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Wind-enabled ember dousing

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Abstract

The greatest danger to homes during catastrophic wind-driven wildfire events comes from lofted brands. This paper describes a novel sprinkler system which is specifically designed to operate in the wind conditions associated with catastrophic wildland fires, and extinguish incoming firebrands. This system uses moderate water flow rates, allowing structure protection times of several hours using commercially available water reservoirs. A case-study of the construction and deployment of this system on a property in San Diego County is discussed. The operation of the system during the Cedar Fire of October 2003 is described, and its role in preventing the destruction of the dwelling is analyzed.

Keywords: Wildland; Urban; Wildland-urban; Wildfire; Bushfire; Interface; Ember; Firebrand; Sprinkler; Wind

1. Introduction—the firebrand threat

Most wildland fire structure loss occurs during catastrophic wind-driven events. The "Fire Siege" in California during the last week of October 2003 destroyed 4000 homes. This is greater than the US loss totals for 1999–2002 combined [1]. The Oakland fire of 1991, roughly equivalent to the 2003 Cedar Fire in number of homes destroyed, was also a wind-driven event [2]. Even in years of lesser loss, larger fires drive the statistics. For instance, the Jones fire near Redding, California in 1999 (also wind-driven) was responsible for over half of the US structure losses for that year. In fact, review of all historical California wildfires which caused significant structure loss reveals that virtually all of them occurred during high-wind conditions [3]. What these events have in common is that the firefighting response is overwhelmed and unable to effectively or safely protect homes over a large and rapidly moving fire front.

In wind-driven fires, the threat to structures from ember attack is greatly increased. Creation of "defensible" space around structures, free of easily combustible material, has been shown to be effective in preventing ignition from radiant heat and flame impingement [4], and this is now becoming part of standard fire codes [5,6]. The proper amount of recommended clearance depends on the fuel type and conditions, but generally does not exceed 30 m. An oft-quoted figure is that 90% of structures will survive which have at least 40 m of clearance [4]. However, a recent study by Chen et al. [7] of two Australian fires which moved from wildlands into developed areas measured a 50% destruction probability at distances of 45 m and 145 m from the fire front, respectively. Only brand-induced ignition can explain significant structure losses at these distances.

It has been long observed and noted [8] and shown theoretically [9,10] that firebrands can travel for great distances ahead of a fire front in high-wind conditions. Australian fire authorities, following Ramsay's classic forensic study of 1148 structures involved in the 1983 Ash Wednesday fires [11] have long believed that firebrand attack is the predominant cause of structure loss during wildland fires [7,11–14]. US experts are now likewise conceding that embers are a significant cause of structure ignition during catastrophic, wind-driven wildland fires [15,16].

The currently accepted best practice in the United States for protecting structures against firebrand threat is by the selection of construction materials and building techniques

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[5,6]. This approach, however, may not be applicable to all structures or acceptable to all homeowners. Historic structures, for instance, cannot benefit from such modifications. Some homeowners may balk at either the cost or aesthetic impacts of the major modifications necessary to ember-proof an existing home. At the more fundamental level, these modifications are only as effective as their weakest points: any open nook or cranny, temporary pile of flammable material, wooden door or window frame or ornament can provide a place for firebrands to lodge and cause secondary ignition. Furthermore, due to extreme wind conditions, ember impingement can be nearly horizontal, meaning that all structure fascia are potential ember targets. The wind can also create gaps under shingles, or cause embers to "burn through" an insufficiently fine wire mesh. Even tile roofs, ubiquitous in the Southern California Wildland–Urban Interface (WUI), can support ignition if there are unsealed gaps under the tiles where brands can enter [17]. Structural solutions are sound, but there can be no breaches in their integrity, even under gale-force wind conditions.

Another approach is an "active defense" strategy in which embers and secondary fires are extinguished. The currently accepted policy of requiring "defensible space" as the primary protection assumes that firefighters will be available to provide this active defense. As stated earlier, this is not a realistic assumption in catastrophic fires. Australian fire authorities have long noted that the probability of a structure being saved is over 90% if able-bodied residents remain to extinguish secondary fires [7,11,12]. In the favored scenario, homeowners act to extinguish firebrands as the fire front approaches, shelter in their homes as it passes, and then emerge to quench embers and secondary fires once it has passed. This approach has been popularized in self-help books which are available to the Australian public [19]. Fire services elsewhere in the world often discourage this approach based upon the premise that many sheltering residents will be ill-prepared for the realities of an intense wildland fire, and thus may be injured or killed, or require rescue from already overtaxed fire personnel. Recent whitepapers from the California Department of Forestry [20], however, provide significant instruction for those sheltering or trapped in a wildland fire, and discuss the decision to evacuate as best left to the authorities rather than something which is inherently preferable.

2. Water-based sprinklers and ember dousing

2.1. Previous external water-based sprinkler systems

One "active defense" strategy is the use of external sprinklers or sprayers to wet the structure and surrounding areas. This idea is old, and has spawned many patents [21]. However, this strategy has not gained widespread acceptance by North American fire protection agencies. There are several counterarguments used against the effectiveness of external sprinkler systems:

- Most such proposals concentrate on the protection of the roof, and since most modern construction in the WUI areas employs fire-resistant roofing materials, the presence of a sprinkling system is redundant [22].
- Wind will disrupt the spray pattern, thus leaving some structure elements vulnerable to brands [4,14].
- In order to span the duration of brand attack (several hours), the system water usage will require the equivalent of a small pond, swimming pool, or dam [14].
- Area sprinklers are prone to wind disruption and can only affect ignition if their water density is very high [2,4].

The Australian fire protection community is currently evaluating a variety of sprinkler plans, the primary goal of which is to douse windborne brands [14]. They evaluate a number of configurations including misting and large droplet fixed head sprayers on the structure, and rotating head area sprinklers. Their conclusion is that the optimal system would (a) require a large amount of water and (b) be best implemented with a drip system that allows water to flow down the walls of the structure, since this is the least subject to wind disruption.

2.2. Using water-based sprinklers against firebrands

Previous designs assumed that one of the duties of the sprinkler system would be to reduce the heat load on the structure, and thus inhibit ignition by radiant heat or flame impingement. This is a significant design requirement, since a large quantity of water would be necessary to affect significant cooling. However, if the heat load is managed by separation from fuels, then the remaining threat is from airborne brands. This is a problem area distinct from thermal protection of the structure, and with different primary design requirements. There are three ways in which external water sprinkler systems can aid in reducing firebrand-induced ignitions:

- direct extinguishing,
- saturation of light fuels and
- creation of standing water zones and surfaces.

2.3. Direct extinguishing

If the spray density from the sprinkler is high enough, the brands may be directly extinguished once they enter the high-density region and remain there for a sufficient time. Considerable work has been done on the extinguishment of wood fires by water sprays. Reviews can be found in Refs. [23,24]. Results from crib experiments give results from 1.2 to $4.0 \times 10^{-3}\,\mathrm{kg/m^2\,s}$ as the critical spray density needed to extinguish burning cribs. Theoretical results, such as those calculated by Novozhilov et al., [23]