# Fire Technology Transfer Note

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## The influence of wind speed on the effectiveness of aerial fire suppression.

By Liam Fogarty and Alen Slijepcevic

### Introduction

New Zealand has areas of steep terrain, dense vegetation and a high number of privately owned helicopters, so it is not surprising that these aircraft have become the mainstay of aerial fire suppression. In many instances, fire control strategies are largely reliant on their use. A shortage of readily available ground-based suppression resources further increases this reliance on helicopters for initial attack.

The effectiveness of aerial suppression operations using helicopters has been questioned in some instances (Fogarty *et al.* 1997, *Fire Technology Transfer Note* (FTTN) 11). Some of the factors blamed for poor "knockdown" of flames were interception by dense canopies of drops made with low volume and low drainage rate buckets, incorrect use of additives, insufficient follow-up by ground crews, inadequate supervision and poor drop placement. Another type of failure occurred during the 1996 Mohaka Forest Fire[1], where aerial operations were restricted by gale force winds (ranging from 50 to 70 km/h).

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 effectives of aerial suppression operations.

[1] The 1996 Mohaka Forest Fire burnt more than 100 ha of mostly logging slash, but also included a small area of mature Douglas-fir (*Pseudotsuga menziesii*) forest. Weather and FWI conditions were 68 km/h wind speed, FFMC 86.6, ISI 85.4, BUI 57, and FWI 62.

### Method

An initial estimate of the effect of wind speed on aircraft performance was obtained from a survey of most aircraft owners and operators used by the Department of Conservation and other forest and rural fire authorities throughout New Zealand. Of the 53 people surveyed in October 1996, 41 (77%) responded. Respondents noted the maximum wind speed that they can fly in, with and without a heli-bucket slung under their aircraft. This information is summarised in Appendix 1.

A second survey of 27 forest and rural fire managers known to have experience in the management of aerial attack operations was also conducted. Of these, 20 (74%) responded. This survey was carried out in June 1997.

The aim of the second survey was to better quantify the impact of wind speed on the effectiveness air attack, rather than to identify conditions that restrict flying. To reduce the influence of fire behaviour on drop effectiveness, the respondents were asked to concentrate on the knockdown of flank and back fire spread when a drop was delivered by helicopters with different horsepower ratings. They were asked to provide an estimate of the wind speed threshold for drop effectiveness in three fuel types (grass, scrub, forest) and two terrain classes (flat to undulating through to steeply divided). The fuel types were included to incorporate the possible influence of increasing fuel quantity and canopy cover on drop effectiveness. Respondents could also provide specific examples of fires where aircraft could not operate effectively.

Many respondents acknowledged the effect of differences in fuel types, terrain and helicopter size. Fourteen respondents (70%) provided a range of wind speeds at which they considered that water-based fire breaks delivered using the currently available helicopters and delivery systems could not achieve knockdown (i.e., the wind speed thresholds for achieving effective knockdown). Respondents provided examples using specific helicopter makes/models, or examples from individual wildfires. Six provided only general comments.

The limited range of the responses prevented the evaluation of the influence of all the factors in the survey through statistical analysis. The data was simply combined to produce an average wind speed threshold plus or minus one standard deviation. Information on the factors that influence drop effectiveness (see FTTN 11) was combined with the comments made by the respondents to provide the wind speed thresholds for when firebombing is likely to be ineffective in different fuel and terrain conditions.

## Results and discussion

A word on drop effectiveness

When helicopter drops are not having a significant impact on flames because the fire is too intense, or they miss their mark, or rotor downwash is fanning the fire, aerial attack is obviously ineffective. The fire managers who responded to the second survey were asked to comment only when helicopter drops were able to place enough water or foam on or ahead of the fire to adequately knockdown flames to a level where they could be contained by ground resources. This approach was adopted because in most instances ground resources should be used in conjunction with air attack.

When can helicopters fly?

The owner/operator survey results (see Appendix 1) show that most helicopters are able to fly in strong to whole gale wind force classes[2] (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), but with some aircraft this does extend to whole gale force winds. The owner and operator responses indicate that horsepower was not strongly correlated with the threshold levels in which helicopters can fly either with (r=0.4) or without (r=0.1) a bucket underslung (see Figure 1).

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 and operator responses also 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), the decision on whether it is safe to fly rests solely with the pilot.

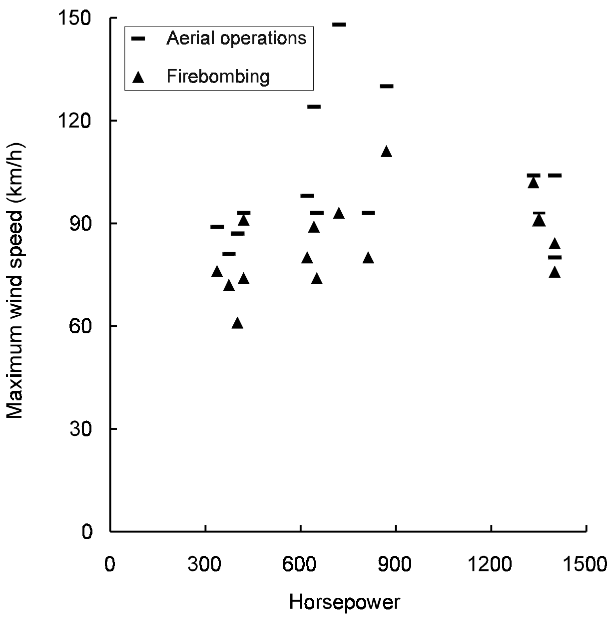


**Figure 1.** Owner/operator estimates of maximum wind speed for flying with and without a bucket underslung versus helicopter horsepower.

When are helicopter drops effective?

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

[2] Wind force classes are based on the Beaufort wind scale shown in Appendix 2.

responsibility of the operations boss or their delegate (e.g., aerial attack supervisor).

From the second survey, the fire manager wind speed thresholds spanned a wide range (35 to 80 km/h), and provided average and standard deviation values of 57 km/h and 14 km/h respectively. Because the responses ranged widely and referred to many types of helicopters operating in different conditions, the value of 57 km/h (±14 km/h) is likely to incorporate much uncertainty. Rather than falsely assume a high level of accuracy, it was decided that the average and standard deviation values should be used to determine the maximum Beaufort wind force classes in which helicopters are likely to be effective in the containment of back and flank fires. This range spans the strong breeze to a fresh gale classes (39 to 74 km/h).

Nine (45%) fire manager respondents suggested that as the terrain becomes more steeply divided, the wind speed threshold for effective firebombing is reduced. Eight (40%) suggested that increasing fuel density also made drops less effective. Only two (10%) indicated that these factors had no effect. The remainder provided only single wildfire examples with no mention of the influence of fuel or terrain on fire drop effectiveness.

Existing information on the factors that influence drop effectiveness can be used to interpret these results. Wind affects fire behaviour and reduces drop effectiveness in a number of ways. Firstly, increasing wind speed enhances the preheating and ignition of fine fuels, which can increase the amount and rate of fuel consumption as well as the fire intensity. While an aerial drop may temporarily reduce flaming combustion, fanning by the wind can help to sustain smouldering combustion and reignition of coarse fuels or organic material in the soil.

As fire intensity increases, an aerially-applied firebreak needs to be deeper and wider to achieve knockdown or containment (Stechishen and Little 1971, Wilson 1988). 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 5.28 $l/m^2$ when the intensity is increased to 2000 kW/m. It takes only 0.19 $l/m^2$ to hold a grass fire at an intensity of 500 kW/m (Loane and Gould 1986). Fires spreading in forest or scrub fuels require greater depths of water to achieve knockdown when compared with light open fuels.

Wind can lengthen or widen the drop depending on whether it is blowing parallel to, or across the drop (Hardy 1976, FTTN 11). At the same time as increasing wind speed causes fires to burn more vigorously, leading to the need for deeper and wider firebreaks to achieve containment, it also causes greater drop dispersal.

Forest and scrublands impact on drop effectiveness because dense canopies can intercept more than half of a drop before it reaches the surface (Rawson 1977). Scrublands and some forests often have heavy loadings of elevated fuels which must be covered by a drop. No only is it necessary to apply a more concentrated drop to achieve canopy penetration in these vegetation types, a greater amount is required to cover the fuel they contain. The effects of drop dispersal are likely to be more pronounced in fuels that are difficult to penetrate and have elevated fuels (e.g., dense scrub greater than 1.5 m tall and plantation forest with a closed canopy).

Drop placement and delivery can influence firebreak effectiveness (Hardy 1976, FTTN 11, FTTN 13). Drops placed on the rear of the flaming zone are likely to have little or no impact on fire spread. Halkett (1982) suggests that wind speeds exceeding 40-50 km/h can reduce the precision of helicopter operations and decrease their effectiveness. While this range is at the lower end of that determined from the fire manager survey, it related to the aerial extraction of logs from forests, which requires greater precision than firebombing operations.

Comments by several experienced fire managers suggests that gale force winds can make manoeuvring around the filling point and drop placement difficult to the point that firebombing operations are ineffective. Precision is most affected in divided terrain where turbulence occurs on lee ridge crests, particularly when wind is blowing across the ridgeline. In these conditions the wind speed at which firebombing using currently available helicopters and delivery systems is effective, may fall to the strong breeze wind force class. Filling or firebombing when the wind is blowing across, rather than parallel to the flight path further reduces precision.

An interim guide

Figure 2 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, increased interception of the drop and reduced drop precision.

Figure 2 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.

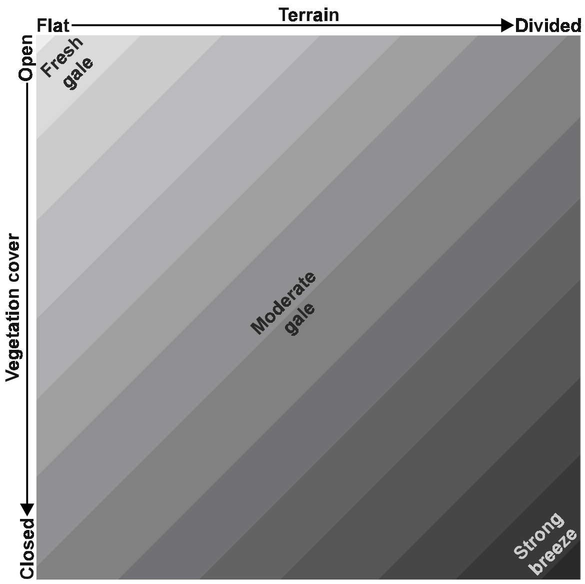


**Figure 2.** Interim guide showing the Beaufort wind force classes in which firebombing with helicopters is likely to be effective. The transition from lighter to darker relates to a reduction in the wind force class from a fresh gale to a strong breeze as vegetation cover increases and/or the terrain becomes more steeply divided.

As with most aspects of aircraft management in New Zealand, there is little quantified information available to support fire managers' decision making. This guide provides a *state-of-our-knowledge* summary that needs to be improved through operational testing and refinement. Use of the assessment procedures presented in *FTTN* 11 and *FTTN* 13 to record the effectiveness of aerial fire suppression will enable the total knowledge base on aerial suppression available to fire managers to be improved.

Unlike the owner/operator responses, ten fire managers (50%) considered that helicopters with greater horsepower often achieved greater knockdown in strong winds. This may be due to slight improvements in the ability of larger machines to conduct precise operations in these conditions, and/or their ability to carry greater payloads which enable them to achieve the deeper and wider breaks needed in more severe burning conditions. The findings reported in FTTN 8 and FTTN 15 showed that larger helicopters are generally able to deliver more water at competitive rates than smaller ones, and that these should be given priority for aerial suppression operations. The fire manager responses support this approach.

This recommendation to use larger helicopters needs to be tempered by the knowledge that if they are not being used effectively, then the operations boss is wasting more money more quickly than if smaller machines were being used. Aerial attack is a costly but important aspect of fire suppression in New Zealand, so assessment and supervision of aerial operations by a member of the fire control team is essential.

The second survey results are by no means conclusive, but they do summarise the factors considered to be important by 20 experienced fire managers. Several managers also stated that pilot skill and experience needed to be considered, two stating that these are the most important factor determining drop effectiveness.

Even though the importance of fire behaviour in drop effectiveness was reduced by asking the respondents to concentrate on flank and back fire behaviour, differences in fire behaviour would have influenced their responses. Changes in fuel types and the severity of the burning conditions can cause back and flank fire behaviour to vary widely. In severe burning conditions, fire intensity, smouldering, and the ease of fire ignition all increase, and the wind speed thresholds may be less than those shown in Figure 2. To ensure that firebombing strategies and tactics are adjusted to suit the conditions, supervision by a trained air attack supervisor, and not the most experienced pilot who is involved in firebombing is essential.

## Conclusion

Steeply divided terrain and dense vegetation are two characteristics of the New Zealand fire environment which necessitate the frequent use of helicopters for fire suppression. However, strong winds are another characteristic of the local fire environment, and they reduce the effectiveness of helicopters for fire suppression as the complexity of the terrain and vegetation density increase.

A survey of owner/operators found that helicopters can operate in strong to whole gale Beaufort wind force classes. However, a subsequent survey of experienced fire managers suggests that for firebombing to be effective, the operating threshold should be reduced to the strong breeze to a fresh gale classes.

An interim guide has been developed to show how the factors of fuel, topography and wind speed interact to effect drop effectiveness. The guide will help fire managers decide when closer supervision of firebombing operations is warranted, and when other strategies and tactics less reliant on aerial support may be needed. This guide provides a *state-of-our-knowledge* summary that needs to be tested and improved at fire suppression operations. Better monitoring and supervision of aerial suppression operations will increase the effectiveness of individual operations and allow fire managers to learn more from each fire experience.

Other factors such as pilot skill and helicopter horsepower were also considered to be important by fire managers. Where possible, more powerful aircraft and experienced pilots should be engaged for fire suppression operations during windy conditions.

## Acknowledgments

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**Appendix 1.** Firebombing and aerial operation wind speed thresholds for different helicopter makes and models.

| Helicopter make/model | Number of responses | Wind speed (km/h) | |
|---|---|---|---|
| | | Firebombing | Aerial operations |
| Hughes 500C | 4 | 76 | 89 |
| Bell 206 Jet Ranger III | 6 | 72 | 81 |
| Bell 206 Jet Ranger II | 7 | 61 | 87 |
| WASP | 1 | 93 | 93 |
| Hughes 500D | 13 | 74 | 93 |
| Hughes 500E | 2 | 93 | 93 |
| AS 350 B Squirrel | 11 | 80 | 98 |
| AS 350 BA Squirrel | 3 | 89 | 124 |
| AS 355 F1 Squirrel | 3 | 80 | 93 |
| MD 530F | 1 | 74 | 93 |
| AS 350 B2 Squirrel | 1 | 93 | 148 |
| Kawasaki BK 117 | 4 | 80 | 104 |
| AS 315B Llama | 1 | 111 | 130 |
| Bell UH 1F | 1 | 93 | 93 |
| Bell UH 1H | 2 | 104 | 104 |
| Bell 205 | 2 | 80 | 80 |
| Average* | | 78 (±15) | 95 (±14) |

* Average values were determined using all owner and operator responses, not the make/model averages shown above.

**Appendix 2.** Beaufort Wind Scale for estimating open wind speed at a height of 10-m over land.

| Beaufort Wind Force | Descriptive term | 10-m wind speed (km/h) | Observed wind effects |
|---|---|---|---|
| 0 | Calm | < 1 | Smoke rises vertically. |
| 1 | Light air | 1 to 5 | Direction of wind shown by smoke drift but not by wind vanes. |
| 2 | Light breeze | 6 to 11 | Wind felt on face; leaves rustle; ordinary vanes moved by wind. |
| 3 | Gentle breeze | 12 to 19 | Leaves and small twigs in constant motion; wind extends light flags. |
| 4 | Moderate breeze | 20 to 28 | Wind raises dust and loose paper; small branches are moved. |
| 5 | Fresh breeze | 29 to 38 | Small trees in leaf begin to sway; crested wavelets form on inland waters. |
| 6 | Strong breeze | 39 to 49 | Large branches in motion; whistling heard in telephone wires; umbrellas used with difficulty. |
| 7 | Moderate gale | 50 to 61 | Whole trees in motion; inconvenience felt when walking against wind. |
| 8 | Fresh gale | 62 to 74 | Breaks twigs off trees; generally impedes progress. |
| 9 | Strong gale | 75 to 88 | Slight structural damage occurs (e.g., TV antennas and tiles blown off). |
| 10 | Whole gale | 89 to 102 | Seldom experienced inland; trees uprooted; considerable structural damage. |