Commercial in Confidence

Client Report No.

Managing Aerial Application of Pesticides.

Stefan Gous and Brian Richardson

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EXECUTIVE SUMMARY

Aerial agrichemical application operations must be designed to optimise the operation. That is to apply the material, liquid or solid, to the target area safely, efficaciously, economically and at the same time avoid off-target drift.

Objective

To produce a reference document to be used by forest managers, aerial agrichemical applicators and regulatory officials to assist in optimising spray applications, i.e. factors affecting spray deposition, which data to collect and calculation methods to evaluate proposed spray operations.

Key results

- Regulatory requirements when applying agrichemicals in New Zealand.
- Important factors to consider for aerial agrichemical application – aircraft calibration, selection of agrichemicals to achieve biological objectives and monitoring weather conditions.
- Assistance from computer model predictions.

Application of results

Aerial applicators should familiarise themselves with the available technology to assist in planning, improving and optimising aerial spray operations.

Further work

Ensis can provide a service to customers to run computer based simulation models to reduce risk and improve aerial application efficiency.

Ensis can assist aerial operators to accurately calibrate aircraft for aerial spray operations.

Keywords: aerial application, calibration, legislation

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Introduction

This document is intended to assist land owners and aerial applicators by emphasising proper procedures and application instructions to minimise environmental risk and maximise pesticide efficacy. Aerial application of pesticides is an important, practical and economical method of crop protection in agriculture and forestry. There are many sources of information and codes of practice relating to aerial pesticide application.

This document is not intended to replace any of the regulatory requirements needed for, transport, handling and application of pesticides, nor the requirements for safe pilot operation and aircraft handling. It simply highlights some of the important considerations when aerially applying pesticides.

1. General considerations when applying agrichemicals

1.1. Regulations

All individuals involved in the commercial distribution, application and handling of agrichemicals should familiarise themselves with the Code of Practice HSNOCOP 3-1 developed by Standards New Zealand (NZS 8409:2004 Management of Agrichemicals). The code covers, management of agrichemicals, land transport of agrichemicals, storage and supply of agrichemicals, use of agrichemicals, disposal of agrichemicals and containers and emergency preparedness and management. It is not feasible to give a summary of the code in this document. This code is not mandatory and if you can meet the requirements of the HSNO regulations and controls in other ways you may do so.

1.2. Management of Agrichemicals

This section covers risk management, responsibility, information, product information sources, documentation and certification, tracking and competency of personnel. Aerial pesticide application must be performed by an operator in possession of the GROWSAFE ® Pilots Agrichemical Rating Certificate. All ground crew handling and mixing agrichemicals must have the Aerial Application Ground Crew Certificate, or be working under direct supervision of a person with such a certificate (Regulation 5 of the H.S.N.O. personnel qualifications regulations 2001). All applicators should be suitably trained and familiar with the agrichemical and application equipment to be used.

See the next section " The National Certificate in Aerial Agrichemical Application" for a detailed list of the unit standards required to satisfy both certificates.

1.2.1. Legislation dealing with hazardous substances.

- The **Hazardous Substances and New Organisms** (HSNO) Act 1996, was brought in to protect the environment, people and communities from the adverse effects of hazardous substances and new organisms.
- The **Resource Management Act 1991 (RMA)**, sets out how we should manage our environment. The R.M.A. deals with the discharge of substances into the environment.
- **Health and Safety in Employment Act 1992 (HSE Act)** deals with the prevention of harm to all people at work.
- **Agricultural Compounds and Veterinary Medicines Act 1997 (ACVM)** is responsible for the regulatory control of agricultural compounds (veterinary medicines/plant compounds), and their importation, manufacture, sale and use on behalf of the New Zealand Food Safety Authority under the Agricultural Compounds and Veterinary Medicines Act 1997.

All of the above legislations and best practices are adequately covered in the GrowSafe courses. For additional information contact the New Zealand Agrichemical Education Trust, or visit www.growsafe.co.nz.

1.3. Transport and Storage of Agrichemicals

All pesticides have to be stored and transported according to their “Dangerous Goods Classification” and in accordance with NZS8409 (Management of Agrichemicals).

1.4. Storage and Supply of Agrichemicals

This section outlines the requirements and recommendations for the safe storage, handling and supply by suppliers and users of packaged agrichemicals that are hazardous substances and/or dangerous goods. Agrichemicals classified as hazardous substances under the Hazardous Substances (Classification) Regulations will be subject to the controls applied under several of the Hazardous Substances controls regulations, according to the hazards associated with the substance. It covers risk management, responsibility, information needs and requirements, documentation, and competency of persons.

1.5. Use of Agrichemicals

This section covers the responsibilities for safe use of agricultural compounds and plant protection products, safe use of veterinary medicines and animal health products, safe use of compounds for agricultural produce, soil or greenhouse fumigation, and safe agricultural use of detergents and other cleaning and sanitizing compounds.

1.6. Disposal of Agrichemicals and Containers

This section deals with the safe disposal of concentrated agrichemicals, surplus agrichemical spray mixtures, empty agrichemical containers and contaminated Personal Protective Equipment (PPE).

1.6.1. Protective clothing and application equipment

All people handling and applying agrichemicals should wear appropriate protective clothing suitable to minimise the risk of exposure from the compound being used. Protective gear includes: respirator, face and eye protection, nitrile or PVC gloves, agrichemical resistant spray suit and work boots/gumboots. Note: make sure to read the instructions of how respirators are used and stored, with special care how to handle opened filters.

1.6.2. Cleaning and rinsing

Rising and cleaning of equipment should where possible be done before removal, in field, away from sensitive areas, on waste ground, diluting the agrichemical as much as possible, never exceeding the allowable application rate, avoiding any run off. This minimises later contact and contamination. Remember that application equipment should be cleaned while the operator is still wearing protective clothing. Alternatively, all contaminated gear should be washed of in a suitable wash down station. This includes the aircraft and attached spray equipment (spray boom, tank, pump and nozzles).

1.7. Emergency Preparedness and Management

This section deals with the need to anticipate incidents or adverse events with agrichemicals, and to have a plan ready to action when such events occur. The Hazardous Substances (Emergency Management) Regulations prescribe the requirements to manage any emergency involving a hazardous substance. This section addresses how to prepare for agrichemical emergencies and the quantities of agrichemicals that trigger the need to have an emergency response plan. An outline of the information needed and actions to take in an emergency is given.

2. The National Certificate in Aerial Agrichemical Application

Table 1 lists the unit standards that make up the Pilot Chemical rating. The Ground Crew Certificate (shaded section) is a separate GROWSAFE Qualification and also is a pre-requisite for the Chemical rating. There are specific requirements that must be satisfied for each unit standard – termed elements and performance criteria.

Table 1 List of unit standards for ground crew and pilot chemical rating.

Ground Crew Course

Unit	**Title**	**Content**
21540	Prepare agrichemicals and equipment for aerial application, and manage a loading site	PPE selected; loading equipment prepared; handling and mixing, disposal and documentation as per NZS8409; loading site security maintained storage as per NZS8409.
21562	Identify and interpret agrichemical product information	Product label interpretation; other information sources identified and used
21563	Demonstrate knowledge of the HSNO Act, and NZS 8409:2004 for the use of agrichemicals	Know HSNO Act; know NZS 8409 for risk management, transport, storage, safe use, disposal and emergency preparedness
6401	Provide first aid	Manage and assess victims condition according to accepted practices for first aid
6402	Provide Resuscitation	Ensure safety of rescuers, bystanders and victim maintained, assess and manage victims condition

Unit	**Title**	**Content**
21541	Plan, prepare to apply, and apply agrichemicals by aircraft	Assess requirements, plan and timetable work, including client needs, objectives for the work, spray drift minimization, application rate, work pattern, timing; compliance with legal and safety requirements, including local Regional Council and NZS8409
21542	Describe the configuration of aerial agrichemical application equipment	Nozzles used for aerial spraying, nozzle and boom selection and configuration
21544	Demonstrate knowledge	Know about the RMA and HSNO for

	of the environmental aspects of agrichemical use	agrichemicals, contamination of surface and groundwater, and the potential for damage from spray drift and how to minimize it.
19145	Describe hydration, nutrition, and sleep in relation to physical well-being of agriculture workers	Know about fluid loss when doing physical work, and the types and amounts of fluids needed for hydration; the role of diet and importance of rest and sleep
21558	Describe calibration, and calibrate agrichemical application equipment	Know about and be able to carry out equipment calibration
21565	Manage agrichemicals in accordance with NZS 8409:2004	Management of agrichemicals according to NZS8409 2004, including transport, storage, safe handling, disposal and emergency preparedness

2.1. Initial Issue of the Rating

By completing all the above unit standards the candidate will gain the National Certificate in Aerial Agrichemical Application. This should be sufficient for CAA to issue the Pilot Chemical Rating.

2.2. Revalidation of the Rating

The rating must be revalidated every 5 years. Revalidation will cover:

- Equipment - nozzle types and performance
- Operating procedures
- Local Government requirements (Council Plans)
- Legislative requirements

3. Aerial Agrichemical Application

3.1. Biological objective

The most important step in all spray operations is to firstly determine the biological objective. This will determine the type of agrichemical (herbicide, fungicide or insecticide), rate and possibly timing of the operation required. The target surface (canopy) and target organism will in turn have an effect on which droplet spectra (nozzle selection) and total volume (number of nozzles, flow rate, and pressure) will be required to optimise the operation. In the field the formulation and application technology are much more important than the lethal potential of the spray mixture (Van Emden, 1984).

For this reason it is important to select the best agrichemical for the task at hand. The best option in most cases is the chemical with the lowest toxicity, applied at the lowest possible rate, ensuring maximum spray deposition while minimising off-target drift, so as to achieve maximum efficacy on the target organism. To achieve this objective it is important to select the correct droplet size, taking into consideration the chemical mode of action, the target crop, terrain and meteorological conditions. The phenological condition of the target species (plants or insects) to a large extent determines the optimum time of the spray operation. Spray operations outside the optimum period in the life cycle will reduce the effectiveness of a spray operation.

Selecting the best agrichemical and adjuvant to achieve the desired biological outcome, applying the spray mixture at the most susceptible phenological condition, using the most desirable droplet spectra to ensure good coverage and uptake by the target species are all factors to carefully consider.

3.2. Types of Aerial Spraying

Spraying techniques can be classified according to the spray volume used. The following classification is accepted as an arbitrary definition by the International Agricultural Aviation Congress.

a) High Volume - more than 80 litres per hectare.
b) Low Volume - 6 to 80 litres per hectare.
c) Ultra Low Volume (ULV) - less than 6 litres per hectare.

Three types of spraying techniques are commonly practised:

3.2.1. Conventional Spraying

This involves low altitude flying with a short boom producing a controlled swath width and not allowing excessive spray to be deposited laterally into the wing tip vortices, thus resulting in free fall droplet deposition onto the target.

3.2.2. Drift Spraying

This is a ULV technique employed for the application of insecticides on large- scale locust and grasshopper control programmes which require high elevated flying to permit full exposure of the non-evaporative spray to the wind motion.

3.2.3. Low Altitude Drift Spraying

This is mainly a ULV technique where long booms are used to allow lateral movement of the spray in the wing tip vortices to obtain large swath widths and horizontal droplet deposition as practised in some cotton spraying with insecticides.

In New Zealand, most aerial spraying in forestry, involves high volume conventional application of herbicides to assist in plantation establishment. This type of spraying requires the accurate placement of the spray mixture to avoid drift and environmental contamination.

3.3. Air Currents produced by aircraft.

3.3.1. Fixed Wing

The wing of an aircraft produces vortices which roll upwards behind each wing tip. These have the effect of spreading the spray out sideways beyond the wing tips and raising the finer droplets away from the ground to a position from which they can drift away altogether.

In addition, the propeller produces a turbulent spiral vortex around the fuselage in the direction of propeller rotation. This is particularly noticeable on the higher powered aircraft, resulting in a displacement of spray emitted from one side of the boom underneath the fuselage and across to the other side. To compensate for this, extra nozzles should be installed on the side from which the spray is displaced.

3.3.2. Rotary Wing

Air currents near the ends of the rotors are outward and upwards producing a trailing vortex somewhat similar to that of the fixed wing aircraft. At low forward speeds of less than 25 kmlh, a violent turbulent wake is also produced on the side to the right of the pilot. Likewise, there is a pronounced downwash in the central portion of the boom. Increasing speed to 50 krn/b and greater, considerably reduces the strength of these vortices and downwash, resulting in a less overall turbulent airflow pattern.

3.4. Swath Widths

Swath widths from both aircraft types are proportional to boom length. Spray booms should not exceed 80 percent of the width of the wing span or rotor length. Adherence to this criterion will help prevent spray droplets being sucked up and out by the wing tip and rotor tip vortices, resulting in more uniform swath patterns.

Increasing spray release height above the target, does not significantly increase swath widths. Therefore, low spray release heights should be used where possible. The best distribution is obtained by flying with the wheels or skid 1.5 to 3 metres above the target where possible. If release heights are lowered even more, stripping often occurs.

3.5. Boom and Nozzle Placement

For both types of aircraft the general rule is number of nozzles required should not be less than one nozzle per metre of swath. Boom diameter should be large enough to enable the largest liquid volume required to flow with minimum friction. Booms should have sufficient plugs to enable the correct number and spacing of nozzles for the desired droplet size and application rate.

Nozzles should be placed relatively even along the boom. Extra nozzles might be required around the fuselage area and inner right hand boom depending on the particular airflow pattern for fixed wing aircraft. The boom should be mounted beneath the wing with a central portion beneath the fuselage. Nozzles should face to the rear in the horizontal position. By turning the nozzles into the airflow, smaller droplet VMD’s are produced. This is not a recommended practise. Correct droplet sizes should be achieved by selecting the correct nozzle size, not changing nozzle orientation.

On helicopters (rotary winged aircraft) the boom should be mounted forward on the skids to minimise wake effects as far as possible. Nozzles are normally evenly spaced along the boom with extra nozzles sometimes required in the central boom portion.

4. Spray Drift and Coverage

4.1. Spray Drift

Spray drift is the movement of airborn agrichemical spray droplets away from the target area. Physical drift is normally due to wind movement. However some weather conditions can prevent the gravitational settling of small droplets and facilitate their movement away from the spray site even during relatively calm conditions.

The volume and distance of spray drift is influenced by many factors. Boom width, nozzle design and orientation, spray pressure, droplet size, release height, horizontal and vertical air movement, temperature and humidity are important considerations.

The control of off-target spray drift is the responsibility of all applicators. For effective control of weeds, pests and diseases, the correct active ingredient rate must be applied through a boom and nozzle that delivers the correct volume at the desired droplet spectra. Off target drift not only reduces the effectiveness of the spray operation, but can also have undesirable impacts on non target areas. All spray operations have a driftable component (Thistle and Barry, 2000). For this reason it is important to accurately calibrate the aircraft for the specific spray task.

4.2. Nozzles and Droplet Spectra

4.2.1. Nozzles

There are two basic types of nozzle available for aerial application: hydraulic and centrifugal energy nozzles. All nozzles should be fitted with diaphragm check valves to prevent dripping when the spray boom is switched off. All nozzles should be regularly inspected for wear. Hydraulic nozzles are especially subjected to the abrasive effects of liquids which can cause wear and alter droplet formation. The flow rate of a nozzle depends on the type and size of the nozzle orifice as well as the operating pressure. An increase in pressure will result in an increase in flow rate.

4.2.1.1. Hydraulic nozzles

Liquid is forced under pressure through a small orifice so that it spreads into a thin sheet. The liquid becomes unstable in the air and breaks up into small droplets, of many different sizes. Droplet size depends on the orifice size, pressure, liquid viscosity, density, surface tension and ambient air conditions. Three types of hydraulic nozzles are used in aerial application, hollow cone, flat fan and CP or anvil type nozzles. Nozzle orientation into the air flow affects the amount of airshear, which in turn affects droplet size.

4.2.1.2. Centrifugal energy nozzles

The most common centrifugal nozzle is the Micronair nozzle. The spray liquid flows through a spinning gauze cage which shatters the liquid into droplets of reasonably uniform size. Droplet size can be altered by changing the rotational speed of the cage, the liquid loading of the cage, the mesh size and diameter of the cage.

4.2.2. Droplet spectra

When a liquid is sprayed through a nozzle it will be divided into droplets that are approximately spherical in shape. Droplet size is very important if agrichemicals are to be applied accurately and efficiently with the minimum off target drift. The **volume mean diameter** (VMD), measured in microns, is the most widely used parameter to describe droplet size (One micron is the size of a sphere whose diameter is 1/1000 of a millimetre). A sample of droplets are divided into two equal parts by volume, so that half the volume contains droplets smaller than the VMD and the other half of the volume contains droplets larger than the VMD.

The size of the droplet determines the sedimentation velocity (vertical fall rate) and with what efficiency it will be intercepted by the target. Larger droplets are less prone to drift than smaller droplets. For a constant spray volume the number of droplets are reduced 8 fold for every 50% increase in VMD, which might have a significant effect on coverage (figure 1). Therefore knowledge of the agrichemical mode of action, the target plant surface and droplet spectra is essential to make decisions on which equipment to use to optimise application.

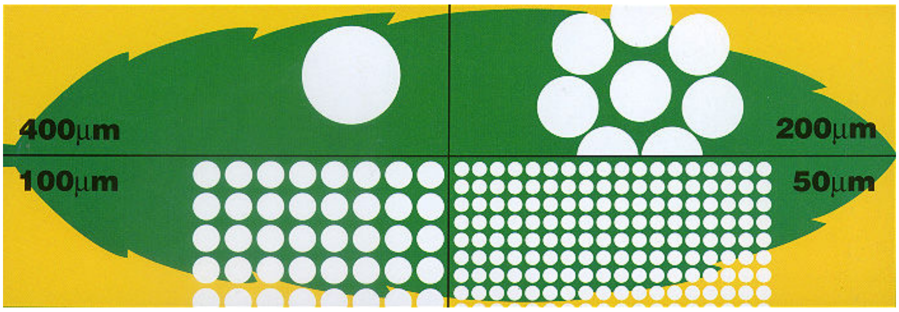

Figure 1. Reducing droplet diameter by 50%, increases the number of droplets 8 fold for the same volume.

Droplet size and number influence biological efficacy along with dose rate and timing. Studies have shown that for aerial application stable herbicide droplet sizes range between 250 and 400 microns. Smaller droplets are more easily influenced by environmental factors that can lead to off-target movement of the herbicide. Droplet sizes over 400 microns tend to be less stable and are subject to fragmentation.

4.3. Nozzle Orientation

The effect of nozzle orientation on droplet spectra is highly significant. It is generally accepted that droplets with diameters < 150 microns are the "driftable fraction". Changing nozzle orientation has the greatest effect on the percentage of spray occurring in droplets with diameters < 150 microns. Trials conducted by the NZ Forest Research Institute (Ensis) have demonstrated that a nozzle pointing vertically downwards from a boom will increase the amount of small droplets < 150 microns by 3-4 times over that produced when the nozzle is pointing horizontally backwards from the boom (figure 2).

Figure 2. Thru Valve Boom with nozzles orientated horizontally into the air stream.

4.3.1. Factors affecting droplet size and deposition

These are air speed, turbulence, nozzle orientation, nozzle size and type, pressure, temperature, humidity and additives.

4.3.2. Droplet density.

The droplet density per unit area determines the coverage of the target. Generally 20-70 droplets per square cm at the target gives adequate coverage.

For systemic pesticides 20 - 40 droplets/cm^2 should provide adequate coverage for uptake and translocation. However, for contact pesticides, efficacy is directly affected by coverage, therefore a much higher droplet density is required, up to 70 droplets/cm^2.

Droplet density is not proportional to the water volume applied per hectare. Droplet density should be checked using dye and cards or water sensitive paper then counting the droplets/cm^2 using a hand lens.

4.3.3. Droplet Size and Wind

Droplet size directly affects coverage, settling velocity, evaporation, movement by air currents and deposition on various targets. Consequently, the droplet size spectrum influences the spray distribution pattern, efficacy of pest control and potential drift hazards in a major way.

Figure 3 shows the relationship of droplet size to drift and is based on droplets falling 3 metres in a 5 km/h cross wind. In this example, a 200 micron droplet when falling 3 metres in this low cross wind will drift 6 metres.

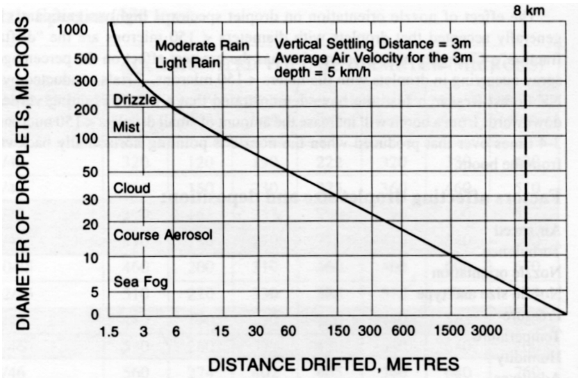

Figure 3. Effect of droplet size on drift distances.

4.3.4. Effect of Droplet Size on Drift

The larger the droplet, the faster it will fall to the ground. The falling droplets do not accelerate but fall at constant velocity. Therefore the distance a drop will drift will vary directly with release height and wind velocity. Droplets smaller than 200 microns is generally considered to be more prone to drift than larger droplets. Small droplets tend to follow the divergent airflow around a solid object as though there is a cushion of air surrounding it and actually never impact or deposit on the target. Small droplets also become susceptible to thermal loss in the form of updraughts. For example, a 200 micron droplet cannot fall against an updraught of 2.5 km/h.

The larger the droplets, the more the pesticide is retained in the target area, giving better control and less drift problems, providing coverage is adequate. Nozzles producing droplet spectra containing a high proportion of droplets less than 150 microns should not be used when applying water based sprays.

4.4. Evaporation

4.4.1. Evaporation Rate of Water Droplets

Figure 4 shows that airborne water spray droplets smaller than 150 microns rapidly reduce in size due to evaporation. This can leave some active chemical which does not evaporate and which may later reform into droplets under cooler moist conditions causing a drift hazard. It should be noted that surface tension and liquid viscosity markedly affect droplet life. This explains why non-evaporative solvents rather than water are used as the carrier in ULV applications where droplet sizes tend to be smaller.

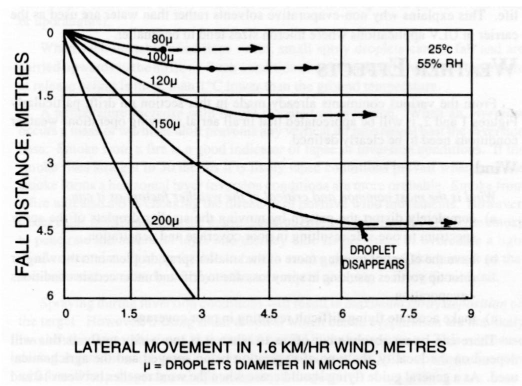

Figure 4. Droplet size reduction due to evaporation a 25°C and relative humidity of 55%.

4.5. Meteorological effects

Smaller droplets are more prone to drift. Weather conditions have a significant impact on drift because wind speed, direction, temperature, humidity and atmospheric stability affect the transport and deposition of droplets and particles. For these reasons it is advisable to always have a weather station (figure 5) on site to monitor meteorological conditions.

Figure 5. Automatic mobile weather station, with sensors, data logger and solar battery.

4.5.1. Wind speed and direction

The wind speed and direction are very important factors to consider when applying agrichemicals. Wind speed and direction not only determines the direction of the spray, but also the influences the degree to which droplets are caught by the canopy. The higher the wind speed the greater the risk of drift. Aerial application of agrichemicals should be avoided if the wind direction is towards sensitive non-target areas. There is no absolute cut off wind speed when it is too windy to fly as this will depend on the locality, the type of vegetation being sprayed and the agrichemical used. Spraying should cease when the wind reaches between 10 and 15 km/h. A rough guide of an 8 km/h wind is when blades of grass or leaves on trees tend to show a definite direction of lean. Spraying with a positive wind (under 8 km/h) is safer than spraying under wind still conditions. This is because under still conditions very small spray particles may move unpredictably in any direction. Other meteorological factors to consider are temperature and relative humidity.

4.5.2. Temperature and Relative Humidity

Temperature and humidity play a major role in the rate of evaporation of water based spray droplets. Aerial spraying should cease once the air temperature reaches 20°C or humidity drops to 50 percent. In New Zealand the humidity rarely reaches this low level. Aircraft performance drops under high temperature and low humidity conditions.

The higher the temperature and the lower the relative humidity, the faster droplets will evaporate and reduce in size which in turn increases their potential to drift. Aerial spraying should only be carried out when the atmosphere is stable, i.e. the air temperature decrease is less than the adiabatic lapse rate. This inhibits upward air movement, so the atmosphere is stable. One of the greatest causes of spray drift is when an inversion layer exists above the target. Inversion layers are formed when the ground surface loses heat by radiation at night, followed by a hot sunny day. The air temperature closer to the ground surface is then cooler than the air above it. Small spray droplets released above an inversion layer will be carried by turbulence in all directions.

4.5.3. Turbulence

The shearing of moving air at the target plant surface causes air turbulence. Therefore, the rougher the target surface the greater the turbulence. Droplets are affected by this type of turbulence according to their size. In low wind conditions larger droplets should be used, so that they settle fast onto the target. The main influence on small droplet dispersal is turbulence. Therefore some advantage can be gained by applying smaller droplets in stronger wind conditions that will increase the capture of droplets more efficiently in the plant canopy.

- Avoid spraying in an inversion (typical of early morning conditions when there is a clear sky and little wind).
- Spraying should cease when wind speeds exceed 10 km/h.
- Wind speeds less than 3 km/h should be treated with caution because of possible variability in wind direction.
- Spray only with a wind blowing away from sensitive areas, and use smoke or other means to observe wind direction.
- Humidity and temperature both affect spray drift by influencing evaporation rates, but humidity is more important than temperature in this respect. There is a significant increase in drift when relative humidity falls below 80% and or temperature rises above 20'C. Where low humidities and or high temperatures are common, sensitive areas should be sprayed when meteorological conditions are most favourable using techniques that minimise drift.

4.6. Anti – Drift Agents

Anti drift agents are added to the spray mixture to reduce the number of droplets less than 150 microns. Generally the two types of additives available are (a) foaming systems and (b) polymer thickening additives.

4.6.1. Foam Systems

These foaming systems involve adding an adjuvant such as Delfoam to the spray mix and applying it through foaming nozzles. The foam nozzle expands the spray mix by adding air to the water. The adjuvant holds the air within the spray droplets after they leave the nozzle, thereby increasing their effective size and reducing drift. This system, when used with water rates of 200 - 400 l/ha, provides good drift control.

4.6.2. Polymer Additives

Polyvinyl polymer additives such as Lo-Drift increase the viscosity of the spray mixture. This leads to an increase in droplet size from any given spray system. These additives can be used through conventional spray systems and nozzles and don't require specialised nozzles as for foaming additives. The addition of a drift control agent may significantly affect the spray mixture flow rate and calibration therefore needs to be made in the presence of the additive. Organosilicone penetrants, used with brushweed herbicides, do not reduce the number of fine droplets.

4.7. Coverage and Target Interception

4.7.1. Coverage

The number of droplets produced and deposited per unit target surface area is normally much more than the minimum required for coverage to control a specific pest. In contact pesticide applications (non - systemic), there are good reasons for a high spray droplet density. In these cases high target surface coverage is required to ensure good pesticide efficacy. Table 2 shows the number of uniform droplets, for different droplet sizes, that would theoretically be produced and deposited per square cm of flat surface from a 110 l/ha spray solution.

Table 2 Number of droplets produced from a 110 l/ha application for different uniform droplet sizes.

Droplet diameter in microns	Number of droplets per cm^2
50	14 297
100	1 821
200	221
400	28
800	4

Nozzles however produce a droplet range. For example a D8/45 nozzle producing a VMD of 410 microns, produces a droplet range from 150 – 750 microns. This nozzle therefore actually produces approximately 90 droplets per cm^2.

4.7.2. Target interception

To control forest pests by aerial application, the aerodynamic characteristics of the target are important (Picot and Kristmanson, 1997). It is therefore important to identify the target surface onto which the spray is to be deposited.

As droplet size increases, the inertia (of the droplet) to change direction also increases. Larger droplets respond less rapidly to airstreams caused by the presence of a target in its path, resulting in greater interception of the droplet. Conversely small droplets with low inertia will tend to follow the air around the target and will not be intercepted. As the target dimension decrease so does the airstreams surrounding it. Therefore at higher wind speeds the amount of spray material intercepted by smaller targets can be increased.

4.8. Equipment

Aircraft spraying equipment should consist of the following:

4.8.1. Tank

Tanks should be free draining, easy to clean, easy access to load and have a removable 50 mesh filter at the filling point. All tanks must, by law, also have an adequate dumping system.

4.8.2. Pump system

Pumps must have the capacity to effortlessly deliver the required spraying volumes without excessive heat production.

The pump must have a bleed line from the top of the pump chamber leading back into the tank to purge the pump of airlocks.

The system must have a three-way valve and by-pass, which enables the complete pump output to be redirected back to the tank. This ensures adequate tank agitation and reduces pump wear.

A pressure control regulator to control the volume passed back through the by- pass when spraying. This controls both the pressure and flow rate to the boom.

A removable in-line filter, with at least a 50 micron mesh, must be placed before the access to the boom. Filters should be cleaned regularly, preferably between tank loads.

A pressure gauge measuring the pressure in the spray boom, not the pressure in the plumbing lines should be installed. This gauge should be situated in the cockpit, easily visible to the pilot.

4.8.3. Spray Boom

The spray boom should never exceed 80% of the wing span for fixed wing aircraft or rotor blade diameter for helicopters. Care must be taken to securely fix the boom in the correct position for each aircraft. All nozzle bodies must be fitted with a 50 micron filters. These filters should also be cleaned regularly during the operation. Nozzle bodies should all have a built-in diaphragm check valve, specially designed for aerial spraying operations. The spring backed diaphragm valve provides instant positive closure when pressure is shut off resulting in drip control. All diaphragm valves must open and close at the same pressure to ensure even flow and shut off from each nozzle.

4.8.4. Flowmeters

Flowmeters are on-board devices that measure the flow of agrochemical spray mixtures to the spray boom and nozzles. These systems require calibration checks to ensure that the measured output matches the actual output.

4.8.5. Geographic information and Positioning technology

The development of both Geographic Information Systems (GIS) and Global Positioning Systems (GPS) has vastly improved aircraft navigation and thereby the uniformity of coverage of sprayed targets.

GIS allows digital map information to be displayed over the spray block to provide a three-dimensional view for fast analysis by computer. It can assist managers in the planning of the spray operation and planning the flight strategy of the target area. GIS maps can also be used to display the actual flown flight paths obtained from GPS systems.

GPS is a navigation or position location system. It uses signals transmitted from polar orbiting satellites to accurately determine position in the earth's atmosphere or on the surface. By using these GPS systems the position of the aircraft can be determined very accurately in real time. Spray aircraft can be monitored in real time; i.e. position in time, spray pump operation (on-off) and weather conditions mapped to aircraft spray position. All this data lends itself to use computer models to predict spray deposition prior to an application as discussed in the next section.

4.9. Aircraft calibration

Before any spray operation, the aircraft applying the agrichemicals should be calibrated. Calibration should be done under a range of suitable conditions which are comparable to the normal operational conditions of use. Before each spray operation the equipment should then be checked to ensure that it performs as expected under the test conditions (Woods, 1984).

4.9.1. Swath patterns

There are several methods to measure aircraft swath patterns or deposition patterns on the ground. All these techniques use some form of artificial spray collecting surface. Samplers are placed perpendicular to the flight line, at equidistant sampling points on the ground. The flight line is placed directly into the prevailing wind. The aircraft is then flown over the collectors spraying onto them. Ensis normally use colorometric detection methods to accurately measure deposition.

The swath produced by an aircraft will depend on the aircraft type, flight speed, release height, droplet size and wind conditions prevailing at the time of application (Matthews, 1979). Figure 2 shows a typical swath pattern produced by an aircraft flying into the wind.

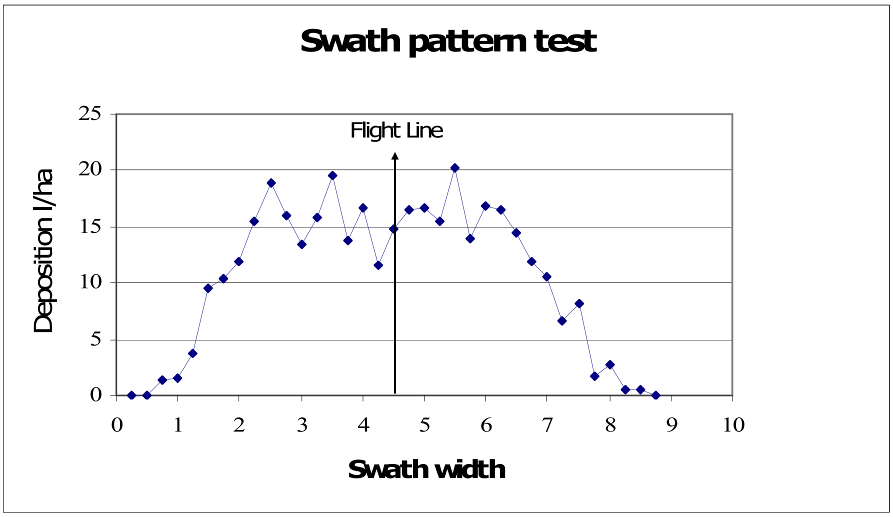

Figure 2. Typical aircraft swath pattern.

4.9.2. Flight line separation (Bout width)

The required accuracy of the deposition determines the distance needed between successive flight lines. The optimum dose required to achieve the desired biological objective must be known, so that the overall dosage applied is sufficient to achieve the goal, but not at a level where unacceptable damage will be caused to the crop or environment.

The coefficient of variation (CV) is used to calculate the optimum flight line separation or bout width. The CV is a measure of the uniformity of the application. Generally the lower the CV the more uniform the deposition becomes. Figure 3 shows that at 30% CV the recommended bout is about 8 metres. (For systemic herbicides a 30% CV is usually acceptable.)

In the example below, to achieve an acceptable coverage the aircraft has to fly consecutive flight lines at 8 metre intervals.

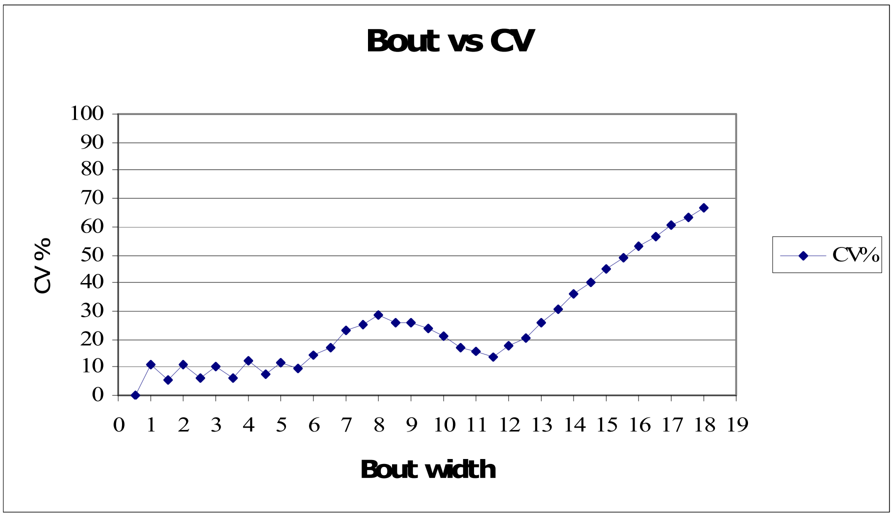

Figure 3. Bout width (flight line separation) measured against coefficient of variation.

4.10. Computer models

Worldwide, several organisations have attempted to create aerial spray models. The first model was known as the Forest Service Cramer Barry Grim (FSCBG) model, developed jointly by the US Forest Service and the US Army (Richardson and Ray, 1993). Ensis has produced Spray Save Manager (SSM), a GIS capable, aerial deposition prediction model. Computer models are used for planning spray operations because they allow the testing of dozens of variables to determine optimal conditions for an effective and environmentally safe operation.

The model predicts spray deposition on the ground and in a plant canopy, and the movement of spray outside the target area, i.e. offsite drift. The model requires detailed inputs on:

- spray droplet sizes;
- aircraft specifications (e.g., type, weight, wingspan/rotor diameter, etc.);
- operating conditions (e.g., aircraft height, speed, nozzle locations, etc.);
- meteorological conditions;
- description of the vegetation canopy.

The complexity and detail of these models provide users with the flexibility to apply SSM or FSCBG to a wide range of situations and problems associated with the application of herbicides, fungicides, and insecticides.

4.11. Conclusions

The development of computer based aerial application simulation models has taken aerial spraying from an art to a science. These models are excellent tools that can be used by people involved with a spray project to determine the drift potential under different meteorological conditions. This information can be used to plan and schedule a spray project that will lessen the possibility of off-target deposition and lead to a more efficient and effective operation.

Operating decisions to improve spraying efficiency and protect the environment can now be based on predictions from a valid computer model. In both forestry and agriculture, the role of aerial application simulation models, and other management decision support system, is likely to increase as future improvements lead to the development of more accurate and faster models.

Many reference books and scientific papers are available to assist managers to improve and optimise aerial spray operations. This document provides a brief overview of the main aspects of aerial application. Below is a list of some reference literature available:

Forestry Pesticide Aerial Spraying, by Picot and Krismanson

Application Technology for Crop Protection, by Matthews and Hislop

Mountain Meteorology Fundamentals and Applications, by Whiteman

Aerial Application Equipment Guide 2003, by USDA Forest Service

Pesticide Application Methods, by Matthews.

What's New in Forest Research No.228, by Richardson and Ray

Operation Spray Safe, Pilots & Operators Manual. Aerial Agricultural Association of Australia LTD. December 1997.

5. Acknowledgements

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