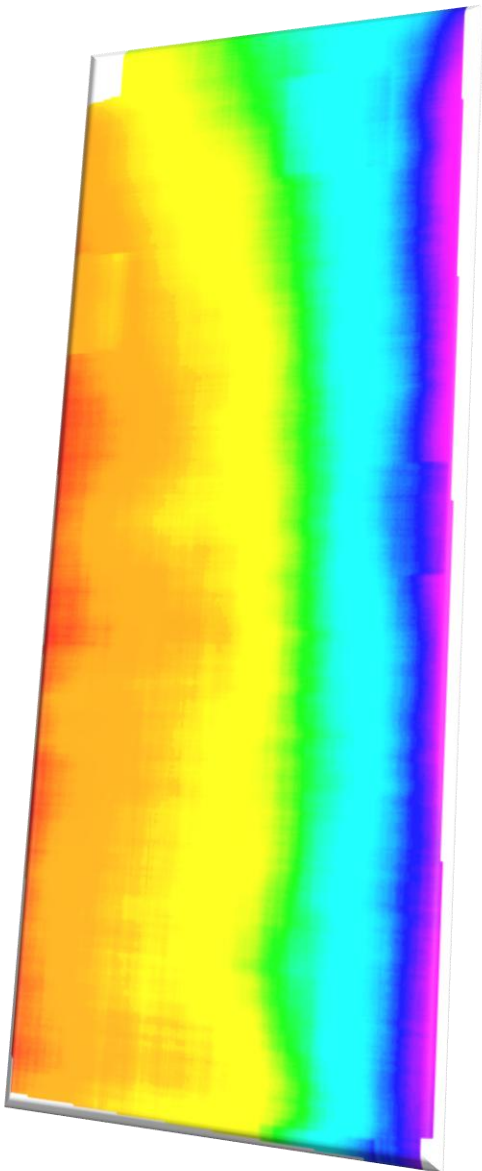


# 2009

## Lab 4: Pressure Gradients over a Wing



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## Lab 4: Pressure Gradients over a Wing

**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.

**Hardware:** The CCD Alta U2000 camera from Apogee is used in conjunction with an LM2X-DM 400nm 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 515 nm long-pass filter. As in the previous labs, the laptop connects to the camera to acquire data through OMS Acquire and then reduces data in OMS Lite. A small NACA 0012 wing is used inside the test window of the low-speed tunnel. Be sure to account for all power supplies and the USB to USB 2.0 cable. Now that all of the equipment is accounted for, it is time to set up the experiment. Users should complete Labs 1-3, which cover basic hardware and software setup and use, before beginning this exercise.



Figure 1: Alta U2000 CCD Camera



Figure 2: LM2X-DM 400 nm LED Array

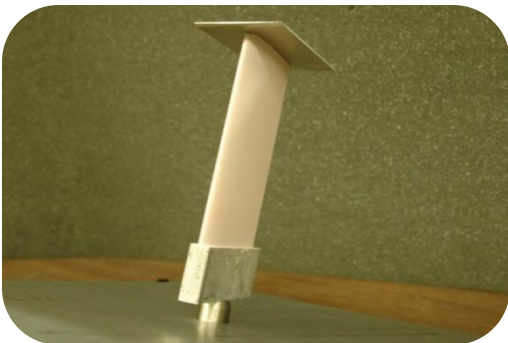


Figure 3: NACA 0012 wing painted with Binary FIB

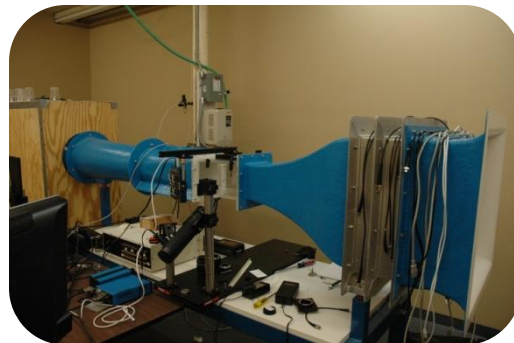


Figure 4: Wind Tunnel

**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. Attach the USB to USB 2.0 cable and the computer

will recognize the connection automatically. More details of experimental setup and data acquisition are explained in Labs 2 and 3.

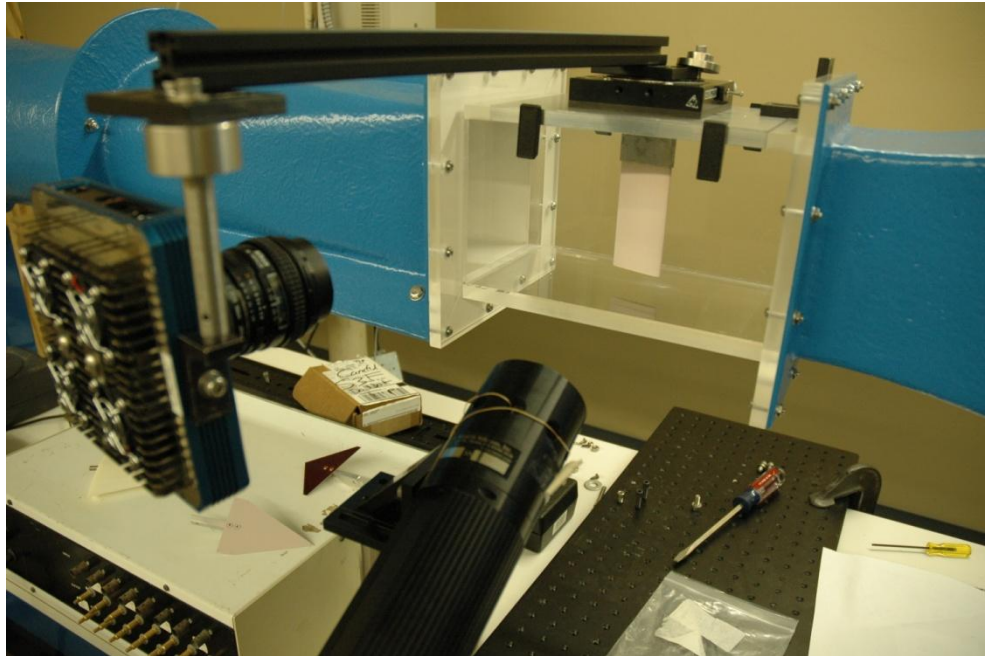



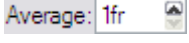


Figure 5: Experimental Setup

The wind tunnel has a 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 OMS Acquire () 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. It is important not to saturate the image by over-exposing it. You can check this by viewing the wind-off image in OMS Lite. Ideally, you want the intensity level to be somewhere in the middle of the spectrum (0-65535 counts). The image is saturated if it is dominated by the highest intensity color on the legend. 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 your 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, shot noise, and wind tunnel speed also have an effect on your data.

Repeat the acquisition process (background, wind-off, and wind-on) with the winglet removed. 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 'PSP Single Channel' option. Select the folder that the image files are saved in. Save the project as *NACA\_0012.ims* or something that will reference the experiment. In the GUI for the Single Channel tab in OMS Lite, load the wind-off, wind-on, and background images. Channel 1 (see Figure 6) will correspond to the signal channel for the camera and should be the image with the highest intensity when viewed. Use this signal channel for each of the images you load if you are using the 'PSP Single Channel' option. View the wind-off and wind-on images to determine what the dark threshold is. The dark threshold is typically around the same value in both images. Compute the

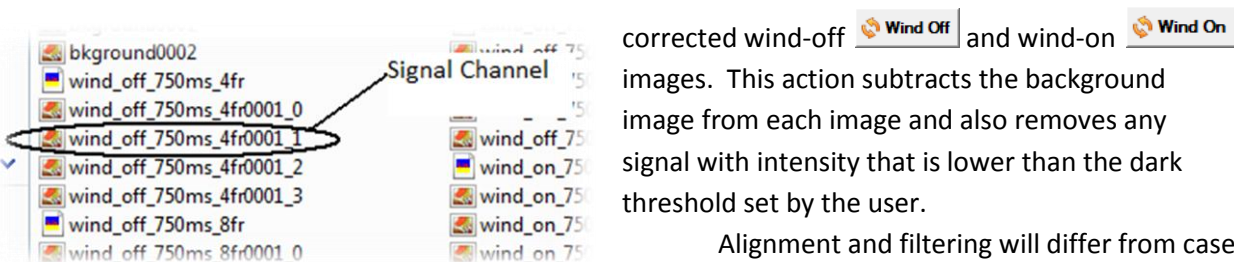




Figure 6: Signal Channel

corrected wind-off  and wind-on  images. This action subtracts the background image from each image and also removes any signal with intensity that is lower than the dark threshold set by the user. Alignment and filtering will differ from case to case. Since we averaged a large number of frames when we captured each image, the pressure distribution should be somewhat visible with little processing. However, since this was done at such a low speed, it is necessary to align and filter the image so that the pressure distribution is more clearly seen by the user. Either one or both of the two alignment tools (Markers and QPED) can be used to align the image. Applying the low-pass smoothing filter (Median Filter,  $D_x=D_y=45$ ) will give a nicer graph of the pressure distribution across the wing and eliminate the small perturbations in the data. Smoothing the aligned images will also thicken the edges of the painted areas, which is undesirable. Thinning (pixel size = 15) will remove/reduce these edge effects. To completely eliminate these edge effects, set the pixel size of the thinning filter equal to the maximum x or y value used for smoothing. In this case, the leading edge should have a significant pressure spike as it is the first point to encounter the flow (see Figure 7).

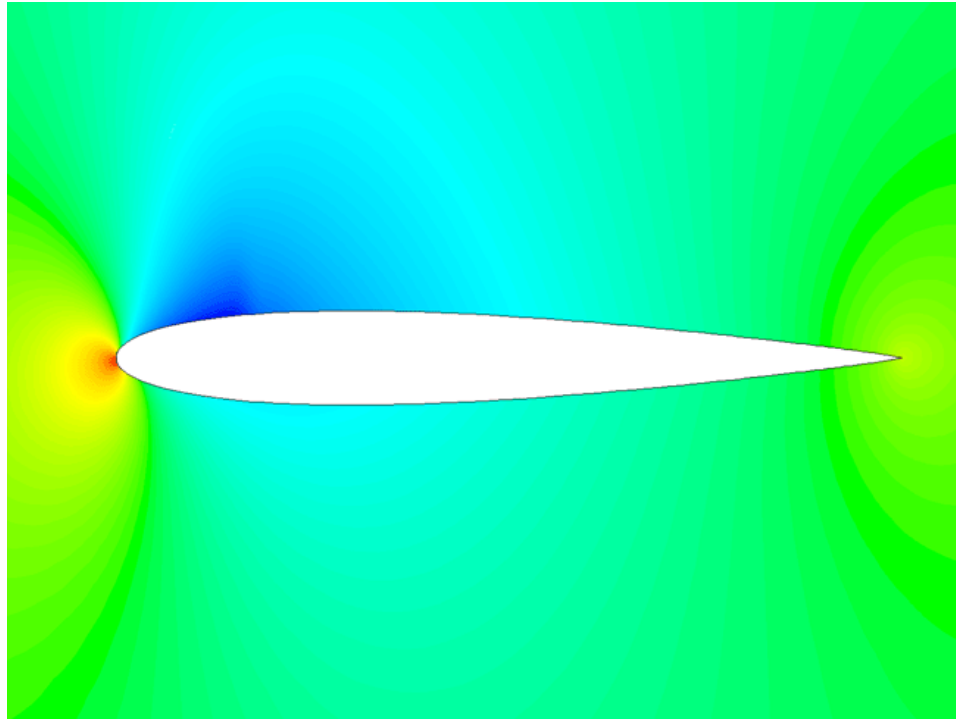


Figure 7: Computational Fluid Dynamics Model of NACA 0012 wing (Courtesy: Fluent online)

The leading edge pressure spike is difficult to see here (Figure 8 and 9) because the wing was placed at a slight angle of attack (5 degrees). Spatial resolution of the camera is also a limiting factor in seeing the pressure spike but it can be seen graphically in Figure 9. The airflow is traveling from top to bottom of the page and the figure shows the top of the wing.

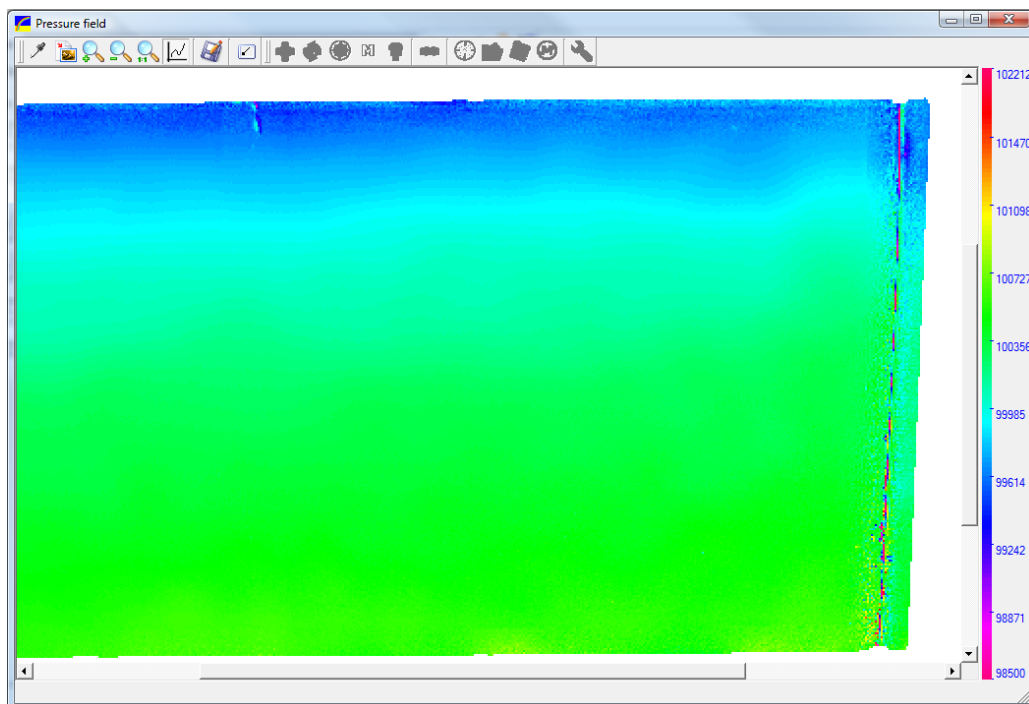
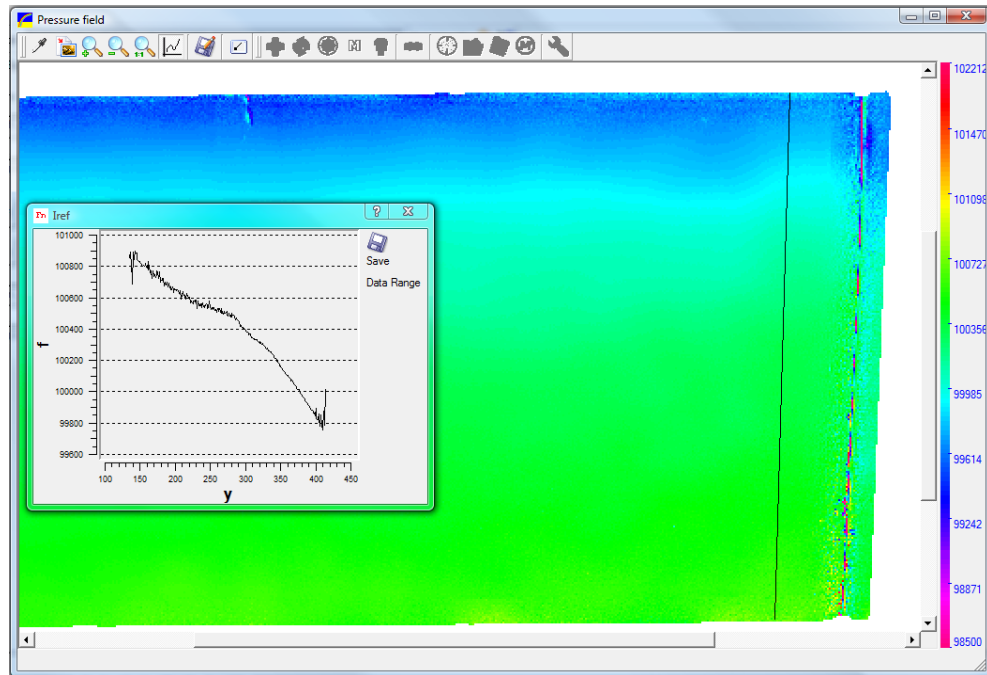



Figure 8: Pressure field with winglet, 5 AOA, 30 m/s

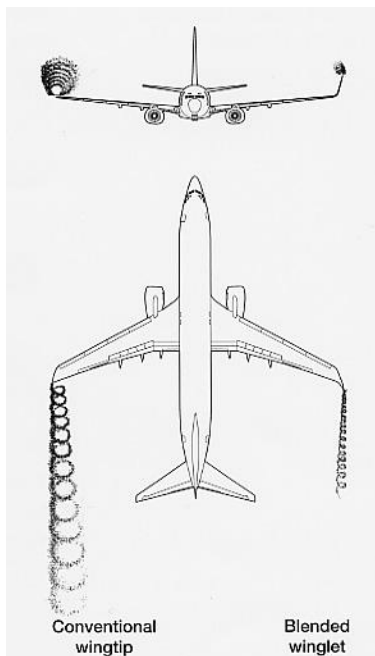





**Figure 9: Graphical representation of pressure field over wing**

Figure 9 shows the pressure distribution over the wing graphically. For this lab, Paint min was set to 98,500 Pa, and Paint max was set to 102,212 Pa to give the displayed images. When graphing this (  ), place the line near the winglet. The graph is read right-to-left corresponding to nose-to-tail on the image. Compare this to Figure 7 and notice the low pressure/suction area near the front of the wing which produces lift. A winglet was used for this run to 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 10, the vortex on conventional wingtip is much larger than one where a winglet is present. The winglet used here is just a flat plate attached normal to the wing for demonstration purposes, but the design behind most winglets is more complex.



**Figure 10: Effects of a winglet**

If we remove the winglet and run the experiment again using the same conditions as before we can see a big difference in the flow over the wing, as expected. Figure 11 shows the pressure distribution over the wing with the winglet removed and you can easily see the difference the winglet makes just by observation. If we apply a graph to the image, it is even more evident that the winglet has a great effect near the wingtip. When using the graphing tool (  ) on the pressure images, pick an area near the end of the wing close to the winglet so that its effect can be better seen.

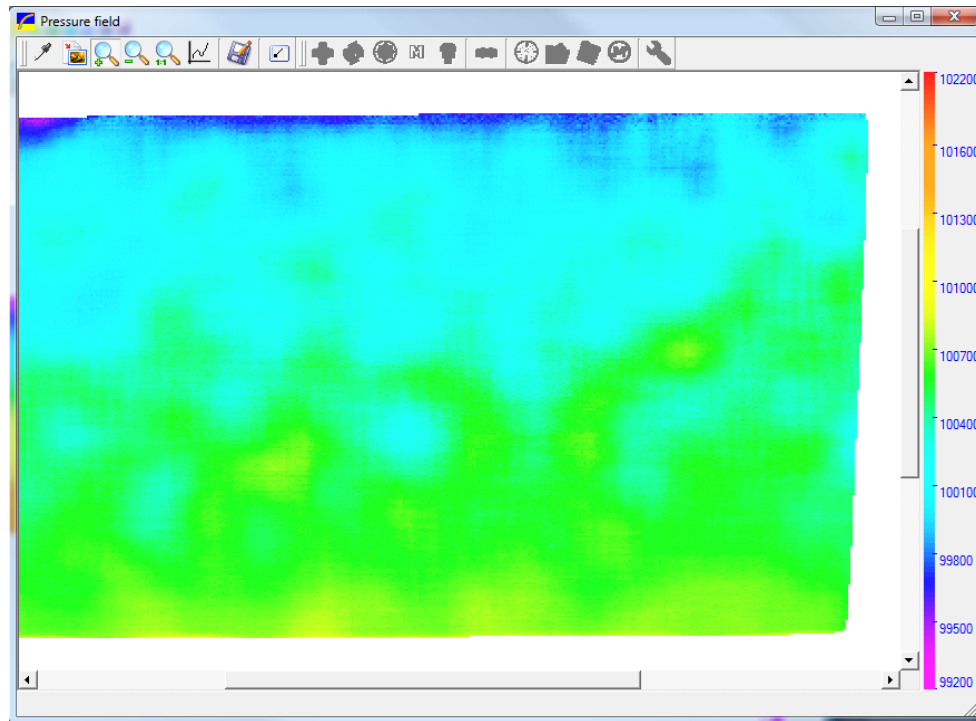


Figure 11: Pressure field with winglet removed, 5 AOA, 30 m/s

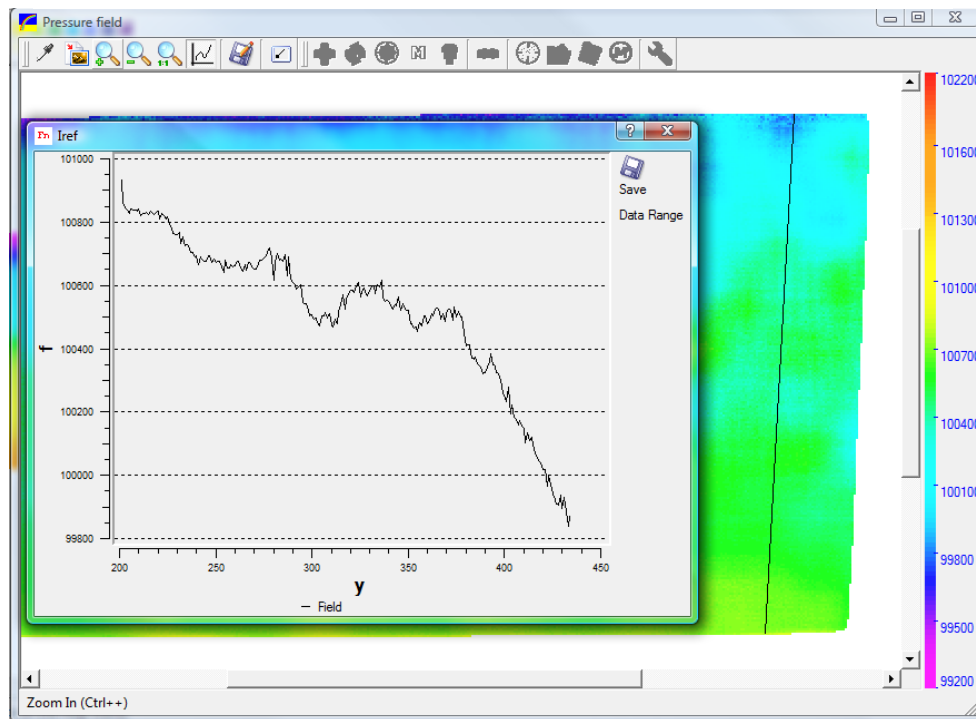


Figure 12: Graphical representation of pressure field over wing

It can be observed by viewing Figures 11 and 12 that the winglet has a large effect on the airflow over the wing. The graph of the pressure field shows disruption of the flow by the vortex and thus increased drag on the wing.

Use the filtering and alignment to fit your model and show the pressure field over the wing. When converting the image to pressure use the calibration file that corresponds to the paint you used. Binary FIB excited at 400 nm was used in this demonstration. Adjust the paint min and max levels after data processing to see the pressure field more clearly. This adjustment does nothing to affect your pressure data; it only enhances what you see. Figures 13-16 show each condition focused on the upper right region of the wing. Zooming in this far with the camera increases the spatial resolution and further illustrates the effect of the winglet. For more explanation of the data reduction procedure and more OMS Lite features, see Lab 3 which covers this process in great detail.

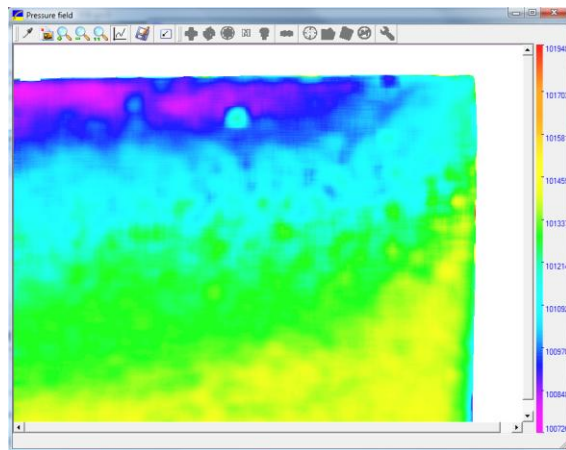


Figure 13: Without winglet

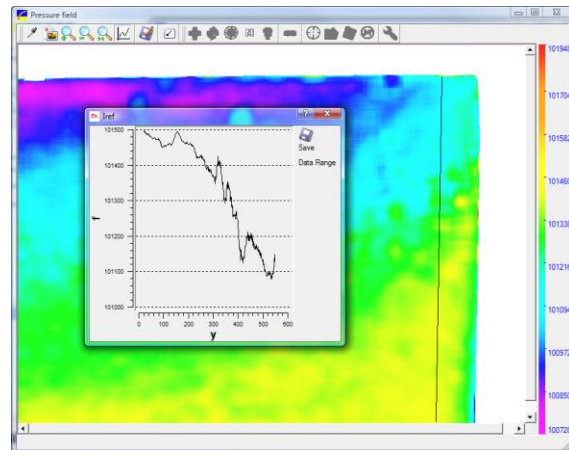


Figure 14: Without winglet graphed

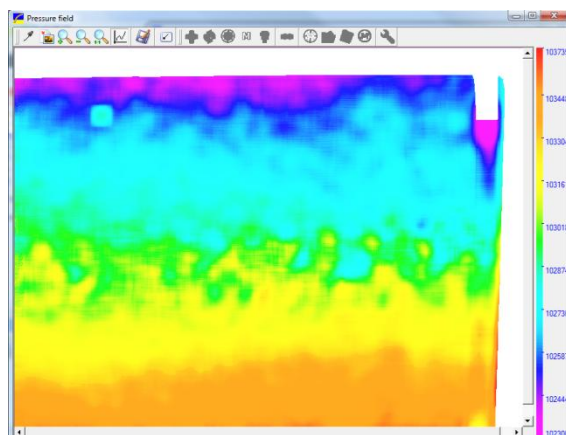


Figure 15: With winglet

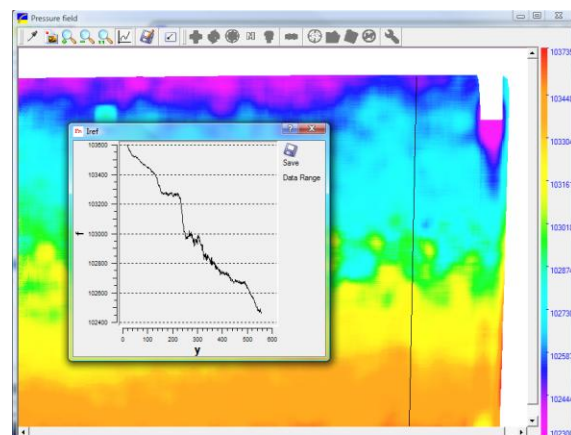


Figure 16: With winglet graphed



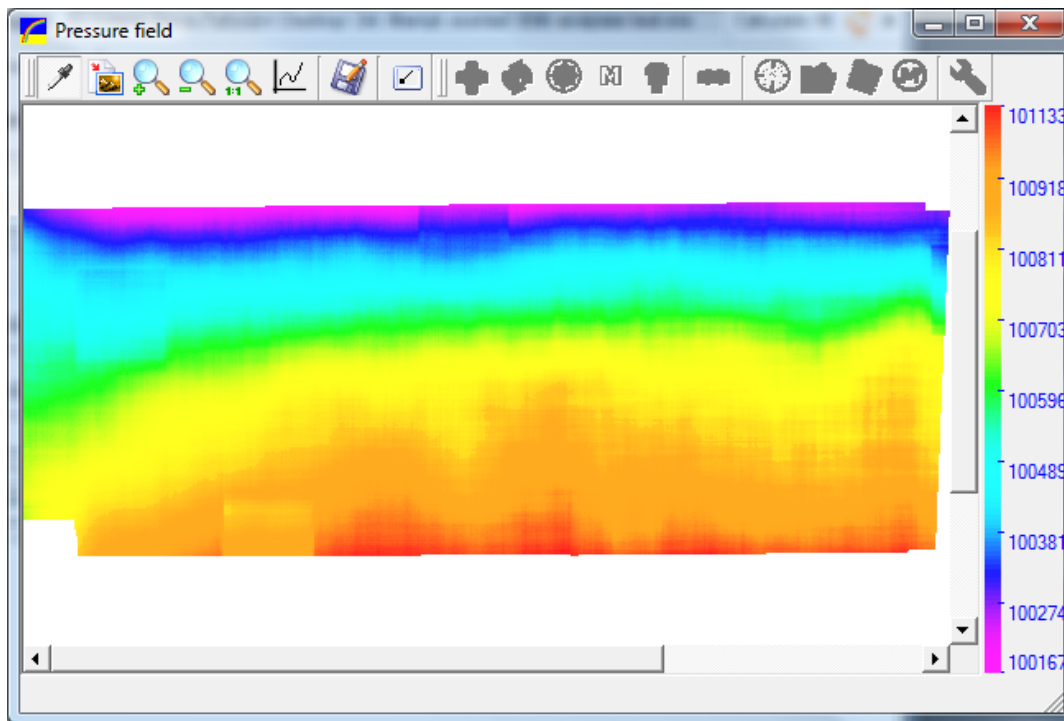


Figure 17: Large smoothing filter with winglet attached

Increasing the size of the low pass filter gives a more visible representation of the disturbance of the flow over the wing as evidenced in Figures 17 and 18. With the winglet attached (on the right side of Figure 17) we have a nice pressure profile along the length of the wing and once the winglet is removed, that pressure profile is disrupted by the vortex leading to an increased drag on the wing.

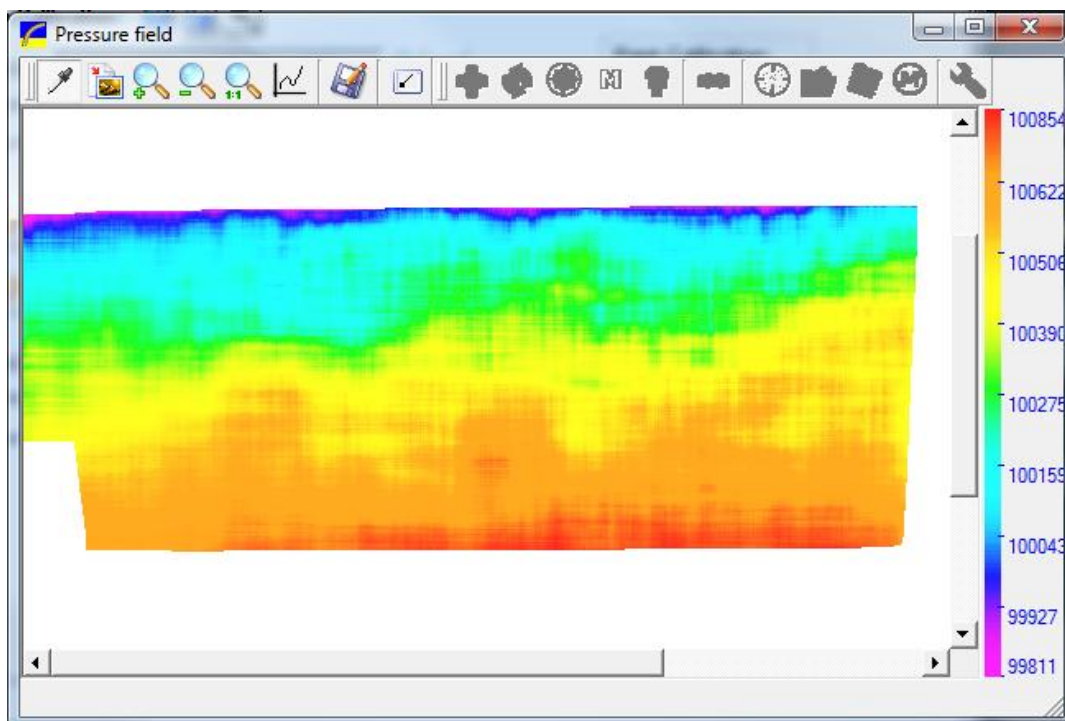


Figure 18: Large smoothing filter with winglet removed