PROJECT FLAMBEAU EXPERIMENTAL FIRE MEASUREMENTS

Thomas Y. Palmer
SWETL Inc., P.O. 278
Fallbrook, CA 92028

I. INTRODUCTION

The general Project Flambeau and Mass Fire Systems experiments have been detailed elsewhere (Countryman, 1969, Palmer 1981) and will not be redescribed here. Other large fire experiments include those of Dessens in France and Project Euroka in Australia. The Project Flambeau experiments were the nearest approach to an instrumented experimental investigation of firestorms, mass fires and conflagrations that have been attempted, the other experiments being either to small or of to low an intensity. Fire conditions are important in both a military and civilian context, but in spite of the long relationship between fire and man, few measurements of large free-burning fires have been made. It is only since World War II that any attempts at fire modelling have been made, while computer simulation has only occurred in the last ten years. Progress in this area has been handicaped by a lack of experimental data to verify model results.

II. MODELS OF FIRE

Until recently most large fire models have been based upon the similarity approach to convection first developed by Morton, et al, (1956) for laboratory convective plumes simulating atmospheric convection. This approach has been extended to fires by many investigators (c.f. Byram, 1966, Morton, 1967, Smith et al, 1975), while overall descriptive models have been proposed by Countryman, (1969), Haines, (1982) and in the numerous fire reports of the state and federal fire agencies.

The numerous partial differential equations describing the physico-chemical processes in free combustion in the atmosphere have been summarized by Emmons, (1970). While in principle they offer a complete description of the mass fire-conflagration they require the use of appropriate initial and boundary conditions before any solution can progress. They require the application of very large computers and investigators include Stein, (1974) Luti, (1981) and Brode, 1982). Progress in this area has been limited by experimental verification. Important information relative is implicit in the Project Flambeau measurements if they are analyzed in light of recent theoretical and laboratory measurements.

III. REALITY-PROJECT FLAMBEAU

The first series of Project Flambeau experiments as described by Countryman, (1969) and Palmer, (1969) were heavily oriented towards understanding fuel combustion in the large fire environment. Although general wind and temperature measurements were made during the experiments the primary emphasis was on finding rates of combustion by measuring weight loss from large platforms and relating these measurements to laboratory experiments. Locally intensive airflow measurements, temperature calorimetric and radiation measurements were made. It is now apparent that there was relatively little difference between these variables during the Project Flambeau experiment except relative to the porosity of the fuel (Palmer, unpublished, ms.). There was some theory due to Byram (personal communication) and outdoor experiments with large pans of fuel which indicated that ignition patterns and fuel arrangments could influence the behavour of large fires. Consequently a second series of experiments using the remaining fuel piles were instrumented for wind and rearranged and ignited in various patterns to study these effects. These experiments culminated in the Plot 6 and Plot 10 fires.

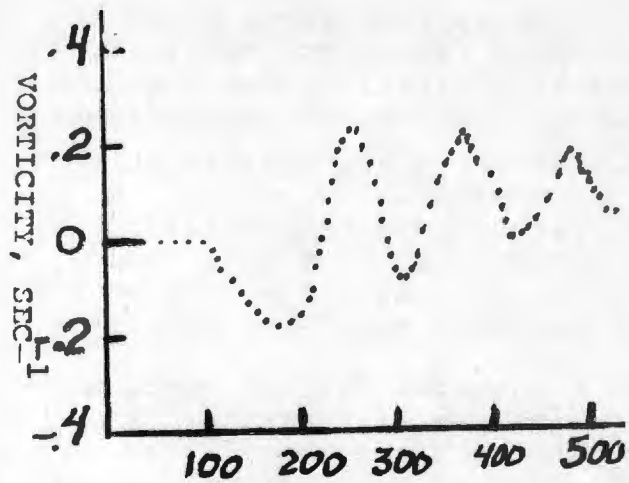


Fig. 2. Vorticity variation inside of Fire 6.

Temperature was not measured in these experiments because of instrumentation and data aquisition systems limitations.

Time lapse cartoons of the wind field around Fire 10 (an example of one frame is given in Fig 1) clearly shows two centers of rotation. The rotating vortex pair varied in strength in a regular manner similar to the rotating patterns in the interior of Fire 6, as shown if Fig. 2. The period of the oscillating vortices was about fifty seconds in both fires.
An intense firewhirl was noted from an aircraft approximately at the center of the east vortex.

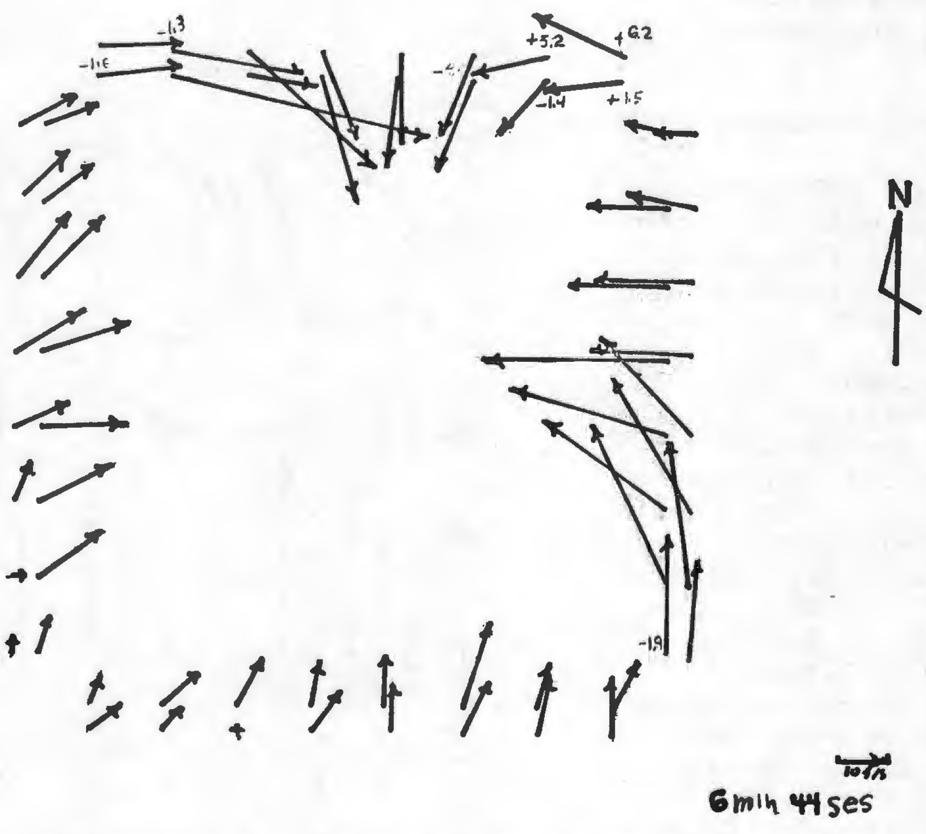


Figure 1. Exterior winds about Project Flambeau Fire 10. The two vortices varied in strength in a regular manner. A lateral gust is beginning on the western margin of the fire.

These time lapse plots of the wind fields and vorticity analysis clearly shows the following features of these fires:

A. The fires are clearly three dimensional
B. Large oppositely rotating centers of vorticity (spin) formed inside the fire on the downwind side when wind were weak.
C. Occasional lateral gusts moved into the fire area
D. The vortices, oscillated in strength in a periodic manner
E. There was mass and momentum exchange between the atmosphere and the fire

This combination of observed phenomena indicates that these large stationary fires can be described in the context of turbulent burst-intermittant-turbulence, layer replacement theory.

IV. INTERMITTANT TURBULENCE

The treatment of turbulence as an intermittant phenomena was apparently first formulated by Higbie in 1935, (although the standard reference to his work is erroneous.). The discription of boundary layer replacement and vorticity generation using this formulation has been used in chemical engineering to describe boiling and heat transfer from pipes for many years. The first formulation of the theory as a stochastic process was presented by Bulling and Dukler (1972). Although there is still controversy about how to treat the downward penetration of the free air gusts, there has been an increasing congruence between theoretical fluid mechanical approaches and this empirical engineering approach.

Observations of the Project Flambeau fires presented here and elsewhere (Palmer, 1981) and the observations of horizontal roll vortices in large forest conflagrations by Haines (1982) clearly show for the first time that there are two types of circulations in large fires with sufficiently large energy and a third type in fires of low energy:

A. Large energy fires
   (1) ones which generate vertical vortices as in Fig. 3,(with light winds)
   (2) ones which generate horizontal roll vortices as in Fig. 4, (strong winds)
B. Low energy fires
   (3) fires which produce small or no vortex motions with extensive direct mixing from the fire into the flames.

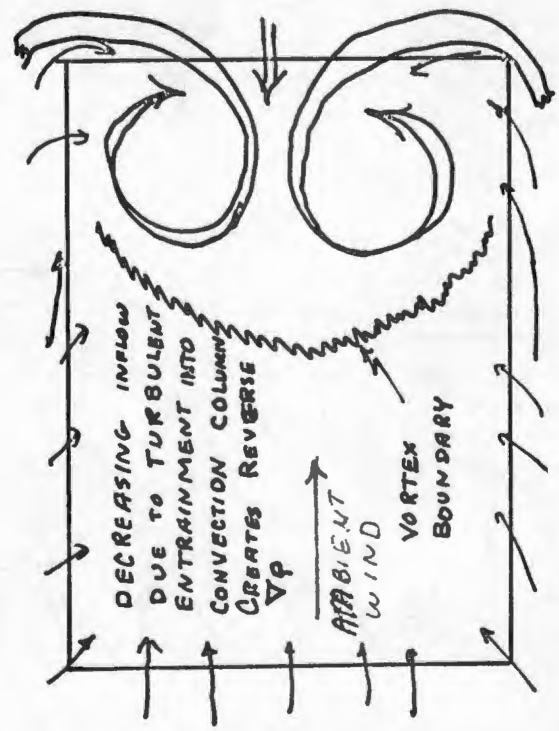
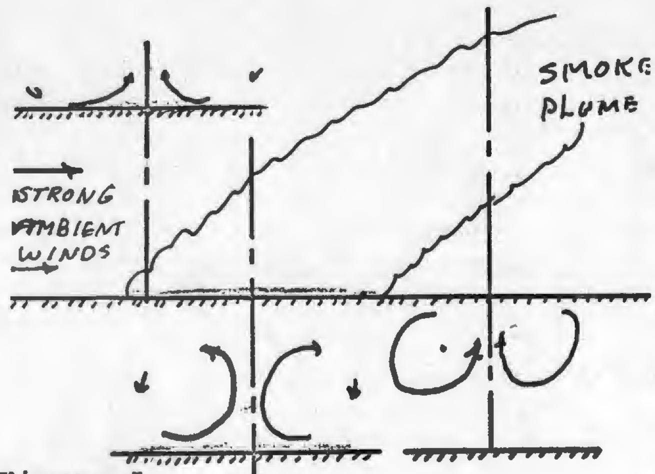


Figure 4. Downward view of vortex pair generated by fire in light winds.



Fiqure 5

Cross-sections through a counter rotating, stream-wise vortex pair associated with strong winds.

The vortex pairs and the downward penetrating turbulent eddies in flows such as in catagory A-1 are strongly affected by the high-speed fluid in the outer flow field (Blackwelder and Eckelmann, 1979), There is usually a critical Rayleigh number associated with this kind of convection which seperates the differing states.

V. CONCLUSIONS

This preliminary analysis and model formulation of the Project Flambeau fires taken together taken together with other information, seems to indicate that mass fires and conflagrations are three-dimensional and oscillatory in nature. Large area fires seem to naturally fall into a strong fire generated vortices. The vortices oscillated with a period of about 50 seconds in these fires.

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