PHANTOM

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CASE STUDY

Understanding Turbulent Flows

How the simultaneous application of PIV and PLIF measurement techniques sheds light on turbulent entrainment, a process that has implications for oil spills, wind farms and more.

Although turbulence plays such a dominant role in fluid dynamics, there's a lot that still remains unknown. High-speed imaging systems, along with flow measurement techniques like particle image velocimetry (PIV) and planar laser induced fluorescence (PLIF), can provide a helpful lens into turbulence, enabling fluid dynamics experts to see things they otherwise couldn't.

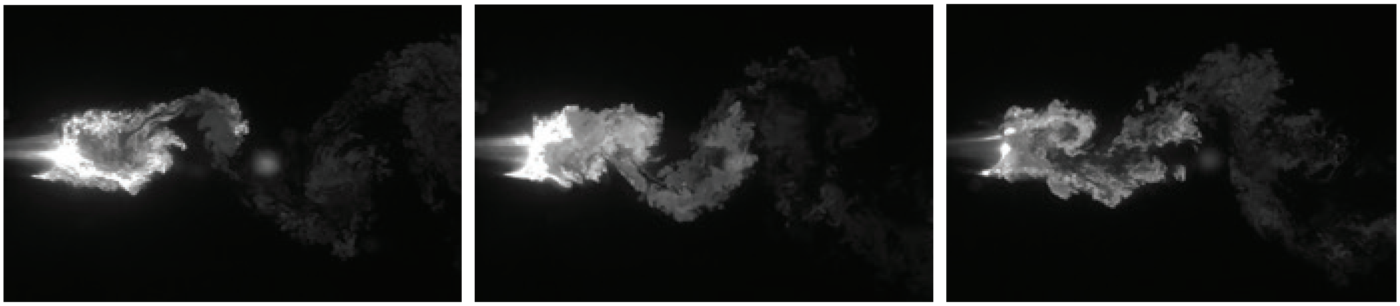
Oliver Buxton is a researcher in the aeronautics department at Imperial College London, where he focuses on the application of laser diagnostics to observe turbulence in compressible and incompressible flow systems. Part of his area of study is entrainment, or the process by which the mass of one fluid is transferred into the body of another fluid. "Think of a plume of smoke rising from a chimney," Buxton explains. "The plume becomes thicker because the background fluid — in this case, the air — travels from the background into the plume. That is entrainment."

Understanding this process, along with the growth rate of the regions surrounding the turbulent fluid, is important for many environmental applications, from oil spills to wind farms. This latter application, which is of particular interest to Buxton, involves a greater understanding of entrainment with turbulent background fluids.

TURBULENT VERSUS NON-TURBULENT BACKGROUND FLUIDS

Although non-turbulent background fluids make up a big part of current entrainment research, it's common for real-world flow systems to have a turbulent background fluid. "Wind farms, for example, experience a turbulent background fluid in the form of atmospheric turbulence," Buxton says. "Understanding how quickly the wind wakes spread from the turbulent background fluid can help us better arrange turbines to optimize the performance of the farm."

To study the effects of turbulent background fluids on the entrainment process, as well as the nature of the interfacial region — or the total area of contact — between the two fluid bodies, Buxton carried out experiments involving a circular cylinder subjected to free-stream turbulence. He then measured the results using simultaneous PIV and PLIF flow measurement techniques, both of which utilize high-speed imaging.



High-speed footage of Buxton's cylinder experiments, captured using the Phantom VEO 640 camera.

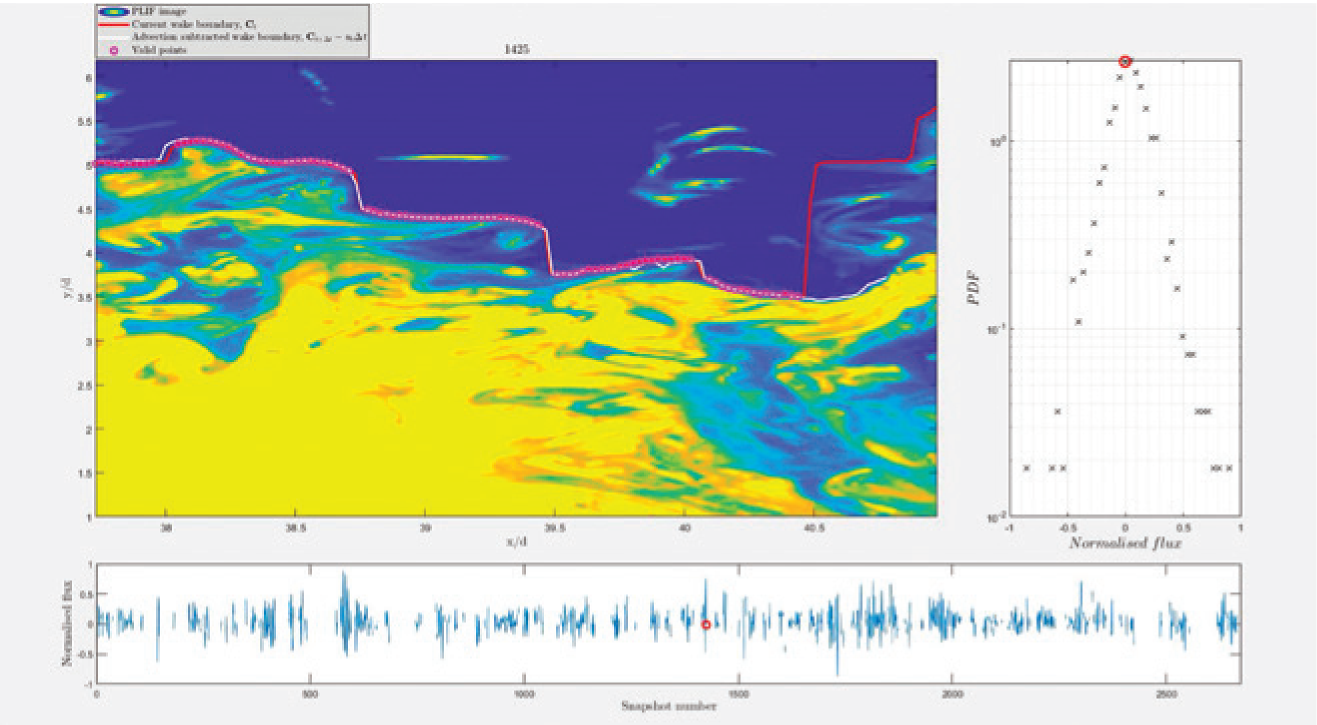
VISUALIZING FLOW WITH PIV AND PLIF METHODS

A non-invasive imaging methodology, PIV enables researchers to visualize and quantify flow fields. Using this technique, Buxton measured the entrainment velocity during his experiments. Turbulence-generating grids, placed upstream of the cylinder, produced the free-stream turbulence within the system, achieving a Reynolds number of 4,000. Buxton seeded hollow glass spheres into the flow, which transported the tracer particles in the same way a storm transports dust particles. Using a 527-nanometer (nm) laser, he illuminated the area of interest and imaged the fluorescent particles using a Phantom high-speed camera.

By outfitting the camera with a bandpass filter, Buxton prevented any reflected light from the dye (Rhodamine 6G) from affecting his measurements. Once he had the PIV images, he ran cross-correlation algorithms to measure the particle displacement over 500 microseconds (μs). "Knowing the displacement of the particles over that short period of time allowed us to measure the velocity of the underlying fluid," Buxton says.

PIC Experimental Parameters		
Light Sheet	Laser Type	Nd:YLF
	Wavelength	527 nm
	Frequency	1,400 Hz
Camera	Resolution	1600 x 2560 px
	Pixel Size	10 µm
Imaging	Viewing Area	32.0 x 51.3 mm
	f_{aq} *(Acquisition Frequency)*	225 Hz
	dt *(Time Separation Between Two Frames)*	500 µs
	N_{aq} *(Total Number of Double Frames Captured)*	2,676
PIV Analysis	Interrogation Area	24 x 24 px
	Window Overlap	50%

PLIF, the second optical diagnostic technique Buxton used, was critical to detect the location of the interface between the two turbulent fluids. This measurement process, which is only necessary when studying entrainment against turbulent background fluids, involves the use of a passive scalar, which refers to "something that can be transported by the flow without affecting the flow itself," Buxton says. As part of this process, he seeded the region of interest with a fluorescent substance, illuminated the area with a laser sheet and then imaged the fluorescence using a Phantom high-speed camera. Using a low pass filter, Buxton ensured the PLIF camera would only capture the tracer data and ignore the seeded particles from the PIV experiment.



Post-processing analysis of entrainment behavior.

A HIGH-SPEED RECIPE FOR SUCCESS

Over the course of his turbulent entrainment experiments, Buxton used two Vision Research Phantom high-speed cameras — one for PIV and the other for PLIF. For many years, his lab had utilized 4-megapixel (Mpx) Phantom v641 cameras, but Buxton recounts how he has recently received the newer and more compact Phantom VEO 640 model. "We need a large field of view for our turbulence experiments, which is why having a four-megapixel camera has been very useful," he says, noting that the camera doesn't sacrifice the temporal resolution he needs for filming at high speeds.

Thanks to its proprietary 4-Mpx CMOS sensor, the VEO 640 can capture over 1,400 frames per second (fps) at full resolution, making it ideal for PIV, PLIF and other scientific imaging applications. By balancing fast frame rates and high resolution, the camera enabled Buxton to capture the flow field of each sphere as it passed through the field of view. In addition, the 12-bit sensor has an ISO rating of 6,400D, providing an excellent balance of sensitivity and contrast to differentiate the seeded particles from the background and analyze flow fields during PIV analysis.

In terms of hardware, Buxton utilized the VEO L-model, which is lightweight at only 5 pounds and offers the I/O interface necessary for scientific studies in laboratory environments. This camera also supports various interchangeable lens mounts. Buxton used a 200mm Nikon lens for his PIV shots and a 100mm Tokina lens for his PLIF shots.

Phantom VEO 640 L Model

LOOKING AHEAD

The results of Buxton's PIV and PLIF experiments proved that a turbulent/turbulent interface does, in fact, exist. By analyzing the structure of the wake boundary, Buxton also concluded that an increase in background turbulence intensity results in a higher interfacial surface area. Building off this work on turbulent entrainment, Buxton is now engaged in a larger, five-year project with the goal of optimizing the layout of wind farms. "We'll be doing more complicated turbulent entrainment studies, and so the Phantom VEO 640 cameras will be more critical than ever," he says.

To learn more, please visit: ***www.phantomhighspeed.com.***

More Information

Kankanwadi, K., & Buxton, O. (2020). Turbulent entrainment into a cylinder wake from a turbulent background. Journal of Fluid Mechanics, 905, A35. doi:10.1017/jfm.2020.755

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