FOREST AND RURAL FIRE RESEARCH

Fire Technology Transfer Note

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Firebombing effectiveness - where to from here?

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Introduction

Aircraft have been used for firefighting in New Zealand since the 1940s. However, at some recent wildfires their effectiveness has been the subject of debate. During the 1995 Berwick Fire[1], a spot fire burnt a 1200 metre swath through an area of continuous plantation forest fuels before running into pasture. Despite aerial attack (by two helicopters) within minutes of ignition, this fire developed rapidly into a crown fire. While this failure may have been due to the head fire being too intense and uncontrollable, many aerial drops were not effective on less intensely burning sectors of the fire. This was attributed to the application of inadequate mix-ratios of retardant or suppressant, although failures were more noticeable in areas with dense canopies.

This type of experience is not limited to forest fuels. Aerial suppression at the 1993 Turangi Wetlands Fire[2] was considered to be effective by the personnel involved. However, video footage showed numerous marks from drops within the burnt out area, indicating that many were ineffective. This was probably due to drops being placed where the fire behaviour was too extreme and because difficult access limited the ability of ground crews to reach and secure bombed areas. The experiences of the Berwick and Turangi wildfires highlight the need to improve our knowledge and understanding of how to use aircraft for fire suppression.

In *Fire Technology Transfer Note* (FTTN) 8[3], the cost-effectiveness (measured in terms of the amount and cost of water delivered to the fireline) of some commonly available rotor and fixed-wing aircraft was compared. The aim of this FTTN is to extend this discussion by considering some of the technical factors that influence the impact of individual drops during the suppression of actively spreading fires (i.e, knockdown). While many

[1] The Berwick Forest Fire burnt an area of 250 ha, including 181 ha of mixed species plantation forest (Fogarty *et al*, in press). Weather and FWI conditions were 33 km/h wind speed, FFMC 98.6, ISI 73.1, BUI 63, and FWI 87.9.

[2] The Turangi Wetlands Fire burned an area of internationally significant wetland that was a habitat for a number of endangered and threatened bird species. Burning conditions were 17 km/h wind speed, FFMC 84, ISI 4, BUI 14, and FWI 6 (Turangi Wetlands fire debrief, 4 December 1993).

[3] "Comparison of the cost-effectiveness of some aircraft used for fire suppression" (Fogarty and Smart 1996).

factors influence the effectiveness of aircraft operations, the better quantification of the drop characteristics required to knockdown fires in a range of fuel and fire danger conditions is an essential first step in defining the performance measures needed to develop guidelines on how to select aircraft types, delivery systems (e.g., bucket design) and flight characteristics (e.g., height and speed) for effective firebombing.

Water, Foam and Retardants

In any discussion of firebombing, it is necessary to understand the properties and uses of different agents (e.g., water, or water and chemical additives) used for fire suppression. Water has remarkable cooling properties, but its high surface tension results in a limited ability to coat and wet fuel. This also means that water drains rapidly through the fuel-bed, so only a small proportion of an aerial drop may impact on the fire. Water is also transparent, enabling radiant energy to heat, dry and ignite fuel particles (Stechishen and Murray 1988). To overcome these problems, suppressants (i.e., foam) and retardants are used to enhance the ability of *water-based firebreaks* to contain fire spread.

Foam is a mixture of water, air and foam concentrate. The combination of water and foam concentrate is termed the *solution*, and when air is added, *foam* is formed. The properties of foam concentrate largely relate to two chemical agents, these are:

- a *wetting agent* which reduces the surface tension, increases the ability of water to spread through and over the fuel and penetrate into the fuel particle itself; and
- a *stabiliser* which slows the rate at which foam bubbles break down, thus reducing the rate of water evaporation and drainage and increasing coating of the fuel (Vandersall 1989).

The factors which most influence the type of foam (i.e., whether the foam is wet, fluid or dry[4]) are the mix-ratio (i.e., the amount of foam concentrate to water) and the expansion ratio (i.e., the amount of air to foam). To generate different foam types, the relative amount of foam concentrate in foam solution (i.e., mix-ratio) and amount of air forced into the solution (i.e., the expansion ratio) needs to be varied. When being delivered by aircraft, the suggested mix-ratios to generate wet, fluid and dry foams are 0.3%, 0.5% and 0.8 to 1%, respectively (NWGC 1995). While it is possible to generate a dry foam using a lower mix-ratio than suggested, the stability of the bubbles will be low because stability (and drainage rate) is influenced more by the amount of stabiliser present than the amount of air captured in the bubble aggregate (Stechishen and Murray 1988).

Each of the three foam types utilises the wetting and stabilising properties of foam to a greater or lesser extent and their subsequent uses are different. For example, a dry foam traps large volumes of air, enabling it to coat and adhere well to fuel particles. However, dry foam has less ability to penetrate the fuel-bed than wet foam and the rate at which the solution drops out of the foam mass and onto fuel particles is slow (i.e, it has a slow drainage rate). Dry foam is used to protect flammable assets such as wooden structures and when used for fire suppression, dry foams may provide the best protection for tree or scrub canopies (NWCG 1992). However, if a dense canopy and understorey prevents dry foam from penetrating to surface fuels, the prior application of a fluid foam may be needed to contain fire spread (Alexander *et al.* 1989).

Fluid foam flows readily through elevated fuels, but still holds water in a bubble structure. This enables it to coat and penetrate fuel particles, but for a shorter time period than dry foam. As well as being useful for penetrating dense canopies, fluid foams are used for suppression of fires burning in grass and other open fine fuels (NWCG 1992).

Wet foam flows readily and penetrates rapidly. NWCG (1992) suggest that it is useful for mopping up ground fires and penetrating very dense scrub or forest canopies, whereas Alexander *et al.* (1989) state that when ground follow-up is available, it should be used to knockdown fires spreading in open fuels (e.g., grass or logging slash). Whatever the application, users need to be aware that the effects of wet foam are short lived.

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[4] Wet - watery, runny, no body, bubble size varies, more water than air, fast draining.
Fluid - watery shaving cream, does not hold peaks, medium to small bubbles, flows readily, moderate drainage rates.
Dry - shaving cream, holds peaks for a long time, mostly air, very "dry" and fluffy, slow draining (NWCG. 1995).

From the review of foam properties, it is possible to suggest that when it is applied for knockdown, it is best placed in unburnt fuels ahead of the fire. This allows the foam to penetrate the fuel-bed and wet the fuel particles before the fire reaches the drop (Vandersall 1989). However, unless high mix-ratios are used (say 1 to 1.5%), between 40 and 80% of the foam breaks down within the 2 to 5 minutes of being generated (Stechishen and Murray 1988). Therefore, the available theory suggests that while it is best to drop away from the flaming zone, the drop should not be placed so far ahead of the fire that foam breaks down and drains away before the fire reaches it[5].

Retardants are a mixture of water and chemicals (e.g., Diammonium phosphate) which physically coat the fuel. While foam allows water to better "wet" the fuel, the impact of water in a retardant drop is secondary to the ability of the retardant to render the fuel particles unavailable for combustion. Water is primarily used to spread the retardant over the fuel particles and, drops should be placed in unburnt fuels ahead of the fire.

Depending on conditions, foam will suppress ignition for 5 to 30 minutes, while retardant produces a firebreak that can remain effective for several days in the absence of rain. If the break is being constructed in an area with difficult access and/or ground crews are not expected to reach the fire before it re-ignites after a foam drop, then retardants should be used instead of foam. If inadequate knockdown and re-ignition remain a problem, drops being placed in areas where the fire is too intense is the most likely cause. However, recent trials *suggest* that a mixture of "wet" foam with retardant, combines the ability of foam to knockdown a fire with retardant and can be more effective than when they are used independently (Rawet *et al* 1996).

Factors influencing drop effectiveness

Fires can burn in sub-surface fuels such as peat or duff (ground fires), understorey litter and scrub (surface fires), and the leaves, twigs and debris that make up the overstorey (crown fires). Of these, surface fires are undoubtedly the most common, and the combustion of surface fuels is generally required for a fire to spread over long distances (Brown and Davis 1973). To contain fire spread with a water-based firebreak, a drop needs to reach surface fuels in sufficient volumes and over a wide enough area to prevent the fire from burning under through or over it. In scrub fuels, it is necessary to wet the whole fuel bed, so that dry elevated or surface fuels do not provide an avenue through the drop.

A discussion of the factors that influence drop effectiveness is assisted by viewing firebombing as a progression from when the drop leaves the aircraft through to when it is tested by the fire. Figure 1 starts with the drop distribution or "footprint" that results when a drop is conducted in the open (*bare ground pattern*), which is then adjusted to incorporate canopy interception and influences from the type of water-based firebreak being used (*actual firebreak characteristics*). The firebreak and fire behaviour characteristics influence how effective the actual drop pattern will be at preventing fire spread (*critical firebreak effectiveness*). These three elements of aerial drop effectiveness and the main factors that influence them are reviewed below.

Bare ground pattern

The factors that influence the bare ground pattern are flight features (speed and height), wind speed and direction, the geometry and flow rate of the bucket (or gate system), and additive properties. Increasing drop height widens the drop, while increasing aircraft speed will lengthen it (Campbell 1959, George 1975). When foam is being used, an increase in the height and ground speed of the drop will induce greater aeration and produce a drier foam than a low and slow drop. Wind speed and direction influence the bare ground pattern but their influence has not been quantified. In general, increasing wind speed will cause greater aeration of foam, and wind direction will lengthen or widen the drop depending on whether it is blowing parallel to or across the drop.

Additive properties also influence the bare ground pattern. For example, it is possible to produce wet and dry foam from the same volume of foam solution (e.g., a 250 litre bucket), but a wet foam with an expansion ratio of 5:1 will form a shallower layer of foam over a given area than a dry foam with a 15:1 expansion ratio. This is also apparent when a wet foam drop is compared with a water drop delivered from similar heights and speeds, as can be seen in Figure 2.

[5] Practice often differs from theory, and drop are usually placed on the flaming zone. This will be discussed in a future FTTN.

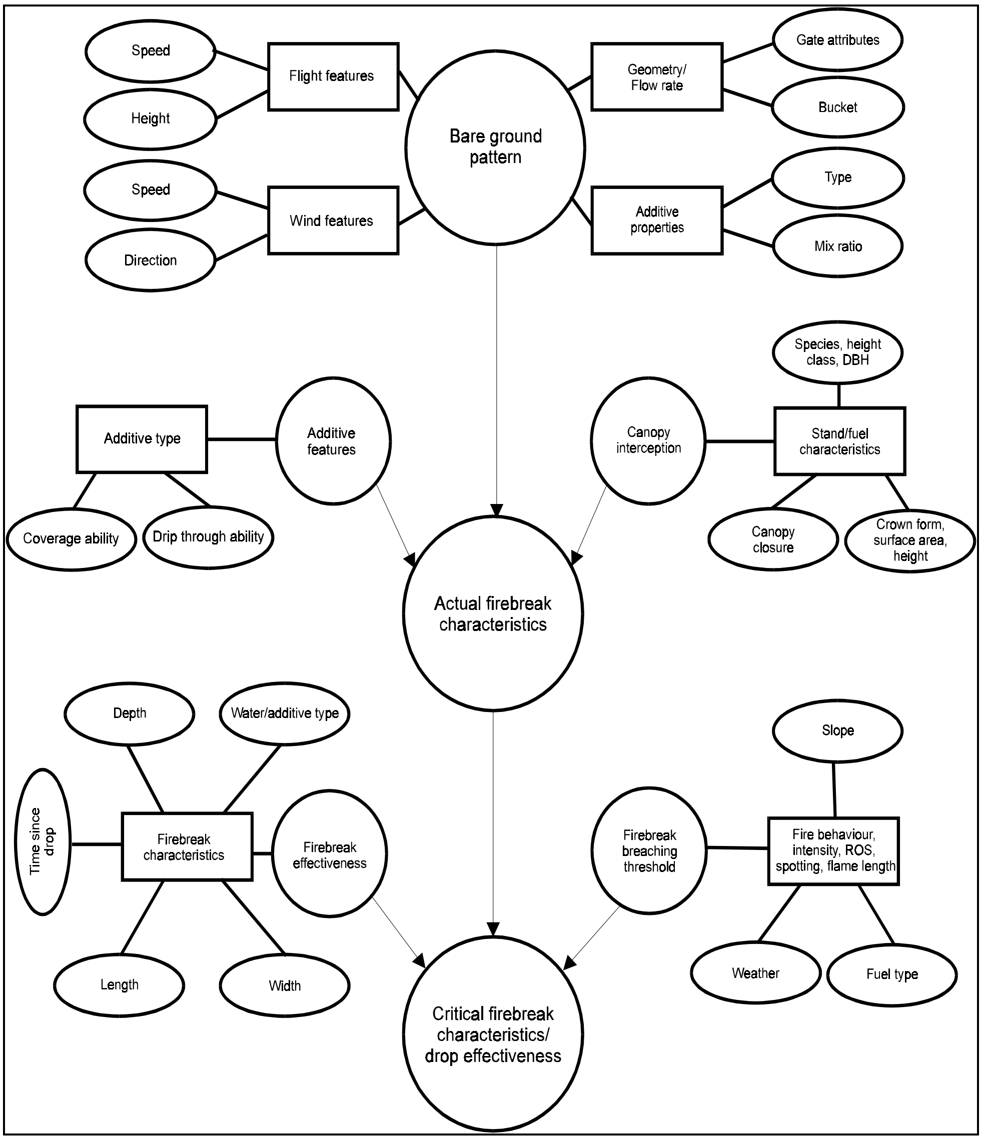

Figure 1. Factors contributing to aerial drop effectiveness (adapted from Hardy 1976).

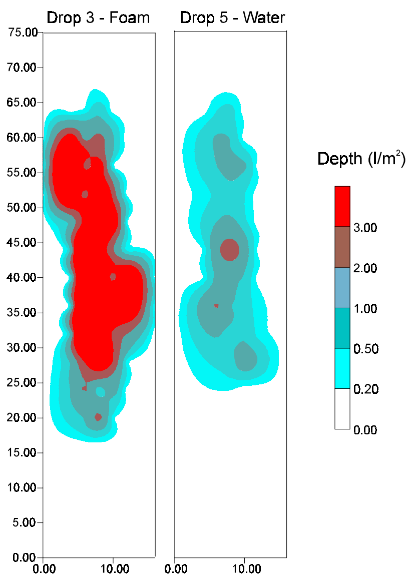

Figure 2: Kaingaroa aerial drop trials[6], output when dropping 3.3% foam solution versus water.

The bare ground pattern is commonly determined by trials that look at the effect of the previously listed factors on drop distribution. These trials have been performed in New Zealand (Campbell 1959), Canada (Newstead and Lieskovsky 1985), United States (George 1975 & 1982, George and Blakely 1973), and Australia (Rawson 1977, Rees 1983, Loane and Gould 1986). However, few studies follow the example of George and Johnson (1990) and attempt to make recommendations about drop height or speed, drainage rate and additive mix-ratio necessary for firebombing to be effective in different fuel, weather and fire danger conditions.

[6] 300 *l* loads were delivered from a Squirrel helicopter carrying a Tru-Test bucket. The flying height was 6.1 m and the speed was 37 km/h. The loads were delivered flying into the wind, and the 10m- wind speed was 25.7 and 19.7 km/h for drop 3 and 5, respectively.

Actual firebreak characteristics

The second step in determining drop effectiveness is to review the actual pattern reaching the ground through a fuel canopy. The important factors influencing the actual drop pattern are additive features and canopy interception.

Chemical (i.e., type of chemical and mix-ratio) and physical properties (e.g., expansion ratio) alter the canopy retention (coverage and drip through ability) of the agent being dropped. From the previous comparison of water with wet and dry foams, it is evident that:

- water will penetrate a canopy and have little ability to adhere to elevated fuels;
- wet foam will penetrate and coat fuels but will drain quickly; and
- dry foam will be suspended in the canopy, coating the fuel particles that it contacts and draining slowly.

Similarly, retardants thickened with gum are more likely to adhere to aerial fuels than unthickened retardants.

Canopy cover (species, height, canopy closure, crown form, and surface area features) also has a significant effect on drop effectiveness (Newstead and Lieskovsky 1985, Rawson 1977, Loane and Gould 1986). The amount of water/additive reaching surface fuels decreases proportionally with an increase in canopy coverage. For example, in a thinned 15 year old *Pinus radiata* stand it was found that 52% of a retardant drop reached surface fuels, while in an unthinned stand of the same age, only 11% was recovered at the surface (Rawson 1977).

Critical firebreak characteristics

Drop effectiveness, or the ability of a drop to contain a spreading fire, is influenced by:

- firebreak characteristics such as depth, length, width, additive used, and time since the drop (see Table 1); and
- fire behaviour[7] characteristics which influence whether a fire can cross a break.

When the fire behaviour reaches a level that enables it to cross a firebreak due to spotting, direct flame contact or radiant heat transfer to unburnt fuels, it has exceeded the *firebreak breaching threshold*.

The firebreak breaching threshold varies between fuel types (Table 1). For example, the quantity of water per square metre of fireline that is needed to hold a 500 kW/m intensity fire burning in pine fuels is 1.32 l/m^2 compared with only 0.19 l/m^2 to hold a grass fire at the same intensity. As fire behaviour increases, the firebreak needs to be deeper (i.e., a greater volume of firebreak solution per square metre) and wider to contain the fire. However, in most fuel types there will be a point at which fire behaviour will exceed the firebreak breaching threshold and it becomes practically impossible to construct a sufficient break by firebombing.

An example

Figure 3 uses information from two drops at Tokoroa as an example of the progression from the bare ground pattern through to drop effectiveness for grass and coniferous forest fires with intensities of 1000 kW/m and 2000 kW/m respectively. A Jet Ranger helicopter, with a 245 litre bucket containing 0.5% foam solution, was used for the trials. These drops were carried out in light wind conditions (0-7 km/h), at a drop height of 20 m and flight speed of 37 and 74 km/h for Tokoroa drop 1 and Tokoroa drop 2, respectively.

The first stage in each series shows the bare ground pattern for the two drops. The second stage shows most of the drop would be effective against a fire in grass fuels up to an intensity of 2000 kW/m (using the water depth threshold for cured grassland shown in Table 1). Stage three indicates the expected pattern if the drop was aimed at a fire burning in coniferous forest greater than 15 m tall. It is anticipated that in this situation, the canopy would intercept approximately 60% of the drop (Loane and Gould 1986). Stages four and five suggest that the drops are not likely to be very effective in pine fuels at fire intensities of 500 kW/m and would be ineffective where the fire intensity exceeds 1000 kW/m (using the water depth threshold for Canadian pine fuel shown in Table 1).

[7] Fire behaviour in turn is affected by slope, weather and fuel type, with the important aspects of fire behaviour being intensity, rate of spread, flame length and spotting potential.

Table 1. Depth thresholds for a range of intensities forest and grass fuels.

Forest type	Fire intensity threshold (kW/m)	Depth threshold (l/m²)	Additive	Effectiveness	Reference
Eucalypt, Australia	520	0.25 - 0.75	Long term retardant[a]		Rawson (1977)
Eucalypt, Australia	500 1000 2000	0.4 0.63 1.2	Water	Hold : 1 hour	Loane & Gould (1986)
Eucalypt, Australia	500 1000 2000	0.3 0.56 0.97	Short term retardant[b]	Hold: 1 hour	Loane & Gould (1986)
Eucalypt, Australia	500 1000 2000	0.13 0.24 0.44	Long term retardant	Hold: 1 hour	Loane & Gould (1986)
Pine fuel, Canada	500 1000 2000	1.32 2.64 5.28	Water	Hold: 1 hour	Loane & Gould (1986)
Pine fuel, Canada	500 1000 2000	0.99 1.98 3.96	Short term retardant	Hold: 1 hour	Loane & Gould (1986)
Pine fuel, Canada	500 1000 2000	0.55 1.1 2.2	Long term retardant	Hold: 1 hour	Loane & Gould (1986)
Red pine needles, Canada	500 690	1.18 1.56	Water	Extinguishment	Stechishen & Little (1971)[c]
Balsam Fir slash, Canada	500 1000 2000	1.7 2.96 5.57	Water	Extinguishment	Stechishen & Little[c] (1971)
Black Spruce slash, Canada	500 690	2.4 3.3	Water	Extinguishment	Stechishen & Little (1971)
Cured grass, Australia	500 1000 2000	0.19 0.35 0.65	Water	Hold: 1 hour	Loane & Gould (1986)
Cured grass, Australia	500 1000 2000	0.18 0.31 0.54	Short term retardant	Hold: 1 hour	Loane & Gould (1986)
Cured grass, Australia	500 1000 2000	0.1 0.17 0.29	Long term retardant	Hold: 1 hour	Loane & Gould (1986)

[a] Long term retardant - inhibits the combustion process in cellulose fuels. Diammonium phosphate was used in Project Aquarius. Gum thickener, corrosion inhibitor, anti-caking agent and orange colouring agent are usually added (Loane and Gould 1986).

[b] Short term retardant - water is still the reducing agent, with thickener (e.g., gum or clay-based) added to reduce dispersion.

[C] Stechishen and Little (1971) conducted tests on fires up to 690 kW/m intensity. Further research by them indicated that the equations for Balsam Fir would fit fires of higher intensity, therefore we have followed the example of Loane and Gould (1986) by extrapolating up to 2000 kW/m for this fuel type.

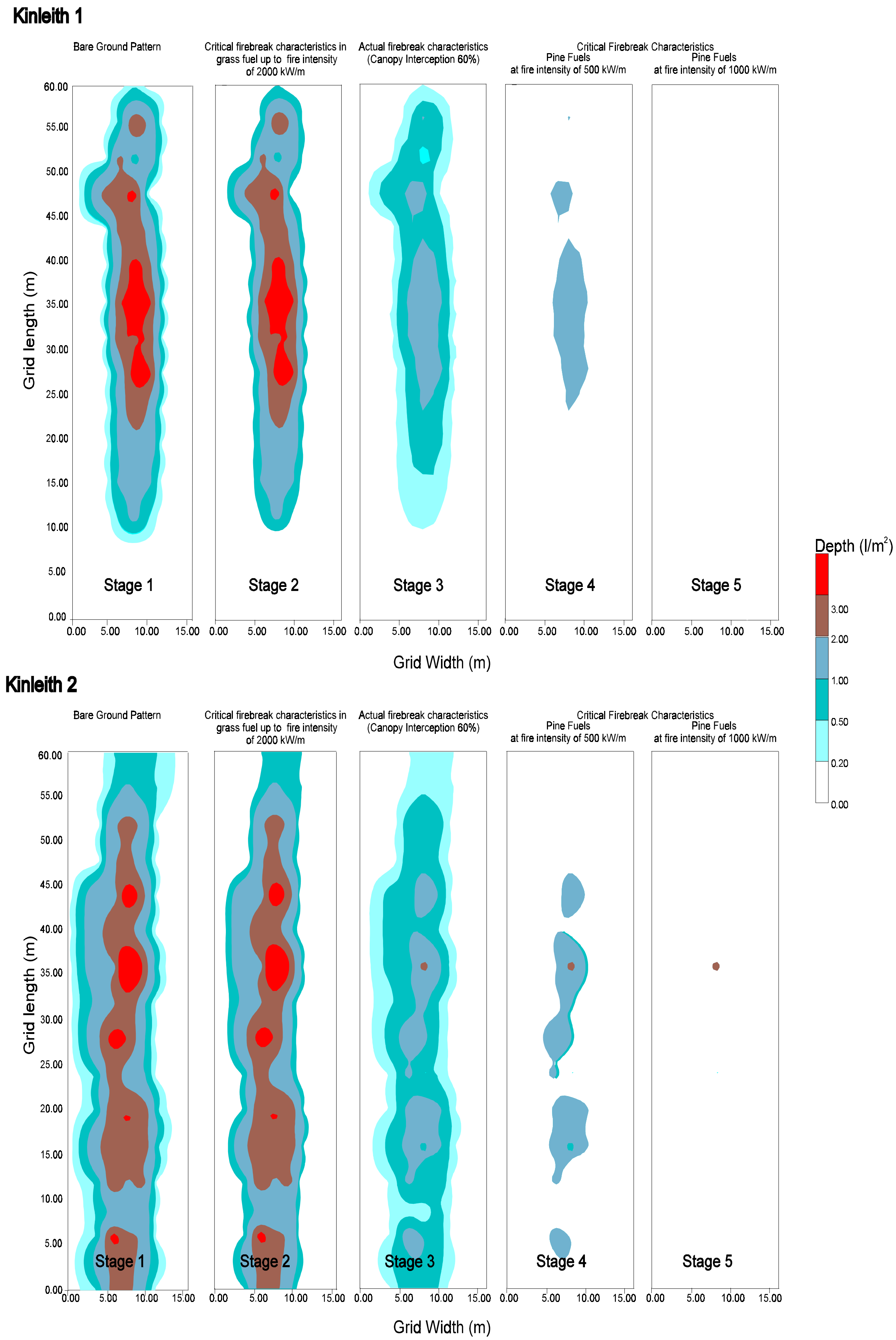

Figure 3. Bare ground pattern for two drops at Kinleith, and the predicted amount of interception and dimensions of effective drop when applied to knockdown fires of different intensities in grass and pine fuels.

Where to from here?

In order to improve the standard of aerial fire suppression operations in New Zealand, the highest priority must be to increase our knowledge of the effectiveness of water-based firebreaks in a range of fuel, weather and fire danger conditions. Critical questions that need to be answered are:

- what types of foam (wet, fluid, dry) work best in different fuel types such as mature or immature coniferous forest, gorse, tussock and pasture; and
- in these fuel types, what depths of water-based firebreak are required to hold fires burning in different fire danger conditions.

Using this information, bucket design and delivery guidelines (i.e., approximate flight heights, speeds, additive types and mixing rates) can be developed to achieve the required type and quantity of water-based break to suit the situation. It will then be possible to extend the example cost-effectiveness analysis presented in FTTN 8 to include the cost of every metre of effective fireline delivered by different aircraft working in a range of fuel and fire danger conditions, rather than a simple comparison of costs per litre of water delivered to the fireline.

Some firebreak effectiveness information can be gathered at experimental fires but, for each burn, this will significantly increase the effort necessary to establish burning areas, the amount of "in kind" support required from local fire authorities, and the quantity of information that needs to be processed and analysed. Where aircraft are being used at wildfires, recording whether drops are effective, together with drop characteristics, fuel, weather and fire behaviour information will provide greater insight into the two points listed above.

So that guidelines (see FTTN 12) for drop effectiveness trials could be developed, some initial trials that recorded bare ground drop patterns were conducted by staff at the Forest Research Institute and interested fire authorities. The trials were carried out at Kinleith, Mossburn, Kaingaroa and Hobsonville (see Acknowledgments). These trials and observations at wildfires have highlighted the following points that require further investigation:

1. There is no standard bucket design in New Zealand, and results from trials using specific bucket types may not be comparable with other buckets. Static testing of different buckets will provide information on a range drainage rates, and the effect of gate and skirt properties on drop distribution patterns (George *pers. comm*).
2. Drainage rates from some New Zealand made buckets are low compared to those used in the U.S. For example, during the 1996 Mohaka Forest Fire[8], a 450 *l* Tru-test bucket used had an average drainage rate of 72 litres per second (*l*/sec) compared with 337 *l*/sec for a 1600 *l* Bambi bucket.

This is not necessarily a problem, as the type and depth of foam or retardant required to contain fires in local vegetation types is largely unknown. However, the slow drainage rate may limit the height and speed that can be used to lay fireline that has a noticeable impact on the fire, and may partially explain why aerial firebreaks made with this type of bucket are commonly applied using slow ground speeds and low drop heights. The wet foam commonly produced does not fully exploit the ability of foam to form bubbles which slow the rate of water drainage and evaporation. Other methods of adding a wetting agent (e.g., hydro-blender capsules or agricultural wetting agents such as Silwet or Pulse) may achieve the same result when only wet foam is needed. An evaluation of the costs and benefits is needed.

3. Foam concentrate tends to sink rather than disperse when poured into water (Stechishen and Murray 1988). Therefore, foam quality will vary throughout the drop. Inadequate mixing may have also contributed to the production of only wet foam during trial drops (George *pers. comm.*). It is important to ensure that foam is well mixed during future trials and suppression operations.
4. There are a number of micro-chemical effects that alter foam performance (e.g., water hardness, temperature, and salt content). For example, the viscosity of some foam brands increases as they cool. More viscous foams are inducted at a slower rate, thus reducing the amount of foam

[8] Mohaka Forest Fire started in slash fuels on the 19/11/96, and firebombing observations were made on 20/11/96.

concentrate in the solution (Stechishen and Murray 1988). The age and type of foam will also influence foam effectiveness (George *pers comm)*. Experiments being carried out by the USDA Forest Service should be monitored and reviewed by forest and rural fire authorities.

5. An evaluation of what pilots/aircraft actually do at wildfires (e.g., aircraft height and speeds) is necessary to benchmark current aircraft operations. For example, aircraft drops observed at the Mohaka Forest Fire were often lower and slower than has been tested in our trials to date. Benchmarking is best achieved using a data logger connected to an aircraft GPS unit (George *pers. comm.*).

6. During the Mohaka Forest Fire, rotor wash was observed to fan the fire during some drops. This was particularly evident when they were delivered from low heights and placed inside the burning zone. In scrub fuels, the fanning effect of rotor wash can negate the impact of an aerial drop (Wallace *pers. comm.*[9]). In general, the flight characteristics of helicopters cause surface winds to (from Teske & Kaufman 1994):
   - strengthen during hover;
   - decrease as ground speed increases;
   - increase as the height of the helicopter decreases; and
   - increase as helicopter and rotor size increase.

To provide guidelines on minimum height, speed and strop length for firebombing with helicopters, the effects of rotor wash from different aircraft in use needs to be evaluated.

7. Once the bare ground pattern has been established, the effect of forest canopy should be investigated. It is necessary to test whether the slow drainage rate of some buckets limits the height and speed from which drops can be delivered and still lay a substantial break through canopy.

   Paired tests, where one grid is set up in the open and another under a canopy, are required to compare the effect of open drops with canopy interception. Paired drops need to be performed under similar wind and flight conditions.

Summary and Conclusion

The factors missing from this FTTN and FTTN 8, are the ability of individual fire managers to develop effective aerial suppression strategies and the skills of a pilot to implement them. Regardless of the extent of our knowledge-base on aerial firefighting and how good our guidelines or decision support systems are, operator influence and the ability to place the correct type of drop in the correct location will have the greatest impact on actual firebreak effectiveness (Figure 4[10]). However, improved selection and implementation of aerial suppression strategies would result if pilots and managers had sufficient knowledge and training to ensure that they understand how factors such as aircraft and additive selection, fuel properties, fire behaviour and weather conditions influence firebombing effectiveness. Aircraft are most commonly used for knockdown during initial and ongoing attack, and their success or failure has a great impact on the final area burned. Therefore, quantifying the factors that influence critical firebreak effectiveness during the knockdown is a necessary first step in improving firebombing standards.

[9] Gavin Wallace, Controller, Wainuiomata Bushfire Force.

[10] It should be noted that the addition of drop placement was originally inlcuded by Hardy (1976). It was excluded from Figure 1 because the primary aim of this FTTN is to discuss technical factors influencing drop effectiveness.

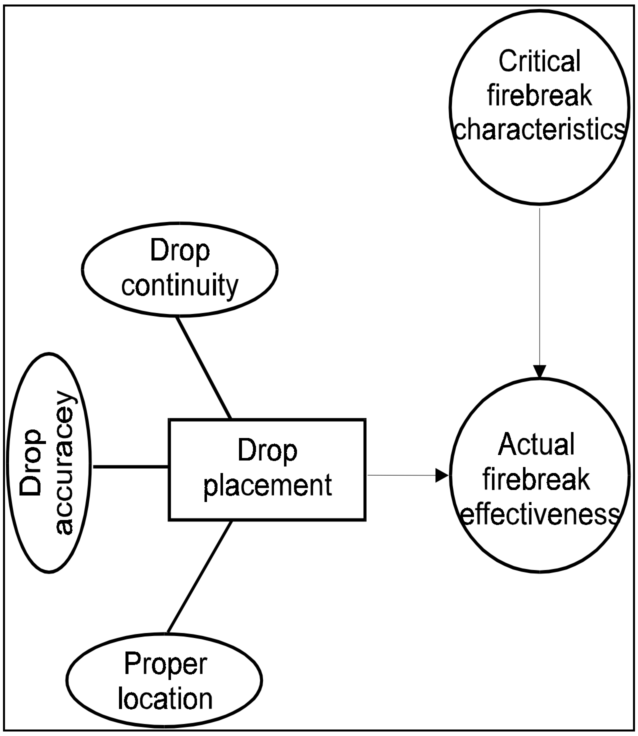

Figure 4. Factors contributing to aerial drop effectiveness (adapted from Hardy. 1976).

A review of the properties of different chemical additives and the factors that influence firebreak effectiveness has allowed us to identify the factors that influence drop effectiveness. The factors influencing the bare ground pattern include flight and wind features, additive properties, and geometry and flow rate of the bucket or gate. Canopy interception and additive features influence the actual firebreak characteristics. Critical firebreak effectiveness is influenced by firebreak characteristics (depth, width, length and additive type) and fire behaviour (intensity, rate of spread, spotting and flame length).

From this review, it is apparent that firebreak breaching thresholds for New Zealand fuel types are needed to develop performance-based guidelines for firebombing equipment design and application methods. Using this information, equipment (e.g., buckets and different types of rotor or fixed-wing aircraft) and additives can be selected or designed to achieve the required result on the ground. For example, while some information on footprints from aircraft configurations currently used in New Zealand would help answer questions such as what height and speed are required to generate wet to dry foams, it is possible that a major alteration to bucket design and delivery systems ***may be*** required to deliver sufficient volumes of water-based firebreak to achieve knockdown (particularly in forests).

In summary, to improve the standards of firebombing in New Zealand we need to:

- quantify the necessary depth and type of water-based firebreak required to hold fires burning in different fuel, weather and fire danger conditions;
- validate interception rates from overseas data for New Zealand fuels and, where necessary, to estimate rates for New Zealand vegetation;
- establish the relationship of height and speed of aircraft, wind speed and direction, foam percentage, and bucket design/setting to foam type and expansion ratios; and
- develop and test guidelines on bucket design, flight characteristics and mixing rates so that pilots can produce different types of water-based firebreak on request.

We have little knowledge about the points listed above. The only point that we can make with certainty is, that if we don't start gathering information now, another forty years will pass before fire managers and pilots have access to adequate decision support systems and training. Currently, no funding is available to support research in this area, so fire managers will need to do much of the work required to gather firebreak effectiveness information. Few wildfires are fought without aircraft, and these provide numerous opportunities to observe aerial drop effectiveness. To assist fire managers to participate in this process, the key points that need to be observed and recorded during suppression operations are included on a the Firebombing Effectiveness Form (Appendix 1). Aerial drop trial guidelines have also been developed (see FTTN 12). If you are interested in gathering aerial drop effectiveness information please contact Kimberly Robertson (phone 07 347 5653).

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Appendix 1. Firebombing effectiveness form

Time	Drop number[1]	Fuel Type	Fuel height (m)	Fuel density[2] (L, M, H)	Location[3] (H,F,B)	Flame height	Fire Type[4] (S - C)	Slope (deg)	Means of delivery[5] (H, FW, GC)	Agent[6] (W, F, R)	Mix-ratio	Aircraft		Foam Type (Wet, Fluid, Dry)	Effectiveness at drop[7] (S, R, N)	Elapsed Time Until:	
												Height (m)	Speed (km/h)			Crews Arrive	Fire reignites

1. Record whether it is a single or multiple drop on a given length of fireline (e.g., 1 of 1 for single drop, 1 of 2 for double etc.)
2. Use (**L**) for open fuels that are easy to walk through, (M) for situations where fuel density impedes progress and, (**H**) when fuel is virtually impenetrable.
3. Use (**H**) for head fire, (**F**) for flank fire and **(B)** for back fire.
4. Use **S** for surface fire, **T** for torching, **I** for intermittent crown fire and **C** for crown fire
5. Helicopter **(H)**, fixed wing **(FW)** or ground crew **(GC)**. If possible identify the aircraft.
6. Use **W** for water, **F** for foam and **R** for retardent.
7. Use **S** for when the fire spread is suppressed, **R** when intensity is significantly reduced and **N** when there is no significant affect.

Time	Temperature (°C)		RH (%)	Wind	
	Wet bulb	Dry bulb		Speed (km/h)	Direction
12 noon					