Modeling a Burning Bush With and Without Wind Using a Semi-empirical Approach

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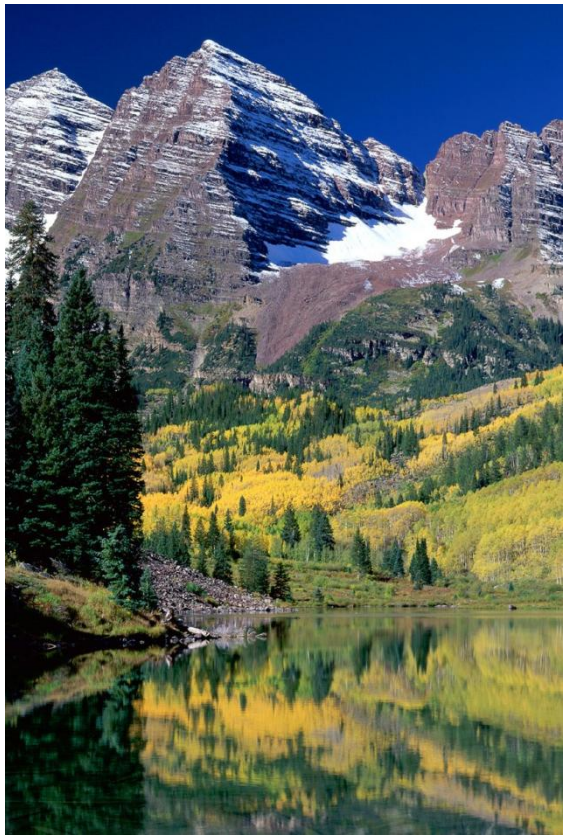
Introduction

- Need to predict fire spread in forest fuels
  - Safety of fire crews
  - Prescribed burning
- What to know:
  - Where the fire will spread.
  - How fast.

Current Predictive Models

Live fuel behaviors



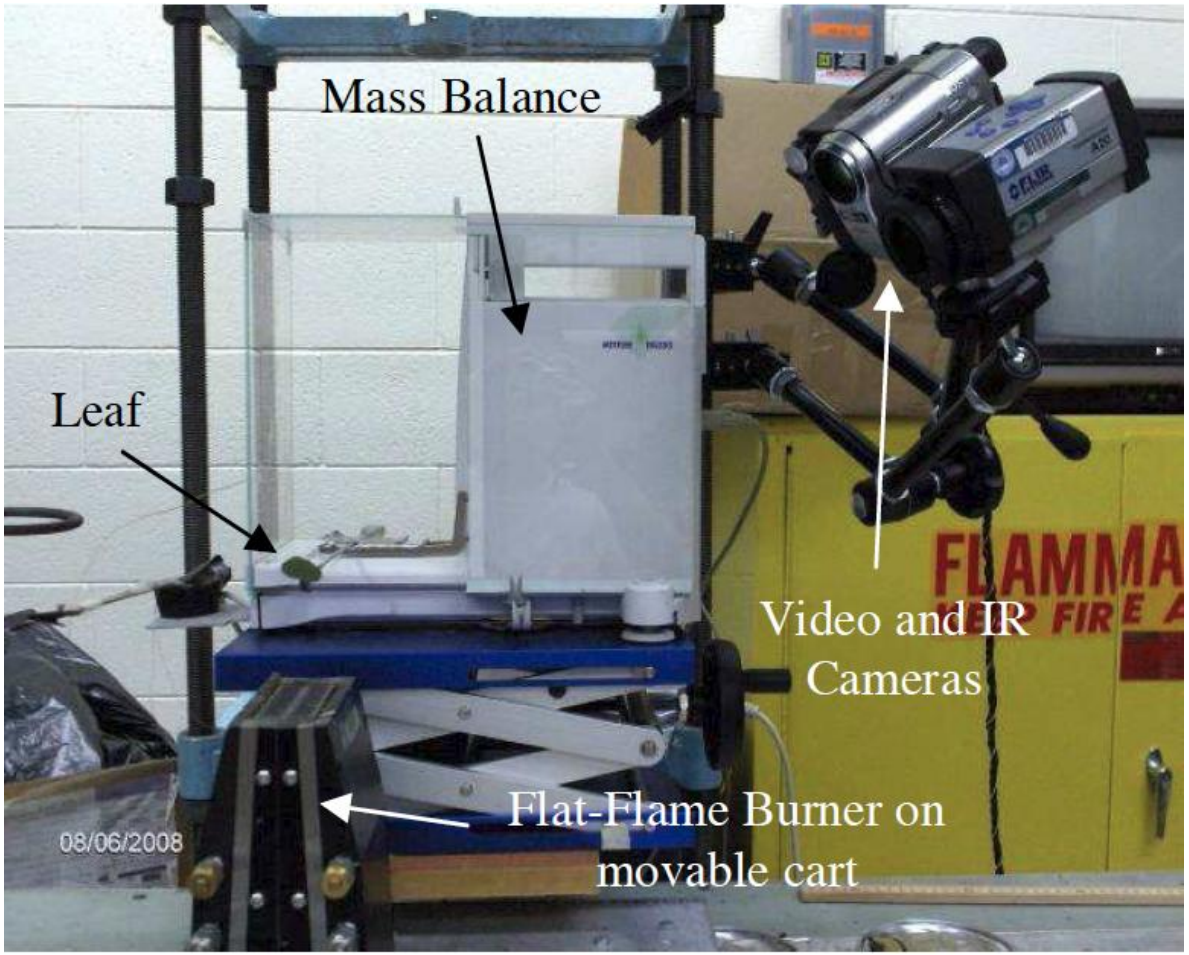
Dead fuel samples

Previous Work

- Over the past six years thousands of live single leaf experiments have been performed on a variety of species
  - This includes over 700 experimental runs on single Manzanita leaves

Manzanita leaves—*Arctostaphylos glandulosa,* from the California chaparral

Experimental Apparatus



Flat Flame Burner

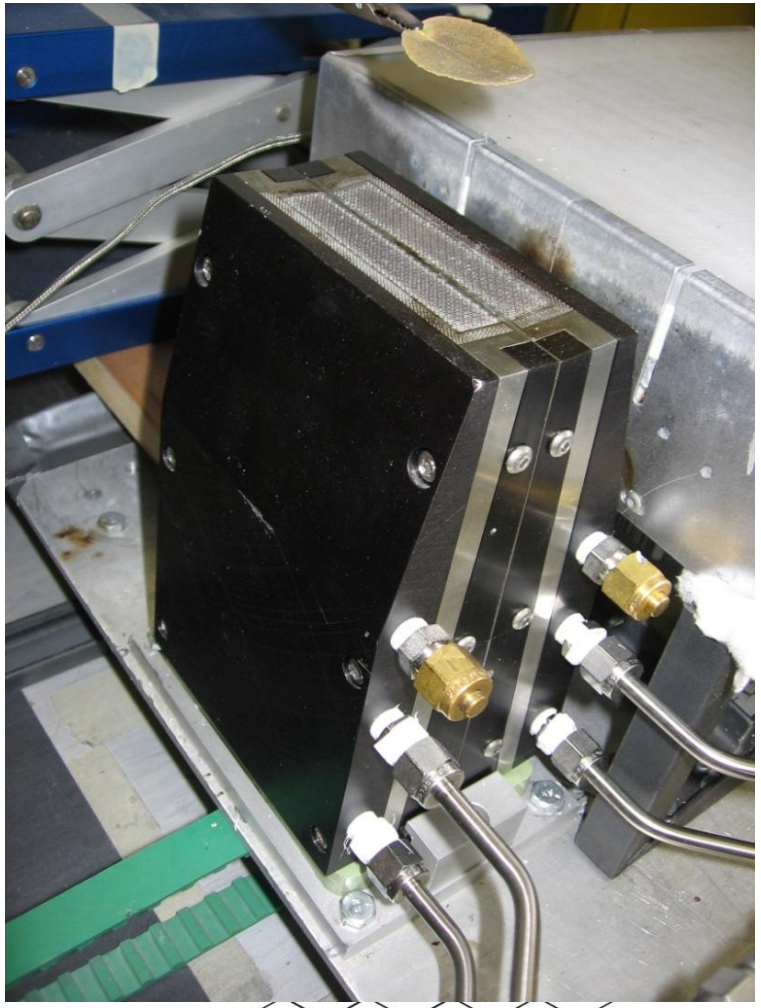
Gases

- Fuels (H_2, CH_4)
- Oxidizer (Air)
- Inert (N_2)

Stoichiometry altered to obtain post-flame conditions:

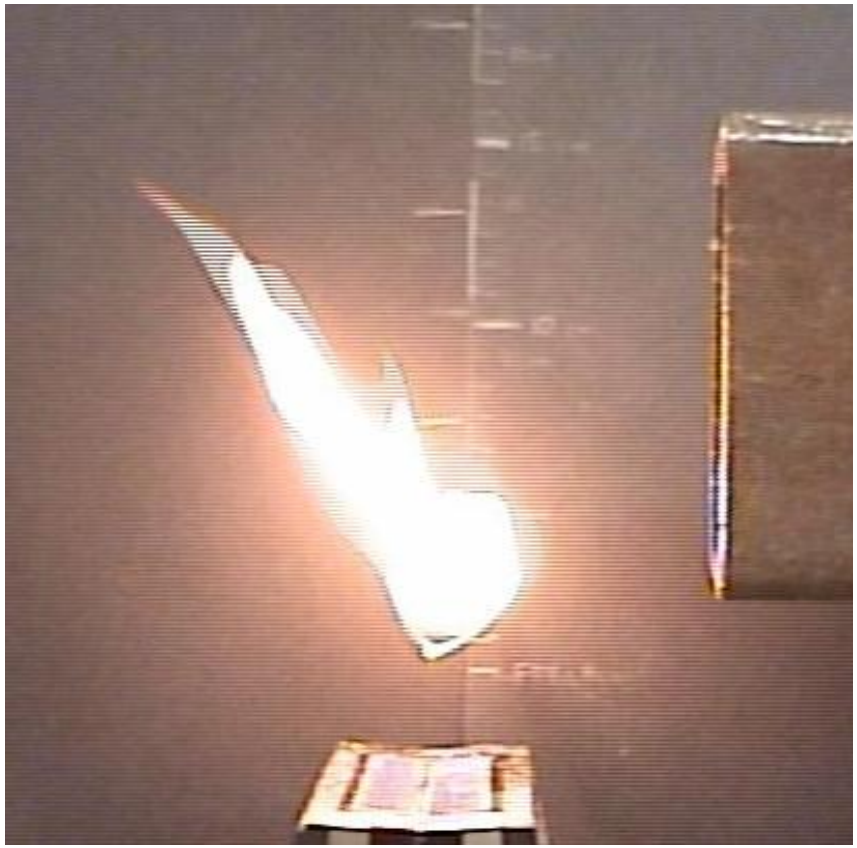
- Temperature ~ 1000°C
- O_2 Concentration ~ 10 mol%
- Flame length ~ 1-3 mm

Repeatable experiment

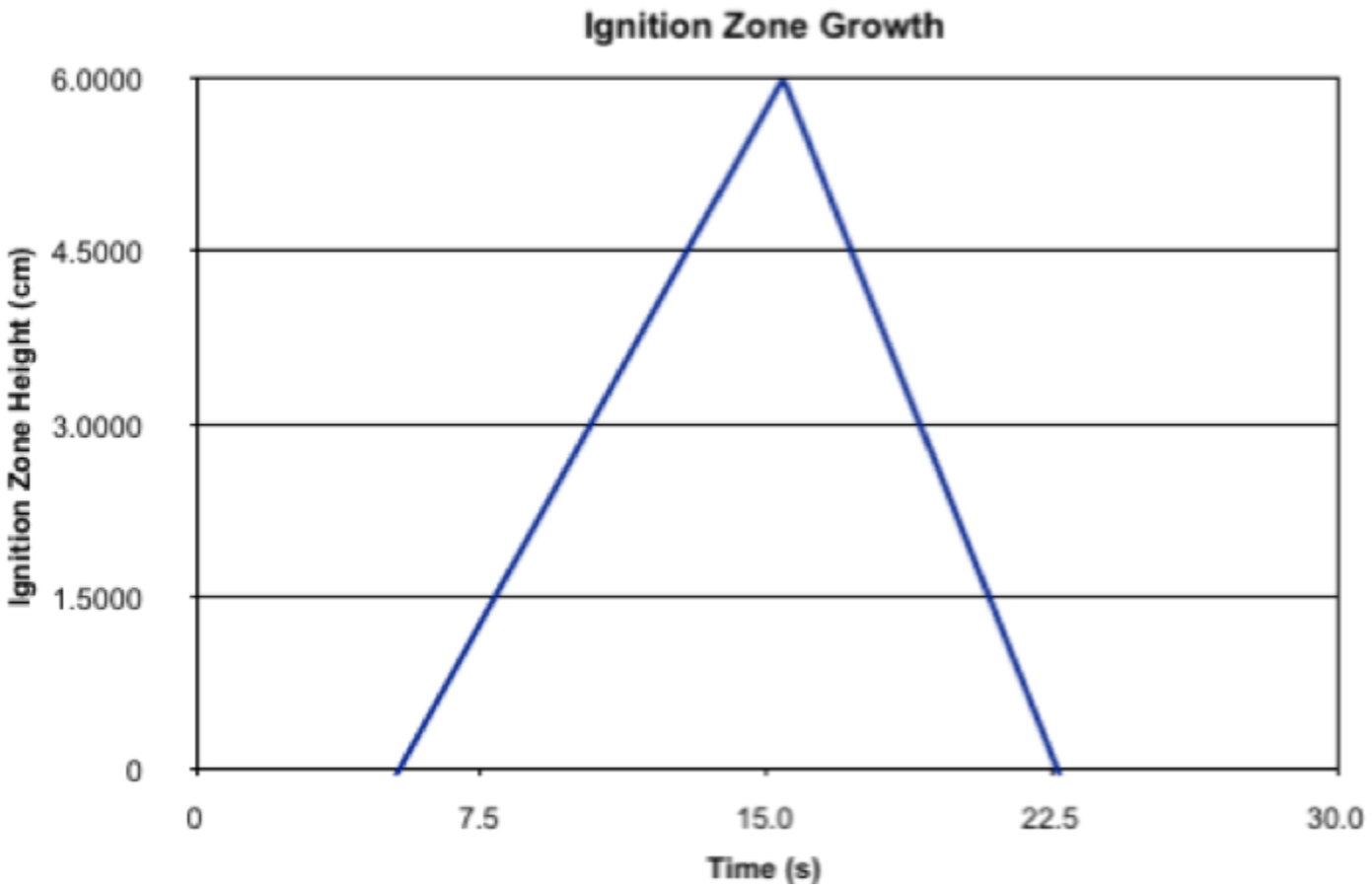


Experiments

- t_{ig}– Time to ignition
- t_{fd}– Time of flame duration
- t_{fh}– Time to maximum flame height
- FH– Maximum flame height
- θ– Flame angle



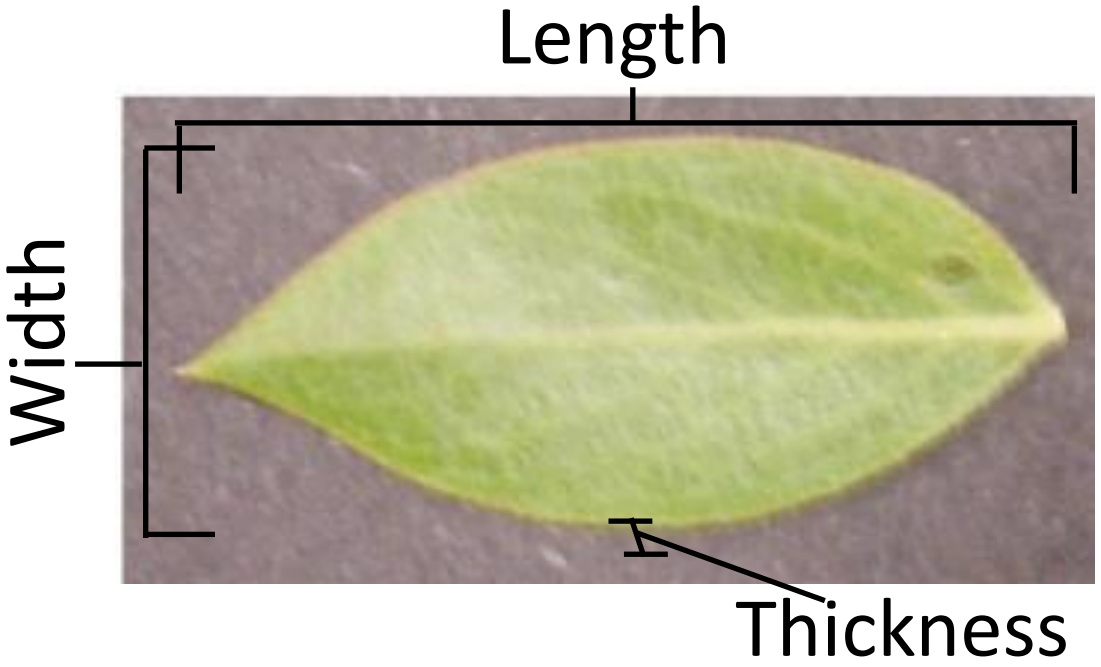
Flame Profile



Physical Leaf Parameters

Measured Parameters:

- Length
- Width
- Thickness
- Moisture Content
- Mass



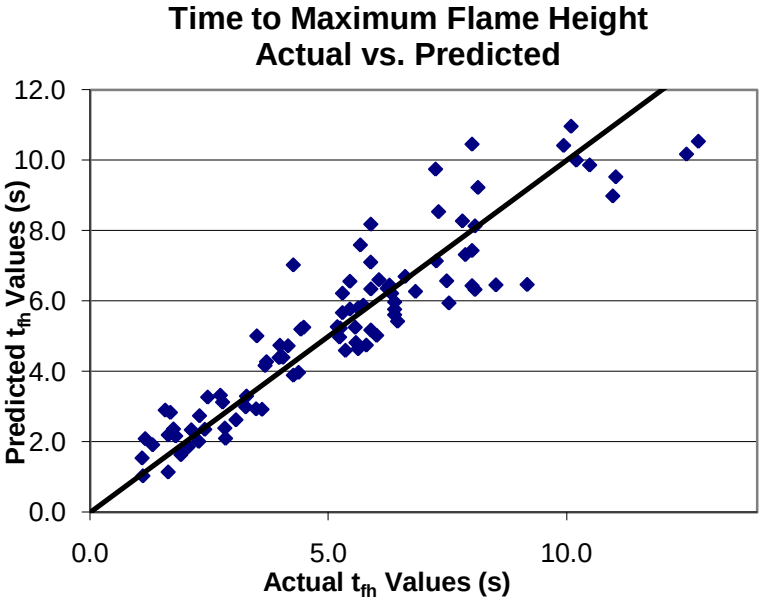
Flame Profile Correlations

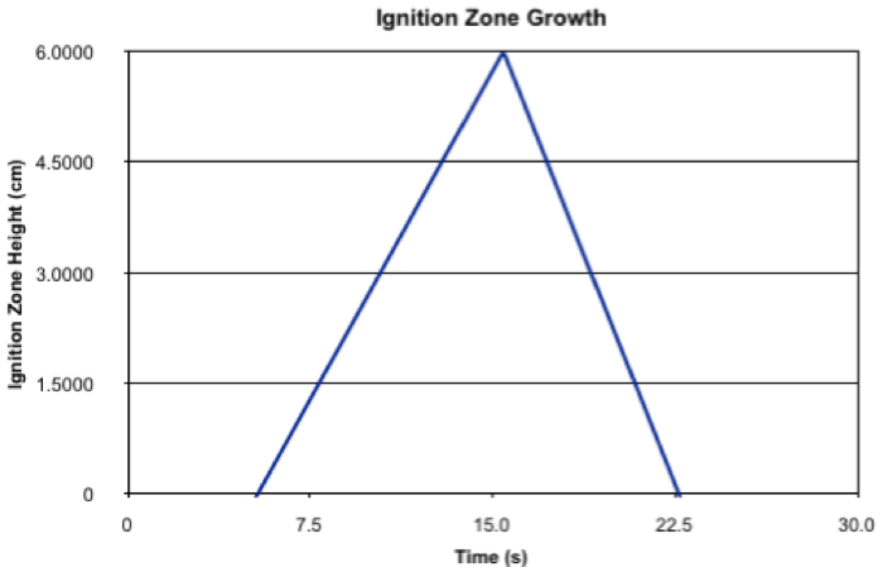
$$t_{ig} = -3.316 + 4.265 * MC + 7.372 * Thick + 3.693 * Mass \qquad r^2 = 0.68$$

$$t_{FH} = -3.323 + 8.106 * MC + 11.062 * Thick + 4.714 * Mass + t_{ig} \qquad r^2 = 0.86$$

$$t_{fd} = 3.768 + 1.307 * \ln(MC) + 12.236 * Thick + 15.005 * Mass + t_{ig} \qquad r^2 = 0.76$$

$$FH = -1.333 * MC + 8 \qquad r^2 = 0.40$$



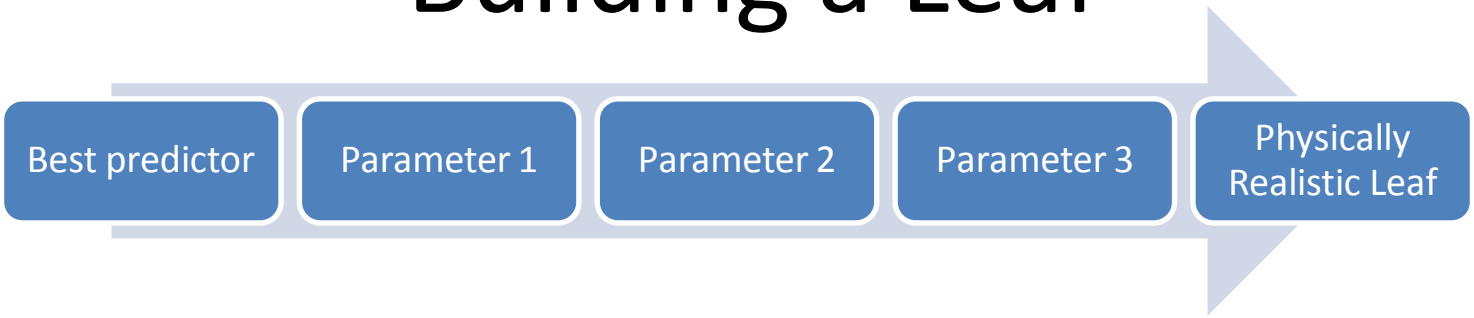


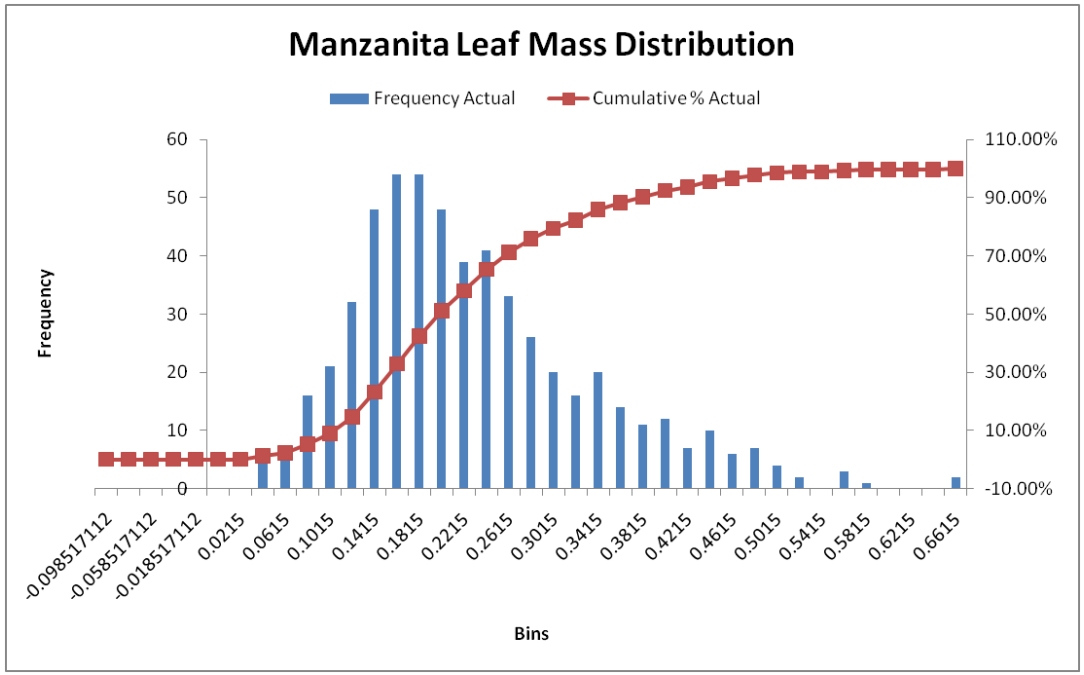
Scaling Up

The bush model was created to provide a method to transfer fundamental leaf combustion information to large-scale fire prediction

- Creating the bush model simulation:
  - Building physically realistic leaves
  - Arranging leaves in a bush structure
  - Using flame ignition zones for leaf-to-leaf propagation.

Building a Leaf





based on 588 leaf samples measured between 2002 and 2008

Best predictor:

- Leaf Mass

Follows beta distribution

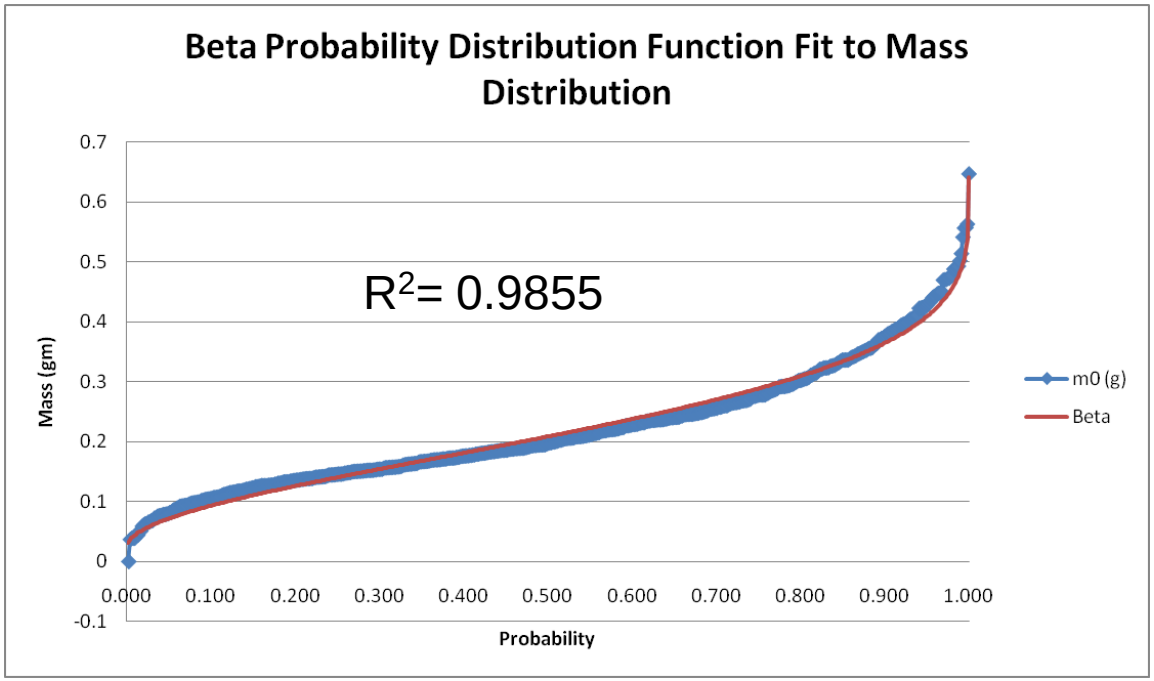
Mass Beta Distribution

The Beta Probability Function was used to achieve a realistic distribution.

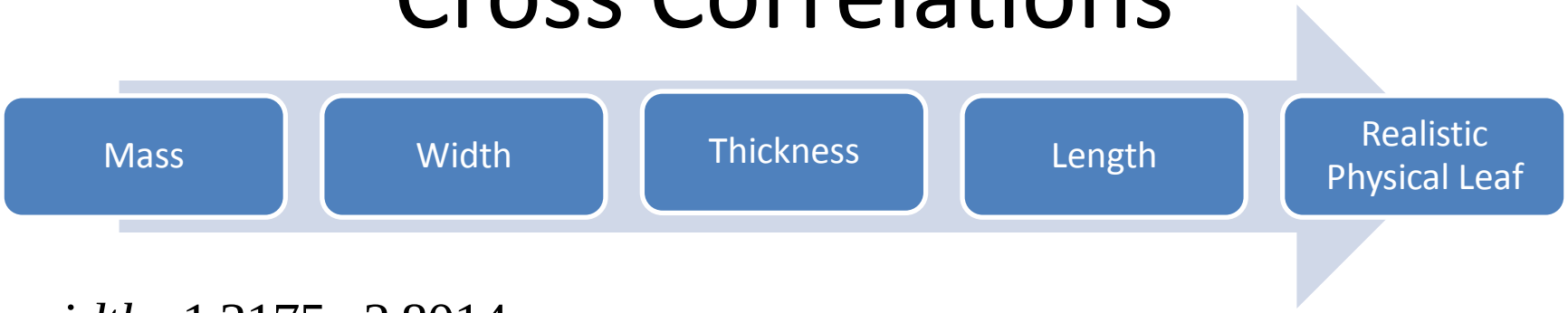
$$f(x;\alpha,\beta) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{\int_0^1 u^{\alpha-1}(1-u)^{\beta-1}\,du}$$

where $\alpha = 2.2486$

$\beta = 4.9878$



Cross Correlations



$$width = 1.3175 + 2.8014 \cdot mass$$

Adjusted $R^2 = 0.607$

$$thickness = 0.6434 + 1.1596 \cdot mass - 0.2142 \cdot width$$

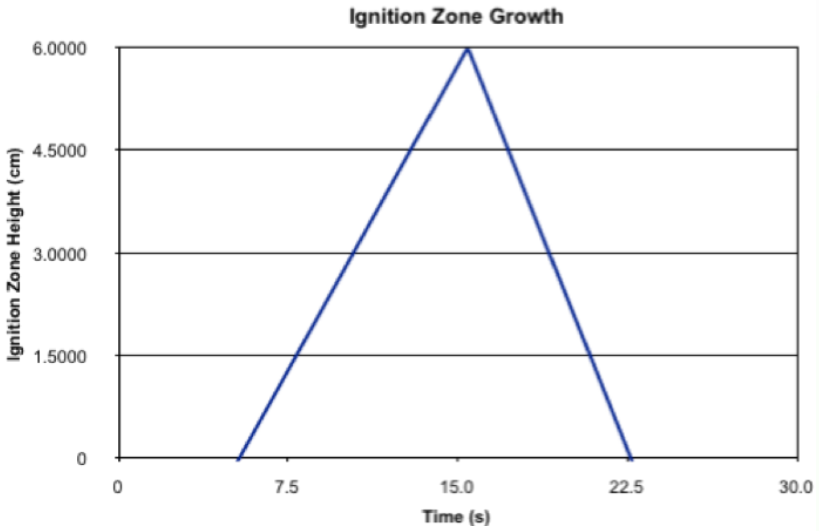
Adjusted $R^2 = 0.580$

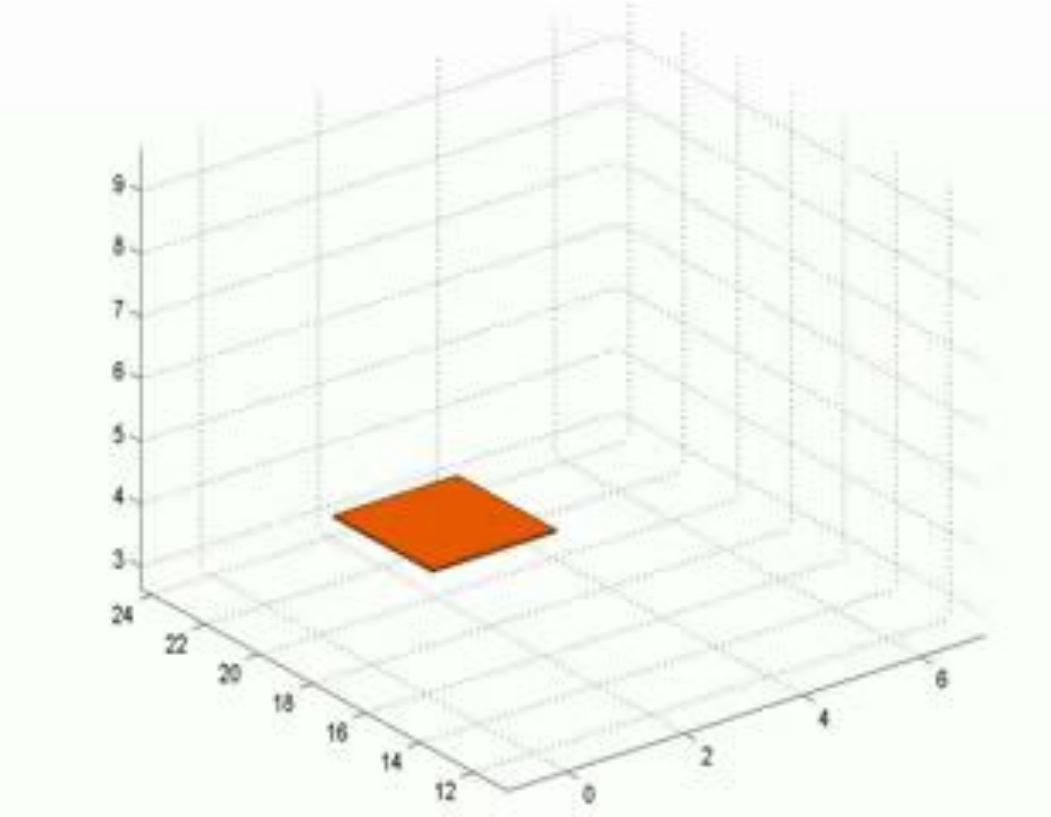
$$length = 3.3567 + 3.8643 \cdot mass - 0.1645 \cdot width - 1.0712 \cdot thickness$$

Adjusted $R^2 = 0.466$

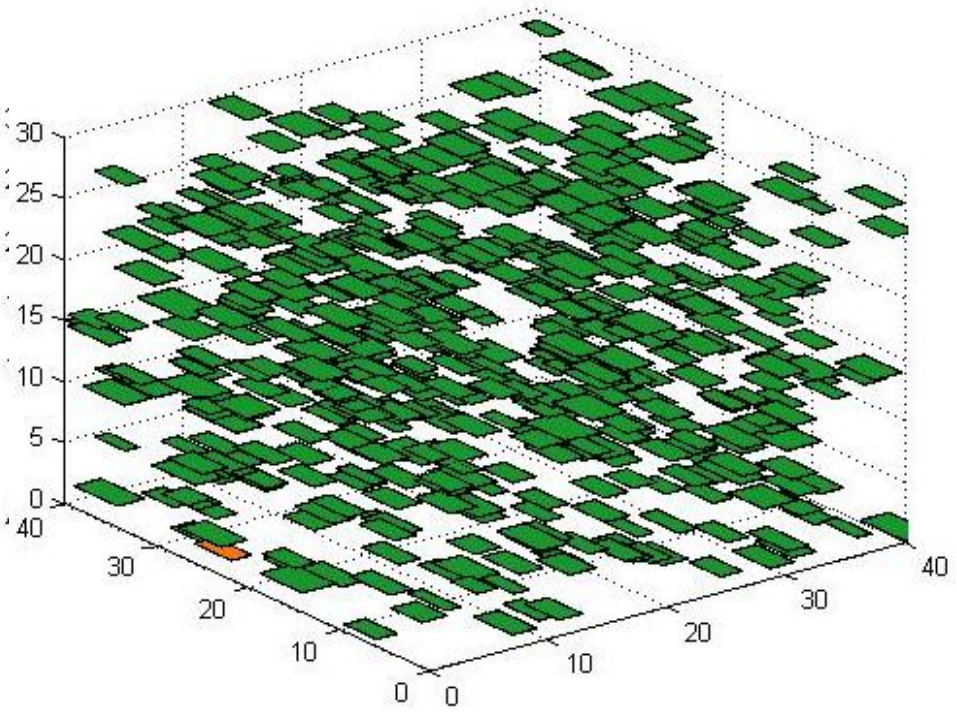
Parameters are given a normal distribution with mean calculated using the above correlations and standard deviation equal to the standard error of correlation's fit.

Burning A Virtual Leaf





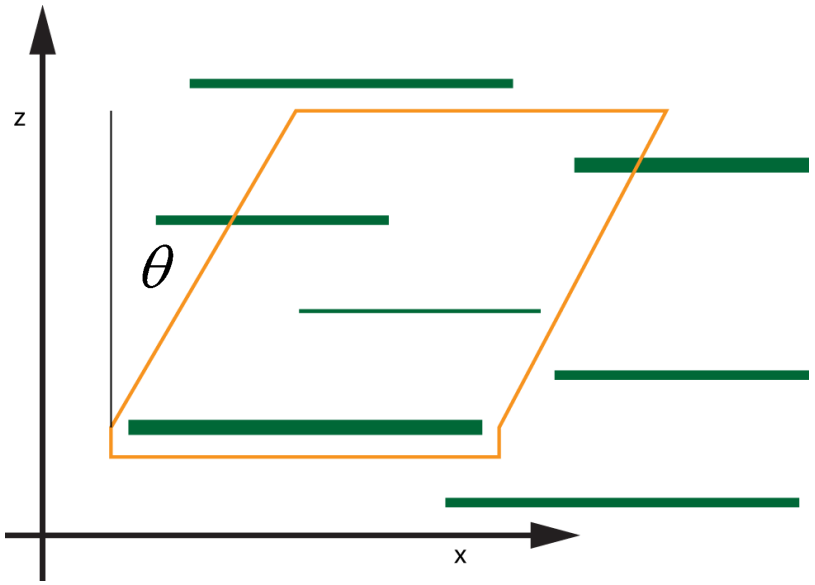
Bush Structure



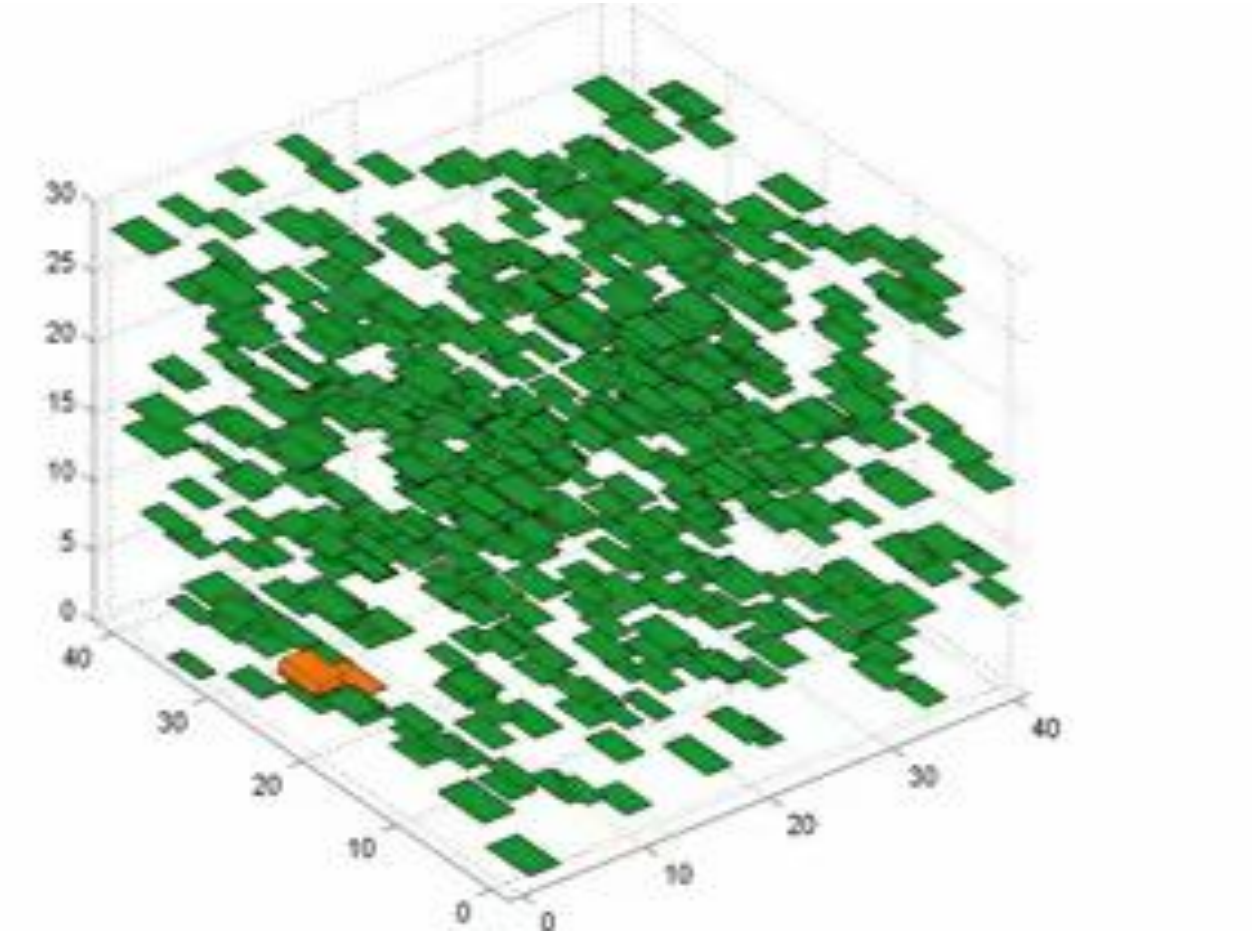
- 27 equal sub-compartments
- Leaves divided equally
- Trunk space left empty
- Randomly assigned x-y-z coordinates
- Vertical or horizontal orientation

Flame Propagation

- Ignitable neighbors are identified for each leaf based on maximum flame dimensions.
- In the presence of wind, flame angles are used to find ignitable neighbors.
- Assume leaves must touch an ignition zone for the entire predicted time to ignition



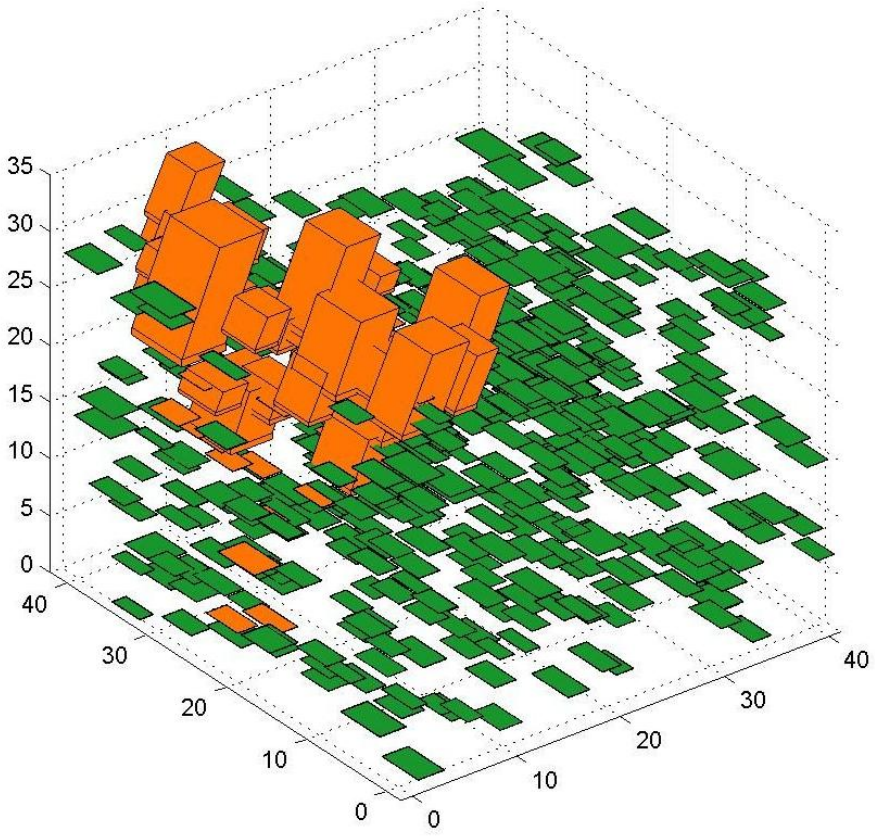
3-D Simulation Run



- Fuel loading: ~.01 leaves/cm^3
- Wind speed: 1 m/s
- Moisture Content: 50%

- Allows visual assessment of flame propagation direction and speed.

Initial Comparison



Conclusions

- Bush model developed to describe leaf-to-leaf flame propagation
  - Based on individual leaf combustion data correlations
- Model comparison with actual bush burning experiments appears reasonable
- Model predictions sensitive to:
  - Leaf properties
  - Bulk density (i.e., leaf spacing)
  - Wind speed

Thank You

- Thanks to BYU and to the USDA Forest Service for providing this opportunity to learn