



THE BARRIER THAT BROUGHT THEM TOGETHER

Shane Ross (left) and David Schmale are using autonomous aircraft to study a pathogen and how it might ride massive air systems to travel long distances across regions.

Autonomous Unmanned Aerial Vehicles (UAVs) are providing evidence that sheet-like barriers may move parcels of air across regions, pushing along microbes, pollutants, and other airborne hitchhikers. Once understood, such Atmospheric Transport Barriers (ATBs) could be used to predict some plant, animal, and human disease movement — or perhaps enable future buoyant autonomous vehicles to travel long distances with minimal on-board energy by hitching rides along the barriers.

VaCAS affiliate members David Schmale, an assistant professor of plant pathology, and Shane Ross, an assistant professor of engineering science and mechanics, are working together on the project, which is supported by a \$413,476 grant from the National Science Foundation (NSF).

Barriers in the atmosphere

Although transport barriers were first suggested 10 years ago to explain movement in the oceans, Ross is pioneering the application

of the transport barrier concept to air movement. “ATBs are moving boundaries between air masses,” he explains. “These undulating boundaries can be hundreds of kilometers long and can extend hundreds of meters or more into the atmosphere.” According to the theory, barriers typically are expected to last only a few days and are constantly being formed and dissipating.

Ross has developed models of ATBs based on weather data and has correlated the framework with data from the 2002 split of the Antarctic ozone hole and the 2007 subtropical storm Andrea. Using weather forecast data, he and Ph.D. student Amir Bozorg Magham have developed a framework that can potentially predict when and how ATBs will travel across a region.

An identifying feature of ATBs is that very little air, pathogens or other airborne particles pass through these moving boundaries. A barrier, he postulates, can sweep the microbes along its path, causing a concentration on one side. “If we can sample the air on both sides of a barrier, the expectation is that the samples will be

different,” he says.

Working with Schmale is providing that opportunity.

Flying UAVs for aerobiology

Schmale is an aerobiologist, and is interested in the flow of life in the atmosphere. His laboratory uses autonomous UAVs to collect samples of airborne microorganisms tens to hundreds of meters above the surface of the earth. His UAVs collect biological samples and capture detailed images of crop fields.

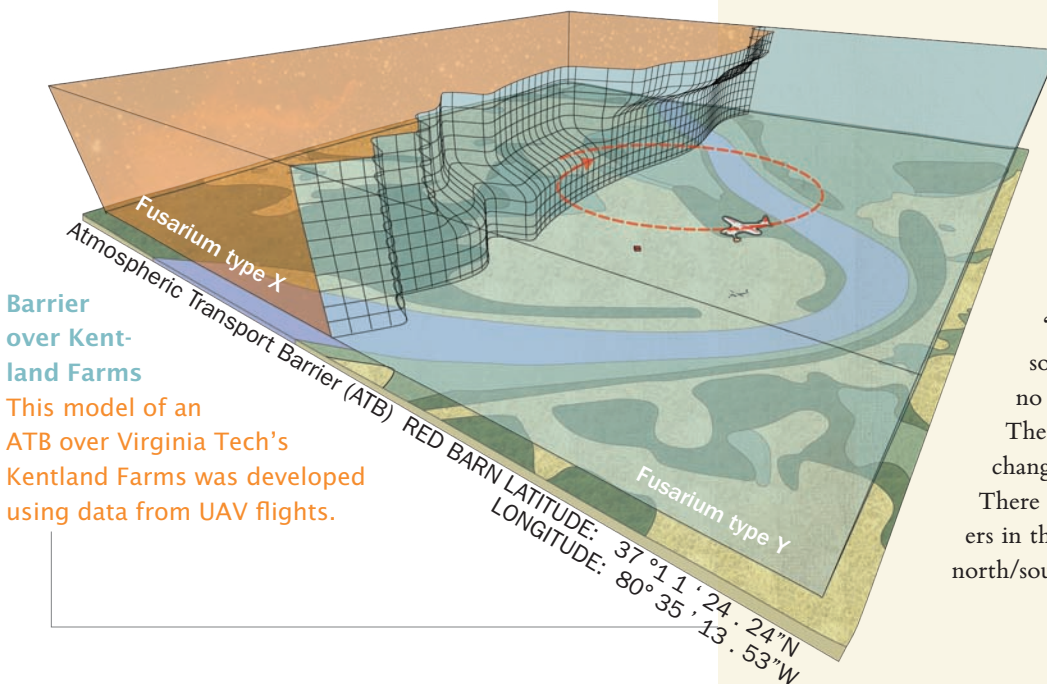
“UAVs allow us to collect a large sample over a short time period,” Schmale explains. UAV flights are guided by an autopilot and an onboard suite of sensors, ensuring a very precise sampling path that can be monitored and even replicated across multiple sampling missions. “We also collect samples on the ground along the same GPS-controlled path to correlate what’s happening in the atmosphere and on the ground,” he says. A team of UAVs can also be set to fly the same path at the same time at different altitudes. Schmale worked with Craig Woolsey, an associate professor of aerospace and ocean engineering, to develop this multivehicle control system which coordinates the sampling of the UAVs at different altitudes by modulating their speeds.

Schmale’s investigations target pathogens that are dangerous to plants, domestic animals, and even people. These investigations include *Fusarium*, a group of fungi that often use the atmosphere to move from one habitat to another. A number of species of *Fusarium* cause rots, wilts, and blights of important crops. Still others cause diseases of the skin, eyes and respiratory system in humans. “*Fusarium* is an organism of high consequence; it always exists in the air, but we know very little about how it gets around,” Schmale says.

To Schmale and Ross, *Fusarium* is the ideal microbe to test Ross’s framework.

Tracking a pathogen

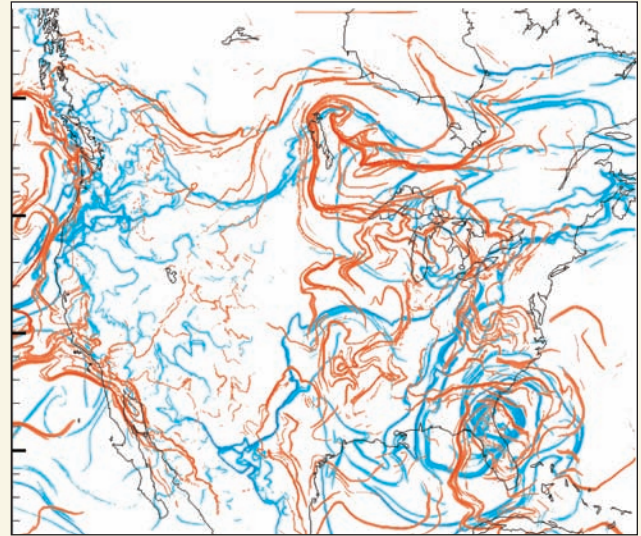
Using a cocktail of fungicides and antibiotics on petri dishes, Schmale’s UAVs can bias their sampling to study just *Fusarium*. Using Ross’s ATB model, the team predicts (Continued on next page.)



Barrier over Kentland Farms

This model of an ATB over Virginia Tech’s Kentland Farms was developed using data from UAV flights.

ATMOSPHERIC TRANSPORT BARRIERS ATB



Model of ATBs across North America

Atmospheric Transport Barriers (ATBs) are moving boundaries between air masses, virtual walls of air. Some repel nearby air parcels (orange lines) and its hitchhikers and some attract (cyan lines). The boundaries are short-lived, appearing for just hours or days, before disappearing. Shane Ross is using techniques from chaotic dynamical systems to identify the network of boundaries and how they affect air movement across and within geographic regions. He uses weather data to develop his models, but ATBs aren’t all related to obvious weather phenomena like storms or fronts.

“We are just starting to catalogue these barriers, but already, we are finding patterns.” For example, Ross’s framework of ATBs across the United States shows greater numbers of barriers in mountain regions. “Over the Plains, we also observe some strong barriers connected with no conspicuous geographic features. These are just associated with rapidly changing wind patterns,” he explains. There are also strong, persistent barriers in the East that generally flow along a north/south path.

when a barrier is coming through Virginia Tech's Kentland Farm, then collects samples before and after the predicted barrier passes over the farm. So far, the experimental data appears to show a good correlation with the model.

"We now have the tools to analyze parcels of air and how they move over time," Schmale said. "This means we can go back in time to see where different microbes might have come from."

Schmale's team has conducted over 100 flights, according to Ross. "He'd fly three or four times a day. We have analyzed his samples and backtracked the data and so far there seems to be a good correlation," he reports. The data is showing two different types of barriers, some repelling and some attracting microorganisms.

Future of the framework

Success of the ATB framework could enable scientists to predict how pathogens spread over weeks or several months, according to Ross. The framework might also apply to events at higher altitudes being studied by space scientists, he says. Future applications might even involve energy-efficient forms of transport for autonomous vehicles. "We imagine the old video game Frogger, but in 3D; we could have a weakly propelled vehicle, like a blimp that could jump on an air current moving in a certain direction. You would have to cleverly know when to jump over an ATB onto another air mass moving in a different direction."

Schmale is excited about being able to better understand the behavior of microorganisms in the air. "When we fly, we collect living microorganisms and culture them in the lab, then work with the organism in living color," Schmale says. "Many of the *Fusarium* species we are working with have never been studied in the lower

atmosphere, and some of them may be new to science".

With continued study of airborne microorganisms and better tools, such as the ATB framework, scientists will come closer to understanding and possibly being able to tap communities or assemblages of airborne microorganisms. "We know that microbial communities perform unique biological functions in the ocean, in the soil, and even on the surfaces of plants. It is not so farfetched to hypothesize that a similar drama is unfolding in the atmosphere, which we already know is teeming with microbial life. Perhaps these communities have the ability to mediate major meteorological events such as rain or even snow," he says. "In order to influence their own transport," adds Ross.

Schmale credits his UAVs and his talented crew with the ability to move ahead in this effort. "The autonomous UAVs are an important tool to be able to ask important questions in aerobiology. How else can we peer into microbial life hundreds of meters above the surface of the earth?" That's why a colleague dubbed his UAVs "scientific vehicles of discovery."

Multidisciplinary expertise required

The effort to understand how microbes behave and travel in the air requires experts from many disciplines, according to David Schmale. "I wouldn't be able to do what I do without close collaboration with my colleagues in engineering.

"I come from a biology background, and I don't have the modeling or meteorological expertise. This is why I work with talented researchers such as Shane Ross and Craig Woolsey in other disciplines.

"We can do some great science by working together." 

John Cianchetti (left) and David Schmale adjust the closed petri-dish collection system.



ADAPTING UAVS FOR BIO-SAMPLING

Like many UAVs, the fleet that collects airborne pathogens had humble beginnings. Schmale's team purchased almost-ready-to-fly (ARF) Rascal aircraft that are typically used by remote control hobbyists. They installed an out-of-the-box GPS-based autonomous control system, with the remote control as a separate backup system. Assembling an aircraft takes about a week and installing the autonomous system another week, he says.

To collect biological samples, the team designed a system of eight petri dishes installed on the UAV wings. The petri dishes are paired and operated like clamshells: they are closed during takeoff and landing, and open during collection at the appropriate altitude. "The petri dishes are low cost and it's fast to swap them out," Schmale explains. His team has recently equipped a UAV with an ionic spore sampler that charges airborne particles and focuses them onto a specific sampling surface. "We expect this system to increase our sampling efficiency."

The collection system impacts how the UAV flies. Although they are lightweight, the open petri dishes create drag that can stall out the aircraft. "It's like opening the flaps," Schmale describes, "and you have to control for dramatic changes during flight." Schmale worked with Craig Woolsey, associate professor of aerospace and ocean engineering and Ph.D. student Laszlo Techy to tackle this problem.

"We investigated the use of adaptive control theory to accommodate these dramatic changes in the aerodynamics safely and automatically," Woolsey explained.

WHY FUSARIUM?

Home gardeners often first encounter *Fusarium* when their tomatoes wilt. For farmers, however, *Fusarium* can devastate crops from grasses to vegetables, as well as produce mycotoxins that threaten the health of animals. *Fusarium* travels easily by air.

"There are more than 80 different biological species of *Fusarium* known today, and probably more than 200 worldwide, many of which have not yet been discovered," says David Schmale, who has been studying airborne *Fusarium* for several years. "Many of these species have not been identified yet," he adds. In a series of more than 100 UAV flights since 2006, his team collected more than 500 strains of *Fusarium*, representing at least a dozen species. For 11 of these species, it is the first report of their ability to be transported great distances above the surface of the earth.



A UAV outfitted with petri-dish sampling system.