ON THE CUTTING EDGE

Physicist Erskine's velocimeter sees the white light

By Jon Bashor
NEWSLINE STAFF

In what could be called a flash of inspiration, Lab physicist Dave Erskine has come up with an idea that dramatically expands the use of ordinary light, sound and microwaves to measure the speed of various objects.

In an article entitled "White Light Velocimetry," published in the Sept. 28 issue of *Nature*, Erskine and fellow physicist Neil Holmes describe a technique that uses any source of light — not just lasers — for detecting the slight Doppler shift used to measure velocities of targets. The Doppler shift is the change in frequency of light or sound from a moving source — like the changing pitch of the horn of a passing car or train.

For light reflecting from a moving automobile, the shift is very small — about 1 part per 10 million. Previously this could be measured only by lasers whose color purity was better than 1 part per 10 million. Now, with Erskine's technique, white light — light having a jumble of frequencies varying 50 percent or more — can be used.

"This is like hearing a mouse squeak in the midst of a loud orchestra, and telling it it is a little off key," Erskine said. "Previous wisdom said it couldn't be done."

Erskine thinks his idea will have applications in fields ranging from laser fusion to wind-tunnel research, to radar and biomedical use of ultrasound.

"The principle works on any wave phenomenon. Everyone has thought that very pure sources of sound, light, radio waves, X-rays are mandatory to measure Doppler shifts," Erskine said. "These are no longer necessary."

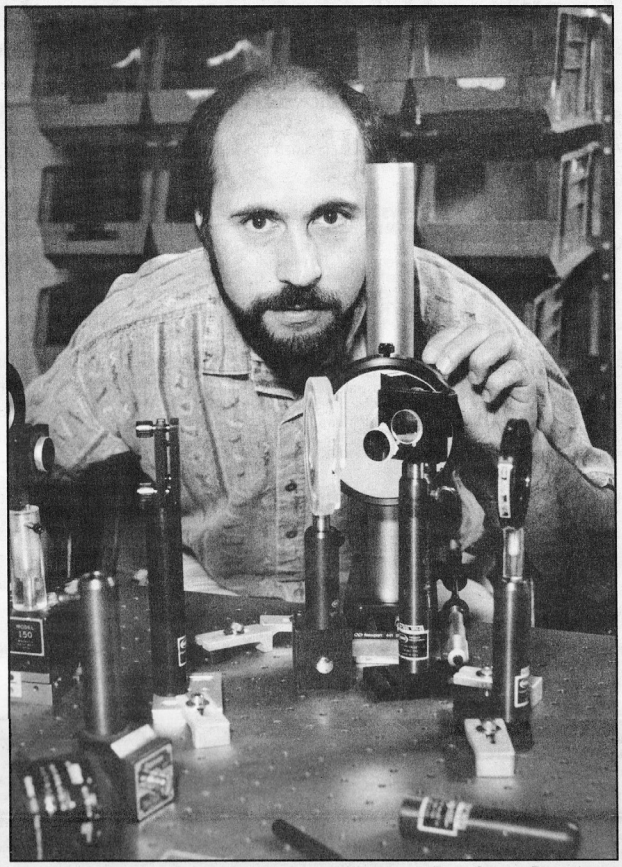
And since pure sources are usually more expensive and finicky than crude sources, a lot of money could be saved, he adds.

For example, until now Erskine has had to use a $50,000 laser system to make his measurements, and every few years had to spend another $25,000 on top of that to replace a worn out laser-tube. "And that laser only puts out a single watt of light of sufficient purity to make my measurement — the old way." Now Erskine can use an ordinary light bulb, or an inexpensive flash lamp which puts out a million times more power.

These un-pure sources, also called incoherent sources, are generally much more powerful than pure, or coherent, sources. The increased power should allow for the first time illumination of large areas of a target.

"Previously I only had enough laser power to measure the velocity at a single point on my target," he said. "Now I should be able to measure the complicated motion of a target over its entire area." He thinks this could revolutionize his area of study (shock physics), and find applications in many other areas of science and engineering.

"Presently, there is no simple way of measuring the velocity of air flowing over a wing in a wind tunnel, instantaneously and precisely throughout the volume" he points out. "Today's methods measure velocity accurately only at a single point."



BRYAN QUINTARD/PUBLIC AFFAIRS

David Erskine thinks his 'White Light Velocimetry' will have applications in such fields as laser fusion, wind-tunnel research, radar and ultrasound.

Erskine thinks that with the increased illuminating power of incoherent lamps, instruments will be able to take a "velocity snapshot."

"This could make possible detailed comparison of supercomputer calculations with experiment," he said. "Right now, the measurements aren't as detailed as the computer outputs — especially for chaotic motion."

Erskine said he never thought it would be possible to use white light to make his measurements — lasers had always been the only way Doppler shifts were ever measured.

He stumbled upon the idea while adjusting his instrument, called an interferometer using white light. An interferometer is any device that splits a signal into two parts, then delays one before recombining them. It had been known for 100 years that white light could be used in an interferometer if it was adjusted to a certain position.

But, the two mirrors that make up the interferometer must be exactly the same distance from a common beamsplitter before "fringes" are seen. Fringes are fluctuations in the light intensity seen in an interferometer when light acts coherently. Fringes are only seen in white light when the mirrors are at the same distance within 1/1000th of a millimeter.

"I was fascinated by the sensitivity to the mirror position," Erskine said. "I thought, 'Gee it would be neat if I could use that sensitivity somehow to measure Doppler shifts.' "

However, to measure Doppler shifts with his interferometer requires the mirrors to be separated by large distances, such as 100 mm to measure one-kilometer-per-second velocities, and four meters to measure automobile speeds. But the fringes disappear with white light when the separation grows beyond 1/1000th of a millimeter. That is why a laser is used; they can produce fringes at large separations.

Erskine brainstormed a week, trying out many ideas until he finally hit upon one that seemed to work. At first, he thought about ways to purify the white light to make it more like the laser. That involved sending the light through a series of filters, called interference filters, to purify the color.

"Then I thought about resonators to store energy, like the way a shower stall can extend the duration of a wannabe singer's note," he said. "Then I realized that if I used an identical interferometer as a filter, it would do the trick!"

The secret is to have two nearly identical interferometers in series. Each interferometer by itself will not produce fringes from white light because their delay is too large — but the two in series will.

"I ran down to the lab and moved a few mirrors around in my apparatus and within an hour I had partial confirmation," he said. "I saw fringes!"

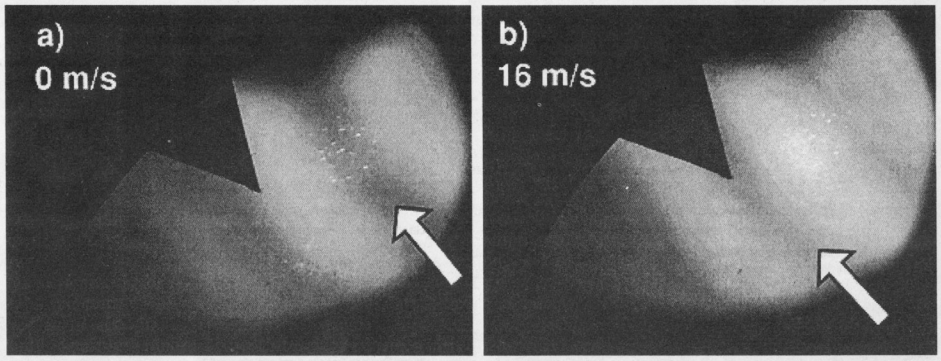
However, the fringes Erskine saw did not involve a moving target. And it would take a few weeks to order some telescope mirrors before he could try for the confirmation. He wanted to measure the velocity of something moving at ordinary velocities, say 35 mph, not the 5 km/s he normally works with. "That way I can make it a tabletop demonstration."

He selected his target to be the blades of a chassis cooling fan, which move at about 16 meters per second, or just under 36 mph. To measure something that slow requires a very long interferometer mirror separation of 4 meters. This requires a special design using high-quality telescope mirrors.

While Erskine waited for his mirrors to arrive, he admits doubts were creeping up on him.

"It was too easy — either it had already been done before, or it won't

See **LIGHT,** *page 7*



These black-and-white images are of color fringes (which appear as light and dark bands) produced by Dave Erskine's white-light velocimeter using incandescent lights. In the right image, the target is stationary. At left, the target is moving at 35 mph (16 m/s), causing the bands to shift. The arrows indicate the central fringe. The movement of the central fringe relative to the reference triangle is the fringe shift, which when multiplied by a constant, yields the speed of the target, in this case a spinning fan blade.

ITEMS OF INTEREST

LIGHT

Continued from page 5

work," Erskine remembers worrying.

Erskine knew that interferometers have been widely explored for 100 years and are in widespread use in many areas of technology. He doubted he was the first one to put two in series, and a literature search showed that, indeed, he was not the first.

But apparently he is the first to put a moving target in between the interferometers, one that is external to both interferometers. That is crucial if the device is going to measure targets out-of-doors.

When the mirrors arrived, Erskine said, he hurried to his lab, where he assembled the mirrors in a special arrangement he had worked out in his notes. He installed reflective tape on the fan blades, shined white light from an ordinary lamp through his system, and peered through a telescope while sitting on an upside-down garbage pail looking for fringes.

"I saw them!" But that was for the stationary target. What would happen when he energized the fan? As he twisted the knob that controlled the fan speed, he saw the fringes shift — meaning he could indeed measure the fan velocity by ordinary light. He ran to his boss and colleagues, and made each of them sit on the inverted trash can to see the fringe shift.

"The exciting thing about it is that it is all done with mirrors — there is nothing 20th century about it," says Erskine. However, there are 21st century problems he wants to address with it.

"We can apply a variation of this technique to measure the expansion of a laser-created plasma with two-picosecond resolution. By using a short chirped pulse and sending the interferometer output through a diffraction grating, we create an optical streak camera that measures velocities accurately on short time scales," he said.

Erskine hopes to work with existing sources of chirped pulses at the Lab, such as in Mike Perry's group in Lasers. Because the white light velocimeter can use all colors, a pulse can be used which begins as red and ends with blue. The grating and the color change cause the output light to sweep across a piece of film. The short time resolution is due to the nature of the pulse, not to any moving part in the device. This camera technique competes with $150,000 electronic streak cameras, but is much less expensive and has the further advantage that many cameras can work off the same illumination source.

Erskine is also confident of many other applications arising from the ability to use a wide variety of light sources. One application would be to observe devices which explode in a complex three-dimensional manner. Several of these velocimeters observing the target at different angles could resolve the direction as well as magnitude of the speeding pieces.

Erskine thinks applications of his interferometry technique may improve the use of ultrasound in bio-medical imaging, which is already an established clinical tool. "By using ultrasound of many widely different frequencies simultaneously, we could image portions of the body moving at very specific velocities," Erskine speculates. "This could produce very interesting pictures of the heart and blood stream in motion."

The Laboratory is filing a patent application for the new technique.

"It is hard to believe there is still something left to invent that belongs to the 19th century," he admitted.

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