CHARACTERISTICS OF A FIRE-INDUCED TORNADO

by A.R. King

Division of Physical Chemistry, Chem. Res. Laboratories,
C.S.I.R.O., Melbourne

(Manuscript received March 1963)

Abstract: A cinematographic film of a tornado which formed over a severe bushfire in 1962 in Victoria has been analysed. Notable findings are that a flame rose in the core to a height of 260 feet, that the core velocities were up to 205 m. p. h. vertically, at least 20-30 m. p. h. horizontally and 15-30 revolutions per minute rotationally, that nearby parcels of air rose at up to 100 m. p. h. without spinning and that despite these conditions the ground winds were not strong enough to damage trees.

1. INTRODUCTION

Many persons experienced in the behaviour of violent rural fires can recount incidents involving tornadoes which have been formed. Unfortunately, the descriptions of the tornadoes themselves are often vague, possibly often very magnified, always subject to misjudgement and infrequently supported by meaningful evidence such as photographs or reliably based measurements. However, it seems fairly well established that tornadoes form over severe fires only, that they range in height up to at least 2,000 feet and that in some the wind is strong enough to lift small logs and branches and even break small trees.

The formation and behaviour of tornadoes formed over "scrub burns"* in Queensland has been described by Whittingham (1958, 1959), and Dessens (1962) has described one which formed during the operation of the "Meteotron" burning one ton of fuel oil per minute. Apparently the tornadoes observed were filled with smoke, no mention being made of any spiralling column of flame. Flames which rise with a whirling motion for up to 50 feet are sometimes seen at fires, but these can hardly be classed as tornadoes and are not surmounted by a whirling column of smoke of any magnitude.

This paper describes a tornado which was photographed with a cinematographic camera and which was additionally interesting because a long, thin flame rose in its core. Fortunately it has been possible to make measurements of its behaviour from the film and to establish the circumstances that lead up to its formation - the topography, fire development, meteorological conditions and the nature of the fuel.

2. RELEVANT DETAILS AND OBSERVATIONS

On 14 January 1962, a fire broke out in the Dandenong Range in Victoria, Australia, and burned in a comparatively mild fashion, until on the afternoon of the 16th it rapidly and unexpectedly developed severe violence; in fact, it developed into a "blow-up fire". During the few hours of extreme violence, the area increased from about 8,000 acres at about 1,000 to 3,000 acres per hour and firefighting became very difficult, mainly because of intense spot fire generation, anywhere but on the rear edge and where the flanks were mild.

* Jungle or rain forest is clear-felled to form a dense pile of trunks, branches and foliage, some 3 to 8 feet deep over areas as large as several hundreds of acres. The mass is allowed to dry out for some months and then ignited, the aim being to leave a clear area suitable for planting with pine seedlings.
Fig. 1 The development of the fire. "T" denotes base of tornado and "P" location of camera.
Fig. 2 Typical fuel.

Fig. 3 Canopy over base of tornado.
In the area (sketched in Fig. 1) where the tornado developed, a tongue of one flank ran some 3 to 8 chains up a slope, crossed a half-chain road and then stopped on reaching another.

It is significant that the tornado was formed between the roads mentioned and that, until this time, the efforts of the firefighters had not been adequate to prevent even much less severe fronts crossing similar roads. Firefighters stationed on the road which was not crossed, state that the fire was burning very violently, that they did not see the tornado which formed within 1½ to 3 chains of them, that the wind seemed to be downhill (across the prevailing wind direction) and that there was much noise — "a rushing noise".

The weather conditions that preceded and prevailed during the fire are mentioned in detail by Whittingham in the article which follows.

The fuel in the area would have been considered light to average for forest areas in eastern Australia and, as illustrated in Fig. 2, it consisted of dead leaf (about 6 tons per acre), fully cured grass and some fine-leaved scrub under poor "messmate stringy-bark" trees (Eucalyptus obliqua) growing 40 to 60 feet high with a fairly open canopy.

Fig. 3 is a photograph taken 1½ months after the fire, at the location of the base of the tornado (T on Fig. 1) — the leaf growth, of course, had occurred after the fire. Fig. 4 is a view of the area surrounding the tornado base, from point P marked on Fig. 1, 1½ months after the fire.

Fig. 4 View of fire area. "T" denotes base of tornado.
Fig. 5  Tornado.  [a] 0.5 seconds after the flames entered the tornado.  [b] 1.25 seconds after the flames entered the tornado.  
[c] 1.75 seconds after the flames entered the tornado.  [d] 3.5 seconds after the flames entered the tornado.
Fig. 5 was printed from the cinematographic film exposed during the fire at point P, the four views being taken $\frac{1}{2}$, $1\frac{1}{4}$, $1\frac{1}{2}$ and $3\frac{1}{2}$ seconds after the flame started to enter the tornado. Fig. 6, also taken from the film, gives scaled drawings of the flame in the tornado at $1/12$ second intervals.

Fig. 7 is a wide-angle photograph taken from point P immediately before the development of the flame and shows the well-defined column of spiralling smoke. The frame height is equivalent to 1530 feet.

3. MEASUREMENTS AND DEDUCTIONS

Unfortunately there were no sharp-edged masses of smoke in the sequence illustrated by Fig. 7 and the speed of rotation and upward velocity of the smoke-filled tornado could not be measured with high accuracy. However, it was possible to ascertain that the column did rotate in the clockwise direction at 15 to 30 revolutions per minute at 200 to 500 feet above the ground, corresponding to a horizontal speed of about 90 m. p. h., 70 feet out from the axis.

During the period when the flame entered the tornado, a puff of dark smoke rose vertically, without spinning, at 90 to 110 m. p. h. at a radial distance of 150 to 200 feet from the tornado axis.

Fig. 7 Smoke column. "T" denotes base of tornado.
The flame itself increased in height at about 250 feet per second (170 m. p. h.) during the first half second and at 300 feet per second (205 m. p. h.) after two seconds. Various theories to explain the origin of the flame are possible.

It is possible that through some odd development a column of unburned combustible gas mixed with air was drawn up into the core and then ignited at ground level. The mixture would have then reacted from the base upwards giving the impression of a flame increasing in height. If the mixture was detonated, then the rate of propagation of the luminous flame up the column would have been 3,000 to 10,000 feet per second (Lewis and von Elbe 1961), which is far greater than that observed. If the mixture had burned by the propagation of a normal combustion wave, then the speed observed would have been about 1 to 3 feet per second (Lewis and von Elbe 1961), which is far slower than that observed. The great difference between these speeds and that observed, and the improbability of the development of such a column, virtually rule out these theories.

A more probable theory is that combustible gas, unmixed with air but burning by the usual diffusion process, or burning solid fuel was sucked up by the vortex to form the column of flame observed. If this was correct, then the upward velocity of the core of the tornado would be that observed for the tip of the flame, increased by the rate at which the tip was descending down through the column of burning gas or fuel. This would indicate that the velocity of the core of the tornado was greater than 205 m. p. h.; unfortunately it is not possible to estimate how much greater.

At times the flame height decreased very rapidly (up to 500 feet per second), but this does not mean that the direction of the tornado core suddenly reversed. Rather, it is more probable that the core still continued to rise at its usual speed, but the supply of combustibles at least temporarily became depleted. This is supported by the observation that the flame became thinnest just before it decreased in height; for instance, when at its greatest height (260 feet) and just before its decrease, the flame was 20, 8, 6 and 3 feet in diameter at ground level and 65, 130 and 195 feet high respectively.

The flame also showed that the whole flame appeared to move in the horizontal direction. Assuming that this motion was due only to horizontal motion and not to the rotation of an irregularly-shaped flame eccentric to the axis of rotation, then the component of its speed at right angles to the line of sight was 20 to 30 m. p. h. at its mid-height.

One might have expected that the tornado would have damaged the trees by tearing off limbs, and possibly that the soil and ash bed would have shown the trace of severe wind, but these were not observed. The only difference that could be attributed to the presence of the tornado was that, for one area of about 50 feet radius, all twigs less than ¼ to ½ inch in diameter were burned away. Apparently the swirling on the ground was non-existent or slight and the surface winds were probably not strong enough to lift large pieces of solid fuel.

The full height of the tornado cannot be measured because appropriate photographs were not taken, but it must have been greater than 1,000 feet, which is the distance between the base of the tornado and the top of the frame of Fig. 7.

4. CONCLUSIONS

From measurements made on one fire-induced tornado, it has been established that during blow-up fires tornadoes can be developed and that streams of burning gases or burning solid material can be drawn up their cores. The core velocity may be as high as 205 m. p. h. vertically and at least 20 to 30 m. p. h. horizontally and the speed of rotation may be 15 to 30 revolutions per minute in the clockwise direction. Nearby, parcels of smoke-laden air may rise at up to 100 m. p. h. without any noticeable spinning motion. Despite the formation of a tornado, ground winds need not be sufficiently strong to damage trees.

ACKNOWLEDGEMENT

Thanks are due to the Newsroom, General Television Corporation, GTV 9, Melbourne for making available film of the tornado.
REFERENCES

