What are the Safety Implications of Crown Fires?

Marty Alexander. University of Alberta
Miguel Cruz, CSIRO Australia
As for big fires in the early history of the Forest Service, a young ranger made himself famous by answering the big question on an exam, “What would you do to control a crown fire?” with the one-liner, “Get out of the way and pray like hell for rain.”

Norman Maclean (1992)
Young Men & Fire
Crown Fire – This is the most spectacular kind of forest fire. Since it is over the heads of ground forces it is uncontrollable until it again drops to the ground, and since it is usually fast-moving it poses grave danger to fire fighters and wildlife in its path. It is the most common cause of fire fighters becoming trapped and burned.

Arthur A. Brown & Kenneth P. Davis (1973) Forest Fire: Control and Use. 2nd Edition
 Fatal and Near-Fatal Forest Fires
The Common Denominators

by Carl C. Wilson

Firefighting large forest fires often is compared to military operations. Each involves a highly structured organization with a "general" at the head, massive mobilization of men and equipment, and tactical aerial support and protection of the troops. The fire enemy finally can be put to flight by means of superior strategy: in suppressing large fires, it is estimated that the United States has lost the fire battle to the fire. Many people have lost the battle to the fire.

The concept is not unlike that of a war in which someone has lost. As this article will show, there are many similarities between the two. The factors that bring about fire deaths on many fires depend on many factors, the most important being that of human behavior.

A review of close calls in fires between 1926 and 1976 shows that near-fatal fires from fire-induced smoke resulted in the greatest number of near-fatal losses in recent years. The largest losses on single fires occurred on the Blackwater fire in Wyoming in 1937 and on the Rattlesnake fire in California in 1953 (Table 1). In each case, 15 people died. A similar analysis made of people lost on fires in areas protected by other Federal agencies and State agencies shows a higher proportion of near-fatal losses.

2. Most of the fires were innocent in appearance prior to the "flare-ups" or "blow-ups". In some cases, the fatalities occurred in the mop-up stage.

3. Flare-ups occurred in deceptively light fuels.

4. Fires ran uphill in chimneys, gullies, or on steep slopes.

5. Suppression tools, such as helicopters or air tankers, can adversely modify fire behavior. (Helicopter and air tanker vortices have been known to cause flare-ups.)

In Tables 3 and 4, near-fatal fires are those close calls which involved a potential threat to life. A review of these tables shows that most of the generalizations made concerning fire behavior apply to near-fatal fires as well as to fatal fires. The hairline difference between the two groups of fires is determined by the individual's reaction to his suddenly critical situation. Escapes may be said to be due either to luck, circumstances, advance planning, a person's ability to stay cool and not panic, or a combination of these factors. Whatever the reasons, individual behavior and circumstances determine between life and death. For the individual fire fighter and crew boss, it becomes increasingly important to be able to identify those conditions under which so many close calls and fatalities occur.
Common Denominators of Fire Behavior on Tragedy Fires

1. Most incidents happen on small fires or on isolated sections of large fires.

2. Flare-ups generally occur in deceptively light fuels, such as grass and light brush.

3. Most fires are innocent in appearance before unexpected shifts in wind direction and/or speed result in “flare-ups.” Sometimes, tragedies occur in the mop-up stage.
Common Denominators of Fire Behavior on Tragedy Fires

4. Fires respond to large and small-scale topographic conditions, running uphill surprisingly fast in chimneys, gullies, and on steep slopes.

5. Helicopters or air tankers can adversely affect fire behavior in certain situations. The blasts of air from low-flying aircraft have been known to cause flare-ups.
Common Denominators of Fire Behavior on Tragedy and Near-miss Wildland Fires

Some common denominators of fire behavior on tragedy and near-miss forest fires

by Carl C. Wilson and James C. Sorenson

U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
BROOMALL, PA 19008
December 1978

A Publication of the National Wildfire Coordinating Group
Sponsored by United States Department of Agriculture
United States Department of the Interior
National Association of State Foresters

Common Denominators of Fire Behavior on Tragedy and Near-miss Wildland Fires

PMS 407 June 1996
NFES 2225

Common Denominators of fire behavior on tragedy and near-miss forest fires

NFES 2225 March 1992
Many firefighters are surprised to learn that tragedy and near-miss incidents occur in fairly light fuels, on small fires, or on isolated sectors of large fires, and that fire behavior is relatively quiet just before the incident. Most of us believe that the high-intensity crown fire in timber or heavy brush is what traps and kills forest firefighters. Yet, with rare exceptions ... most fires are innocent appearing just before the accidents.

Wilson and Sorenson (1978)
Common Denominators of Fire Behavior on Tragedy Fires

There are four major common denominators of fire behavior on fatal and near-fatal fires. Such fires often occur:

1. On relatively small fires or deceptively quiet areas of large fires.

2. In relatively light fuels, such as grass, herbs, and light brush.

3. With unexpected shifts in wind direction or wind speed.

4. When fire responds to topographic conditions and runs uphill.

Alignment of topography and wind during the burning period should be considered a trigger point to reevaluate tactics.
Some Examples of Firefighter Fatalities Associated with “Timber” Crown Fires

- 1937 Blackwater Fire – Wyoming (15 fatalities)
- 1958 Wandilo Fire – South Australia (8 fatalities)
- 1967 Sundance Fire – Idaho (2 fatalities)
- 1977 Bass River Fire – New Jersey (4 fatalities)
- 1980 Mack Lake Fire – Michigan (1 fatality)
- 1990 Dude Fire – Arizona (6 fatalities)
- 1994 Sabie – South Africa (10 fatalities)
- 2001 Thirtymile Fire – Washington (4 fatalities)
Fire behavior is defined as the manner in which fuel ignites, flame develops, fire spreads and exhibits other related phenomena as determined by the fire environment.
The more important fire behavior characteristics from the practical standpoint of fire suppression are:

- Forward Rate of Spread
- Fireline Intensity
- Flame Front Dimensions
- Spotting Pattern (densities & distances)
- Fire Size and Shape
- Rate of Perimeter Increase
- Burn-out Time
Thermal Environment of a Wildland Fire

Time-temperature trace recorded as the moving flame front of a grass fire passes by a given point.
In-fire video from International Crown Fire Modelling Experiment

See “Inside the Fire”

http://www.youtube.com/
Contrasting Fire Behavior Potential: fuel type characteristics

**Grass**
- Fuel load – 1.6 T/acre
- Fuel height – 1 ft
- Degree of curing – 100%

**Conifer Forest**
- Surface fuel load – 5 T/acre
- Stand height – 45 ft
- Canopy base height – 20 ft
- Canopy fuel load – 4.5 T/acre
- Canopy bulk density – 0.14 lb/ft$^3$ (0.23 kg/m$^3$)
Contrasting Fire Behavior Potential: environmental conditions

Slope steepness: 0% (flat topography)

Air temperature: 86 deg F

Relative humidity: 20%

Grass fuel moisture: 4.8%

Conifer forest – surface fuel moisture: 6%
Contrasting Fire Behavior Potential: predictive models or systems

Australian Work

Cruz, Alexander & Fernandes (2008)

Input: Weather, Canopy fuel layer structure, Surface fuel bed structure

Within stand weather: - wind speed, - fuel moisture content.

Surface fire behaviour

Crown fire initiation model

Crown fire spread model

CAC > 1? 

Yes: 

Van Wagner (1977) 

Is CFROS > SFROS? 

Yes: Active crown fire spread

No: Passive crown fire spread

No: Surface fire spread

Cruz et al. (2005)

Is crowning possible?

Yes: 

Cruz et al. (2006a)


What distinguishes wildland fires from structural or urban fires is their horizontal spread potential.
Rate of Fire Spread vs. Wind Speed

- Grass
- Conifer Forest

Onset of crowning
Fireline Intensity

\[ I = H \times W \times R \]

- **Fireline Intensity** (Btu/sec-ft)
- **Heat of Combustion** (Btu/lb)
- **Fuel Consumed** (lb/ft²)
- **Rate of Fire Spread** (ft/sec)
Fireline Intensity = 30 x (Flame Length)$^2$
Fireline Intensity vs. Wind Speed

Conifer Forest

Flame length – 90 ft

Onset of crowning

Flame height – 12 ft

Grass

0 0
5 5
10 10
15 15
20 20
25 25
30 30
35 35
20–ft wind speed (mph)

Fireline intensity (BTU/sec ft)
Flame Depth = Flame Front Residence Time x Rate of Fire Spread
Flame Depth vs. Wind Speed

- Conifer Forest
- Grass

Onset of crowning
Relative Fire Behavior Potential

Grass
- Rate of Fire Spread: Highest
- Fireline Intensity: Lowest
- Flame Length: Lowest
- Flame Depth: Lowest

Brush
- Rate of Fire Spread: Intermediate
- Fireline Intensity: Intermediate
- Flame Length: Intermediate
- Flame Depth: Intermediate

Conifer Forest
- Rate of Fire Spread: Lowest
- Fireline Intensity: Highest
- Flame Length: Highest
- Flame Depth: Highest
Relative Fire Behavior Potential

<table>
<thead>
<tr>
<th>Grass</th>
<th>Brush</th>
<th>Conifer Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rate of Fire Spread</strong></td>
<td><strong>Fireline Intensity</strong></td>
<td><strong>Flame Length</strong></td>
</tr>
<tr>
<td><strong>Highest</strong></td>
<td>Intermediate</td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Lowest</strong></td>
<td>Intermediate</td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Lowest</strong></td>
<td>Intermediate</td>
<td>Highest</td>
</tr>
</tbody>
</table>

**Relative Fire Behavior Potential**
## Other Fire Behavior Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Grass</th>
<th>Brush</th>
<th>Conifer Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame Front Residence Time (seconds)</td>
<td>5-10</td>
<td>10-20</td>
<td>30-60</td>
</tr>
<tr>
<td>Firewhirls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate-sized</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Spotting Distances (miles)</td>
<td>&lt; 0.1</td>
<td>~4.0</td>
<td>~10</td>
</tr>
<tr>
<td>Maximum Burn-out or Smoulder Time (minutes)</td>
<td>1</td>
<td>1-3</td>
<td>10-20</td>
</tr>
</tbody>
</table>
Grass fires are certainly far more responsive to the influence of wind than surface and crown fires in conifer forests which can easily lead to very sudden changes in the rate of spread and the direction of fire spread as a result of the natural variability in winds.

However, the heavy fuel loads associated with conifer forests easily lead to far more intense flame fronts than grass fires are capable of producing, thereby requiring larger safety zones for firefighters, especially for crown fires.
The Significance of the Surface Fire – to – Crown Fire Transition in Conifer Forests

If a conifer forest stand is capable of active crown fire propagation, the most obviously thing that occurs with the onset of crowning is the dramatic increase in flame height (and in turn the radiant heat flux) -- from perhaps 6 feet to 90+ feet in a span of a few seconds.

This abrupt change in fire behavior is not presently modeled by all predictive systems.
Recent fire research in Australian has identified similar patterns in shrubland fuel complexes.
Sudden changes in ROS in Mallee and Heath is related to onset of sustained surface fire spread in both these fuels followed by active crown fire propagation in the Mallee type.
Key Take-home Message #1

We need to re-emphasize that there are many aspects or characteristics of wildland fire behavior and should **strive to relate fire behavior more directly to fire suppression** (e.g., fireline production rates, firefight travel rates) - - in other words, a more holistic approach.
Key Take-home Message #3

Provide scientific explanation for Wilson’s common denominators in light of fire behavior research completed since 1977 and incorporate this information into fire behavior training.
Key Take-home Message #3

Look to incorporate the latest insights into the dynamics of wildland fire behavior into training and operations.