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AN OPERATIONAL PERSPECTIVE ON MEASURING AEROSOL CLOUD DYNAMICS

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ABSTRACT. Three areas are discussed in this paper: 1) U.S. Air Force Reserve/USDA bioassays to determine the effective swath width of ultra-low volume (ULV) aerial applications conducted with the C-130 Modular Aerial Spray System (MASS), 2) the use of aerial spray computer models to predict spray offset distance and their use as a substitute for field testing, and 3) a demonstration on an aerial spray expert system called ASPEX being developed at the U.S. Air Force Reserve Aerial Spray Branch.

AIR FORCE SPRAY PROGRAM OVERVIEW

Mosquito-borne or other fly-borne epidemics occurring during war or natural disasters may require rapid large-scale aerial adulticiding as the sole means for curbing an imminent disease threat. The logistical complexities of war or natural disasters and the ever-present threat of disease makes the Air Force C-130 Aerial Spray Program uniquely suited as a national asset for rapid large-area aerial applications. The Department of Defense tasks the 910th Airlift Wing of the U.S. Air Force Reserve to maintain an aerial dispersal capability. The unit's assets include 6 Modular Aerial Spray Systems (MASS) and 4 C-130H aircraft modified for spray missions. This is the Department of Defense's sole fixed-wing aerial application asset. The 757 Airlift Squadron of the 910 Airlift Wing at Youngstown Air Reserve Station, Vienna, OH, maintains and performs the aerial spray mission.

CHARACTERIZING LARGE AIRCRAFT FOR ULV MOSQUITO CONTROL USING BIOASSAY CAGES

In June 1988, the Air Force Reserve and the USDA-ARS jointly conducted the initial C-130/MASS prototype characterization trials for ultra-low volume (ULV) mosquito control at Avon Park Air Force Range, near Sebring, FL. The characterization trials employed the methods used by Mount et al. (1970) and Haile et al. (1982). The test site was predominately an open area. In the test area, intersecting roadways allowed cages to be set for 3 different wind directions. The number of cages set for each test varied from 10 to 22 (covering a distance of 0.5 to 2.1 mi.) depending upon the type of test, roadway length, and availability of caged mosquitoes. Cages were set at 0.1-mi. intervals for tests conducted with the desired wind direction perpendicular to the flight path (crosswind) as in normal adulticide applications. For tests to determine the minimum effective swath width, the desired wind direction was parallel to the flight path (into the wind) and cages were set at 0.05-mi. intervals. Two to 4 cages of mosquitoes were used as checks for each replicate.

Female *Aedes taeniorhynchus* (Wied.) mosquitoes reared in the USDA Gainesville laboratory were used in all tests. Mosquitoes used were 3–5-day-old adults. The adult mosquitoes were immobilized in a cold room at 2°C for sex determination and placement into cages. Each cage contained 25 mosquitoes. The cages were cylindrical (3.5 cm diam × 12 cm long) and made of 16-mesh screen wire for exposure to insecticide treatment. The screen wire cage was attached to an uncontaminated sealed plastic cage of the same dimensions, which held the mosquitoes after exposure. The cages of mosquitoes were placed in an ice chest with a cotton pad moistened with water and a container of ice for transport to the site. Mosquitoes were transferred from the screen cage to the plastic holding cage approximately 15 min after exposure. A cotton ball moistened with a 10% sugar–water solution was placed on each holding cage and the cages were held in another ice chest for approximately 12 h before mortality readings were made.

Malathion (American Cyanamid, Wayne, NJ) and Dibrom (Valent USA, Walnut Creek, CA) were used in these tests because they are most often used in military adulticiding operations. Application rates were 0.75 oz./acre for Dibrom and 3 oz./acre for malathion. All applications were made with a U.S. Air Force C-130E aircraft modified to accommodate the Modular Aerial Spray System prototype. Desired flight paths were marked with vehicles and smoke. All bioassay tests were flown at 150 ft. above ground level. For crosswind tests, 3 passes were normally flown over the cage line tests using a 2,000-ft. swath width, and 2 passes were used

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in 3,000-ft. swath width tests. Only one pass was made for each "into-the-wind" test with calibration for a 1,000-ft. swath width. The MASS was equipped with Spraying Systems Company TeeJet® 8005 nozzles on wing booms. The number and size of nozzles, as well as pressure were varied to obtain the proper flow rate for each of the above treatments with a 1,000-, 2,000-, or 3,000-ft. swath width and 200 knots ground speed. For calibration, the flow was collected and measured from 8 nozzles for 30 sec. Calibration for each test was complete when the flow was adjusted to within ±1% of the desired rate.

Minimum swath tests (into wind): The results of these tests show the difficulty of spraying with no crosswind component, especially with light and variable winds or a vertical wind direction gradient. Of 6 measurements (3 replications for each chemical) only 2 gave mortality results that indicated the spray was flown nearly into the wind. Wind direction measured on the ground does not necessarily represent the wind effect on the spray. The results for the 2 measurements suggest minimum effective swaths of 1,000 ft. and 500 ft. for malathion and Dibrom, respectively. The difference between these measurements should be attributed to weather variations rather than a difference between pesticides. From these results, an estimate of 750 ft. can be made for the minimum effective swath width.

Crosswind tests: Results showed excellent mortality of caged mosquitoes in all crosswind applications except the first test application (ULV-4 Rep. 1). This application was faulty because of low chemical load, acceleration effects, and aircraft flight attitude, which caused pump cavitation and intermittent flow. Pump cavitation problems were resolved for subsequent tests. In all other tests, kill of caged mosquitoes was 90% or better for the calibrated swath. Slight reductions in mortality resulted from deviation of wind direction from direct crosswind or light and variable winds. Even a single pass provided excellent mortality for an unusually long distance due to a strong, steady crosswind.

USE OF A FOREST SERVICE COMPUTER MODEL FOR ULV PESTICIDE APPLICATIONS FOR CONTROL OF MOSQUITOES AND OTHER FLIES

The Air Force is the only organization we know of that is currently using the Forest Service Cramer–Barry–Grim (FSCBG) aerial spray computer model for ULV aerial mosquito control. The FSCBG has supplemented the Air Force's spray program in 3 areas. These areas include determining our spray offset, and buffer distance, as a substitute for field research, and evaluating the swath widths and droplet paths of experimental boom and nozzle configurations. For this paper, we will address our use of the FSCBG for predicting offset and as a substitute for field research.

The Air Force's spray program has found the FSCBG to be most useful for estimating spray offset, defined as the horizontal distance the pesticide cloud travels from the aircraft until it first hits the ground. This will differ with each release altitude and wind speed. Offset prediction is extremely important for coastal treatments or applications near environmentally sensitive areas. Determining where a pesticide cloud first hits the ground helps us achieve the best possible coverage of a target pest habitat, particularly those located near environmentally sensitive areas.

Since 1987, Air Force C-130 aerial spray operations have successfully treated Parris Island Marine Corp Training Depot SC for *Culicoides* biting midges and mosquitoes. Prior to the Air Force spray program, new recruits lost thousands of man-hours due to secondary skin infections associated with the *Culicoides* bites. On 4 independent offset spray trials, prior to actual spray missions, data were collected and compared to computer model offset predictions. For 3 of the 4 trials, the FSCBG accurately predicted the spray offset within 100 ft.

The offset field trials used TeeJet® oil-sensitive cards wrapped around the top of ¾-in.-diam, 1-m-long dowel rods. The contrast of the small black spots on the white card background can be easily seen. Using a measuring wheel, the dowel rods were spaced every 100 ft. for several thousand feet. Because the Air Force does all of its ULV sprays using a crosswind, the card lines were oriented with the dominant wind direction and 90° to the aircraft flight path. The spray cloud was allowed to settle for about 10 min before the cards were collected. Weather data was recorded during the run. After the spray cloud had settled, the offset information was radioed to the aircrew who could use the information to effectively treat upwind coastal spray boundaries.

The FSCBG has also proven to be extremely useful as a substitute for field testing. When field trials are unfeasible, the FSCBG provides a best guess for developing a spray strategy.

While preparing for Operation Desert Storm in 1991, planners anticipated a need for Air Force aerial spray services. Massive filth fly and other insect problems were expected in and around Kuwait City due to disruption of sanitation services and accumulation of human corpses and dead animals. To minimize the danger to aircrews, a strategy employing the maximum possible swath width using the fewest number of passes needed to be developed. The Air Force's aerial spray equipment had never been tested against filth flies or in an arid environment. It was unknown if the C-130 aircraft and spray system could consistently generate a swath a mile or more in width. Meteorologists from Dugway Army Proving Grounds helped set up the model to predict the widest possible swath that would be lethal to mosquitoes or other flies in an arid urban environment.

Using field data from the initial C-130 MASS prototype characterization trials discussed in the section on bioassays, the model was run to simulate the field trials using 3 of the single-pass crosswind ULV scenarios. The cage lines were placed every 0.1 mi. for several miles and placed parallel to the dominant wind direction and perpendicular to the aircraft flight heading. Bioassays showed that 90% mosquito mortality ceased at about 8,000 ft. downwind from the aircraft release point. With the help of very capable colleagues at Dugway Army Proving Grounds, the FSCBG was set up and run to simulate the bioassay scenario at Avon Park Air Force Reserve, FL. Using the model results, a dosage of between 0.1 and 0.3 mg/min/m^3 of 85% naled was expected to be lethal to 90% of caged mosquitoes. These values were used to run the model using the conditions expected for Kuwait City. Because of the dangerous nature of using a large, relatively slow-flying aircraft to spray pesticides over a war-torn populated city, our objective was to determine our largest possible swath, enabling us to minimize the number of passes and amount of time aircraft and crews would be exposed to potential ground fire. A spray strategy opening up all nozzles on the wing booms of the C-130 showed we could potentially throw a 3-mi.-wide swath with a 6–10-mph crosswind.

The FSCBG has been a useful tool for improving the effectiveness of our ULV aerial adulticide program. The Air Force has collected preliminary data that validated accuracy of the FSCBG for predicting offset at different release altitudes and wind speeds. With the advent of more stringent environmental laws, computer models can be a very useful tool in developing good aerial mosquito control programs using rotary or fixed-wing aircraft. Additional work needs to be done to validate these models for aerial adulticiding.

AERIAL SPRAY EXPERT SYSTEM

The Aerial Spray Expert System (ASPEX) is being developed at the USDA-ARS Medical and Veterinary Entomology Research Laboratory in Gainesville, FL, in cooperation with the U.S. Air Force and the Armed Forces Pest Management Board. The initial system development team included Danel G. Haile, Terry L. Biery, Gary A. Mount, Daniel L. Kline, Eric Daniels, Murat Taner, Douglas A. Burkett, and Terry Carpenter. This team worked together to capture the expertise of experienced scientists involved with Department of Defense aerial spraying for a combined 80 years. This system will enable their corporate knowledge to be used to the benefit of future aerial spray missions.

Aerial application of pesticides has long been used as an effective weapon against adult mosquito populations and the threat of mosquito-borne diseases. Aerial applications are useful in normal mosquito abatement programs and as part of the emergency response to natural disasters, such as hurricanes Hugo and Andrew (Biery 1989, 1993). These applications also represent a potential source of avoidable environmental contamination and human exposure to pesticides.

There is a need for easier, more user-friendly access to the available information on technology and procedures for safe and effective use of aerial applications for mosquito control. The objective of this project is to develop an expert system that incorporates knowledge from past research and experts in aerial spray technology that will provide information to reduce or eliminate pesticide use and chance of errors, thereby reducing environmental hazards and maximizing efficiency of essential aerial spray missions.

The primary objective of this project is to develop a knowledge-based expert system for control of mosquitoes and other medically important flies. Specific system objectives are:

- To furnish easy access to knowledge from research and experts in aerial spray technology.
- To provide expert opinion and information to inexperienced users.
- To eliminate unnecessary applications.
- To minimize environmental contamination.
- To promote safe and effective use of aerial application technology.
- To provide mission planning guidance.
- To serve as an instructional tool.

Aerial application of pesticides is a very complex and risky business, and many of the factors that must be considered are crucial to achieving an effective application without unwanted collateral effects. In developing ASPEX, the following main elements are being considered:

- Chemicals and biologicals—adulticides primarily, with capability for larvicides, etc.
  - Material Safety Data Sheets
  - Labels
  - The Forest Service computer-based graphics (FSCBG) model—offset, drift
  - Calibration
  - Literature review
  - Maps
  - Equipment configuration
    - Nozzles
  - Droplet spectrum determination
    - Other spectrum information
  - Swath width
  - Weather
    - Observation support
  - Safety/worker protection
  - Costs
  - Go/no-go decisions
  - Drift monitoring
  - Release height
  - Buffer zone/spray offset
  - Pesticide availability and selection
  - Standoff spray
  - Spills
  - Flush and purge procedures
  - Canopy penetration
  - Legal factors
    - Federal, state, local, international
  - Paint spotting
  - Area description/size and terrain
  - Equipment maintenance and cleanup
  - Waste disposal
    - Drums, flush, contaminated equipment
  - FAA requirements
  - Applicator certification
  - Environmental assessment and spray validations
  - Department of Defense, Air Force, Environmental Protection Agency, international, and other pertinent spray or environmental regulations
  - Flight safety
  - Command and control
    - Task force/working group
  - Logistics
  - Flight parameters
  - Spotter/control aircraft
  - Barrier treatment
  - Environmentally sensitive areas
  - Species-specific control strategies
  - Vector biology, behavior, and distribution
  - Population monitoring
  - Urban/rural/open
  - Mission planning
    - Maps
    - Boundaries
  - Crosswind vs. into-wind application
  - Premission aircrew instruction
  - Crew responsibilities
    - Aircrews
    - Ground crews
  - Natural disaster/epidemic/military contingencies
  - Navigational aids
  - Deposition monitoring requirements
  - Efficacy monitoring
    - Target
    - Nontarget
    - Environmental
  - Installation/location spray history
  - Public relations (what to say/not to say)
  - Contingency/emergency/routine requests

The status of the ASPEX program is as follows. In 1994, the team began developing the reference list and reviewing the literature to lay the knowledge groundwork for the system. We obtained funding from the Department of Defense's Legacy Resources Management Program, selected the experts, and met to develop the system framework. We also selected the program language and developed the prototype software for the framework. In 1995, we began expanding the prototype database by reviewing the literature, developing the decision support system, and meeting to identify what factors to consider for determining operational parameters, environmental effects, and success probabilities. We are currently continuing expansion of the software. By the end of 1996, our goal is to finalize the information database and decision support system, conduct extensive software tests, and prepare the software documentation, user's manual, and final report. We anticipate expanding the project to include CD-ROM supportability, which will require some additional funding.

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