Journal of the American Mosquito Control Association, 12(2):353–358, 1996

AN INTRODUCTION TO AERIAL SPRAY MODELING WITH FSCBG

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ABSTRACT. The FSCBG aerial spray drift and deposition model predicts the dispersion of material released from aircraft into the atmosphere, and particularly downwind from the release point. The effects of aircraft wake structure, droplet evaporation, local meteorology, penetration through forest or agricultural canopies, and prediction of ground or canopy deposition, air dosage, and concentration are all included in the model. The long developmental and validation history of the model, a brief summary of its assumptions and underlying approximations, and its present user-friendly operation on personal computers are reviewed and highlighted in this paper.

HISTORICAL OVERVIEW

Over the last 25 years the USDA Forest Service, in cooperation with the U.S. Army, has been pursuing the development of computer codes to predict the dispersion and deposition of aerially released material. The USDA Forest Service selectively uses aerial spray applications to control forest pests, whereas the U.S. Army is interested in assessing the effectiveness of chemical and biological defensive strategies and vector control. These agencies are interested in achieving a more complete understanding of the behavior of spray material from the time the spray is released from the aircraft until it is deposited, or, in the case of spray drift, diffused to concentration/dosage levels that are environmentally insignificant. Because mathematical spray dispersion models are useful in determining the interactions of the many factors affecting spray operations, the USDA Forest Service and the U.S. Army have supported the continuing development and application of these models. The cost advantage of numerical simulation over field testing is obvious.

The 2 currently available computer models are the agricultural dispersal (AGDISP) model (Bilanin et al. 1989) and the Forest Service Cramer–Barry–Grim (FSCBG) model (Teske et al. 1993b). The FSCBG model predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP near-wake model solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on the aircraft. The FSCBG far-wake model begins with the results of the AGDISP model at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover ground deposition. The FSCBG model includes an analytic dispersion model for multiple line sources oriented in any direction to the wind, an evaporation model for volatile spray components, a canopy penetration model for forest or agricultural canopy interception, and an accountancy model to recover environmental fate of the released material.

The FSCBG model is a result of a long-standing USDA Forest Service and U.S. Army partnership to develop a method to predict dispersion, drift, evaporation, canopy penetration, deposition, and total accountancy and environmental fate of aerially released sprays. By the late 1960s provision had been made in the U.S. Army's Gaussian plume modeling techniques to account for the loss of material by gravitational settling of drops from elevated spray clouds, and to predict resulting surface deposition patterns (Cramer et al. 1972). Additional work (Grim and Barry 1975; Dumbauld et al. 1975, 1977) led to the development of algorithms for considering the penetration of drops into canopies and simple expressions for wake effects of spray aircraft. By 1980 the model included an algorithm to consider evaporation of the spray drops as well (Dumbauld et al. 1980a).

A prototype model was first applied to forestry use in 1971 to determine application rates in testing of insecticides under consideration at that time for forest insect control in western forests (Barry et al. 1974, Barry and Ekblad 1983). The first reported application of this technology (Waldron 1975) estimated the amount of spray material needed to control an outbreak of western spruce budworm. The implications of these early efforts in the use of mathematical models to improve the planning, conducting, and subsequent analysis of spray operations and results were noted (Dumbauld et al. 1975) and led to field evaluations (Boyle et al. 1975) and further development of the model (Dumbauld et al. 1977). The model was subsequently used to determine offset distances in environmentally sensitive areas of Maine (Dumbauld and Bjorklund 1977). Then, the FSCBG model was applied to the development of optimum swath widths, application rates, and aircraft release heights in other projects (Dumbauld et al. 1980b), and in a pilot project in the Withlacoochee State Seed Orchard in Florida (Barry et al. 1982, 1984; Rafferty et al. 1982) that led to wide acceptance of aerial application in forestry seed orchards in the Southeast.

Continued success in simulating field experiments and control operations led to the inclusion of the near-wake AGDISP model (Bilanin et al. 1989) in the FSCBG model (Bjorklund et al. 1988). A personal computer version followed (Curbishley and Skyler 1989), succeeded by the development of a more user-friendly interface (Teske and Curbishley 1991) and continued model improvements (Teske and Curbishley 1994a). The model has been applied to the determination of swath widths (Teske et al. 1990) and a complete sensitivity study of parameters affecting aerial application (Teske and Barry 1993a).

MODEL OVERVIEW

In its present configuration the FSCBG model takes input data entry from meteorological conditions, aircraft details, nozzle specifications, spray material information, canopy characteristics, and flight path scenario, all through menus managed by the user on a DOS-based personal computer. The FSCBG then predicts the behavior of the released spray material near the wake of the aircraft and into the far downwind environment. The FSCBG considers every aspect of the spray process when making its predictions.

The solution procedure is as follows. Drop size distributions give the mass distribution of material as it is atomized by each nozzle. Drops containing volatile materials (such as water) begin to evaporate immediately upon entering the atmosphere, with the local temperature, relative humidity, and wind speed determining the evaporation rate. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the spray material. Canopy deposition removes spray material from the air and prevents nonvolatile components from reaching the ground. Every aspect of the spray process is affected by the size and significance of atmospheric and aircraft-generated turbulence. Meteorological calculations average the background wind speed and direction, temperature, and relative humidity. Evaporation calculations track the time rate of decrease of drop size. Canopy calculations remove additional material through impaction on vegetation. Near-wake calculations follow the behavior of released spray near the aircraft, and when out of wake influence or at the top of the canopy, hand off to the dispersion calculations at user-designated downwind locations.

The FSCBG contains physically based models that represent the behavior of aerially released sprays. Throughout its development process, attempts have been made to enhance the predictive ability of the model by reducing the amount of unknown information needed to run the model. These steps have involved the following:

1. Collecting specifications for more than 100 aircraft used in aerial spraying in the United States (Hardy 1987) and combining these entries into a library accessed by the model, thereby avoiding the need to locate these specifications whenever a specific aircraft is desired.
2. Collecting more than 300 drop size distributions from nozzles tested principally in the University of California (Davis) wind tunnel (Skyler and Barry 1991) and combining these entries into a library accessed by the models, thereby also avoiding the need to approximate a drop size distribution when the actual distribution is available.
3. Developing a standard approach to interpreting meteorological measurements, clearly deducing consistent model inputs for temperature, relative humidity, wind speed, and direction (Teske 1992a).
4. Developing a standard approach for inferring spread factor from field and laboratory experiments (Teske 1992b), and collecting these data into an extensive database (Teske et al. 1995) to provide a consistent interpretation of actual drop size.
5. Enhancing a standard analytical technique to assess spray droplet stains on witness cards (Teske 1992c), and how these data lead to the recovery of the drop size distribution on witness cards.
6. Quantifying the decay of aircraft vortices in the atmosphere (Teske et al. 1993a), and modeling their influence on the released spray.
7. Performing an extensive sensitivity study of the influence of all inputs into the FSCBG (Teske and Barry 1993a), clarifying which variables are more important in field application.
8. Adding an environmental accountancy module to the FSCBG to indicate how much spray reaches the tree crown and forest floor, drifts off target, or remains in the atmo-

sphere. The interaction of the spray within the tree crown, the collection of drops by foliage elements, and spray deposition on the forest floor are all part of accountancy and environmental fate.

9. Performing model validation studies from past and recent field studies (Mickle 1987; Teske et al. 1991, 1993c; Anderson et al. 1992; Barry et al. 1993a; Rafferty and Bowers 1993; Teske and Barry 1993b; Teske 1994), resulting in reliable predictions and high model confidence. Barry et al. (1993b) overviews all canopy penetration and deposition field studies conducted and interpreted by the USDA Forest Service to date. A concentrated effort is now underway to visit old data sets with the model and compare model predictions with field data (MacNichol and Teske 1993a, 1993b, 1994a, 1994b, 1995).

Our current work involves additional model improvements in the FSCBG, additional field data comparisons, and model visualization and demonstration programs. In all aspects of the modeling, we are looking to the implications of off-target drift and the environmental fate of the total released spray material. Anticipated field studies will look at the effect of time of day (how changes in atmospheric conditions during the day change deposition), and a significant model extension will involve adding the valley drift (VALDRIFT) model (Allwine et al. 1993) as an additional available computation in the FSCBG. The continuing development and improvement of the model for predicting the fate of released material is a priority need.

AREAS OF USEFULNESS

All of these features enable the FSCBG to be used for any of the following:

1. Planning an aerial spray project: mitigating the potential for environmental impact and supporting efficiency and efficacy by selecting the best aircraft and nozzle for a particular spray project; deciding on the best application rate, tank mix, aircraft flying height, and distance between flight lines; mapping spray-on and spray-off points; developing contract specifications and an operations plan; and helping to instill public confidence in the safety of the spray project.
2. Conducting an aerial spray project: updating spray parameters as weather conditions change, feeding these changes into the model, and predicting the effects of these changes even as the spray project is proceeding, and thereby monitoring the performance on the spray project by the contractor.
3. Postspray evaluation of an aerial spray project: comparing model predictions with observations (thereby identifying opportunities to improve, update, and enhance the model, or point out shortcomings of the spray project); assisting in the preparation of the project report and evaluating what went right and what went wrong; and critiquing the spray project and evaluating contractor performance.
4. Documenting an aerial spray project, especially in case of possible use in lawsuits or as a tool for an expert witness.
5. Research and development: designing field trials in a way to reduce trial and error that comes from field testing, evaluating tank mix formulations based upon their physical properties (atomization), and identifying parameters that need further research.
6. Regulatory: establishing criteria for regulating the aerial use of pesticides and developing pesticide label statements.

MODEL IMPROVEMENTS

Several areas of future usefulness of the FSCBG are now being developed:

1. Continuing to develop the FSCBG for the personal computer. Much of our user base is placed in the United States, in the USDA Forest Service and the private sector. These persons would want to maintain the model and be able to access it at any time, and for any sets of input data.
2. Extending the applicability of the model into real time, for use with onboard Global Positioning Systems (GPS) to track the precise location of the spray aircraft (Teske et al. 1996). Currently, a real-time version of the FSCBG (Teske 1995) is being offered to the GPS community.
3. Assisting the U.S. Environmental Protection Agency (EPA) and the industry-based Spray Drift Task Force (SDTF) with porting the near-wake model of the FSCBG into their spray materials database. When this process is complete, the near-wake model (renamed AgDRIFT) will become the program that must be run to satisfy U.S. government spray drift restrictions.
4. Assisting the Canadian Spray Drift Task Force with the further specific development of the FSCBG for their regulatory needs, training them in the use of the model, and including them in the decision-making process for model improvements. The near-wake model—with the user interface of the FSCBG—appears to be the model of choice

in Canada for conducting all spray studies and evaluating all drift complaints.

5. Porting the FSCBG into the GypsES Decision Support System. The GypsES system is an expert system developed by the USDA Forest Service Forest Health in Morgantown, WV, and contains extensive databases to monitor the spread of the gypsy moth, and the spray projects meant to contain it. At present a simplified version of the FSCBG (Teske and Curbishley 1994b) is operational within GypsES as a first step towards implementing a predictive capability, and we expect to continue development of the model within this environment. Plans are underway to expand GypsES into a more general Pest Management Decision Support System, which will greatly enhance its usefulness to the USDA Forest Service, and to state and private users. The FSCBG provides the decision support system with the predictions to decide what to do, with the chance to perform what-if scenarios, and with the opportunity to see what happens to a spray project almost immediately after every spray mission.
6. Porting the FSCBG into the cooperative New Zealand and USDA Forest Service Aerial Application Decision Support System. At present the New Zealand Forest Research Institute has selected the FSCBG as its model of choice for predicting aerial applications and drift in that country. The decision support system will track the buffer offset distances required for certain herbicide/plant species combinations, and will seek to set productivity levels for aerial spraying. In all cases the impact on nontarget species and environmental fate is of most importance.
7. Continuing to foster partnerships with researchers and natural resource managers in both the public and private sectors, for their cooperation in development and technology transfer.

CONCLUSIONS

The USDA Forest Service FSCBG aerial spray dispersion model contains physically based models that represent the behavior of aerially released sprays. The model includes the effects of meteorology, droplet evaporation, canopy penetration, aircraft near-wake, and dispersion, and emphasizes the fate of spray released through nozzles into the wake of an aircraft, by generating a prediction of the dosage, concentration, and deposition patterns over and downwind from a spray site.

The FSCBG is a computer model ideally suited for the prediction of spray material released aerially for the control of mosquitoes, by enabling the prediction of the deposition and drift of this material. The FSCBG takes the user through the various data inputs needed to describe the problem to be modeled, then solves the modeled problem and presents graphical and plot options. The model is available from Continuum Dynamics, Inc., P. O. Box 3073, Princeton, NJ 08543-3073, and includes training, instruction manuals, and 2 hours of telephone consultation. The FSCBG User Group numbers over 160 members, principally in the United States and Canada, in government and private industry. Formal model training is held periodically, and model updates are released frequently.

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