Wind tunnel experiments; Whirlwind Japanese study tour: air movement in a greenhouse.

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Editor's note: As part of a University of Arizona/Japan collaboration to study greenhouse cooling in a semi-arid climate, Sadanori Sase--Japan's National Institute for Rural Engineering (NIRE)--extended an invitation to Nadia Sabeh to perform experiments using their wind tunnel facility The main objective, or "tunnel vision," of her Ph.D. project is to minimize water use by evaporative cooling systems. To maximize evaporation with the high-pressure **fog system**, it was Sabeh's desire to predict the best location for high-pressure fog nozzles. The wind tunnel at NIRE allows study of air movement under natural ventilation conditions inside a 1/15 scale model of her research greenhouse. Sabeh received travel grant money through a USDA National Needs Fellowship to study in Japan for three months.

The wind tunnel at NIRE in Tsukuba, Ibaraki, is the largest agriculture-based wind tunnel in the world, measuring a total length of 68 m (223 ft) from fan to outlet. The testing section itself is 20L x 4H x 3W m (66L x 13H x 10W ft). The wind tunnel allowed study of the effects of four wind speeds, two wind directions, four greenhouse vent openings, and three heated floor temperatures on air movement and temperature distribution within a model of my greenhouse. I used Particle Image Velocimetry (PIV) to study air movement and 20 thermocouples, strategically placed inside the model, to measure temperature distribution.

[ILLUSTRATION OMITTED]

The PIV system uses two Level-3 lasers (YAG) and a CCD camera to illuminate and photograph smoke particles as they move within a fan-generated airstream. Air velocity and direction are measured by calculating the distance that smoke particles travel over a specified period of time. After a series of cross-correlation calculations by the PIV software, a velocity vector map is produced in a display of green arrows of various lengths, illustrating the direction and magnitude of airflow.

Overcoming and fine tuning the details

When first requesting use of the PIV system, I was greeted with a series of looks that I soon realized were indicative of, "She has no idea what she is getting herself (and us) into." I quickly learned that the PIV system does not simply mean turning on a laser, taking a photograph, and receiving a pretty picture of arrows. Atsuo Ikeguchi, my primary wind tunnel collaborator and advisor, taught me how to operate the wind tunnel facility and helped me set up nearly every experiment.

Aligning the lasers was the most time-consuming part of the study. Every morning we checked that the lasers were accurately aimed at the reflector, which projected the laser downward through a lens, which in turn spread the laser beams into laser sheets that were 1 mm (0.04 in.) thick and produced an illuminated area about 0.75 m (2.5 ft) wide. Re-aiming the lasers was especially important on mornings after an earthquake, and there were about 10 small ones during my three-month stay. Once both lasers were both hitting the reflector, they had to be "tuned" to align their end points on the reflector. Sometimes, when the lasers were out of alignment, a loud "clap, clap, clap!" was heard as the lasers smacked into each other midstream toward the reflector.

[ILLUSTRATION OMITTED]

Before every picture (three for each of my 15 experiments), we moved the reflector into the desired position, then ensured that the laser sheets were wide and intense enough for the PIV system to detect the necessary amount of smoke particles to produce a coherent velocity vector map. The width of the laser sheet was important, too, because if it was too wide, the light intensity would be too low; if the sheet was too narrow, many pictures would have to be taken inside the model. By taking three pictures along the width of the greenhouse, the number of images was limited while achieving a high enough laser sheet intensity for the PIV system.

All of this was accomplished in the dark, and with every adjustment made by a slight twist of a knob, the modified laser beams and sheets had to be viewed. The first time I stood inside the dark tunnel to make adjustments, smoke swirling about, I thought, "All that's missing is dance music!"

"I can't hear you!"

There tended to be a lot of yelling during these experiments. Usually Ikeguchi-San stood inside the wind tunnel making adjustments to the reflector, lens, and lasers as I stood outside looking at the computer display trying to see smoke particles and laser sheet intensities. At first we wore radio head sets to communicate with each other over the sound barriers of fan, smoke generator, double-plated glass, and masks worn to protect from the non-toxic smoke. But eventually we found it easier to just yell at each other: "NO!" ... "Back! BACK!!" ... "Okay!" ... "OKAY?!"

On a good day, it took 30-60 minutes to set up one picture. On a bad day it took about four hours. (Remember: three pictures for each experiment!) Taking the actual picture was easy. Within a minute of clicking four buttons, the PIV software had averaged 40 snapshots to produce a velocity vector map. We always created at least two velocity vector maps to validate our results. If we were unsure of our results after producing three maps, we'd return to tuning our lasers, adjusting the reflector angle and lens, with more yelling at each other, and then ... try, try again.

On the third day of experiments, I was exhausted and ruminated: "I thought modeling was supposed to be easier than full-scale experiments." But, by the time I left Japan, I realized just how much I had accomplished: 15 experiments under controlled wind speeds and directions and floor temperatures ... unheard of in full-scale experiments! More importantly, these experiments provided me with a greater understanding of the dynamics of airflow within my greenhouse and validated my own predictions of where fog nozzles would be best positioned to maximize evaporation. Most of all, I learned that an automated PIV system would be extremely valuable for future wind tunnel designs and experiments.

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