Full-scale Wind-Driven Fire-Spread Experiments on Woodpiles

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U.S. DEPARTMENT OF COMMERCE

NIST WUI DAYS 2023 – Session 3.8

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with Marco Fernandez, Shonali Nazare, Wei Tang, Mariusz Zarzecki, Will Saar, Phil Deardorff, Mike Selepak, & Stephen Fink

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NIST Technical Note
NIST TN 2251

Wind-Driven Fire Spread to a Structure from Firewood Piles

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Outline

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- Introduction
- Experimental Design
- Results
- Key Findings
- Mitigation
- Recommendations & Future Work

Introduction

Introduction – How Does Fire Spread in the WUI?

- Direct Flame Contact
- Radiation
- Firebrands (Embers)
  - "Spot Fires"
  - Vegetation
  - Combustible objects
  - Structure-to-structure
  - >50 % of ignitions

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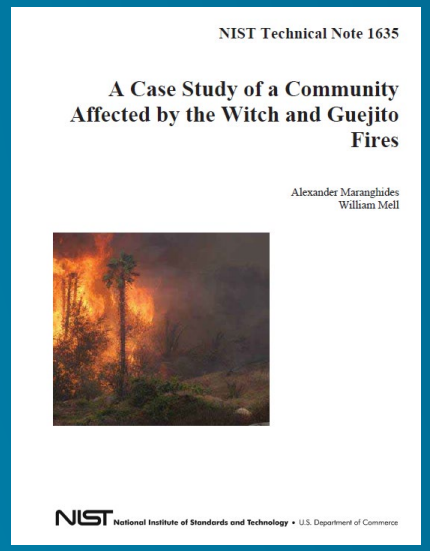
Introduction – WUI Fire Case Studies – NIST Collaborations


NIST Technical Note 1635

A Case Study of a Community Affected by the Witch and Guejito Fires

Alexander Maranghides
William Mell

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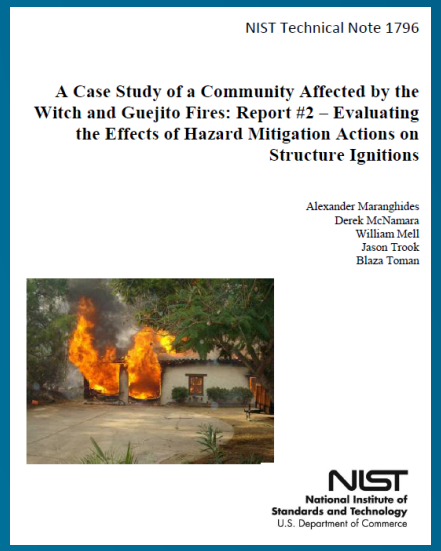
NIST Technical Note 1796

A Case Study of a Community Affected by the Witch and Guejito Fires: Report #2 – Evaluating the Effects of Hazard Mitigation Actions on Structure Ignitions

Alexander Maranghides
Derek McNamara
William Mell
Jason Trook
Blaza Toman

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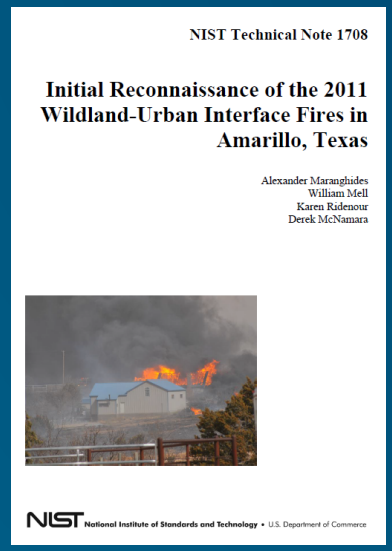
Amarillo fires 2011, TX

Witch-Guejito fires 2007, CA


NIST Technical Note 1708

Initial Reconnaissance of the 2011 Wildland-Urban Interface Fires in Amarillo, Texas

Alexander Maranghides
William Mell
Karen Ridenour
Derek McNamara

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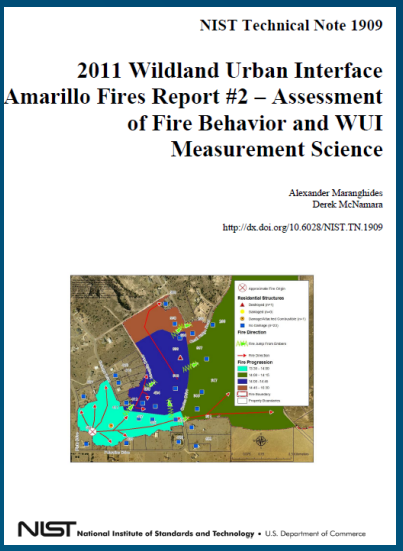
NIST Technical Note 1909

2011 Wildland Urban Interface Amarillo Fires Report #2 – Assessment of Fire Behavior and WUI Measurement Science

Alexander Maranghides
Derek McNamara

http://dx.doi.org/10.6028/NIST.TN.1909

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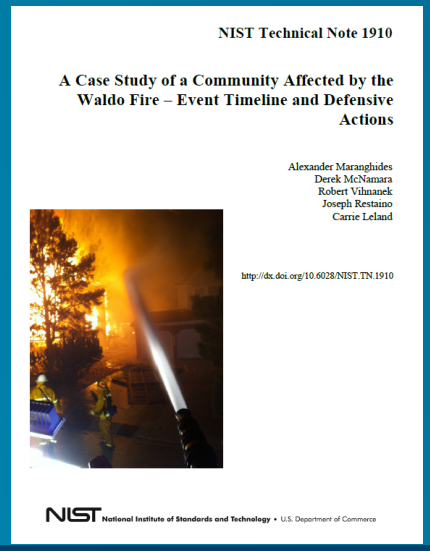
NIST Technical Note 1910

A Case Study of a Community Affected by the Waldo Fire – Event Timeline and Defensive Actions

Alexander Maranghides
Derek McNamara
Robert Vihnanek
Joseph Restaino
Carrie Leland

http://dx.doi.org/10.6028/NIST.TN.1910

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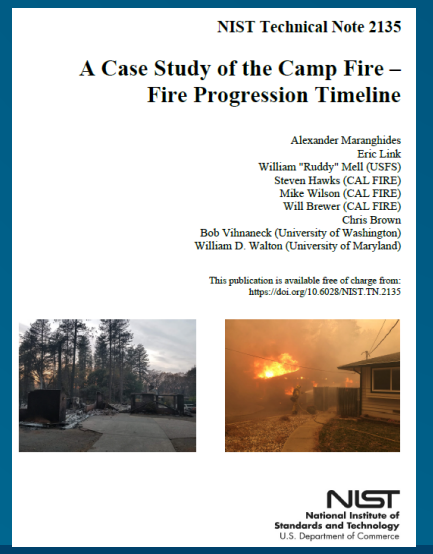
Waldo Canyon fire 2012, CO

Camp Fire 2018, CA


NIST Technical Note 2135

A Case Study of the Camp Fire – Fire Progression Timeline

Alexander Maranghides
Eric Link
William "Ruddy" Mell (USFS)
Steven Hawks (CAL FIRE)
Mike Wilson (CAL FIRE)
Will Brewer (CAL FIRE)
Chris Brown
Bob Vihnaneck (University of Washington)
William D. Walton (University of Maryland)

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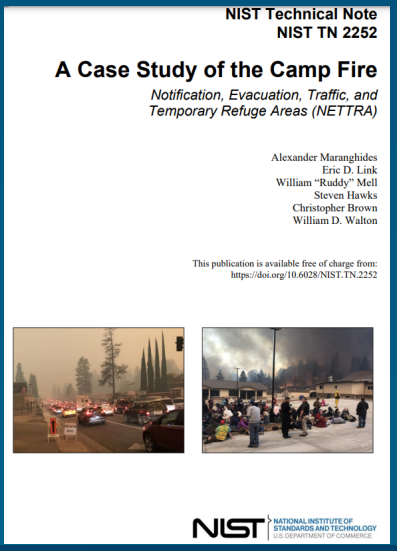
NIST Technical Note
NIST TN 2252

A Case Study of the Camp Fire

Notification, Evacuation, Traffic, and Temporary Refuge Areas (NETTRA)

Alexander Maranghides
Eric D. Link
William "Ruddy" Mell
Steven Hawks
Christopher Brown
William D. Walton

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Introduction - Structure Vulnerabilities

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- From WUI Fire Case Studies
- Both Flame Spread + Firebrand Ignition/Generation
  - Structural Components
    - Roofs, attic vents, siding, eaves etc.
  - Attached Combustibles
    - Decks and projections
  - Detached Combustibles…

Introduction - Structure Vulnerabilities

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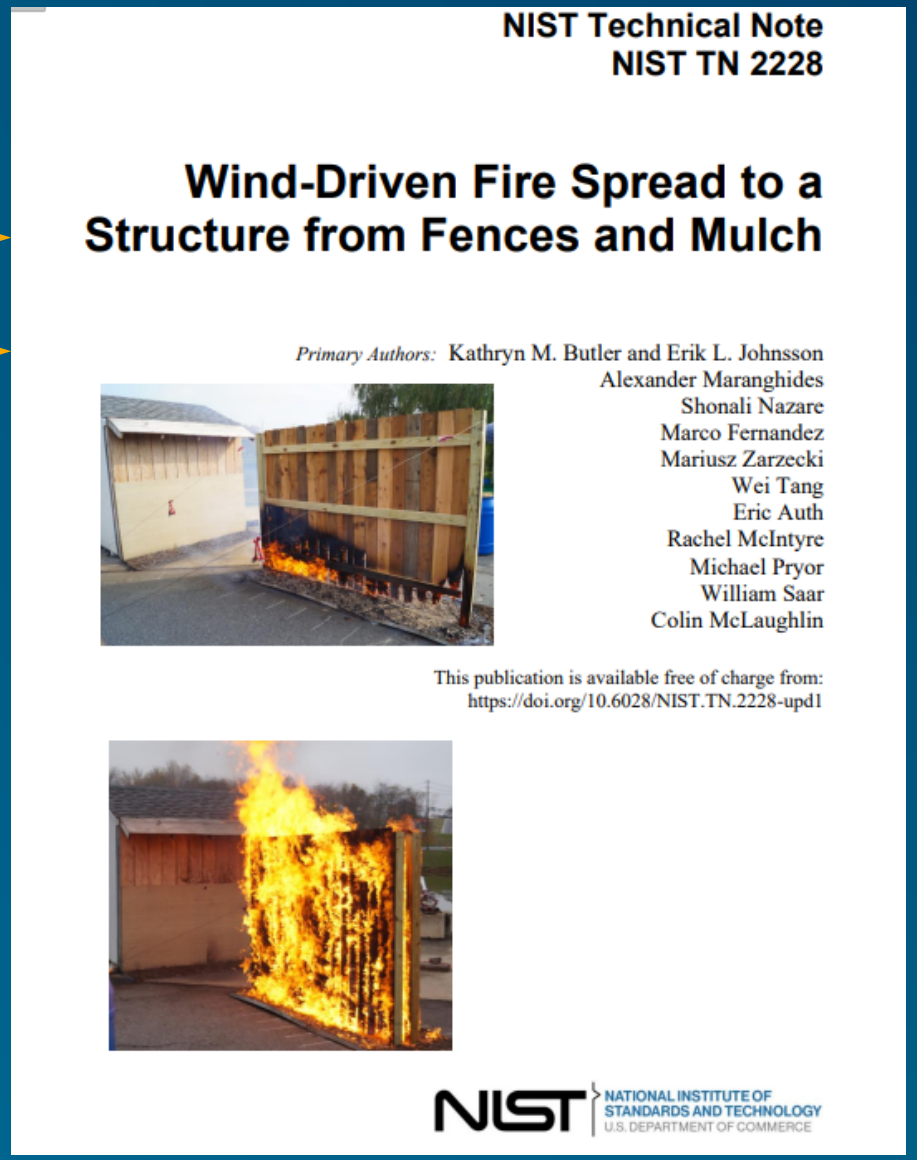
- **Detached Combustibles**
  - Mulch beds / ground cover
  - Fences
  - Woodpiles
  - Landscape timbers, railroad ties, and retaining walls
  - Sheds, gazebos, playsets, furniture, etc.



NIST Technical Note
NIST TN 2228

Wind-Driven Fire Spread to a Structure from Fences and Mulch

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https://doi.org/10.6028/NIST.TN.2228-upd1

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Introduction – Firewood Piles as Pathways for Fire Spread

- Provide a pathway for direct flame spread to adjacent combustibles
- Act as sources of firebrands
- Use firefighter resources
  - Deep-seated fires in piles and within logs
  - Require a lot of water
  - Require spreading the pile

Introduction - Woodpile Examples

Introduction - Objectives of This Study

- Confirm the hazard
- Quantify the hazard under realistic conditions
  - Time for spot fires in target mulch bed
  - Time for spot fire to reach target shed wall
  - Flame extent toward target shed wall
- Identify and develop ways to mitigate the hazard

Experimental Design

Experimental Design

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- Site/Setup
- Measurements
- Procedure
- Variables Tested

Experimental Design - Site

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Frederick County Fire & Rescue Training Facility

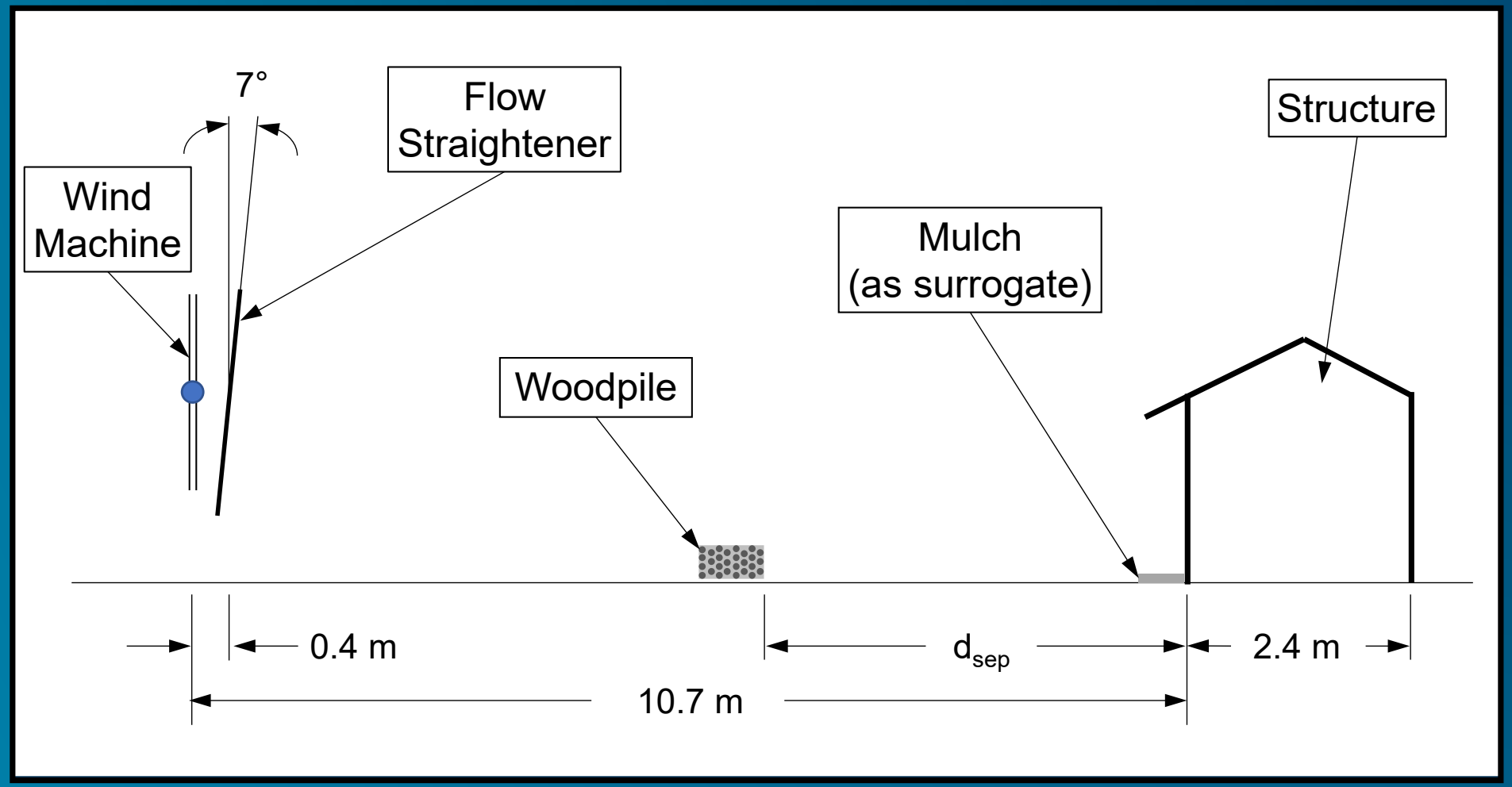
- 

Experimental Design - Site

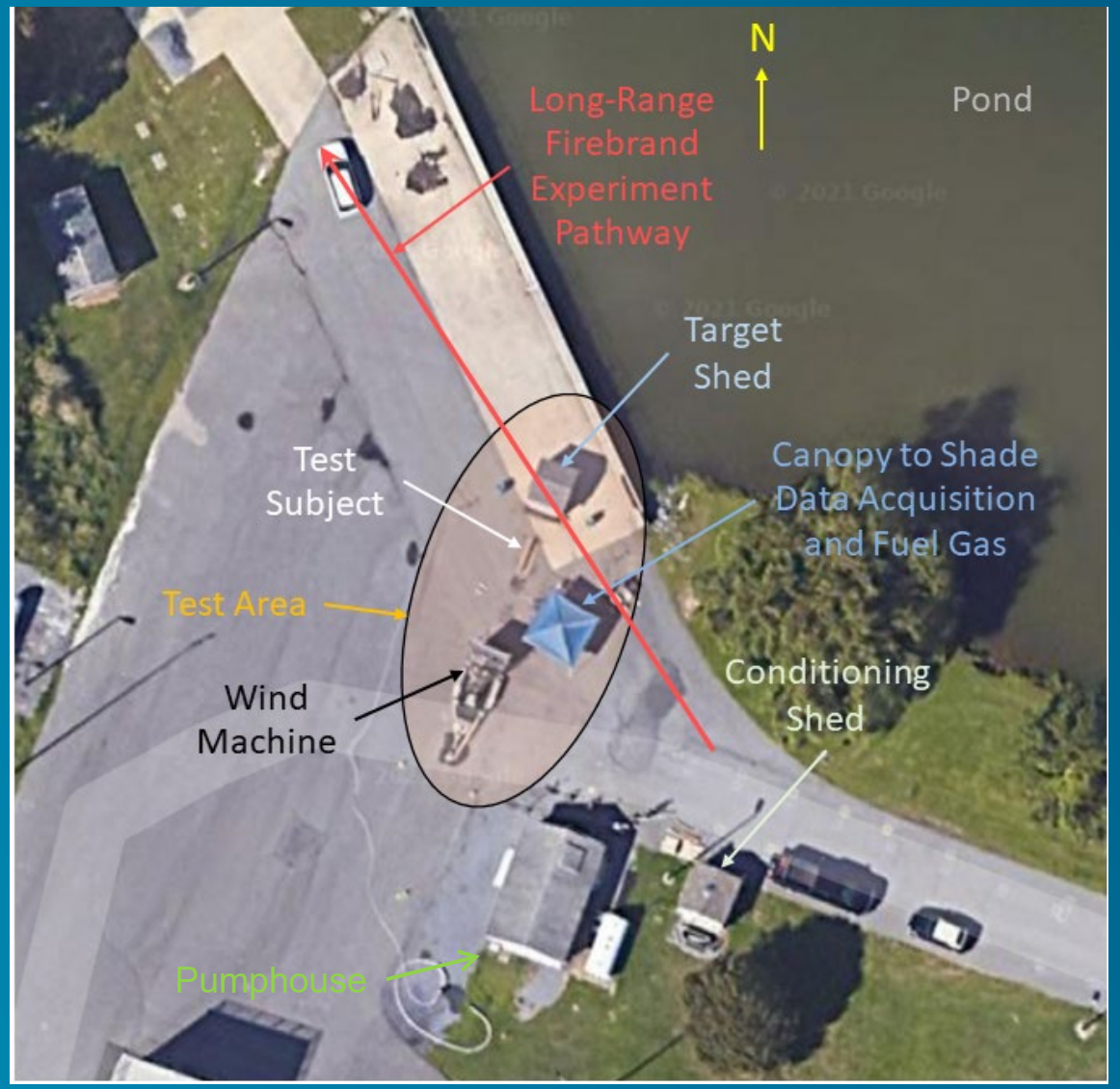
Experimental Design - Setup

- **Similar Setup to Fence/Mulch Experiments:**
  - Target shed and mulch bed
  - Surrogate ignition source (burner)
  - Almost same procedure
- **Differences from Fence/Mulch Experiments:**
  - Different variables
  - Used a propane ring burner adjacent to or under the firewood pile
  - Larger separation distances explored

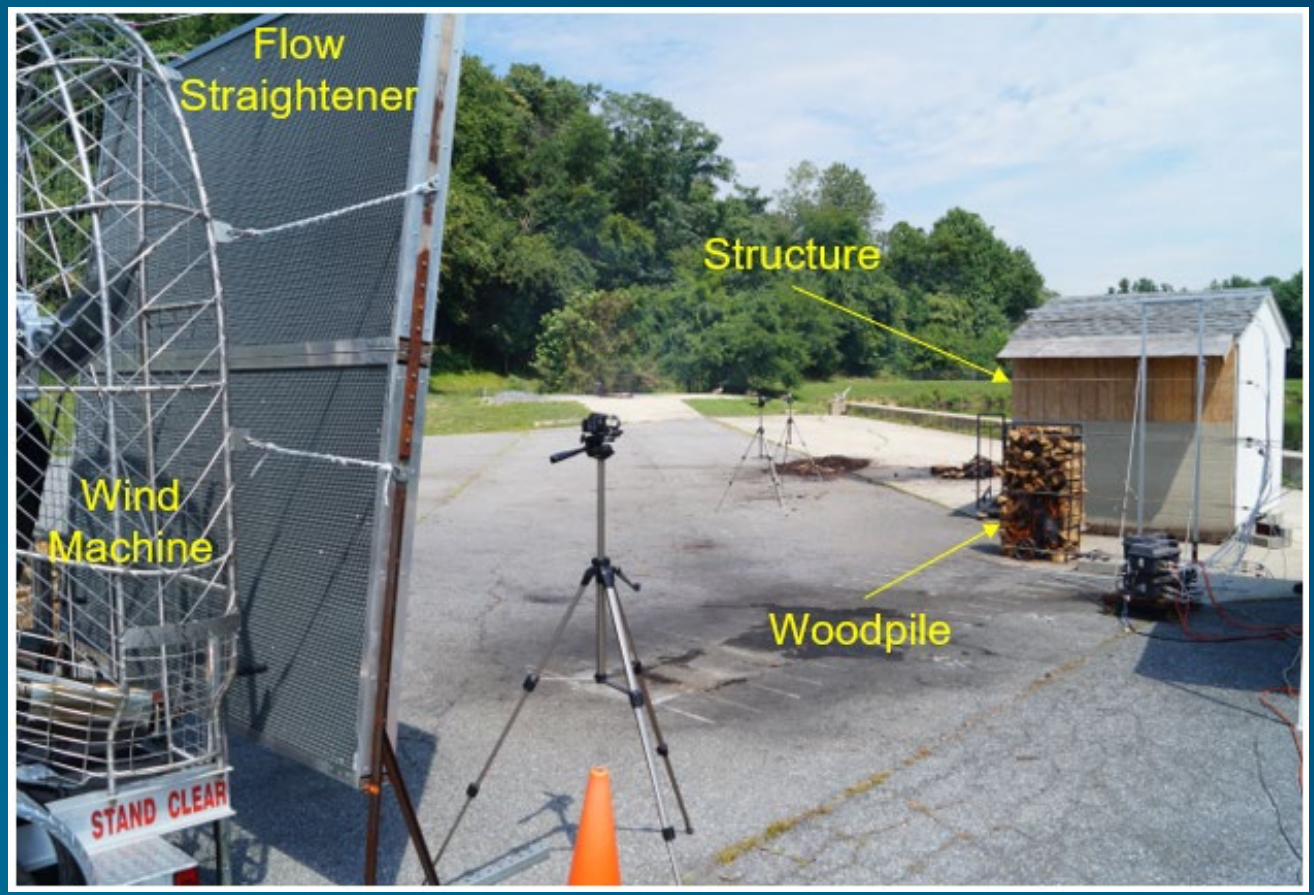
Experimental Design - Setup



Experimental Design - Setup



Aerial View



Test Area

Experimental Design - Setup

Wind Machine + Flow Straightener

Experimental Design - Setup

Structure (shed) + mulch at base

Experimental Design - Measurements

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- Video Recordings – for phenomena timing
- Imposed Wind Speed
- Ambient Wind Speed, Direction, Temperature
- Still Photographs

Experimental Design - Measurements

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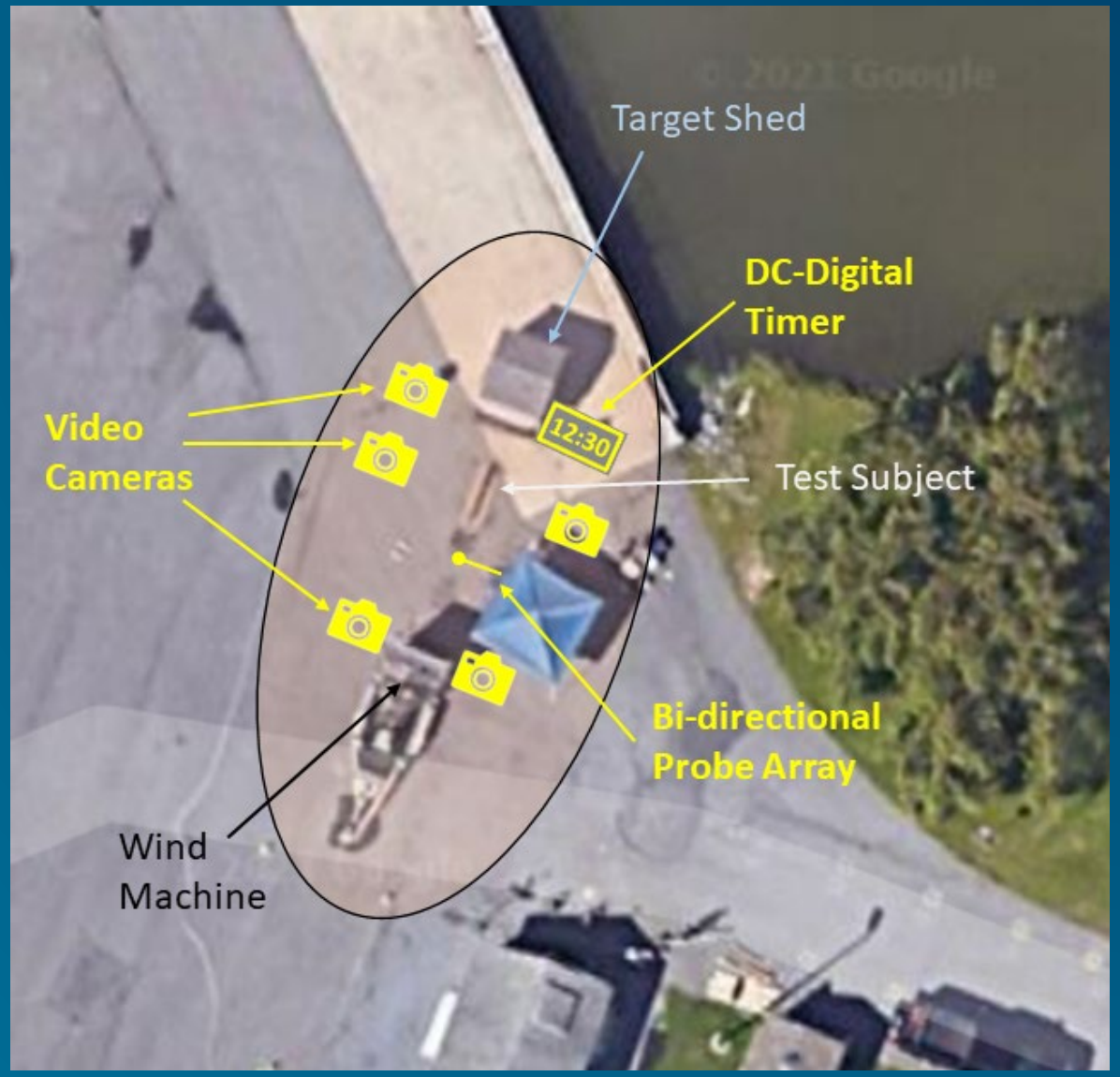
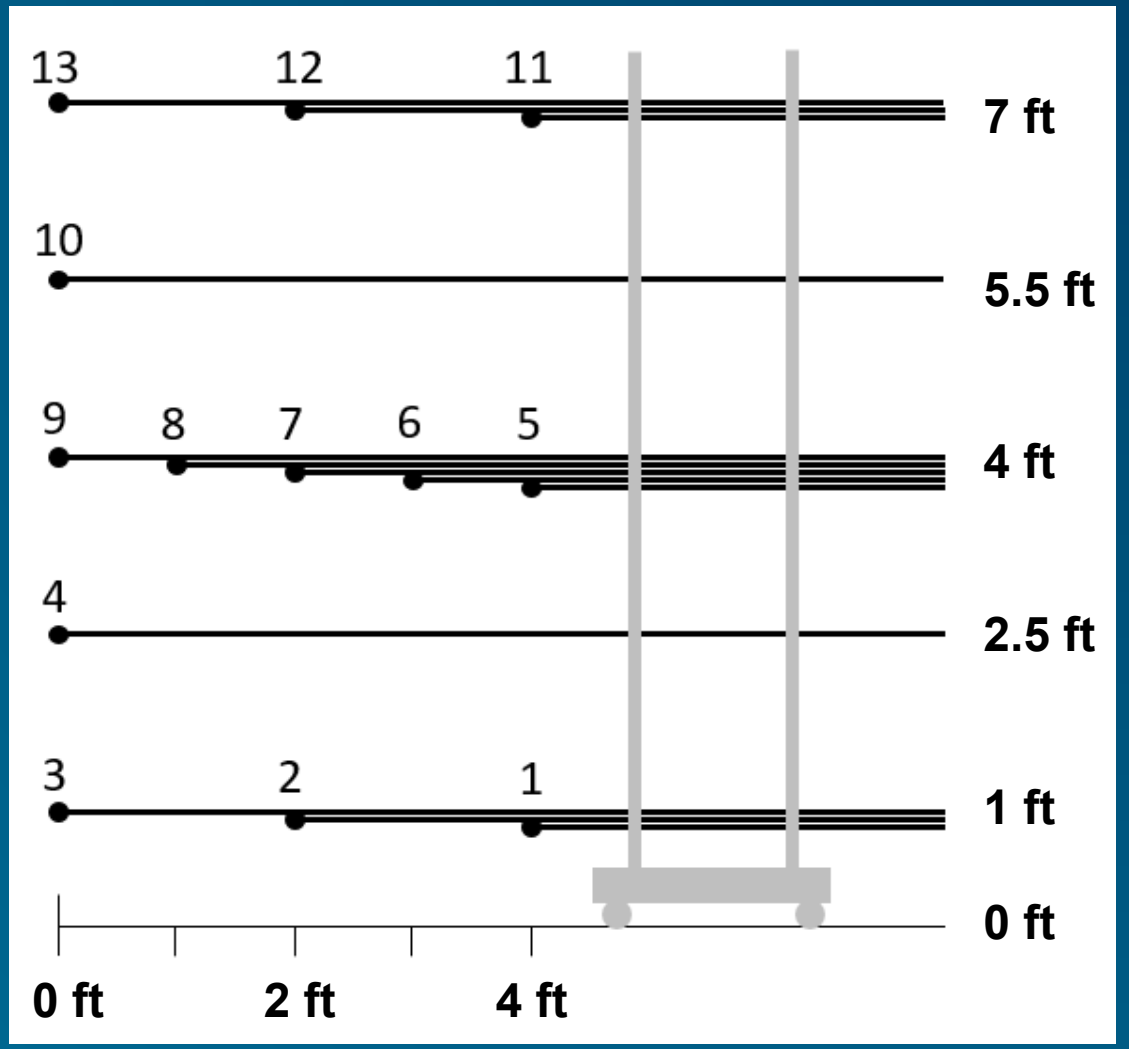
Visual Recordings:

- 4 or 5 HD digital video records
- Digital still photos



Video Camera Arrangement

Experimental Design - Measurements



Wind Measurements:

- 13 velocity points w/bi-directional probes
- Ambient wind speed and direction via sonic anemometer plus temperature

Experimental Design - Procedure

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- Wood and Mulch Conditioning
- Burner Ignition
- Condition Requirements
- Testing Procedure

Experimental Design - Procedure

NIST Wood Conditioning Kiln

- Relative humidity set to 30 %
- Moisture content for mulch and wood = 6.5 % ± 1 %

Experimental Design - Procedure

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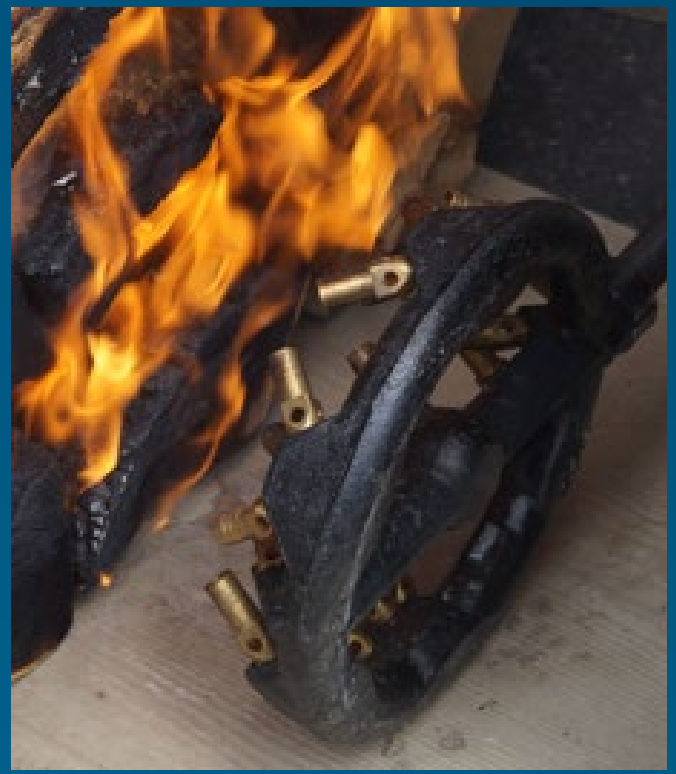
Burner Ignition

- Burner used for consistent ignition
- Burner ignition surrogate for flaming debris
- Propane 23-torch ring for large, intense contact area
- ≈35 kW total output (120000+ BTU/h)

Ring Burner

Under woodpile rack



Next to woodpile w/o rack

Experimental Design - Procedure

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Condition Requirements

- Availability of site
- Weather:
  - No rain (forecast likelihood < 40 %)
  - Not too cold (Temperature > 46 °F/8 °C), propane doesn't easily vaporize
  - Not too hot (Heat Index < 88 °F/31 °C) for reasonable work conditions
  - Ambient wind speed < 30 % of planned imposed wind
  - Low crosswind or headwind
- Availability of staff
- Materials in hand and conditioned
- Equipment functioning

Experimental Design - Procedure

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(Time in minutes:seconds)

0:00 – Wind data collection begins, cameras on

1:00 – Propane ring burner ignited

4:00 – Fan on (t = 0), Propane turned off

End of Test – A spot fire spreads to shed

Experimental Design - Variables Tested

- Wood Type
- Pile Height/Aspect Ratio
- Orientation
- Rack
- Separation Distance
- Wind Speed

Experimental Design - Variables Tested

Wood Type

- Oak (mixed, dried and undried)
- Maple (mixed)
- Softwood (Eastern White Pine)

Experimental Design - Variables Tested

Pile Height/Aspect Ratio

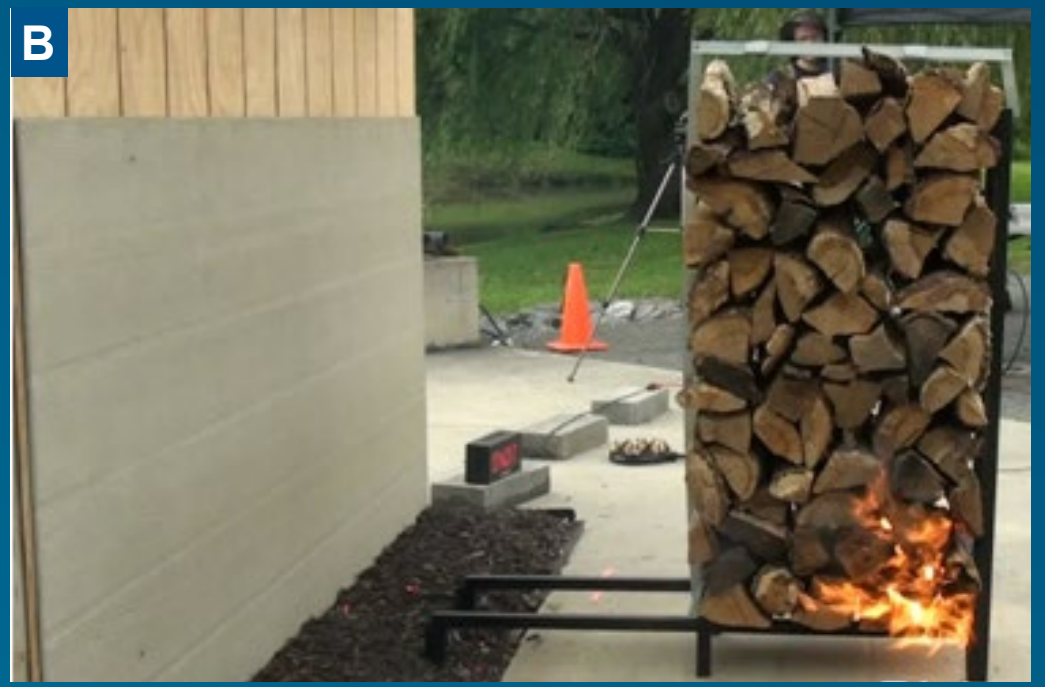
- Tall (A): 4 ft High x 16 in Wide x 2 ft Deep
  (1.22 m H x 0.41 m W x 0.61 m D)
- Short (B): 2 ft High x 16 in Wide x 4 ft Deep
  (0.61 m H x 0.41 m W x 1.22 m D)

= 1/12 cord of wood

Experimental Design - Variables Tested

Orientation

- Logs aligned with wind direction (A)
- Logs transverse to wind direction (B)



Experimental Design - Variables Tested

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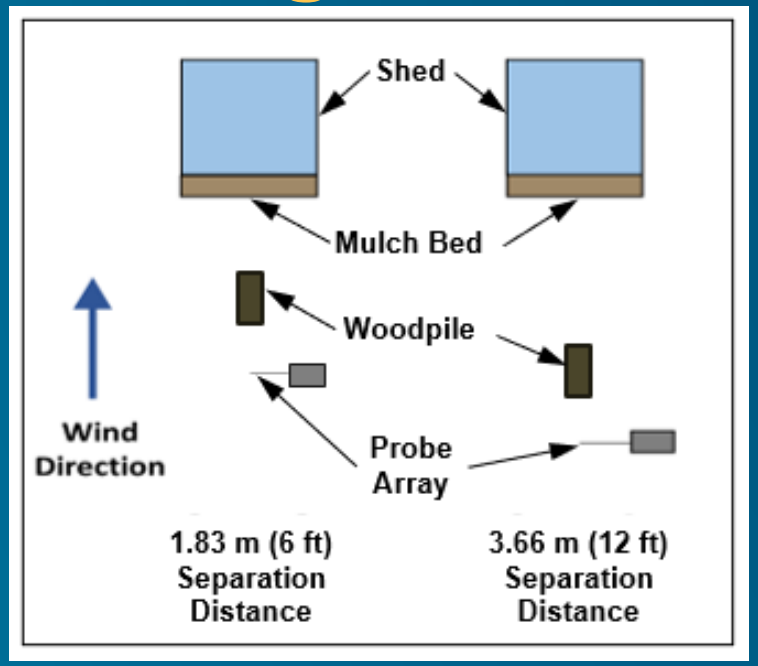
Rack

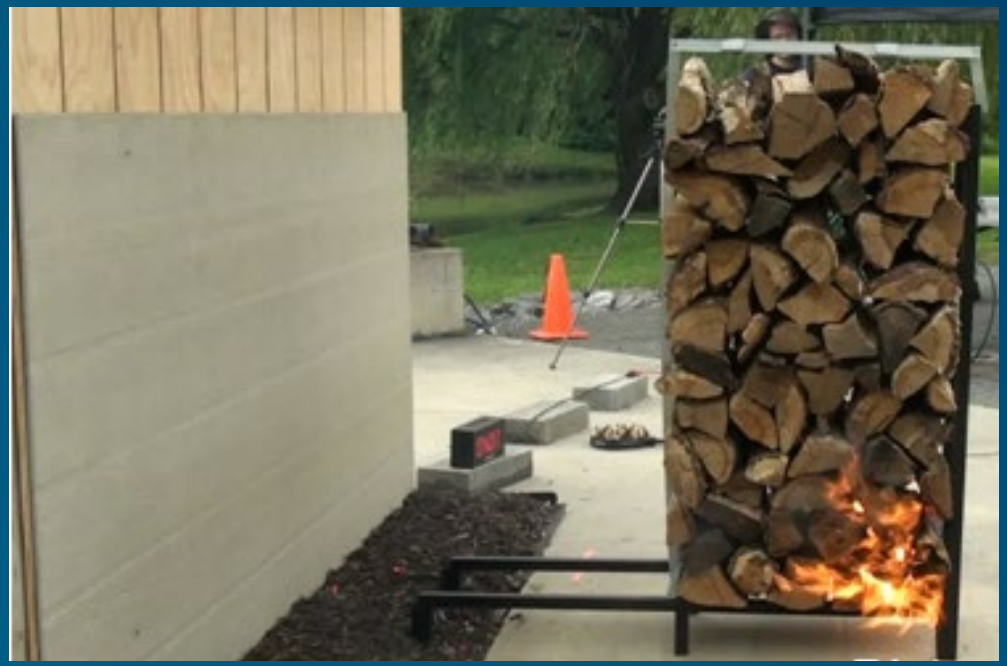
- Wood on the ground (A, B)
- Wood on a rack (C, D)

Experimental Design - Variables Tested

Separation Distance from Shed

- 3 ft (0.9)
- 6 ft (1.8 m)
- 12 ft (3.7 m)
- 18 ft (5.5 m)
- 22 ft (6.7 m)
- 24 ft (7.3 m)

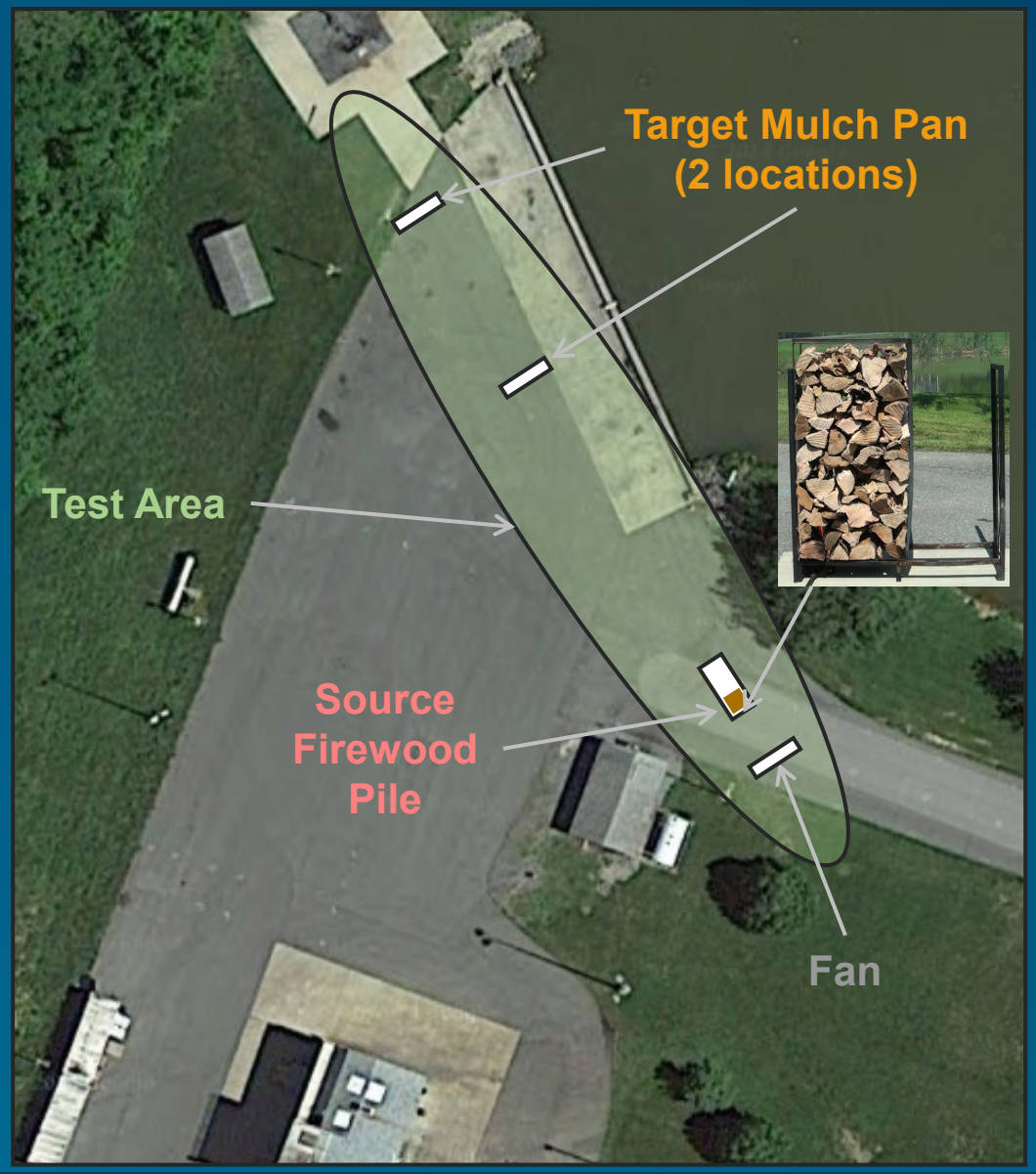




Experimental Design - Variables Tested

Long Distance Spotting Potential

- **Firebrand Source**
  - Located 3.4 m from fan, 31 mi/h (14 m/s) wind
  - Maple firewood (1/12 cord), tall, sides, on rack
- **Spotting Target**
  - Located 88 ft (26.8 m) downwind of woodpile
  - 8 ft x 20 in (2.4 m x 0.5 m) pan at ground level
  - 1 in (3 cm) deep shredded hardwood mulch
- **Additional Tests**
  - Other sources: pan of mulch and lattice fence
  - Located 125 ft to 131 ft (38 m to 40 m) downwind of source



Experimental Design - Variables Tested

Nominal Wind Speed

- Low = 13 mi/h (6 m/s)
- Medium = 22 mi/h (10 m/s)
- High = 31 mi/h (14 m/s)

Experimental Design - Variables Tested

Experiment Statistics – 62 Experiments Conducted

Series		Type of Wood		Pile Shape	
1: Combustible wall	0	Dry Oak	45	Tall	53
2: HWM as surrogate	61	Moist Oak	3	Low	9
3: No shed	1	Maple	10		
		White Pine	4	Pile Orientation to Wind	
Separation Distance				Ends of logs	30
3 ft	2	Wind Speed		Sides of logs	32
6 ft	24	6 m/s (13.5 mph)	19		
12 ft	12	10 m/s (22.5 mph)	21	Mitigation	
18 ft	11	14 m/s (31 mph)	22	Shield	1
22 ft	2			FR Tarp	1
24 ft	10	Mounted on Rack		Aluminum screen	1
>50 ft	1	Yes	53	None	59
		No	9		

Results

Results - Videos

Results - Videos

Results - Spot Fire Timing

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Spot Fire Timing vs Wind Speed

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Nominal Wind Speed

Low = 13 mi/h (6 m/s)

Medium = 22 mi/h (10 m/s)

High = 31 mi/h (14 m/s)

Separation Distance from Shed

3 ft (0.9)

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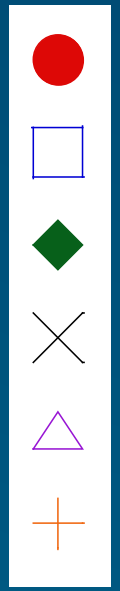
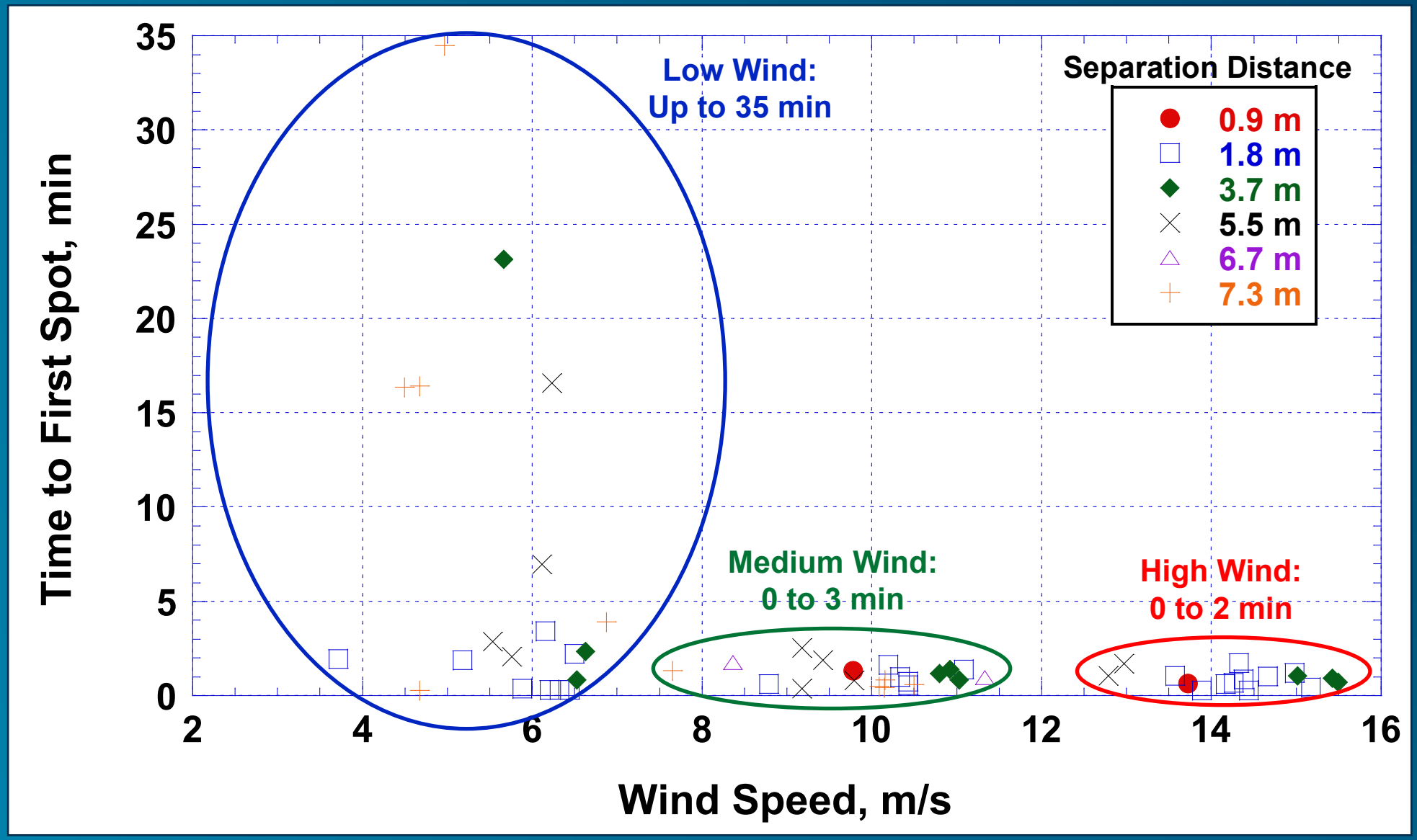
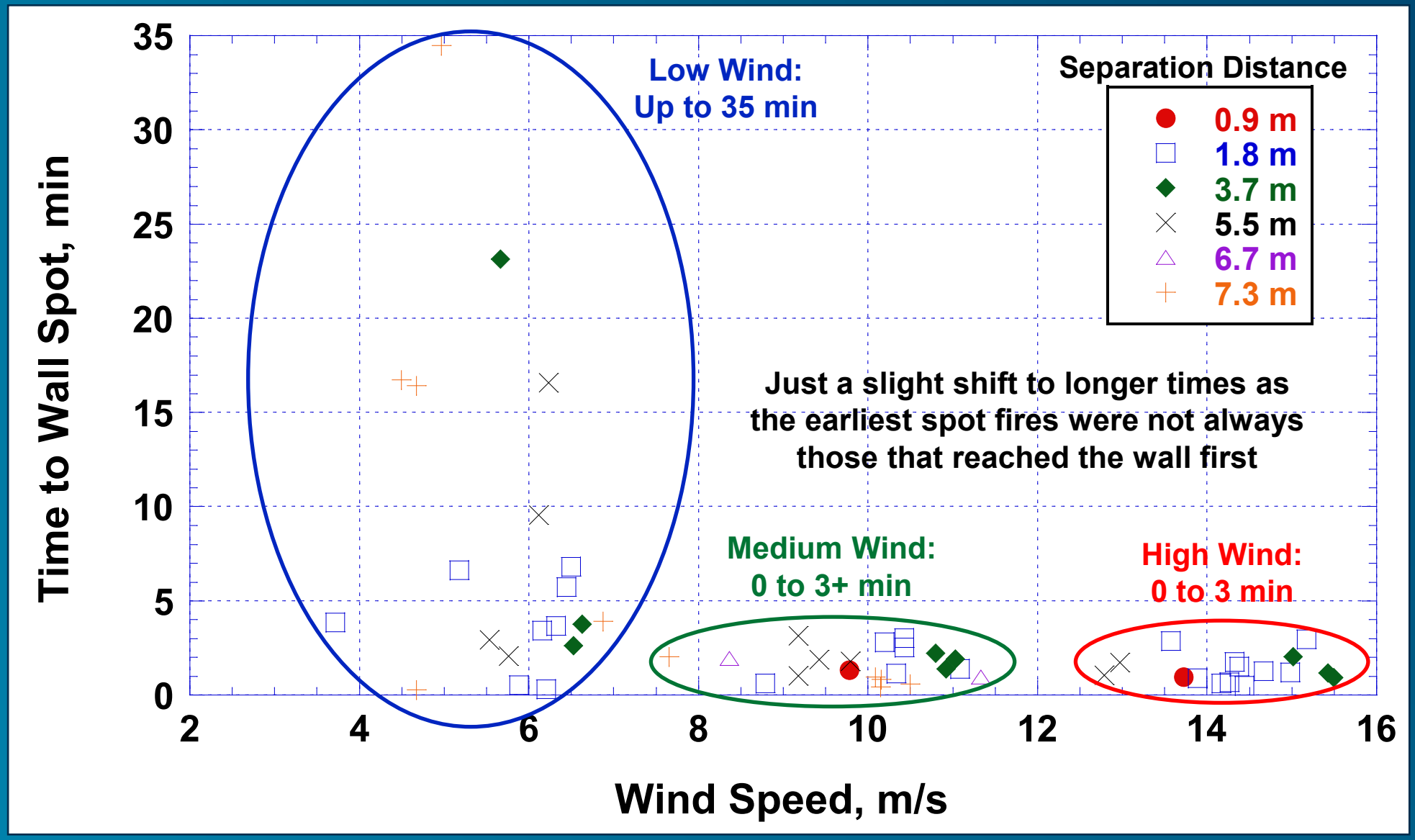


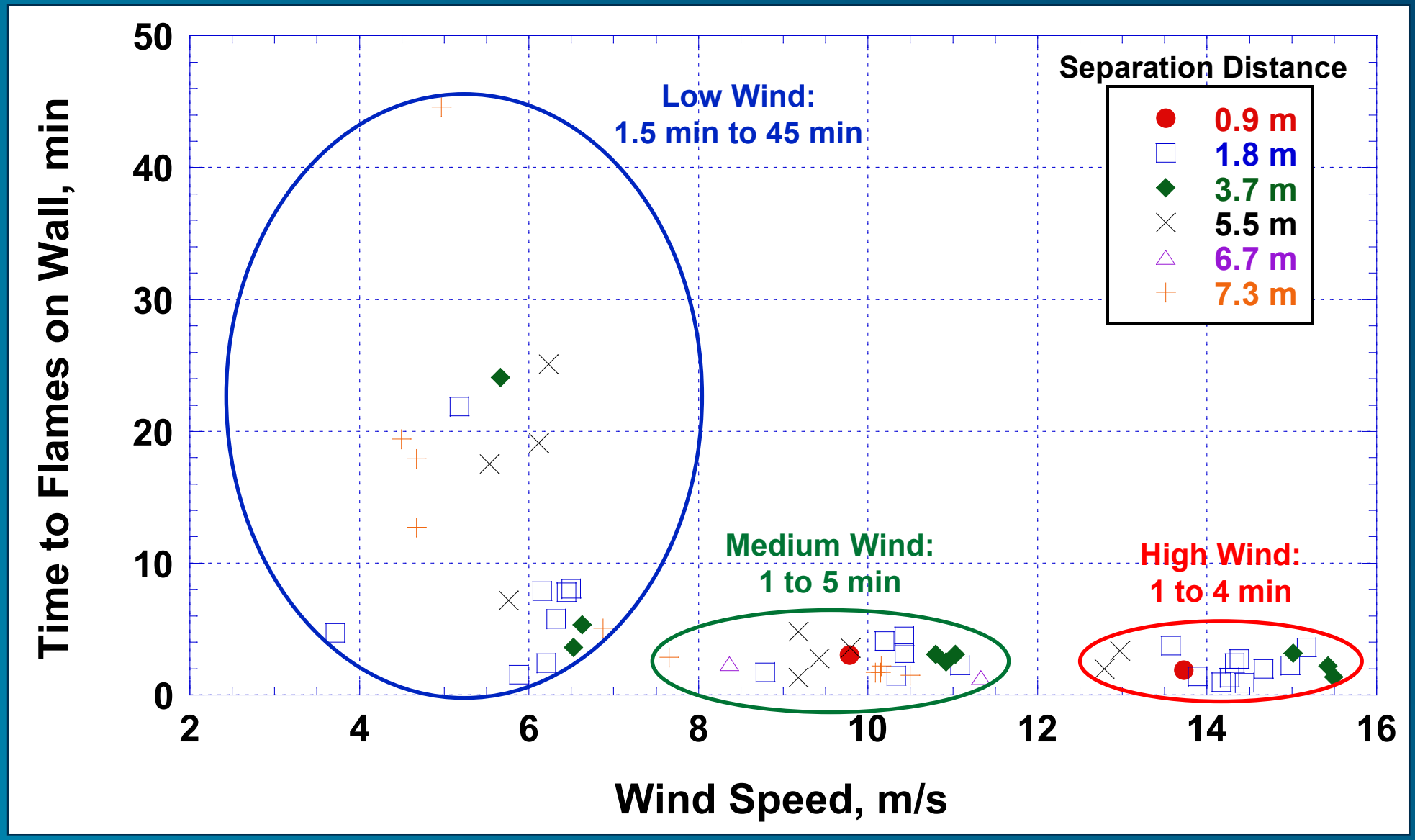
First Spot vs Wind Speed



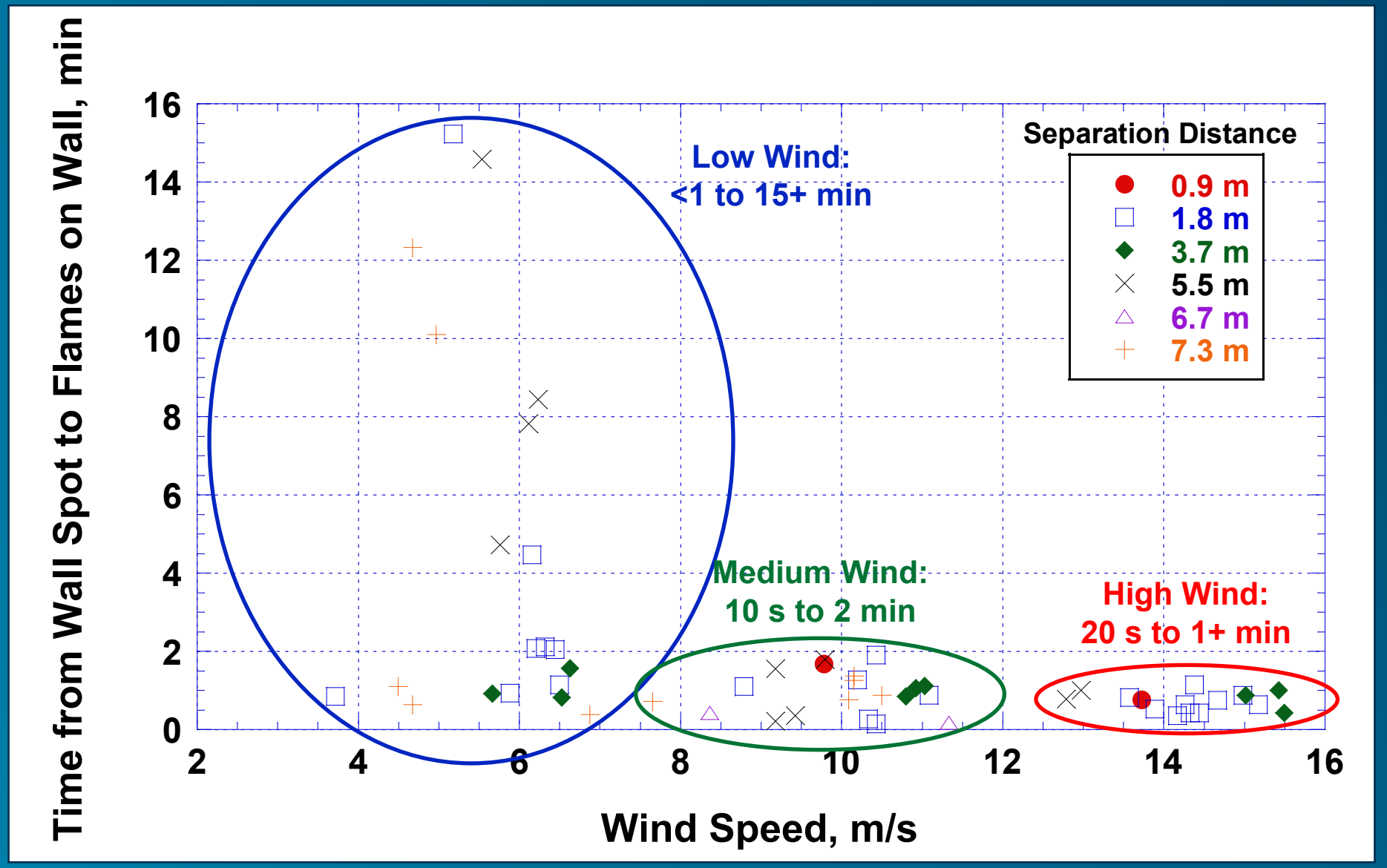
Wall Spot vs Wind Speed



Wall Flames vs Wind Speed



Spot to Flames vs Wind Speed



Spot Fire Timing vs Separation Distance

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Separation Distance from Shed

3 ft (0.9)

6 ft (1.8 m)

12 ft (3.7 m)

18 ft (5.5 m)

22 ft (6.7 m)

24 ft (7.3 m)

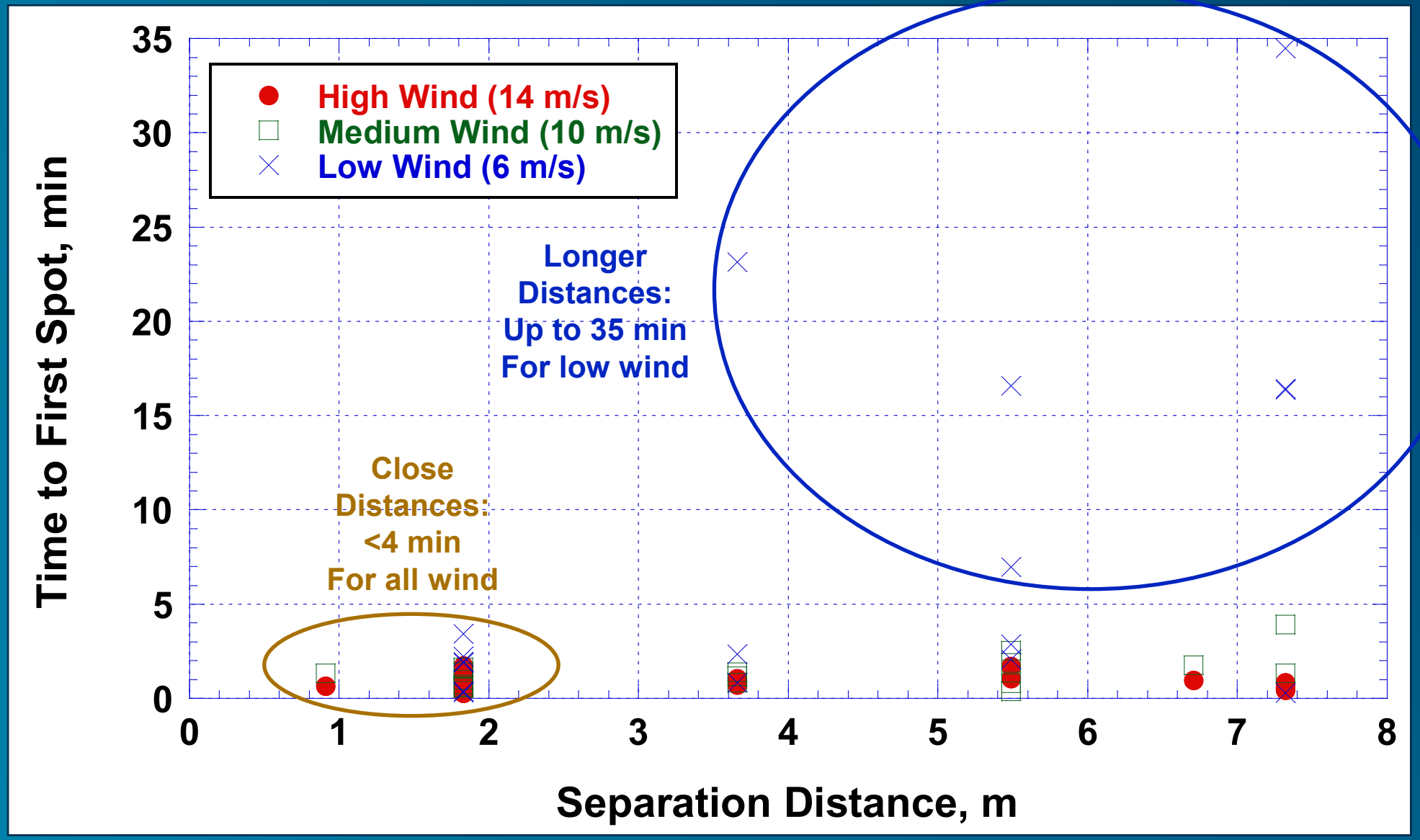
Nominal Wind Speed

Low = 13 mi/h

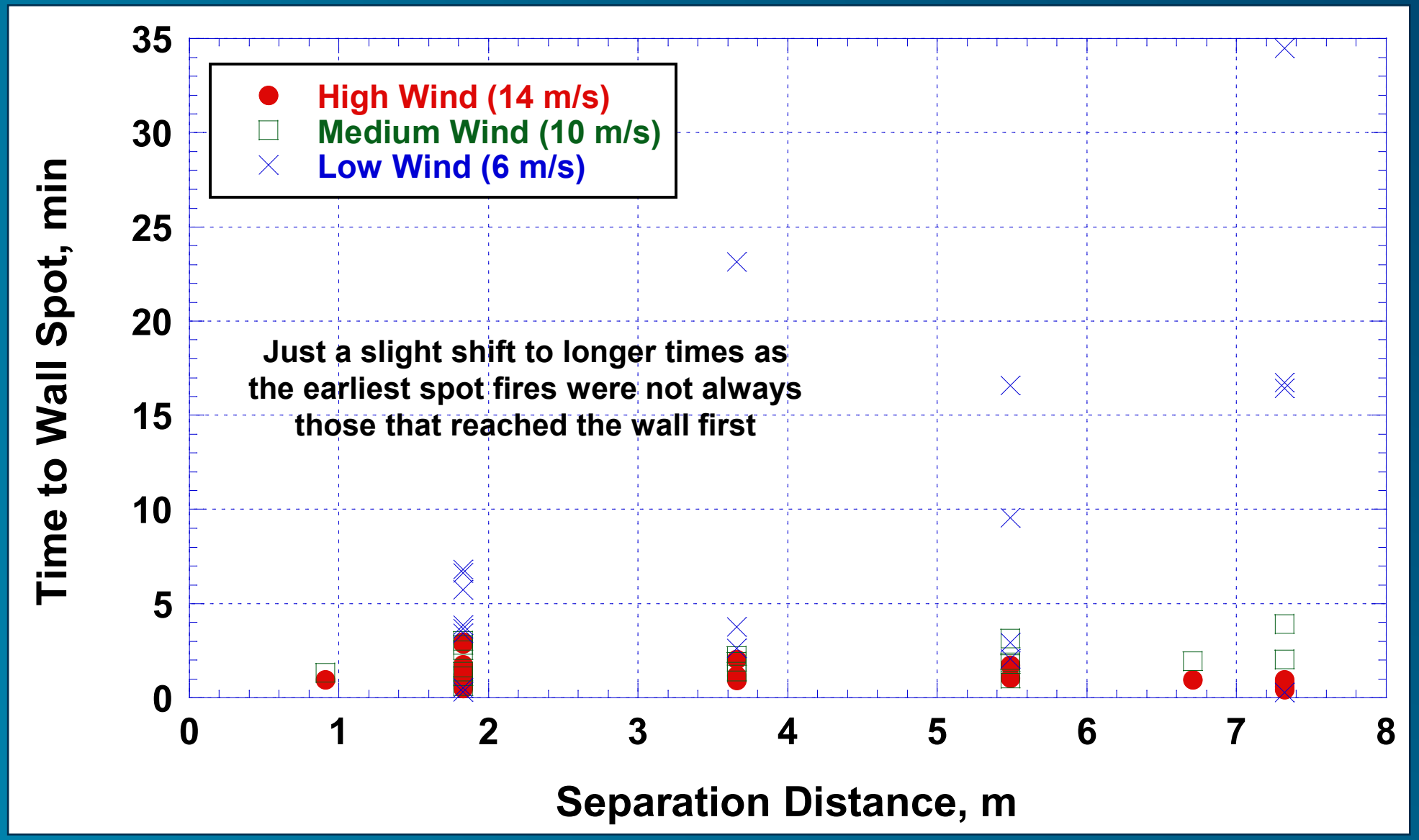
Medium = 22 mi/h

High = 31 mi/h

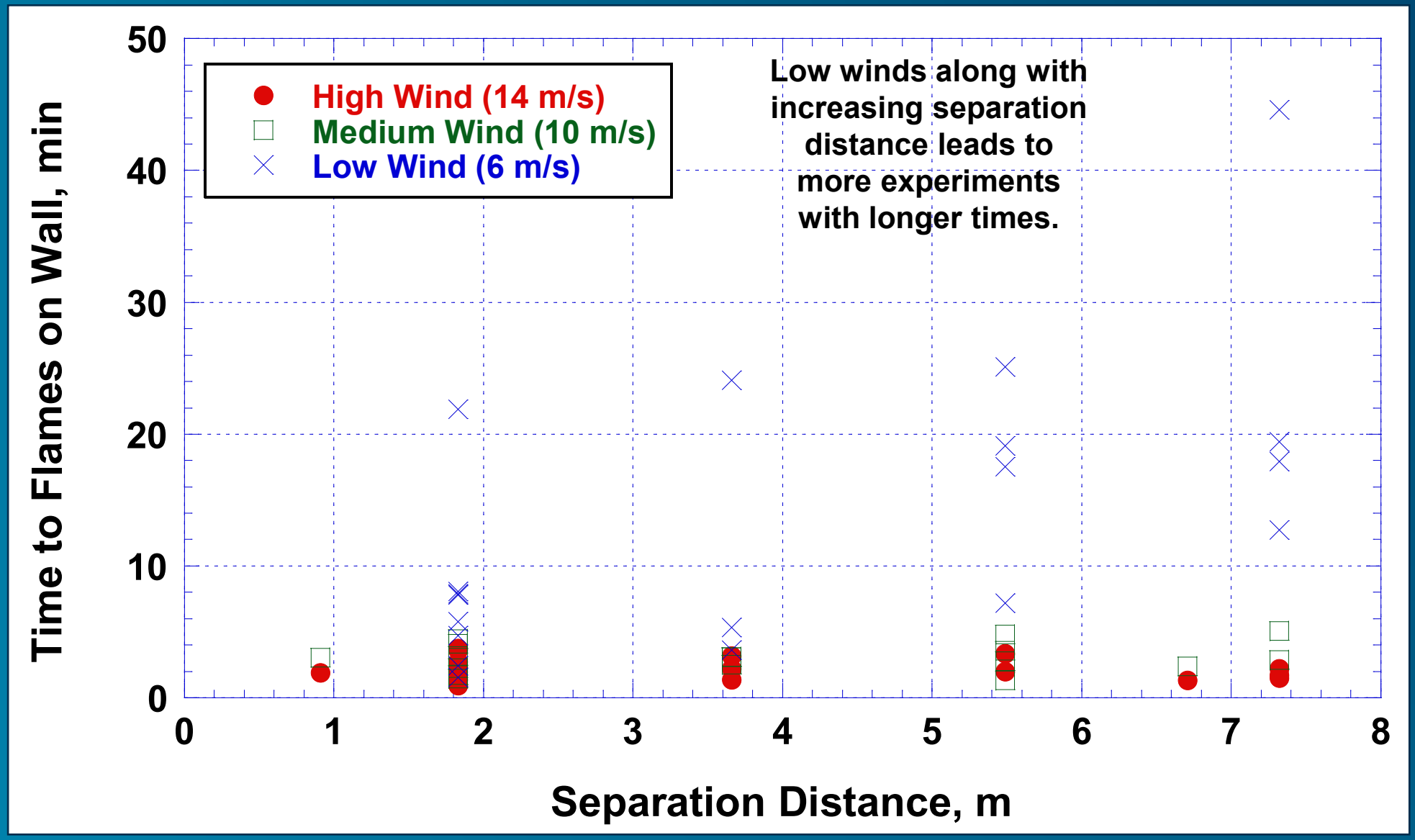
First Spot vs Separation Distance



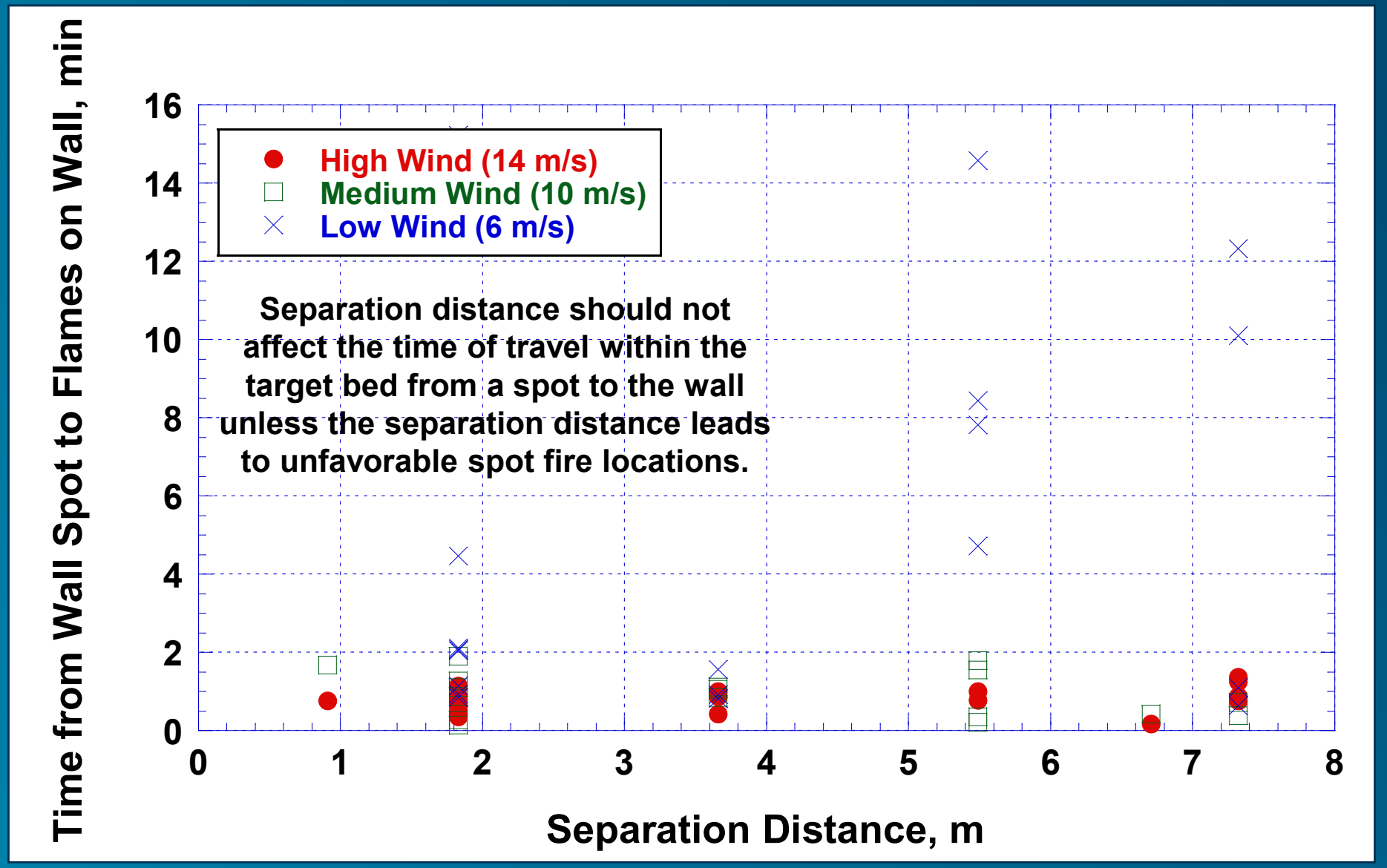
Wall Spot vs Separation Distance



Wall Flames vs Separation Distance



Spot to Flames vs Sep. Distance



Summary of Results

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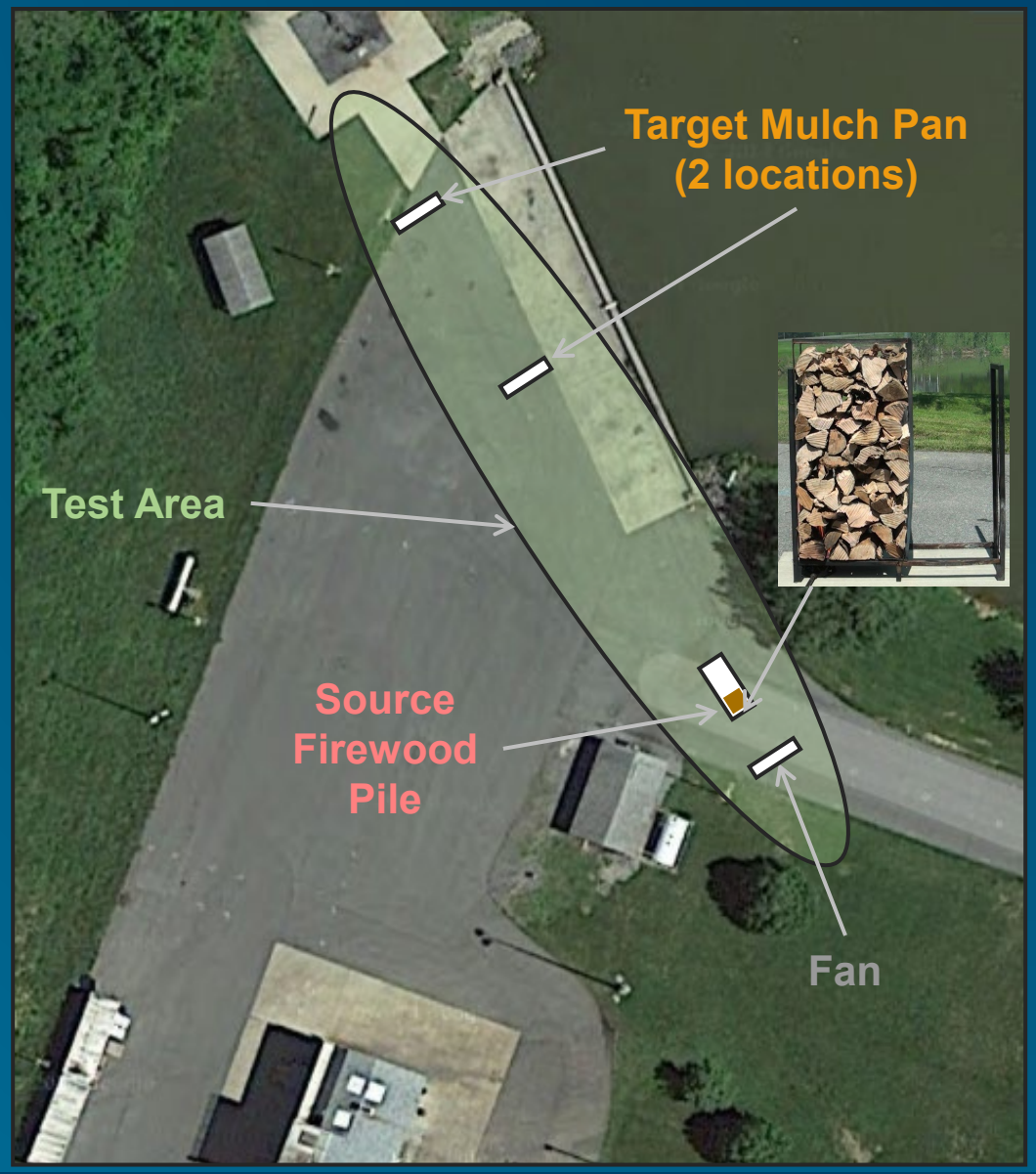
- 62 experiments conducted
- No significant trends with rack usage, wood type, pile height, or log alignment (except at the low wind speed)
- Separation distance has very little affect on spotting. This is unfortunate since locating woodpiles far away would be an intuitive solution.
- Wind speed has some effect:
  - Spotting time decreases with increasing wind speed, but only from low to medium.
  - Medium and high winds cause similarly fast spotting with multiple spots within 1 min.
- All winds produce spotting within a few minutes.

Experimental Results -

Long Distance Spotting Potential

- Woodpile time to spot fire at target mulch bed: 1 min 54 s at 13 m/s
- No spot fire ignitions at low or medium wind speeds



Limitations

- Few experiments are repeated
- Many fire processes are random
  - Firebrand generation
  - Firebrand ignition of spot fires
  - Wind turbulence
- Woodpiles are ignited in one location
- Only one wind direction was tested
- Only one volume of wood was tested

Therefore, this is a survey → Trends, key hazards

Key Findings

Key Findings

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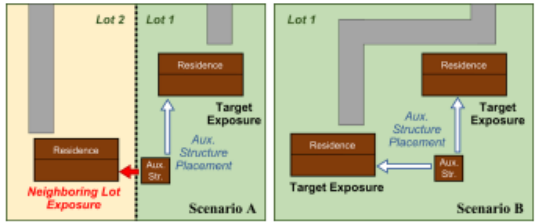
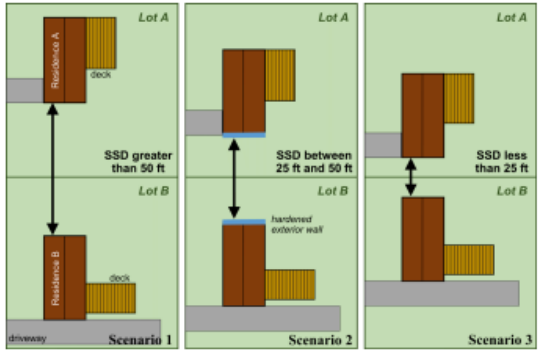
- Woodpiles generate copious amounts of firebrands that are capable of igniting spot fires in downwind combustibles.
- Wind-blown firebrands from woodpiles can ignite spot fires in 3 min or less in fine combustible materials over significant distances and bring flames to a structure adjacent to the combustibles in less than 5 min.
- Wind-blown burning woodpiles can generate fire plumes with steady flames that extend over 1 m (3.3 ft) which could ignite nearby combustibles through flame impingement or thermal radiation.
- Burning woodpiles may collapse, which changes the hazard.

Mitigation

NIST Technical Note 2205

WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology





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Fire Spread Mitigation Options

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For Mitigating *Fire* Exposure Hazards:

- **Reduce** the woodpile,
- **Relocate** the woodpile,
- **Remove** the woodpile, or
- **Harden** structures for *fire* exposure

From NIST TN 2205 (HMM), Section 5.

Study of Possible Firebrand Hazard Mitigation Approaches

Wind/Ember Blocking Wall

Fire-retarded Tarp

Study of Possible Firebrand Hazard Mitigation Approaches

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Screen Enclosure

Mitigation Using a Screen Enclosure

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Captures Embers

Study of Possible Firebrand Hazard Mitigation Approaches

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Proposed FireSCREEN Solution

- Simple Compact Reusable Ember Enclosure Net
- A screen enclosure could prevent
  - Firebrand ignition of the firewood pile
  - Fire spread by embers if a woodpile should somehow ignite
- Would allow retaining the woodpile on the property

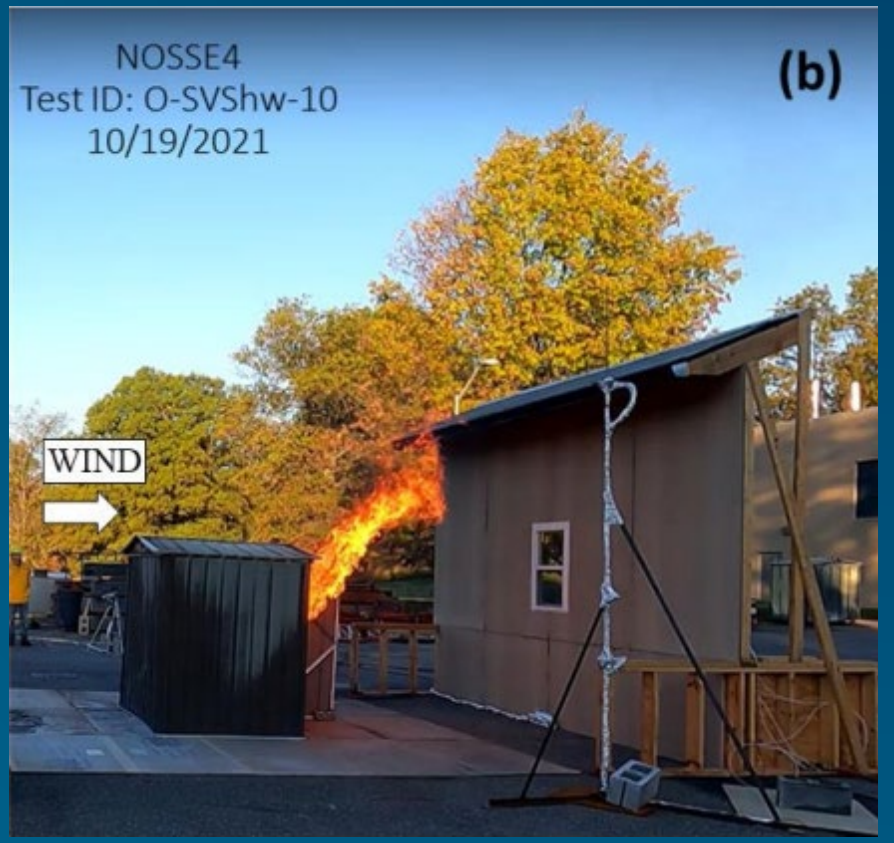
Potential Improvements

- Determine:
  - Best ember-proof screen hole size
  - Best screen material for fire and corrosion/weather resistance
- Design for reliability:
  - Anchor against wind
  - Seal openings against embers
- Design for utility:
  - Lightweight for easy installation
  - Protective cover for rain/snow
  - Access to firewood

Firewood Pile Enclosures

Requirements

- Access to load, unload firewood
- An open door or vent with a burning wood source creates a fire jet.
- Doors or vents must be closed!
- Fresh air circulation must be provided in a way that prevents firebrand entry and fire escape.



Fire Spread Mitigation Options

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For Mitigating *Firebrand* Exposure Hazards:

- Harden structures for *firebrand* exposure
- Remove the woodpile, or
- Enclose the woodpile with a *fire and ember resistant design*

From NIST TN 2205 (HMM), Section 5.

Recommendations and Future Work

Recommendations

- In WUI-fire prone areas, protect firewood piles from potential ignition by flames or firebrands to reduce fire spread.
- Avoid proximity of exposed woodpiles to the residence and other parcel structures, as well as neighboring structures, to prevent direct ignition by flames or flame radiation.
- Avoid proximity to other combustible fuels, to reduce fire intensity and limit fire spread.
- Harden structures against firebrands, to prevent structure ignition from firebrands produced by woodpiles and other combustible sources.
- Continue research to identify other effective methods to mitigate the firewood pile hazard in WUI-fire prone areas.

Future Work and Plans

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- Report on landscape timber and retaining wall experiments
- Report on wood-plastic composite fence experiments
- Use a firebrand generator for ignition testing on landscape combustibles and structural features
- Improve mitigation design for firewood piles
- Test other combustible objects and configurations
- Generate data useful for further model development and validation
- Characterize realistic firebrands with the NIST Emberometer
- Utilize our dual-fan wind machine (used for the NOSSE experiments) for larger objects/structures

Questions?

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