Fire Technology Transfer Note

Number - 18 November 1998

Aerial Fire Suppression Workshop

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Introduction

Aircraft have been used for firefighting in New Zealand since the 1940s and are now commonly used during initial attack and ongoing suppression of forest and rural fires. New and specialised equipment has been developed and the aircraft industry regularly assists at forest and rural fires.

Inefficiencies in aerial fire suppression have been noted at wildfires throughout the country. These experiences together with the results from an initial series of aerial drop trials has highlighted the need to improve our knowledge and understanding of how to use aircraft for fire suppression. In recent months, a number of issues of *the Fire Technology Transfer Note* (FTTN) have been devoted to discussing some of the issues involved.

This FTTN documents an aerial fire suppression workshop that was held in Southland in early May 1998 to discuss these and other issues surrounding the use of aircraft at wildfires. Twenty eight people participated in this workshop, including fire managers from rural fire authorities and forest companies, the Department of Conservation, City Councils, District Councils, pilots from Southland and Otago, as well as the author from the Fire Research programme at *Forest Research*.

Issues Raised

Some of the issues covered were: the effective use of aerial fire suppression resources; use and application of retardant and suppressant, and aircraft management at wildfires.

<u>Effective use of aerial fire suppression resources</u>

Productivity and aircraft effectiveness research has been carried out at some recent wildfires by Forest and Rural Fire Research staff. Observations showed that many drops were ineffective and this could be put down to one of the following reasons:

- Drops laid on areas of fire that are too intense.
- Drops not penetrating the canopy.
- No supervision of aircraft operations.
- No follow up or slow follow up by ground crews.

Other issues also identified during these observations and field trials were that the drainage rates of New Zealand bucket designs are significantly lower than overseas models, and that often only wet and wet/fluid foam was produced at drop trials. Similarly, smaller aircraft were shown to be less cost effective.

To begin addressing some of these questions several preliminary aerial drop trials have been carried out. A table showing the flight, load and drop pattern details of aerial drops carried out to date can be seen in Appendix 1.

Appendix 2 provides some suggested recommendations for future helicopter aerial drop trials that cover a range of flying heights, aircraft speeds, and foam concentrations (see FTTN 12 for aerial drop guidelines). Without replication the suggested recommendations require at least 180 drops. When the drops have been carried out and aerial drop patterns derived, the bucket volume, aircraft speed and height can be increased in any further trials. Recommendations have not been developed for fixed wing aircraft.

These results of preliminary aerial drop trials and observations at wildfires indicate the following points require further investigation:

1. Quantification of the influence of height and speed of aircraft, wind speed and direction, foam percentage and bucket design/setting on foam types and expansion ratios on aerial drops.
2. Quantification of the necessary depth and type of water-based firebreak required to hold fires in different fuel, weather, and fire danger conditions.
3. Validation of interception rates from overseas data for New Zealand's forest fuels and to estimate rates for other New Zealand vegetation types.
4. Development and testing of guidelines on bucket design, flight characteristics and mixing rates so that pilots can produce various types of water based firebreak as required.
5. Evaluation of what pilots/aircraft actually do at wildfires is necessary to benchmark current aircraft operations.

A brief summary of the previous FTTN's (No's 12, 13, 15, 16 and 17) relating to aircraft operations was presented to participants and a copy of this overview is attached as an appendix (see Appendix 3).

<u>Use and application of foam and retardant</u>

Foam is a mixture of water, air and foam concentrate. Foam contains a *wetting agent* which increases the ability of the foam to spread through and over the fuel and penetrate into the fuel particle itself. From a 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%), 40 to 80% of the foam breaks down within 2 to 5 minutes of being generated (Stechishen and Murray 1988). This 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. Foam can only be used as a short term firebreak. It was also recommended by workshop participants that a foam dispenser unit such as C Dax or a similar product is used for direct injection of foam into the bucket.

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 thus 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. Retardant is used as a long term firebreak and must be laid in unburnt fuels ahead of the fire with sufficient time allowed for it to coat fuels before the fire reaches it.

Some general points and recommendations from this discussion were:

- A filling pump of 1600 litres/minute or two at 800 l/m must be provided for the operation to be cost effective.
- All aerial operations must be supervised by a dedicated person or people.
- Fire managers must be aware of and cater for pilot rest breaks.
- Helipads should be maintained on a regular basis especially to keep flight paths open.
- Extreme care is required when pouring additives in windy conditions.
- Safety issues regarding the use of foam and retardant were also raised.

Safety issues are paramount in all operations. Adequate protective clothing must be worn to protect from any additive being used. All staff working with foam or retardant must be aware of OSH requirements and extreme care is required when pouring additives in windy conditions. It was noted that a newly developed firetrol dispenser unit eliminates the need for crews to stand under the helicopter to pour firetrol into buckets.

<u>Aircraft management at wildfires</u>

Some key points and recommendations which came out of this discussion were:

- There must be communications between the ground and aircraft.
- When aircraft are being used at any wildfire the operations must be supervised by a dedicated position in the command structure.
- Everyone including pilots must be part of the command structure.
- Pilots must first report to the Incident Controller/Fire Boss or Air Boss when arriving at any fire ground.
- Everyone, including pilots must be briefed prior to being engaged on any fire suppression activities. This briefing must include who they report to, what they are responsible for and the job they have been assigned to do as well as information on the fire behaviour, communications, etc.

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Appendix 1. Aerial drop trials to date.

	Aircraft type	Bucket Volume (l)	Air Speed (km/h)	Wind Speed 10m (km/h)	Ground speed (km/h)	Height of bucket base (m)	Foam Concentration	Drop Length (m)	Drop Width (m)
Tokoroa - Tawa Rata Airstrip									
Drop 1	Bell Jet Ranger	245	37	0	37	15.3	0.5	48	5.7
Drop 2	Bell Jet Ranger	245	74	0	74	15.3	0.5	80.4	7.8
Hobsonville Airbase									
Drop 1	Iroquois	350	37	8.35	25	15.3	0.5		
Drop 2	Iroquois	400	74	6.25	65	15.3	0.5	87	17
Kaingaroa Golf Course									
Drop 1	Squirrel	300	46.3	11.6	34.7	12.2	4	62	12.8
Drop 2	Squirrel	300	37	17.1	19.9	6.1	3.3	54.5	9.8
Drop 3	Squirrel	300	37	25.7	11.4	9.1	3.3	58.5	10.3
Drop 4	Squirrel	300	37	10.7	26.4	12.2	3.3	49.5	12
Drop 5	Squirrel	300	37	19.7	17.4	9.1	water	49	4.8
Mossburn									
Drop 1	Cresco 750	1800	241	24.2	217	9.1	0.5	96	54
Drop 2	Cresco 750	1800	222	23.1	199	9.1	0.5	88	44

Appendix 2. Suggested recommendations for future aerial drop trials.

Bucket Volume (l)	Ground speed (km/h)	Height of bucket base (m)	Foam Concentration (%)
300	20	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
300	40	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
300	60	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
500	20	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
500	40	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
500	60	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
700	20	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
700	40	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0
700	60	10	0.0, 0.3, 0.5, 0.7, 1.0
		20	0.0, 0.3, 0.5, 0.7, 1.0
		30	0.0, 0.3, 0.5, 0.7, 1.0
		40	0.0, 0.3, 0.5, 0.7, 1.0

Appendix 3.

***FTTN 12:* Guidelines for determining aerial drop patterns in open areas.**

To improve standards of firebombing, we need to know how firebreak characteristics (width, depth, additives, time since drop, etc) affect the ability of a fire to cross a firebreak (the firebreak breaching threshold), in different fuel, topographical, and fire danger conditions. As a part of this work, we need to learn more about aerial drop patterns or "footprints" (Figure 1) in open areas. Guidelines have been developed to quantify the aerial drop pattern in open areas While the bare ground pattern is only one of many elements (e.g., additives, fuel types, canopy, slope, and weather) that interact to determine firebreak breaching thresholds, knowledge of the basics of footprints allows us to understand how:

- available equipment, aircraft, additives, and wind and flight conditions interact to produce a footprint;
- to achieve nominated footprints (i.e., depth thresholds) for open grasslands (see Table 1, FTTN 11);
- to produce guidelines on the production of wet, fluid, and dry foams under different flight and wind conditions; and
- to improve the design and selection of equipment, additives, and aircraft used for firebombing.

***FTTN 13:* Firebombing effectiveness - interim recommended foam consistencies and aerial attack guidelines.**

Some *interim* recommendations for foam consistencies and aerial attack guidelines have been proposed (Table 2). The guides are an adaptation of those used in Canada, which are based on the assumption that decisions about the most appropriate foam types should consider the factors of canopy cover, fuel depth, the length of time until follow-up by ground crews, and the chances of re-ignition. While the interim guidelines require further testing and refinement, they should provide a useful starting point for air attack decision making. Information from further research, as well as feedback from operational testing, is necessary to produce comprehensive aerial attack guidelines.

Table 2. Section of the interim recommended foam consistencies and aerial attack guidelines for knockdown of wildfires in New Zealand fuel/vegetation types (adapted from Alexander *et al.* 1989).

Tree or Scrub	**Ground support within 5 to 10 minutes**	
	Understorey	
	Shallow	Deep
Open canopy	Foam type: WET Example fuel types: Light logging slash (S-1), pasture (O-1) and low open tussock grasslands, recently thinned coniferous forest (C-6) with litter understorey.	Foam type: FLUID Example fuel types: Heavy logging slash or slash with scrub understorey, scrub or tussock less than 1.5 m, and recently thinned coniferous forest with fern, sedge or scrub understorey.
Closed canopy	Foam type: FLUID Example fuel types: Coniferous forest (C-6) or tall manuka/kanuka with litter understorey.	Foam type: WET followed by FLUID Example fuel types: Coniferous forest and tall scrub/tusscock fuels (> 1.5 m) with fern, sedge or other scrub understorey, "old man" gorse.

***FTTN 15:* Comparison of the cost-effectiveness of some aircraft used for fire suppression - Part 2.**

This FTTN extended the information presented in FTTN 8, which compared the cost-effectiveness of some commonly available rotary-blade and fixed-wing aircraft. It estimates the cost of delivering each litre of water to the fire, and the volume of water delivered to the fire. This included using different methods (dip filling, and filling with high and low volume pumps) over a range of distances from the fire.

The general conclusions drawn in FTTN 8 were:

- Fixed-wing aircraft can deliver large volumes of water to a fire at very competitive rates, especially when suitable filling points for helicopters are greater than 2 km from the fire.
- The selection of smaller helicopters based on lower hourly running costs is a false economy that may result in larger fires, because larger helicopters can deliver greater volumes of water than smaller ones.
- Dip-filling will enable a helicopter to deliver the greatest volume of water and suppressant at the lowest cost, provided adequate filling points are located near the fire and the aircraft has the capacity to inject foam concentrate when needed.
- Delays in filling due to poor filling point management and/or the use of lower volume pumps will result in considerable "opportunity costs".
- The use of buckets that are below the safe carrying capacity of a helicopter will result in considerable "opportunity costs".

FTTN 15 collates information collected from a survey of aircraft companies on the cost and performance of some commonly available aircraft makes, models and types. This information will help fire managers to select and better utilise aircraft for aerial fire suppression operations. Methods for estimating when a filling point is likely to be over-utilised, and the rate of fuel, water and additive usage have been developed. In doing so, the following general conclusions were also drawn:

- Aircraft with higher load/speed (L/S) ratios should have priority for filling.
- The total time that a filling point is utilised (as estimated from Appendix 4) should not exceed 50 to 55 minutes per hour.
- When the available filling capacity has been exceeded, aircraft with the lowest L/S ratios should be stood down.

The “2 × 2” rule should be adopted as a general rule of thumb. This suggests that when 2 aircraft are flying more than 2 km to the firebombing zone, additional filling points should be established closer to the fire.

***FTTN 16:* Reducing the influence of helicopter rotor wash on fire behaviour.**

In some instances, the fanning effect of rotor wash from helicopters involved in fire suppression can negate the impact of their drops (FTTN 11). For example, some drops at the recent Whakarewarewa and the Mohaka fires (FTTN 11) fanned, rather than knocked down flames along the fire perimeter. This was most evident when drops were made from a hover and placed inside the burning zone.

The aim of this FTTN is to use some United States Forest Service research findings to provide guidelines on how to minimise the impact of rotor wash on fire behaviour. This can be achieved by specifying helicopter speeds and heights where only minimal rotor wash will reach the surface, thus increasing effectiveness of the air attack operation. Not all helicopters cause the same amount of rotor wash, and this FTTN will allow fire managers to select machines that least influence fire behaviour.

The general findings of the USDA Forest Service research were that rotor side-wash (adapted from Teske *et al.* 1995):

- increases as ground speed decreases:
- increases as the height of the helicopter decreases;
- increases as helicopter mass increases; and
- increases as the rotor span decreases.

This research quantifies rotor side-wash and provides a valuable tool for reducing its effect on fire behaviour. Fire managers can achieve this in two ways. Firstly, it is possible to estimate the rotor side-wash- induced Initial Spread Index (ISI) and specify flight characteristics that produce an acceptable level of downwash for different conditions and helicopter type. Otherwise, fire managers can derive some general *rules-of-thumb*, where rotor side-wash will be negligible in *most* instances.

It is necessary to define a maximum acceptable rotor side-wash-induced ISI that will not fan the fire so much that it will negate the effects of a drop. For fires burning in open fuels such as logging slash, pasture, gorse or tussock, that are responsive to changes in wind speed (Fogarty 1996, Rasmussen and Fogarty 1997), this may be a side-wash-induced ISI of 5 or lower. In standing forest where the canopy will buffer some of the downwash, a more appropriate side-wash-induced ISI may be 10.

The acceptable level of rotor side-wash will vary because:

- ISI increases as FFMC increases; and
- ISI increases as wind speed increases.

To provide an estimate of rotor side-wash, helicopter flight characteristics and rotor span have been used to produce tables for a range of helicopter weight classes (1000-2000 kg, 2000-3000 kg, 3000-4000 kg, 4000-5000 kg and 5000-6000 kg. For example, if we are using a Hughes 500D and we want to keep the wind speed less than 30 km/h, the drop must be carried out using a height/speed combination shown by the shaded area marked in Table 1.

Table 1. The influence of helicopter ground speed (km/h) and rotor height (m) on rotor side-wash, for helicopters weighing between 1000 and 2000 kg with a rotor span of 8 to 9 m. The shaded area delineates the height and speed combinations that can be used to keep side-wash less than 30 km/h.

Ground speed (km/h)	Rotor height (m)					
	15	20	25	30	35	40
1	63	50	42	37	32	29
5	31	25	21	18	16	14
10	23	18	15	13	12	11
20	17	13	11	10	9	8
30	14	11	9	8	7	6
40	12	10	8	7	6	6
50	11	9	8	6	6	5

As an alternative to calculating individual flight characteristics, two general *rules-of-thumb* have been developed for helicopters less than and greater than 2000 kg, where rotor side-wash will be negligible in *most* instances (for helicopters up to 5000 kg). If applying these rules, lighter machines should fly at a height of 25 m and at a ground speed of 25 km/h (the “25 × 25” rule), whereas larger machines should follow the “35 × 35” rule. If they do nothing else, fire managers should ensure that pilots deliver drops from outside the fire perimeter and avoid drops from a near-hover.

***FTTN 17:* The influence of wind speed on the effectiveness of aerial fire suppression.**

The aim of this FTTN is to better quantify the impact of wind on helicopter operations, and to describe how the interaction of wind with other elements of the fire environment (i.e., steep terrain and dense vegetation) alters the effectiveness of aerial suppression operations.

The results from a survey of owner/operators (see Appendix 1) show that most helicopters are able to fly in strong to whole gale wind force classes (75 to 102 km/h). When a bucket is underslung, the more typical operating range is reduced to the fresh to strong gale wind force classes (62 to 88 km/h).

It is evident that most helicopters are capable of being used for reconnaissance and transportation in gale force wind conditions. This interpretation needs to be tempered by the likelihood that the owner/operator responses incorporate pilot experience, skill, attitude and local factors that may have influenced their experience (e.g., some may do only high altitude flying which will also influence helicopter performance). Therefore, the wind speed thresholds are only a guide for planning purposes and, provided firefighting resources are not at risk (e.g., the filling point crew during hover filling).

Being able to operate with a bucket underslung should not be confused with being able to contribute to the control of forest and rural fires in these conditions. While the decision on whether it is safe to fly rests with the pilot, the assessment of whether aircraft involved in suppression are being effective is the responsibility of the operations boss or their delegate (e.g., aerial attack supervisor).

An interim guide:

Figure 1 is an interim guide which shows how the maximum wind speed (as described by the Beaufort wind speed classes) for effective firebombing decreases as vegetation cover increases, and the terrain becomes more steeply divided. The reduction in wind speed threshold is shown by the move from lighter to darker shading, and relates to the need to lay deeper and wider firebreaks, as increased interception of the drop and reduced drop precision occurs.

Figure 1 is not intended as a prescription for determining when firebombing will be effective, but as a guide to help managers determine when other resources (e.g., additional ground crews, heavy machinery) or suppression strategies (e.g., indirect attack, burning out) may be needed for initial and ongoing attack. Most importantly, it indicates when close monitoring of drop effectiveness is necessary.

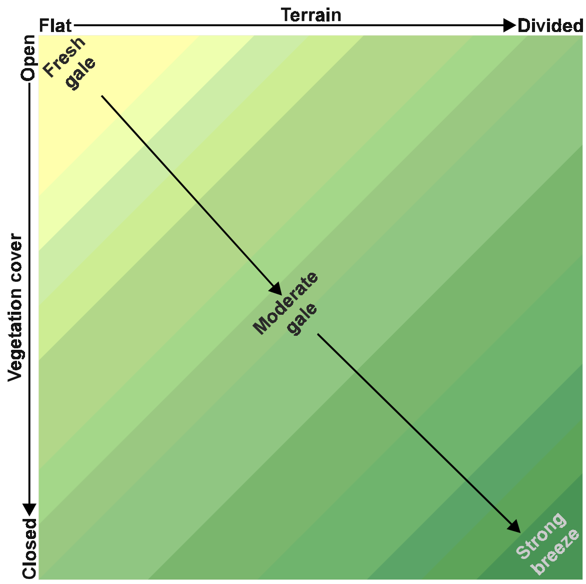

Figure 1. Interim guide showing the Beaufort wind force classes in which firebombing with helicopters is likely to be effective. The transition from lighter to darker relates to a reduction in the wind force class from a fresh gale to a strong breeze as vegetation cover increases and/or the terrain becomes more steeply divided.