# An Analysis of Dodge's Escape Fire on the 1949 Mann Gulch Fire in Terms of a Survival Zone for Wildland Firefighters[1]

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## Abstract

The Wildland Fire Operations Research Group of FPInnovations - Feric Division in collaboration with the University of Alberta initiated a project in late 2007 at the request of its stakeholders to examine and define the limits of wildland firefighter safety and survival zones. Part of this project involves examining past wildfire incidents in relation to hindsight simulations of the thermal environment associated with the area of refuge taken by firefighters in various burn-over and entrapment situations. Here we examine the case involving the survival of Smokejumper Foreman Wag Dodge on the 1949 Mann Gulch Fire. Based on a thorough review of all the available written documentation and photographic evidence coupled with existing fire behavior knowledge and predictive models, new estimates are presented for the area burned by Dodge's escape fire (0.2 acre or 0.08 hectare) and the height of the flame front that swept around his "island" of safety (10 ft or 3 m). The question of whether he was physically lifted off the ground during the ordeal is also touched on.

## Prologue

*Sky had turned red, smoke was boiling*
*Two hundred yards to safety, death was fifty yards behind*
*I don't know why*
*I just thought it*
*I struck a match to waist high grass running out of time*
*Tried to tell them, step into this fire I set*
*We can't make it this is only chance you'll get*
*But they cursed me ran for the rocks above instead*
*I lay face down and prayed above the cold Missouri waters*

from James Keelaghan's (2004) song "Cold Missouri Waters" (Then Again CD)

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[1] A summary of this paper was presented at the 10th Wildland Fire Safety Summit sponsored by the International Association of Wildland Fire, Phoenix, Arizona, April 27-30, 2009.

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## Introduction

As part of a project looking to develop criteria for defining the minimal requirements of survival zones for wildland firefighters, several past wildfire incidents are being examined (Alexander et al. 2009)[5]. One particularly valuable incident or case study concerns the escape fire[6] set by Smokejumper Foreman Wag Dodge on the 1949 Mann Gulch Fire in northwestern Montana in which 12 smokejumpers and a local fire guard were overrun by a rapidly advancing grass fire and subsequently died. In addition to Dodge, two other smokejumpers, Walt Rumsey and Bob Sallee, survived by fleeing to a rockslide.

There are two elements to Dodge's escape fire that require estimates of as a survival zone: (1) the dimensions or size of the burned area created just prior to being overrun by the main advancing fire front and (2) the height of the flames associated with the main fire front that engulfed or swallowed up his burned out area. The general approach taken to addressing these two elements of Dodge's escape fire involved a comprehensive review of (i) primary and secondary sources (e.g., written statements, popular literature) and (ii) photographic evidence coupled with the (iii) the application of fire behavior knowledge, and (iv) expert review and consultation[7]. Eyewitness observations or immediate post-fire measurements or discussions/interviews were deemed preferable to modelled values although modelling and the incorporation of established principles of fire behavior science into the analysis may help to substantiate or explain what transpired late in the afternoon of August 5, 1949.

It's assumed that the reader has a good general understanding of the sequence of events that lead up to Dodge's use of his escape fire on the Mann Gulch Fire, having read either Maclean (1992), Rothermel (1993) and/or Turner's (1999) account of the incident for example. Quantities referenced in the paper are generally given in both English and the International System (SI) of units.

## How big an area did the escape fire burn out?

Unfortunately this subject was not discussed in Norman Maclean's (1992) book nor was it a direct focus of the Board of Review's investigation even though the concept of using

[5] For further information on this project, including the PowerPoint presentation associated with this paper, visit http://fire.feric.ca/.

[6] It's been widely speculated that Dodge came up with his escape fire as a survival option on the spur of the moment (e.g., Stahl 2005; Walinga 2007; Lehrer 2008). However, at least one smokejumper who had worked with Dodge sometime prior to the Mann Gulch Fire indicates that Dodge had openly discussed the idea as early as 1943 (Schmidt 2001). Another smokejumper who worked with Dodge in the early 40s recalls that Dodge "was savvy about fire" and openly discussed ways of avoiding entrapments or burn-overs by getting into a previous burned area and lying down with you face in the ground (Budenholzer 2004).

[7] Note that the senior author of this paper visited the Mann Gulch Fire site in late June 1994 as part of a field trip associated with a fire behavior workshop held in Missoula, Montana and sponsored by the Northern Region (R-1) of the USDA Forest Service.

escape fires presumably became part of a smokejumper's training[8] in the years following the Mann Gulch Fire. It has been difficult to find evidence that this actually came to be. Presumably the best estimates of the escape fire size would have come from one of three Mann Gulch Fire survivors.

Neither Dodge, Sallee or Rumsey provided any indication of the size of the escape fire in their written statements. However, in February 1961, Walt Rumsey prepared a written statement on the Mann Gulch Fire which was published posthumously with the permission of his family many years later (Rumsey 2006). In that statement, Rumsey indicates that Dodge lit his escape fire "with his cigarette lighter quickly burning out an area several hundred feet long". No disrespect, but it's quite well established in Dodge's Board of Review testimony (p. 119) that he used a "go-for" match or book match (Rothermel 1993) to light his escape fire. Whether this point and several other errors of fact within Rumsey's statement should distract from his recollection of the fire size is open to conjecture.

No mention is made of the size of Dodge's escape fire in the books by Cooley (1984), Maclean (2003) or Matthews (2007) or in any of the essays written on the Mann Gulch Fire (e.g., Gidlund 1966; Weick 1993; Useem 1998; Rothermel and Brown 2000; Berwick 2002; Maclean 2004; Stahl 2005; Lillquist 2006; Benson n.d.). However, at two places in the book by Jenkins (1995, pp. 160 and 178) he mentions that Dodge's escape fire burned a half an acre (i.e., 0.2 hectare) in 30 seconds. In 1949, Starr Jenkins was a Missoula smokejumper. Jenkins (1995, p. 147) indicates that the primary sources for the chapter on the Mann Gulch Fire in his book was Cooley (1984) and his "recollections of what survivors Walt Rumsey and Bob Sallee said around camp after this disaster", although he did acknowledge Maclean (1992) and Rothermel (1993) as additional sources.

Butler and Cohen (1998c, p. 75) on the other hand state the following regarding the size of Dodge's escape fire:

> *Rothermel (1993) indicates that the escape fire burned about 90 m* [~295 feet] *before the main fire overran it. Assuming an elliptical shape for the burned area, with its width approximately half the length, the safety zone created by the escape fire would have been about 45 m wide* [~148 feet].

For reference purposes this represents a fire about 0.8 acre (34,285 $ft^2$) or 0.3 hectare (3181 $m^2$) in size based on an elliptical shaped fire (Figure 1) with a length-to-breadth ratio (L/B)[9] of 2.0:1 and a major axis (i.e., the total length of the fire) of ~295 ft 90 m

[8] The Board of Review for the Mann Gulch Fire made four recommendations. The third recommendation was to "Include in training the use of escape-fire method of avoiding catastrophe, even though occasions for and opportunity to use this method are relatively rare" (*see* Mann Gulch Fire Board of Review report or Cooley 1984, p. 121). According to an article published in *Fire Control Notes*, Missoula smokejumper training included "fire suppression lecture, fire behavior and escape, 8 hours" (Division of Fire Control, Region 1, U.S. Forest Service 1959).

[9] The breadth constitutes the point of maximum width, not the average width (Figure 1B).

representing both the combined forward and backward spread distances (Van Wagner 1969; Alexander 1985).

The dimensions of Dodge's escape fire given by Butler and Cohen's (1998c) represents a very sizeable area to have been burned over in the space of some 30 seconds or so from a point source fire (i.e., a single match ignition), even given the critically dry fuel conditions (Rothermel 1993; Alexander 2000), the highly flammable state of the continuous "flashy" grass fuels (Mutch 1967; Barrows 1951), and the exceptionally steep terrain slope (76%)[10]. A fire on a 76% slope can be expected to spread more than ten times faster than a fire on level terrain (Van Wagner 1977), all other factors being the same.

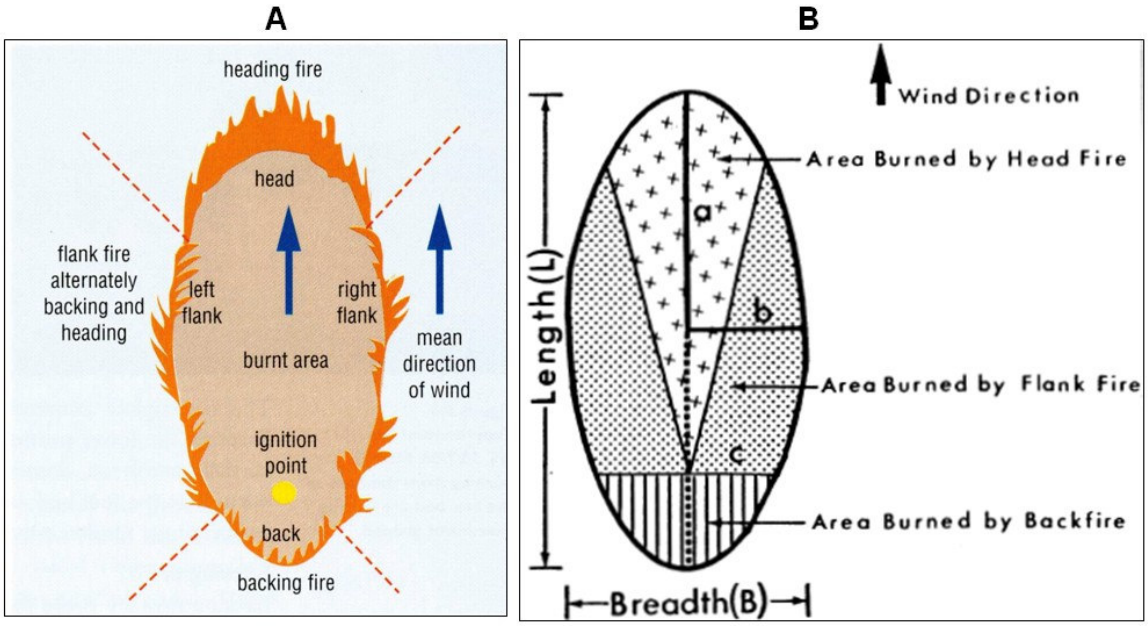


**Figure 1. Elliptical fire shapes (A) illustrating the flame behavior at the head and back and along the flanks (from Cheney and Sullivan 2008) (B) simple fire growth model and the dimensions of length and breadth (from Alexander 1985; adapted from Van Wagner (1969). Both ellipses have length-to-breadth ratios of ~2:1.**

Rothermel (1993) does not directly indicate the size of Dodge'e escape fire, although he does give some indication of its shape in Figure 4 of his publication. In saying this, it appears that Butler and Cohen (1998c) have inadvertently misinterpreted the dimensions of Dodge's escape fire based on the information presented in Rothermel (1993). The following passage from Rothermel (1993, p. 6) is pertinent to the discussion here:

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[10] Using the 1952 topographic map of the Mann Gulch Fire area (*see* Cohen 1983, p. 150; Maclean 1992, plates 8-9; Matthews 2007, p. 42), this 76% upslope steepness value mentioned by both Maclean (1992) and Rothermel (1993), was independently confirmed by the senior author of this paper.

> *From point 2, where the crew dropped their tools, to point 3, where Dodge lit the escape fire, is about 240 yd; if the fire were spreading from 360 to 610 ft/min, it could have covered the distance in 1 to 2 min. Its arrival time at point 3 would have been between 5:55 and 5:56. If the slowest members died at about 5:56, as indicated by Harrison's broken watch*[11]*, the estimated time of the fire's arrival is reasonable. We can set the time that the main fire overran Dodge's escape fire at about 5:55:30.*
>
> *This estimate is consistent with Dodge's statement that the main fire was only 50 yds* [i.e., 150 feet or 46 m] *away when he stopped to light his escape fire. The main fire could cover 50 yd in 15 to 30 s if it were spreading from 360 to 610 ft/min. If the men near Dodge died at 5:56, when Harrison's watch stopped, then Dodge and those with him arrived at point 3 were he lit his fire at about 5:55.*

The map presented in Figure 4 of Rothermel (1993, p. 9) implies that Dodge's escape fire spread to the ridgeline, some 100 to 140 yards (i.e., 300-420 ft or some 92-128 m) away according to Maclean (1992). It's worth noting that Rothermel (1993) indicates that his Figure 4 map is "Not to scale".

The 1952 topographic map of the Mann Gulch Fire area included in the books by Cohen (1983, p. 150), Maclean (1992, plates 8-9) and Matthews (2007, p. 42) as well as various essays, notes the two separate locations of where "Dodge set escape fire" and "Dodge survived here". As Maclean (1992, p. 204) notes, it appears the two locations are separated by about three 20-ft contour intervals (i.e., a 60 ft or 18 m "rise"). Assuming a 76% slope (Maclean 1992; Rothermel 1993), this equates to a horizontal or slant distance (i.e., "run") of 79 ft or 24 m.

In his Board of Review testimony (p. 118), Dodge made the following statement regarding his escape fire:

> *After setting a clump of bunch grass on fire, I made an attempt to start another one, but the match had gone out and upon looking up, I had an area of 100 feet square that was ablaze. I told the man nearest to me that we would wait a few seconds to give it a chance to burn out inside, and then we would cross through the flames into the burned area …*

[11] Matthews (2007, p. 260) indicates that the small second hand on James Harrison's watch is stopped at 45 seconds. In other words, the time on his watch is frozen at 5:56:45 p.m. While this is interesting because it isn't mentioned in Maclean's (1992) book or any other accounts of the Mann Gulch Fire, there are at least two reasons to discount placing any significance on it. First of all, it's unlikely that the watch would have been precisely set to the actual correct time in the first place. Secondly, the watch would have not instantly frozen at the moment that the fire caught Harrison. Any matter of time may have elapsed. Interesting, the report of the Board of Review (p. 10) indicates a "recovered watch stopped at 5:57 p.m.". According to Maclean (1992, p. 233) there seven or eight recovered watches. Furthermore, as pointed out by Dave Turner (personal communication), in the photo of Harrison's watch presented in Matthews (2007, p.193) and also on www.nifc.gov/safety/mann_gulch/, the time looks closer to 5:59 p.m.

It's worth noting that Dodge technically meant to say "100 feet squared" (i.e., 10 x 10 ft) not "100 feet square" (i.e., 100 x 100 ft) or perhaps this was simply a typographical error on the part of the stenographer or typist (i.e., to have not included the "d" at the end of the sentence). In Turner's (1999) summary account of the Mann Gulch Fire he explicitly indicates that the initially burning area observed by Dodge was "10' x 10' ".

In report of the Board of Review (p. 9) it's noted that after lighting the escape fire and explaining his actions to the men that were near him that:

> *Dodge then walked around to the north* [i.e., the upslope] *side of the fire he had started as an avenue of escape. He called to the men to go into the burned area, but was unsuccessful in getting them to do so. He then walked*[12] *through the flames into the burned area for about 30 feet, lay down, and continued to call the men to join him. (The identical spot Foreman Dodge occupied has been definitely located and marked.) At this time, the main fire was very close to the spot Dodge had fired to provide a retreat area …*

Thus, it would appear that Dodge's escape fire at the time he entered it would have been approximately 109 ft (i.e., 79 + 30 ft) or about 33 m in length. According to Matthews (2007, p. 160) the flames were waist high but I suspect this reference comes from Walt Rumsey's Board of Review testimony (p. 104) as no such mention is made by Wag Dodge in his Board of Review testimony regarding the height of the flames associated with his escape fire.

If we take Dodge's initial estimate of the fire size after a few seconds – for convenience lets assume 2.5 seconds (i.e., between 2-3 seconds) elapsed between the time he ignited the grass with the first match and then looking up after attempting to light a second match. Thus, assuming 10 ft or ~3 m upslope spread after 2.5 seconds – the total upslope spread after 30 seconds would have been on the order of 120 ft (i.e., 30 seconds x 4 ft/sec) or some 37 m; downslope spread would have been very minimal -- perhaps a few feet at most (Forestry Canada Fire Danger Group 1992). This estimate is viewed as a conservative one given that there would have been a slight increase in the rate of spread within the 30 seconds elapsed time since ignition for a point source fire (cf. McAlpine and Wakimoto 1991; Forestry Canada Fire Danger Group 1992; Cheney and Gould 1997), although the unidirectional spread of the fire would have limited (Cheney and Gould 1995).

Wind and slope have the combined effect of increasing the radiation and convective heating of fuel ahead of the advancing flame front, there by increasing the fire's spread rate of spread and intensity (Figure 2A). The spread rate of Dodge's escape fire would have been strongly aided by the flame attachment phenomenon (Figure 2B) that commonly occurs on very steep slopes (Van Wagner 1977; Luke and McArthur 1978; Rothermel 1985; Cheney and Sullivan 2008).

[12]According to Gidlund (1966) "Dodge crossed his arms before his face, dashed through the waist-high flames and skidded downhill for 30 feet, still calling for his men to join him as he dropped to the ground."

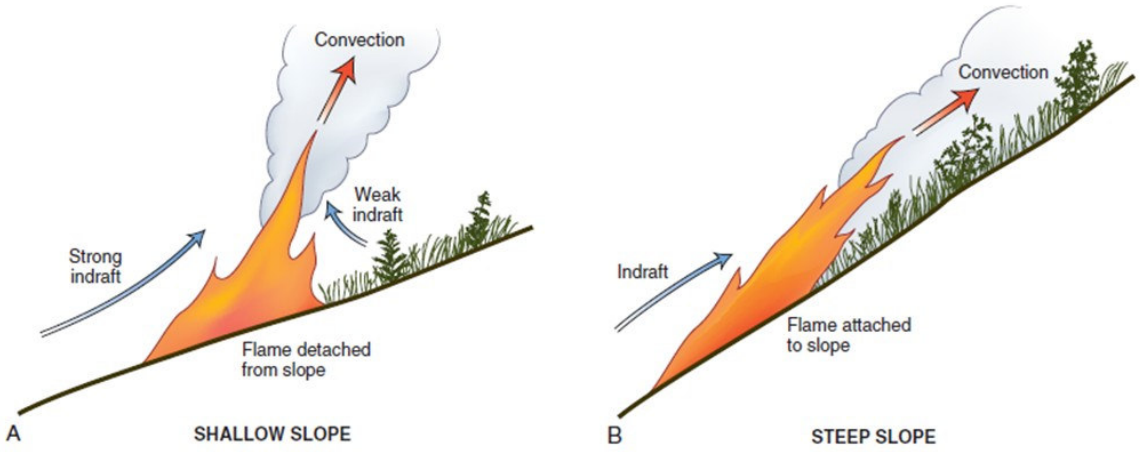


**Figure 2. Effect of slope steepness on degree of flame attachment and convective heat transfer for shallow sloping (A) and steep sloping (B) terrain (from Alexander et al. 2007; adapted from Rothermel 1985).**

In any event, 120 ft or 37 m appears reasonably logical given the estimate of 109 ft or 33 m as deduced above and therefore at odds with the "several hundred feet long" suggested by Rumsey (2006). According to these calculations, Dodge would have entered his escape fire with about 3 seconds left before his burned area was overrun by the main advancing fire front. This time might be off by a couple of seconds but probably not much more.

The question now becomes how wide would Dodge's escape fire have likely been? On a 76% slope in grass, a point source fire would in the absence of any appreciable wind, as suggested by Rothermel (1993, p. 7)[13], have a final L/B of around 8:1, thereby suggesting that a 76% slope is equivalent (McAlpine et al. 1991) to a wind of 44 mph or 70 km/h; this is a good indication of the "power of the slope" in this case. This estimate[14] of L/B is based on the standing (O-1b) grass fuel type in the Canadian Forest Fire Behavior Prediction System (Forestry Canada Fire Danger Group 1992; Wotton et al. 2008) assuming a fine, dead fuel moisture content of 3% as suggested by Rothermel (1993). This L/B of 8:1 would have been achieved once the fire has reached its final, equilibrium rate of spread. A point source fire initially has a circular shape soon after ignition (even on a very steep slope) as implied by Dodge's initial assessment of his escape fire after looking up after attempting to light a second match. The fire becomes more elongated or elliptical in shape with time (Cheney and Gould 1995). We have estimated on the basis of the recent work by Wotton et al. (2008) dealing with L/B variation with elapsed time since ignition (Figure 3), that the L/B at 30 seconds would have been about 1.4:1. For comparative purposes the L/B after a minute or 60 seconds would be 1.8:1. Given a

[13] Immediately downwind of the main advancing fire front, there would have been a zone of still, smoke-free air in which the ambient wind would have been blocked by the fire and its convection column (Sullivan et al. 2007).

[14] To our knowledge, no point source experimental fires in grass on steep slopes have been carried out to date anywhere in the world in order to validate this estimate.

overall length of 120 ft or 37 m, this places the width of the escape fire at around 86 feet (i.e., 120 ft/1.4) or 26 m for an elapsed time since ignition of 30 seconds.

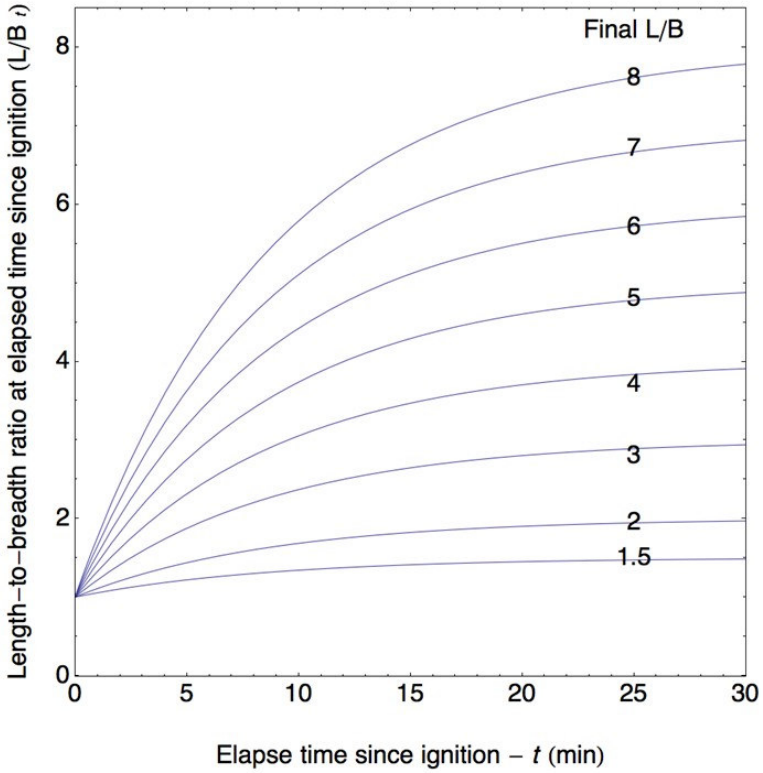


**Figure 3. Length-to-breadth ratio for point source fire as a function of elapsed time since ignition according to Wotton et al. (2008).**

Thus, Dodge's escape fire would have been about 120 ft in length by 86 ft in width (37 x 26 m). This constitutes an elliptical shaped area of 8082 $ft^2$ (0.2 acre) or 768 $m^2$ (0.08 ha). If the escape fire was in fact narrower (i.e., L/B > 1.4:1 at 30 seconds elapsed time since ignition) then the area burned would correspondingly be less.

How soon would the area in the middle of Dodge's escape fire have begun to burnout (Figure 1A)? Initially when Dodge looked up after trying to light a second match we are led to believe from his Board of Review testimony that he observed a more or less solid blazing area (Figure 4A). Given a flame front residence time of 5-15 seconds for grass (cf. Cheney and Sullivan 2008), the soonest any burned out area would have begun to appear would have been after the head of the fire had spread 20 ft or so upslope -- i.e., after about 5 seconds elapsed time since ignition (Figure 4B). Give a forward spread rate of ~4 ft/sec or 1.2 m/sec (i.e., 10 ft in 2.5 seconds), the horizontal flame depth (Figure 5) or the band of the actively spreading flaming combustion zone would have been have been of the order of 20-60 ft (6.1-18.3 m) at the head of the fire, the range being a function of the assumed flame front residence time (flame depth = rate of fire spread x flame front residence time). The depth and other dimensions of the flame front would accordingly be less as you proceed from the head of the fire down along the flanks to the back or rear of the fire (Catchpole et al. 1992) as illustrated in Figure 1.

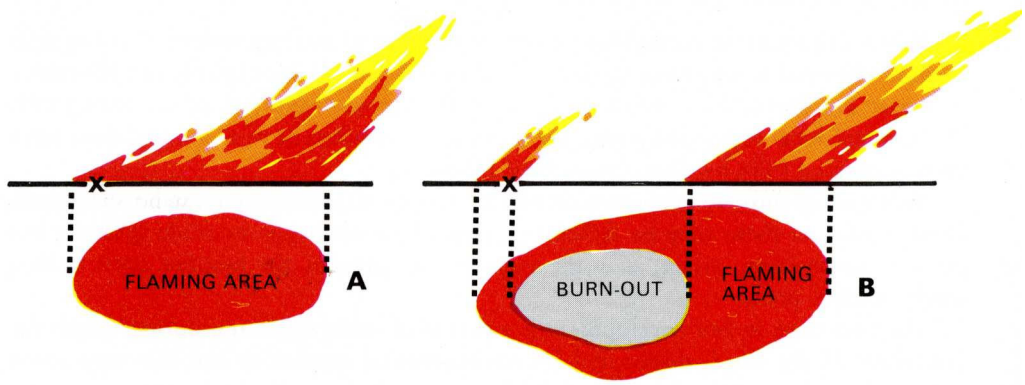


**Figure 4. Initial stages in the development of a point source fire: (A) shortly after ignition with flames leaning upslope and/or with the wind and (B) after the centre burns out the rear spreads slowly downslope with low flame heights while the head fire spreads rapidly upslope and/or with the wind (from Luke and McArthur 1978).**

### How tall were the flames of the main advancing fire front?

We now turn our attention to the second issue regarding Dodge's escape fire as a survival zone, namely how tall were the flames of the main advancing fire front that swept around the "island" of safety that he had created? First of all, it is important to distinguish between what is meant by flame length versus flame height and the connection between the flame length and flame depth as illustrated in Figure 5. Furthermore, it's worth noting that the flame depth of the main advancing front on the Mann Gulch Fire would have been quite deep as a result of the fire's rate of advance. Given the flame front residence time of 5-15 seconds for grass and a spread rate of at least 6 ft/sec (360 ft/min) or 1.8 m/sec on a 18% slope[15] with estimated mid-flame winds of 15 to 20 mph (24-32 km/h) as indicated by Rothermel (1993), the horizontal flame depth would have varied from at least 30 to 90 ft (9 to 27 m), again the range or variation being a reflection of the presumed flame front residence time

Given a nominal spread rate and an estimate of available fuel, we can compute a fireline intensity and in turn a flame length (Byram 1959). Grass fuel quantities in Mann Gulch in 1949 were known to be plentiful given the abundant rainfall the previous year and the restriction on livestock grazing (Maclean 1992). Rothermel (1993) considered that the grass fuels in the area associated with Dodge's escape fire were equally represented by fuel model 1 - short grass) and fuel model 3 - tall grass (Anderson 1982). This would imply an available fuel load of 1.87 tons/acre or 4.2 tonnes/hectare. This compares favorably with the result (i.e., 1.78 tons/acre or 4.0 tonnes/hectare) from Brown and Marsden's (1976) equation for estimating grass fuel load based on height (i.e., 1.5 feet or 46 cm) and the proportion of ground covered (i.e., 100%). Making a small allowance for the rocks in the area (say ~20%), the estimate for the available grass fuel load is 1.56 tons/acre or 3.5 tonnes/hectare

[15] Using the 1952 topographic map of the Mann Gulch Fire area (*see* Maclean 1992, plates 8-9; Matthews 2007, p. 42), this 18% cross-slope steepness value mentioned by both Maclean (1992) and Rothermel (1993) was independently confirmed.

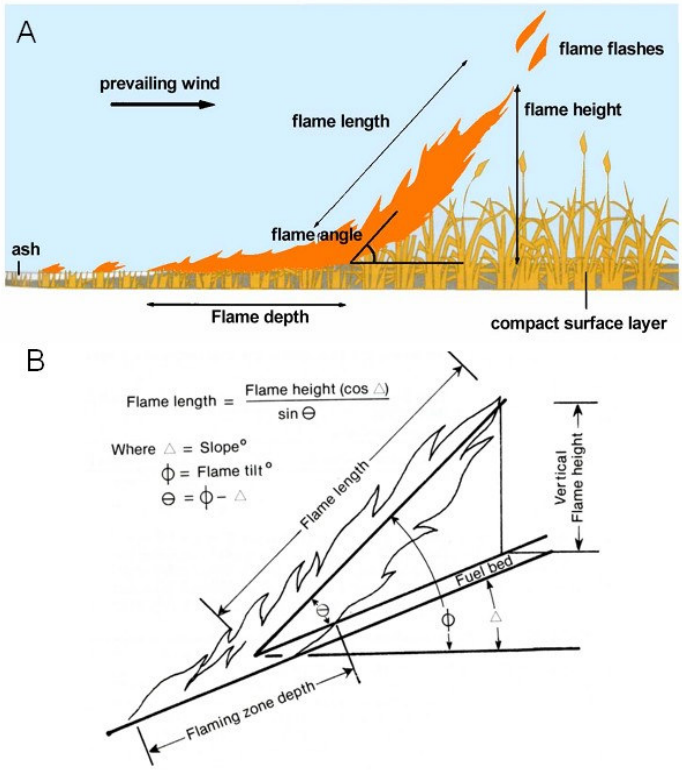


**Figure 5. Idealized cross-sections of a (A) surface head fire in grass fuels on level terrain (from Cheney and Sullivan 2008) and (B) and the case of a surface head fire spreading upslope (from Ryan 1981), illustrating various flame front dimensions.**

On the basis of the estimates of spread rate and available fuel load coupled with a low heat of combustion of 7744 Btu/lb or 18,000 kJ/kg (Forestry Canada Fire Danger Group 1992), the calculated fireline intensity is 3333 Btu/sec-ft or 11,529 kW/m. According to Byram's (1959) fireline intensity-flame length relation, this equates to a flame length of around 19 ft or 5.7 m. In turn, the flame height prediction model of Nelson and Adkins (1986) based on fireline intensity and wind speed at ground level (assumed to be 17.5 mph or 28 km/h) suggests that the average flame height have been ~12.5 feet or 3.8 m.

Butler and Cohen (1998c, p.75) indicate that the "Flames were 10 m high (Rothermel 1993)." This would seem quite implausible given the general lack of flame defoliation in the ponderosa pine overstory (i.e., torching and crowning) in the area immediately adjacent to Dodge's escape fire evident in the photos presented in Figure 6. A similar impression is gained from viewing the photo given on plates 12-13 in Maclean's (1992) book and the one photo in Jenkins' book (1995) indicating the location of where Smokejumper David Navon died plus several aerial oblique photos that were taken soon after the fire (Fig. 7)[16].

[16] Photographs contained in other sources (e.g., Friedrich 1951) taken very soon after the Mann Gulch Fire certainly attest to the widespread torching and crowning that occurred throughout the drainage, notably in the bottom of the gulch, all along the north-facing slope (see Maclean 1992, plate 3), and in sections of the south-facing slope. However, the photographic evidence does not support this claim in the area immediately adjacent to Dodge's escape fire (Figures 6-8).

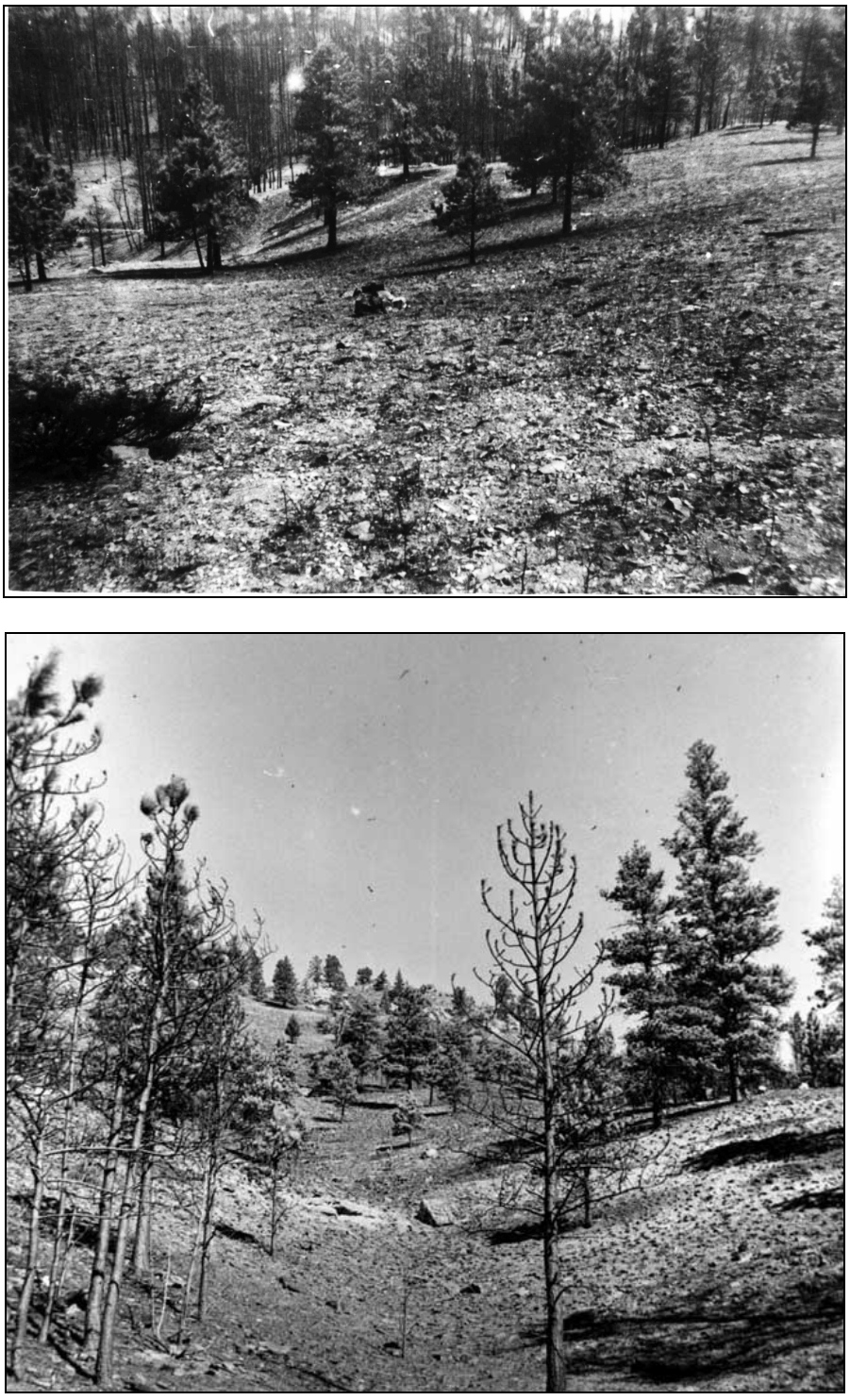

**Figure 6. Post-fire views of the general area of Dodge's escape fire area (from www.nifc.gov/safety/mann_gulch/). Top photo is view looking south, downslope towards the point of ignition (marker in center of photo). Bottom photo is view looking, north upslope towards the escape fire area. Black and white photographs make it virtually impossible to determine the exact extent of lethal crown scorching.**

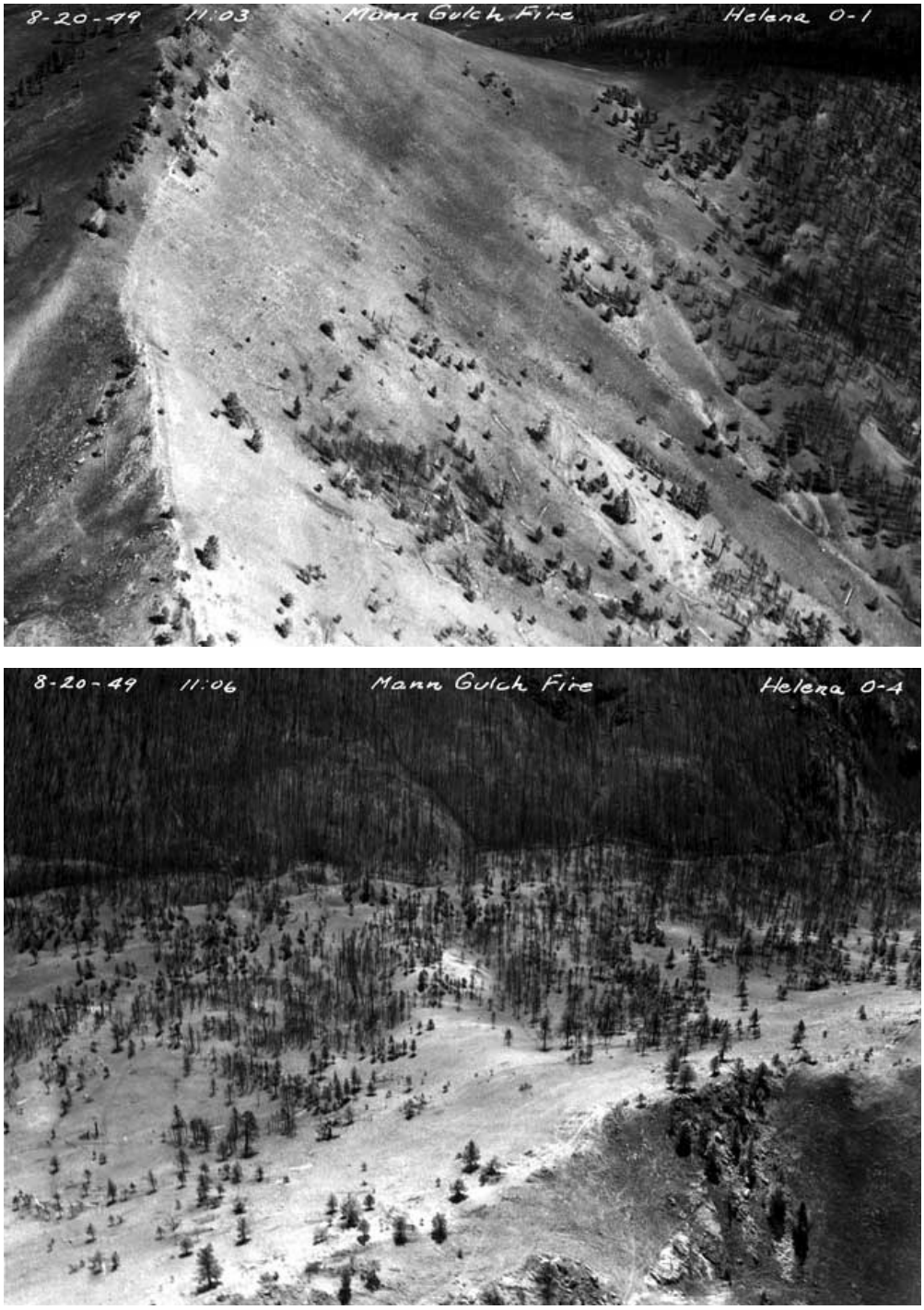


**Figure 7. Post-fire oblique aerial photos of the upper south-facing slope of Mann Gulch associated with the fatality sites (from www.nifc.gov/safety/mann_gulch/). The bodies of David Navon, Henry Thol Jr. and others were retrieved from area in the lower part of the top photo. The bottom photo shows the ridge line separating Mann Gulch and Rescue Gulch (lower right corner of bottom photo). The black and white photographs make it virtually impossible to determine the exact extent of lethal crown scorching.**

Additional photos illustrating the lack of any flame defoliation in the tree overstory can also be found at the National Wildfire Coordinating Group's Wildland Fire Accident Virtual Site – Mann Gulch Fire (www.nifc.gov/safety/mann_gulch/). However, probably one of the most revealing post-fire photos associated with Dodge's escape fire is that included in Cohen's (1983) book (Fig. 8).

**Figure 8. Cohen (1983, p. 152) indicates "Dodge started a fire here that saved his life. Photo from Jack Nash collection." This black and white photograph makes it virtually impossible to determine the exact extent of lethal crown scorching.**

In actual fact, Rothermel (1993, p. 6) indicated that the flames would have "ranged from 10 to 40 ft [3-12 m] long" based on his simulation modeling of fire spread and intensity; nowhere in his report does he make any mention of flame heights, only flame lengths. This point is reiterated in a short essay by Rothermel and Brown (2000) based on Rothermel (1993) who state that "flame lengths might have reached 40 feet (12 m)".

In other versions of their 1998 *International Journal of Wildland Fire* article, Butler and Cohen (1998a, 1998b) have indicated that flame heights of 10 – 40 ft or 3-12 m were estimated to have occurred and cited Rothermel (1993) as their source – once again just indicating that they had deliberately interpreted Rothermel's (1993) flame length estimates to represent flame heights. This was likely done on the grounds that flame lengths -- a quantity commonly available from fire behavior guides and simulation modelling systems (Rothermel 1983; Andrews et al. 2008) -- are always greater than flame heights, with one exception -- they are only equal under no wind and no slope conditions (Rothermel 1972; Alexander 1982). Thus, flame length represents a "worst-case estimate" of flame height (Andrews 2008).

Maclean (1992, p. 274) claims the flames of the main advancing fire front in the clearing where Dodge lit his escape fire "would have been thirty feet tall". This statement is based on the fire behavior analysis and simulation modeling work on the Mann Gulch Fire undertaken by Dick Rothermel as mentioned in Maclean (1992). In the fall of 1993, Rothermel was kind enough to provide the senior author of this paper with a copy of these written materials which were the basis for his formal publication on the Mann Gulch Fire (Rothermel 1993). Based on a read of Rothermel's documentation, we believe that Norman Maclean simply interpreted the predicted flame lengths provided by Rothermel as flame heights.

The best estimates of the flame heights associated with the main advancing fire front would ideally have come from the three survivors – i.e., Wag Dodge, Bob Sallee and/or Walt Rumsey. Unfortunately no mention is made of the flame heights associated with the main advancing fire front in the Board of Review testimony as the question was never directly asked of them.

When asked at the Board of Review about the flames on the right flank of Dodge's escape fire, Bob Sallee (p. 79) indicated that "In places it was burning about a foot high – from a foot to 3 feet, I would say." and Walt Rumsey (p. 104) thought "Waist or shoulder high. I don't know." Very similar information is included in the statements they made in 1951 that are included in Cooley's (1984) book (i.e., p. 102 and p. 108).

Dodge makes no mention of flame sizes associated with his escape fire or of the main advancing fire front in either his Board of Review testimony or his summary statement included in Cooley's (1984) book. However, according to Matthews (2007, p. 160) "shoulder-high flames raced around his sanctuary in pursuit of his crew" – in making this statement we believe the author has mistakenly made reference to Rumsey's claim regarding the size of the flames associated with the right flank of Dodge's escape fire.

No mention of the flame height of the main advancing fire front is mentioned by Rumsey or Sallee in either Maclean (1992) or in Gidlund's (1966) essay. Nor is there any mention in subsequent interviews with Sallee by Smith (2000) and Maclean (2003, 2004).

Jenkins (1995) made two specific mentions of the flame heights associated with the main advancing fire front: "The wall of flame is solid and higher than a man's head." (p. 160) and "an eight-foot wall of flame" (p. 161). Eight feet or 2.4 m is certainly higher than any man's head.

These estimates contained in Jenkins (1995) match up reasonably well with the empirical relationship (Figure 9) established between forward rate of fire spread and flame height for natural pastures presented in Cheney and Sullivan (2008, p. 38, Fig. 4.6) based on experimental fires carried out in grass as documented by Cheney et al. (1993). Thus, for a grass fire spreading at 6 ft/sec or 1.8 m/sec which equals ~6.5 km/h, average flame heights would be about 3 m (10 ft) which is in reasonable agreement with the estimate of flame height deduced earlier on the basis of a computed fireline intensity and presumed prevailing wind speed.

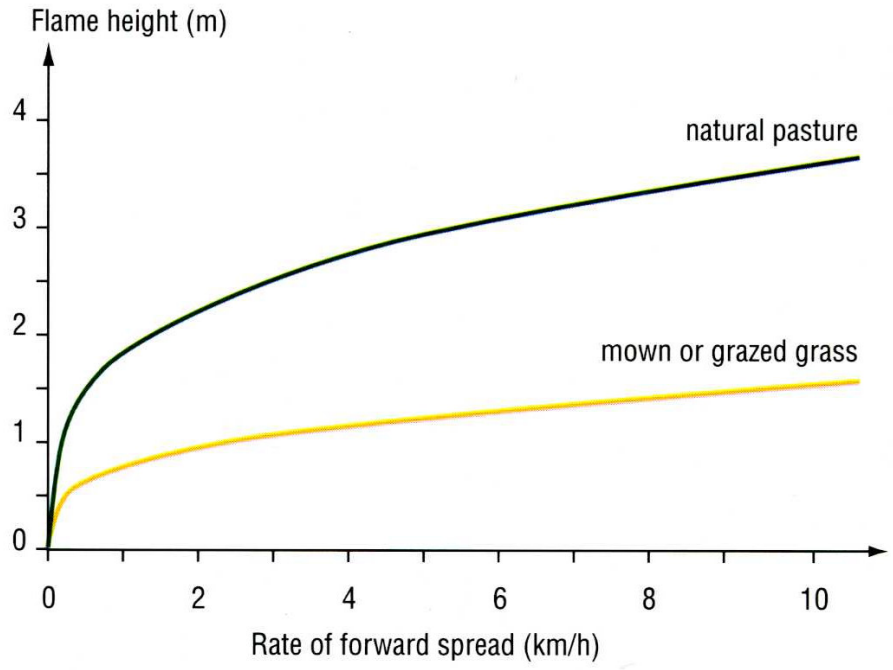


**Figure 9. Relationship between flame height and rate of fire spread in natural or ungrazed pastures (20-32 in. or 50-80 cm in height) and mown or grazed grasslands (<10 in. or 25 cm in height) (from Cheney and Sullivan 2008).**

## Discussion and Conclusions

After looking at an earlier review draft of this paper, Missoula Smokejumper Foreman Wayne Williams indicated that: "I think what your trying to do is impossible. Even if Wag was alive, I doubt he could tell what the size was". While there is certainly respect for this opinion, it's felt that on the basis of the foregoing analysis and review it is nevertheless possible to arrive at the following "best estimates" and at the same time correct some misinterpretations that have crept into the literature. Assuming an elliptical shape, Dodge's escape fire was about 120 ft (37 m) long and 86 ft (26 m) wide at its maximum breadth (Figure 10) at the time it was overrun by a flame front approximately 10 ft (3 m) high and exceeding 30 ft (9 m) in depth.

We know of course that Dodge survived (without any burn injuries or singed marks on his clothing) from being overrun by the main advancing fire front within the area burned off by his escape fire. Question is, could his escaped fire have safely accommodated a total of 16 firefighters?

A reasonable area for each firefighter is 6 x 2 ft (18 $ft^2$) or 1.8 x 0.6 m (1.08 $m^2$). Taking into account the shape of the burned out area of the escape fire, the optimum configuration would have the firefighters with their heads and bodies lying directly uphill (either on their sides with their backs turned towards the main advancing fire front or on

their stomachs) in five rows of three firefighters each (i.e., a 5 x 3 matrix) and then a single firefighter in the sixth row. Assuming a foot (0.3 m) separation between each individual firefighter and the same between each row, this amounts to a minimum area of around 41 x 8 ft (12.5 x 2.4 m) as illustrated in Figure 10. The firefighters on the far left or western edge of the refuge area would have had a separation distance of some 39 ft (11.9 m) from the advancing flame front. Firefighters on the north and south ends of the refuge area would have a maximum separation distance of about 39.5 ft (12 m).

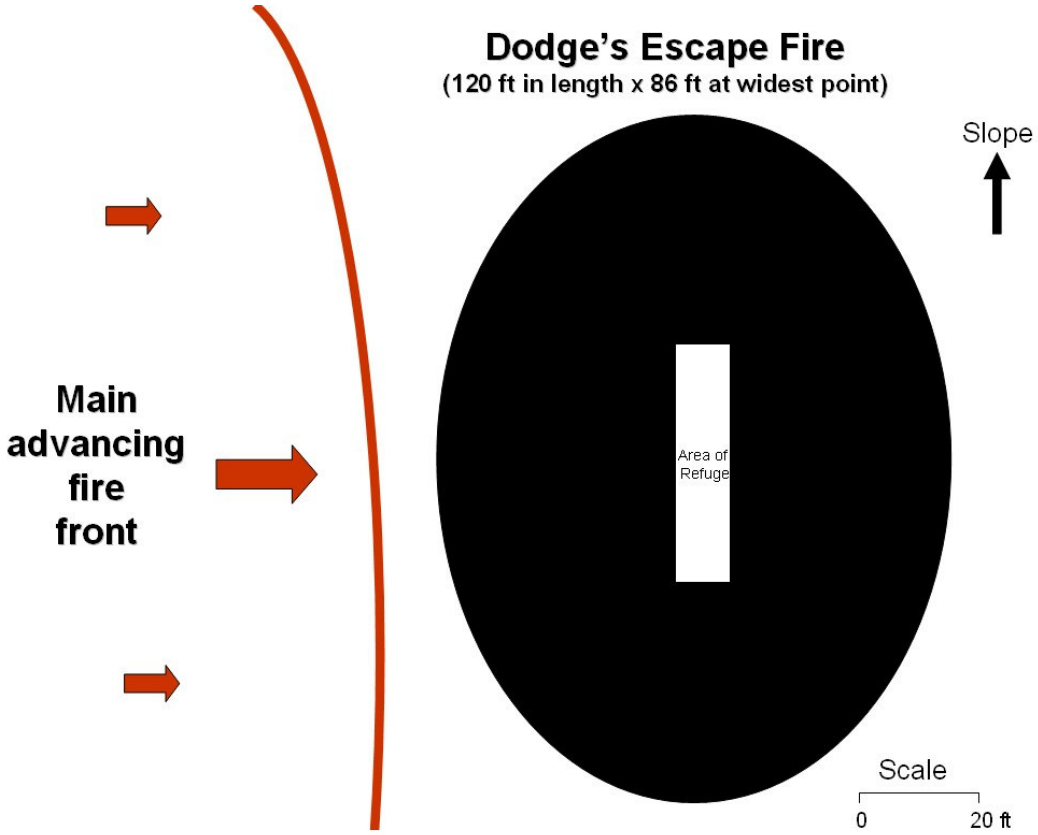


**Figure 10. Conceptualization of the minimum area of refuge (41 x 8 ft or 12.5 x 2.4 m) that could be occupied by 16 firefighters within the area burned off by Dodge's escape fire on the Mann Gulch Fire just prior to the arrival of the main advancing fire front. Note: the exact orientation of the main advancing fire front relative to the escape fire area is unknown.**

Assuming 10 ft (3 m) tall flames, the refuge area would have not met the 4X flame height safety zone guideline of Butler and Cohen (1998c) for all of the firefighters. Furthermore, if the separation distance was reduced to account for the horizontal reach or flame intrusion into the burned area, which is not accounted for directly in their safety zone guideline, there would not have been sufficient space or separation distance. Note that the Butler and Cohen (1998c) guideline assumes that firefighters are standing as opposed to lying down.

The issue of whether the refuge area could have constituted a survival zone for all of the firefighters laying flat against the slope now remains to be assessed based on the methodology initially developed by Alexander et al. (2009) for simulating the thermal environment (cf. Sullivan et al. 2003) associated with wellsite clearings or openings as survival zones. This assessment will be reported on in greater detail at a later date. A short synopsis is presented here. In the present case, the clearing represented by Dodge's escape was modeled as an ellipse with major and minor axes parallel to the principle coordinate axes (Figure 11). The size of the clearing is determined by the major and minor axis dimensions, A and B, as follows:

$$\left[\frac{x}{A}\right]^2 + \left[\frac{y}{B}\right]^2 = 1$$

The clearing was judged to be 120 x 86 ft (37 x 26 m) in size. The flame front was assumed to be parallel to the major axis of the elliptical shaped clearing created by Dodge's escape fire (Figure 11). The flame front is judged to be 328 ft (100 m) wide and it is always positioned so that its center follows a line between the center of the front and the center of the ellipse. In this manner the portion of the flame front to either side of the ellipse center remains equal. The flame front has a constant depth of 33 ft (10 m) associated with it. The flames were assumed to be 10 ft (3 m) tall and it was further assumed that there was no blockage of the radiation from the flames to the receiving surface within the clearing. Finally, in a survival zone its assumed that a firefighter is lying prone on the ground. This position produces a lower shape or view factor between the flame front and the person on the ground.

When the flame front approaches the clearing the energy transfer from the front to a position in the clearing is determined as the shape factor between the emitting and receiving surface multiplied by an arbitrary emission from the flames (i.e., 100 kW/m$^2$ which is equivalent to a black body radiator at 880 $^o$C or 1620 $^o$F). As the flame front reaches the clearing it will begin to wrap or go around the clearing. Initially the front will form a line with a curved section in the center that corresponds to the elliptical shape. When the back of the flame reaches the edge of the ellipse it was assumed to split into two separate fronts which go around the clearing.

The magnitude of the heat flux that a person can tolerate without receiving thermal injury is a very nonlinear relationship between radiant heat flux and time. According to Stoll and Green (1959), the onset of a thermal injury to bare skin would occur within 10 seconds at a radiant heat flux of slightly less than 10 kW/m$^2$. Clothing affords some protection by blocking the incident thermal radiation and its effect depends on the material properties as well as whether it is in contact with the skin. With typical clothing materials, the radiant heat flux required to produce a thermal injury within a 10 second time period is judged to about 30 kW/m$^2$. The resultant simulations of radiant heat flux are presented in Figure 12. Thus, based on currently available information, there is no reason to believe that Dodge and the other 15 firefighters could not have survived lying on the ground within the clearing created by his escape fire of the size indicated.

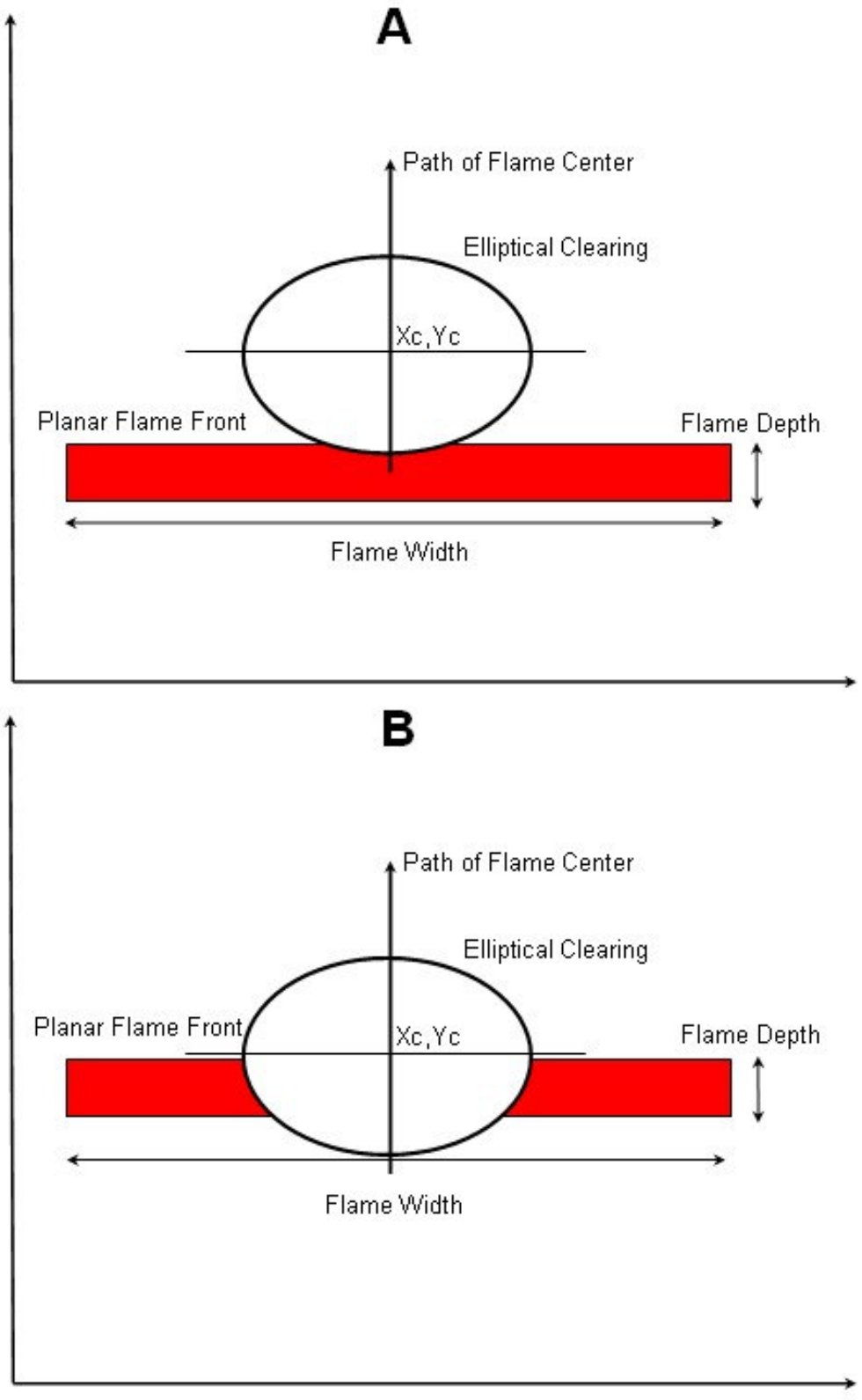


**Figure 11. Geometry of the simulation associated with the flame front of the main advancing fire (A) intersection and (B) splitting around the elliptical-shaped clearing created by Dodge's escape fire.**

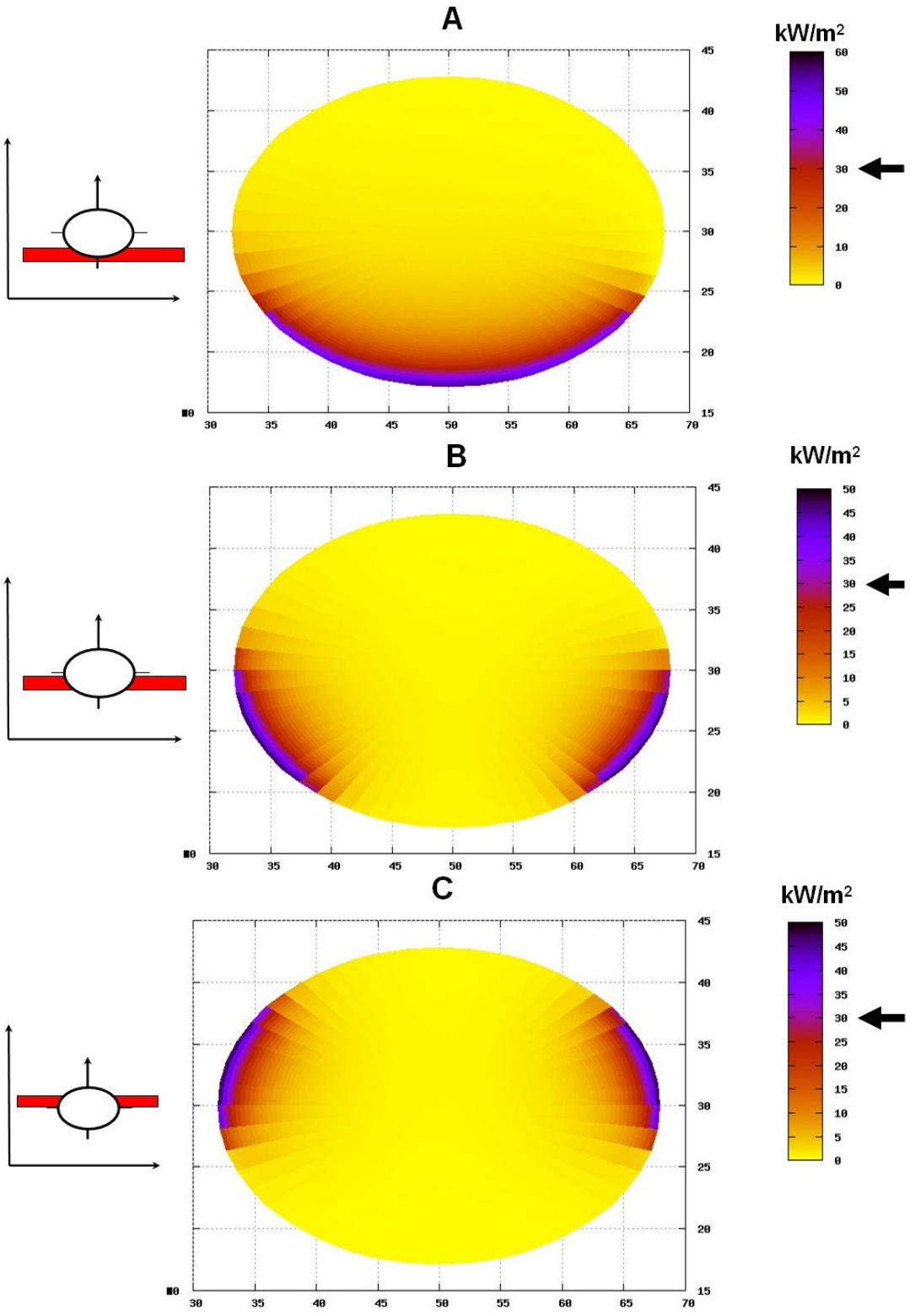


**Figure 12. Simulation of maximum radiant heat flux on the ground surface as the flame front of the main advancing fire (A) intersects, (B) begins to split and (C) passes the center of the elliptical shaped area burned out by Dodge's escape fire.**

## Epilogue

Dodge indicates in the 1951 statement included in Cooley's (1984, p. 98) book that:

> *When the main fire reached my area, I lay down on the ground on my side and poured water from my canteen on my handkerchief over my mouth and nose and held my face as close to the ground as I could while the flames flashed over me. There were three extreme gusts of hot air that almost lifted me from the ground as the fire passed over me. It was running in the grass and also flashing through the tree tops. By 6:10 p.m. the fire had passed by and I stood up. My clothing had not been scorched and I had no burns.*

In his Board of Review testimony (p. 117-125) Dodge made no mention of the fire's buoyancy effects on himself while he lay on the ground inside his escape fire. This would been the result of the strong in-drafts and outflows associated with the oscillations in the fire's buoyant plume or convection column as the main fire front surged and temporarily stalled as it met and then made its way around the area burned off by his escape fire (Figure 13).

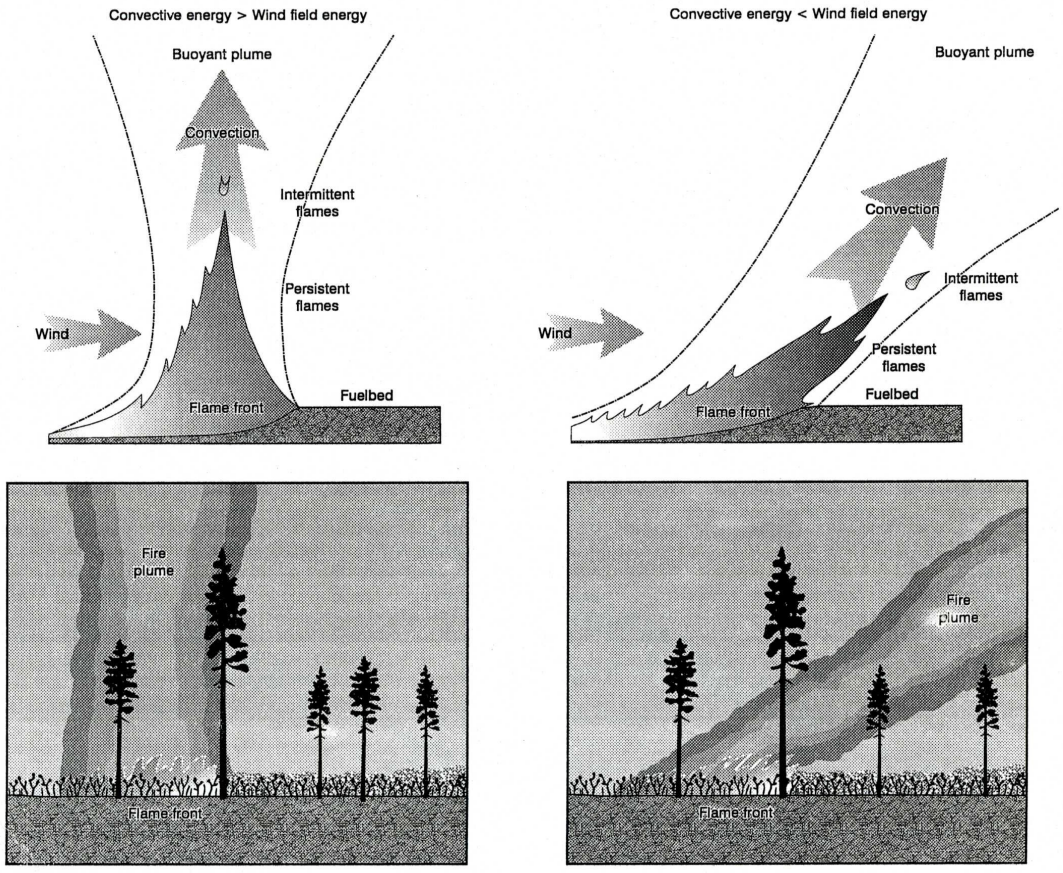


**Figure 13. Schematic illustration of the plume or convection column angle characteristics associated with surface fires in (A) calm or light winds and (B) moderate to strong winds (after Alexander 1998).**

In reviewing the existing written materials on Dodge's escape fire, we have detected the possibility of an inconsistency which may have crept into the literature concerning what happen to Dodge after he lay down on the ground. Several authors claim that Dodge was physically lifted off the ground as evident by the following statements:

> *Dodge later told Earl Cooley that, when the fire went over him, he was lifted off the ground two or three times.* (Maclean 1992, p. 106)
>
> *Dodge said fierce winds lifted him off the ground three times during the few minutes it took the fire to pass over him …* (Rothermel 1993, p. 7)[17]
>
> *But the winds and suction of that oxygen-devouring monster all around the pod are enough to pick Dodge up off the ground and flop him back down on it tow or three times as successive waves of fire battle for his soul.* (Jenkins 1995, p. 162)
>
> *As the main fire passed, it picked him up and shook him like a dog with a bone.* (Maclean, 2003, p. 180)
>
> *Wag suddenly felt buoyant, as if he were in a big vacuum, and the extreme gusts of hot air lifted him from the ground three separate times*. (Matthews 2007, p. 160)
>
> *The foreman of the crew later said that the extremely high winds from the firestorm lifted him from the ground several times as they passed over him* ... (Frantz 2007, p. 225)
>
> *Dodge was lifted off the ground two or three times by the strong updrafts (convection) generated by the fire.* (Benson n.d., 9. The race is on.)

Lillquist (2006, p. 567) on the other hand, citing a front page story in the 14 August 1949 issue of *The Missoulian* newspaper, claims that "Three violent gusts of superheated air nearly lifted him from the ground". When this subject was recently raised with Mike Hardy (2009) he indicated to us that "I sat on a log with Wag the day after the big run. He told me directly that when the fire went over him he was lifted from the ground bodily three times."

Flow over a body on the ground was examined to determine the required flow acceleration that would result in sufficient pressure reduction to balance the weight. The Bernoulli principle was applied between a point upstream and at the point of maximum flow acceleration, directly above the body. The change in velocity necessary to produce a low pressure sufficient to just lift a 175 lb (80 kg) mass was thereby estimated. This

[17] Rothermel (1993) credits a personal communication with C.E. Hardy for this statement. Charles E. "Mike" Hardy worked in fire research for the U.S. Forest Service in Missoula, Montana, from 1951 until his retirement from the Northern Forest Fire Laboratory (NFFL) in 1973. Wag Dodge worked for the Division of Fire Research (the forerunner of the NFFL) in the winters during the early 1950s as an "instrument repairman" (Cooley 1984, p. 128). In this regard, Dodge would have had frequent contact with Hardy who also worked in this same division.

crude means of estimation was used to determine whether the required wind speed changes were within the realm of possibilities for the type of fire that was likely present at the time of Dodge was overrun within his escape fire. On this basis, it's estimated that the winds would have had to exceed 87 mph (140 km/h) in order to have lifted Dodge off the ground. While this is certainly within the range of entrainment winds observed on fires involving large quantities of fuel, such winds have not been measured on grass fires (Trelles and Pagni 1997). Of course it's quite possible that fire-induced vortices could have produced such wind velocities

## Acknowledgments

Thanks to Starr Jenkins, John Maclean, Mark Matthews, Dick Rothermel, Darrin Woods and especially to Dave Turner for their review and comments on various drafts of this paper. The assistance of Doug Houston, Chuck Sheley, and Steve Smith of the National Smokejumpers Association, Dr. Karl Weick of the University of Michigan, Dr. Mike Wotton of the Canadian Forest Service and University of Toronto, and Dr. Miguel Cruz of CSIRO Australia in providing pertinent information and advice is also gratefully acknowledged.

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