EVALUATION OF THE EFFECTIVENESS OF THE *10 TANKER AIR CARRIER* DC-10 AIR TANKER, VICTORIA 2010

M.P. Plucinski

Bushfire Dynamics & Applications, CSIRO Sustainable Ecosystems and CSIRO Climate Adaptation Flagship, Canberra, Australia

June 2010

Cover photo: First drop at Shelford–Mount Mercer, 3 March 2010, Ryan Becker

CONTENTS

EXECUTIVE SUMMARY

EVALUATION OF THE EFFECTIVENESS OF THE *10 TANKER AIR CARRIER* DC-10 AIR TANKER, VICTORIA 2010

M.P. Plucinski, *Bushfire Dynamics & Applications, CSIRO Sustainable Ecosystems and CSIRO Climate Adaptation Flagship, Canberra, Australia*

A DC-10 air tanker was trialled in Victoria, Australia, during the 2009–2010 fire season. This aircraft is categorised as a Very Large Air Tanker (VLAT) and is substantially larger than any aircraft regularly used in Australia for bushfire suppression. This air tanker has three tanks with a total capacity of 45,400 litres and can be used to deliver retardant and suppressant mixes to fires at a range of coverage levels. This report details the methodology and results of missions used to evaluate the effectiveness of this aircraft for suppressing Australian bushfires.

Initially, the intention of the trial was to deploy the aircraft to active wildfires in Victoria, with a few additional non-fire missions to understand and evaluate its operation in Australian fuel and weather conditions. However, because of the mild fire season, this air tanker could only be deployed to one wildfire, at which it dropped one load. While the drop was on target, the fire behaviour did not seriously challenge the drop owing to moderated weather and discontinuous fuels, leaving the question of its effectiveness in wildfire conditions unanswered.

The five subsequent planned missions were specifically aimed to address issues relating to the firefighting capabilities of this aircraft. Owing to prevailing conditions of the 2009–2010 fire season, none of the missions were conducted under conditions associated with severe wildfires. Most of the drops studied featured a distinct pattern of break-up of the drop cloud in which a series of alternating thick and thin sections could be seen. The resulting drop footprints exhibited a corresponding pattern of heavy and light sections of coverage. Many of the light-coverage sections within these footprints were observed to allow fire to pass across them with minimal slowing effect on spread rates. This problem is likely to be related to the combination of the fast drop speed and the design of the delivery system.

Two drops delivered in open eucalypt forests penetrated through the canopy and provided a good coverage of surface fuels. One of these drops rained gently through the canopy under the influence of a headwind without causing any detectable damage to the vegetation. The other drop caused severe damage and snapped a number of young healthy trees. This drop had considerable forward momentum when it reached the canopy as it was apparently released at a height lower than the minimum specified for this air tanker. This drop could have potentially injured people or damaged buildings, and highlights the need to ensure that people are not in the drop zone. Clearly, the significant potential for damage from a drop precludes a role in an urban interface situation while safe drop heights cannot be guaranteed.

The use of the aircraft in open eucalypt forests to create long (0.5-km) retardant lines in a single drop was shown to be feasible. The ability of retardant lines to halt fire spread in eucalypt forests is limited to low fire intensity conditions (<2 MW/m) because of the spotting potential associated with higher-intensity fires. Retardant lines require support from ground firefighting resources to be effective.

The scope of this evaluation was severely limited by the lack of tracking data from the DC-10. Tracking data would have allowed flight characteristics to be determined and enabled better comparisons between drops. Tracking data had been requested from the aircraft provider at the start of this evaluation.

Notwithstanding this limitation, the drops from the DC-10 were found to have limited effectiveness during this trial. On the evidence collected, this aircraft is not suitable for achieving effective suppression under most Australian wildfire conditions.

ACKNOWLEDGEMENTS

The successful execution of the evaluation missions could not have been achieved without the knowledge, skills and dedicated commitment of a number of key individuals. Hayden Biggs shared his broad expertise in all things related to aerial suppression delivery systems, management and operations, and helped develop some of the evaluation methodologies. John Gledhill took care of the project management, problem-solving and other odd jobs. Stephen Walls and Wayne Rigg organised missions in an extraordinarily tight timeframe, overcoming a number of hurdles in the meantime. Ryan Becker shared a deep knowledge of air tankers, delivery systems and conventional evaluation methods. Lee Gleeson made the Wombat and Enfield Forest sites available and provided considerable support for research undertaken in this area. Special thanks are owed to the landowners (Dave Stephens and John Chapman) for their cooperation and assistance, and the brigades and groups within CFA, particularly the brigades in the Leigh Group (CFA Region 7) and Westmere Group (Region 16), who made the Shelford–Mount Mercer and Streatham missions possible.

A number of others also made significant contributions to the project. They include: Tim McGuffog, Sam Crothers, David Pearce, Marcus Skelly, Bill St Ledger, David Nichols, Michael Doreian, Tim Holland, Paul Hopkins, Gary Morgan, Russell Manning, Greg Lovellette and Adam Damen.

John Gledhill, Andrew Matthews and Richard Thornton provided helpful feedback on draft versions of the report.

Photo credits

Ryan Becker: Figures 2.1b, 4.3.11, 4.3.12b, 4.4.4a, 4.4.5a

David Bruce: Figure 4.4.5c

Peter Bullen: Figures 2.2, 4.3.3c, d, 4.5.7c

Michael Doreian: Figures 2.4b, c, 3.2a, 3.9c, 4.3.1b, 4.3.9, 4.3.12a

Britt Coulson: Figures 3.7, 3.8a, 3.9a, 4.3.3e, f, 4.3.4a, 4.5.4a, 4.5.6a, 4.5.8b, 4.5.9a

Anthony Heard: Figure 4.5.7b

Eain McRae: Figures 4.5.1b, 4.5.4b, c, 4.5.6b, 4.5.7a, d, 4.5.8a

David Pearce: Figures 2.4a, 4.1.7, 4.2.4

Wayne Rigg: Figures 4.1.1a, 4.1.4, 4.2.5b, 4.3.1a, 4.3.3a, b, 4.3.4b, 4.4.1b, 4.4.4b, 4.4.5b, 4.4.7, 4.4.8, 4.4.9, 4.4.10

Simon Scharf: Figures 3.2b, 3.8b, c, 3.9b

Stephen Walls: Figure 4.2.5a

All other photos and figures were taken or prepared by the author.

1) INTRODUCTION

1.1) BACKGROUND

The Victorian Government trialled a very large air tanker (VLAT) from January to March 2010. VLATs are the largest firefighting aircraft and are capable of delivering a volume greater than 41,640 L (11,000 US gallons) (e.g. Cox *et al.* 2009). The contracted air tanker became part of the Victorian aerial firefighting fleet managed by the State Aircraft Unit (SAU) on behalf of the Country Fire Authority (CFA) and Department of Sustainability and Environment (DSE). Arrangements were made for it to be available for deployment to wildfires in Victoria and neighbouring states as needed. During its contract period, the air tanker was subject to evaluation trials, which are described here.

A DC-10 air tanker owned by the US company *10 Tanker Air Carrier* was selected for the Victorian trial, operating with the call sign 'Bomber 391' in Australia. This aircraft operates under the call sign 'Tanker 911' in the United States. A description of the characteristics of Bomber 391 is given in Section 1.5. This air tanker and another DC-10 with the same delivery system ('Tanker 910') have substantial experience operating in the United States, with around 350 operational drops made during the previous four years between them. The vast majority of these drops have been in California, where the air tankers have been contracted to CALFIRE, the agency responsible for fire suppression on California state lands. Most drops have been made using retardant indirectly on fires (creating control lines ahead of the fire) in chaparral shrubland vegetation.

The DC-10 air tanker has a potential capability that has not previously been available in Australia. A trial was necessary to determine the suitability of this aircraft for Australian conditions because of the great differences in wildfire fuels and behaviour, and differences in fire management organisations between Australia and other countries that use large air tankers.

The overall aim of the 2010 Victorian trial of the DC-10 air tanker was to determine its suitability for suppressing Australian bushfires. This report documents the evaluation missions conducted by the DC-10 air tanker during the 2010 Victorian contract that were used to estimate its potential effectiveness for suppressing Australian bushfires.

1.2) AIMS

Four separate aims were identified for the evaluation of operational effectiveness during this VLAT trial. They were to:

1) determine the effect of drops on fire behaviour;
2) quantify drop characteristics;
3) determine if there are any ground safety issues; and
4) provide reliable data for other aspects of the evaluation.

The first aim is the most important and centres on the need for aerial suppression drops to have a significant impact on fire that reduces fire intensity, enabling control. The length of fire edge (perimeter) that is halted (stopped from spreading) and the duration of spread cessation are of key importance. The length of fire edge suppressed is a key measure for assessing a drop's effect on a fire. It provides critical information for determining aircraft productivity, which is required for cost/benefit assessment of the evaluation (also required for the fourth aim).

The second aim is to quantify of the dimensions of drops on the ground along with an assessment of drop quality. Drop quality is judged by the consistency of coverage across the drop footprint. The assessment of drop characteristics must consider the ability of drops to penetrate through tree canopies to affect the ground fuel in forests.

The third aim is to identify any safety issues related to the impact of drops that may affect ground crews and structures under drops. Safety concerns are related to the DC-10's substantially greater drop volume than those from aircraft that are commonly used in Australia.

1.3) EVALUATION LIMITATIONS

This evaluation is necessarily limited by the conditions used in the trial missions. Time and budgets available meant it was not possible to assess the aircraft on **all** of the main vegetation classes or landscape types found in Victoria or to replicate **all** of the possible tactics that this resource type may be used for. Thus the planned missions that were conducted were prioritised to represent the most likely scenarios for the deployment of this resource. The missions conducted did not include drops in tall closed forests, sites with complex terrain, direct attack on fire in forest vegetation or the use of gel suppressants. In order to obtain the most critical information in the time available some variables were deliberately excluded in order to focus on others. The excluded variables included drop speed, door configuration and terrain. All drops were requested to be made with an air speed of 278 km/h (150 knots) and using all drop doors. These characteristics fit into the suggested flight parameters (see Section 1.5.2). All sites selected for planned drops were relatively flat, which minimised the role of drop height as a variable, as drops made in areas with complex terrain have to be made at greater heights than those in flatter areas (Cox *et al.* 2009). Limiting terrain as a variable allowed testing to occur in conditions that did not disadvantage the outcome because of this issue. It should be expected that steep and or broken terrain would reduce effectiveness of the aircraft. Therefore, the trials on level terrain are likely to represent the best case in relation to this performance-influencing factor.

This evaluation was originally intended to be focused on assessing the effectiveness of operational drops on going wildfires. Additionally, planned drops were to be undertaken to investigate issues such as canopy penetration, where site assessments were needed before and after drops.

The period of this evaluation saw unusually mild conditions prevail during the peak of Victoria's fire season, with very few large wildfires occurring. As a result of this the DC-10 was only able to be used to deliver one operational drop and this occurred during very mild conditions (see Section 3.1). It became apparent during the trial that it was not going to be feasible to achieve the aims of this evaluation by relying on deployments to wildfires.

Missions involving planned drops with purposely lit fires were therefore organised as a contingency to the limited operational data collection. The schedule for these missions was tight because of limited suitable weather windows during the final weeks of the DC-10's contract period. The short planning time available for these missions limited some methodologies, such as fuel sampling.

There could only be a small number of planned trial drops using fire, owing to the limited time period available for organising sites and resources, combined with the high operating costs of conducting such events. While these missions were able to give some indication of the impact of fire on drops, the fire behaviour, weather and smoke conditions were not representative of wildfire conditions. As a result of the mild season and reliance on planned missions, the DC-10 air tanker was not assessed in strong winds or on fires with significant smoke.

1.4) AERIAL SUPPRESSION

1.4.1) Aerial suppression chemicals and drops

Most aerial suppression drops contain chemical additives. These fit into three classes: foam surfactants, water-enhancing gels and long-term retardants. Foam surfactants and water enhancers are primarily designed for direct application onto the flaming fire edge and are only effective while wet. Long-term retardants are designed to be laid ahead of the fire as they work by inhibiting flaming combustion and remain effective after the water used to deliver them has evaporated.

The effectiveness of suppression chemicals depends on the coverage level (depth) required on the critical fuel. The more intense the fire, the greater the depth required (Loane and Gould 1986). Coverage levels vary across drop footprints, with the heaviest concentrations generally located in the centre of the drop and areas of lighter coverage found around the edges. The dimensions of aerial suppression drops vary with a number of factors such as drop volume and viscosity, aircraft speed and height, delivery system (e.g. gravity or pressurised) and wind speed and direction. A range of retardant coverage levels has been recommended for different vegetation types in the US (George 1981) and is listed in Table 1.1. Coverage levels are most commonly expressed in US gallons per 100 square feet (GPC), which can be converted to litres per square metre by multiplying by 0.407.

TABLE 1.1. Recommended retardant coverage levels from George (1981)

Coverage level (GPC#)	L/m^2 (mm)	Vegetation types
1	0.4	Annual and perennial Western grasses, tundra
2	0.8	Tall grasses, conifer (with grasses/forbs/needles and/or woody shrub understorey), hardwoods (winter and summer)
3	1.2	Light slash (conifer or hard wood), intermediate brush (green), sawgrass, Western woody shrubs
4	1.6	Short-needle conifer (heavy dead litter)
6	2.4	Southern rough, Alaska black spruce, intermediate brush (cured)
>6	>2.4	California mixed chaparral, medium and heavy slash, high pocosin
For creeping or smouldering fires, reduction of one coverage level may be considered		

#US gallons per 100 square feet

Drops can be breached by fire by three means: spotting, burn-around, or burn-through (Plucinski *et al.* 2010). Spot-fire breaches occur when embers are lofted across drops, igniting fuels on the other side. Drops are often breached by spotting when the fire behaviour is too intense for them to hold fire. Burn-around breaches occur when fire passes around treated fuels. This is usually a tactical problem related to poor placement or fire spread being considerably greater than line construction rates. Burn-through breaches occur when fire passes over weak coverage sections within drops. This form of breaching occurs when the coverage level at some point across the drop is not adequate or when there are breaks within the drop coverage.

1.4.2) Aerial suppression effectiveness

Aerial suppression effectiveness can be defined in a number of ways depending on scale and objectives. At a broad scale, strategic-level aerial suppression effectiveness can be judged by the contribution made to the achievement of fire management objectives for an area, such as the maintenance of acceptable rates of initial attack success, fire area burned and damage incurred. The contribution of aerial suppression to the achievement of fire management objectives can be difficult to isolate from that of other resources and management actions. Some research focused on the success of initial attack operations using aircraft has been able to determine factors influencing aerial suppression effectiveness at this scale (e.g. Plucinski *et al*. 2007, 2008).

The rate at which drops are delivered to the fire edge and the rate at which suppressed fire edge or fire retardant line is produced (line production) also provide a measure of suppression effectiveness. Delivery and production statistics can be expressed in terms of volume delivered or length of line produced per unit of time. Productivity rates are key inputs required for calculating and comparing the cost effectiveness of different suppression resources.

At a tactical level, aerial suppression effectiveness is primarily defined by the effects that drops have on fire behaviour. The effects that drops have on fire behaviour should be judged in respect to the objectives for the drop, which may vary from the complete extinction of fire edge to a reduction in intensity and spread rate. As the effects of aerial suppression drops are usually temporary, the durability of such effects should also be considered.

This evaluation is concerned with the tactical effectiveness of aerial suppression drops from the DC-10 air tanker made during missions conducted as part of the Victorian trial. The aims discussed in Section 1.2 were used to guide this evaluation.

1.4.3) Evaluation of air tanker effectiveness

The majority of air tanker evaluation work has been conducted by the United States Forest Service (USFS) on behalf of all federal US fire agencies. This work covers topics such as retardant effectiveness (e.g. Hardy 1977, Blakely 1983), delivery systems (e.g. George 1981, 1992, Blakely *et al*. 1982, George and Johnson 1990, George and Fuchs 1991) and drop tactics (e.g. George and Blakely 1973, Lovellette 2000). This work has been used to develop air tanker evaluation procedures used for approving air tankers for operational use (e.g. George and Johnson 1990, George and Fuchs 1991, George 1992). The USFS has a rigorous testing regime focused on cup grid tests (an accepted test to quantify coverage levels across the drop footprint) and static flow tests (Suter 2000, 2002, Lovellette 2004, 2005, Fisher 2006). Before being approved for operational use, new air tankers must have their drop patterns measured over a grid when their drop patterns cannot be predicted from existing data. Reports containing drop patterns determined using cup grid tests exist for all of the aircraft and delivery system types contracted to United States federal fire agencies. Evaluation test results specific to DC-10 air tankers are discussed in Section 1.5.3.

Air tanker approval processes are not as formal outside the United States, though many agencies (including Australian agencies) consider results from these evaluations. Australian fire agencies also specify desired capabilities when tendering contracts for firefighting aircraft and expect these to be proved operationally. The agencies rely on knowledge acquired through operational experience when selecting aircraft types for contracts.

None of the USFS air tanker approval tests involve active fire and there has been very little formal evaluation of aerial suppression drops on fire. Some formal assessments of aerial suppression drops were made as part of the Operational Retardant Effectiveness program (George 1985, 1990). This program investigated drop characteristics in field situations, including monitoring of drop effectiveness on operational fires using infrared cameras (George *et al*. 1989). While this study came up with a number of recommendations for safe and effective tactical application of retardants, there is little documentation of the methodology or data collected.

Project Aquarius was an Australian aerial suppression cost–benefit study conducted in the early 1980s that investigated some aerial suppression drops from a DC-6 air tanker made on experimental fires (Loane and Gould 1986). This study found aerial suppression drops to have a similar fire intensity limit to that of bulldozer-constructed fire breaks (~3 MW/m with a ground crew), beyond which spot fires ignited from embers tend to overcome most forms of suppression. This study also highlighted the differences in the depth of water and long-term retardant required to hold fires of different intensity. The cost–benefit study concluded that the most economically efficient aircraft fleet would be a combination of helicopters and agricultural aircraft, and that a large air tanker would only be beneficial in severe seasons.

The most recent investigation of the effectiveness of aerial suppression drops on fires was conducted in 2008 in South Australia (Plucinski *et al*. 2010). Drops were made on three experimental fires burning in mallee-heath vegetation. These fires were lit in wildfire conditions and were allowed to fully develop before being attacked by drops from two single-engine air tankers (Airtractor AT-802F). Each of the fires was attacked using a different suppression chemical (gel, retardant or foam). These experiments were able to highlight the importance of drop tactics and demonstrate the suitability of infrared cameras for assessing aerial suppression experiments. The experimental design and basic assessment techniques used for the 2008 experiments built on a previous trial involving drops from a Type 2 helicopter on stubble fires (Plucinski *et al*. 2006).

1.4.4) Previous trials of large air tankers in Australia

Previous trials of large air tankers have been conducted in Australia in order to determine the suitability of specific aircraft types. The trials involved a Hercules with a temporary delivery system, a scooping Canadair CL-415, and the Erickson S-64F Air-Crane helitanker.

The first of these trials involved a Royal Australian Air Force Hercules fitted with a 11,355-L Modular Airborne Fire Fighting System (MAFFS). This aircraft was trialled during the 1981–82 and 1982–83 seasons (Rawson *et al*. 1982, 1983). Operational assessments of this aircraft were made on fires it was deployed to during 1982 (Cheney *et al*. 1982). These assessments found the MAFFS-equipped aircraft to be effective on small, low-intensity fires but ineffective on large, high-intensity fires.

The trial of the Canadair CL-415 involved non-fire drops observed and was reported by representatives of the member organisations of the Australasian Fire Authorities Council (AFAC 1996). This trial involved observations drops and scooping manoeuvres from this multi-engine aircraft. A report recommended an operational trial of this aircraft over a season.

The operational performance of the Erickson S-64F Air-Crane was assessed during its first season of operation in Australia. A report from this assessment documents the operational requirements, performance, safety and effectiveness of the helicopter, which is now in regular use in three states (Biggs 2004a).

1.5) 10 TANKER DC-10

Bomber 391 is a converted McDonnell Douglas DC-10-30, a swept-wing three jet-engine-powered aircraft, which formerly operated as a commercial passenger airliner. It is the second aircraft of this type to be converted and operated for firefighting by the *10 Tanker Air Carrier* company. The converted DC-10 air tankers have tanks with a total capacity of 45,400 litres. The DC-10 air tankers operate in conjunction with a lead plane that has the role of liaising with the incident air attack supervisor to determine the locations for drops and the safest flight path for the DC-10. When approaching the fire, the DC-10 follows the lead plane, which flies the profile of the intended drop and may use a smoke generator to indicate the prevailing wind conditions. The DC-10 is operated by two pilots and a flight engineer, and the lead plane operates with a pilot and a dedicated air attack supervisor from a fire suppression agency. Details of the air tanker, its specifications and airbase requirements are given in the VLAT trial operational program (Biggs 2010).

The two DC-10 air tankers operated by *10 Tanker Air Carrier* have collectively made around 350 operational drops in the United States, mainly in California. The majority of these drops have been for the construction of long retardant lines in remote areas in support of large fire operations.

The DC-10 air tanker is considerably different to other aircraft used for firefighting in Australia. The most obvious difference is the payload capacity. The much larger capacity of this aircraft potentially enables a range of alternative capabilities, particularly related to the building of long continuous sections of retardant line. Other differences relate to the flight characteristics, particularly during drops. Aircraft within the VLAT category cannot fly as low as other fire-suppression aircraft used in Australia because they are required to maintain greater clearance than smaller aircraft (Cox *et al*. 2009). The flight speed during drops from VLATs is significantly faster than for smaller aircraft. The DC-10 air tanker must fly at 142 knots (263 km/h) or more during drops (SDTDC unpublished 2006), whereas smaller fixed-wing aircraft used in Australia typically travel at less than 120 knots when making drops.

Bomber 391 was based at Avalon airport (38°01.10′S, 144°30.20′E) near Geelong for the duration of this trial. An airbase was set up to support it and is described in Biggs (2010).

1.5.1) Delivery system

The DC-10 air tanker has a series of three main gravity-flow tanks with a smaller fairing tank attached to each of the two end tanks. The tanks are mounted to the centreline of the aircraft belly. The three central tanks have two longitudinal doors and are not connected to each other. The centre tank has the largest capacity and is wider than the other tanks. There are vents at the top of the tanks to allow airflow during drops and when the tanks are being filled. The tanks are designed and manufactured by the Erickson Air-Crane company and are similar to those used on the S64 Erickson Air-Crane helicopters (see Biggs 2004a). Each of the main tanks is filled individually through a standard 3-inch camlock port. It takes around 8 minutes to fill all tanks using three hoses (Biggs 2010).

The controls for the tanks are in the cockpit and are operated by the flight engineer. They are capable of dropping variable quantities at a regulated flow rate using different combinations of the tanks. The control can also be used to split loads into a number of drops. As with other air tankers, the targeting of drops relies on the judgement of the flight crew. The doors compress rubber seals when closed. All drops made during this trial involved three doors opening together. The flow rate from the tanks is controlled by using the doors and adjusting the amount that they are opened. This is controlled by a computerised processor with programmed settings for achieving different coverage levels as dialled up on the tank controls. There are eight standard coverage level settings (1–8) on the control panel.

More detailed information on the delivery system is available in the operational program (Biggs 2010).

1.5.2) Flight parameters

Flight parameters for the DC-10 air tanker during this trial have been specified in the Standard Operating Procedures section of the Operational Program (Biggs 2010). The DC-10's air speed during drops is normally 278 km/h (150 knots). This drop speed was requested for all drops during the evaluation missions.

The Operational Program states that the normal drop altitude should be 90 m (300 ft) above ground level and no lower than 60 m (200 ft) above any hazard, such as terrain or vegetation. These drop heights are consistent with those recommended for VLAT category aircraft in Cox *et al*. (2009) and the recommendations from the USFS San Dimas Technology and Development Center drop tests (SDTDC unpublished 2006). The 60-m minimum drop height was recommended because it would allow the retardant cloud to reach terminal velocity before hitting the vegetation or the ground, thereby preventing harmful forward momentum that has the potential to cause damage.

Greater clearance is required in areas with complex terrain. A report evaluating the safety and utility of the VLAT category air tankers (Cox *at al*. 2009) recommended that VLAT aircraft maintain 120 m (400 ft) terrain clearance in steep and rugged areas. This report also suggested that VLATs not be used in areas with steep and rugged terrain unless drops can be made with minimal manoeuvring.

1.5.3) Previous assessments of DC-10 air tanker capabilities

A number of assessments of the DC-10 air tanker capabilities have been made as part of the USFS approval testing regime and as informal reporting on operational wildfires in California.

In 2006, the San Dimas Technology and Development Center (SDTDC) section of the USFS prepared an internal report on the cup grid tests undertaken by the first DC-10 air tanker (Tanker 910) produced by *10 Tanker Air Carrier* (SDTDC unpublished 2006). The air tanker met most of the relevant required criteria during this cup grid testing but was required to undertake further static testing after some modifications were made. A total of 18 cup grid drops were made. A summary of these is presented in Appendix 1.

The static testing was undertaken in 2009 (SDTDC unpublished 2009). This testing revealed some problems with drainage of the final section of the load from the tanks during full load drops. This testing was conducted on both DC-10 air tankers.

A number of qualitative operational evaluation forms containing written evaluations from observations during wildfire operations have been completed for the US Interagency Airtanker Board. These forms, titled ‘Provisionally Approved Airtanker Evaluation’, relate to a number of Californian wildfires to which a DC-10 was deployed that occurred between July 2006 and October 2008. They were completed by air base managers, air personnel with supervisory responsibilities and ground observers. The evaluations on the completed forms are very positive for the operational use of the DC-10 air tankers, although they lack detail.

2) EVALUATION METHODOLOGY

The effectiveness evaluation of the VLAT trial had two complementary data collection components: operational drops and planned drops. Operational drops were those that were made on going wildfires. Planned drops were those that were made in non-operational conditions to test one or more predefined objectives. The use of operational drops for evaluation involves detailed assessment of drop characteristics and their effect on fire behaviour. A document outlining the methodology for data collection from operational drops was prepared for data collection teams and is included as Appendix 2. The use of pre-planned drops allows the flexibility to target sites and conditions for specific aims to be addressed, such as quantifying canopy penetration and physical damage. Some drops were conducted in conjunction with purposely lit fires. These fires were not representative of wildfires but they did give some insight into the interactions between drops and fires.

Six missions were available for this evaluation. Only one of these involved an operational wildfire. The basic characteristics of the evaluation missions are summarised in Table 2.1. The first two missions did not involve the application or occurrence of fire.

TABLE 2.1. Summary of missions conducted during the 2010 DC-10 evaluation

Date	Mission type	Location	Number of drops	Agent	Vegetation
29/01/2010	Planned	Wombat Forest	1	Retardant	Eucalypt forest
30/01/2010	Planned	Avalon	3	Retardant	Stubble
31/01/2010	Operational	Werrimull-Pheeny's track wildfire	1	Retardant	Mallee
3/03/2010	Planned	Enfield Forest	1	Retardant	Eucalypt forest
3/03/2010	Planned	Shelford-Mount Mercer	2	Retardant	Stubble
4/03/2010	Planned	Streatham	3	Foam	Stubble

2.1) OBSERVATION METHODS

Data collection for each of the VLAT missions used in this evaluation centred on observations recorded using still and video photography. This was normally taken from a number of vantage points. Airborne observations were a key component of this. The application of infrared technologies was vital for capturing key details that could not be determined by other means.

The use of multiple vantage points for filming allowed a broad perspective of the application and effects of drops. These were necessary for characterising drop cloud characteristics. Photography taken in line with the flight path axis captured the characteristics of crosswind dispersal and drift, while that captured perpendicular to the flight path illustrated the drop height, relative height of terminal velocity and the break-up of the drop cloud. Incidental photographs and footage of drops taken by people at different locations often captured unique perspectives of events. As all of these photographs were digital, they were able be time synchronised. The time synchronisation technique used is described in Plucinski *et al.* (2010).

Airborne observations were necessary for capturing the drop imagery in locations where there were considerable obstructions on the ground. These also provided a full perspective of the drops and fires that could not be captured on the ground. Both video and still photography was taken from observing helicopters for all missions.

High-definition airborne footage captured for the first three drops came from a Sikorsky S-76 helicopter set up for fire monotoring. This helicopter was specifically contracted for this evaluation and operated with the call sign Firebird 376. The later three missions were filmed using a similar high-definition camera operated by Helifilms Australia in another helicopter, Firebird 326. Both high-definition cameras operated in Axsys gyro-stabilized gimbals fixed under the nose of each helicopter and captured 1920 × 1080 pixels. The camera in Firebird 376 recorded high definition video on a specific track, whereas footage from the camera in Firebird 326 was blended with infrared footage captured simultaneously.

Visible observations of changes in fire behaviour from drops can be limited because of visibility issues related to smoke and vegetation. Infrared imagery captured from observing platforms can be used to monitor drops without being affected by these. Infrared imagery is also able to differentiate drops from the surrounding environment because of differences in temperature. The ability of the infrared sensors to distinguish areas cooled by drops and to do this through smoke allows drops to be monitored during conditions where other methods are unable to work. There were two airborne infrared data capture methods used in this project: forward-looking infrared (FLIR) videography and line-scanning. These are described in Sections 2.1.1 and 2.1.2 respectively.

2.1.1) Forward-looking infrared (FLIR)

FLIR cameras are infrared detection systems that can be used for close-up infrared aerial viewing. They are typically mounted in a gimbal attached to the base of a helicopter so that they can be rotated to view objects from multiple angles (Zajkowski *et al*. 2008).

Helicopter-mounted infrared cameras are often used by fire agencies for mapping fires, locating spot fires and identifying hotspots during mop up. The operational use of FLIR cameras has been assessed in North America and found to reduce the initial assessment time, improve the guidance of air tankers and allow the immediate assessment of drops so that tactics can be adjusted (George *et al*. 1989; Ogilvie *et al*. 1995). Infrared imagery proved to be the most useful method of evaluating aerial suppression drop effectiveness during recent aerial suppression experiments (Plucinski *et al*. 2010) and a method for analysing infrared imagery for this purpose is described in Perez *et al*. (2009).

During this evaluation, helicopter-mounted FLIR cameras were used to record drops as they were made and to monitor them and record their interaction with fire. The FLIR cameras operated in the same gimbals as the high-definition video cameras (described in Section 2.1). FLIR imagery from the first three missions was captured from Firebird 376 using an Axsys V9 MS with 640 × 480 pixels. The FLIR camera operated in Firebird 326 was an Axsys V14 MSII with 640 × 512 pixels. Both cameras operated in the 3–5-μm range. The imagery from the Firebird 376 FLIR camera was recorded on a unique video track. The FLIR imagery recorded from Firebird 326 was blended with the high-definition video footage.

2.1.2) Infrared line-scanning

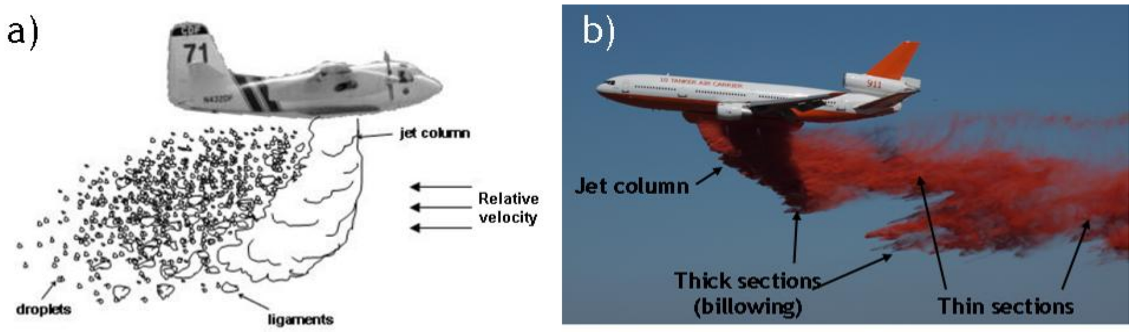
Infrared line-scanning involves an infrared scanner installed in a fixed-wing aircraft that is used to provide data for fire boundary maps used for intelligence and planning purposes by incident management teams during wildfire suppression operations (Matthews 1997, Zajkowski *et al*. 2008). A detailed explanation of the design and development of line-scanning systems is given in Matthews (1997). This document also details the development of the system used by Victorian fire agencies for mapping fires.

During these trials, line-scan aircraft were used to film drop areas before and after drops and during and after fire impact. These scans were geo-rectified images and were compared with the ground drop assessments.

2.1.3) Retardant cloud

The retardant (or foam) cloud formed as Bomber 391 released its load was described for each drop based on still and video imagery captured from a range of vantage points. The terminology used to describe the features of retardant clouds is presented in Figure 2.1. The term billowing has been used to describe the formation of thick and thin sections within the drop cloud as it breaks up while dropping. A comprehensive explanation of the break-up mechanisms of aerial suppression drops is given in Amorim (2008).

FIGURE 2.1. (a) Schematic representation the break-up of an aerial suppression cloud, from Amorim (2008); and (b) terminology used to describe the break-up within a retardant cloud from Bomber 391.



2.2) FLIGHT CHARACTERISTICS AND DROP SETTINGS

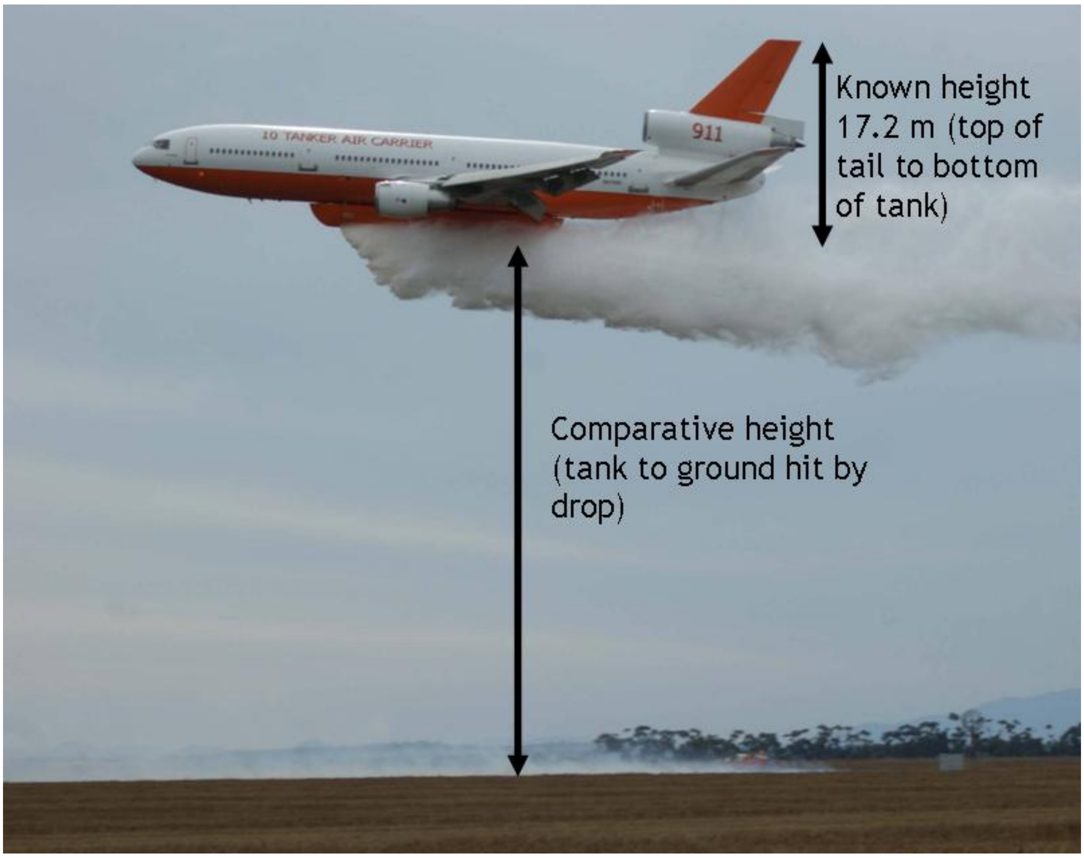
Information regarding flight characteristics and delivery system settings at the time of all drops is required for making comparisons between drops and for determining causal factors for drop outcomes. The flight characteristics of interest are drop speed, height above ground and flight path. The delivery system settings of interest are the coverage level dialled, tanks used and drop volume.

The flight characteristics are most easily captured using a standard GPS (Global Positioning System) unit that produces a downloadable tracking file that is set to log data very frequently (~1 second). Track files from these units give a three-dimensional location for each point in time that can be used to calculate height above ground, travel speed and the direction heading. At a one-second logging interval, such a system could provide useful information about flight changes during drops. Despite a number of clear, repeated and emphatic requests for one of these low-cost and readily available devices to be used, such a system was regrettably not made available in Bomber 391. This method has been used for field evaluation of aerial suppression drops previously and is discussed in Plucinski *et al.* (2006, 2007, 2010). GPS logging devices are also used to obtain flight data during USFS cup grid tests and were used to obtain the data for the drops made by the other DC-10 air tanker in 2006 (SDTDC unpublished 2006).

Bomber 391 did have a tracking system that was designed for a flight-following function. This system produced tracking data at 2-minute intervals, which proved to be too coarse for obtaining any useful flight data during drops. None of the log points occurred close enough to drops to provide any relevant data for this evaluation.

In the absence of GPS logging data, an alternative method for estimating air tanker height was investigated. This was an image analysis method used by the USFS during cup grid tests[1]. This method requires a suitable image taken from the side of the flight path at a sufficient distance from the drop site for the angle between the delivery system and the observer to be low. A reference section of known height within the image is compared with the height of the delivery system above the ground. Here, the vertical height difference between the tip of the tail fin and the base of the tank was used for the reference height (Figure 2.2). For the DC-10, this reference height is 17.2 m. The method has a degree of error that varies depending on the flight deck angle and the identification of the correct location on the ground and is likely to be in the order of 3 m (10 ft) (G. Lovellette, pers. comm.).

FIGURE 2.2. Photo-reference method for estimating aircraft drop height (G. Lovellette, pers. comm.).



Other information on flight and drop load characteristics was sourced from Bomber 391's flight log book. A table containing relevant information, such as dial settings, drop height and drop volume, from the flight log book, is given in Appendix 3.

[1] Height reference methodology provided by Greg Lovellette, Physical Scientist, Missoula Technology & Development Centre, US Forest Service, Missoula, Montana.

2.3) ENVIRONMENTAL AND SITUATIONAL VARIABLES

This section describes the collection of variables required for describing the environmental conditions where missions were conducted.

2.3.1) Terrain

Basic terrain descriptors such as elevation, slope and aspect were measured across drop sites using clinometers, compasses and hand-held GPS units.

2.3.2) Vegetation and fuel

Vegetation height and cover and cover were assessed for the drops conducted in forests. The height of trees was estimated on the ground with the aid of a clinometer. Vegetation cover was assessed in terms of percentage projected foliage cover above the ground. Projected foliage cover was estimated using reference diagrams (McDonald *et al.* 1990), an example of which is given in Appendix 2.

Fuel characteristics in forest and shrubland sites were assessed using the visual fuel hazard rating systems of McCarthy *et al.* (1999) and Gould *et al.* (2007). The fuel hazard rating method allowed quick descriptions of fuel layers based on the continuity, depth, height and portion of dead fuel. This incorporated four fuel layers: surface (litter), near-surface fuel (suspended low fuel), elevated fuel (shrubs), and bark fuels, with these components used to determine an overall fuel hazard rating (McCarthy *et al.* 1999).

Fuel assessment in stubble paddocks was limited to basic descriptions with visual estimates of curing and grazing state. The two paddocks that were burnt during evaluation missions consisted of stubble planted at regular intervals and cut at a uniform height. Destructive fuel assessment methods were not used at the planned drop sites because of the limited time available for conducting these missions.

2.3.3) Weather

Basic weather data were collected for all drops. The weather components recorded were average and gust wind speed, wind direction, temperature and relative humidity. Where possible, measurements were made on site and compared with nearby permanent Bureau of Meteorology weather stations with anemometers and wind vanes sited in a standard meteorological setting.

A range of instrumentation was used for making onsite measurements for planned drops depending on availability. These included Portable Automatic Weather Stations (PAWS), weather stations associated with forward command units, and hand-held instruments. Wind conditions were also assessed using observations of smoke drift. Weather estimates for the operational drop were sourced from nearby Bureau of Meteorology weather stations.

The Forest Fire Danger Index (FFDI) (McArthur 1967) and Grassland Fire Danger Index (GFDI) (McArthur 1966) were calculated using the equations from Noble *et al.* (1980)

2.3.4) Fire behaviour and suppression

Imagery and observations were used to describe ignition, fire development and the behaviour of fire interacting with suppression drops for evaluation missions involving fire. Any actions of ground suppression crews were also documented. Ground suppression crews were asked to refrain from suppressing fire around drop sites until the outcome of the drop was evident. The methodology for evaluation of operational drops (Appendix 2) contains instructions for assessing fire behaviour and documenting fire suppression actions.

2.4) DROP FOOTPRINT AND IMPACTS

Drop footprints and impacts were assessed using a combination of ground and aerial observational methods.

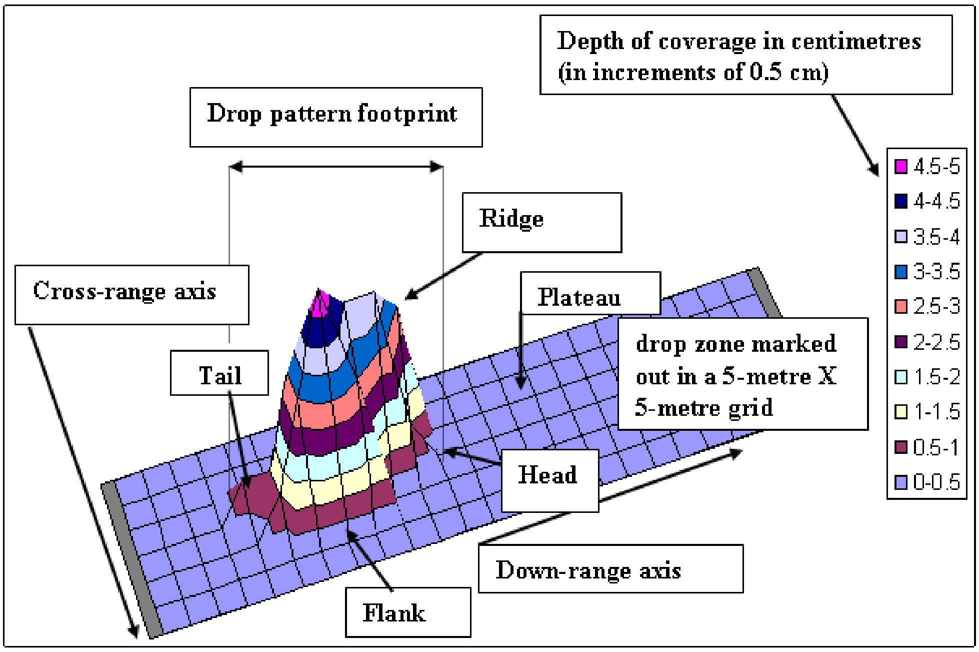
2.4.1) Drop placement

The accuracy of drop placement was assessed with regard to the proximity to the requested target for the drop. Clear instructions for target areas were given for all planned drops. These were given either as coordinates or were clearly marked on the ground for indirect drops during planned missions. Instructions were given for the placement of the direct attack drops for the final mission involving the use of foam suppressants.

2.4.2) Drop pattern footprint

The drop pattern footprint is the outline of the area affected by the drop on the ground. A range of terminology has been used for describing aspects of the drop pattern footprint. An example of these from Biggs (2004b) is illustrated in Figure 2.3. In this figure, the area identified as the plateau represents areas where there is little or no moisture, or only traces of moisture were found in the drop zone. Some agencies (e.g. USFS) use the term heel in place of tail.

FIGURE 2.3. Drop pattern terminology (Biggs 2004b). This drop was from a Conair belly tank fitted to a Bell 212 helicopter flying from left to right.



The length and width of drop pattern footprints are the most usual descriptors of drop pattern dimensions. Drop length is the most important descriptor because it is used for the calculation of fire line production rates, which can be used to compare different aircraft types and is tactically important for suppression planning during wildfire operations.

The dimensions of drop footprints can be estimated from a plotted outline of the drop perimeter. Defining the outline of the drop perimeter can be difficult as there is usually a gradation of coverage from the centre of the drop outwards. In drop patterns plotted from cup grid tests, the outline can be defined using a specific coverage level. For other drops, it can be estimated from post-drop ground assessment and line-scan image analysis.

The outline of the drop perimeter can be estimated on the ground using a suitable GPS unit. The GPS unit must be capable of recording a track file at regular intervals and maintaining adequate satellite reception for the duration of the plot. The bounds of a plot estimated on the ground need to be clearly defined and should be based on the area coverage of surface fuels. The drop footprint edge plotted on the ground during the evaluations presented here was based on estimated 50% retardant coverage of ground fuels. This could be estimated for retardant drops because of the red colouring distinguishing it from ground fuels. Drop footprint length and width could be determined from plots of drop outlines.

Drop pattern footprints were also estimated using line-scan images captured soon after drops were made. The line-scanner can detect temperature differences between the drop and the surrounding environment and can provide geo-rectified images suitable for determining drop dimensions. The resolution of images varies with the altitude of the scan.

The effective drop footprint is the section of the drop that will not burn when challenged by fire. This can only be determined after a drop has been completely burnt around by fire and is really only relevant for drops containing long-term retardants. It varies for a given drop depending on the fire intensity (Loane and Gould 1986, Gould *et al*. 2000). The effective drop footprint was plotted on the ground by having an observer with a logging GPS unit walk along the interface of the burnt and treated edge of the whole drop.

The consistency of coverage across drop footprints is also important and requires assessment. Breaks in coverage across the drop are points where the drop will not be as effective at holding fire. The consistency of drop patterns on the ground was assessed visually and using line-scan images and FLIR footage. Inconsistencies in coverage across drop footprints were noted and mapped. FLIR footage was captured along the drop axes soon after drops were made to provide a high-resolution scan of the drop footprints.

2.4.3) Canopy penetration

The ability of drops to penetrate eucalypt tree canopies was assessed in order to determine the effectiveness of the DC-10 in forested areas.

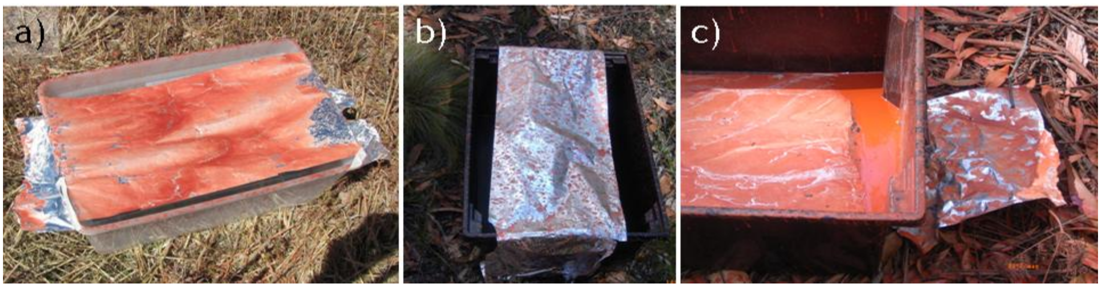
The Wombat Forest mission (Section 4.1) was specifically designed to assess canopy penetration. For this mission, large pieces of paper were placed on litter fuels prior to the drop and were later assessed for retardant coverage. The sheets of paper were placed at points along transect lines traversing the drop target area. These points were assessed for canopy projected foliage cover prior to the drop. The sheets were labelled according to the site and were secured to the ground with a roofing nail. The proportion of retardant covering each sheet of paper was estimated visually after the drops.

2.4.4) Impacts and damage

The planned drop sites in forest areas were surveyed for evidence of canopy damage such as dislodged limbs and freshly fallen twigs. The paper sheets used for assessing canopy penetration were kept free of debris prior to drops and were assessed for fallen material afterwards.

Plastic tubs with domestic aluminium foil stretched across the open top were placed in drop target areas for some planned drops (Figure 2.4). These exposed a horizontal surface around 0.5 × 0.3 m. Heavy impacts on this surface resulted in tears or holes in the aluminium foil.

FIGURE 2.4. Foil impact test structure used to test the physical impact of drops. Images show a structure placed at Avalon (a), and structures placed at Enfield that were hit indirectly (b), and hit directly and torn (c).



2.5) DROP INTERACTIONS WITH FIRE

The effect of drops on fire behaviour, where fires interacted with drops, was assessed in order to address the primary evaluation aim.

2.5.1) Drop outcome and holding time

The final fire outcome following each drop is a key measure of its success. Drops can either hold fire for an adequate period of time or be breached. When drops were breached, the causal mechanisms were thoroughly investigated. There are three mechanisms causing drops to be breached: spotting, burn-around or burn-through (see Section 1.4.1). Drops can be breached by more than one of these causes.

Airborne infrared imagery captured during each mission was the main method used to monitor fire behaviour around drops and to determine drop outcomes and causes for breaching. This imagery was also used to determine drop holding times. This can be defined as the time between contact of the fire with the drop and the drop being breached.

2.5.2) Drop effect on fire behaviour

The effect of drops on fire behaviour was quantified using comparative descriptors of fire behaviour made before and after drops were impacted by fire. Fire behaviour parameters related to flame dimensions and spread rates were used for making these comparisons. These were estimated on the ground during the missions and from footage captured from the air.

Post-fire ground assessments were used on the wildfire, as much of the interaction between the drop and the fire occurred during the night. In this situation, post-fire indicators such as leaf scorch and consumption heights were compared between areas affected and not affected by drops. The methodology developed for assessing fire behaviour effects at operational drops is presented in Appendix 2.

3) OPERATIONAL MISSION

The unusually mild summer experienced in Victoria during this trial saw very few large wildfires after the New Year and subsequently Bomber 391 was only deployed to one operational wildfire.

3.1) WERRIMULL-PHEENY'S TRACK WILDFIRE

Bomber 391 was used to deliver a single full-load retardant drop on an active wildfire in mallee vegetation in far northwest Victoria (Figure 3.1). This fire was 460 kilometres northwest of Avalon airport (34°39.97'S, 141°30.90'E).

FIGURE 3.1. Location of the Werrimull fire and closest weather stations (blue).

3.1.1) Fire conditions and location

The Werrimull–Pheeny's track fire was suspected to have been started by lightning at around 14:30 on 31 January 2010. The fire burned within the Murray-Sunset National Park, approximately 35 km south-southwest of Werrimull (Figure 3.1). The area is flat, with occasional low sand dunes and is less than 70 metres above sea level.

The fire burned in mallee-woodland vegetation that had not been previously been burned for 31 years. The woodland was dominated by clumps of mallee eucalypts separated by bare ground. A moderate layer of leaf litter was concentrated at the base of the mallee stands and there were occasional small shrubs and *Triodia* spp. hummock grasses. The overall fuel hazard rating for the area was estimated to be low to moderate. Surface, elevated and bark fuel hazard scores were also in this range. The mallee clumps were up to 5 metres tall and had very open canopies. Figure 3.2 shows the typical vegetation in the area.

The day of the fire saw the passing of a cold front across western Victoria (Figure 3.3), with some scattered storms associated with a prefrontal trough and winds becoming south-southwesterly throughout the day. The area had not received rain in the previous three weeks and the drought factor (McArthur 1967) had reached 10.

FIGURE 3.2. Mallee vegetation of the Werrimull–Pheeny's track fire area from the ground showing gaps between Mallee clumps (a); and from the air showing burnt sections on the left, fuel treated by retardant in the centre and unburnt fuels on the right (b).

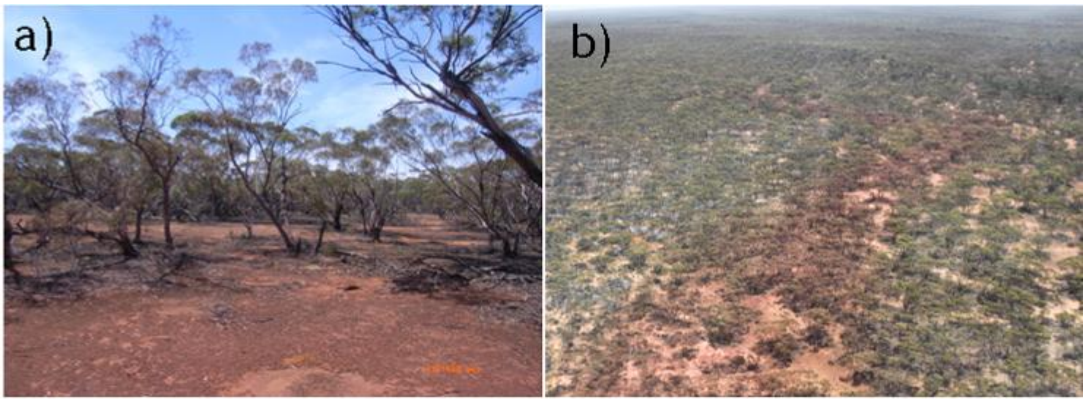
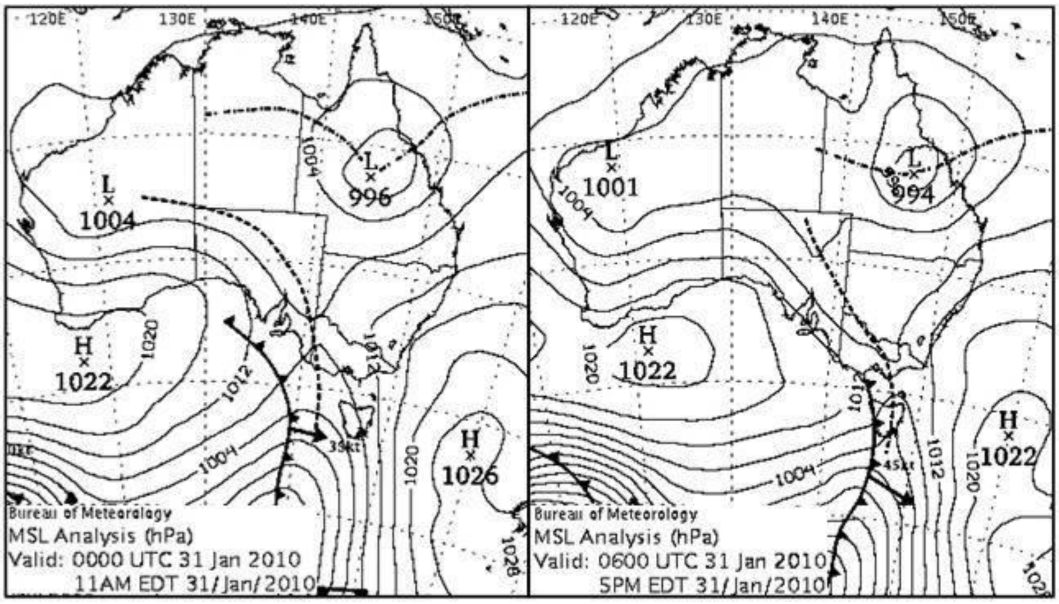


FIGURE 3.3. Synoptic charts for 11:00 and 17:00 (Eastern Daylight Time) for 31 January 2010.



The nearest Bureau of Meteorology weather stations to the fire were at Mildura (48 km northeast), Walpeup (67 km southeast), Loxton (88 km west) and Lameroo (120 km southwest) (Figure 3.1). The FFDI peaked at 43 (very high) in Mildura on 31 January and reached similar peaks at the other stations. The FFDI had dropped to 13 (high) at the time of the drop (18:54). Temperatures peaked in the high 30s in the early afternoon and gradually declined during the afternoon (Figure 3.4a). Relative humidity climbed throughout the day in response to the changing air mass (Figure 3.4b). Some of the weather stations experienced dips in temperature and rapid increases in humidity associated with isolated rainfall events.

FIGURE 3.4. Temperature (a), and relative humidity (b) observations at weather stations surrounding the Werrimull-Pheeny's track fire for 31 January 2010.

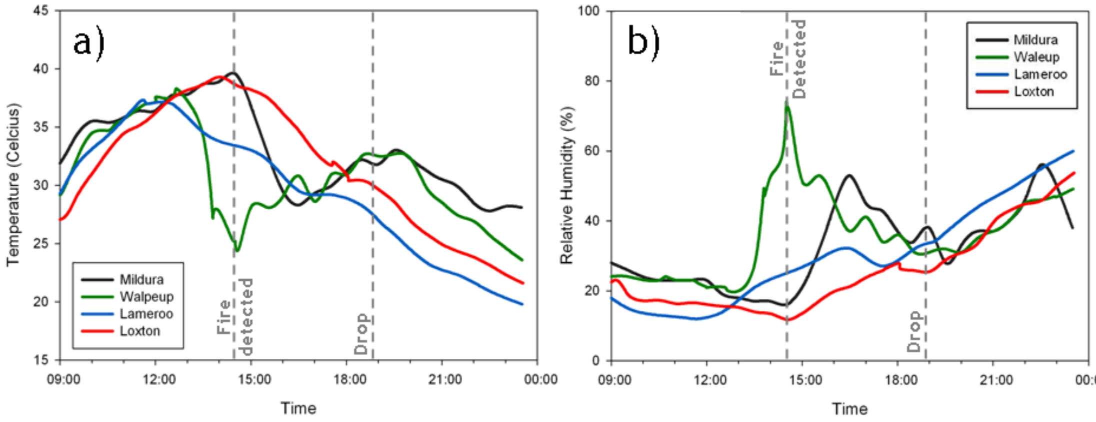
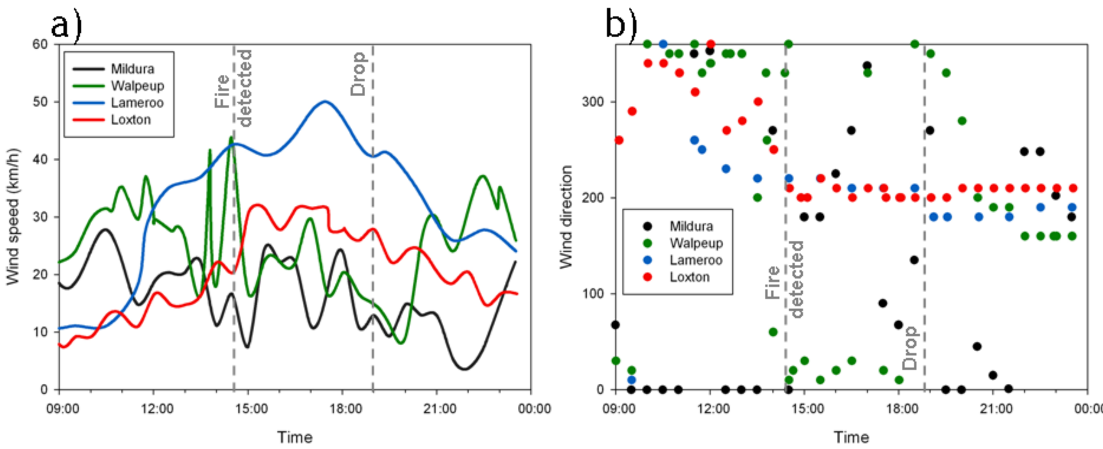


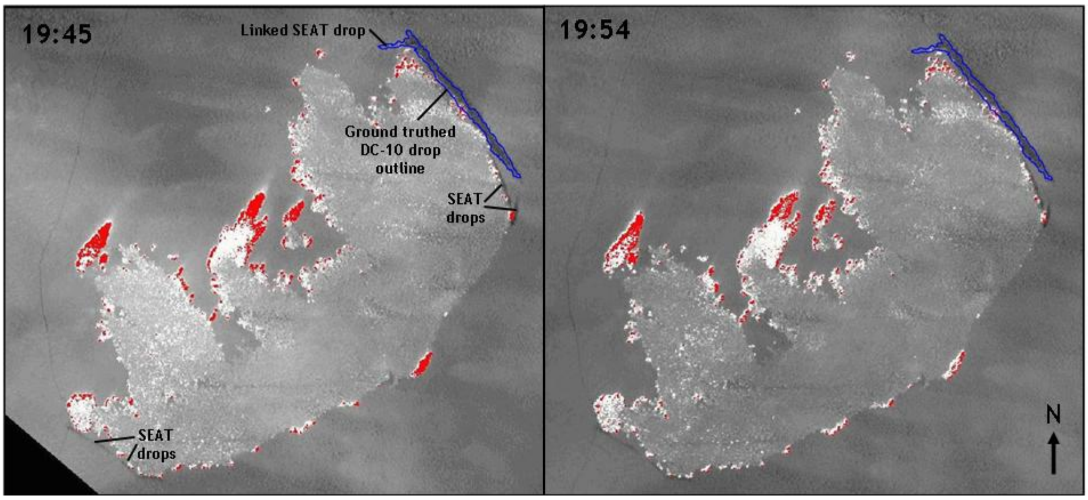
FIGURE 3.5. Wind speed (a), and direction (b) observations at weather stations surrounding the Werrimull-Pheeny's track fire for 31 January 2010.



Wind speed and direction varied throughout the day owing to the passing cold front (Figure 3.5). Wind speeds reported at the fire ground were much lower than those reported at the weather stations. At 18:00, the wind speed reported on the fire ground was 9 km/h, gusting to 17 km/h. Further reports made later in the evening also had wind speed below 10 km/h. The video recordings of the drop and the drop site indicate light wind conditions (south-westerly) when the drop was laid, with smoke rising nearly vertically. Footage taken an hour and a half after the drop indicated a light southerly wind. Differences in wind speed are evident in the two line-scan images captured from this fire at 19:45 and 19:54 (Figure 3.6). Situation reports from before and after the drop stated that a strong south-southwesterly wind change was expected in the early evening. While the wind did change to this direction, the predicted increase in speed did not eventuate at the fire.

Fire spread in mallee vegetation is strongly dependant on wind and fuel moisture conditions (Cruz *et al.* 2010). Fires will spread when the fuels are dry enough to burn and the wind is strong enough for a fire to breach gaps in the fuel complex. On elevated fire danger days, such as 31 January 2010, fires will spread in response to the wind with deep flames at the head and relatively quiet flames on the flanks. Mallee fire spread is very sensitive to wind direction, with wind changes causing flanks to develop into head fires.

FIGURE 3.6. Line-scan images of Werrimull fire showing the location of DC-10 drop.



The Werrimull–Pheeny's track fire developed with variable wind directions prior to the drop. The fire was estimated to have burnt 50 ha at 15:58, 200 ha at 18:07 and 250 ha at 19:36 in the situation reports. The final reported fire area was 270 ha. Flames were not visible from the airborne footage captured during the drop. The fire edge near the drop appeared to be barely moving, if at all, in the FLIR imagery. The fire edge affected by the drop was essentially a quiet flank with a few short-distance spots on the northeast side. There was still some active flaming present at 20:15; however, it was evident from the visual and FLIR footage that the retardant line had not been seriously challenged.

The deployment of Bomber 391 had been discussed from 15:35 within the incident management team and the State Control Centre. The opportunity for evaluation was considered during these discussions. Bomber 391's departure from Avalon airport was delayed so that Firebird 376 could reach the fire in time to record the drop. Bomber 391 departed from Avalon airport just after 18:00 and made the drop at 18:54:46 after spending a few minutes flying around the fire.

Prior to the drop, the suppression of this fire had mainly been limited to retardant drops made by two single-engine air tankers (SEATs) and a small dozer followed by some slip-on units. The SEAT drops were mainly around the southwestern corner of the fire. Two drops had also been placed on the eastern end of the fire, one of which became linked to the DC-10 retardant drop. A later SEAT drop was placed at the northern end of the DC-10 drop. The dozer and slip-on units had been working on the western side of the fire with two slip-on units from around 18:00. A mineral-earth line was made along the southern edge of the fire all the way to the DC-10 drop on the morning of 1 February 2010.

3.1.2) Evaluation of drop and effect

This drop was filmed from Firebird 376, which monitored the area for 10 minutes before departing from the fire for fuel. This drop was not filmed from any other sources. Firebird 376 returned to the fire at 20:20 and monitored the area for a further 15 minutes before running out of daylight. Line-scan images were taken at 19:45 and 19:54. The line-scan aircraft was delayed by storms around Melbourne. An evaluation crew surveyed the drop site from the air and the ground on the following day. This crew was familiar with the assessment method as they had assisted with data collection from an evaluation drop two days earlier. They surveyed the drop perimeter, assessed fuels and made post-fire observations of burn pattern and severity.

The drop was laid in a southeast to northwest direction on the north eastern edge of the fire, which, tactically, was the most appropriate location for it considering the weather forecast (Figure 3.6). his drop was of limited value to the evaluation because the forecast strong southerly winds did not eventuate at the fire ground. With the forecast wind change, this section of fire would have become a head fire and made a significant run into the wilderness area of Murray–Sunset National Park. This section of the fire perimeter was also the most distant from any roads and it would have taken a considerable amount of time for ground resources to work their way around it.

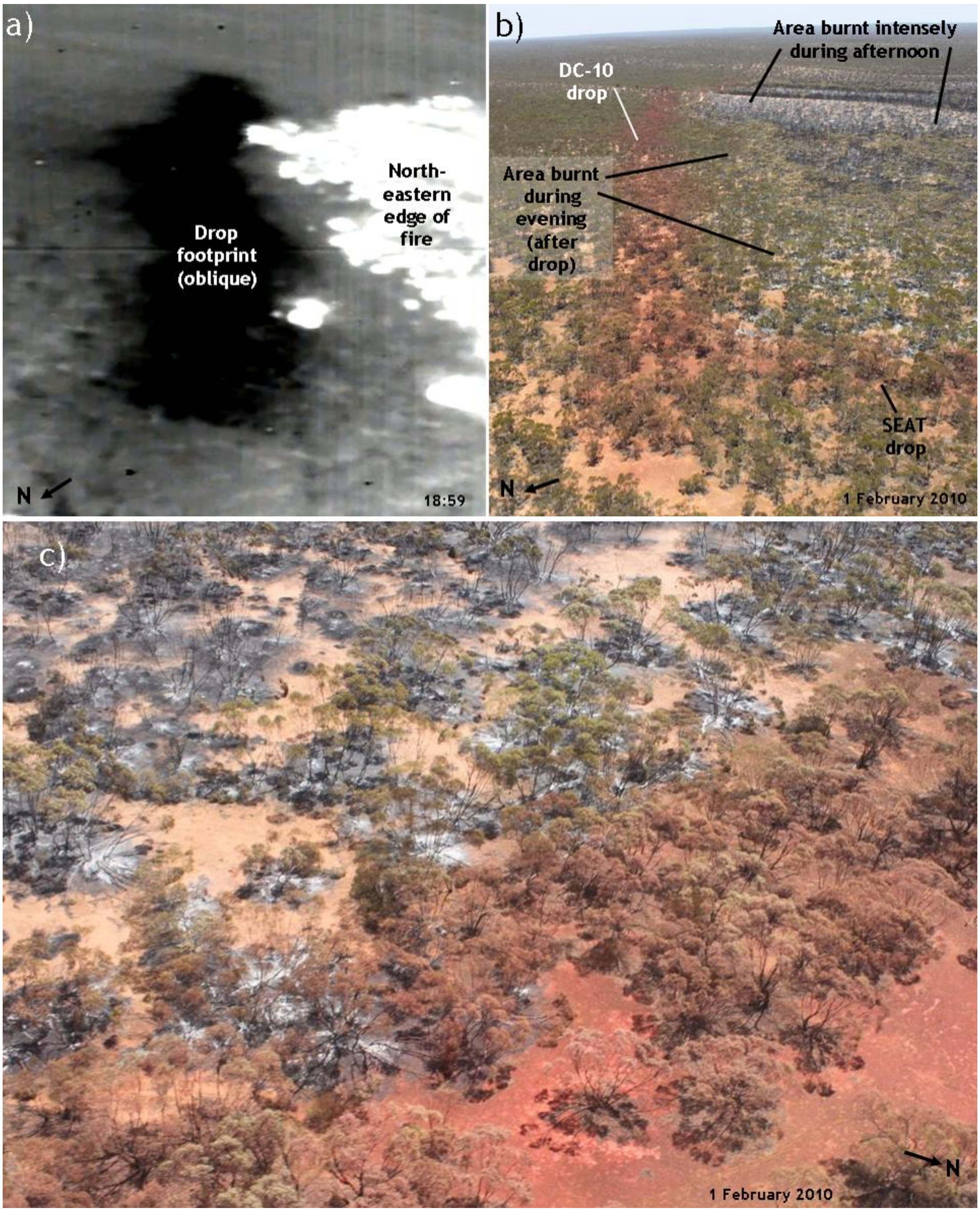
According to the flight engineer's log book records (Appendix 3), this drop was made at 60 m (200 ft) with the coverage level dial setting 6. The volume of the load was 42,215 L (11,152 US gal). As with all other drops, the air speed would have been close to 278 km/h (150 knots). There is no way of checking this information as the nearest point in the only GPS tracking source was 24 seconds after the start of the drop (18:55:10). This point is not likely to be representative of conditions during the drop. The footage from the Firebird 376 helicopter shows Bomber 391 gained altitude during the drop. The duration of the drop could not be determined as the end of the drop was not in the frame captured by Firebird 376. The lead plane was not visible in this footage.

The retardant cloud was only filmed from Firebird 376 (Figure 3.7). This footage indicated that there was some billowing within the retardant cloud and some forward momentum present as the drop reached the vegetation. The vegetation made it difficult to determine if there were any gaps in the retardant drop as a result of the billowing in the cloud and remaining forward momentum.

FIGURE 3.7. Bomber 391 dropping retardant at the Werrimull fire.

The fire behaviour was relatively mild at the time of the drops and the fire was barely spreading as a result of the light winds and large gaps between clumps of fuel. The drop was laid indirectly, but close to the fire edge for the majority of its length. The drop directly impacted on a short section of fire edge along the southern end (Figure 3.8a). The fire burnt up to the retardant line along the length between the two tagged SEAT drops during the night of 31 January 2010 (Figure 3.8b). This fire was of a lower intensity, as indicated by the lack of tree scorch, compared with the large amount of scorch that occurred prior to the time the drop was made. (Figure 3.8c). There was a hotspot within the drop that appeared to be a spot fire burning prior to the drop (Figure 3.9a). No active flames were visible in this hotspot five minutes after the drop (Figure 3.9b). The fire intensity was very low when the main fire edge reached the retardant drop. The drop held the fire at all points where the fire reached it. Despite the low spread conditions, the fuels were very dry and most dead coarse fuels burned to white ash (see example in Figure 3.9c).

FIGURE 3.8. Werrimull drop showing location with respect to fire (a and b), and the burn pattern along the edge of the retardant line (c).



The final fire perimeter was essentially the same as that illustrated in Figure 3.6. None of the fingers in the northwestern section of the fire (which had the most active fire edge) progressed much further than shown in the line-scan images. It is very unlikely that the fire near the retardant line would have travelled much further had the retardant line not been there.

The drop perimeter plotted by the ground observation team and detected by the line-scanner is illustrated in Figure 3.10. Both methods were close in their estimation of the drop footprint. The estimated length of the drop was 703 m. Of this, 498 m had been impacted by fire. There was no evidence of gaps in the drop footprint and no evidence of damage to the mallee trees or shadowing effects from the sparse mallee crowns.

FIGURE 3.9. Spot fire within the Werrimull drop, from FLIR (a), and aerial video (b) 5 minutes after drop, and from the ground the following day (c).

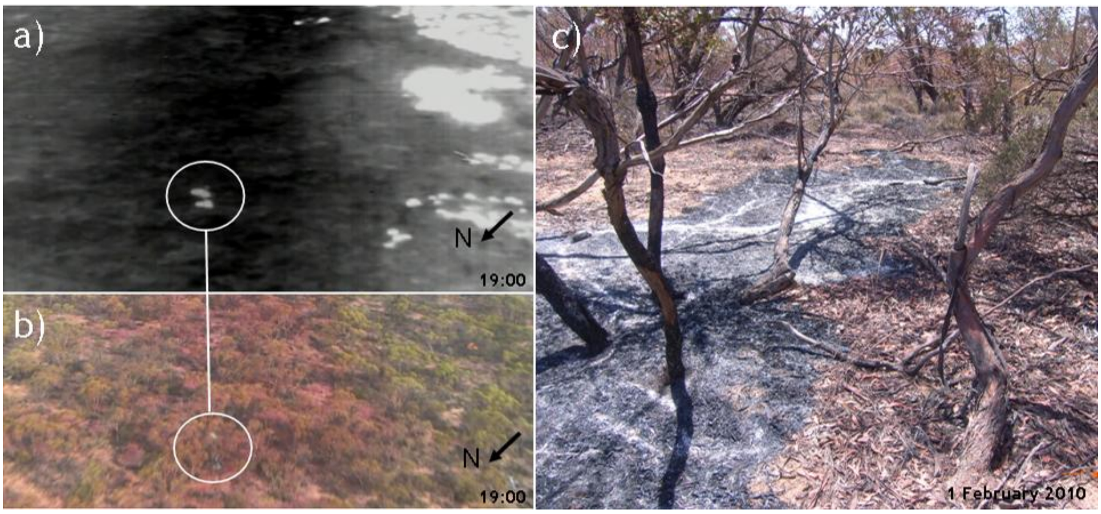
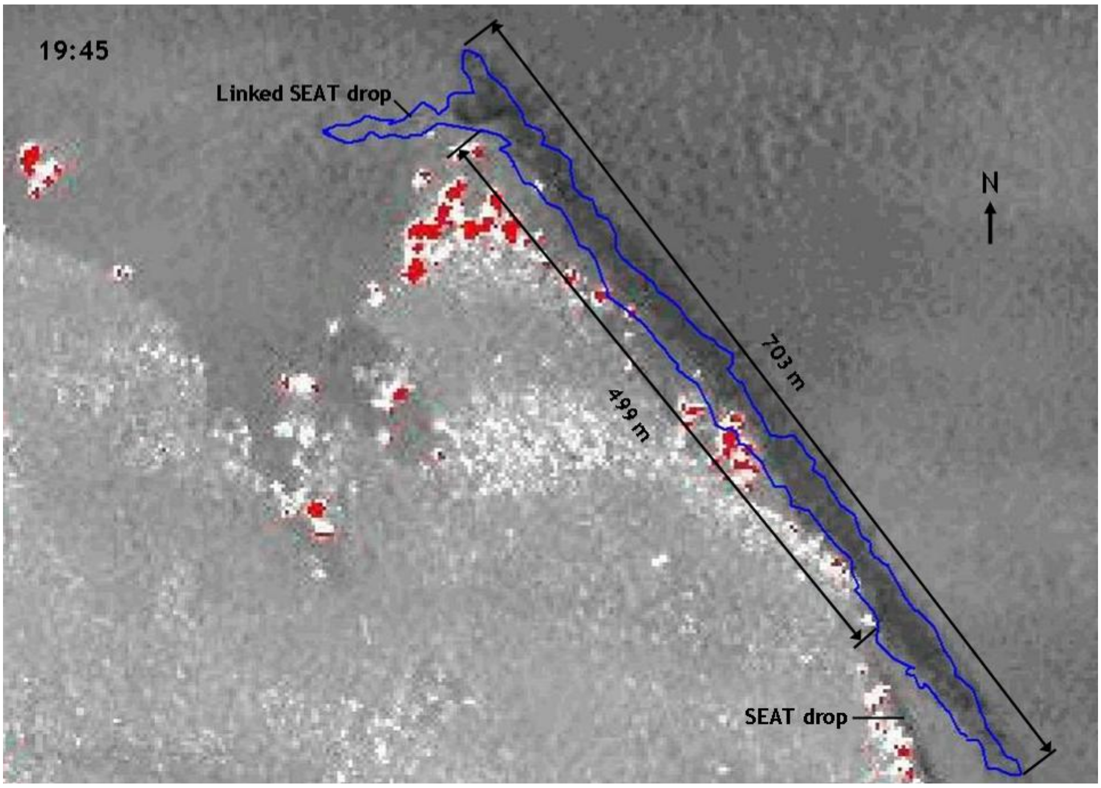


FIGURE 3.10. Werrimull drop footprint showing drop outline from line-scan image and ground truthing.



3.1.3) Discussion

This drop was of limited value for testing the effectiveness of the drop because of the mild fire behaviour and weather conditions. The drop would have been of greater value to the evaluation had the forecast increase wind conditions eventuated.

The methods and procedures used for assessing this drop worked well and the use of an experienced team for undertaking the ground-based assessment kept the methodology consistent with what had been used during planned drop assessments.

4) PLANNED MISSIONS

There were five planned missions specifically conducted for this evaluation. Three of these involved application of fire. The location of these missions is illustrated in Figure 4.1. The planning of these missions evolved during the project, with some of the results from the missions influencing the objectives and design of later missions. The findings of the five planned missions are presented in chronological order in Sections 4.1–4.5.

FIGURE 4.1. Location of the planned drop sites (green dots) and permanent Bureau of Meteorology weather stations used (blue dots).

4.1) WOMBAT FOREST

The first evaluation drop for this project occurred in Wombat State Forest on 29 January 2010. This site is 65 km north of Avalon airport (37°26.8524′S, 144°24.988′E).

4.1.1) Aims

The evaluation aims for this mission were:

1) to determine the ability of a drop to penetrate through eucalypt forest canopy;

2) to assess any collateral damage or safety concerns arising from this drop; and

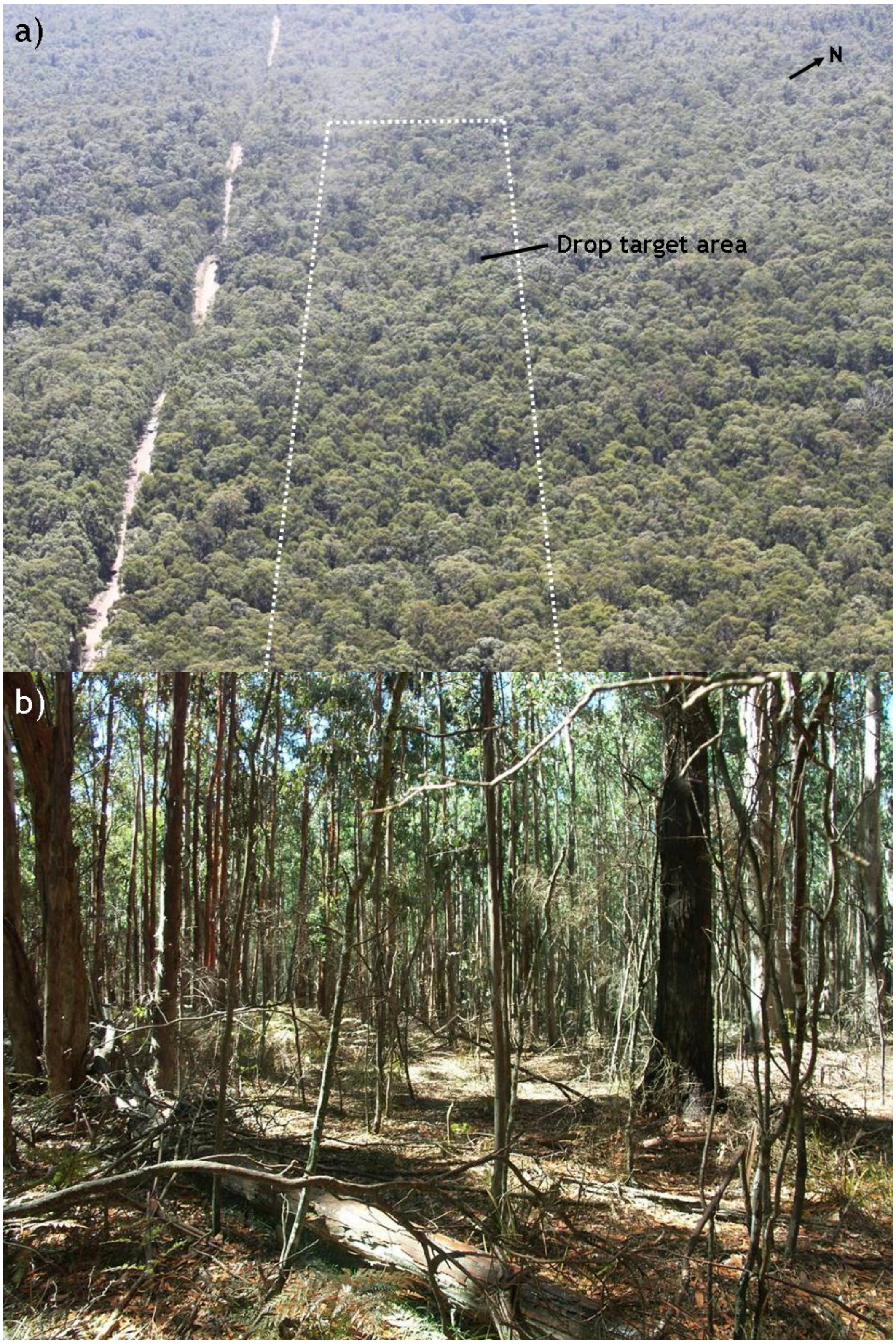
3) to measure the drop footprint.

4.1.2) Site and conditions

The site used for this drop was a mixed eucalypt forest that had regrown after being burnt in 1983. The site was located to the northeast of a straight stretch of Firth Road within Wombat State Forest. This site was selected for its terrain, vegetation and accessibility. The terrain was slightly undulating and was approximately 740 metres above sea level.

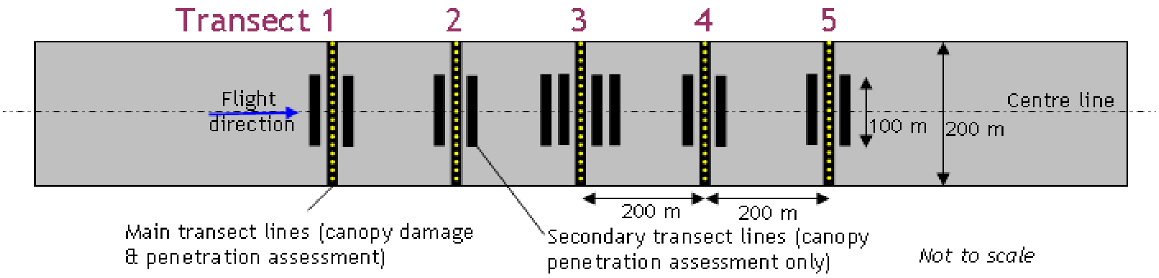
The vegetation at the site is representative of most Australian dry eucalypt forests (Figure 4.1.1). The maximum tree height across the site varied between 20 and 25 m (65 and 80 ft) above the ground. The projected foliage cover across the site was 45 % on average. There was only a very light elevated fuel layer present and the surface fuels were thick and continuous.

FIGURE 4.1.1. Vegetation at the Wombat Forest site from the air (a), and under canopy (b).



A 200-m-wide plot parallel to Firth Road was identified. The plot was on a 150° (true North) axis. Five groups of transects marked through the centre of the plot were used to characterise the canopy and layout sample points for estimating coverage and canopy damage (Figure 4.1.2). Each group had a 200-m transect in the centre with at least one 100-m transect, centred on the centre line, on either side. Cars were parked along Firth Road adjacent to each transect to mark them for the aircraft. Attempts were made to mark the centre line of the plot with helium-filled weather balloons at the mid-point of the first and third transects. These balloons kept blowing back into the canopy and could not be seen clearly by the aircraft.

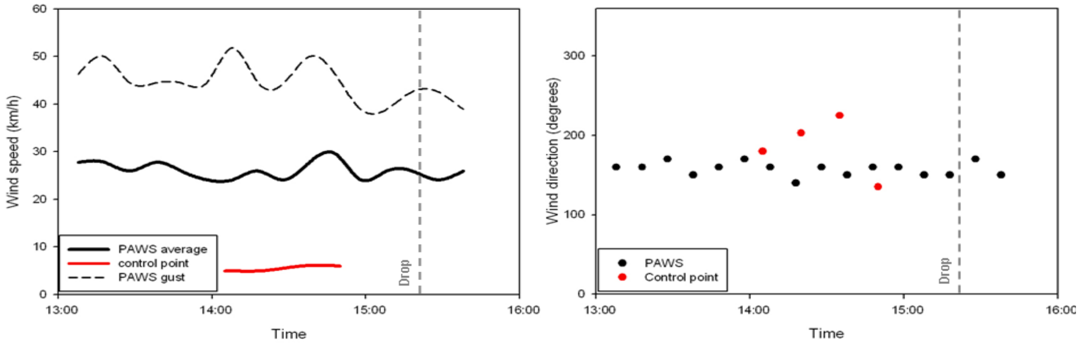
FIGURE 4.1.2. Plot transect layout.



Large sheets of paper used for estimating canopy interception (see Section 2.4.3) were placed at 10-m intervals along the transects. These points were assessed for projected foliage cover. The centre (third) group of transects had a number of extra sheets of paper placed around tree trunks in order to determine if there were any shadowing effects from the drop drifting. Two video cameras were set up around the centre transects to film the drop coming through the canopy from two different directions. Foil impact tests (see Section 2.4.4) were also set up in this area.

A portable automatic weather station with a 6-m mast was erected in a cleared paddock 4 km north-northwest of the plot. This was the closest cleared area to the site. The control point 1 km north of the plot also had a weather station with a 10-m wind mast. The anemometer and vane for this station were well below the canopy and experienced turbulence associated with their location. Observations from this weather station were logged in a communications book. The temperature was around 16°C and relative humidity was 60% at the time of the drop. There was a high layer of cloud present for the majority of the day. The wind conditions experienced during this mission are plotted in Figure 4.1.3 and show that wind speed was consistently around 25 km/h (13.5 knots) from the south-southeast. Observations at nearby permanent Bureau of Meteorology stations (Melbourne Airport 44 km southeast, Redesdale 48km north, Ballarat Airport 56 km west) were similar to those on site. This wind direction provided a direct head wind for the orientation of the plot.

FIGURE 4.1.3. Wind conditions during the Wombat Forest drop.



4.1.3) Drop evaluation

The flight and drop parameters requested for this drop were retardant, coverage level 8, 278 km/h (150 knot) indicated air speed and a height of 60 m (200 feet) above the canopy. These parameters represent those that would be used during an operational drop in forest vegetation. According to the flight engineer's log, this drop was 90 m (300 ft) above the ground, which is around 75 m (250 ft) above the canopy and the load was 42,578 L (11,248 US gal). The target location for the drop was given to the flight crews as coordinates and indicated on a site map.

The drop was made at 15:18:15. The nearest point in the flight log was 13 seconds after the start of the drop and 2 seconds after the end. At this time, the aircraft was travelling at 146 knots on a bearing of 148 degrees. The elevation of the aircraft at this point was 830 m (2,721 ft) above sea level, giving it a height of approximately 90 m (295 ft) above the ground and 65 m (215 ft) above the canopy. Video taken during the drop indicates that Bomber 391 gained altitude at this point. The video taken from Firebird 376 indicates that Bomber 391 was flying slightly faster than it. The GPS output in the footage indicates that Firebird 376 was travelling at 260 km/h (140 knots). Given the strong head wind (25 km/hour at 6 m above ground), it is likely that Bomber 391's air speed was around 296 km/h (160 knots). The lead plane was not visible in the footage during the immediate lead-up to the drop.

This drop produced the most uniform retardant cloud obtained during the evaluation with very few clumps breaking away from the main cloud (Figure 4.1.4). This drop reached terminal velocity quickly and the retardant drifted into the canopy under the influence of the wind direction (i.e. against the travel direction).

The drop footprint perimeter was estimated by two independent groups and plotted using GPS track files. These groups aimed to map the footprint of area with 50% or more coverage of litter fuels. The drop perimeter estimates were in close agreement, with total drop lengths estimated at 550 and 560 m (Figure 4.1.5). The drop width in these estimates was between 25 and 40 m for the majority of the length. These estimated perimeters corresponded with the area affected by the drop indicated in the line-scan images. Another group of ground observers estimated the area with any visible retardant on the surface fuels, including sections with isolated fragments. The length of this area was 690 m.

The drop was aligned along the plot centreline, which was 150 m northeast and parallel to Firth Road. The start of the drop was earlier than anticipated and it only crossed two of the five groups of transects. The drop stopped short of the centre transect and canopy penetration was not captured by the video cameras located there.

FIGURE 4.1.4. Retardant cloud during Wombat Forest drop.

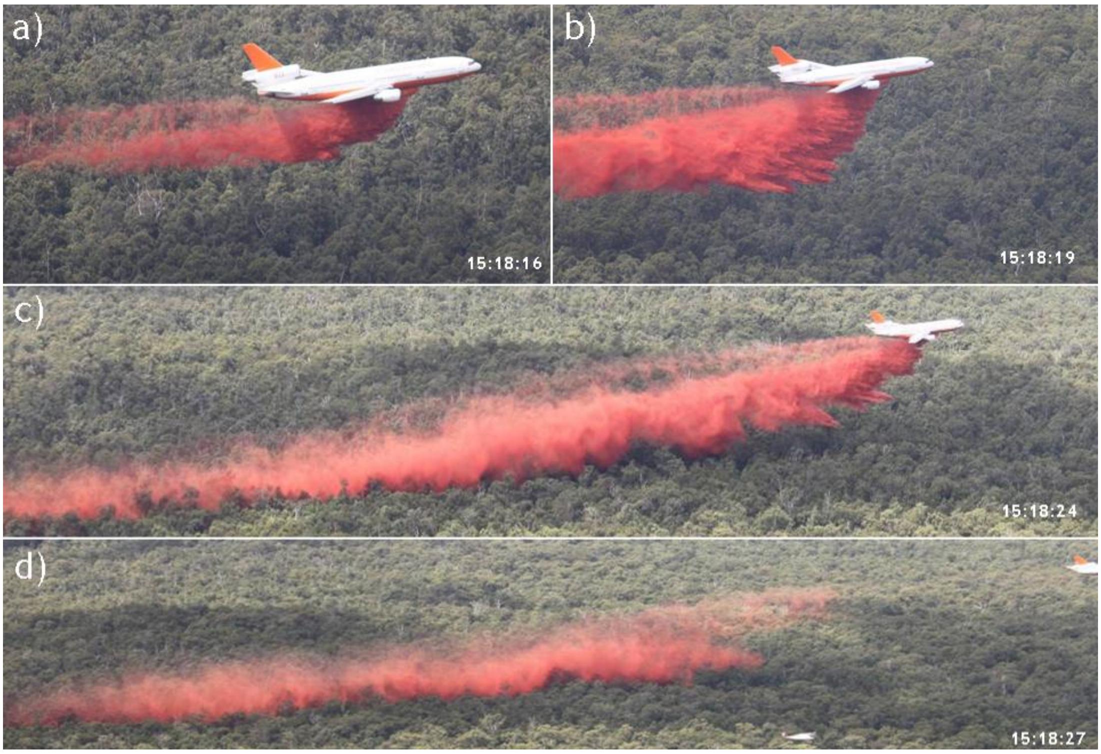
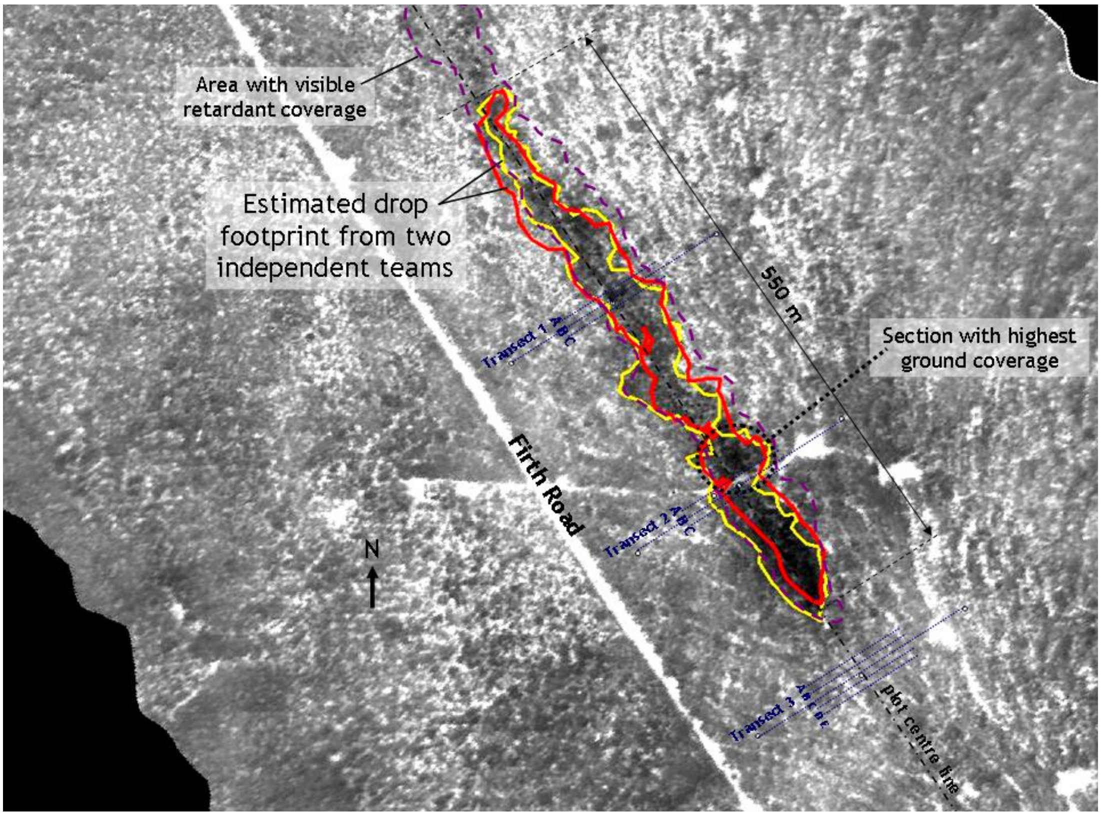
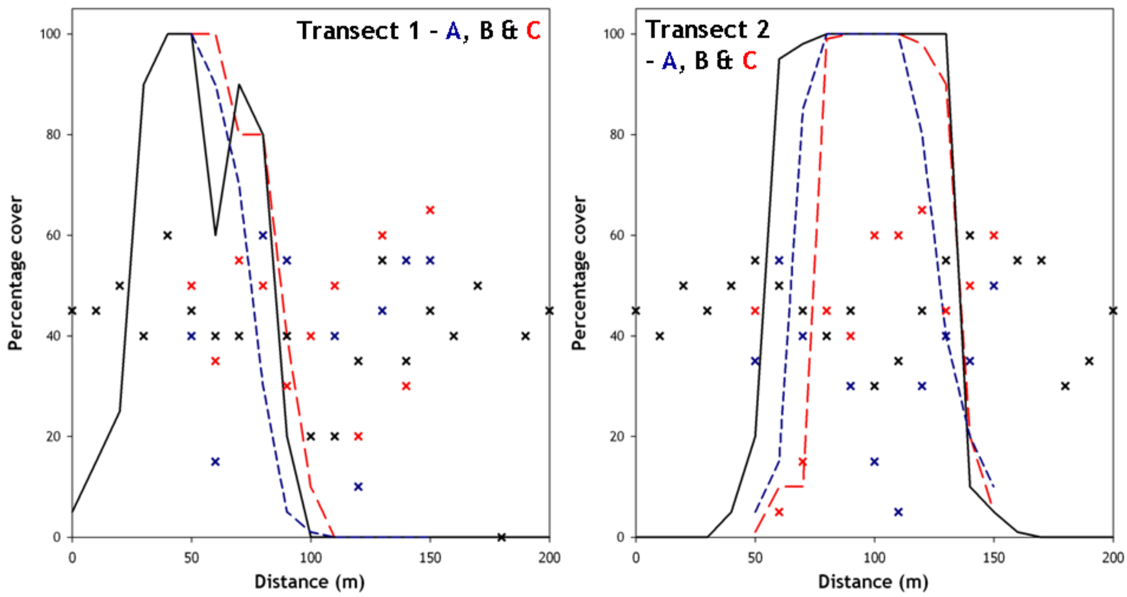


FIGURE 4.1.5. Estimated drop footprint from the Wombat Forest drop overlayed on top of a line-scan (with increased contrast).



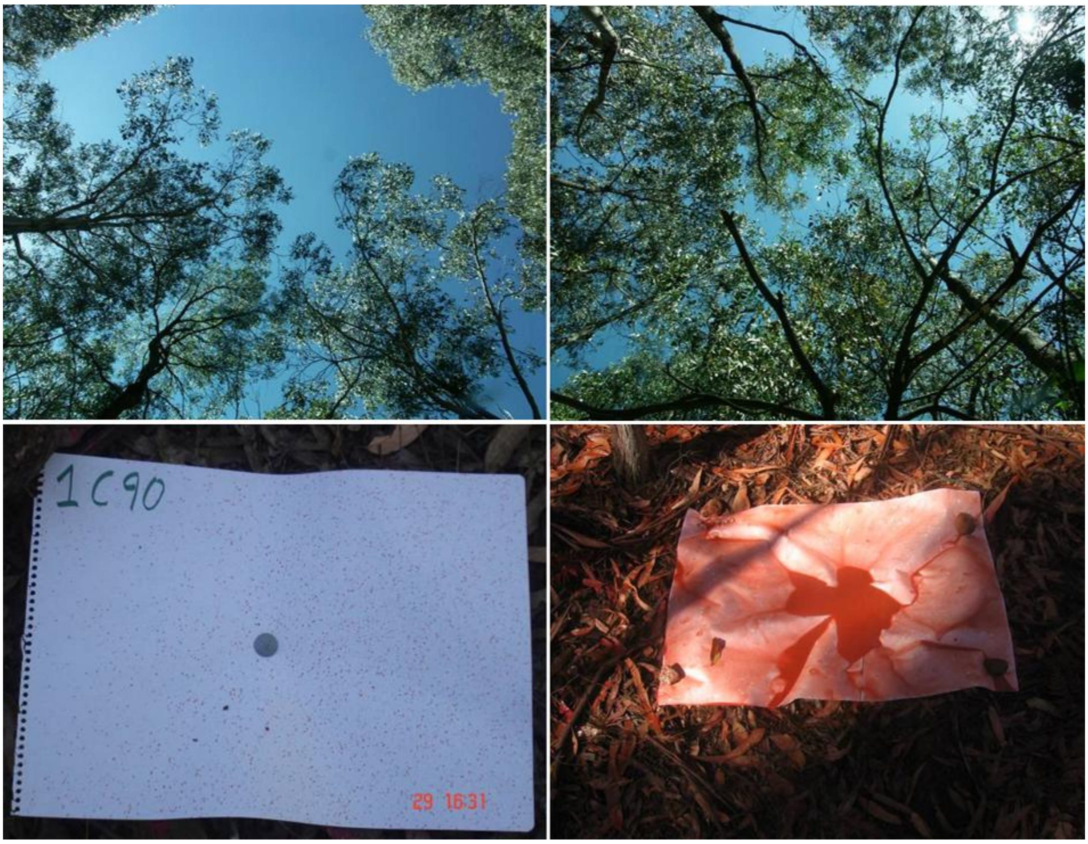
Observations from sample points along the transects indicate that there was a good penetration of the canopy, with all large sheets of paper located within the drop perimeter having coverage of surface fuels ≥80%. Ground fuels outside of the main drop zone received a light spray of retardant. There was no correlation between canopy cover and ground coverage within the main drop area (Figure 4.1.6). This was probably because the drop drifted through the canopy under the influence of the wind rather than raining down vertically. Examples of the canopy cover and corresponding retardant coverage on the large sheets of paper are given in Figure 4.1.7. There was a section of the drop that seemed to have a considerably greater depth of retardant than other sections. This was located near transect 2 (Figure 4.1.5). Some sections of lighter coverage were evident along the heel (northwestern) end of the drop. These were not associated with dense canopy.

FIGURE 4.1.6. Ground coverage on paper sheets (lines) and percentage foliage cover (crosses) for transects 1A, 1B and 1C, and 2A, 2B and 2C on the Wombat Forest drop.



There was no evidence of any damage to the canopy resulting in dislodged or fallen limbs or twigs within the drop area, including the section of very high coverage. The drop was observed to penetrate the canopy with the intensity of light to moderate rain. Shadowing on tree boles within the main drop area showed that the drop cloud was influenced by the wind direction below the canopy. The foil impact test structures placed near transect 3 were not within the drop area.

FIGURE 4.1.7. Examples of canopy cover and retardant ground coverage at the Wombat Forest drop site.



4.1.4) Discussion

This evaluation drop was successful in achieving the main aims of assessing canopy penetration and damage from the drop impact, and quantifying the drop dimensions. The drop penetrated the canopy well with no detectable damage. The retardant coverage on the surface fuels was thick and consistent. The only sections with lighter coverage were around the heel of the drop.

The length of the drop was estimated to be 550 m. This estimate is based on visual assessment of coverage on surface fuels. The most reliable method of determining the effective drop length would have required a fire to be lit around the drop area. This was not possible at this site between the day of the drop and a rainfall event two days later.

The drop was placed exactly on the centre line of the plot. The drop started about 100 metres earlier than the vehicle marking the line of the start of this drop, that was difficult to see from the air. The centre transect of the plot was not impacted by the drop because of this early start and because the drop was shorter than anticipated.

This mission demonstrated a drop from Bomber 391 can penetrate through an open canopy eucalypt forest with a headwind. The next priorities identified for testing this air tanker were (1) with a crosswind, and (2) in a forest with a closed canopy.

4.2) AVALON

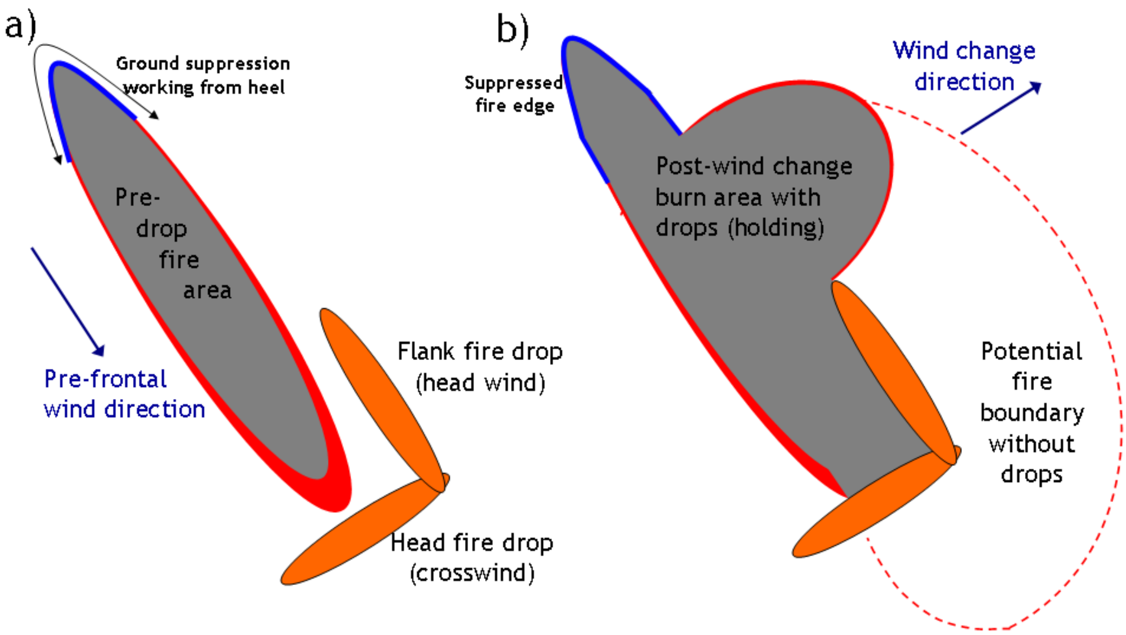
The second planned evaluation mission was conducted in an open stubble paddock east of Avalon Airport (38°01.10'S, 144°30.20'E) on 30 January 2010. This paddock was an area designated for dumping of air tanker loads prior to landing, labelled 'Drop Zone Alpha' (Biggs 2010). This mission also served as a demonstration of the DC-10 air tanker for media and government officials.

4.2.1) Aims

The aim of the mission was to evaluate a suppression tactic that would be used on running grassfires if the DC-10 was deployed. A thorough appraisal of drop quality was required to address this aim. This mission was also used to determine the drop's potential to cause damage to structures.

The grassfire suppression tactic being evaluated involved two drops made perpendicular to each other from a single load. One of these drops would be in the path of the head fire and the other parallel to the front end of a flank fire (Figure 4.2.1). Both drops would be made with coverage level 4, the SAU's recommended level for fires in grass fuels (Biggs 2010). This tactic would be used on fast-running grassfires, which often occur on days when a cold front is passing over Victoria. They are notorious for running under the influence of a northwesterly wind before passage of the front, and then having their northeastern flank develop into a head fire once the wind has changed direction with the passing of the front (e.g. Luke and McArthur 1978, McArthur *et al.* 1982, Cheney *et al.* 1993, Cheney and Sullivan 2008).

FIGURE 4.2.1. VLAT suppression tactic for a fast-running grassfire occurring during the passing of a cold front. (a) Drops made before wind change; (b) fire perimeter after wind change.

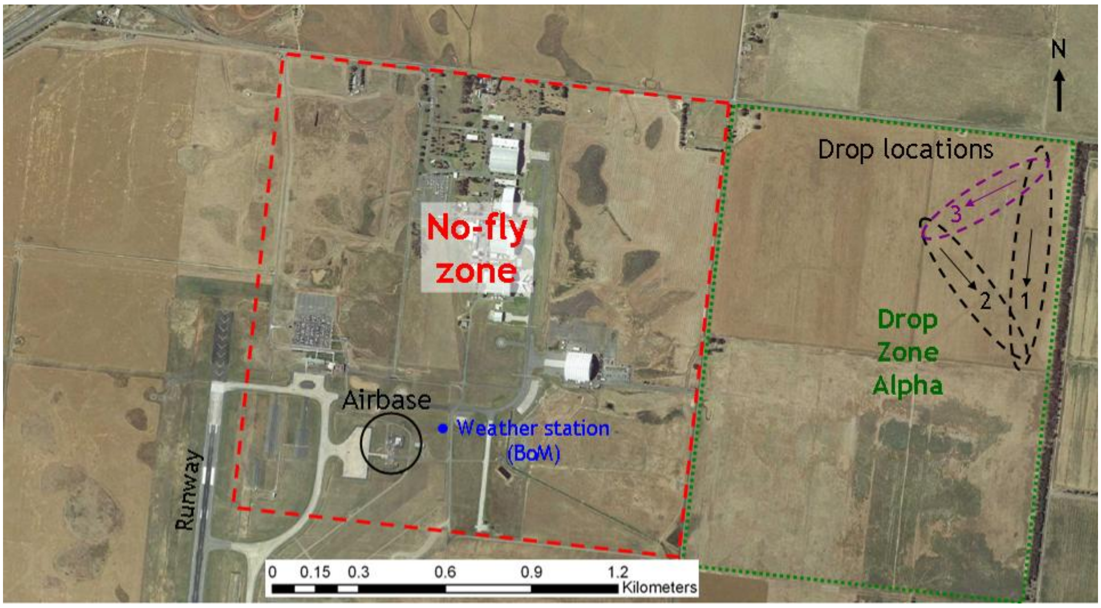


4.2.2) Site and conditions

This tactic required a site that was flat and had minimal vegetation. Drop Zone Alpha was available for use and was located close to the airbase at Avalon airport (Figure 4.2.2). This site was about 15 m (50 ft) above sea level. This site required minimal preparation for the evaluation. A no-fly zone associated with an aircraft maintenance facility at the airport restricted flying in east and west directions across the site;

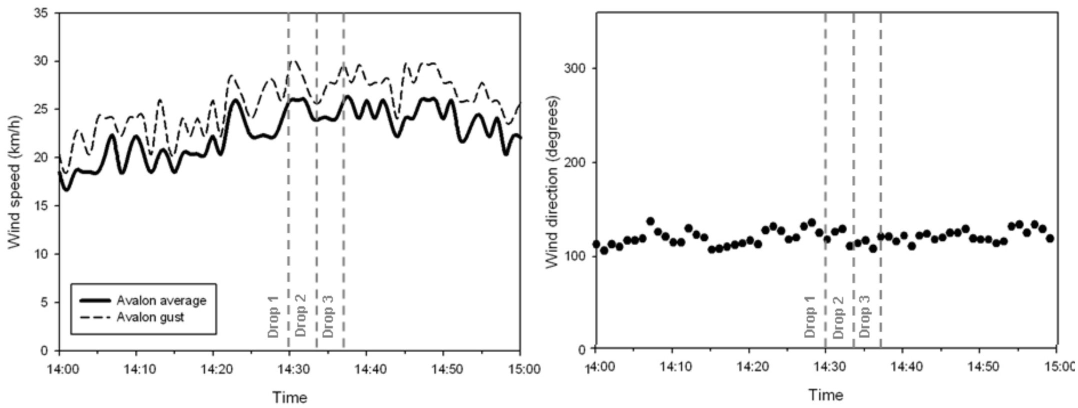
however, drops could still be made along a northwest-to-southeast axis. The drops were requested at the eastern side of the site in order to maximise the distance between them and the no-fly zone.

FIGURE 4.2.2. Avalon site map.



This site was 2 km from the permanent Bureau of Meteorology (BoM) weather station at Avalon Airport (Figure 4.2.2). The temperature was around 26°C and relative humidity was 44% during this mission. A consistent sea breeze was blowing from the east–southeast (Figure 4.2.3). The wind was lighter than ideal for this trial as it was much lower than that typical of running grassfires. The wind speed recorded at the weather station during this mission was 25 km/h, gusting to 30 km/h (Figure 4.2.3). The wind at the site felt significantly lighter to the observation team than was recorded at Avalon Airport, probably because of the protection afforded by a row of mature trees immediately to the east.

FIGURE 4.2.3. Wind speed and direction recorded at Avalon Airport weather station during the Avalon mission.



4.2.3) Drop evaluation

Two drops were requested for this mission, both with coverage level 4, 278-km/h (150 knot) indicated air speed and a height of 60 m (200 foot) above the ground. The first drop was to be laid in a north-south direction and the second was to be laid in a northwest-southeast direction.

Unexpectedly a third drop was made during this mission, as the aircrew had decided to use the remaining retardant in the tank to link the start points of the first two drops. The first two drops were made at 14:30:11 and 14:33:53 along bearings of 187° and 147° respectively. Both of these drops were made with the coverage level setting 4. The volumes recorded in the flight log (Appendix 3) were 18,927 and 17,034 litres. The flow of these two drops was stopped because the tank doors were closed as Bomber 391 reached the end of the paddock each time. These drops were estimated to be 690 and 650 metres long respectively based on retardant coverage on the ground.

The third drop involved the remains of the load after the second drop (7,446 litres) at 14:37:17. It was laid between the start of the first drop and the start of the second drop at coverage level setting 3 and was estimated to be 560 metres long. This drop was not expected and would have compromised data collection from the requested drops had there been a greater overlap with the requested drops.

The nearest points in the tracking data were not suitable for determining flight characteristics during any of the drops. The reported height for all drops in this mission was 60 m (200 ft). Height determination from analysis of suitable images estimated drops 2 and 3 both to be 65 m (214 ft). A suitable image was not available for drop 1.

The start point for the first drop was marked with a 5-m line of aluminium foil laid across the ground. The actual start of the drop was only a few metres earlier than this. The instruction for the second drop was to start at the fence line and to head straight towards the southeastern corner of the paddock. The aluminium foil impact tests were placed in three different locations along this path. This drop was also placed in the requested location and all of the foil impact test points were directly hit. None of these were damaged by the drop (see Figure 2.4a for example).

A considerable amount of drift was evident in the retardant cloud from the first drop, as can be seen in Figure 4.2.4. This drop was made with a crosswind. The wind strength on site was estimated to be between 10 and 15 km/h, and is lower than that recorded at the Avalon weather station (25 km/h) because of the row of trees 150 m up-wind and parallel to the drop.

Imagery taken from the side of the drops shows that there were thin and thick spots within the retardant cloud (Figure 4.2.5). Both retardant clouds had lost forward momentum by the time they reached the ground along most of their lengths. All drops featured a scalloping pattern on the ground, with a series of crescent-shaped sections with thicker coverage along the drop axis (Figure 4.2.6). There appear to be sections with very light coverage in between these. The pattern was very difficult to define and map visually on the ground (Figure 4.2.6c). The infrared sensors were able to detect the ground patterns of the drops well while the drops were still wet. All drops conducted in this mission had sections of heavy and light coverage (Figure 4.2.6).

The areas with of sections of light and heavy coverage were determined. Samples of stubble were collected from each, as were samples from unaffected areas within the paddock. These were later subjected to ignition tests using a cigarette lighter. The samples collected from unaffected areas and areas of light coverage were easily ignited and sustained flaming, while samples from sections of heavier coverage were unable to sustain flaming. There were many sections of light coverage within the drop perimeter that spanned the width of the drop and would potentially let a fire pass through.

FIGURE 4.2.4. Wind drift in drop 1 retardant cloud. Images have increased contrast. Time elapsed since drop started is given in parentheses.

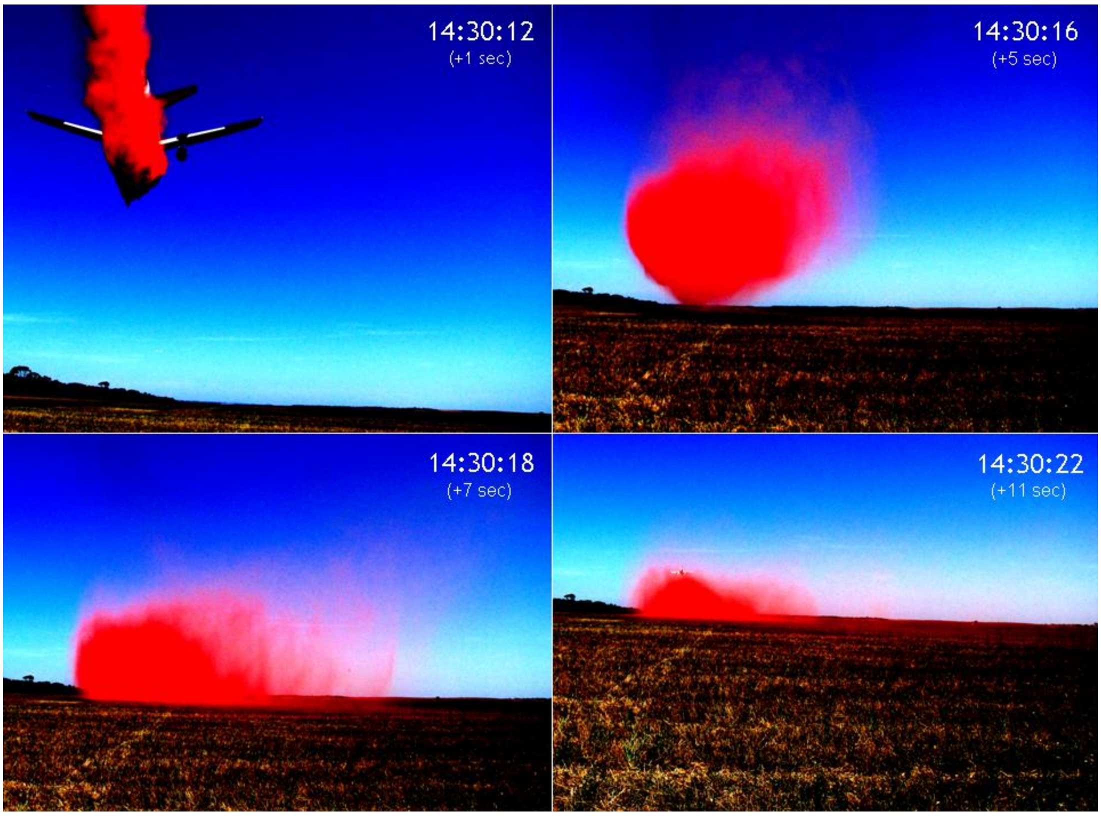


FIGURE 4.2.5. Side views of drops 1 (a), and 2 (b) showing thick and thin spots in retardant clouds. Time elapsed since drop started is given in parentheses.

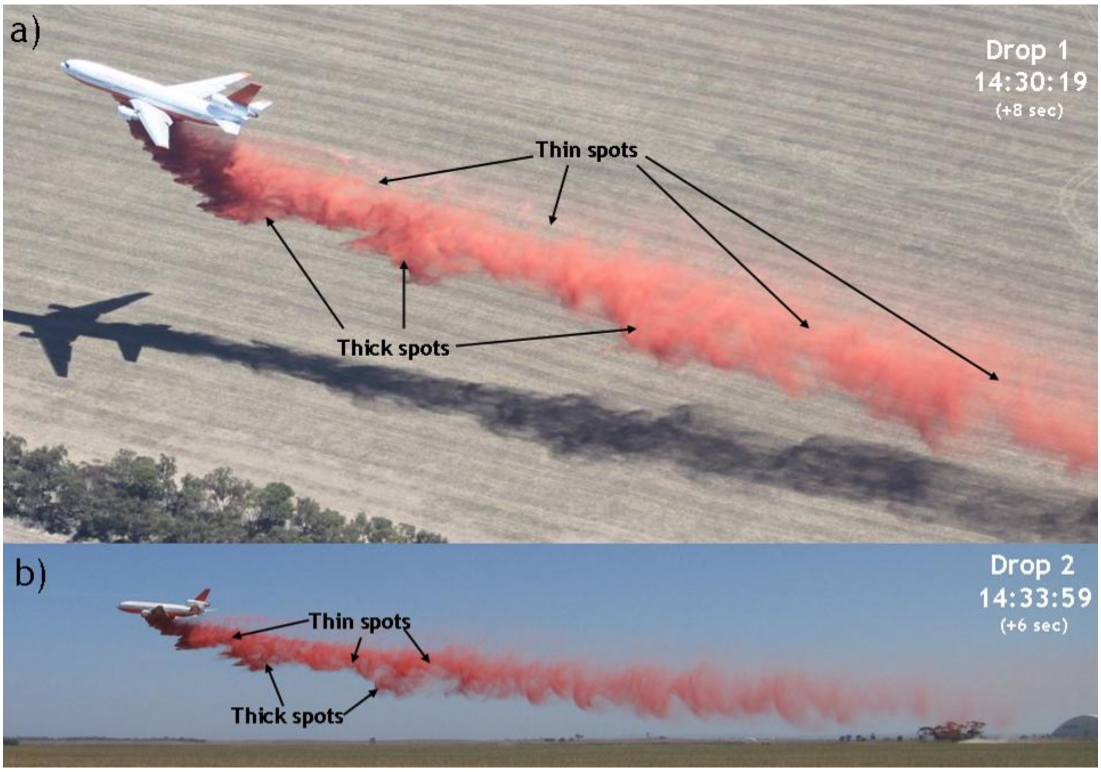
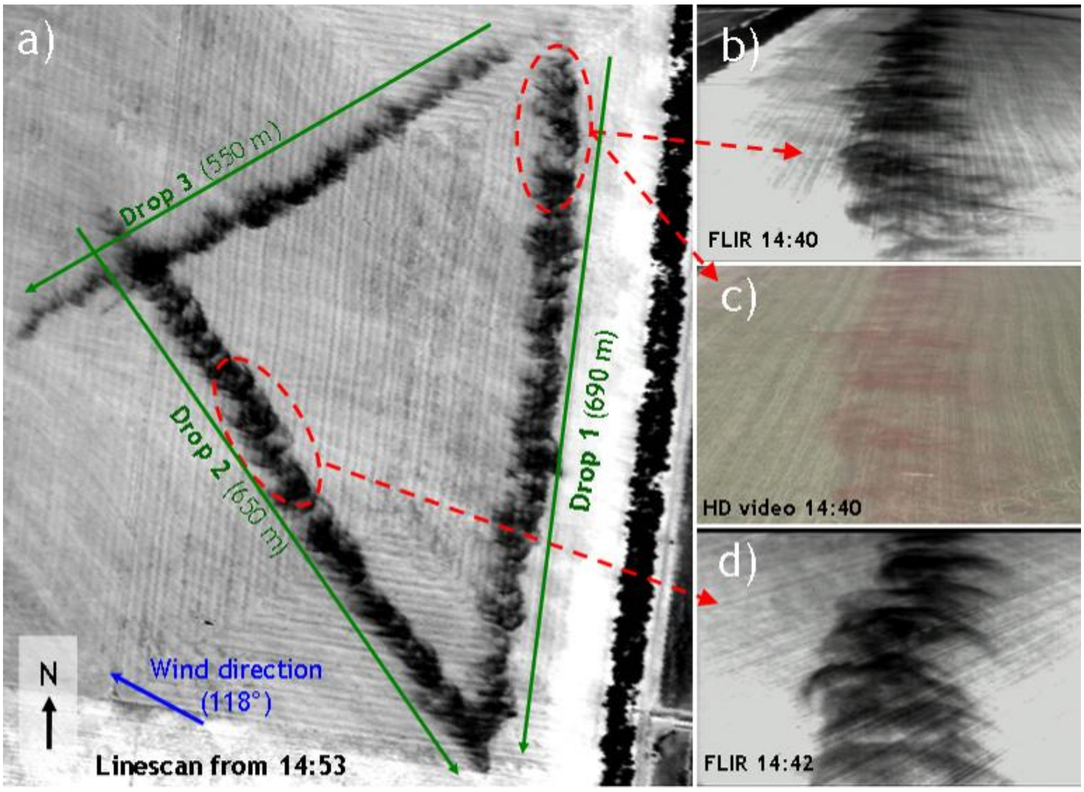


FIGURE 4.2.6. Scalloping patterns and gaps in retardant line



4.2.4) Discussion

The drop patterns from this mission appeared to be of lower quality than that of the previous mission, as indicated by the inconsistent coverage levels. These drop patterns could potentially let fire pass through them very easily. The low drop quality is concerning given the light wind conditions that prevailed during these drops. Stronger crosswinds would cause the drops to disperse more and would result in lighter coverage levels (e.g. George and Blakely 1973).

Although the combined lengths of these drops add up to a very considerable distance, such a length of line is meaningless if it is unable to hold fire at multiple points.

The retardant in these drops was observed to rain down relatively gently with some forward momentum and did not damage any of the foil damage test points laid out. It is unlikely that drops made at this height and coverage level would cause damage to people or buildings underneath them. The potential for a fire to pass over areas with low coverage within the drop would need to be tested in another trial by burning a fire into a similar drop.

4.3) ENFIELD FOREST

This planned evaluation mission was conducted in conjunction with a prescribed fire in Enfield Forest. The site was 70 km west-northwest from Avalon airport (37°44.67′S, 143°45.52′E) (Figure 4.1).

This mission was conducted on 3 March 2010. Another mission was conducted on the same day (Shelford-Mount Mercer, see Section 4.4). The scheduling of these two missions was arranged because the Bureau of Meteorology had forecast widespread significant rainfall starting on 5 March that would make conditions too wet for adequate data collection during the remaining contract period for Bomber 391.

4.3.1) Aims

This mission had multiple aims, including some that were the same as those for the Wombat Forest mission. The aims were:

1) to determine the drop effects on fire behaviour;
2) to quantify the drop footprint determined by the fire and compare this with that estimated prior to the fire;
3) to determine the ability of drops to penetrate through eucalypt forest canopy; and
4) to assess any collateral damage or safety concerns arising from this drop.

4.3.2) Site and conditions

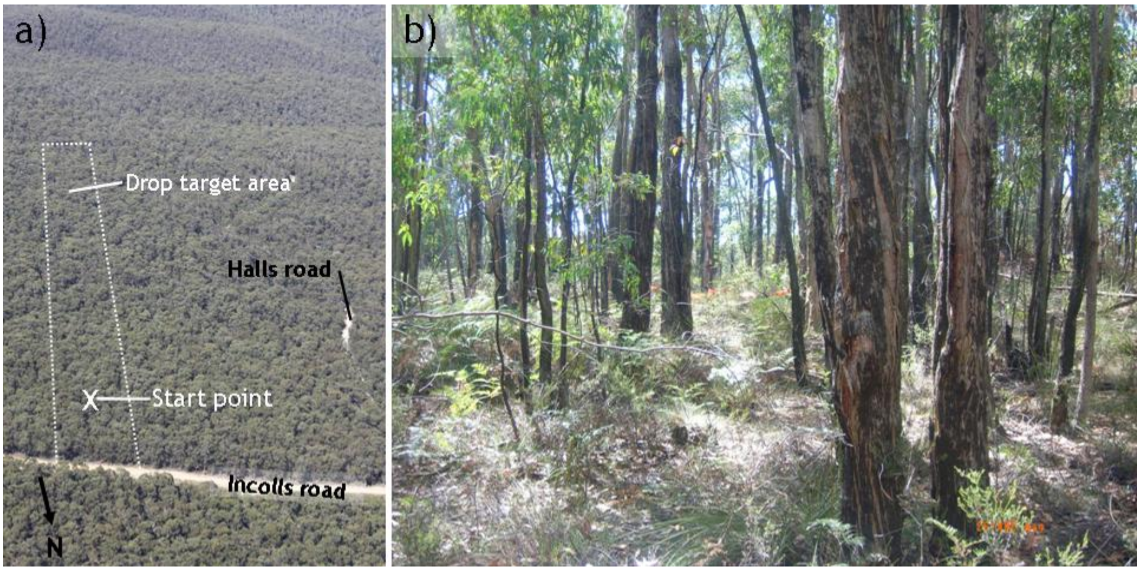
The site selected for this mission was near the corner of Halls and Incolls Roads in Enfield Forest. This site was selected because it was within an area marked for a prescribed burn. The site was the most suitable area within the burn perimeter because it had the flattest terrain and most uniform vegetation and was accessible. The site selected also fitted within the timing schedule for the prescribed burn. The site had a low slope with a southern aspect. The highest section of the site was at the northern end, which was 460 m (1500 ft) above sea level. The lowest section of the site was 430 m (1400 ft) above sea level.

The vegetation at the site was a mixed-species dry eucalypt forest (Figure 4.3.1). This site was drier than the Wombat Forest site, and the canopy was more open and tree height was generally lower, at around 15 to 20 m (50 to 65 ft). The projected foliage cover across the site was 35% on average. Common canopy species in this forest included *Eucalyptus obliqua* (Messmate Stringybark), *E. viminalis* (Manna Gum), *E. rubida* (Candlebark), *E. leucoxylon* (Yellow Gum), *E. goniocalyx* (Long-leaf Box), *E. radiata* (Narrow-leaf Peppermint), *E. dives* (Broad-leaf Peppermint) and *E. macrorhyncha* (Red Stringybark). The site was last burnt in February 1995.

The overall fuel hazard (McCarthy *et al.* 1999) had been assessed for the prescribed burn and was found to vary between high and extreme across the site. The overall fuel hazard score around the drop site was very high. The surface, near-surface and elevated fuel hazards were high and the bark fuel hazard was moderate.

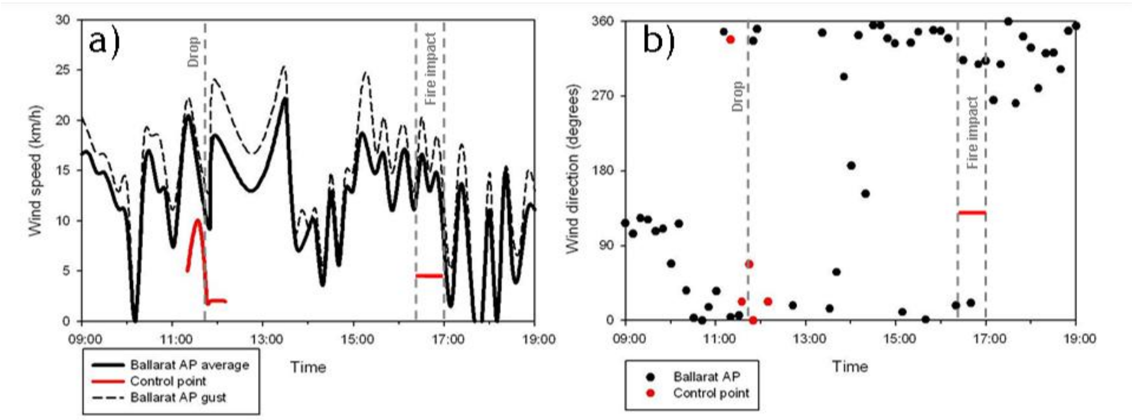
Ideally, a crosswind would have provided a greater contrast in conditions to those of the Wombat Forest mission. However, there was not much scope for targeting weather conditions for this mission because of the need for it to fit in with the prescribed burn and the other mission that afternoon, prior to the forecast rainfall.

FIGURE 4.3.1. Vegetation at the Enfield site from the air (a), and under canopy (b).



The wind conditions were less than 5 km/h on site at the time of the drop and for the majority of the day. Estimates of wind speed from Ballarat Airport, the nearest Bureau of Meteorology weather station (26 km north), were higher than those recorded on site (Figure 4.3.2a). The wind direction had a northerly influence for most of the day, although it was easterly early in the morning (Figure 4.3.2b). The onsite temperature was 23°C and relative humidity was 44% at the time of the drop. The maximum temperature onsite during the burn was 32°C and minimum relative humidity was 30%. The wind speed remained below 5 km/h for the duration of the burn. The FFDI was 15 at Ballarat Airport when the drop was being impacted by fire. It would have been considerably lower on site (~10) owing to the lighter winds.

FIGURE 4.3.2. Wind speed (a), and direction (b) recorded at Ballarat Airport (AP) weather station and the control point on site during the Enfield drop and burn.



4.3.3) Drop evaluation

The request for this mission was a single drop with dial setting 8 starting at the pre-marked point. As with the previous drops, the height above canopy was to be 60 m (200 ft) and the air speed 278 km/h (150 knots).

The starting point was easy to find from the air because it was close to the corner of two roads (Halls Road and Incolls Road) and near a highly distinguishable feature (Bald Hill). The coordinates for the point were provided to the aircrew (37°44.6′S 143°45.5′E) and a large cross (5 × 5 m) made from bright orange plastic sheeting was used to mark it. The direction for this drop was defined by the expected wind direction at the time of the drop. As this was expected to be easterly, the drop was requested in a southerly direction from the start point to maximise the chance of there being a crosswind.

The drop was laid at 11:49:23. Light spray from the drop was evident on the northern side of Incolls Road, ~100 metres north of the requested start point. The axis of the drop was about 20 metres east of the marked start point at a bearing of 191°. According to the flight engineer's log, this drop was 60 m (200 ft) above the ground, which is around 40 m (130 ft) above the canopy. The reported load was 42,234 L (11,157 US gal). The nearest point in the flight log was 16 seconds after the start of the drop (11:49:39) and not representative of flight conditions during the drop.

There were no photographs suitable for applying the photo-reference height determination as trees obscured the view from any suitable locations and observing helicopters had to maintain a height separation. It was however apparent from photographs taken from different vantage points that the start of the drop was very low and the height relative to the tree canopy increased during the drop because of the slope and Bomber 391 gaining altitude (Figure 4.3.3). There was considerable billowing within the retardant cloud during this drop (Figure 4.3.4).

This drop caused considerable damage to trees (Figure 4.3.5). The damage was most likely due to the combination of low drop height and issues related to the fast drop speed and design of the delivery system, which caused the drop to enter the canopy with considerable forward momentum. Sections that received the worst damage appeared to align with large clumps within the drop released when Bomber 391 was at its lowest height. The damage was concentrated at the northern (start) end of the drop and extended over 240 m (Figure 4.3.6). The worst damage occurred in three pockets in this area, where a number of trees were brought down. One tree was snapped at the base, while others were snapped part-way up the trunk or had their crowns removed. Some sections of the drop only had smaller branches damaged. A significant amount of force would have been required to snap these trees, as they were generally young and healthy, with diameters ranging from 100 to 250 mm with no pre-existing defects. None of the trees inspected had any notable faults or weak points. The majority of these trees were stringybarks (most likely *Eucalyptus obliqua*), which were the most common type of tree on site.

Three aluminium foil impact tests were placed within the anticipated drop zone. Only one of these was within the central portion of the drop. The foil on this sample was completely ripped across this test point (Figure 2.4c). The retardant coverage on the ground was close to 100%. The nearest damaged trees were 5 m away.

Similar large sheets of paper used for testing canopy penetration by quantifying the retardant coverage of surface fuels at the Wombat Forest drop were used for this drop. These were placed at points within the expected drop area between 30 and 200 m south of the marked start point. The locations were selected to cover the range of different canopy projected foliage cover in the path of the drop and next to the foil impact tests. As with the Wombat Forest mission, sheets that were inside the main drop area had very high area coverage, while those outside this area had lower coverage.

FIGURE 4.3.3. The start and end of the Enfield drop photographed from the three main vantage points, (a) and (b) from the northeast, (c) and (d) from bald hill (northwest) and (e) and (f) from the west.

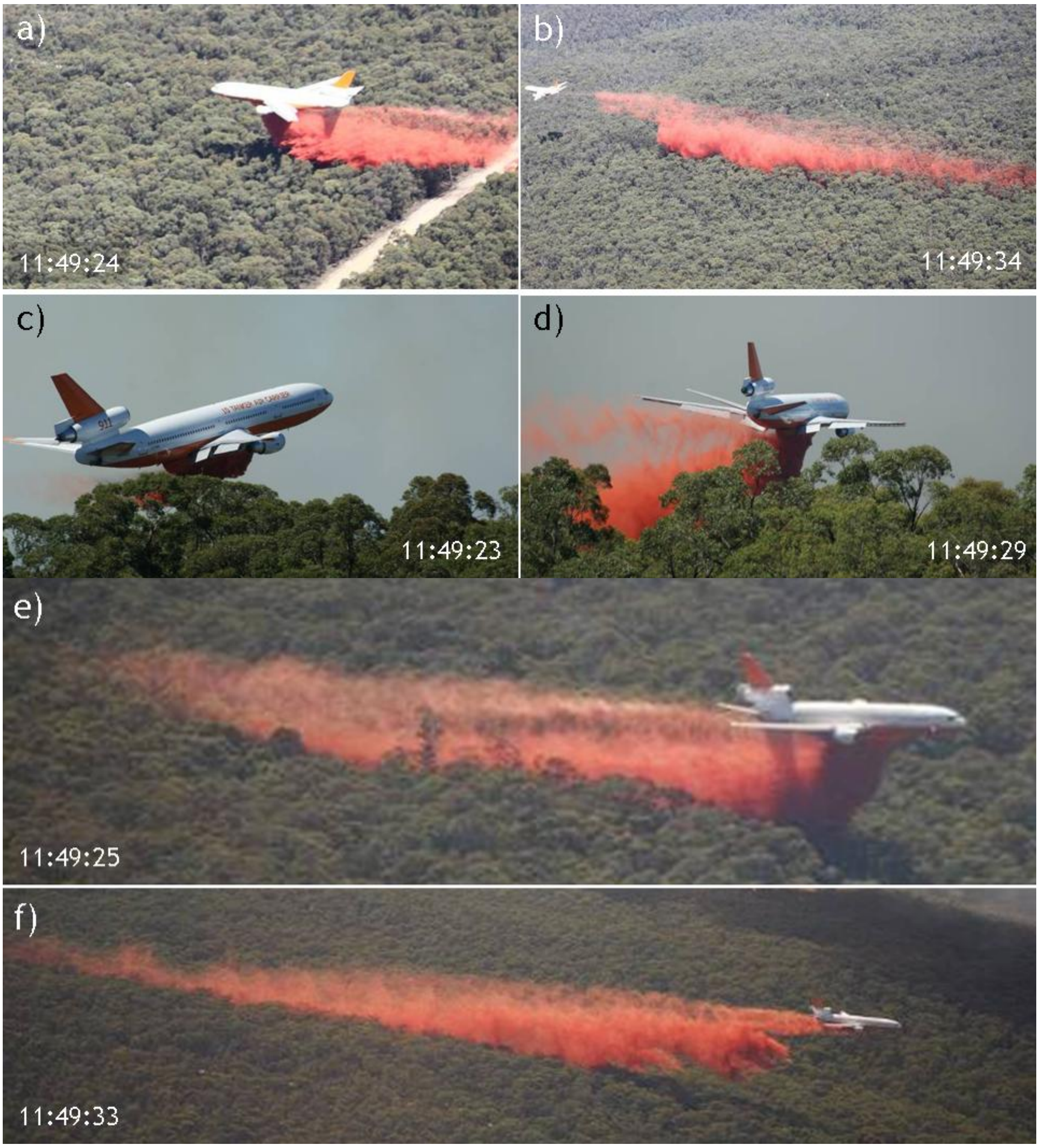


FIGURE 4.3.4. Billowing in retardant cloud at the Enfield drop, photographed from the west (a) and northeast (b).

FIGURE 4.3.5. Examples physical damage to trees from the retardant drop at the Enfield drop.

A slow-moving front of fire approached the drop from the southeast under the influence of a light south easterly wind (Figure 4.3.7). Two spot fires ignited near Halls Road on the western side of the retardant line. The subsequent development of these spots prompted the burn coordinator to start igniting the north western corner of the block. The fire impacted on the retardant line between 16:15 and 17:00, 4.4 to 5.2 hours after the drop was laid. The retardant would have been nearly dry by this time. Some sections of fire on the western side of the retardant line were drawn towards fire on the eastern side (Figure 4.3.8). It was only possible to get a relative location of the fire boundary from line-scans and FLIR footage. Rates of fire spread could not be determined from this and were complicated by the deliberate ignitions along the roads.

Flames in surface fuels in this section of the prescribed burn were generally 0.5 m, with occasional flare-ups reaching 1 to 1.5 m (Figure 4.3.9a). Fire climbed to considerable heights up the stringybark trees (Figure 4.3.9b). The FLIR imagery indicated that these were generating firebrands. Flame heights in litter fuels with light retardant coverage were generally much lower (~0.25 m) than in the other sections (Figure 4.3.9c).

FIGURE 4.3.6. Location of physical damage to trees from Enfield retardant drop.

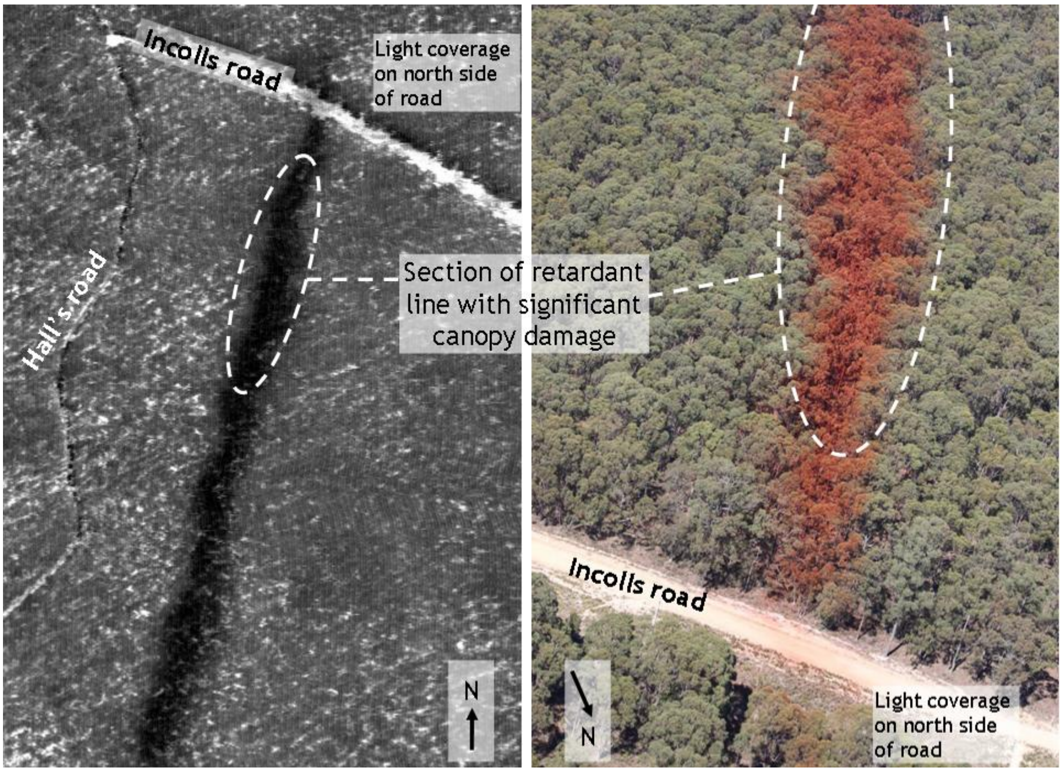


FIGURE 4.3.7. Estimated fire progression towards the Enfield retardant drop.

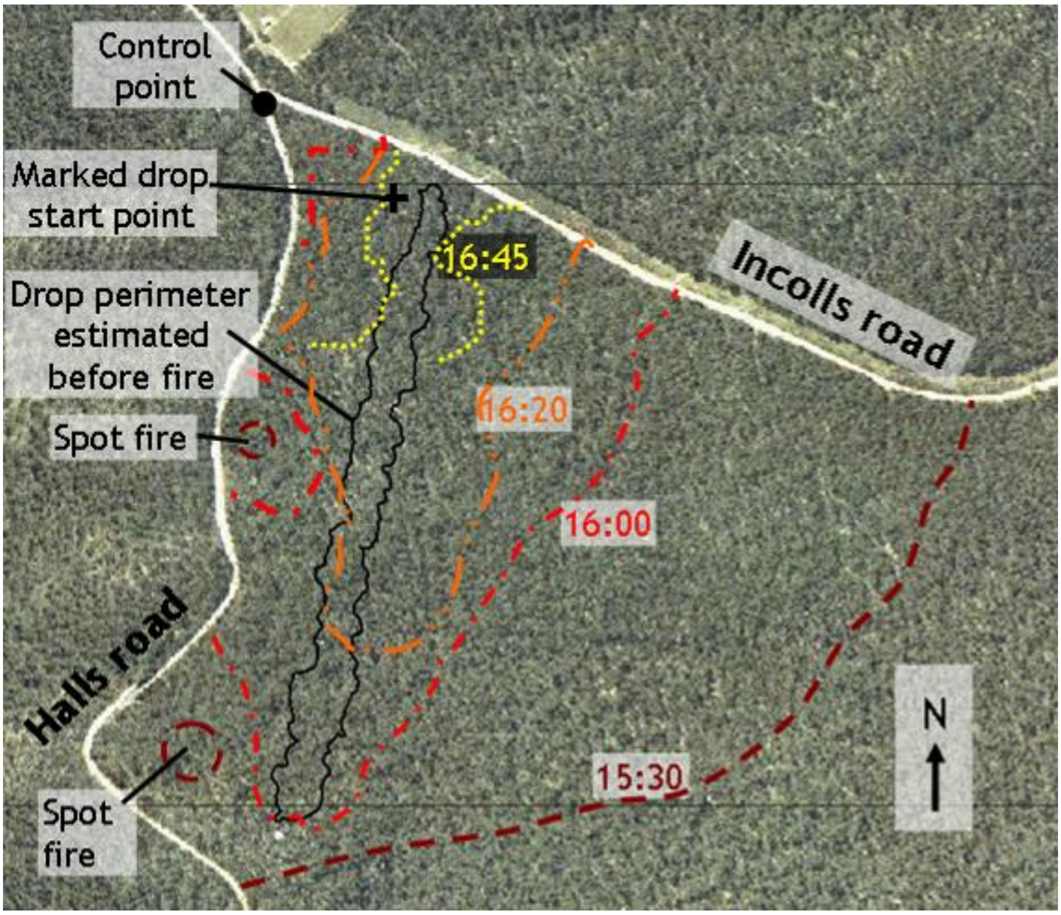


FIGURE 4.3.8. Fire around the northern end of the Enfield retardant drop viewed from FLIR (a), and visual cameras (b).

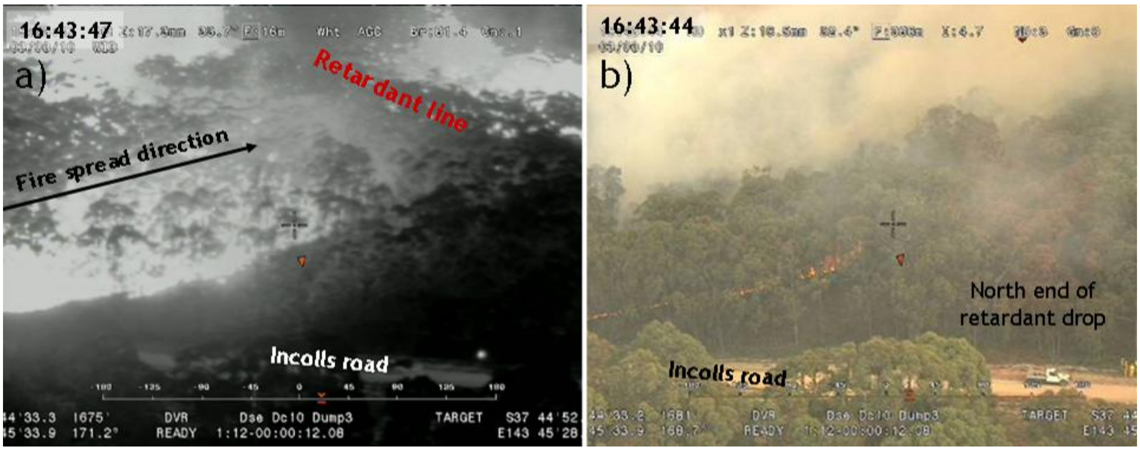
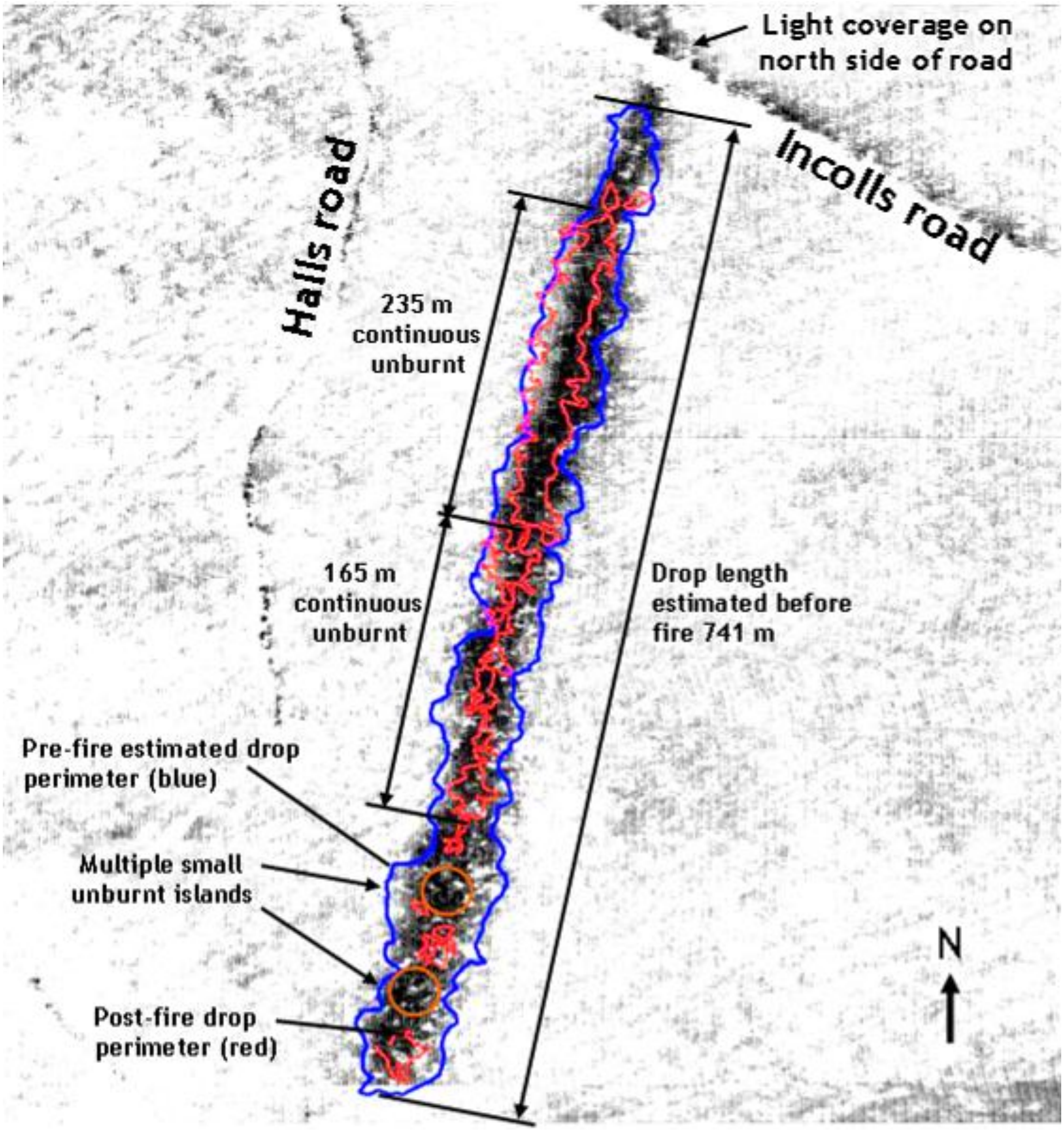


FIGURE 4.3.9. Fire behaviour around the Enfield retardant drop (a), climbing stringy barks (b), and flaming reduced in fuels with light retardant coverage (c).

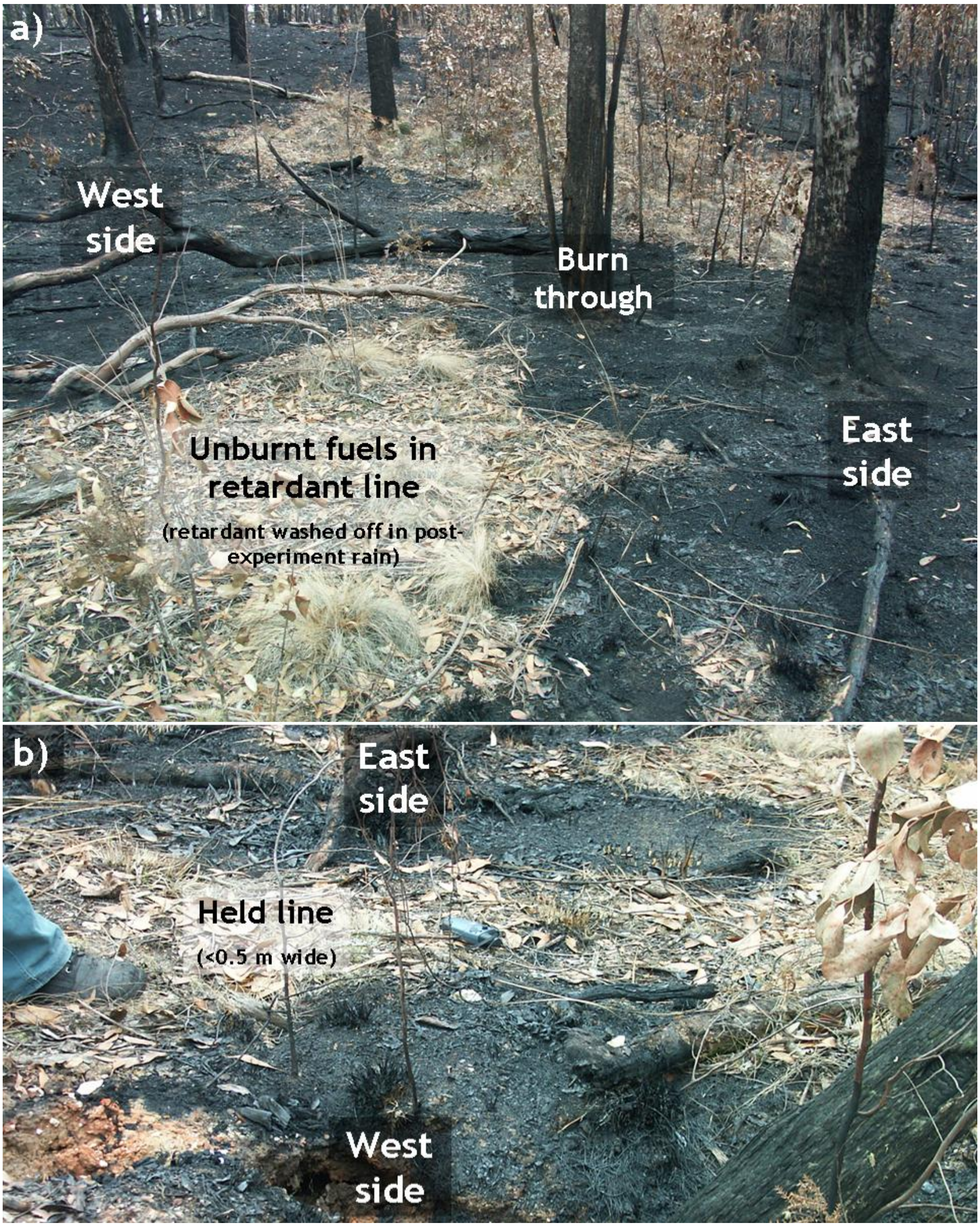
The drop footprint was mapped soon after it was laid and well before there was fire in the area. This was done in the same way as for the Wombat Forest drop. The unburnt fuels within the drop area were also mapped after the fire had burned around it in the same way as the Werrimull wildfire drop was mapped. This was conducted a week after the drops as it was not safe to enter the site that afternoon because of falling trees, and the following few days were wet. A line-scan image was captured immediately after the drop. The resulting estimates of the effective drop footprint are shown in Figure 4.3.10. This figure shows that fire burnt into areas that were thought to have adequate coverage during the first post-drop survey.

FIGURE 4.3.10. Footprint of the Enfield retardant drop estimated before and after being impacted by fire overlayed on a line-scan (with increased contrast) captured 1 minute after the drop.



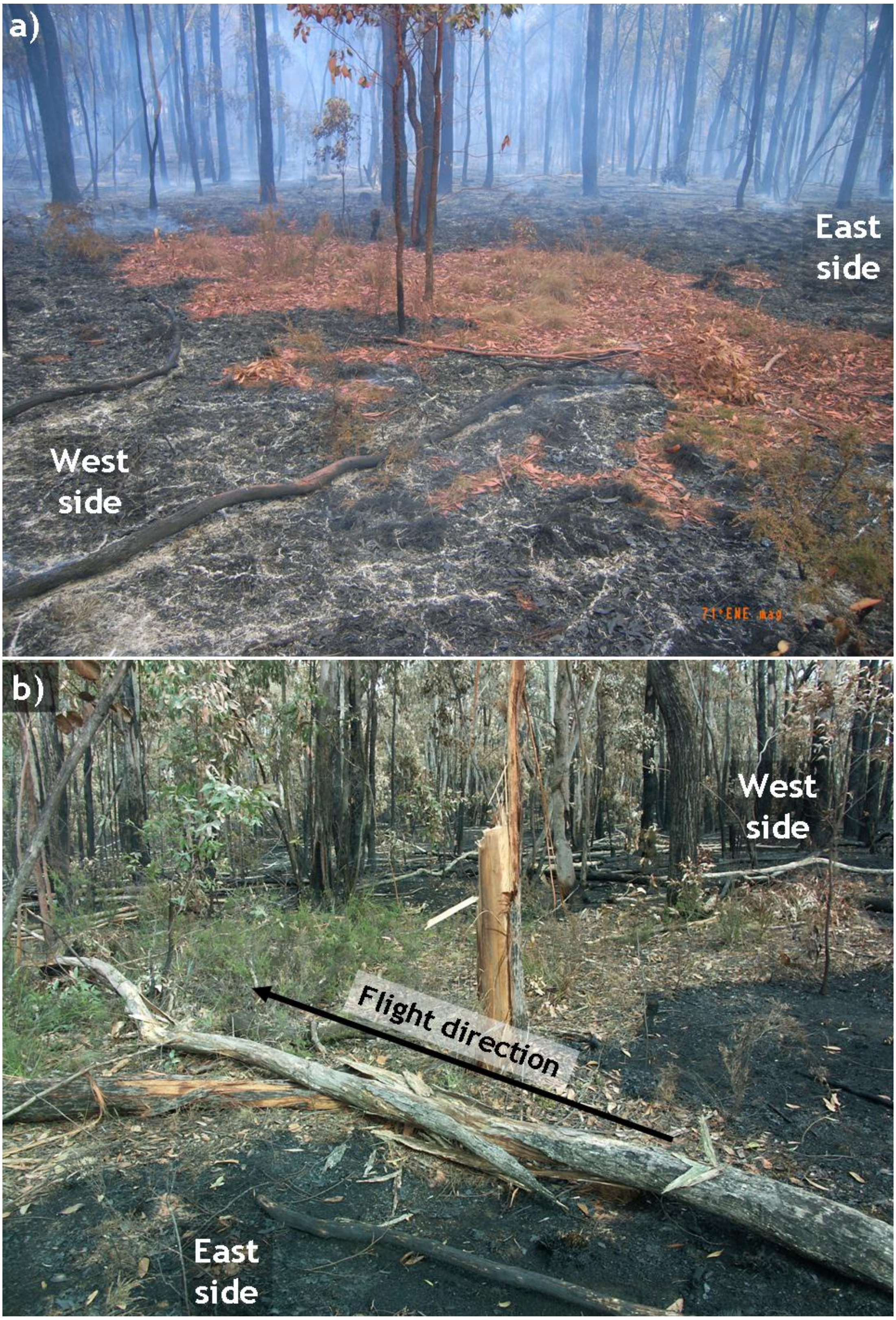
The true effective retardant line is that depicted by the post-fire mapping. The post-fire retardant line here was divided into two main sections separated by a small burn through area where the fire just burnt through the line (Figure 4.3.11a). The first (northern) section was 235 m long and the second was 165 m. Another part of the retardant line 25 m to the south of the burn-through section nearly burnt through the line (Figure 4.3.11b). The retardant line in this small section was less than 0.5 m wide. It is likely that this burn-through point and near-burn-through point aligned with sections of lighter coverage between billowing sections within the retardant cloud, as there were no noticeable differences in the canopy density or vegetation structure.

FIGURE 4.3.11. Burn-through (a), and near-burn-through (b) sections of the Enfield retardant line.



Other burn-through areas at the start and end of these two continuous sections were wider and frequent. These sections had many small unburnt islands of retardant-coated fuel (e.g. Figure 4.3.12a). The northern tip of the unburnt section of retardant line was less than 0.5 m away from the first snapped tree (Figure 4.3.12b). This illustrates the implications of the billowing within the retardant cloud, as it would have required a considerable volume of retardant or a great force to snap the tree, yet fuels adjacent to this damage did not receive a high enough coverage to stop the fire burning through the line.

FIGURE 4.3.12. (a) Unburnt island of retardant-coated fuel at the northern end of the Enfield retardant line, and (b) snapped tree next to burnt fuels at the northern tip of the continuous section of drop.



4.3.4) Discussion

The most significant finding from this mission was the damage from the impact of the drop. This damage was severe and highlights the potential for large drops to cause damage when retardant cloud clumps enter the canopy with significant forward momentum.

The air tanker's height at the time of the drop is likely to be the main contributing factor for this damage. This appeared to be much lower than the 60-m (200-ft) minimum drop height specified in the operations program (Biggs 2010) and the minimum height for VLAT-category aircraft recommended in Cox *et al.* (2009). The height of Bomber 391 during this drop could not be quantified owing to the lack of a system providing adequate tracking data within the aircraft. The height relative to the ground and canopy increased during the drop. Tree damage was only evident in the northern end of the drop, where the drop height was lowest.

The damage demonstrates the need to remove all ground personnel and other people from areas where drops are being laid while the aircraft has the potential to drop loads below the minimum specified drop height. The extent of this damage also indicates that drops from this air tanker may not be suitable for use in areas where there are buildings.

The light winds experienced during this mission prevented any investigation of crosswind drops during this evaluation. It is likely that a crosswind drop would have also had considerable billowing within the retardant cloud, as observed during the Avalon mission. The quality of a footprint from a crosswind drop passing through canopy after reaching terminal velocity (i.e. drop height ≥60 m (200 ft)) is unknown.

This drop was initially breached by spotting. Had there been no spotting at this fire, it is likely that it would have been burnt through in the gaps in the line indicated in Figure 4.3.10. The fire conditions experienced during this mission were relatively mild compared with those that would occur on a day of very high or extreme fire danger. A drop such as this is likely to be much less effective under such conditions.

4.4) SHELFORD-MOUNT MERCER

This mission was conducted on 3 March 2010.

4.4.1) Aims

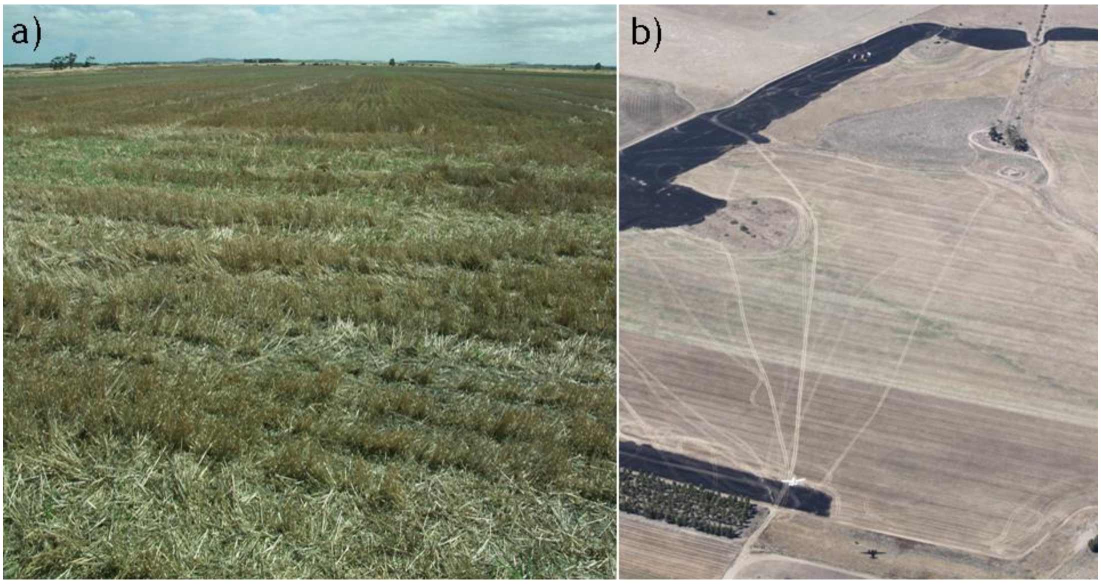
This mission was planned following the results from the Avalon mission. This mission involved similar tests using one drop with the coverage level dial set at 4 and another with the dial set at 6. The primary aim of this mission was to test the ability of these drops to hold a grassfire.

4.4.2) Site and conditions

The site selected for this mission was a privately owned paddock on the Shelford–Mount Mercer Road 50 km west-northwest from Avalon Airport. The site was a flat stubble paddock, 230 m (760 ft) above sea level.

The fuel in the paddock was stubble from three successive barley crops (Figure 4.4.1). Some sections of the paddock had small amounts of short green grass growing among the stubble. Based on the stubble height and density, the fuel load for this paddock would have been around 2 to 4 t/ha (Tolhurst *et al.* 2008, Sullivan 2010). There were also some sections of raised ground with ungrazed cured natural grasses in the paddock.

FIGURE 4.4.1. Barley stubble fuels at the Shelford–Mount Mercer site.



The site was set up for an anticipated southeasterly sea breeze. Two locations were marked out for retardant drops to be laid perpendicular to the wind (Figure 4.4.2). The end-points for these drops were marked out with 5-m-long strips of orange plastic laid across the ground. Ignition lines were marked out 250 and 350 m up-wind and parallel to the retardant lines. A grader line was constructed around the perimeter of the paddock and around a small stand of trees in the centre. Buffer burns were used to widen fuel breaks around the north, east and western edges of the paddock.

A portable automatic weather station was erected to the west of the paddock. Readings from this were compared with the nearest permanent Bureau of Meteorology weather station at Sheoaks, 20 km east of the site. The onsite temperature was 28°C and relative humidity was 30% during the drops and fires. The wind speed measured on site was around 16 km/h, gusting up to 28 km/h (Figure 4.4.3a). Wind measurements were similar at the Sheoaks weather station. The wind was consistently from the southeast during the afternoon (Figure 4.4.3b). The GFDI would have been around 10 (high), assuming 100% curing.

FIGURE 4.4.2. Site layout for the Shelford–Mount Mercer drops and fires (CL, coverage level).

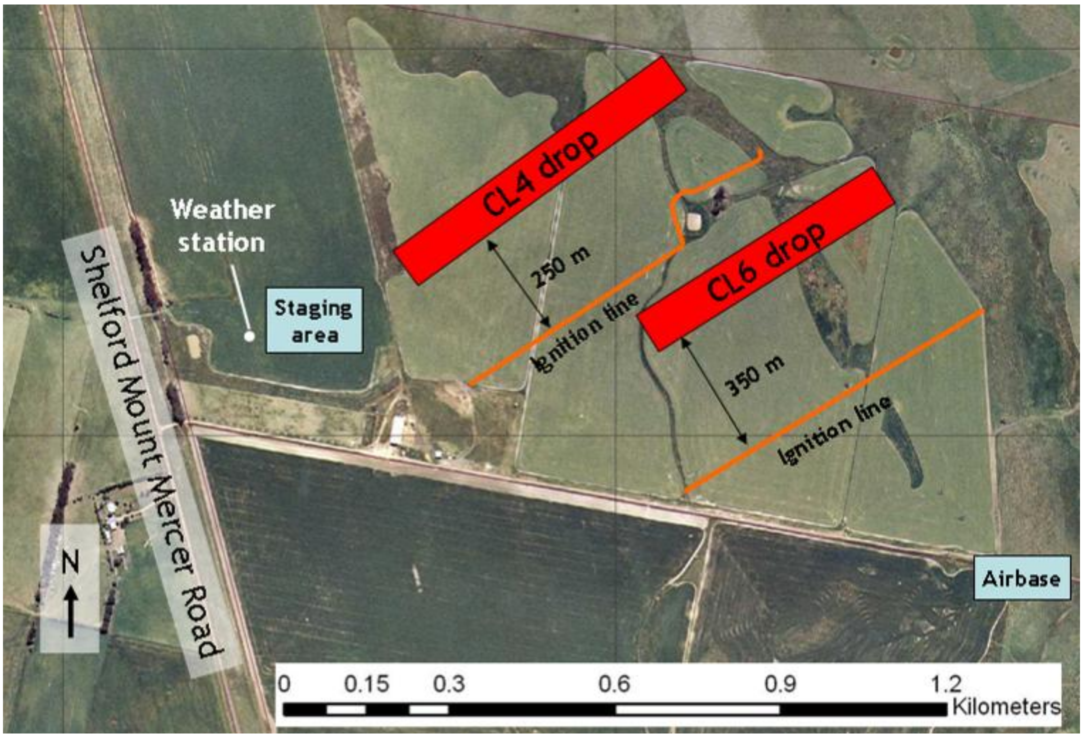
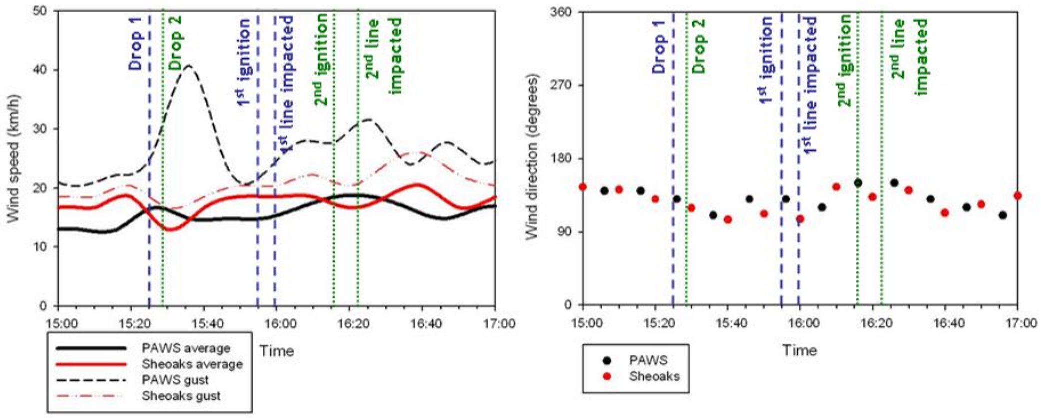


FIGURE 4.4.3. Wind conditions during Shelford–Mt Mercer drops and fires.



4.4.3) Drop evaluation

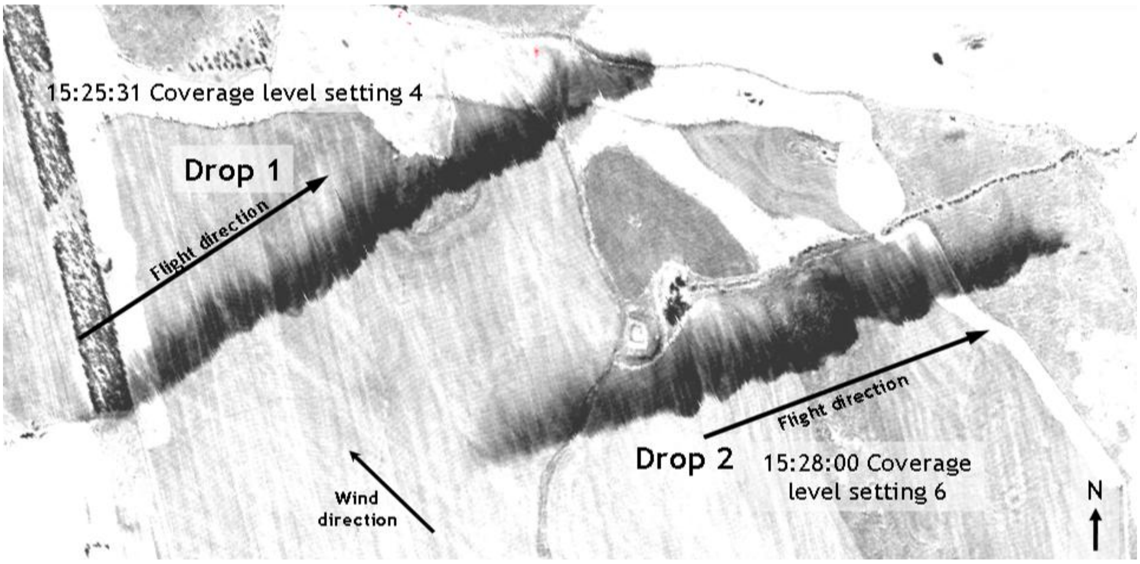
The request for this mission was for two drops to be laid on the areas marked on Figure 4.4.2. The flight parameters requested for the drop were a height of 60 m (200 ft) above the ground and an air speed of 278 km/h (150 knots). The coverage level dial settings requested for these drops were 6 and 4. While the drops were placed in the correct locations, they were not made in the order requested. This did not affect the outcome of the mission, but it did prevent some photographs from being taken in line with the flight direction The drops were delivered at 15:25:31 and 15:28:00. The flight log lists the volumes of these drops as 18,927 and 22,974 L (5,000 and 6,069 US gal) for the coverage level 4 and 6 drops respectively. The nearest points in the tracking data were 56 and 34 seconds after the start of the drops, and so were not relevant to the flight characteristics during the drop. The log lists both drops as being made at 60 m (200 ft) above ground level. Analysis of images taken during the drops estimated them to be 49 and 56 m (160 and 185 ft) above the ground respectively. Both drops were placed within the pre-marked locations.

Images taken during the drops (Figure 4.4.4 and 4.4.5) show that the retardant clouds had similar billowing to that seen during the Avalon mission (Section 4.2). Both drops were close to reaching terminal velocity when they hit the ground. Patterns within the line-scan image captured one minute after the second drop (Figure 4.4.6) illustrate the influence of wind drift on the shape of the drop footprints, with sharp boundaries on the windward sides and blurred edges on the lee sides. Scalloping patterns evident in the Avalon drops could not be detected in the line-scan. Striation patterning could be seen in the line, presumably because of the stronger crosswind. The variation in coverage level along the drop axes did not seem as strong as in the Avalon drops.

FIGURE 4.4.4. Drop 1 cloud photographed from (a) the northwest, and (b) the southeast.

FIGURE 4.4.5. Drop 2 cloud photographed from (a) the northwest, (b) the southeast, and (c) the southwest. The bottom sequence (c) has increased contrast.

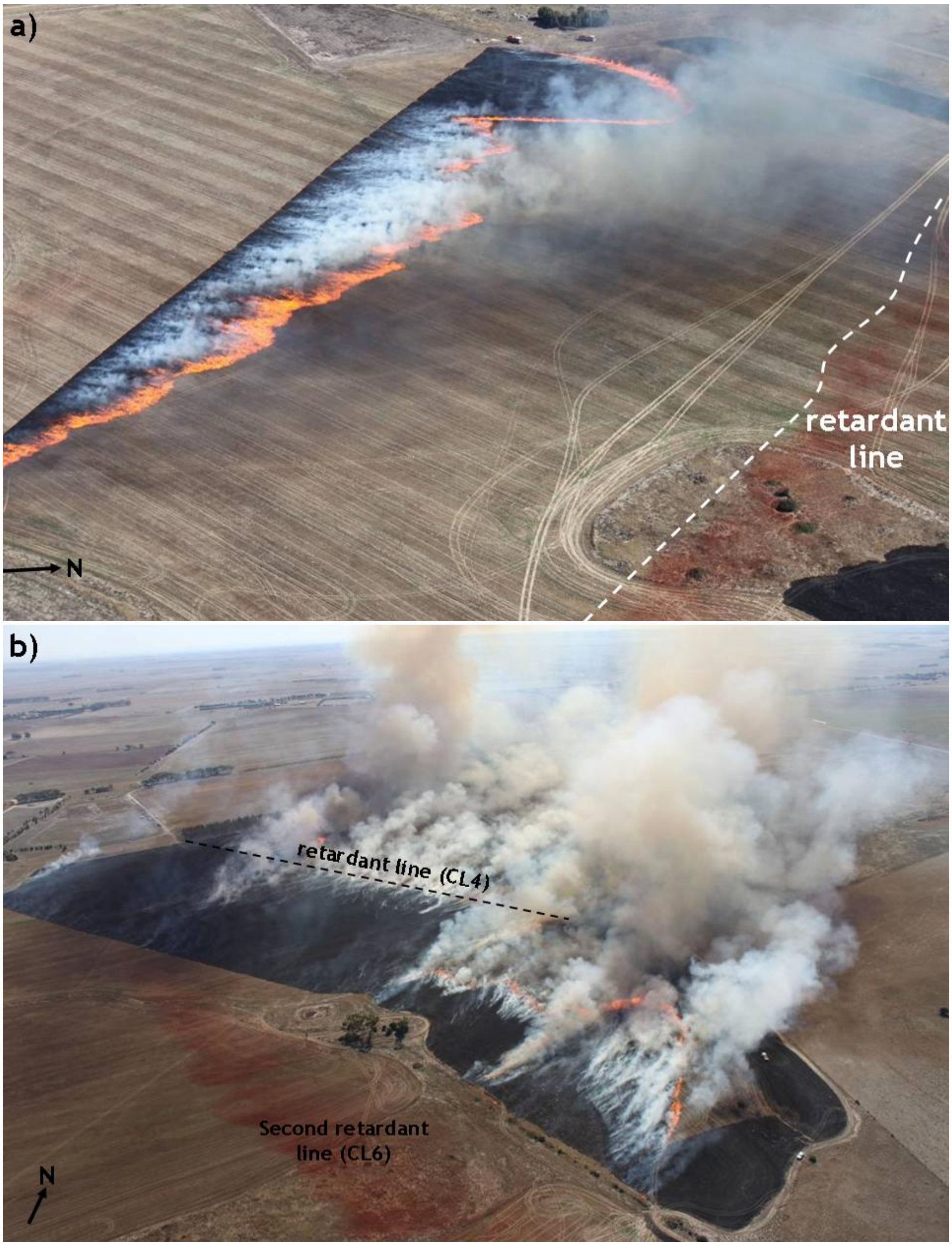
FIGURE 4.4.6. Line-scan image showing pre-burn drop footprints. This image was captured at 15:29, 3.5 minutes after drop 1 and 1 minute after drop 2.



Two lines of fire parallel to the drops and perpendicular to the wind direction were ignited 250 and 350 m up-wind of the drops, as indicated in Figure 4.4.2. The lines were ignited quickly using a drip torch mounted in a trailer towed by a vehicle driving along the pre-marked line.

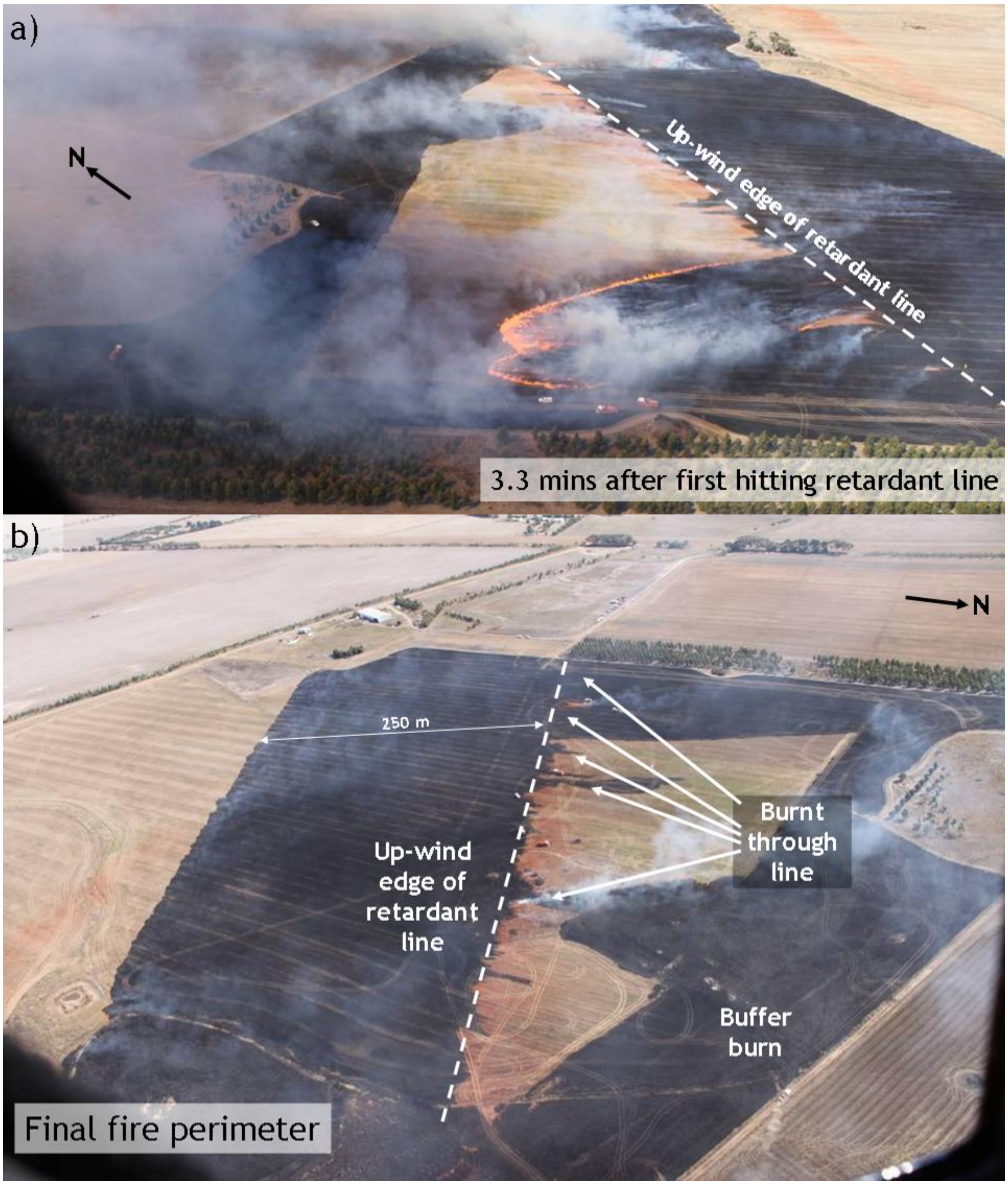
The first fire was ignited from 15:55:33. This fire spread faster in some sections than others, probably as a result of differences in fuel (Figure 4.4.7a). The fire had flame heights between 1 and 1.5 m across the head. This fire reached the coverage level 4 retardant line at 15:59:42 (Figure 4.4.7b) and the maximum rate of spread was calculated to average 3.6 km/h. The intensity of this fire (Byram 1959) was estimated to be between 3.2 and 6.4 MW/m, assuming a heat of combustion of 16,000 kJ/kg (Cheney and Sullivan 2008) and fuel loads between 2 and 4 t/ha.

FIGURE 4.4.7. The first fire progressing towards (a), and through (b) the coverage level 4 retardant line.



This fire burnt through the retardant line in at least three sections. The most notable of these was at the western (tail) end of the line, where the first 200 m of the line were completely burnt through (Figure 4.4.8a). The fire burning through this part of the retardant line barely slowed as it passed through. No weaknesses were detected in this section of the retardant prior to the fire either in the line-scan (Figure 4.4.6) or on the ground. The fires that burnt through the other sections of the retardant line slowed noticeably as they passed through the line and quickly gained speed afterwards (Figure 4.4.8b). The most easterly of the burn-throughs was in a section of rough ground with ungrazed cured native grasses.

FIGURE 4.4.8. Impact of the first fire on the coverage level 4 retardant line, (a) 3.3 minutes after first hitting retardant line; (b) final fire perimeter.

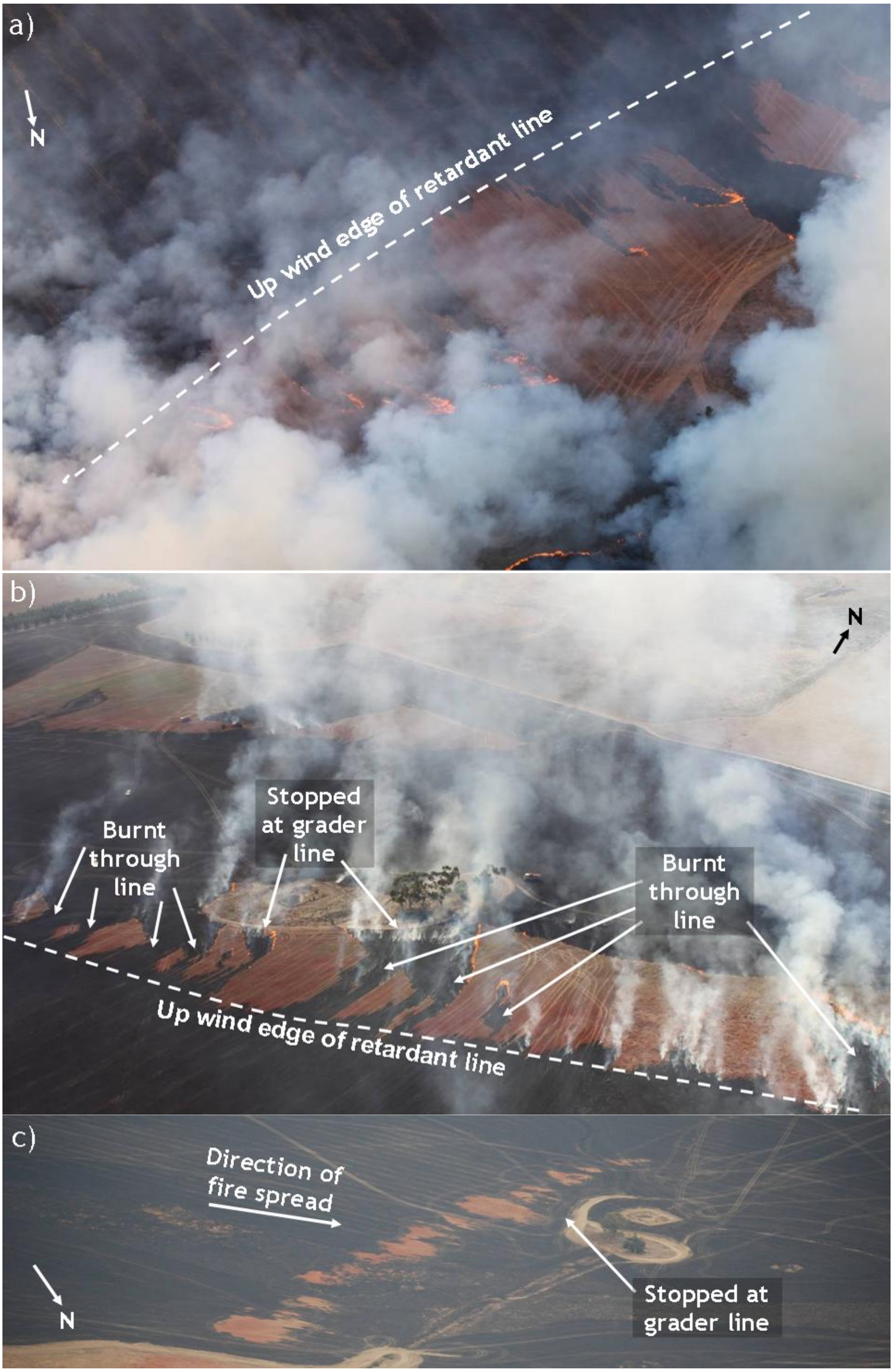


The second fire was ignited at 15:16:19. It developed in a similar way to the first, with variable spread rates across the length (Figure 4.4.9). The maximum rate of spread was 3.75 km/h, which was slightly faster than the first fire. The maximum intensity was estimated to be between 3.3 and 6.7 MW/m.

The second fire burnt through the coverage level 6 retardant line in many sections spread along the entire length. The majority of these were narrow (≤5 m wide). The fire spread slowed as the fire progressed through the drop, though a temporary change in wind direction contributed to this (Figure 4.4.10a). The sections of fire that burnt through the line continued to spread for a short distance until they reached burnt fuels. Some of these sections towards the western end of the line burnt up to a grader line and stopped at this (Figure 4.4.10b and c).

FIGURE 4.4.9. The second fire, (a) ignition, and (b) progressing towards the coverage level 6 retardant line.

FIGURE 4.4.10. The coverage level 6 retardant line (a) during and (b) immediately after impact.



4.4.4) Discussion

The results of this mission confirmed the main concerns of the Avalon mission relating to the inability of these retardant lines to hold fire spread in grassland fuels. These results are significant as they indicate that retardant drops from the DC-10 are not effective at stopping head fire spread along the total length of a drop in grassland fuels. They are therefore not suitable for application in the grassfire suppression tactic outlined in Figure 4.2.1. The Shelford–Mount Mercer mission was conducted in weather conditions that were mild compared with those likely in fast-moving grassfires.

It is worth noting that the mineral-earth line (a tried and proven fire-control method) created by a grader, around the trees behind the coverage level 6 drop, stopped fire progression. The fire impacting the grader line had a reduced intensity relative to the fire that impacted the retardant line. Mineral-earth lines such as this are of value in stopping fires because, unlike the retardant drops, they do not have weak points along them that can be burnt through.

4.5) STREATHAM

This mission was conducted on 4 March 2010.

4.5.1) Aims

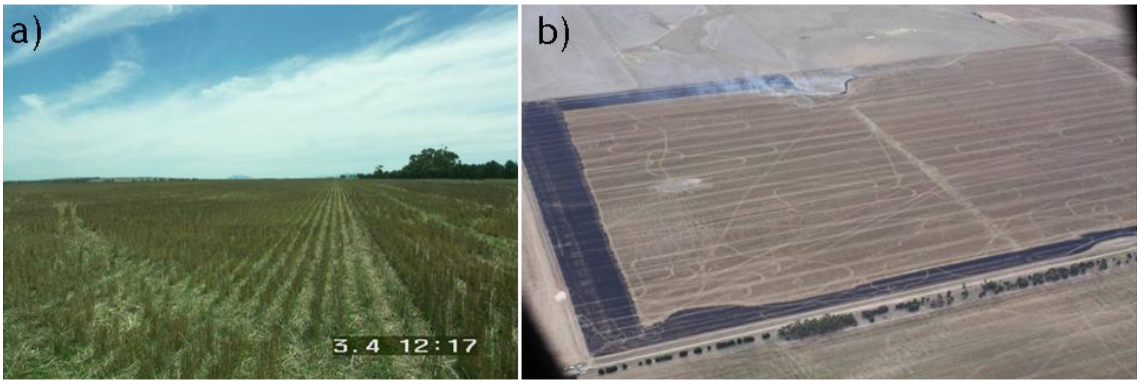
The purpose of this mission was to evaluate the DC-10 air tanker use for direct suppression of a grassfire using foam. The mission was designed to test the ability of drops to suppress head and flank sections of a stubble fire. The aim was to light a line of fire in stubble and attempt to extinguish it using directly placed foam drops from Bomber 391 once the fire developed its maximum intensity and rate of spread.

4.5.2) Site and conditions

The site used for this mission was a privately owned stubble paddock on the western site of Hintons Road, northeast of Streatham. It was a relatively flat stubble paddock, 270 m (885 ft) above sea level and 125 km west-northwest from Avalon Airport. The site was selected because it had suitable and uniform fuel, was relatively flat, was of a sufficient size and the owners were willing to accommodate the trial.

This paddock contained stubble from a wheat crop (Figure 4.5.1). It was estimated to have a similar fuel load to the paddock used at the Shelford–Mount Mercer mission. However, here the stubble was cut higher (0.3 m) and was at a lower density, with less fuel and greater distances between rows. There was a light cover of green grasses and weeds between the stubble lines in some areas in this paddock, particularly near a windmill just north of the ignition line.

FIGURE 4.5.1. Wheat stubble fuels at the Streatham site from the ground (a) and air (b).



The site was set up for an anticipated north–northwesterly wind (Figure 4.5.2). Buffer burns were used to create breaks around the western, southern and eastern boundaries of the paddock. A 150-m ignition line was marked out on the northern boundary of the paddock soon before ignition. This was offset westwards for a north–northwesterly wind.

Onsite weather readings were taken at half-hour intervals using hand-held instruments. These were compared with measurements from the nearest permanent Bureau of Meteorology weather station at Westmere, 18 km southwest of the site. The onsite temperature was 30°C and relative humidity was 30% during this fire for the duration of this mission. The wind speed measured on site was around 10–15 km/h (Figure 4.5.3a). Wind measurements at the Westmere weather station were stronger, with an average speed around 20 km/h. The wind direction on site was variable, ranging between northeast and northwest. This was not picked up by the measurements taken at Westmere or on site (Figure 4.5.3b), but was evident from the smoke and had a significant effect on the conduct of this mission. Assuming curing of 100%, the GFDI was calculated to reach 7 (moderate) on site.

FIGURE 4.5.2. Layout of the Streatham site.

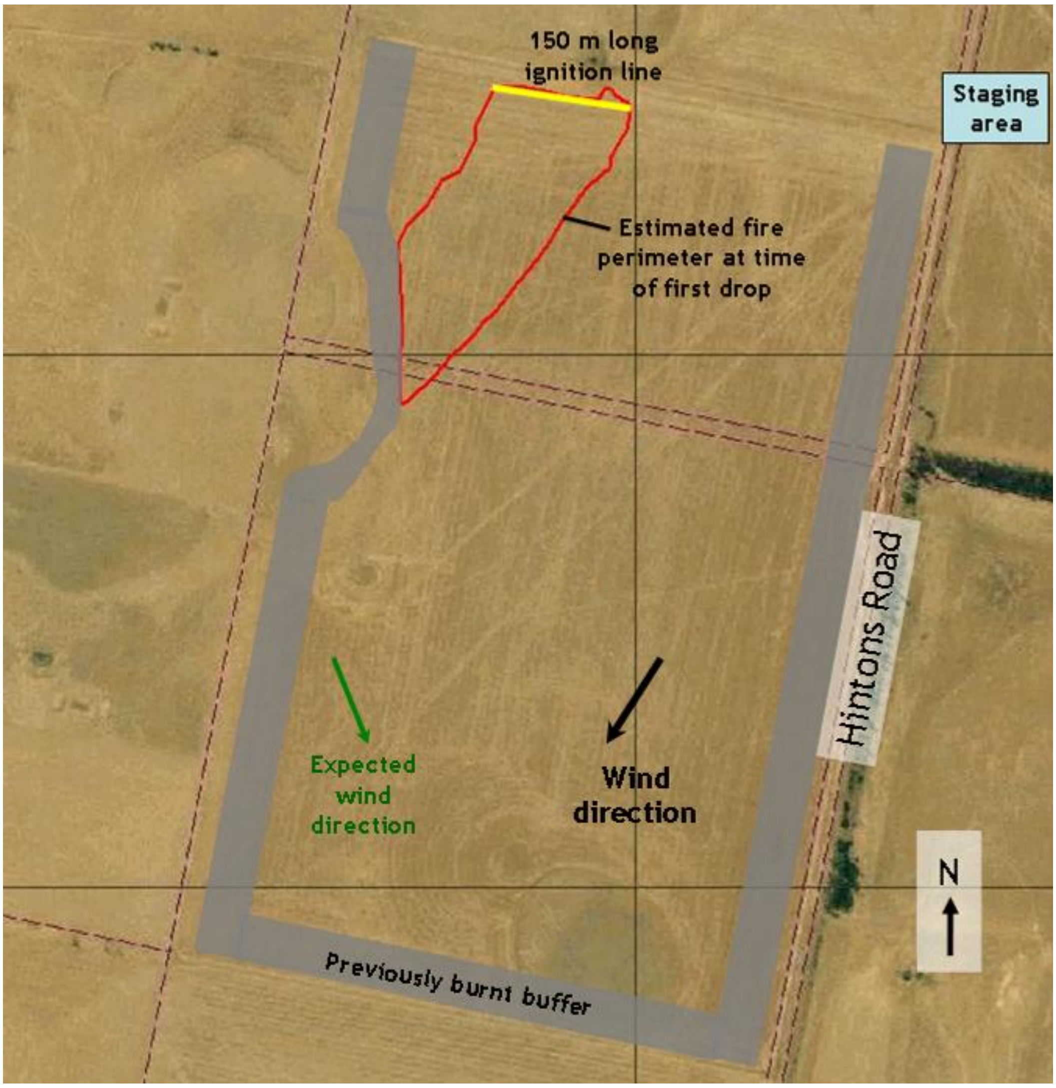
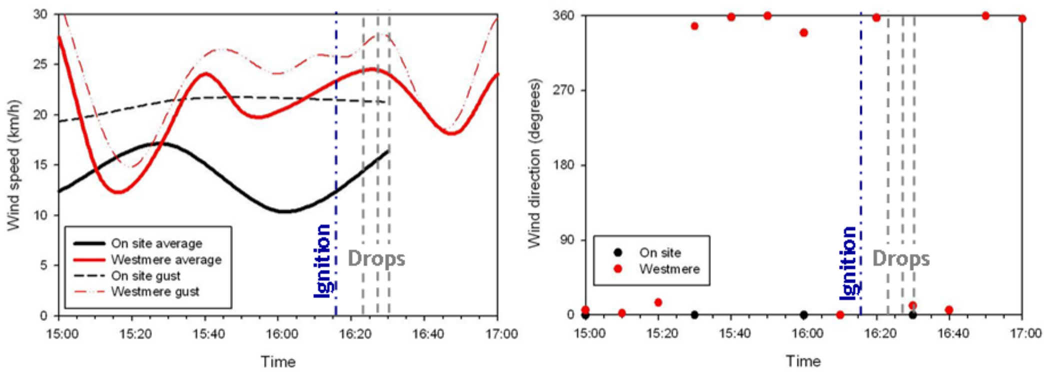


FIGURE 4.5.3. Wind conditions during Streatham fire and drops.

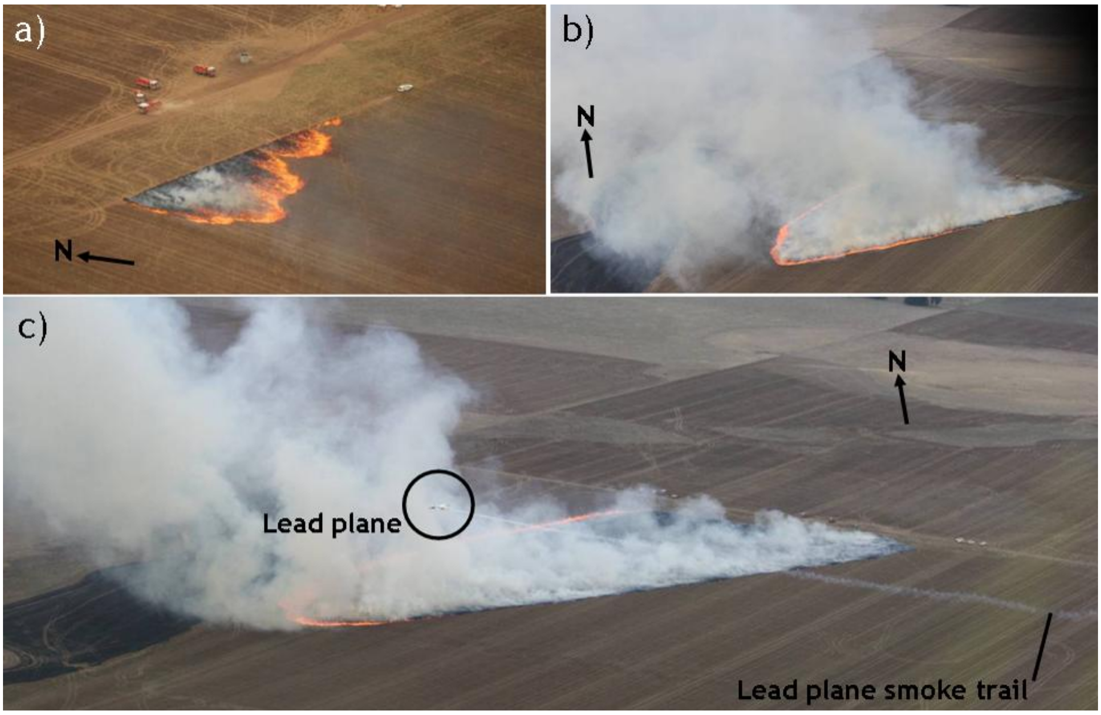


4.5.3) Drop evaluation

The drops requested for this fire were a coverage level 8 drop placed directly on the head fire using approximately half of the load volume, followed by one or more drops at coverage level 4 placed directly on the flanks using up the remainder of the load. As with the other drops, the flight parameters requested for the drop were 60 m (200 ft) above the ground and an air speed of 278 km/h (150 knots). The suppressant requested for this mission was foam, mixed at 0.3%.

The evaluation fire was ignited from 16:16:00 using a vehicle towing a small pile of burning fuel (Figure 4.5.4a). The fire quickly developed a narrow head under the influence of a north-northeasterly wind (Figure 4.5.4b). Unfortunately, the wind had more of an easterly influence after ignition, which pushed the fire into the western edge of the plot (Figures 4.5.2 and 4.5.4c). This limited the total length of flank that could be used for this evaluation.

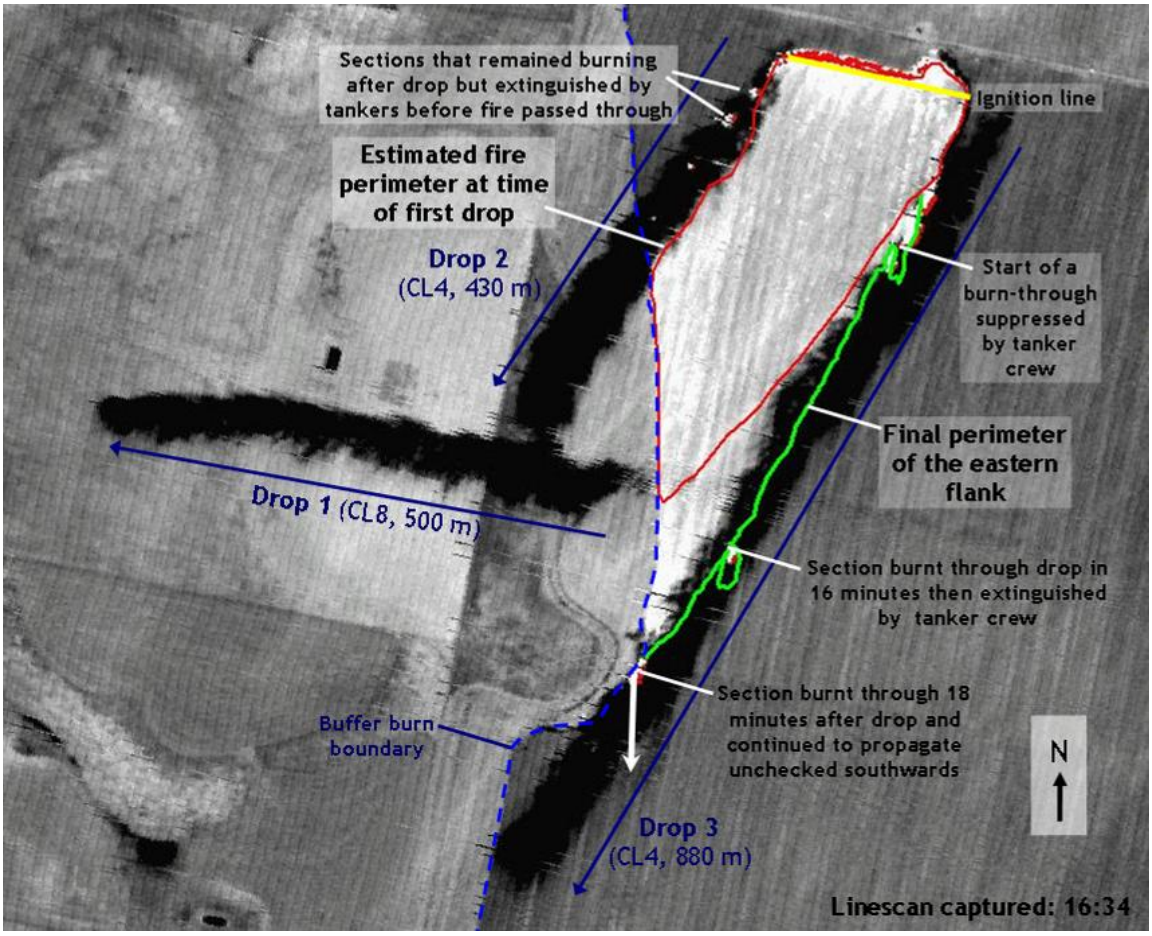
FIGURE 4.5.4. Development of the Streatham fire, (a) from the southwest during ignition, (b) from the south 5 minutes after ignition, and (c) 20 seconds before the first drop.



Head fire flame heights were generally 1–1.2 m, while those on the flanks did not exceed 0.5 m. The maximum rate of spread of the head fire was calculated to be 3.2 km/h. The intensity of the head fire was estimated to be between 2.8 and 5.7 MW/m (Byram 1959), assuming a heat of combustion of 16,000 kJ/kg (Cheney and Sullivan 2008) and fuel loads between 2 and 4 t/ha. The flank fires would have been less than half the intensity of the head.

Three drops were made during this mission. The first was placed near the head and the second and third were placed on the flanks (Figure 4.5.5). The flight log (Appendix 3) indicates that these were made at the requested coverage levels, and used 22,712, 4,418 and 15,142 L (6,000, 1,167 and 4,000 US gal) respectively. There was a small volume of foam left in the tank after this mission, which was dropped elsewhere. The nearest points in the tracking for these drops were between 22 and 36 seconds after the start of the drops, so could not be used to provide relevant flight information. The heights of the second and third drops were estimated to be 42 and 46 m (138 and 150 feet) using the image analysis method discussed in Section 2.2. A suitable image was not available for the first drop. The drops were estimated to be 500, 430, and 880 m long from the line-scan image (Figure 4.5.5). Both flank drops were made with a tail-wind and had forward momentum when hitting the ground.

FIGURE 4.5.5. Drop placement and fire perimeter at the Streatham mission (CL, coverage level).



The first drop was made at 16:23:41. This drop was late and missed the head fire completely (Figures 4.5.5 and 4.5.6). The suppressant load was not released until the aircraft was over the fire, and by this time, the forward momentum took the drop to the western side of the head fire. The drop timing is most likely attributable to flight crew error. The lead plane released a smoke trail starting well before the head fire (Figure 4.5.4d). Had Bomber 391 opened the tank doors at the start of the smoke trail, it would have hit the head directly.

The second drop was made at 16:27:48 along the western flank (Figure 4.5.7). Although it was 430 m long, only 240 m of this was on the fire edge, as by this stage, the head end of the flank had burnt into the previously burnt buffer (Figure 4.5.5). There was some billowing evident within this drop cloud (Figure 4.5.7). The drop directly covered this flank and extinguished nearly all flames. Two points at the rear of this flank remained alight after the drop (Figure 4.5.5). These were observed to spread 19 minutes after the drop. They were burning slowly along the drop axis under the influence of the north-northeasterly wind and did not burn outside the drop area before tanker crews had extinguished them.

The third drop occurred along the eastern flank at 16:30:09 (Figure 4.5.8). The entire 620 m of this flank were directly hit by the drop. This drop provided the best opportunity for evaluation during this mission. The drop cloud appeared to be fairly consistent, with less billowing than the previous drops (Figure 4.5.8). The fire behaviour on this flank had quieted just before this drop (Figure 4.5.8) as a result of the wind turning more to the east. The flank was nearly completely extinguished. Three small sections remained burning after the drop (Figure 4.5.5). The first of these was extinguished by a tanker crew before completely burning through the drop. The second took 16 minutes to burn completely through the fuels wet by the drop, and was then extinguished by a tanker crew (Figure 4.5.9). The third section was adjacent to the buffer burn at the most southerly section of the fire perimeter. This point continued to burn through wet fuels after 18 minutes, and then went on unchecked, quickly gaining speed as it burnt into unaffected fuels.

FIGURE 4.5.6. Placement of the first drop at Streatham.

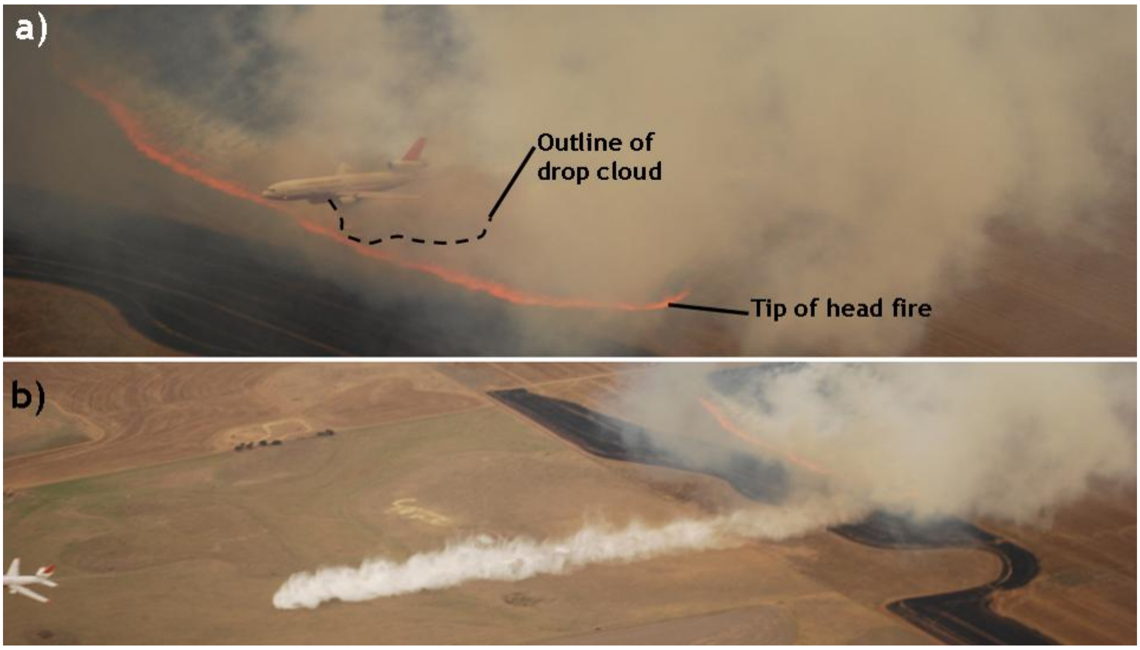
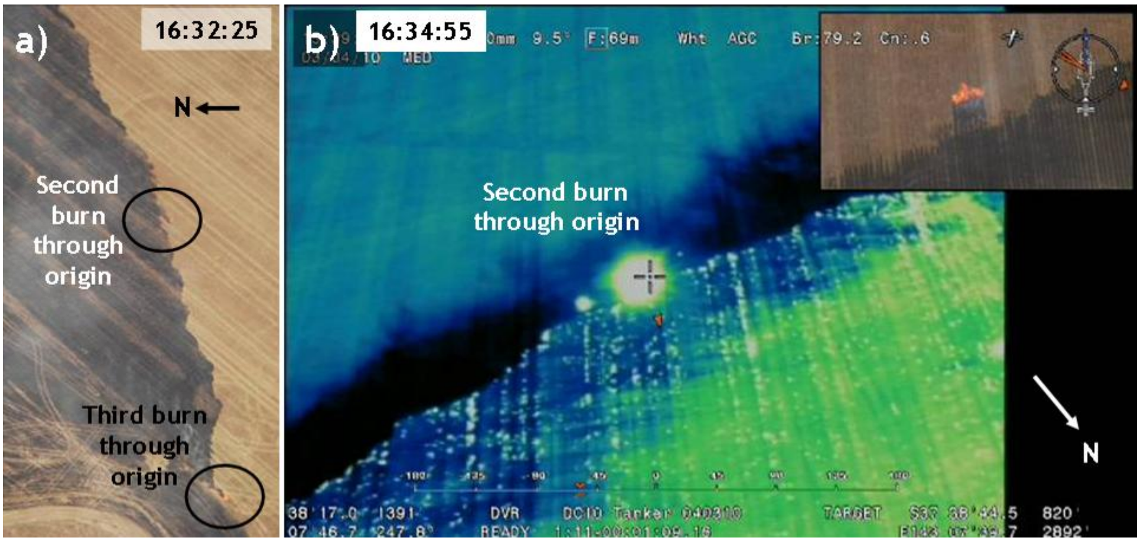


FIGURE 4.5.7. Placement and drop cloud of the second drop at Streatham: (a) from the southeast, (b) from the north, (c) from the east, and (d) 30 seconds after the drop from the east.

FIGURE 4.5.8. Placement and drop cloud of the third drop at Streatham viewed from the east (a), and west (b).

FIGURE 4.5.9. Fire burning into the third drop at Streatham 2 minutes after the drop (a), and 4.5 minutes after the drop (b) (screen capture from FLIR footage).



4.5.4) Discussion

Only the two flank drops from this mission are useful for analysis as the first drop did not impact the fire. The misplaced first drop prevented the evaluation of any direct attack drops on a head fire during this trial.

The flank fires were hit directly by the second and third drops. These drops were able to hold low-intensity fire for between 16 and 20 minutes. The drop hold times would be significantly shorter during extreme grassfire danger conditions as the fires would be more intense and weather conditions would cause the drops to evaporate quickly.

These drops extinguished flaming combustion along the majority of their lengths. The footprints for both of these drops appeared to have consistent coverage along their lengths (Figure 4.5.5). It is unlikely that the sections that remained flaming occurred in areas of low suppressant coverage.

If this air tanker is to be used for direct attack of grassfires, it could be used to reduce flame intensity on sections of flanks ahead of ground crews who would enter drop areas soon after to extinguish the residual flaming. This tactic is often used with firefighting aircraft in the existing Australian fleet. On typical grassfires, there would probably be more sections of residual flaming following drops. It would be more difficult for drops to be placed accurately with the associated strong winds.

The coverage levels from the two flank-fire drops were appropriate for the fire activity as they achieved a satisfactory result.

This fire generated only a moderate amount of smoke, which did not appear to limit the operation of Bomber 391. The presence of dense smoke would be likely to limit the safe application of direct attack drops on a head fire during wildfire suppression, as it does with other aircraft.

5) DISCUSSION

This evaluation was limited by the test conditions and the number of missions that could be conducted as discussed in Section 1.3. A further unforseen limitation for this evaluation was the inability to quantify the flight characteristics during drops. Flight characteristics could not be quantified because of the lack of a suitable logging device within Bomber 391. Data on flight characteristics would have enabled better comparisons to be made between drops and would have allowed flight characteristics to be checked against those requested and those specified in the operations program.

5.1) SATISFACTION OF AIMS

The ability of the six missions to provide an adequate evaluation of this air tanker requires the first of the three aims outlined in Section 1.2 to be satisfactorily addressed. The final aim of the research was to provide data for other aspects of the project; this final aim was an internal deliverable and is not reported separately here.

5.1.1) Effect on fire behaviour

The effects of drops on fire behaviour were determined for the single wildfire deployment and three planned missions.

The Werrimull wildfire drop was able to successfully halt 500 m of fire edge and directly extinguish a small spot fire within the drop area. This drop was made on a fire that was relatively mild as a result of light winds and discontinuous fuels.

Fire behaviour conditions were more challenging for the drop made during the Enfield mission. Although this drop was breached by spot fires before being reached by the fire edge, this mission still provides some insight into the interaction between a drop and a surface fire. The post-fire footprint (Figure 4.3.10) from this drop would be similar to the footprint remaining had there been not spotting and the drop burnt around by a surface fire. This footprint indicates the drop would have held nearly 400 m of fire edge, with one or two sections that would have burnt through. These burn-through sections would have required quick action from ground suppression resources for this drop to have adequately held a non-spotting fire. The difference between the post-fire drop footprint and drop footprint estimated visually prior to burning would suggest that the dimensions estimated for the Wombat Forest drop are exaggerated.

The breaching of the Enfield drop by spotting typifies the difficulty of fire suppression in dry stringybark eucalypt forests. This spotting would have easily breached any other sort of fuel break, such as a road or purposely constructed mineral-earth break. The breaching of this drop by spotting during these mild conditions is consistent with the findings of Loane and Gould (1986), who reported unsupported retardant drops in this type of vegetation being ineffective when fire intensities are greater than 2 MW/m because of spotting. The tactical role of a VLAT for suppressing fires in eucalypt forests requires further investigation.

The Shelford–Mount Mercer mission highlighted the effects of some serious deficiencies in the drop pattern quality from this air tanker. The moderately intense (3.2-6.7 MW/m) grassfires that impacted these drops easily burnt through numerous sections of light coverage. The drops had only a short-lived effect on slowing fire progression. Effective drop lengths were not determined for these drops as they had too many breach points to be of any use for line construction. This mission indicates that drops from this aircraft would be ineffective on the head of a grassfire.

The direct-attack foam drops made on the flanks of the fire during the Streatham mission were effective in extinguishing low-intensity flames and holding fire spread for up to 16 minutes. The holding time of these drops on higher-intensity fire is likely to be much shorter as the footprints would dry out more rapidly.

5.1.2) Drop characteristics

The retardant clouds from most of the drops conducted during this evaluation were uneven in their structure, with thin and thick sections alternating along much of the cloud length. This billowing characteristic (Figure 2.1b) resulted in areas of light and heavy coverage in the drop footprint. The sections of low coverage severely limited the effectiveness of some drops. It was most evident in the footprints of the drops made during the Avalon mission, where variations in coverage were clearly visible in the post-drop infrared imagery (Figure 4.2.6). This effect could not be seen in the line-scans for Shelford-Mount Mercer drops but was evident in the burn patterns. The cup grid testing undertaken for the DC-10 by the USFS identified similar inconsistencies within drop footprints. Some examples illustrating sections of light coverage during USFS grid tests are presented in Figure 5.1[2].

Billowing was least evident in the retardant cloud from the Wombat Forest drop. This drop reached terminal velocity before reaching the canopy level, probably as a result of the strong headwind and the adequate drop height. This drop appeared to have the highest quality footprint of all the drops, as it had the most consistent ground coverage along its length. The effective footprint of this drop could not be determined because the fuels around it were not burnt.

The most probable reason for billowing within the retardant cloud is the fast drop speed in combination with other design issues (H. Biggs, pers. comm.[3]). This aircraft is limited to dropping at air speeds from around 278 km/h (150 knots). Drops made at fast speeds also tend to be longer and have lower coverage levels than those made at slower speeds (e.g. Swanson *et al.* 1976). The ground effects from billowing are likely to be more evident for drops made with lower coverage level dial settings, as the weak points in these drops have lighter coverage than the weak points in higher coverage level drops, and are therefore more exposed to being burnt through.

The only available means of moderating the effects of drop speed is to increase height. When drops are made at greater heights, drop clouds are more likely lose forward momentum before reaching the ground and have a better opportunity for cloud inconsistencies to be mitigated. High drops are more exposed to drifting under the influence of wind and tend to be wider because of this (e.g. George and Blakely 1973, Swanson *et al.* 1976). Drop patterns from the DC-10 air tanker have not been investigated under strong wind conditions during this evaluation or the USFS cup grid testing (SDTDC unpublished 2006). The effects of drop height have been incorporated into drop pattern and dispersal models (e.g. Swanson *et al.* 1975, 1977, George and Johnson 1990, Amorim 2008). The effect of drop height on drop footprint characteristics could not be quantified for the missions described here because of the lack of a suitable logging device within Bomber 391.

Sections of light coverage were evident along the tail (heel) of drops. While tail sections of the drops appeared to have adequate coverage in photographs, in line-scans and infrared imagery capture prior to fire impact, they were found to be the weakest section of the drop. Drop tails were easily burnt through during the Enfield and Shelford–Mount Mercer missions. Light coverage in the tail sections of drops from this air tanker were also evident in the drop patterns determined from the USFS cup grid tests (see Figure 5.1).

Despite the issue of drops having variable coverage across their footprints, the two drops made in forest vegetation were found to have good penetration through the canopy onto surface fuels. These two sites had moderate canopies (projected foliage cover 35–45%) representative of many open *Eucalyptus* spp. forests across Australia. The ability of drops to penetrate denser canopies is not known.

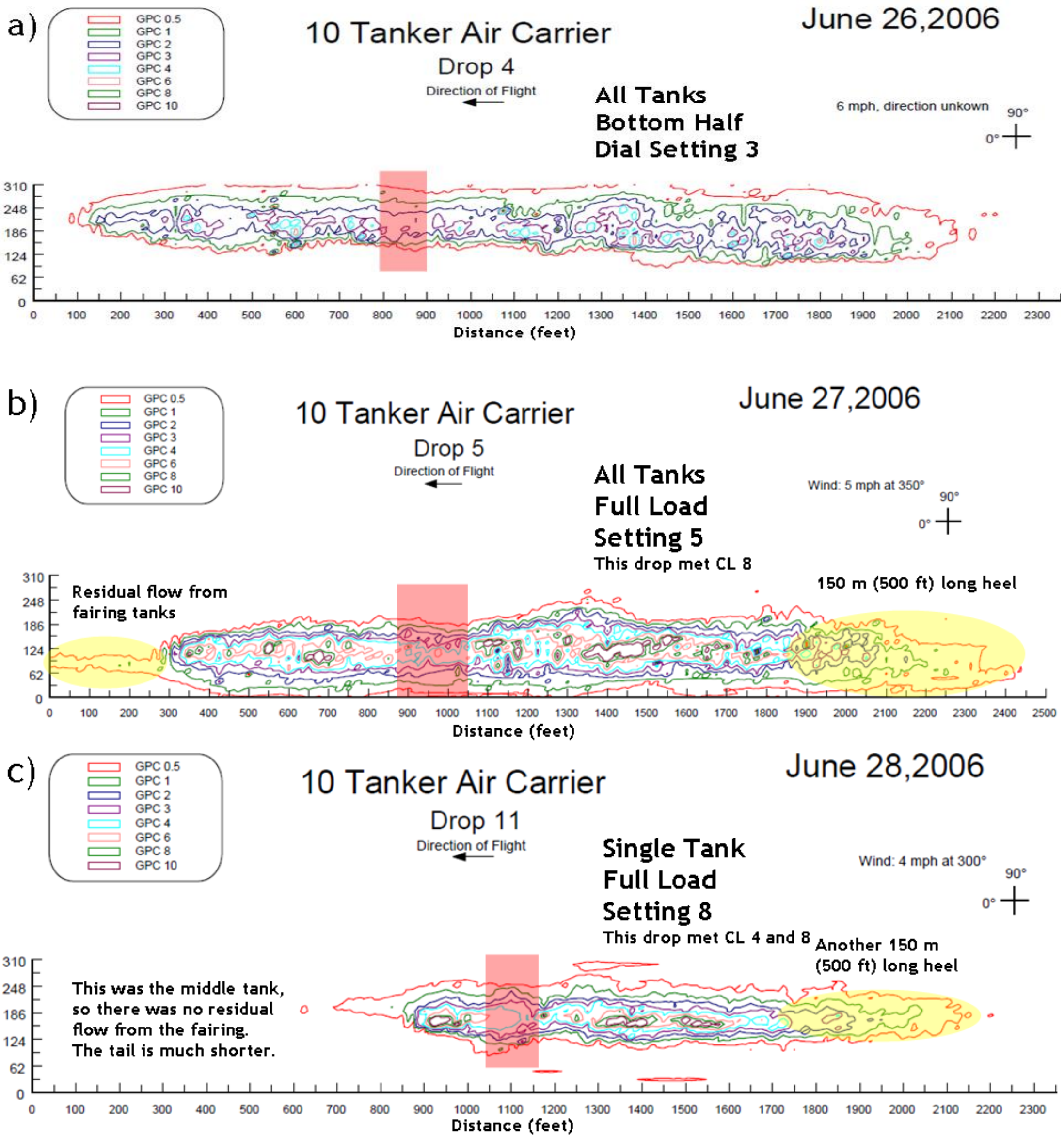
---

[2] Examples provided by Ryan Becker, San Dimas Technology and Development Center, USFS.

[3] Hayden Biggs, State Aircraft Unit of Victoria.

The retardant mixture observed on the ground for all drops appeared to be consistent and high quality. There was no evidence of variations in concentration or viscosity within or between drops.

FIGURE 5.1. Examples of inconsistent drop coverage within USFS cup grid drop patterns from drops numbered 4 (a), 5 (b) and 11 (c) (provided by Ryan Becker, SDTDC). The red highlighted sections show gaps in the line where maximum cross-section coverage level dropped to less than 50% of surrounding maxima. Flight characteristics for these drops are tabled in Appendix 1. GPC is the coverage level measured in US gallons per 100 square feet.



5.1.3) Ground safety issues

Damage resulting from drop impact was only detected during one drop during this evaluation. The damage from this drop was severe, would have required a significant amount of force and indicates that there is potential for drops to harm people and damage buildings. The most likely causal factor for the damage resulting from this drop was low drop height. The height of this drop cannot be determined because of the inability to quantify flight characteristics. Imagery from this drop indicates that it was low and probably below the height specified for this aircraft (Cox *et al.* 2009, Biggs 2010).

A study that used load cells to measure impact pressure from drops from Martin Mars air tankers (McCulloch and Mooney 2008) found that the amount of force from drops increases as drop height decreases. Their study did not find any relationship between impact force and coverage level. A number of house-shaped test structures were placed in the path of drops to estimate the impact that drops would have on buildings; however, none of them were damaged by the drops.

The minimum safe drop height for air tankers has been defined as the height at which the retardant begins to fall vertically (Lovellette 2000). This height is likely to be around 60 m (200 ft) above ground or canopy for the DC-10 (Cox *et al*. 2009, Biggs 2010), though it may vary with wind speed and direction. This height is greater than that for smaller aircraft because of the faster drop speed. Drops that are made at safe heights should not result in any damage. The damage incurred at the Enfield drop indicates that drops made below the specified safe drop height can occur and can cause significant damage. At the commencement of the Victorian trial, there was a strong desire to use this aircraft on fires in the urban interface if safe. Clearly, the possibility of the lack of adherence to the recommended drop heights and the proved potential for damage from low drops precludes a role in an urban interface situation. While outside of the scope of this evaluation, the human factor in the precision of the conduct of the drops is an important factor which should be considered particularly with respect to safety issues.

6) CONCLUSION

This evaluation was limited to six missions that occurred during relatively mild conditions.

The results from these evaluation missions indicate that there are often problems with the consistency of many drops from the DC-10 air tanker. In this context it is also important to note the lack of tracking data from the DC-10 was a considerable weakness in this evaluation and limited the ability for comparisons to be made between drops and to determine if drops were made within the correct flight conditions. Tracking data would have allowed flight characteristics to be determined and should be included in any subsequent air tanker evaluations.

Retardant and suppressant clouds for these drops contained alternating thin and thick sections along much of the cloud length. This was found to result in drop footprints that had corresponding sections of light and heavy coverage. This characteristic in the drop cloud is likely to be caused by the relatively fast speed of the aircraft when dropping in conjunction with the design of the delivery system. Sections of light coverage within drop footprints were found to be easily burnt through when challenged by fire. The presence of sections of light coverage that allow fire to easily pass across drop footprints indicates serious limitations in the effectiveness of drops from this air tanker.

One of the evaluation drops caused severe damage to trees. This drop was probably made at a height below the specified minimum drop height (60 m, 200 ft above canopy) for this aircraft. The impact of this drop could have injured people or damaged buildings underneath it. This drop illustrated the potential for severe consequences when specified flight parameters are not adhered to and demonstrates the need to remove people from areas where drops are being laid. A drop that was made at a height that allowed all forward momentum to cease before it passed into a forest canopy did not cause any detectable damage.

The two drops made in forest vegetation were found to have good penetration through a moderate canopy and provide an adequate coating of retardant onto surface fuels.

Direct attack foam drops made on the flanks of a low-intensity stubble fire were found to hold fire spread for 16 minutes.

REFERENCES

AFAC (1996) CL-415 evaluation report for fire bombing in Australia. Australasian Fire Authorities Council, Melbourne, Victoria.

Amorim JH (2008) Numerical modelling of the aerial drop of products for forest firefighting. PhD Thesis thesis, Departamento de Ambiente e Ordenamento. Universidade de Aveiro, Aveiro.190 pp.

Biggs H (2004a) The operation of the Hevilift Erickson 64 Heavy Helicopter in NRE firefighting operations in Victoria during season 1997/98. Department of Sustainability and Environment, Victoria, Research Report No. 72.

Biggs H (2004b) An evaluation of the performance of the Simplex 304 helicopter belly-tank [Fire Management Research Publication]. Department of Sustainability and Environment, Victoria; Research Report No. 71. 50 pp.

Biggs H (2010) Very large air tanker operational trial project, Approved draft operational program 2010, Version 1 draft 2 (February 2010). State Aircraft Unit, Victoria.

Blakely AD (1983) 'Monoammonium phosphate: effect on flammability of excelsior and pine needles.' USDA Forest Service, Research Paper INT-313, Intermountain Forest and Range Experiment Station, Odgen Utah.

Blakely AD, George CW, Johnson GM (1982) Static testing to evaluate airtanker delivery performance. USDA Forest Service, General Technical Report INT-78, Intermountain Forest and Range Experiment Station, Odgen, Utah.

Byram GM (1959) Combustion of forest fuels. In ‘Forest fire: control and use’. (Ed. KP Davis) pp. 61-89. (McGraw-Hill: New York)

Cheney NP, Sullivan A (2008) ‘Grassfires, fuel, weather and fire behaviour.’ (CSIRO Publishing: Collingwood, Vic.)

Cheney NP, Fenwick R, Hutchings PT, Nicholson AJ (1982) Aerial suppression of bushfires: assessment of MAFFS/Hercules operations. CSIRO Division of Forest Research, Canberra, ACT.

Cheney NP, Gould JS, Catchpole WR (1993) The influence of fuel, weather and fire shape variables on fire-spread in grasslands. *International Journal of Wildland Fire* **3**, 31–44.

Cox T, Bunce T, Graham M, Batteas F, Chen T, Klyde D, Sobczak J (2009) USFS Very Large Aerial Tanker Operational Test and Evaluation Summary Report delivered under Modification 2 to Interagency Agreement SAA2-402113 between NASA and the U.S. Forest Service, March 2, 2009. NASA and US Forest Service.

Cruz M.G., Matthews S, Gould J, Ellis P, Henderson M, Knight I, Watters J (2010) Fire dynamics in mallee-heath; fuel weather and fire behaviour prediction in South Australian semi-arid shrublands, Bushfire Cooperative Research Centre Technical Report, East Melbourne, Victoria.

Fisher S (2006) Proceedures and criteria for interagency airtanker board. National Interagency Fire Center, Boise, ID.

George CW (1981) Determining airtanker delivery performance using a simple slide chart-retardant coverage calculator. USDA Forest Service, General Technical Report INT-113, Intermountain Forest and Range Experiment Station, Ogden, Utah.

George CW (1985) An operational retardant effectiveness study. *Fire Management Notes* **46**(2), 18-23.

George CW (1990) An update on the Operational Retardant Effectiveness (ORE) program. In 'The Art and Science of Fire Management. Proceedings of the First Interior West Fire Council Annual Meeting and

Workshop'. (Eds ME Alexander and GF Bisgrove) pp. 114-122. (Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta, Information Report NOR-X-309)

George CW (1992) Improving the performance of fire-retardant delivery systems on fixed-wing aircraft. USDA Forest Service, Research Note INT-400, Intermountain Forest and Range Experiment Station, Ogden, Utah.

George CW, Blakely AD (1973) An evaluation of the drop characteristics and ground distribution patterns of forest fire retardants. USDA Forest Service, Research Paper INT-134, Intermountain Forest and Range Experiment Station, Ogden, Utah.

George CW, Fuchs FA (1991) Improving airtanker delivery performance. *Fire Management Notes* **52**(2), 30-37.

George CW, Johnson GM (1990) Developing air tanker performance guidelines. USDA Forest Service, Technical Report INT-268, Intermountain Research Station, Ogden, Utah.

George CW, Ewart GF, Friauf WC (1989) FLIR: A promising tool for air-attack supervisors. *Fire Management Notes* **50**(4), 26-29.

Gould JS, Khanna PK, Hutchings PT, Cheney NP, Raison RJ (2000) Assessment of the effectiveness and environmental risk of the use of retardants to assist in wildfire control in Victoria. Department of Natural Resources and Environment, Victoria, No. 50.

Gould, JS, McCaw WL, Cheney NP, Ellis PF, Matthews S (2007). Field guide – Fuel assessment and fire behaviour prediction in dry eucalypt forest. Ensis–CSIRO, Canberra ACT, and Department of Environment and Conservation, Perth, WA.

Hall JE, Hull JB, Johnson K, McKinney EH, Scott WB (2002) Blue Ribbon Panel Report to the Chief, USDA Forest Service and Director, USDI Bureau of Land Management. National Interagency Fire Center, Boise, Idaho

Hardy CE (1977) Chemicals for forest fire fighting, National Fire Protection Association, Report No. 79, Boston, Massachusetts.

Loane IT, Gould JS (1986) 'Aerial suppression of bushfires: cost–benefit study for Victoria.' (CSIRO Publishing)

Lovellette G (2000) Safe drop height for fixed-wing airtankers. USDA Forest Service, Technology and Development Program, Report No. 0057 2317, Missoula Technology and Development Center, Missoula, Montana.

Lovellette G (2004) How to conduct drop tests of aerial retardant delivery systems. USDA Forest Service, Technology and Development Program, Report No. 0457 2813, Missoula Technology and Development Center, Missoula, Montana.

Lovellette G (2005) How to conduct static tests of aerial retardant delivery systems. USDA Forest Service, Technology and Development Program, Report No. 0557 2812-MTDC, Missoula Technology and Development Center, Missoula, Montana.

Luke RH, McArthur AG (1978) 'Bushfires in Australia.' (Australian Government Publishing Service: Canberra, ACT)

Matthews, AG (1997) FIRESCAN: A technique for airborne infra-red mapping of wild fires. PhD Thesis, Department of Earth Sciences, Monash University, Melbourne.

McArthur AG (1966) Weather and grassland fire behaviour. Department of Natural Development, Forestry and Timber Bureau, Report Number 100, Canberra, ACT.

McArthur, AG (1967) Fire Behaviour in Eucalypt Forests. Commonwealth Department of National Development, Canberra, ACT 36 pp.

McArthur AG, Cheney NP, Barber J (1982) 'The fires of 12 February 1977 in the western district of Victoria.' (CSIRO Division of Forest Research, Canberra, and Country Fire Authority, Melbourne: Canberra, ACT)

McCarthy GJ, Tolhurst KG, Chatto K (1999) Overall fuel hazard guide, third edition. Victorian Department of Natural Resources and Environment, Fire Management Branch, Research Report Number 47, Melbourne, Victoria.

McCulloch W, Mooney C (2008) Martin Mars aerial delivery trials: May 2008. Contract Report CR-3611A-1 to Coulson Flying Tankers, FPInnovations, Feric, Vancouver, Canada.

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) 'Australian soil and land survey field handbook.' (Inkata Press: Melbourne, Vic.)

Noble IR, Bary GAV, Gill AM (1980) McArthur's fire-danger meters expressed as equations. *Australian Journal of Ecology* **5**, 201–203.

Ogilvie CJ, Liekovsky, RJ, Young, RW, Jaap, G (1995) An evaluation of forward-looking infrared equipped air attack. *Fire Management Notes* **55**, 17-20.

Pérez Y, Gould J, Pastor E, Planas E, Plucinski M (2009) Computing aerial suppression effectiveness by IR monitoring. In '6th Mediterranean Combustion Symposium'. Ajaccio, Corsica, France.

Plucinski M, McCarthy G, Gould J (2006) Aerial Suppression Experiment, Cambridge, Tasmania, 21–23 February 2005. Ensis Technical Report No. 153, Canberra, ACT.

Plucinski M, Gould J, McCarthy G, Hollis J (2007) The effectiveness and efficiency of aerial firefighting in Australia, Part 1. Bushfire CRC, Technical Report A0701, Melbourne, Vic.

Plucinski MP, McCarthy GJ, Hollis JJ, Gould JS (2008) Factors influencing the success of initial attack of bushfires in Australia using aircraft. In proceedings of 'Fire, Environment and Society: from research into practice, International Bushfire Research Conference incorporating the 15th AFAC conference', Adelaide Convention Centre, 1-3 September 2008, pp. 341–348.

Plucinski M, Cruz M, Gould J, Pastor E, Perez Y, Planas E, McCarthy G (2010) Project FuSE Aerial Suppression experiments. Bushfire Cooperative Research Centre Technical Report, East Melbourne, Victoria.

Rawson R, Rees B, Stuckey E, Turner D, Wood C, Woodman M (1982) Project MAFFS/Hercules - The Modular Airborne Fire Fighting System in Victoria. Forests Commission Victoria, Fire Research Branch, Research Report No.15, Melbourne Victoria.

Rawson RP, Billing PR, Duncan SF (1983) The 1982–83 forest fires in Victoria. *Australian Forestry* **46**(3), 163–172.

SDTDC (unpublished 2006) USDA Forest Service airtanker drop test report, 10 Tanker Air Carrier DC-10 Tanker 910. Available from Aviation Program Leader, San Dimas Technology and Development Center, San Dimas, California.

SDTDC (unpublished 2009) USDA Forest Service aerial delivery static test report, 10 Tanker Air Carrier DC-10 Tanker 910 and conformance test results for tanker 911, May 19, 2009. Available from Aviation Program Leader, San Dimas Technology and Development Center. San Dimas, California.

Sullivan AL (2010) Grassland fire management in future climate. *Advances in Agronomy* 106, 173–208.

Suter A (2000) Drop testing airtankers: a discussion of the cup-and-grid method. USDA Forest Service, Report No. 0057-2868-MTDC, Technology & Development Program, Missoula, Montana.

Suter A (2002) Estimating methods, variability, and sampling for drop-test Data. USDA Forest Service, Missoula Technology and Development Center, Report No. 0257 2826, Missoula, Montana.

Swanson DH, Luedecke AD, Helvig TN, Parduhn FJ (1975) Development of user guidelines for selected retardant aircraft. Honeywell Contract 26-3332 to Intermountain Forest and Range Experiment Station.

Swanson DH, George CW, Luedecke AD (1976) Air tanker performance guides: general instruction manual. USDA Forest Service, General Technical Report INT-27, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Swanson DH, Luedecke AD, Helvig TN, Parduhn FJ (1977) 'Supplement to: Development of user guidelines for selected retardant aircraft. Honeywell contract 26-3332 to Intermountain Forest and Range Experiment Station.

Tolhurst K, Egan J, Duff T (2008) A review of the effect of farming practices including continuous cropping, minimal tillage and direct drilling, on bushfire risk and prevention. Technical Report prepared for the South Australian Minister for Emergency Services University of Melbourne and Bushfire CRC, Creswick, Victoria.

Zajkowski T, Hinkley E, Queen L, VanBuren D (2008) Infrared field users' guide and vendor listings USDA, Forest Service - Engineering, Remote Sensing Applications Center, Report No. RSAC-1309-RPT4.

APPENDIX 1: SUMMARY OF US FOREST SERVICE DROP DATA

TABLE A.1. Summary of drops undertaken during the 2006 USFS cup grid testing (SDTDC unpublished 2006).

Drop Number	Coverage level dial setting	Volume (L)	Tanks	Measured flow rate (L/s)	Height start (m (ft))	Height end (m (ft)))	Ground speed (km/h (kts))	Wind speed (km/h (kts))	Wind direction (°)#	Total line length (m)* at or above coverage level number (GPC)				
										2	4	6	8	10
1	4	39,864	All	4,387	50 (165)	62 (205)	276 (149)	4.8 (2.6)	110	686	351	122	19	4
2	4	36,359	All	4,304	65 (214)	105 (343)	272 (147)	6.4 (3.5)	30	621	320	175	76	42
3	2	20,827	All	*1,893*	60 (198)	73 (241)	263 (142)	12.9 (7.0)		472	73	8	0	0
4	3	20,903	All	*2,953*	66 (215)	86 (283)	274 (148)	9.7 (5.2)		537	118	30	8	0
5	5	40,765	All	*6,549*	68 (223)	91 (299)	272 (147)	8.0 (4.3)	350	545	488	396	225	137
6	5	14,975	Tank 2	2,377	72 (236)	91 (299)	261 (141)	12.9 (7.0)	0	457	152	34	12	4
7	4	19,801	All	4,482	52 (169)	73 (241)	259 (140)	9.7 (5.2)	20	370	312	198	99	34
8	5	19,222	All	5,360	69 (227)	91 (300)	228 (123)	37.0 (20.0)	15	305	221	137	80	27
9	4	11,735	Tank 3	1,283	46 (150)	45 (147)	259 (140)	3.2 (1.7)	45	541	76	15	0	0
10	6	12,272	Tank 1	2,366	53 (174)	66 (217)	272 (147)	4.8 (2.6)	320	373	179	69	42	8
11	8	15,198	Tank 2	3,861	54 (177)	55 (182)	257 (139)	6.4 (3.5)	300	316	248	172	114	69
12	5	18,700	All	7,090	85 (280)	94 (307)	272 (147)	8.0 (4.3)	320	347	259	168	84	27
13	7	18,897	All	7,896	94 (307)	90 (294)	278 (150)	8.0 (4.3)	20	286	202	137	88	50
14	8	37,502	All	11,477	136 (445)	174 (570)	257 (139)	14.5 (7.8)	330	339	263	164	95	38
15	8	7,336	Tank 2	4,898	57 (186)	52 (171)	269 (145)	8.0 (4.3)	110	198	118	73	23	15
16	6	13,457	Tanks 2&3	4,630	62 (202)	62 (202)	283 (153)	8.0 (4.3)	30	290	164	107	73	34
17	4	19,968	All	5,175	89 (291)	94 (307)	282 (152)	11.3 (6.1)	110	381	229	73	27	8
18	7	20,051	All	8,154	131 (431)	141 (461)	293 (158)	12.9 (7.0)	110	236	168	91	27	0

Where 0° is a direct headwind and 180° is a direct tailwind.

* Sum of total line above coverage level (not just continuous line)

APPENDIX 2: OPERATIONAL DATA COLLECTION NOTES

BACKGROUND

The Victorian government are trialling a Very Large Air Tanker (VLAT) during the 2009–10 fire season. A DC-10 converted for fire suppression has been contracted for an operational trial. The aircraft has been given the call sign 'Bomber 391' and is operating from Avalon Airport.

A major part of the VLAT trial is to evaluate its effectiveness during suppression operations on wildfires. The main aims for the evaluation of operational effectiveness are to:

1) determine the effect of drops on fire behaviour;
2) define the drop characteristics, including the drop pattern under canopy; and
3) identify any safety issues in drop areas.

These aims will be achieved through the evaluation of planned and operational drops. Two planned drops were conducted in January 2010 to specifically address the second and third aims. The first (and most important) aim can only be assessed on drops made on fires. Operational drops will be evaluated using a variety of methods including ground assessment and analysis of line-scan, airborne infrared and video imagery.

This document details information required for conducting ground-based assessments of Bomber 391's drops on operational wildfires.

EVALUATION METHODS

Three data collection forms will be used to guide the collection of data during ground evaluation. The main form for data collection (VLAT Operational Drop Ground Assessment form) provides a means for recording details of the main data fields for the evaluation. The other two forms are designed to provide a log of photographs and waypoints. The full forms are included as Attachments 1–3 here and are explained below. Each data sheet is two-sided and should be printed on a single page.

Equipment

The main instruments required for data collection are a digital camera and a hand-held GPS (Global Positioning System) unit.

Digital photographs will be used to provide evidence for a number of issues. These are listed on the photograph log data sheet. For each drop, a photograph of the GPS with the time showing should be taken to allow for the exact location of each photograph (even when using a GPS-enabled camera). The exact time (to the nearest second) should be recorded for the photograph in the photograph log. Where relevant, scale references should be used in photographs. This may be as simple as asking someone to stand in a photo to provide a reference point. All photographs should be downloaded and saved as soon as possible. They should also be forwarded to the VLAT evaluation team as soon as possible.

A GPS should be switched on and set to log a track (bread-crumb) file with frequent points for the duration of each evaluation. Waypoints will be used to identify specific sections of tracks and points of interest. These will be logged on the waypoint log sheet. All drops and fire boundaries near drops should be mapped using GPS track files. It will only be possible to map retardant drops, as other drop agents are difficult to distinguish soon after drops. Retardant drops should be mapped by walking around the perimeter with a logging GPS. The GPS should be used to log a track where retardant is covering 50% of the ground (litter) fuels. Burnt edges should be mapped by walking the edge of the fire near or within the drop footprint. All GPS waypoint and track files should be downloaded at the earliest convenience and sent on to the VLAT evaluation team.

Those conducting operational drop evaluations should be familiar with and may carry reference material, such as fuel hazard guides, and projected foliage cover diagrams. Either the Victorian fuel hazard guide (McCarthy *et al*. 1999) or the Project Vesta field guide (Gould *et al*. 2007) should be used for assessing fuels. Photographs should be taken to support fuel assessments.

When estimating the projected foliage cover above drops, the reference diagram given in Attachment 4 should be used.

VLAT Operational Drop Ground Assessment form

This form is attached as Attachment 1. One or more copies of this form should be filled for all operational drops. Additional data sheets should be attached to the first of these. Additional copies of this form are to be filled when multiple transects are used to compare differences in fire behaviour in the three survey zones (defined below), or when more than one interview is undertaken.

Sections of the form are explained here:

General Information

Data collectors: names of data collectors.

Contact details: contact details for data collectors.

Sheet #: order and number of copies of this form filled.

Fire name and ID: name and number of fire used on official records.

Drop date & time: date and (24-h) time VLAT drop was made.

Eval. date & time: date and (24-h) time that VLAT evaluation was conducted.

Agent: circle the relevant suppression agent used in drop; W = water, F = foam, R = retardant, G = gel.

Direct/Indirect: indicate whether the drop was direct (on or immediately adjacent to fire).

Photo log: number of pages of the photograph log sheet that are filled.

Waypoint log: number of pages of the GPS waypoint log sheet that are filled.

Slope: estimated slope (degrees).

Aspect: aspect given as a bearing (degrees).

Elevation: in metres above sea level.

Drop site sketch

Provide a sketch of the drop site, indicating the shape of the drop and areas that are burnt and not burnt. Include a north point, show the relative locations of key waypoints, evaluation transects and any relevant ground suppression locations.

Fuel and vegetation

This section needs to be completed at least once for each VLAT drop. If there are differences in fuel across the drop, then a fuel assessment should be completed for each distinct fuel type. Fuel hazard should be assessed in areas with unburned fuels representative of the site. Supporting photographs should be taken to illustrate vegetation and fuel layers.

Fuel hazard scores and heights: give average fuel hazard scores for the whole area for all fuel layers. List the average heights for all fuel layers and depth for litter fuels. If there are differences in fuel hazard across the site, indicate average fuel hazard conditions for each and show locations on site sketch. This field is not relevant for grassland sites.

Tree height: estimate the height of canopy trees (m) where possible.

Projected foliage cover: estimate of the projected foliage cover for the site, or sections of the site. Use the diagram in Attachment 4 to assist with estimates and take example photographs.

Grassland curing: estimate the % curing in grass fuels, accounting for any green weeds throughout the profile. Take supporting photographs.

Pasture type and condition: (for grassland sites only) describe the grass type as natural, improved, grazed/ungrazed, crop and type, stubble, etc. Take supporting photographs.

Additional fuel and vegetation information: give any extra relevant information about fuels and vegetation that is not covered, such as species, time since last fire.

Drop area comparison

Drop area comparisons should be made as a number of transects across the drop. Transect locations should be picked based on differences in fire behaviour, fuel or suppression intervention, with at least one transect completed for each combination of these. The general location of each transect should be entered in the top left corner of the drop area comparison table. This is best given as a waypoint.

Each transect should include a sample taken in an area burnt by the fire before the drop (approach side), within the drop area, and in an area burnt after the fire has burned through or around the drop (departure side) if the drop has not held the fire.

Attachment 1: VLAT operational drop ground assessment form (first page)

bushfire CRC

VLAT operational drop ground assessment form

Data collectors:		
Contact details:		**Sheet #:** /
Fire Name & Id:		
Drop date& time: / /	**Eval. Date & time:** / /	
Agent: W / F / R / G	**Photo log:**	**Waypoint log:**
Slope: °	**Aspect:** °	**Elevation:** m ASL

Drop site sketch *(include N point, key waypoints, drop boundary, burnt boundary, evaluation transects)*

FUEL AND VEGETATION

From burnt sections with representative fuels, add waypoint for sites in waypoint list

Fuel layer	Fuel hazard score	Height	Tree height(m):
Bark			
Elevated fuel layer		m	Projected foliage cover across site(s):
Near-surface fuel layer		m	
Surface fuel layer		depth cm	

Grass curing: %	**Pasture type & condition:**
Additional fuel information:	

VLAT operational drop ground assessment form (second page)

DROP AREA COMPARISON

Do this for a number of transects along the drop length if there are differences in fuels or fire behaviour

Transect location:	Post fire assessment locations (Defined according to direction of fire spread)		
	Approach side	**Drop zone**	**Departure side**
Fuel layers burnt (circle):	Surface, N. Surf., Elev., Canopy, Bark, Log	Surface, N. Surf., Elev., Canopy, Bark, Log	Surface, N. Surf., Elev., Canopy, Bark, Log
Surface/ grass % burnt:			
Leaf cons. height:	m	m	m
Leaf scorch height:	m	m	m
Bark burn height:	m	m	m
Fire direction (from leaf freeze):	°	°	°

Drop pattern burn description:

Reason for fire passing through or stopping at drop zone (if can be determined):

DETAILS OF OTHER SUPPRESSION

Evidence of ground suppression (circle):	Tanker / hand crew / dozer / not present / unknown
Location with respect to drop area: *(also show on drop site sketch)*	
Ground Suppression Interview:	**Role(s)/ call sign:**

Name(s), agency & contact(s):

Timing, access & locations:

Fire behaviour:

Resources and personnel:

Tactics:

Other relevant observations and information (Photos):

Attachment 2: Photo log

Photo log

This sheet is designed to log photographs taken during operational VLAT drop evaluations
Key topics for photos should include: Fuel assessment; foliage cover, drop coverage, site panorama, and fire severity in key locations (for drop area comparison – see ground assessment form).

Start date & time:	/ /	Fire name/ location:			
Name:		Camera:		Downloaded?:	

GPS calibration photo:	Take a photograph of the GPS being used for the site evaluation so that the time can be synchronised with the track file. Fill in the exact time displayed on the GPS here.		
Time displayed on GPS: (hh:mm:ss)		Photo filename:	

Photo filename	Time	Description/ subject	Bearing

Continued over page

Attachment 3: Waypoint log

Way point log

Date:	/ /	Start time:		General location/ subject:	
Name:		GPS:		Downloaded?:	

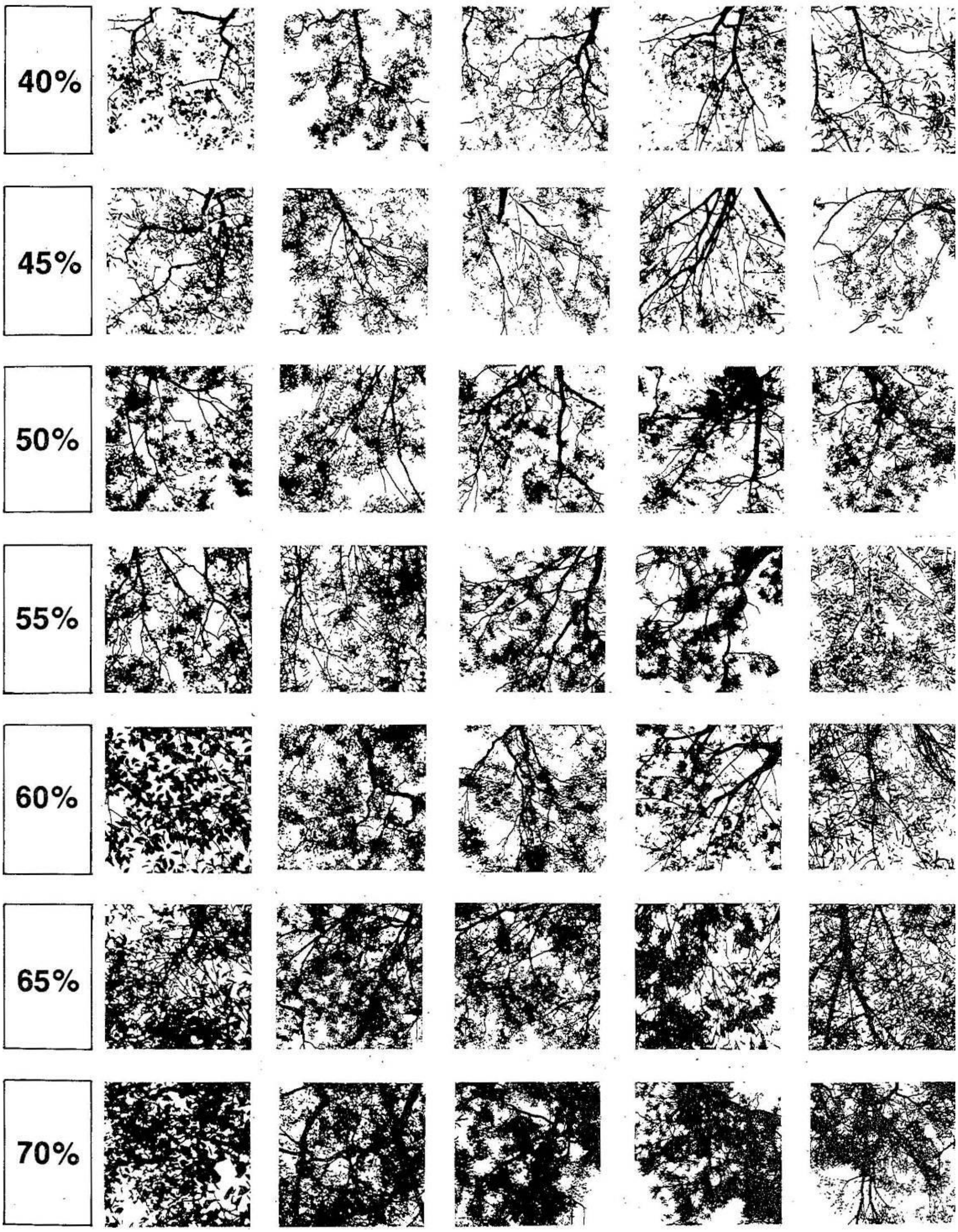
This sheet is designed to log waypoints taken during operational VLAT drop evaluations Waypoints should be taken at all key points where fuel; foliage cover, and fire severity assessments are made. Points of interest, such as spot fires, gaps and areas of low or high coverage should be marked. Waypoints should be given (and labelled) at the start and end of all tracks used to mark drop and fire boundaries.

Waypoint	Position *Only required if can't be downloaded*	Description/ comments

Continued over page

Attachment 4: Projected foliage cover diagram

This diagram is to be used as a guide to assist with estimating foliage cover. These diagrams are for crown cover and do not account for gaps between crowns. Gaps between crowns should be incorporated into assessments done for the VLAT trial.



The rows show similar crown types for different leaf sizes (large to small, left to right)

Figure from: McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) 'Australian soil and land survey field handbook.' (Inkata Press: Melbourne)

APPENDIX 3: MISSION DATA FROM BOMBER 391 LOG BOOK

Date	Product	Load size (L)	Coverage level (GPC)	Split load (yes/no)	Split load volume (L)	Drop height (m (ft)) above ground level	Log page
29 Jan	Retardant	42,578	8	No		90 (300)	41430-1
30 Jan	Retardant	43,407	4	Yes	18,927	60 (200)	41431-1
			4		17,034	60 (200)	
			3		7,446	60 (200)	
31 Jan	Retardant	42,215	6	No		60 (200)	41433-1
3 Mar	Retardant	42,234	8	No		60 (200)	41448-1
3 Mar	Retardant	41,901	4	Yes	18,927	60 (200)	41448-2
			6		22,974	60 (200)	
4 Mar	Foam	42,272	8	Yes	22,712	60 (200)	41251-1
			8		15,142	60 (200)	
			4		4,418	60 (200)	