PHANTOM®

2020
CASE STUDY

Stopping the Spread

How a high-speed imaging technique called Background Oriented Schlieren can help medical researchers understand the critical role masks play in minimizing contagion.

As COVID-19 continues to keep people indoors and grocery shoppers six feet apart, many researchers are looking to understand the efficacy of face masks. From N95 respirators to handmade cloth coverings, not all masks are created equal. One way to evaluate how well a mask works is to actually see what's happening when its wearer coughs or sneezes.

Fortunately, "seeing" a cough is not only possible—it's been done. Dr. Kyle Gilroy, a field applications engineer for Vision Research, recently performed a series of experiments in his home during the coronavirus pandemic. His aim was to study mask performance using a high-speed imaging technique called Background Oriented Schlieren (BOS), which visualizes airflow based on local refractive index variations.

The results of these experiments remind us how important it is to cover our mouths while in public. The proper use of face masks can limit our exposure to the virus while helping to keep others safe.

BOS VERSUS TRADITIONAL SCHLIEREN IMAGING

BOS is a modern, digital version of traditional Schlieren Imaging, a non-invasive imaging technique that allows researchers to visualize gradients within otherwise invisible air flows. These gradients are determined by environmental factors such as pressure or temperature variations. As light rays scatter from a speckled background and through a medium, only slight variations in the air are necessary to induce a change in the direction of light in a way that can be imaged using high-speed cameras.

Unlike traditional Schlieren Imaging, which uses specialized parabolic mirrors, BOS requires a simpler optical setup. In fact, Gilroy performed these experiments in his home using materials he already had. He painted a large piece of drywall flat-white and then added thousands of small, black dots to the surface. "Gradients in the air distort the speckles much like how light appears to shimmer on the road on a hot day," Gilroy explains. "Any variation in temperature changes the refractive index of the air—whether you breathe, cough or light a match. The measured distortions reveal the air flow, which we can image using the camera."

TRADITIONAL SCHLIEREN: A COMPLEX OPTICAL SETUP

Traditional Schlieren Imaging often requires a suitable optics table, a pair of concave mirrors, a point light source, a high-speed camera and a knife edge. In a typical Z-type system, one mirror collimates light rays onto the second mirror, which evenly directs light to the camera. Variations in the refractive index gradient around the subject (located between the two mirrors) change the direction of the light. Adding a knife edge to the focal point of the second mirror blocks some of the light, which provides contrast to local gradients in the air that become visible for the camera.

In addition to a speckled, white backdrop, the BOS experimental setup included two, high-intensity LED lights and a Phantom VEO4K 990 high-speed camera.

THE BASEMENT SETUP

In addition to the speckled backdrop, Gilroy's BOS experiments included two, high-intensity LED lights, which he set up on each side of the drywall. These lights illuminated the board while keeping the subject dark. The setup also included a Phantom VEO4K 990, which recorded the test subjects at 938 frames per second (fps). The camera's 4K sensor made it an ideal choice for the mask experiments, which require high resolution to detect the small, granular variations in airflow generated by talking, sneezing and coughing. In terms of scale, the typical size of respiratory droplets falls between 10 and 150 micrometers, while the viruses themselves—which are believed to spread through these droplets—are roughly 200 to 1,000 nanometers. "Characterization of the droplets themselves necessitate the use of advanced imaging techniques, like coupling with high-magnification optics or some sort of dark-field light-scattering scattering strategy," Gilroy says.

A black marker is being used make small dots in places on the drywall with relatively low speckle areal density. The image of these speckles by the camera are what become distorted by slight changes in the air, revealing the air flow that can be imaged using a high-speed camera.

To improve image quality even further, Gilroy operated the VEO4K in rolling shutter mode, a feature typically found in CMOS sensors. As a result, the camera collects data sequentially row by row rather than all at once. Rolling shutter mode increases dynamic range, reduces image noise (granular distortion in shadowy areas) and yields higher-quality images. "BOS is extremely sensitive to noise, so you want to eliminate it as much as possible," Gilroy explains. "We had to take additional steps when setting up our mask experiments like turning off the heat in the house. We also had to make sure the camera fan was off when we recorded, and we could only turn on the lights and camera right before each shot."

Once the experimental setup was complete, Gilroy recorded his subject talking, sneezing and coughing. For some takes, the subject wore a simple, single-use surgical mask. For other takes, the subject wore no covering at all. All images were captured at 938 fps, which is the camera's maximum speed at full 4096 x 2304 resolution, and processed by Dr. Callum Gray (CEO, LaVision) using LaVision software.

MORE ON THE PHANTOM VEO4K 990

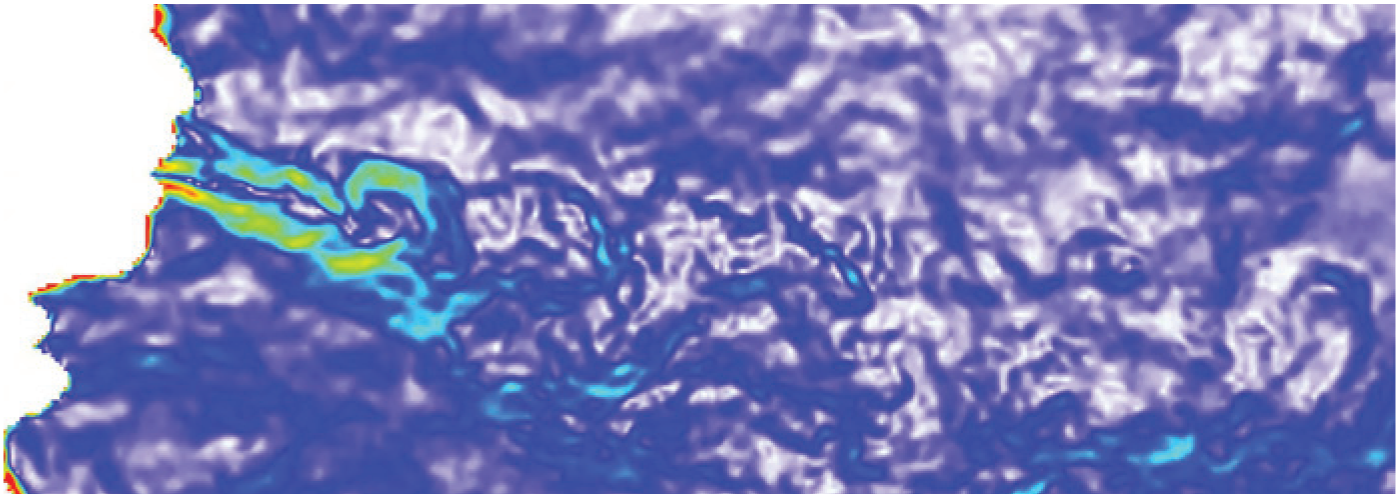
The Phantom VEO4K 990 is an ideal imaging tool for BOS, which requires high resolution and low noise:

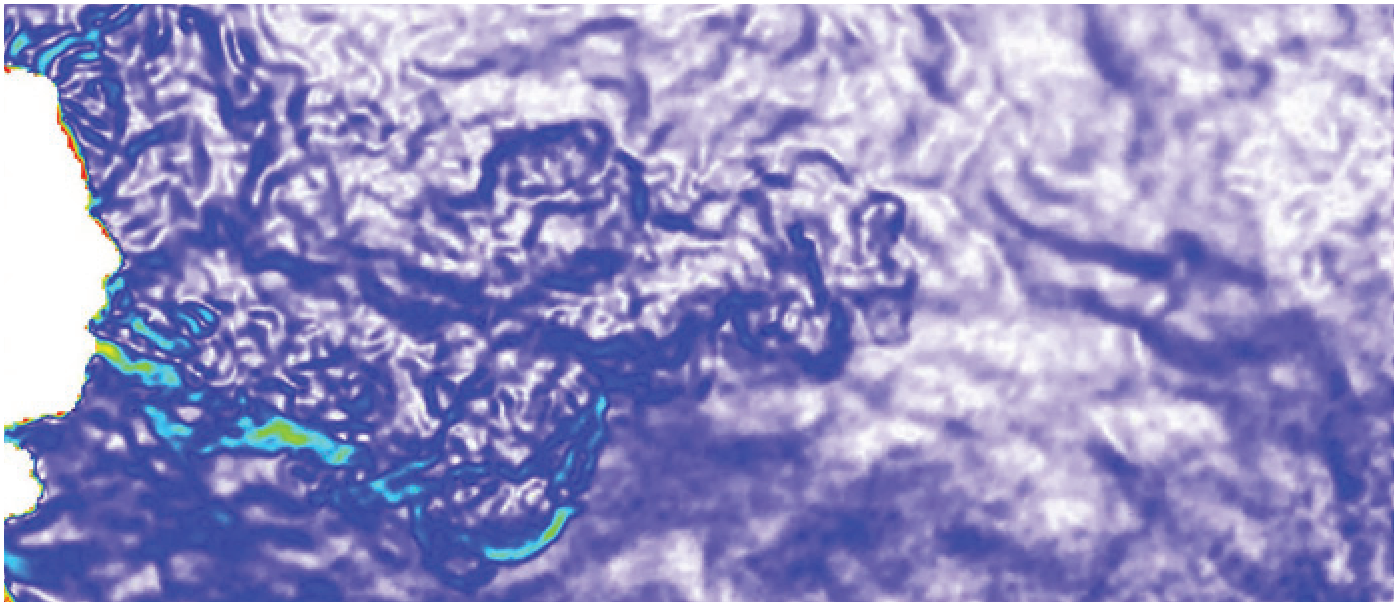
- **Resolution.** The VEO4K 990 utilizes a custom 9.4-megapixel CMOS sensor, which provides exceptional resolution—especially in applications that demand resolving fine object features. In addition to Schlieren techniques for visualizing airflow, it's very effective in applications like particle tracking analysis, which involve subtle movement across large spaces.
- **Low noise.** The VEO4K's rolling shutter mode features extremely low read noise at less than 10 electrons. It also features quiet fans, eliminating audible noise and vibration in sensitive applications. This feature played a critical role in Gilroy's BOS experiments, which relied on the elimination of vibration in order to effectively visualize airflow variations due to temperature, pressure and density.
- **Flexibility.** A perfect fit for the at-home BOS experiments, the VEO4K is designed to be flexible. It features a compact, portable body and is also compatible with a variety of lenses, including Nikon, PL, C and Canon EF.

Phantom VEO4K 990

THE IMPORTANCE OF COVERING OUR MOUTHS

The high-speed footage revealed that when people talk or cough without a mask, they emit a large volume of hot, saturated gas from their mouths. As shown in previous research studies, gravity pulls many of the large droplets downward while other small droplets, called bioaerosols, float around like a cloud and remain in the air. In this case, the footage showed how effective masks are at minimizing variations in *airflow*—and therefore the spread of gases into the immediate volume. "We can't see any of this happening without the help of advanced imaging techniques," Gilroy says. "That's what makes the spread of this virus so dangerous. It's not like we can just go out in public and avoid people's clouds."





As evident by the footage, when people talk or cough without a mask, they emit a large volume of hot, saturated gas from their mouths.

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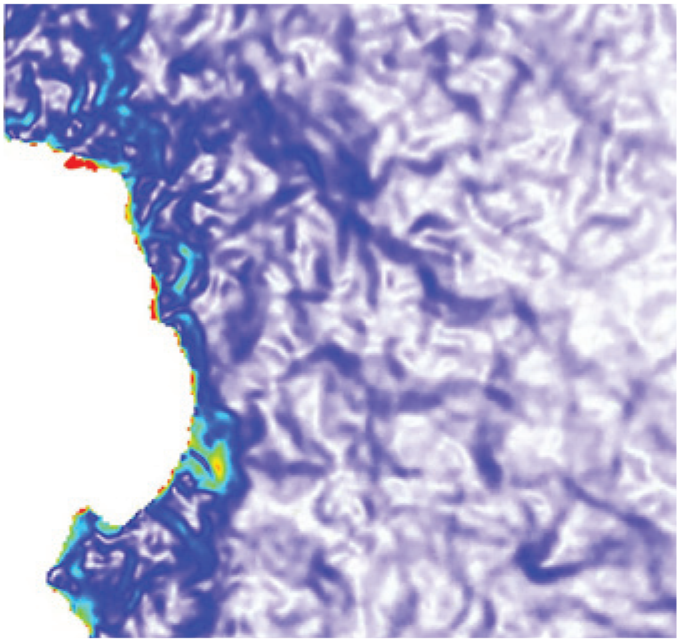
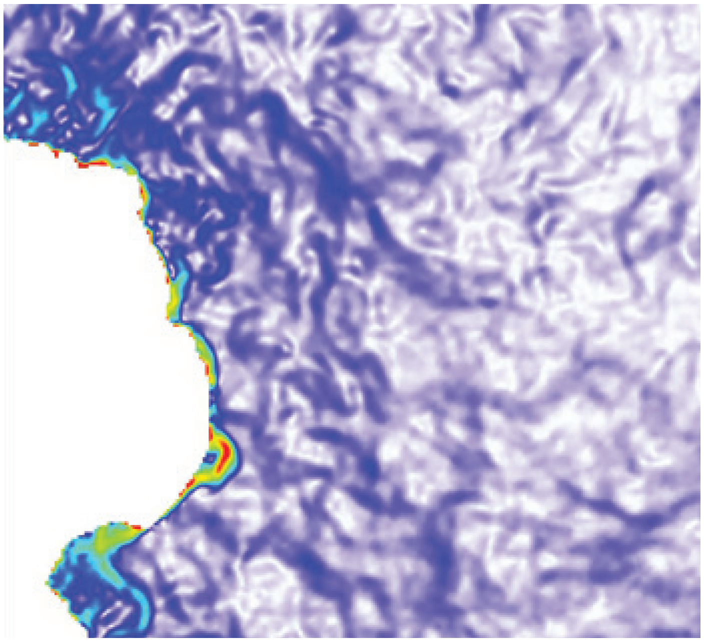
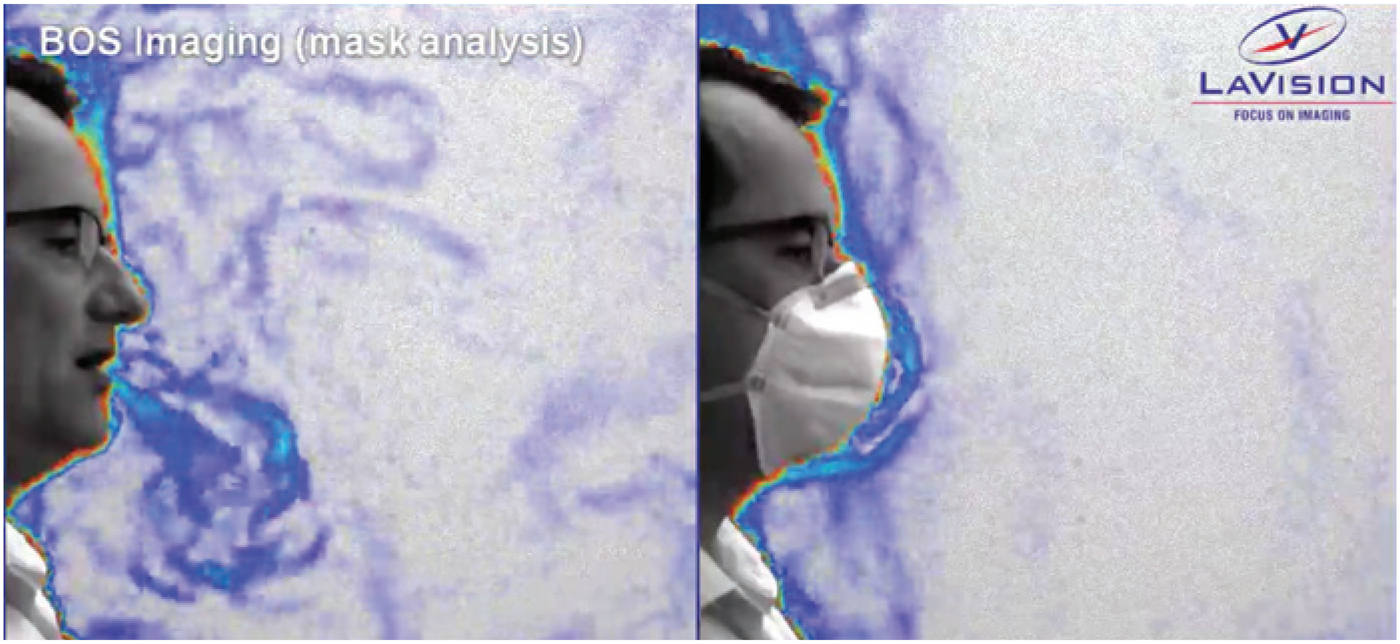




The high-speed footage also showed how effective masks are at minimizing variations in airflow—and therefore the spread of gases.



BOS images generated by LaVisions Imager M-Lite & BOS software. This shows talking with and without a mask.
(Re-printed with permission from Dr. Callum Gray of LaVision Inc)

A key takeaway from these experiments is the importance of wearing masks in public—even cheap, single-use variants. As demonstrated by the coughing subject in the high-speed video, masks play a critical role in minimizing the spread of respiratory gases to others. "A lot of people might have their doubts about covering their faces," Gilroy says. "But whether they breathe, talk or cough, you can see very clearly the gases originating from their mouths and then spreading—possibly to others. This footage demonstrates why we need to take mouth-covering during this pandemic seriously."

So far, Gilroy and Gray have evaluated single-use surgical masks and have extended these BOS experiments to many others—including homemade and knitted masks, as well as medical-grade N95 masks. He conducted this research in conjunction with Dr. Legna Figueroa Cosme, physical chemist and independent researcher, and Dr. Callum Gray, CEO of LaVision.

To learn more about Vision Research high-speed expertise and equipment,
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