Fundamental Combustion Rates of Live Fuels

Thomas H. Fletcher, Larry L. Baxter,
Josh Engstrom, Jordan Butler

Overall Objective

- To better understand the combustion behavior of live fuels.
  - Why do some fuels burn differently than others?
  - Causes of flare-ups.
  - Causes for ground to crown transitions
- To add physics into forest fire modeling

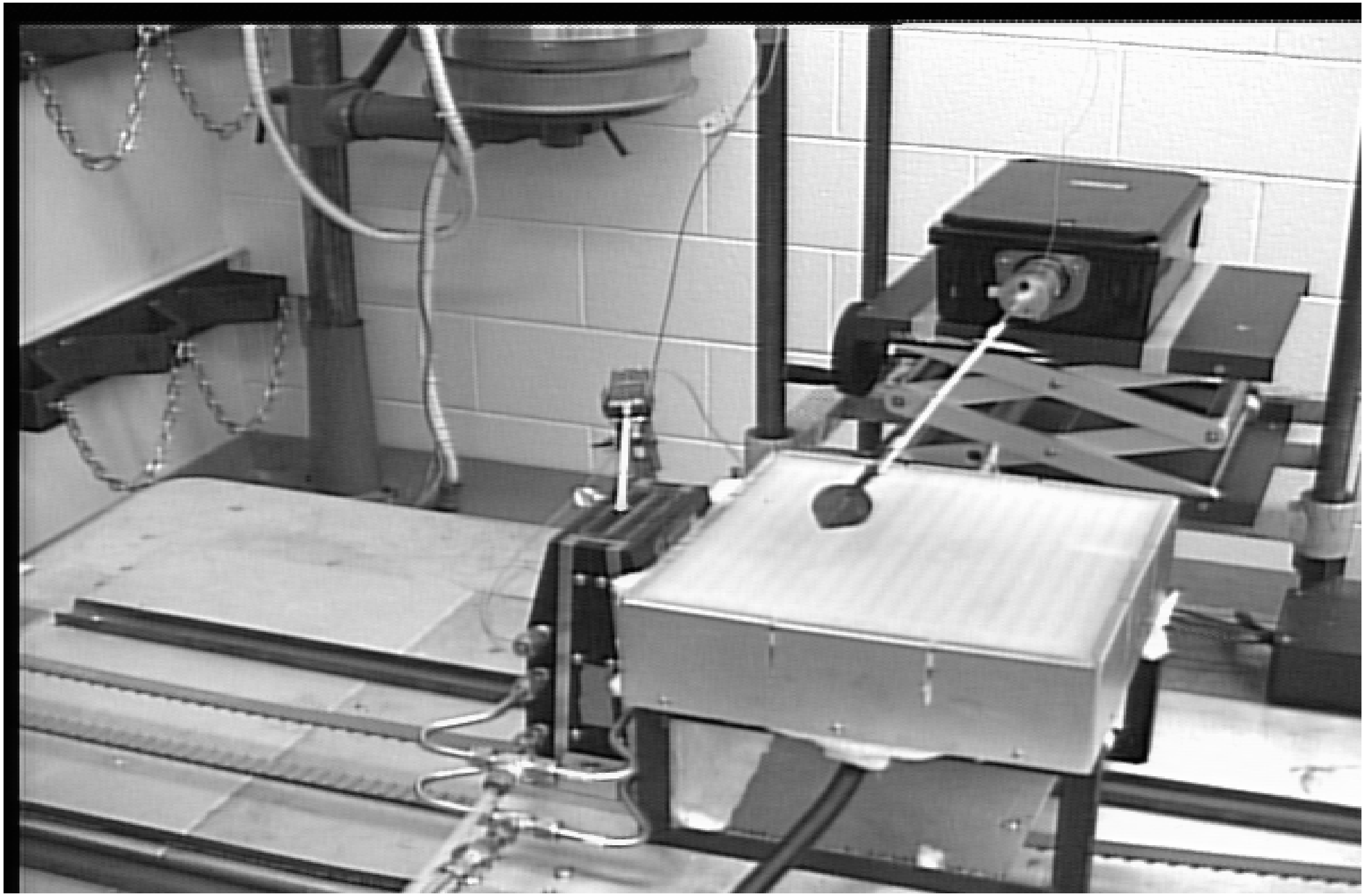
Sussot’s Work

- TGA data don’t tell how fuels burn (rates all the same)
- If chemistry is not dominant, then shape and mass transfer may have importance

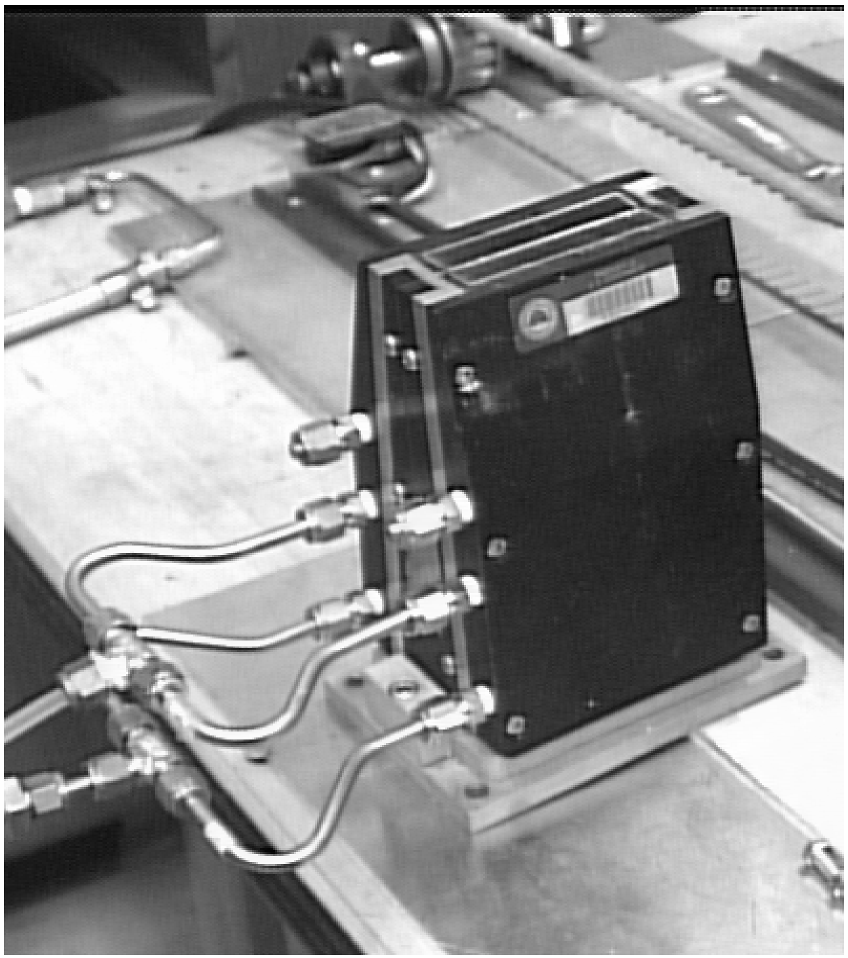
Experimental Approach

- Single Leaf Sample
- Optical/Visual Access for Observation of Ignition
- Measure the Temperature and Mass as a Function of Time
- Heating Rates Typical of Fires (~100 K/s)

Experimental Apparatus

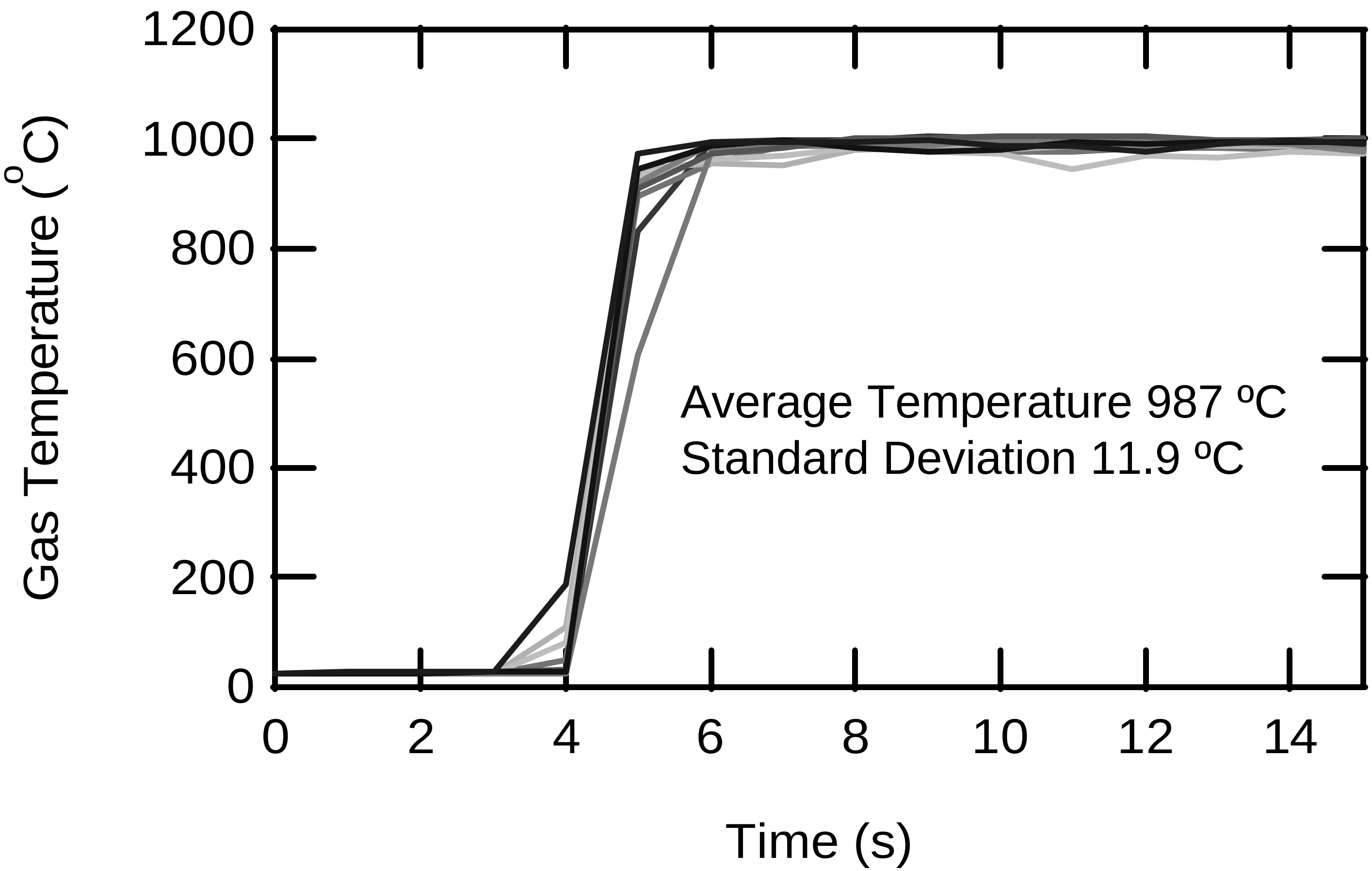


Flat Flame Burner



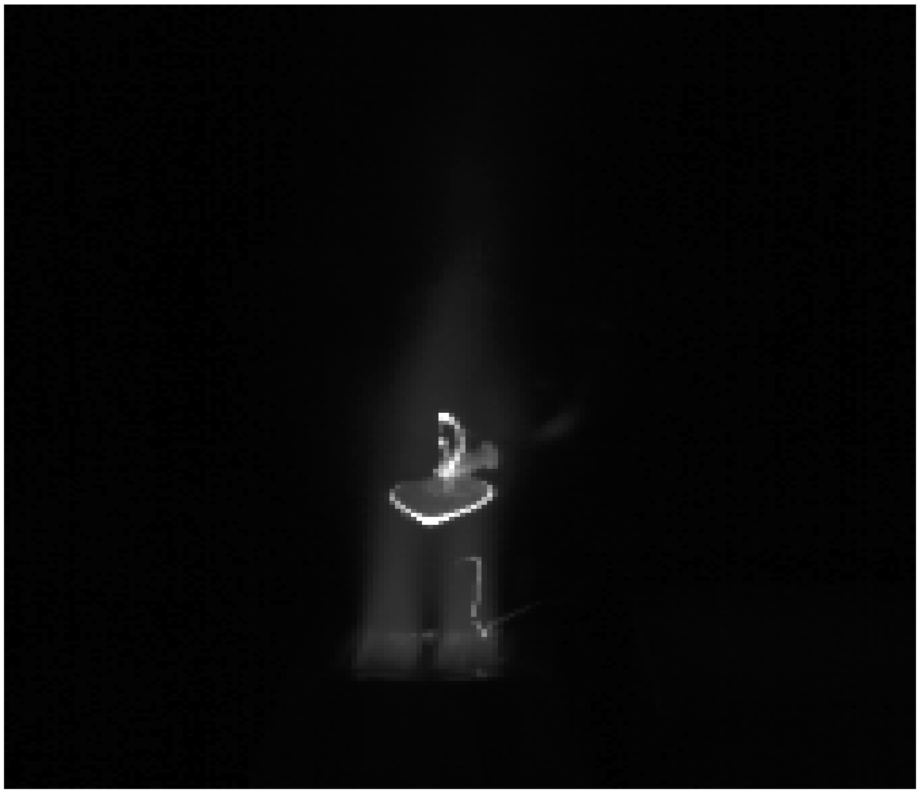
- Gases Used
  - Air, H_2, CH_4, N_2
- Stoichiometry adjusted to manipulate post-flame conditions
  - T, O_2 (~10%)
- Very repeatable experiments within 2 inches of the burner surface

Gas Temperature Profiles



*127 μm diameter type K thermocouple 2” above the FFB

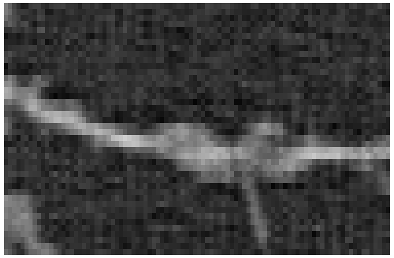
Infrared Images

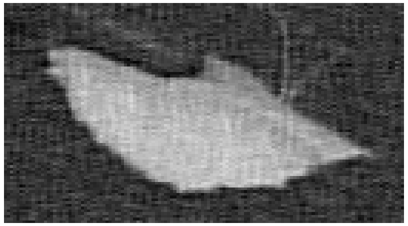


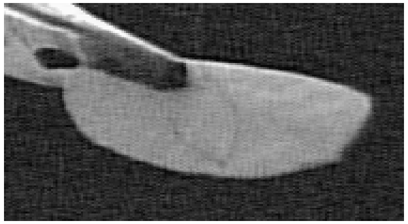
- Optimal sample placement determined with IR camera (FLIR)
- Sharp interface between the post-flame gases and surrounding air
- Sample height of 2” is well within the hot zone of the post-flame gases

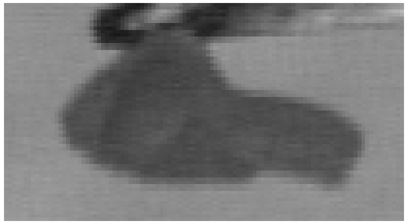
Representative California Chaparral Samples

- Chamise
- Scrub Oak (Quercus berberidifolia)
- Manzanita (Arctostap hylosdensiflora)
- Hoaryleaf Ceanothus (Ceanothus crassifolius)







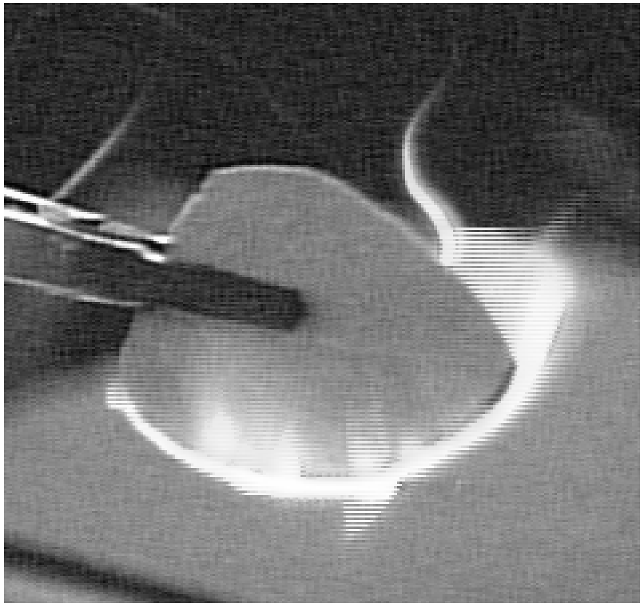


Fresh Samples Wanted

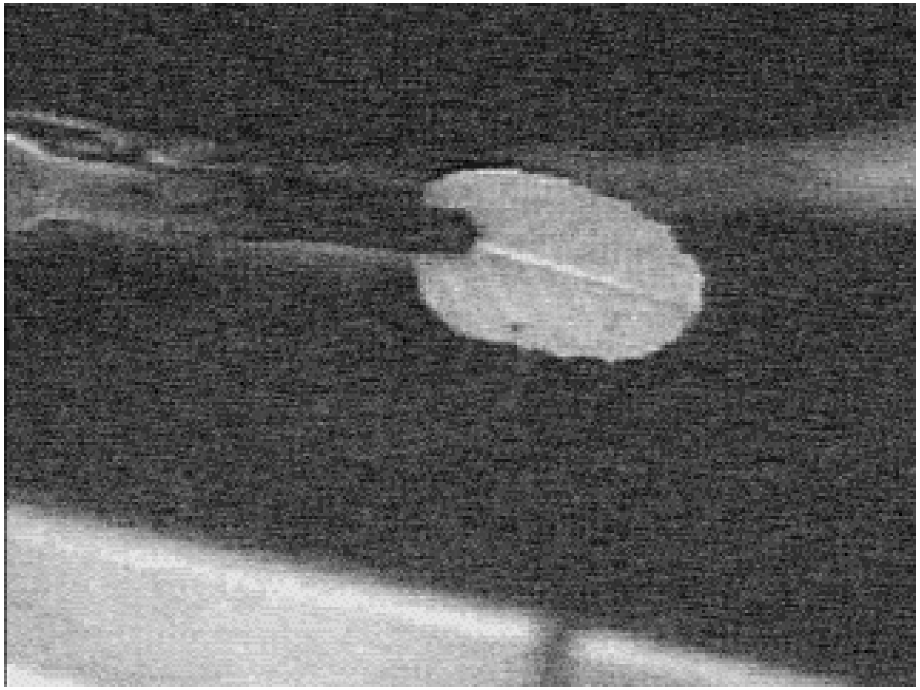
- ❖ Old Samples Used for Current Experiments
- ❖ Fresh Samples Will Be Burned Within 1 Day of Arrival

Orientation Effects

- Horizontally-oriented square-shaped samples ignite first at corners
- Horizontally-oriented round-shaped samples ignite along the entire edge
- Vertically-oriented samples ignite at edge closest to the flame

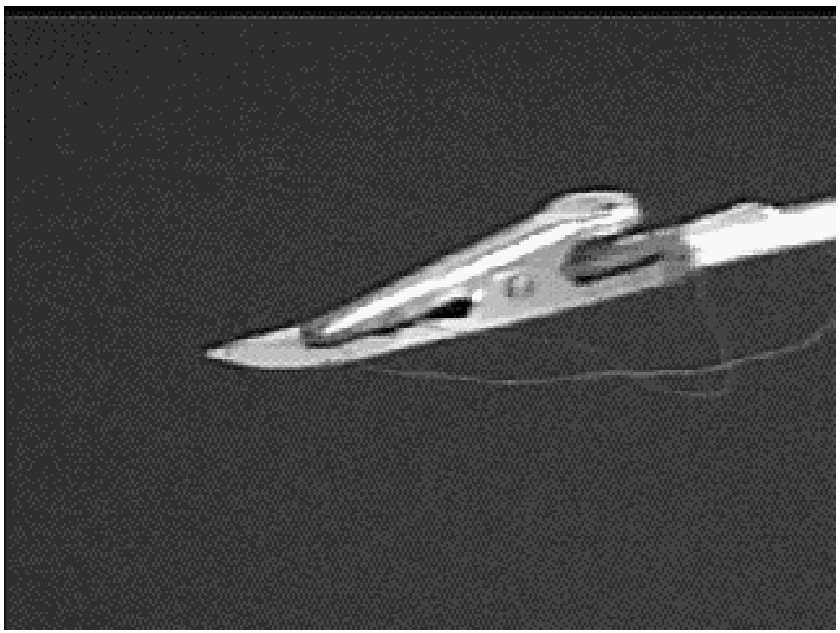


Orientation Effects (Cont.)
Sample Oak



Orientation Effects (Cont.)
Ignition Location

Square-Shaped Manzanita

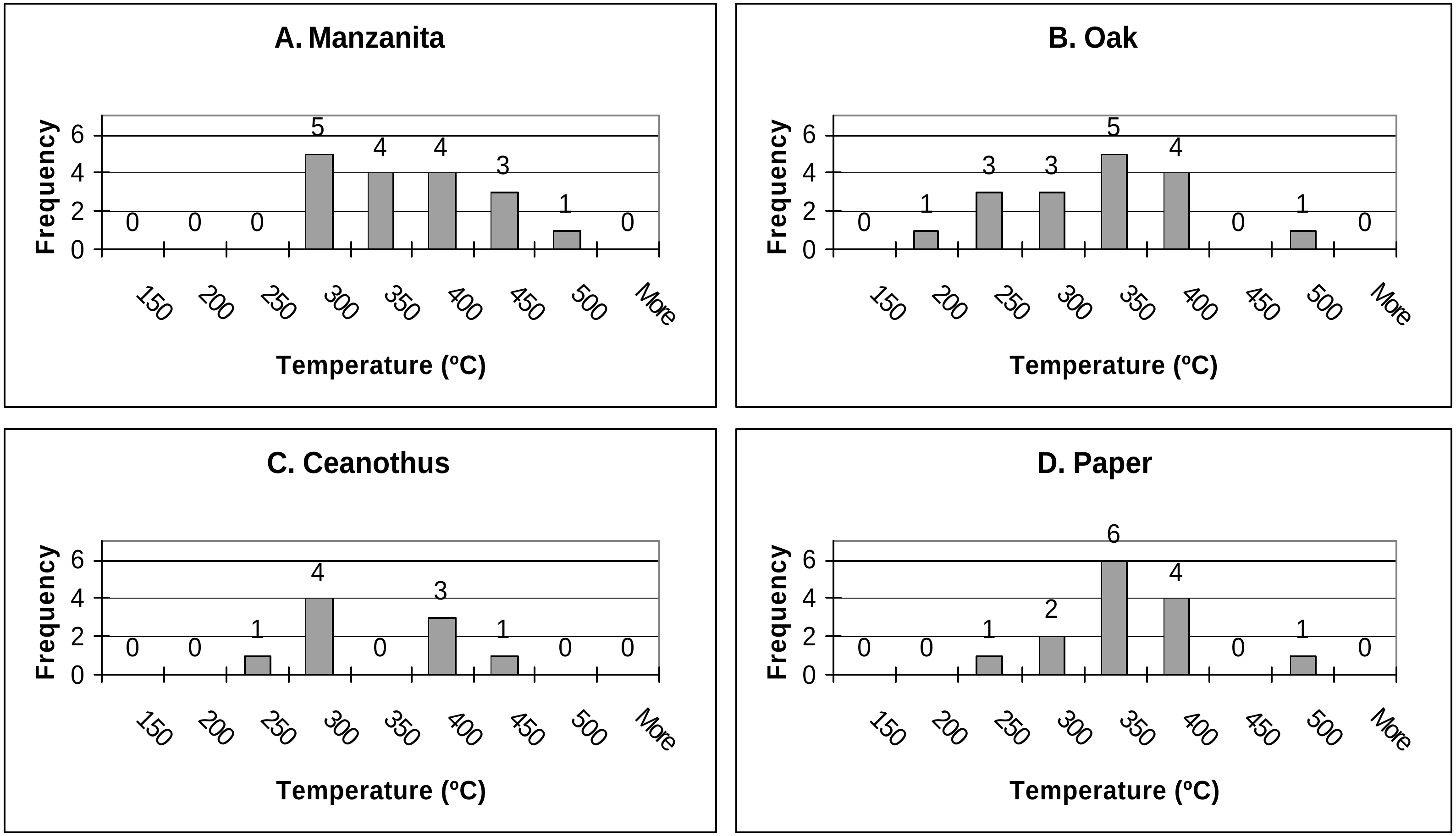


Round-Shaped Manzanita

Orientation Effects (Cont.) Orientation Effects

- Vertical Manzanita
- Horizontal Manzanita
- Vertical Chamise
- Horizontal Chamise

Ignition Temperature

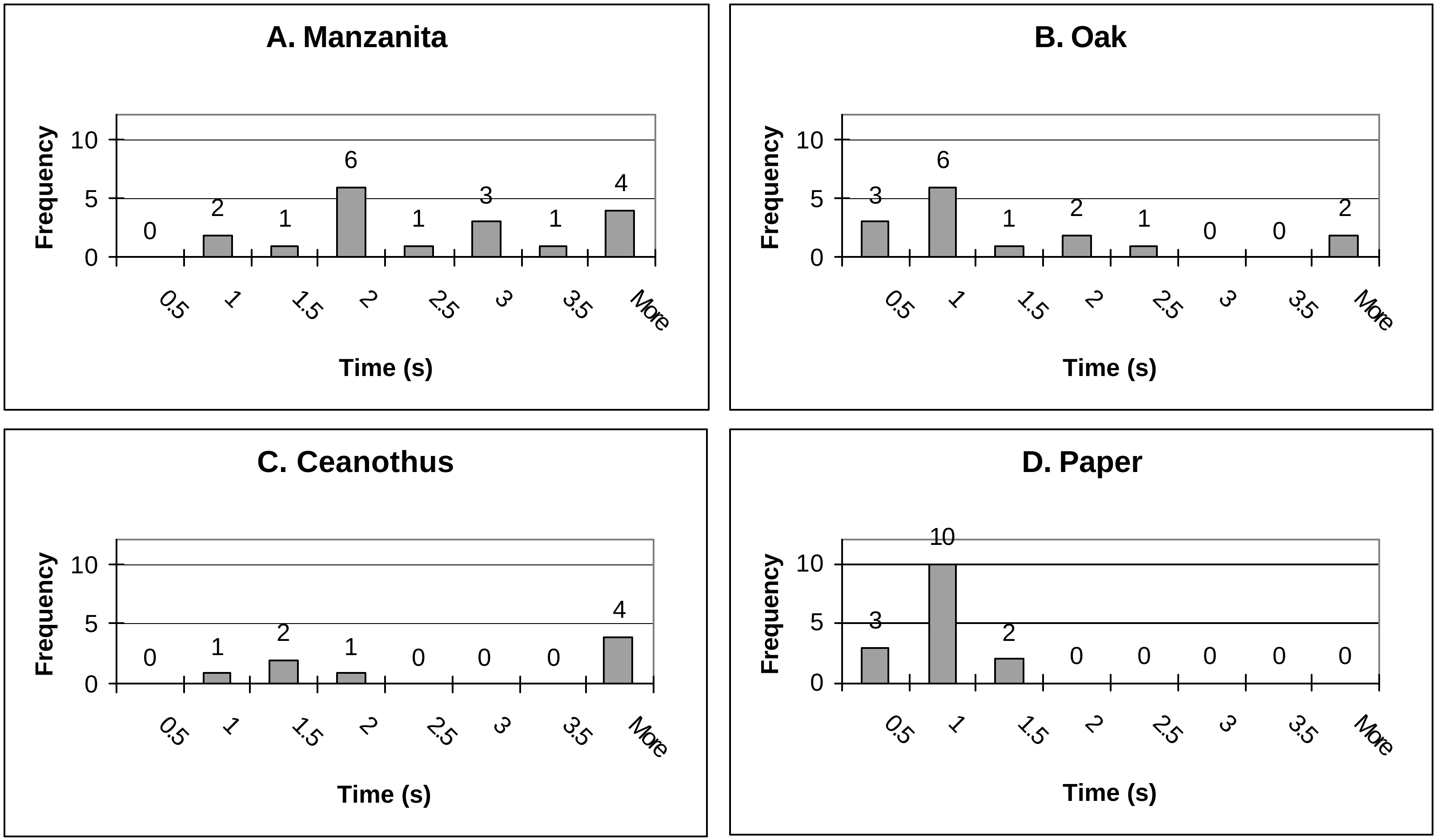


- **Scatter due to variations in sample shape, size, etc.**
- **Paper samples showed much less variation**

Ignition Temperature (Cont.)

	Average Ignition Temperature (ºC)	Standard Deviation (s)	Range (+/- 3*s)
Manzanita	346	61	164-528
Oak	311	74	88-534
Ceanothus	319	59	141-497
Paper	339	62	152-526

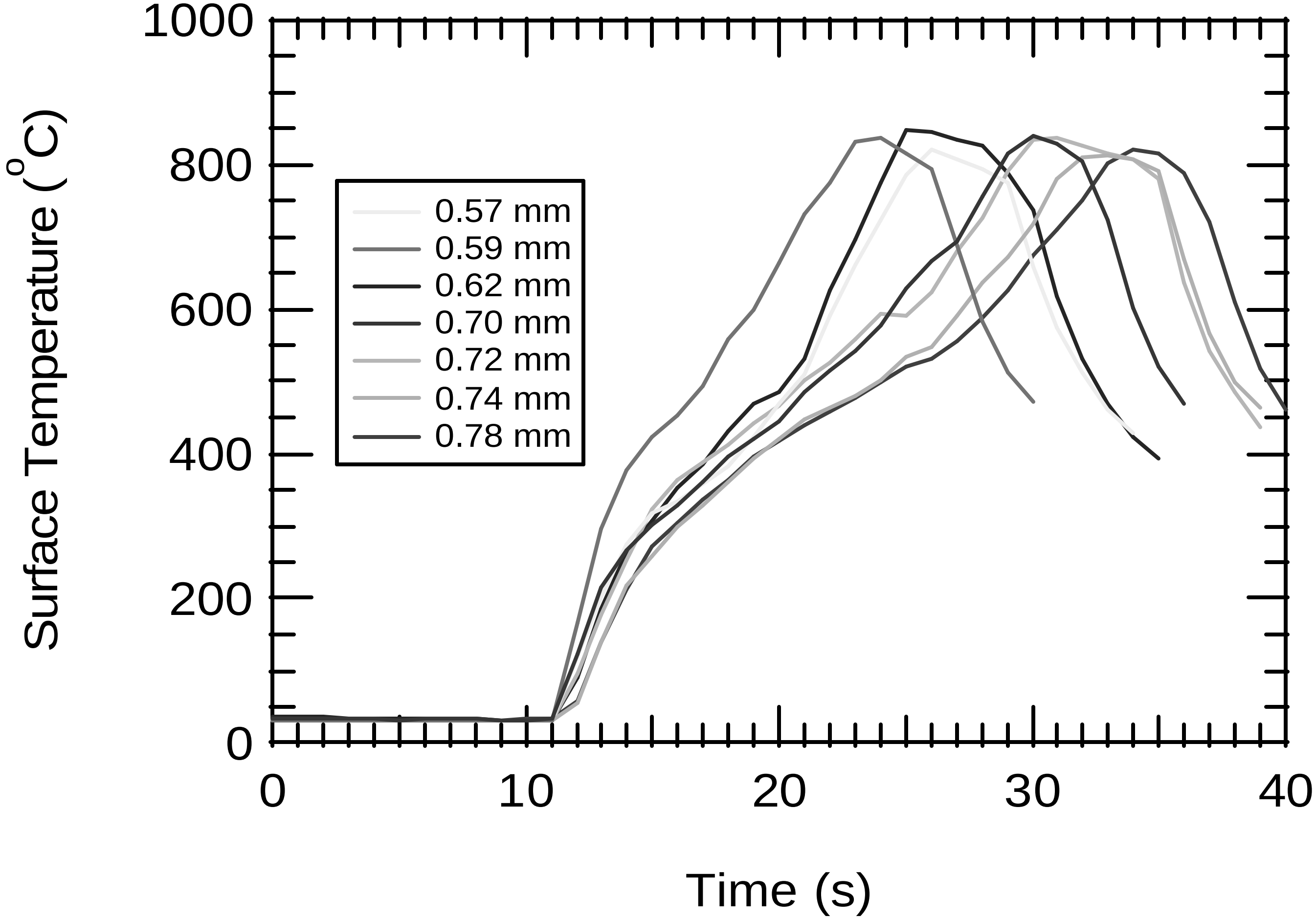
Time to Ignition



Discussion

- Samples not adjusted for thickness and weight resulting in greater scatter
- More scatter in time to ignition than ignition temperature data
- Time to ignition influenced more by heat and mass transfer effects and moisture content

Temperature Profiles of Manzanita with Varying Thickness



Conclusion

- Fire behavior influenced by sample orientation and shape
- Sample types are important in determining ignition temperature
- Heat and mass transfer effects play an important role in sample heat-up time
- Time to ignition significantly affected by size, shape and orientation

Future Work

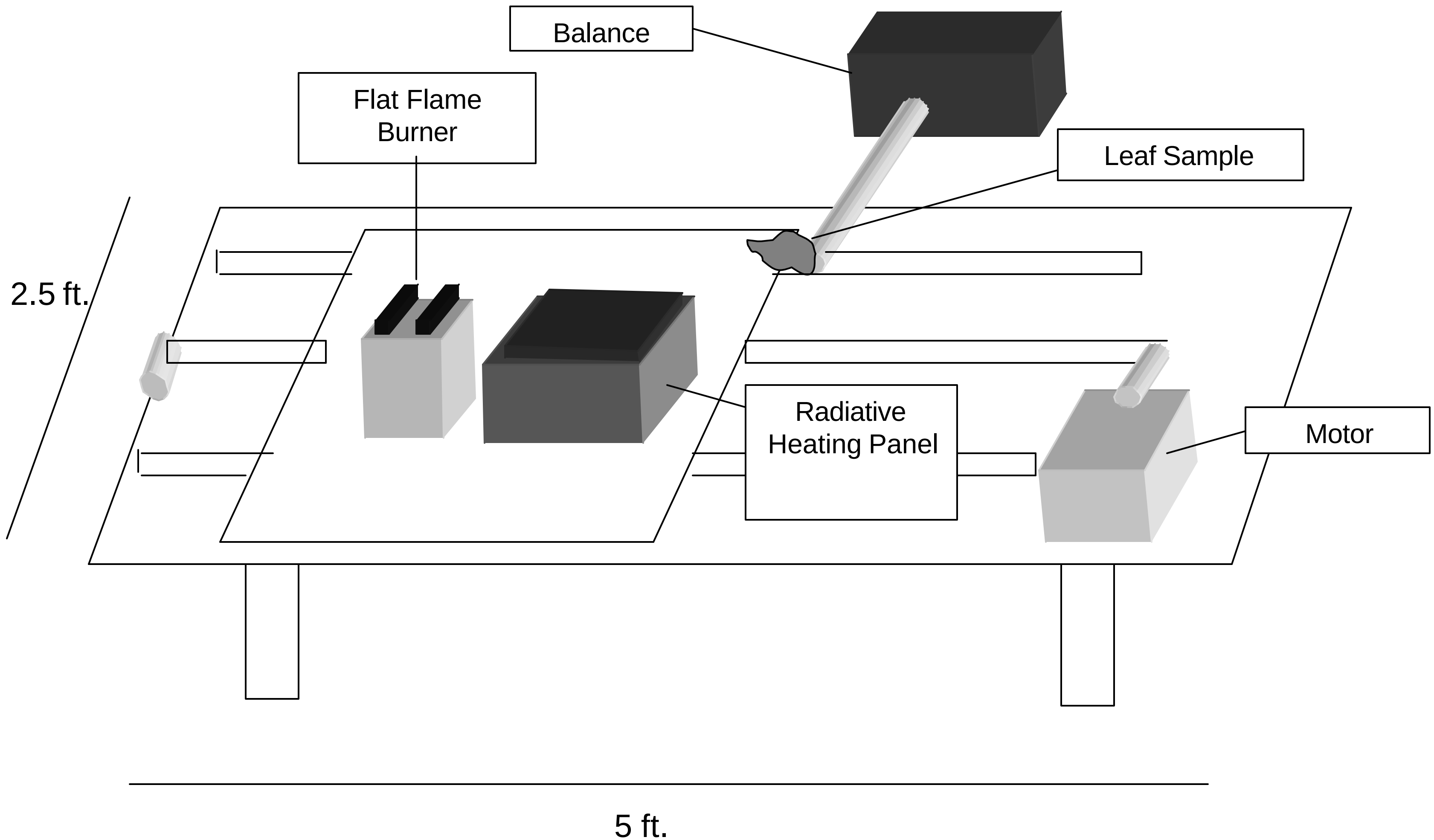
- Improve technique to determine accurate ignition temperature and time to ignition
- Develop heat transfer correlations to avoid excessive computational costs
- Incorporate knowledge of leaf burning into models of bush burning

Acknowledgments

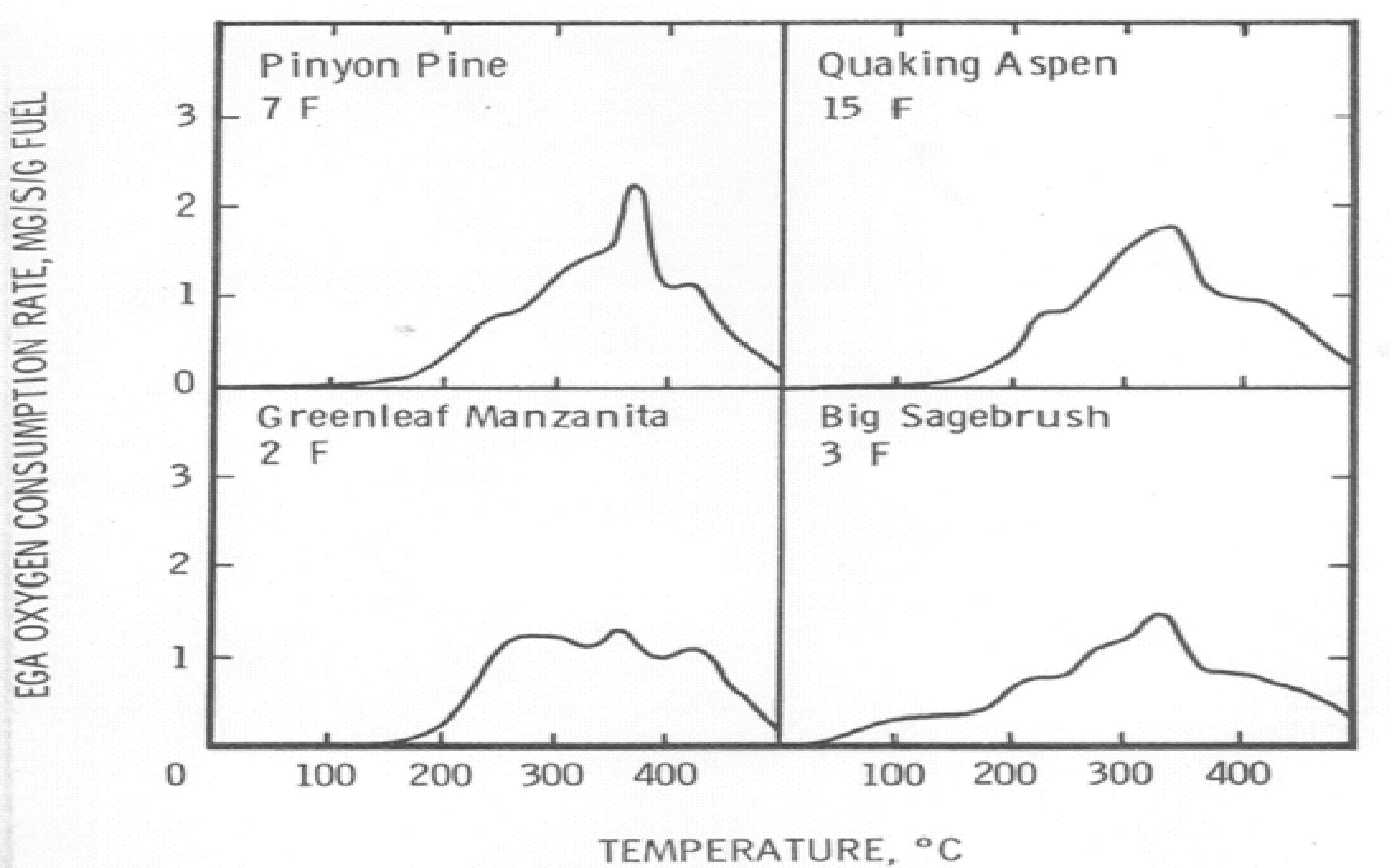
Thanks to:

- David Weise, USDA Forest Fire Research Center, Riverside, CA
- Bret Butler, USDA Forest Fire Research Center, Missoula, MT

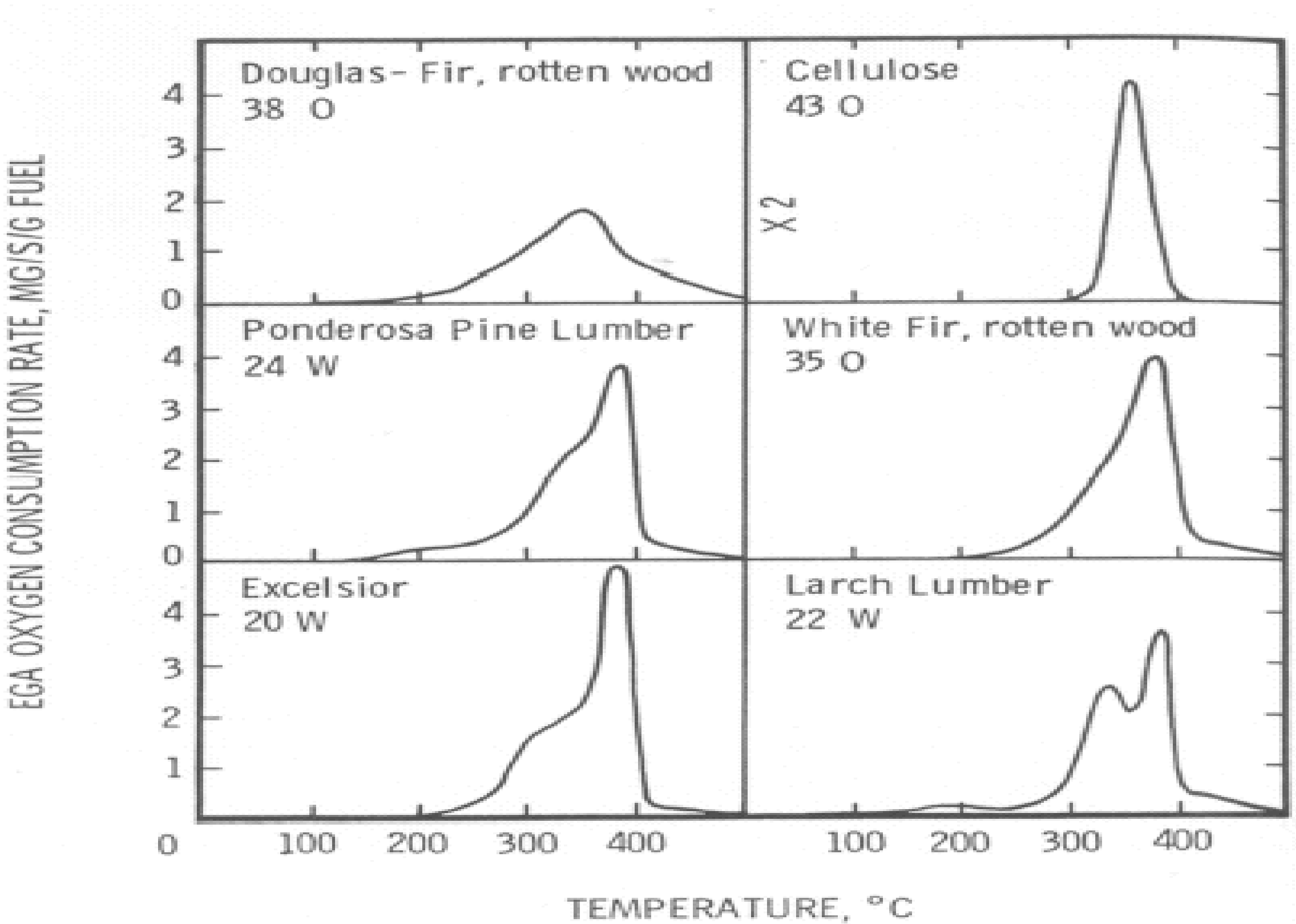
Experimental Apparatus-Schematic



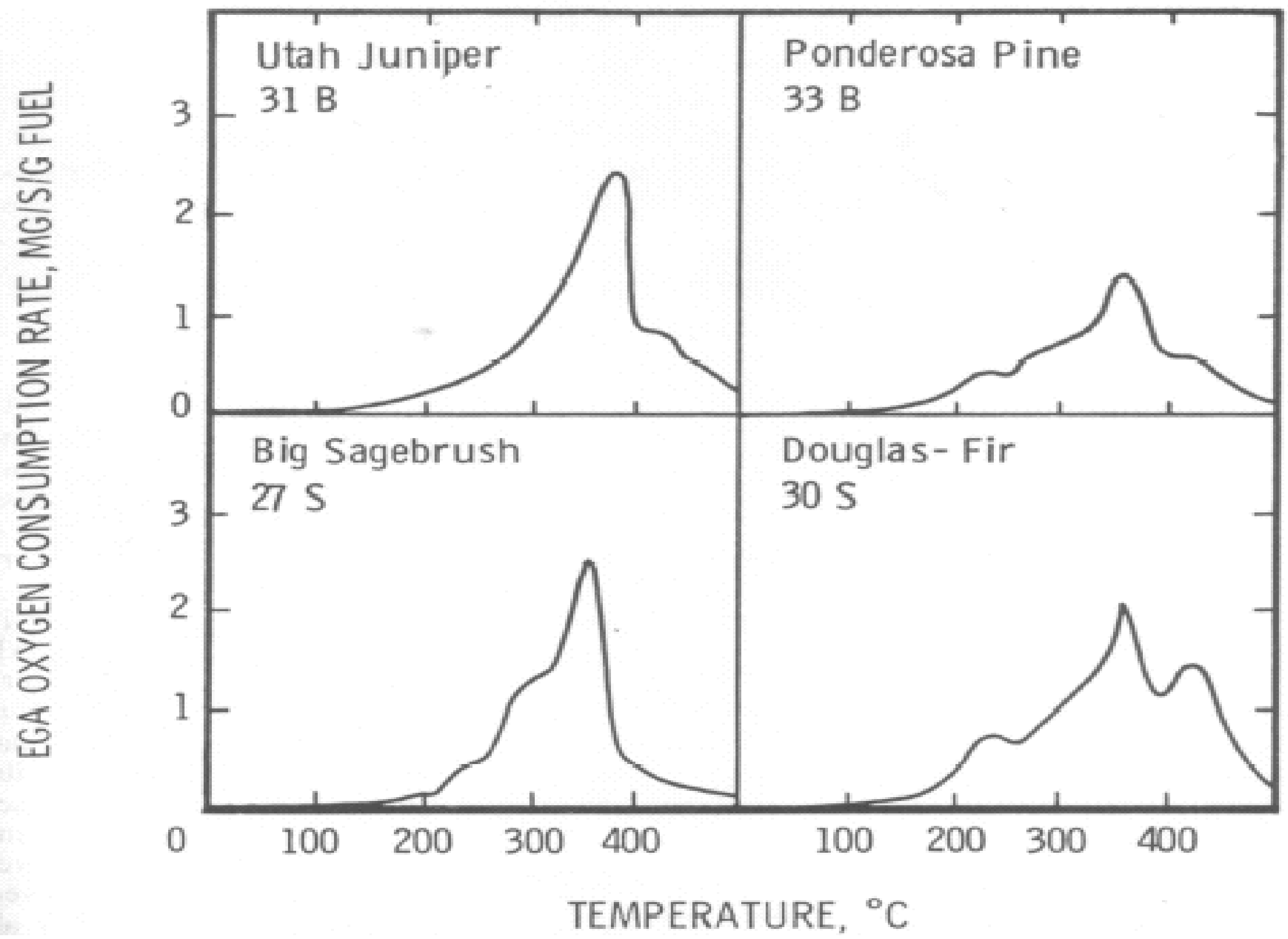
EGA Analysis-Foliage



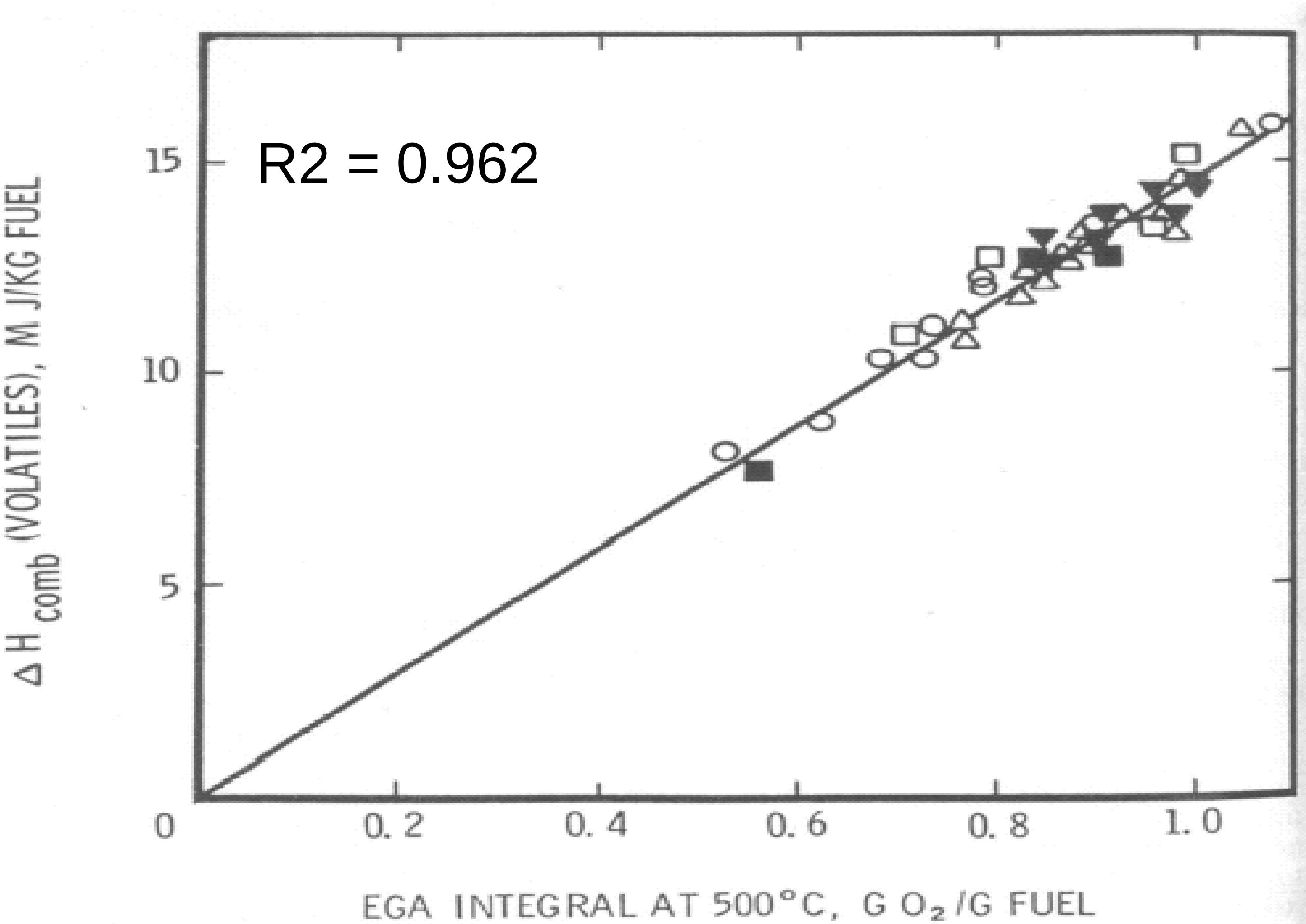
EGA Analysis-Wood



EGA Analysis-Bark and Stems



Volatile Heat of Combustion vs. Oxygen Consumption



Extending Sussot’s Work

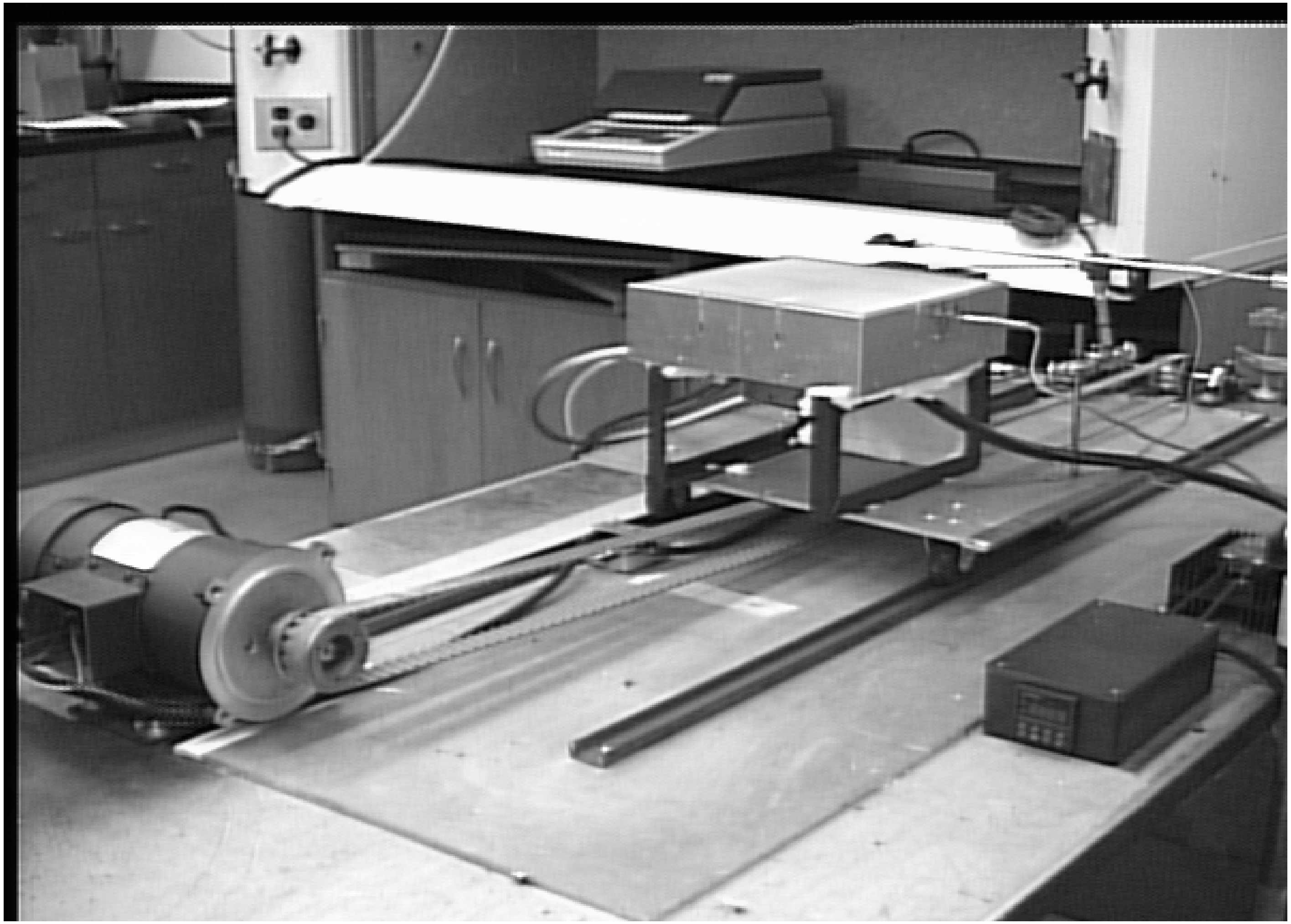
- Burn whole samples instead of shredded samples
- Record mass loss per time
- Calculate heat-up time to ignition
- Record ignition temperature

Compare data to Sussot’s results

Current Work-Qualitative

- Experimentally represent forest fire conditions
- Video record burning samples
  - Determine where sample first ignites
  - Observe flaming characteristics with change in sample orientation and sample type

Experimental Forest Fire Conditions Cont.



Experimental Forest Fire Conditions Cont.

Work in Progress-Quantitative

- Determine ignition temperature
- Calculate heat up time to ignition
- Measure mass loss rate per time

Sussot's Work

- Heats of Combustion of Volatiles
- Evolved Gas Analysis (EGA)
  - Different Curves for foliage, wood, and bark and stems
- Correlation between oxygen consumption and volatile heat of combustion

Heats of Combustion of Volatiles and Char (from Sussot, 1982)

- Overall Pyrolysis Reaction

Fuel $\xrightarrow{\text{heat}}$ **Volatiles** + **Char**

- Volatile Heat of Combustion Calculation

DH°_{comb}(**volatiles**) = DH°_{comb}**(fuel) -** DH°_{comb}**(char) x fract. char**

- Table from Sussot

Experimental Apparatus- Schematic