Modeling the Wind Disturbances on Fires Near a Slope

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1. Introduction

Wildfires are increasingly common. Safe Separation Distance (SSD) is a measure used by firefighters to determine the minimum distance away from the wildfire front firefighters must remain. Research on the Coanda effect and wildfires has been conducted, but the additional effect of wind on the system has not been researched thoroughly. Due to the difficulty of designing a physical experiment that can precisely control wind velocity, it was determined to take a modeling approach to study how wind affects fire behavior near slopes. The ultimate goal of this research aims to establish guidelines for firefighters to establish better SSD's, especially near slopes with the presence of wind.

2. Computational methods

FDS (McGrattan et al., 2010) and STARCCM+ (CD-adapco, 2016) were used to simulate experiments performed by Gallacher (Gallacher, 2016; Gallacher et al., 2018). The experiment consisted of a 12 cm × 7 cm stainless steel pan containing 5 ml of burning n-heptane, located next to a metal sheet that could be raised to different angles, as shown in Figure 1. These combustion experiments were performed without wind. Prior simulations were performed to mimic these original experiments, and to determine the validity of the simulative results (Ripa et al., 2016). These comparisons showed that the flame attachment length, and convective heat flux were comparable between simulated results and experimental data. Radiative heat flux was comparable at low slope angles, but at higher slope angles the simulated radiative heat flux was drastically higher.

The simulative set up used in the wind experiments was slightly different from the original experiments. The total domain was increased from 0.5 m × 0.2 m × 0.5 m in the x, y, z directions respectively 0.5 m × 0.2 m × 0.6 m. The simulated grid size was 2.5 mm × 2.5 mm × 2.5 mm. The total domain was split into three nodes along the lines where z was equal to 0.2 and 0.4 m. Based on the previous simulations, the total simulation time for each run was 20 s.

Wind was created with two different ways in FDS: one was created with a dynamic pressure gradient and one was created by setting a wind velocity. STARCCM+ set wind boundaries by specifying a velocity. Simulations were performed in FDS with wind velocities of 0, 0.25, 0.5, and 0.75 m/s. STARCCM+ simulations were performed with wind velocities of 0, 0.2, 0.3, and

0.4 m/s. For each wind velocity simulations were performed at the 10 different slope angles used in the experiments.

In FDS and STARCCM+ there is no easy way to measure flame attachment length, or other flame properties such as height or area. One of the things easy to measure in FDS and STARCCM+ is the oxygen mass fraction. The flame perimeter was thus defined to be where the oxygen mass fraction was equal to zero. To efficiently analyze the results from the simulations a MATLAB code was created to analyze pictures from FDS and STARCCM+. The code was set up to allow the user to select the color that represents when the oxygen mass fraction was equal to zero. The code then converts the image to binary images, only identifying the area where the oxygen mass fraction was equal to zero. The code then counts the number of pixels adjacent to the slope and converts that value to a length in meters. This flame length is measured for every picture, and the results are averaged to give an average flame attachment length.

3. Results and Discussion

The predictions from the simulations with wind were compared to the previous predictions involving no wind. Figure 2 shows the slope angle versus the simulated heat flux for STARCCM+. Figure 3 shows the slope angle versus the average flame attachment length for STARCCM+. Figure 4 shows the convective heat flux in FDS at different wind speeds using the dynamic pressure gradient. Figure 5 shows the convective heat flux in FDS at different wind speeds using the set wind velocity. Figure 6 shows the radiative heat flux in FDS at different wind speeds using the dynamic pressure gradient. Figure 7 shows the radiative heat flux in FDS at different wind speeds using the set wind velocity.

The results shown are promising. Flame attachment length for STARCCM+ is very high. One possible reason is because STARCCM+ sets a fuel mass flow rate instead of having the mass flow rate vary based on outside conditions. This is problematic since the reaction model STARCCM+ uses means the fuel must react, even if normally there would not be that much fuel in the air. This means the fuel, and resulting flame is pushed up against the slope, possibly artificially inflating those values.

STARCCM+ has overall lower heat fluxes, which is consistent with what was seen in the previous simulations. The two different wind models used in FDS show similar trends in heat fluxes, but different values. The dynamic pressure model has a higher convective heat flux than the set wind velocity model. However, the set wind velocity model has a higher radiative heat flux than the dynamic pressure model.

4. Conclusions

The simulated results appear promising. Heat flux data trends appear similar for the two different FDS models, even though the specific values are different. STARCCM+ heat flux data appears different; this effect is probably due to the mass flow rate of the fuel being fixed. The fixed mass flow rate of the fuel also affects the flame attachment length, and possibly inflates those values.

The wind speeds tested above are very small, especially considering the size and typical wind speeds of wildfires, it was observed in the simulations at the higher wind speeds simulated that the flame had begun to be extinguished by the wind velocity. A dimensional analysis will need to be performed to scale up the findings to more realistic values and sizes typically found in forest fires.

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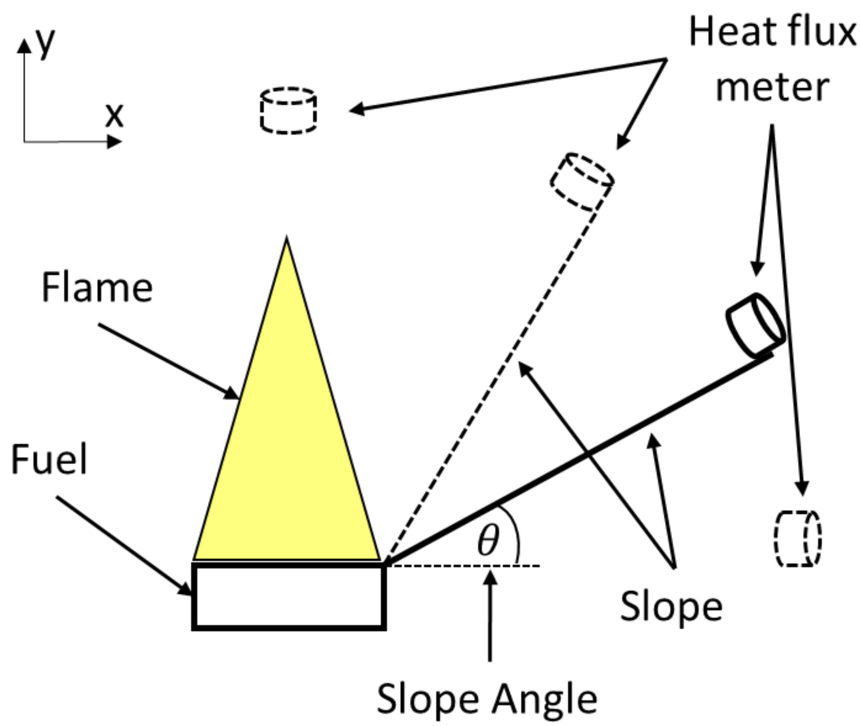

Figure 1. Experimental apparatus showing fuel pan, flame, slope and heat flux sensor placement (from Gallacher, 2016).

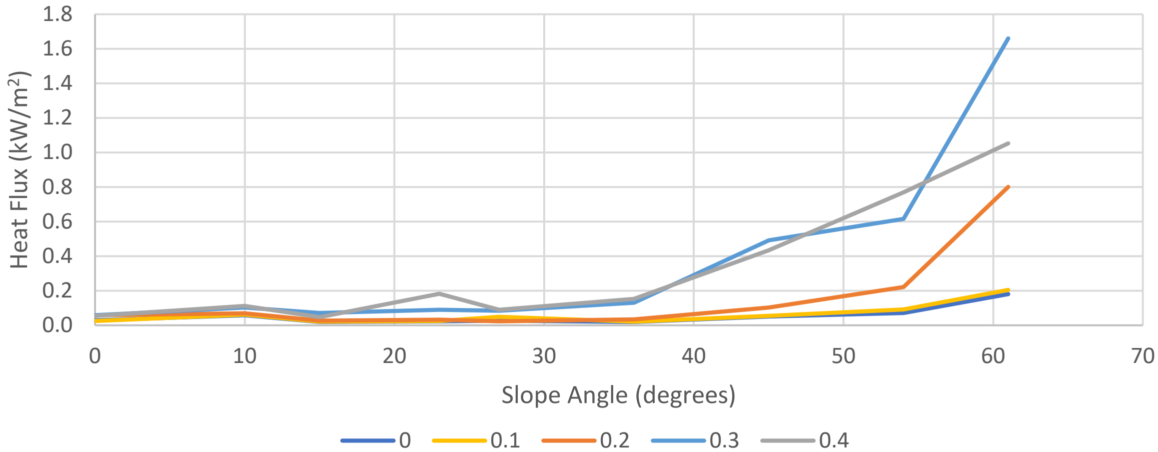

Figure 2. The comparison of the slope angle versus the simulated heat flux in STARCCM+ at wind speeds between 0 and 0.4 m/s.

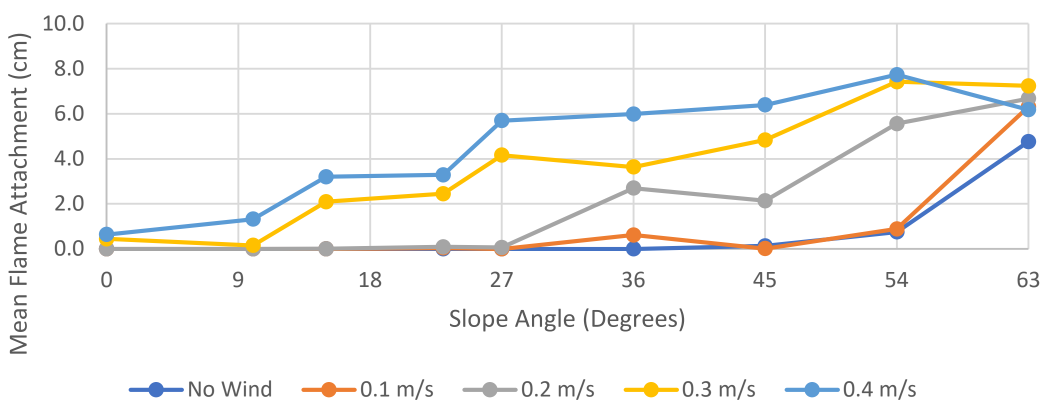

Figure 3. The comparison of the slope angle versus the average flame attachment length (cm) in STARCCM+ at wind speeds between 0 and 0.4 m/s

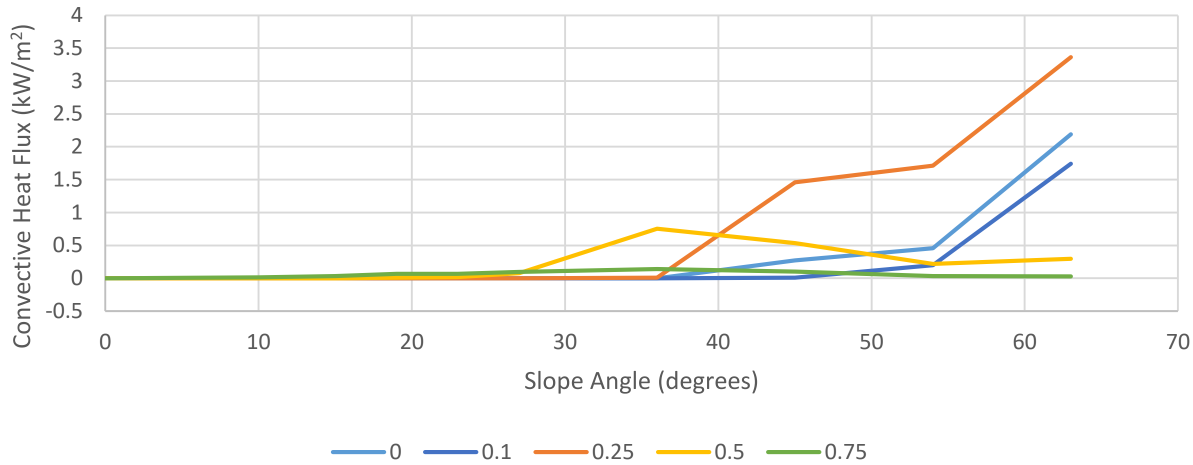

Figure 4. **The comparison of the slope angle versus the simulated convective heat flux in FDS with dynamic pressures between 0 and 0.75 m/s wind speeds.**

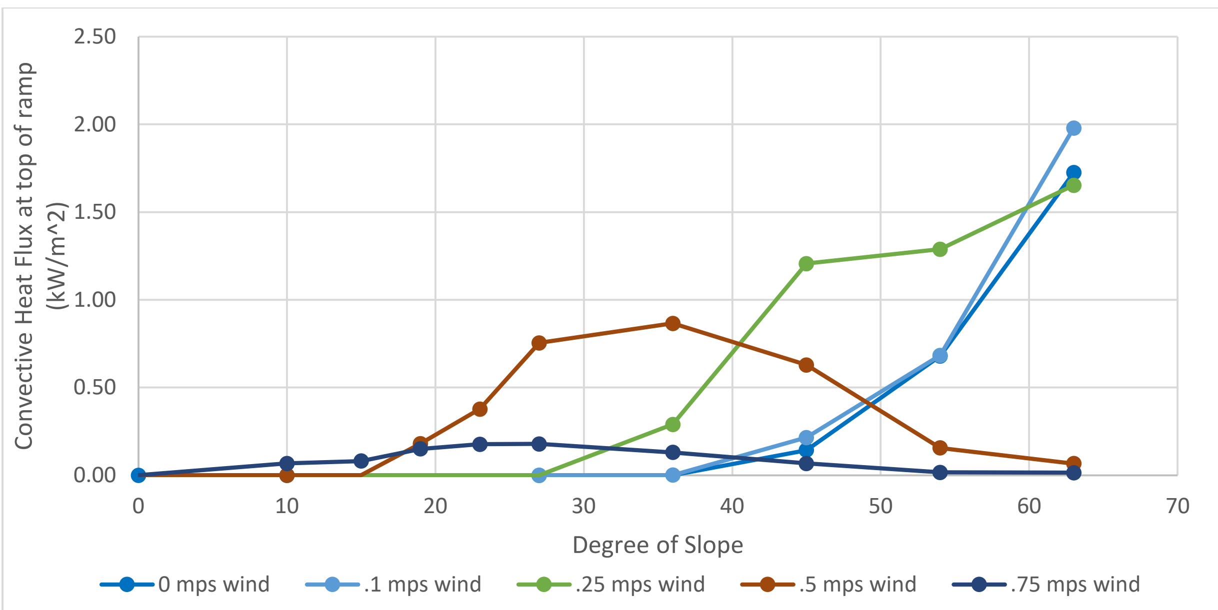

Figure 5. **The comparison of the slope angle versus the simulated convective heat flux in FDS with a set wind velocity between 0 and 0.75 m/s wind speeds.**

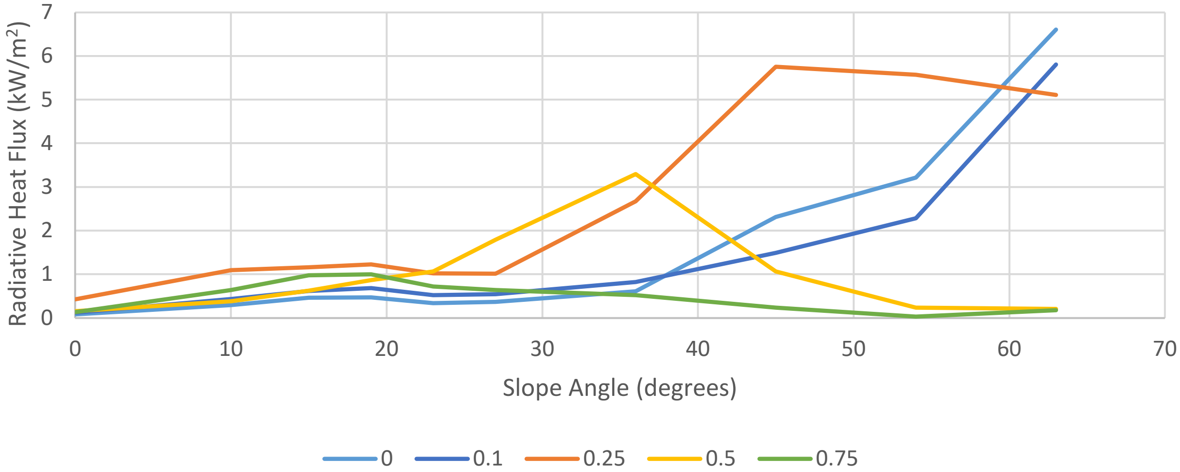

Figure 6. The comparison of the slope angle versus the simulated radiative heat flux in FDS with dynamic pressures between 0 and 0.75 m/s wind speeds

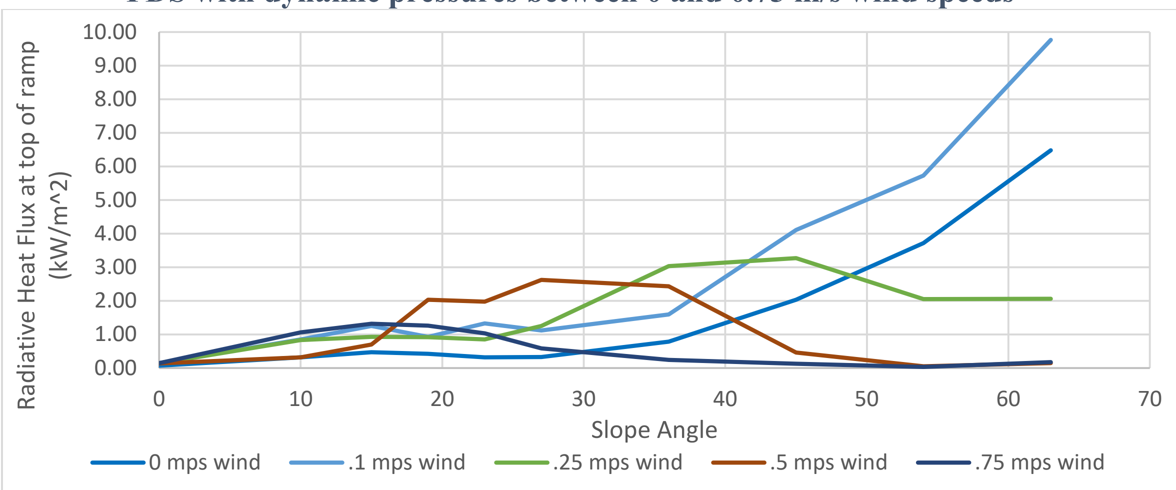

Figure 7. The comparison of the slope angle versus the simulated radiative heat flux in FDS with a set wind velocity between 0 and 0.75 m/s wind speeds.