THE IMPORTANCE OF CONTROLLING YOUR LAB ENVIRONMENT

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Technical Notes from the Instron® Product R&D Team
on CDAT Airflow Technology in the AVE3

The Invisible Problem

The experienced lab manager, engineer, or operator understands that even our best efforts cannot make lab conditions perfect. Environmental variables such as lab temperature and humidity constantly fluctuate. We try our best to control and record these factors to keep our tests and experiments consistent and our uncertainty low.

One variable, however, has a great impact on data captured by video extensometry devices: fluctuations in air density. You've likely witnessed the effect of air density fluctuations with your own eyes on a macro scale – these effects manifest themselves as optical mirages or heat haze. See Figures 1 and 2 below for examples.

Since the air in a lab is almost never constant with respect to air densities, video extensometry is subjected to this same mirage/heat haze effect but on a "micro" level. This means that the gauge dots you paint on your specimen will appear to move and shimmer, even though your specimen isn't moving. Figure 3 shows an image of a specimen with dots applied – there is no visible mirage to the eye, but they are there on a micro scale, and it should be remembered that we are measuring at micron scale with the video extensometer. We will prove it to you later in this paper.

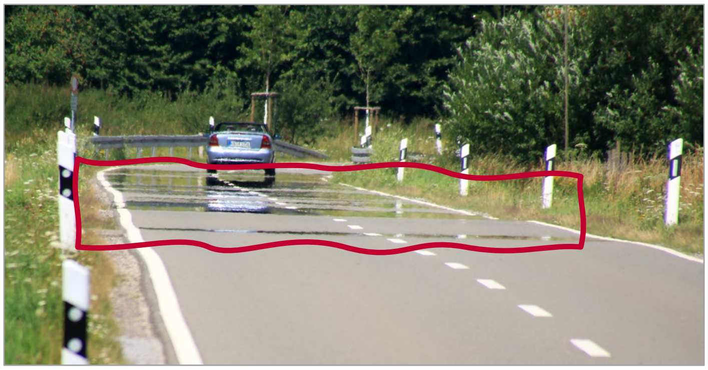


Figure 1
A mirage appears on a road on a hot day.

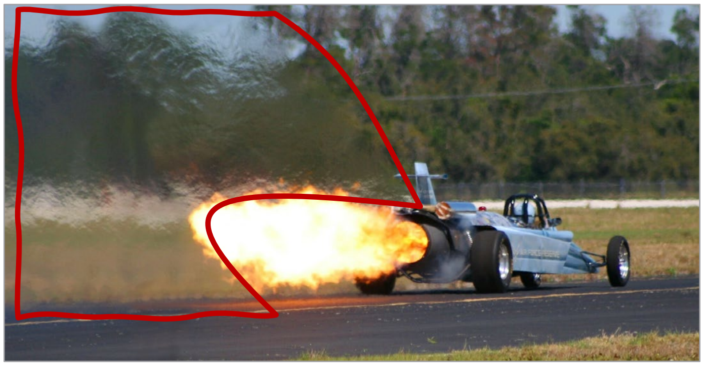


Figure 2
Heat haze from the exhaust of a rocket car.

Figure 3
An image from the AVE 2

The Experimental Setup

Instrumentation manufacturers typically apply filtering to reduce signal noise, but any given low pass filter frequency comes at the expense of an associated signal lag. However, by doing this, the recorded data will have a lag: i.e., the most recent data that is displayed to you is representative of the specimen's state at a previous point in time. Data with significant lag now means that the load data is out-of-sync with strain data, which brings data integrity into question. Laggy data also poses significant issues for tests that require closed loop control.

Instead of applying heavy averaging and filtering to overcome this problem, Instron has decided to tackle the core of the issue by mitigating the effects of air density fluctuations up front. To make any change to our design, we must first get a visual grasp of what is happening in the test space with our system with respect to changes in air densities – we need to see the invisible.

To see the invisible, we conducted speckle-based Background Oriented Schlieren (BOS) experiments with our system using the Instron AVE3 advanced video extensometer as the image capture device. BOS has been used with great success in other industries such as aerospace, automotive, and medicine to better visualize invisible gas flow. (See Figures 5 and 6.)

BOS works by having a static reference object (typically a speckle target – see Figure 7), placing this object roughly 350 mm away (a common working distance for video extensometry) from the camera, then capturing images and observing the changes in the static reference. Ignoring noise sources in the digital image capture process, any changes in the static reference as seen by the camera can be said to be due to changes in air density – i.e., mirage/heat haze effects.

Instron's experimental setup can be seen in Figure 4. We inserted a speckle target (Figure 7) into manual wedge grips to emulate the location of the specimen and placed a hot plate in between the AVE3 and the speckle target to introduce a controlled level of heat haze/disturbances.

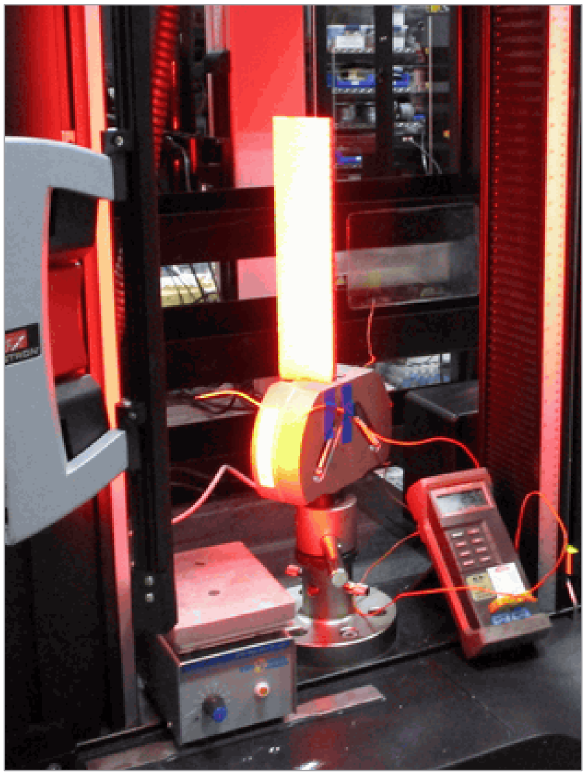


Figure 4
Instron's BOS experimental setup.

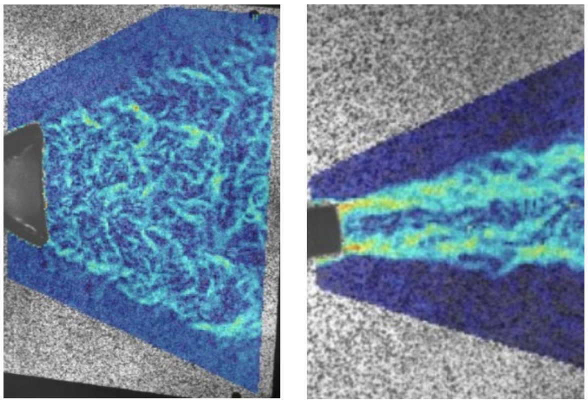


Figure 5
BOS data of a flat nozzle heat gun viewed from the top and side
(Source: Weisberger et al., NASA)

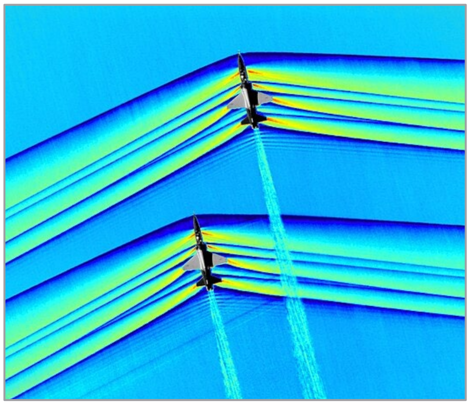


Figure 6
BOS data of supersonic shockwaves
(Source: JT Heineck, NASA)

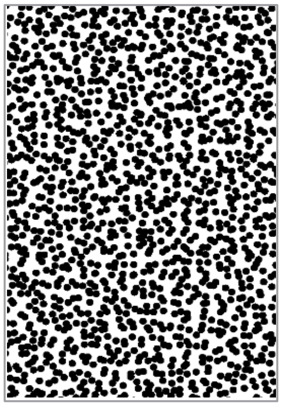


Figure 7
A speckle target

BOS Experimental Data, Observations, and Results

To set the scene, the capture rate of the BOS/image data is 500 Hz, so the time difference between any two image frames is 2 ms (0.002 seconds). Figures 8a and 8b are sequential image frames; likewise with Figures 9a and 9b. The experimental setup is as shown in Figure 4, but with the hot plate off.

With this in mind, let's take some images and process the BOS data for ambient lab conditions. The results can be found in Figure set 8 below:

Figure set 8: Ambient lab conditions, with fans off

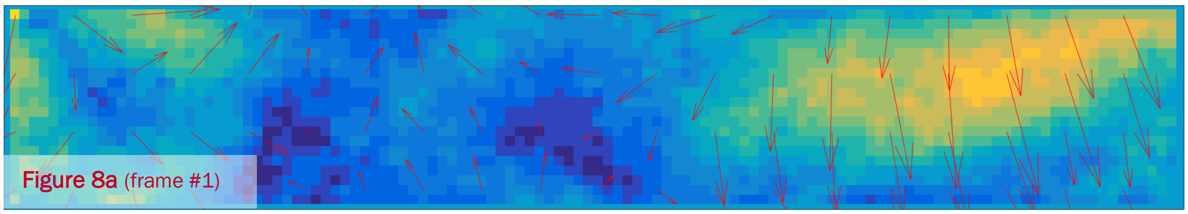


Figure 8a (frame #1)

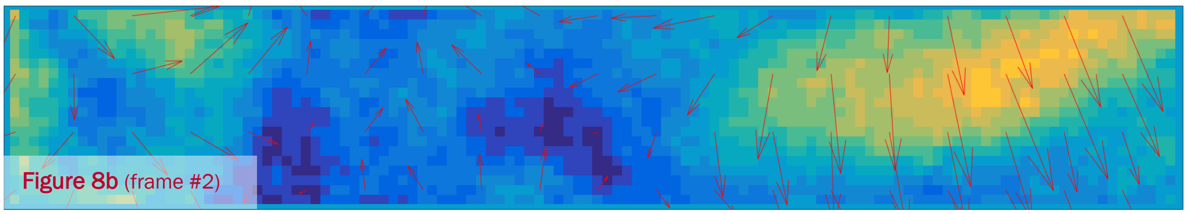


Figure 8b (frame #2)

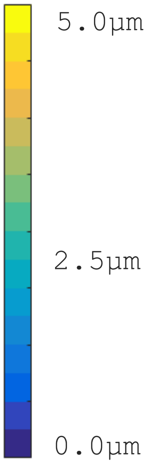


Figure 11
Color legend for BOS displacement data

Two salient features can be observed from Figure set 8:

- There exist large localized "blobs" of relatively **large** displacement.
- These "blobs" **persist** between sequential frames.

If one of your gauge length dots is inside this blob and the other isn't, you will see change in your gauge length reading even though your specimen hasn't moved! This error will persist for as long as the "blob" decides to stick around. This could be tens of milliseconds up to a second or two – there's no guarantee or control as to how long it will stick around since there is no active or passive method of controlling the air density fluctuations.

The result of this with respect to a gauge length measurement is shown in **Figure set 12 in the "Hotplate OFF" figure observing the "CDATs OFF" plot line.** Translating the salient features of the BOS figures into strain data that Bluehill Universal software would observe:

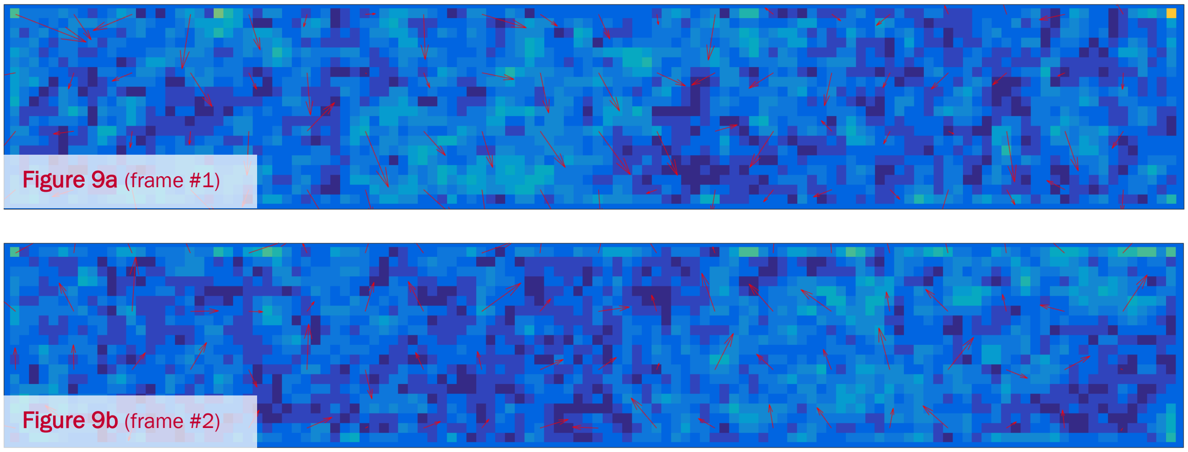
BOS Data Observations		Bluehill Universal Equivalent Observations
There exist large localized "blobs" of relatively **large** displacement.	➔	This can be seen by the **large** spikes in the data at around 2, 4, 8, and 12 seconds, etc.
These "blobs" **persist** *between sequential frames*.	➔	The **persistence** can be seen at around 15 seconds where the data "hangs high" at a value for around a second. Also, at around 26 - 27 seconds where the signal "hangs low" and does not cross above the 0μm displacement line. This "hanging" without crossing the 0μm line significantly is an indication of low-frequency signal content.

The red arrows represent the proportional magnitude of change and direction of change with respect to the speckle target.

The color scale between the Figure sets 8 and 9 is kept the same – i.e., the same "blue" color represents the same magnitude of change across both figure sets. See Figure 11 for the quantitative scale.

Now, let's take images and process the BOS data for ambient lab conditions, but this time we will turn the fans on. The results can be found in Figure set 9 below:

Figure set 9: Ambient lab conditions, with fans on



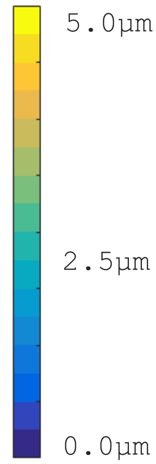


Figure 11
Color legend for BOS displacement data

Comparing the situation with fans off and fans on, two main observations can be made:

- The displacements of any localized blobs are **small**.
- These "blobs" **do not persist** between sequential frames. Frames look almost completely different.

The result of this with respect to a gauge length measurement is shown in **Figure set 12 in the "Hotplate OFF" figure observing the "CDATs ON" plot line**. Translating the salient features of the BOS figures into strain data that Bluehill Universal would observe:

BOS Data Observations		Bluehill Universal Equivalent Observations
The displacements of any localized blobs are **small.**	➔	Comparatively, notice how there are only **small** spikes in the data. The noise on the signal is roughly cut in half.
These "blobs" **do not persist** between sequential frames. Frames look almost completely different.	➔	Comparatively, notice how the **data does not persist** in a high or low state for very long or as often. It is significantly crossing above and below the 0µm displacement line constantly – more frequently than with the fans off case. The signal more frequently and significantly crossing the 0µm line is an indication of comparatively less low-frequency content.

Finally, to give a sense of scale to this data, Figure 10 shows a human hair (50µm in diameter) and a carbon filament (6µm in diameter) under a microscope. Observed displacements in this experiment are no greater than 5µm – which explains why you cannot see these displacement changes with the naked eye like in Figures 1 and 2.

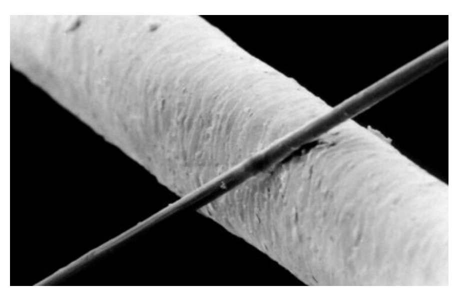


Figure 10:
Carbon fiber filament and human hair under a microscope
(Source: Marcus, Wikimedia)

The Instron® Solution

We have empirically tested variables such as (but not limited to):

- Fan intake and exhaust design
- Fan size/power
- Fan installation location

As a result, Instron has developed a new and improved, patent-pending CDAT (Constant Density Air Tunnel) technology. This new technology has been incorporated into the AVE3 product.

To highlight the effectiveness of the CDAT design outside of the BOS analysis, data was collected on a static test (no crosshead/specimen displacement/movement) in Bluehill® Universal with a hot plate turned on and placed in front and below the specimen (the same experimental setup as shown in Figure 4). This is an example of introducing air density fluctuations (say compared to breathing near the test space, or a nearby HVAC system kicking on), but it demonstrates the robustness and effectiveness of our solution when it comes to mitigating effects of changing air densities.

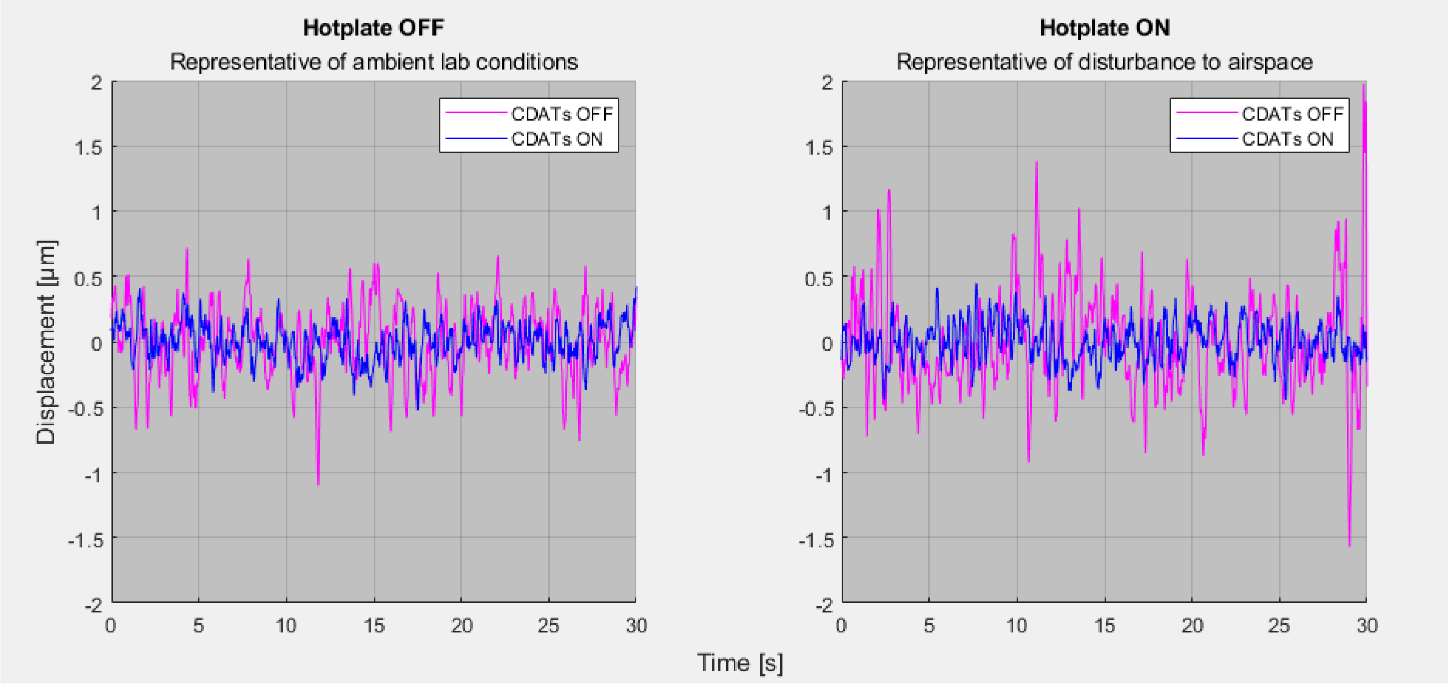


Figure set 12: Detrended hot plate time domain data†

Notice how in both hot plate cases with the CDATs ON, there is little change in the noise signature. The same cannot be said with the CDATs OFF – the noise signature is different and contains much more noise with the hot plate ON.

The amount of noise seen in Figure 13 will directly be recorded onto the stress-strain plot.

† The raw data is captured at 500 Hz and 200 ms averaging applied to demonstrate gross effects – i.e., the Y axis units should be considered arbitrary and for comparative purposes only since increasing the averaging window will lower the amount of noise in the data.

From these sets of observations with CDATs on and off, we can conclude the following:

- The correct use of fans lowers the amount of noise in the output signal (the strain data).
- The correct use of fans decreases the low-frequency content in the output signal – as seen in the detrended signal significantly crossing the 0µm displacement line more often.
- The correct use of fans provides a level of immunity to environmental disturbances.
- The correct use of fans means that we can use less filtering with the fans ON output signal to get a comparatively equivalent output signal to the fans OFF case.
    - With less filtering, the data by nature now has less lag/latency.

As a confirmation that the low-frequency content is indeed lower with the fans ON (since the frequency of zero-crossings is not the sole/definitive indicator of frequency content), Figure 13 is an analysis in the frequency domain (i.e., spectral content) of the "Hot plate OFF" data from Figure 12. Observe that with the CDATs ON, there is less frequency content between 0-10 Hz compared to CDATs OFF.

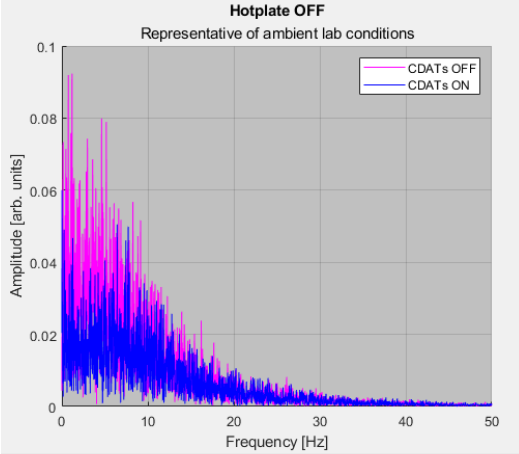


Figure 13:
FFT of "Hot plate OFF" data from Figure set 12.

Conclusion

Instron's CDAT technology provides a way to lower the amount of noise in your data, as well as making it more repeatable and consistent in any lab environment without compromising the test data in static tests. We have demonstrated this empirically with real experimental data, as shown in this white paper.

This means that without active control of the air density in the test space, large amplitude effects – such as breathing on or near the test space, opening the lab door, people walking near the test setup, lab air conditioning, etc. – will all directly be recorded into the test data.

No matter the image processing algorithm used, number of cameras used, etc., all video extensometers must obey the laws of physics – i.e., be subject to the effects brought on by air density fluctuations. **If your video extensometer system doesn't use CDAT technology, how truly accurate and consistent is your data?**

About the Author

Chadwick Aryana, a Senior Engineer at Instron, has been a key player in the R&D department since 2021, leveraging his mechatronic expertise to support the design of cutting-edge materials testing instruments. As a team member of Instron's Advanced Development Group, he works to ensure that Instron's future products remain at the forefront of technology through means of: rigorous research, experimentation, and ideation of new technologies. His collaborative efforts in researching the effects of air density fluctuations on video extensometry highlight the team's contributions to advancing strain measurement technology at Instron.