Radiant Ignition of Adjacent Upholstered Furniture - A Simple Approach

By

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Acknowledgements

- Flora Chen – *Radiant Ignition of Upholstered Furniture* conducted over 900 ignition experiments

- Simon Weaver – Spent hours staring at video tapes for the flame height.

- Tony Enright – Looked after the furniture experiments

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Radiant Ignition of Adjacent Upholstered Furniture - A Simple Approach

- Introduction
- Radiation from the Source
  - Experiments
  - Radiation Modeling
  - Results
- Radiant Ignition of Upholstered Furniture
  - Experiments
  - Results
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Radiant Ignition of Adjacent Upholstered Furniture - A Simple Approach

- NZ CBUF - Combustion Behavior of Upholstered Furniture
- Flame radiation side benefit
- Previous research
  - Heskestad
  - Will the second item ignite? Babrauskas
  - SFPE Engineering guide – *Assessing Flame Radiation to External targets from Pool Fires, Beyler et. al.*

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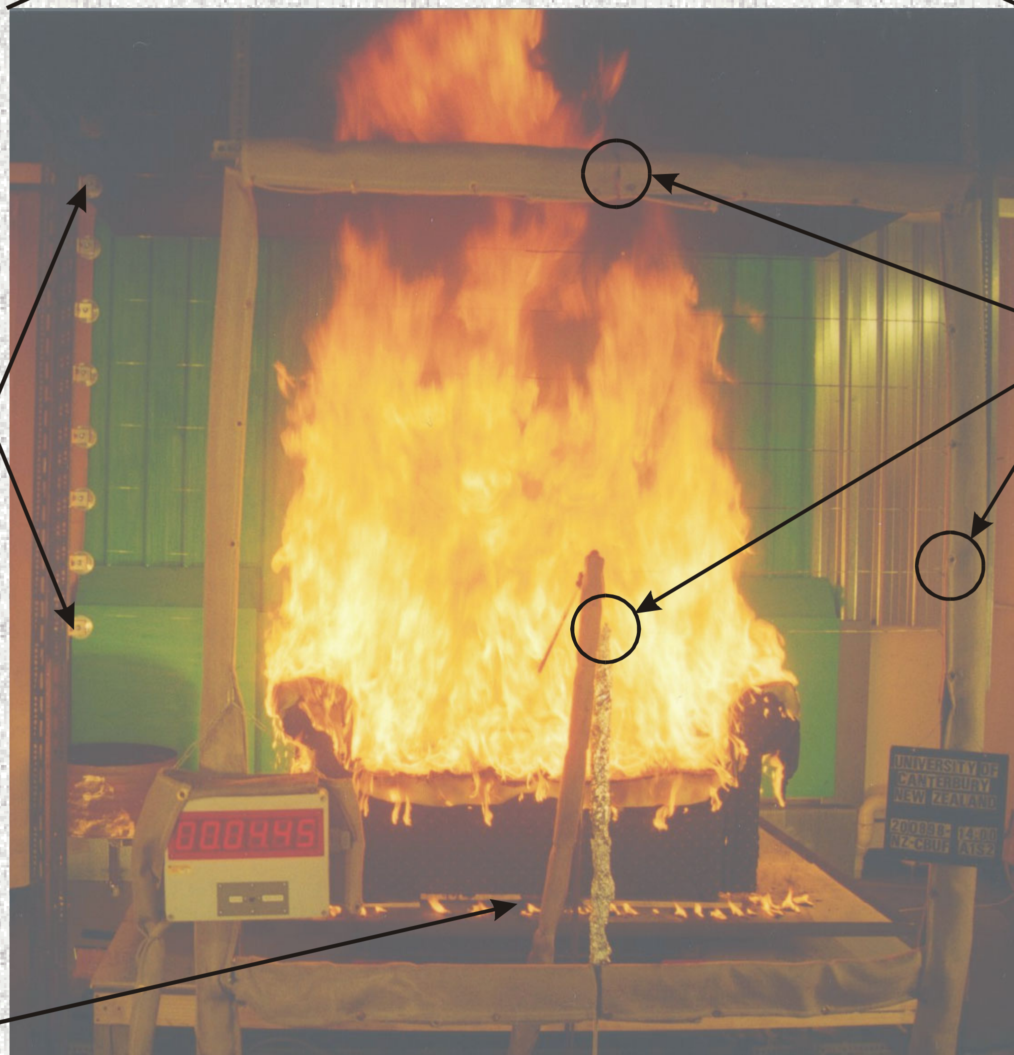
Experimental Setup



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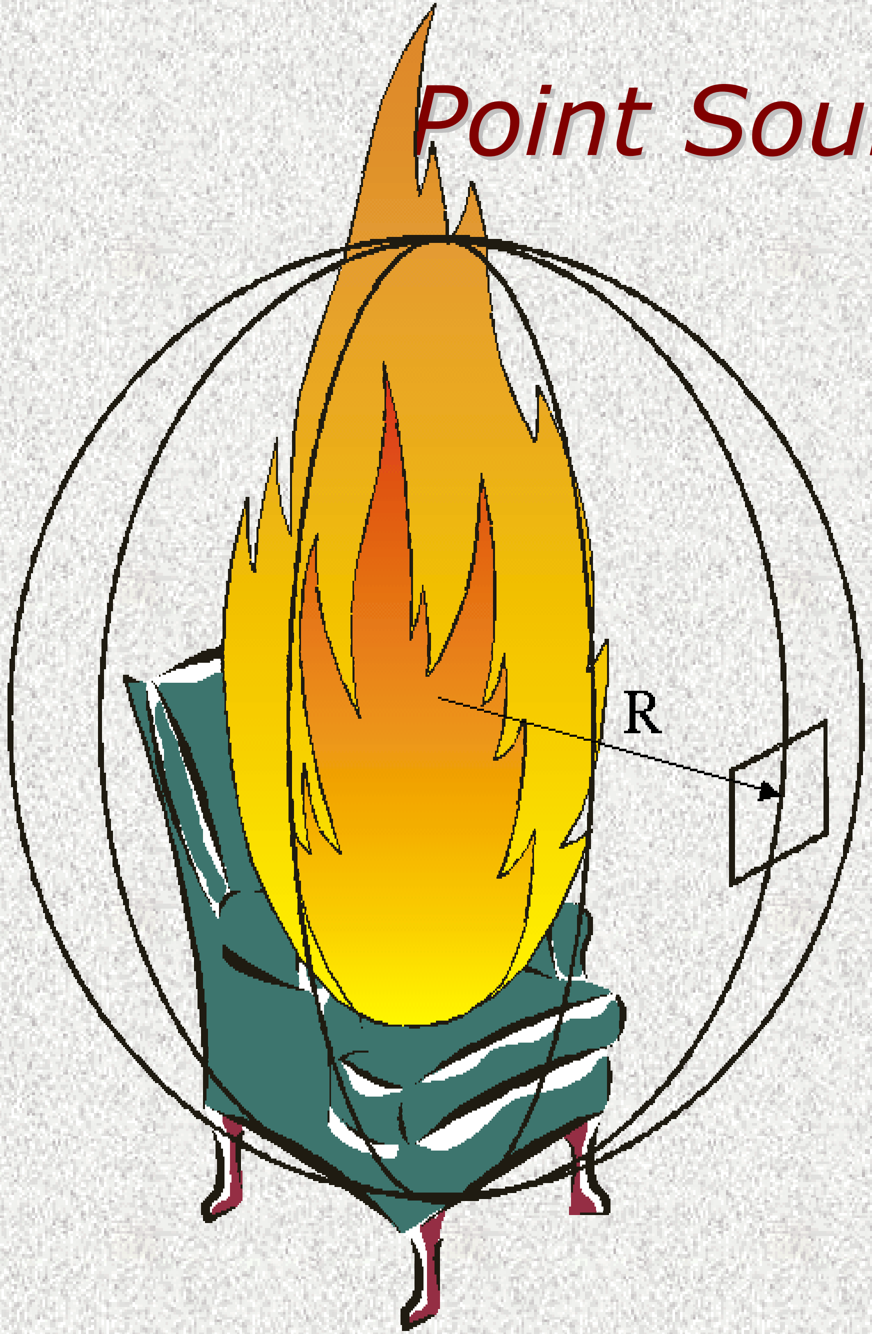
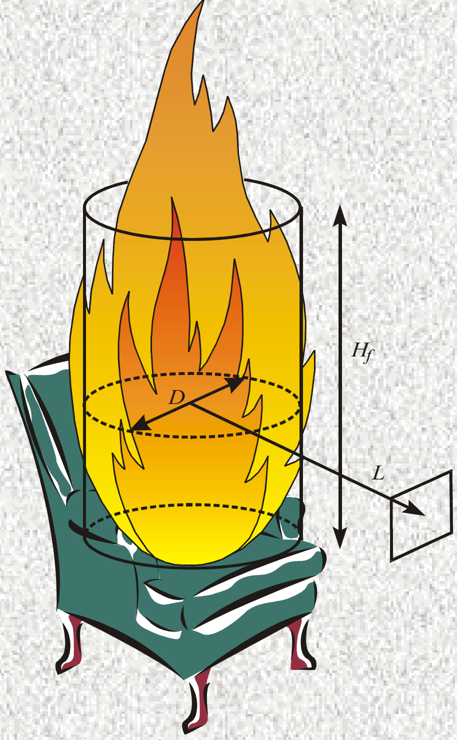
Furniture Styles

Point Source Model



$$\dot{Q}'' = \frac{Q_c}{A_{sphere}} = \frac{0.45 Q_T}{4\pi R^2}$$

Cylindrical Model



$$\dot{Q}'' = F \cdot \varepsilon \cdot \sigma \cdot T_{Flame}^4$$

$$F_{d1-2} = \frac{1}{\pi H}\tan^{-1}\frac{L}{\sqrt{H^2-1}} + \frac{L}{\pi}\left[\frac{X-2H}{H\sqrt{XY}}\tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{H-1}{H+1}}\right]$$

$$\varepsilon = 1 - exp(-\kappa D)$$

$$T_{Flame} = 800°C$$

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Heskestad's Correlation

$$H_f = -1.02D + 0.235\,Q^{.2/5}$$

Where:

$$D = \sqrt{\frac{4A}{\pi}}$$

$$A = \frac{\dot{Q}}{\dot{Q}''_{cone}}$$

$\dot{Q}$ = measured by ODC

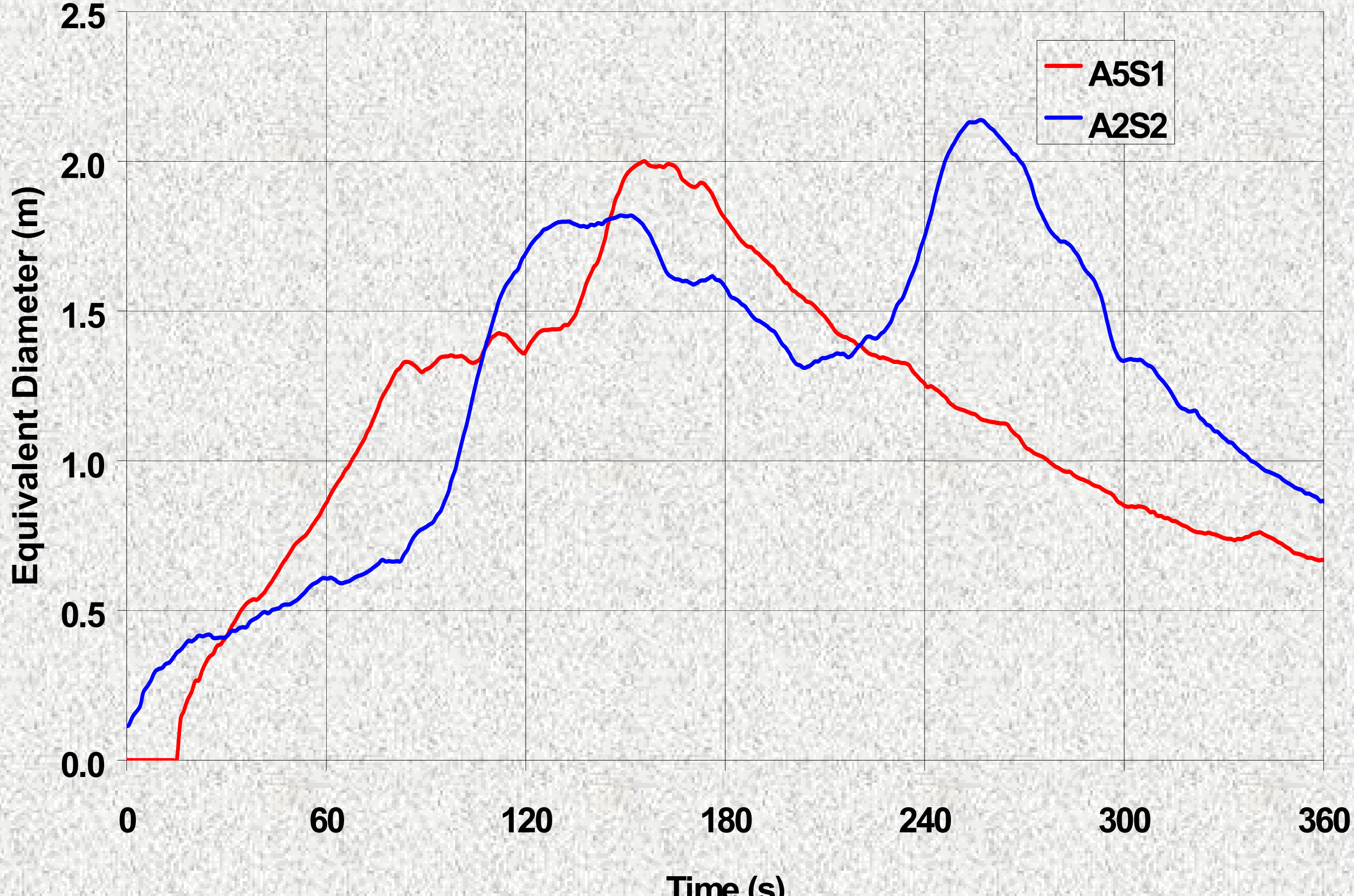
$\dot{Q}''_{cone}$ = peak RHR Cone calorimeter

H_F = height of the flame

Equivalent Diameter

$$D = \sqrt{\frac{4A}{\pi}}$$

$$A = \frac{\dot{Q}}{\dot{Q}''_{cone}}$$



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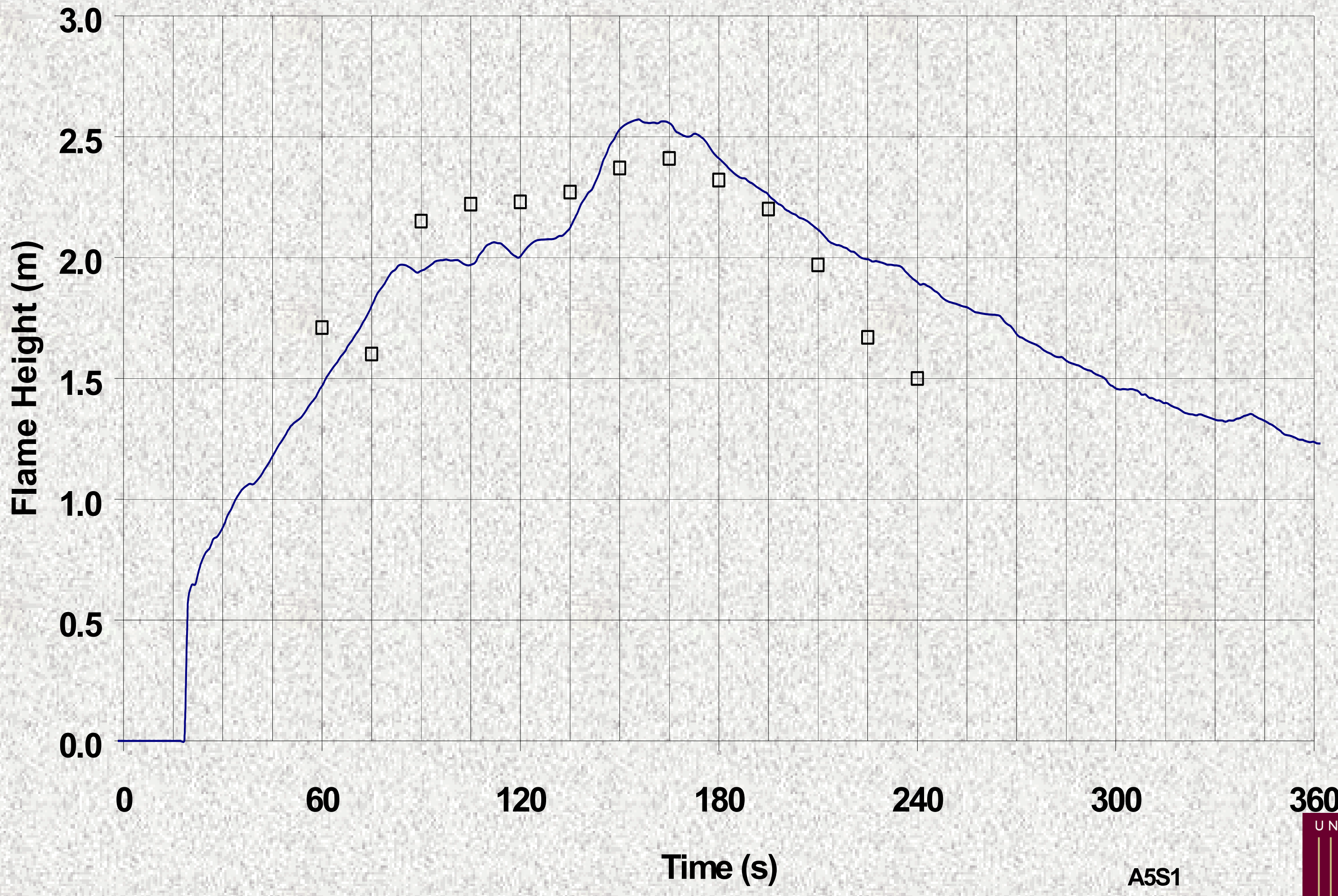
Flame Height
Data Versus Correlation



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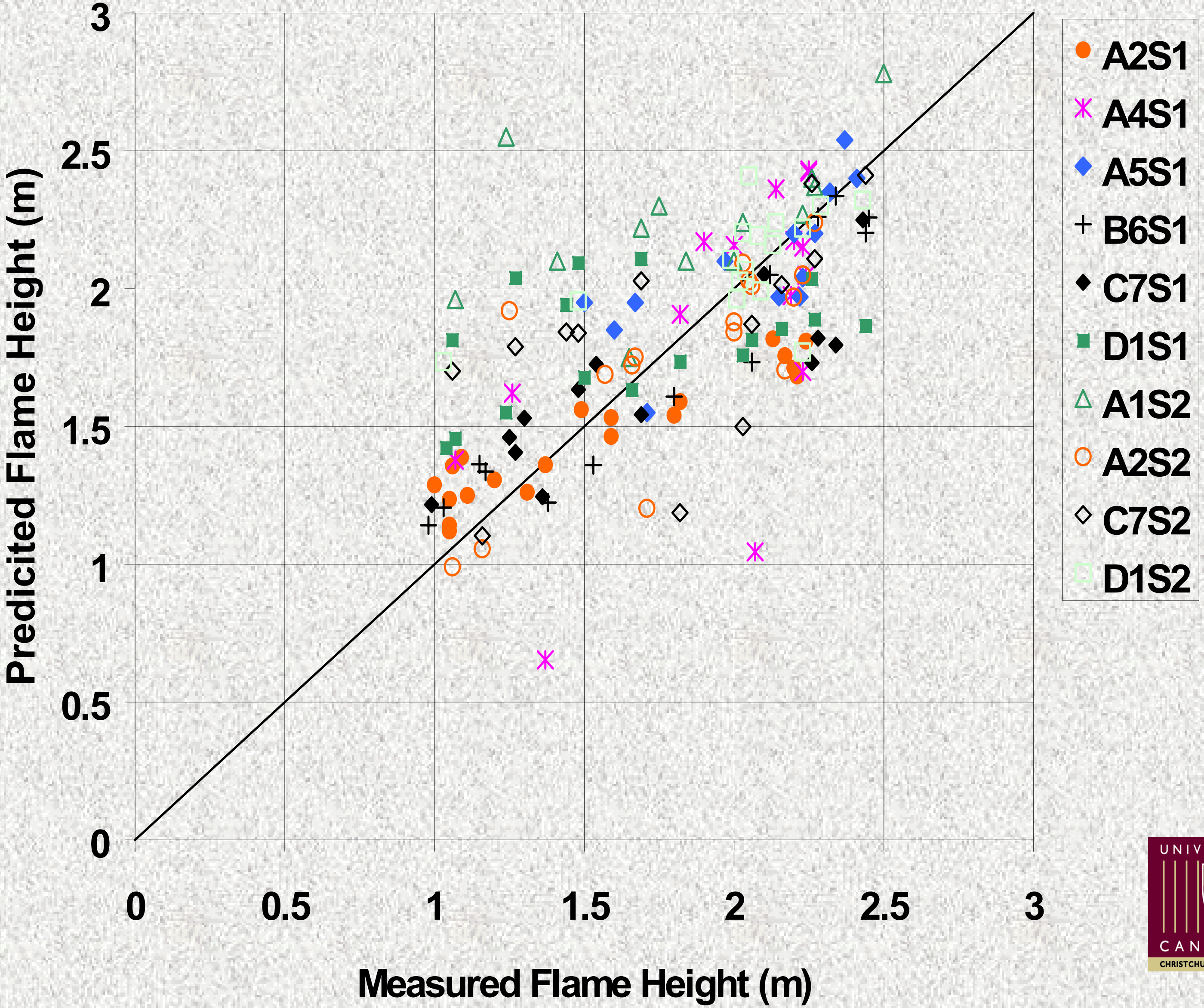
Comparison of all experiments



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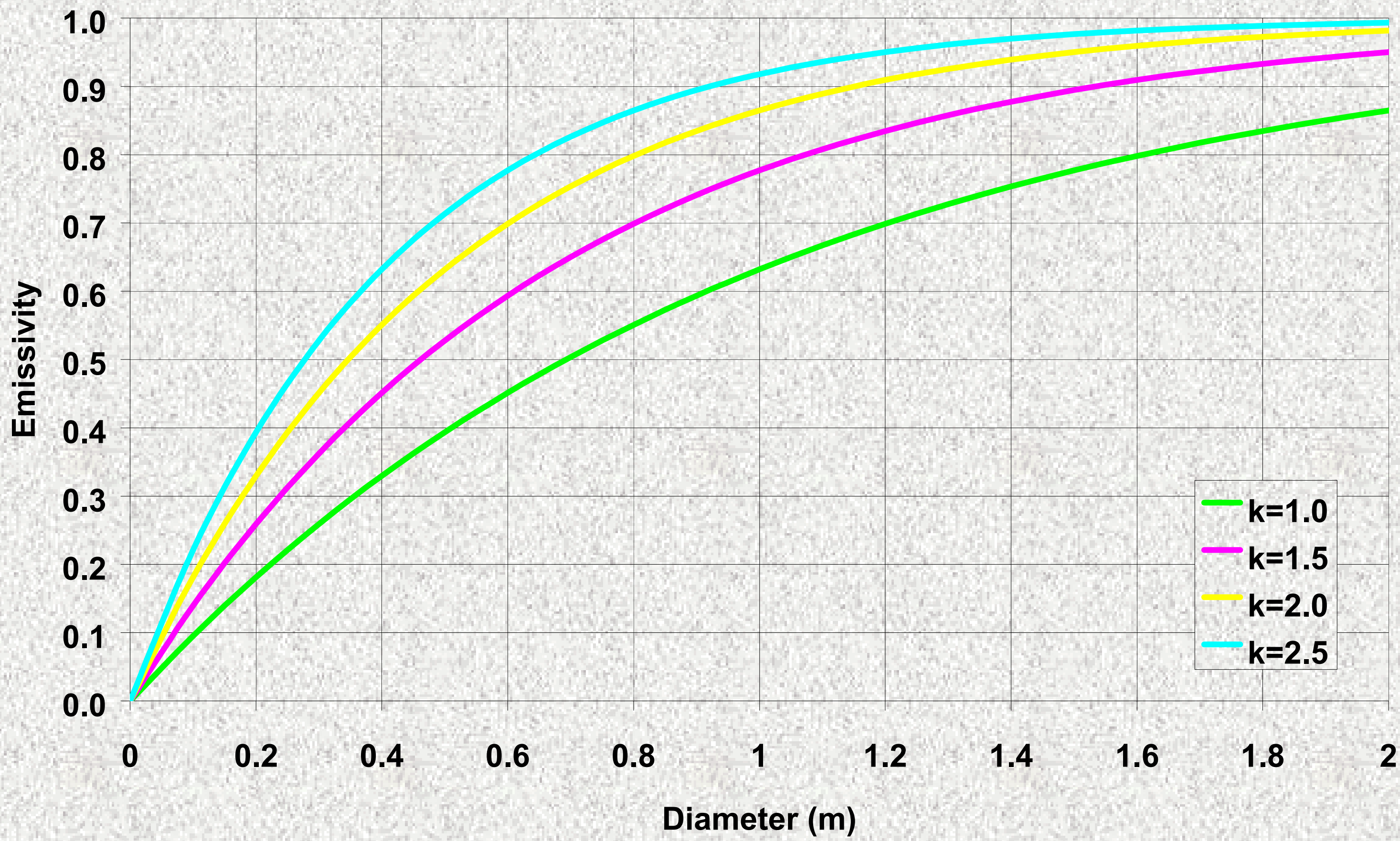
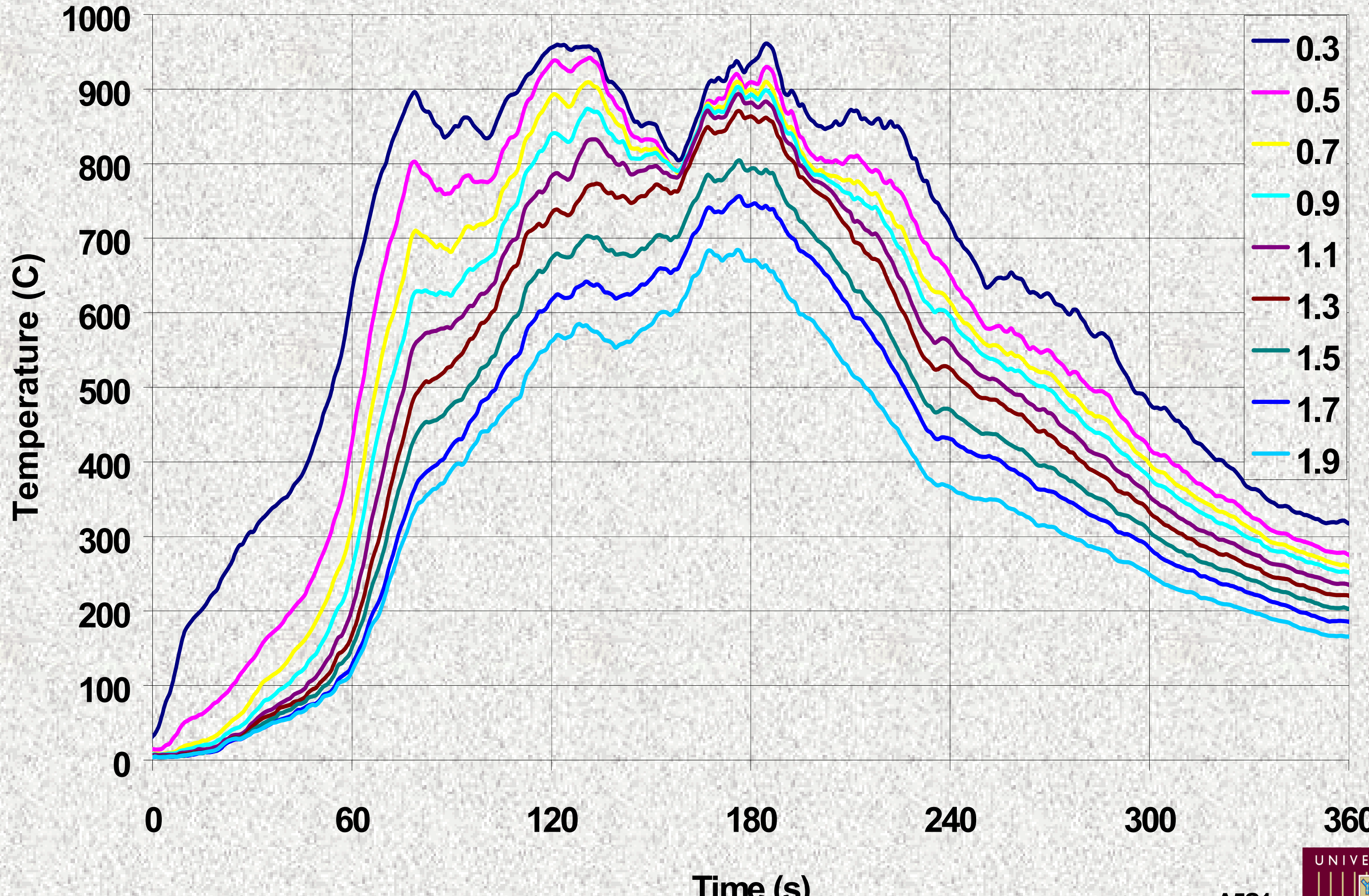
Emissivity of Flame

$$\varepsilon = \left(1 - e^{-kD}\right)$$



Flame Temperature Data



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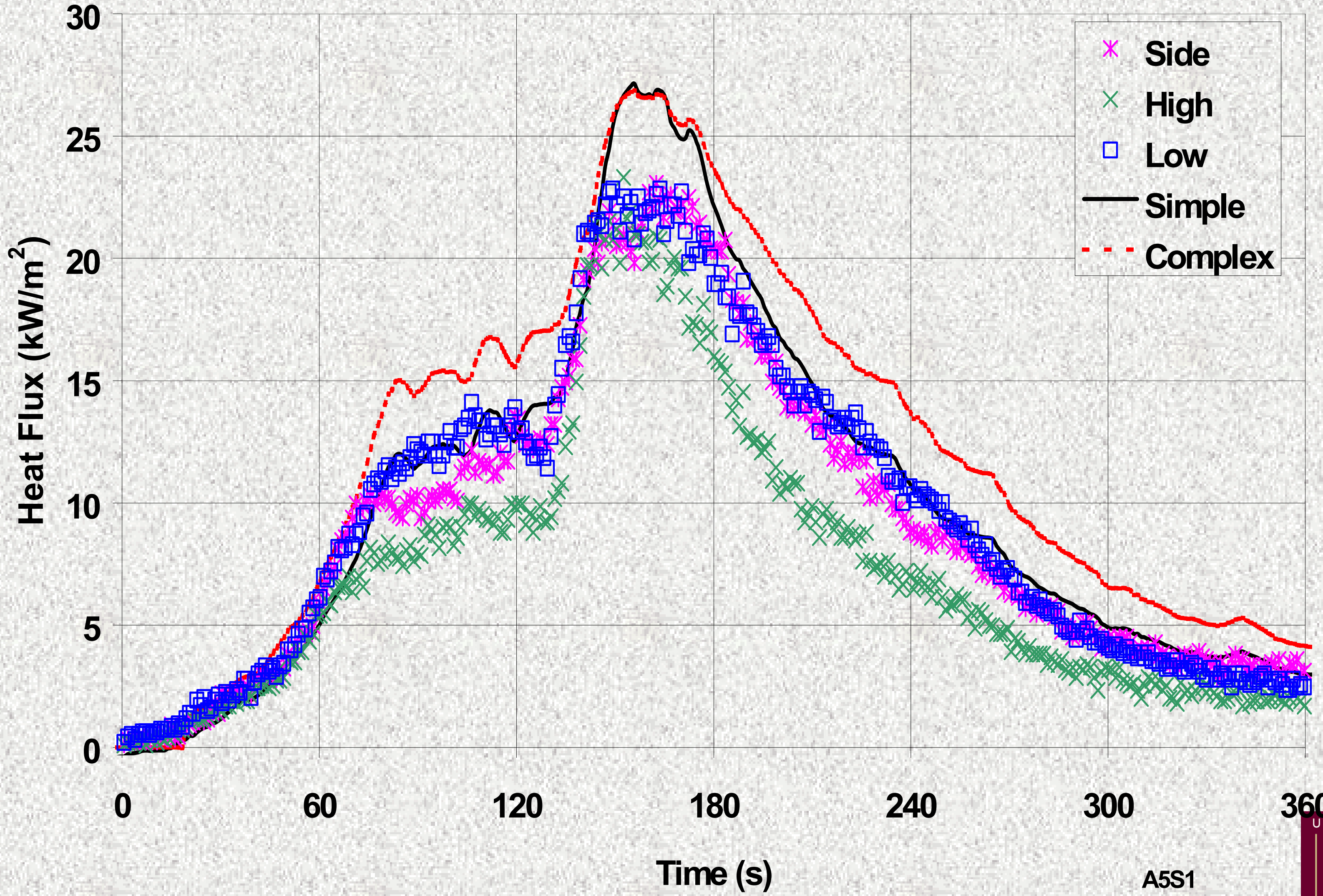
Single Seater Results



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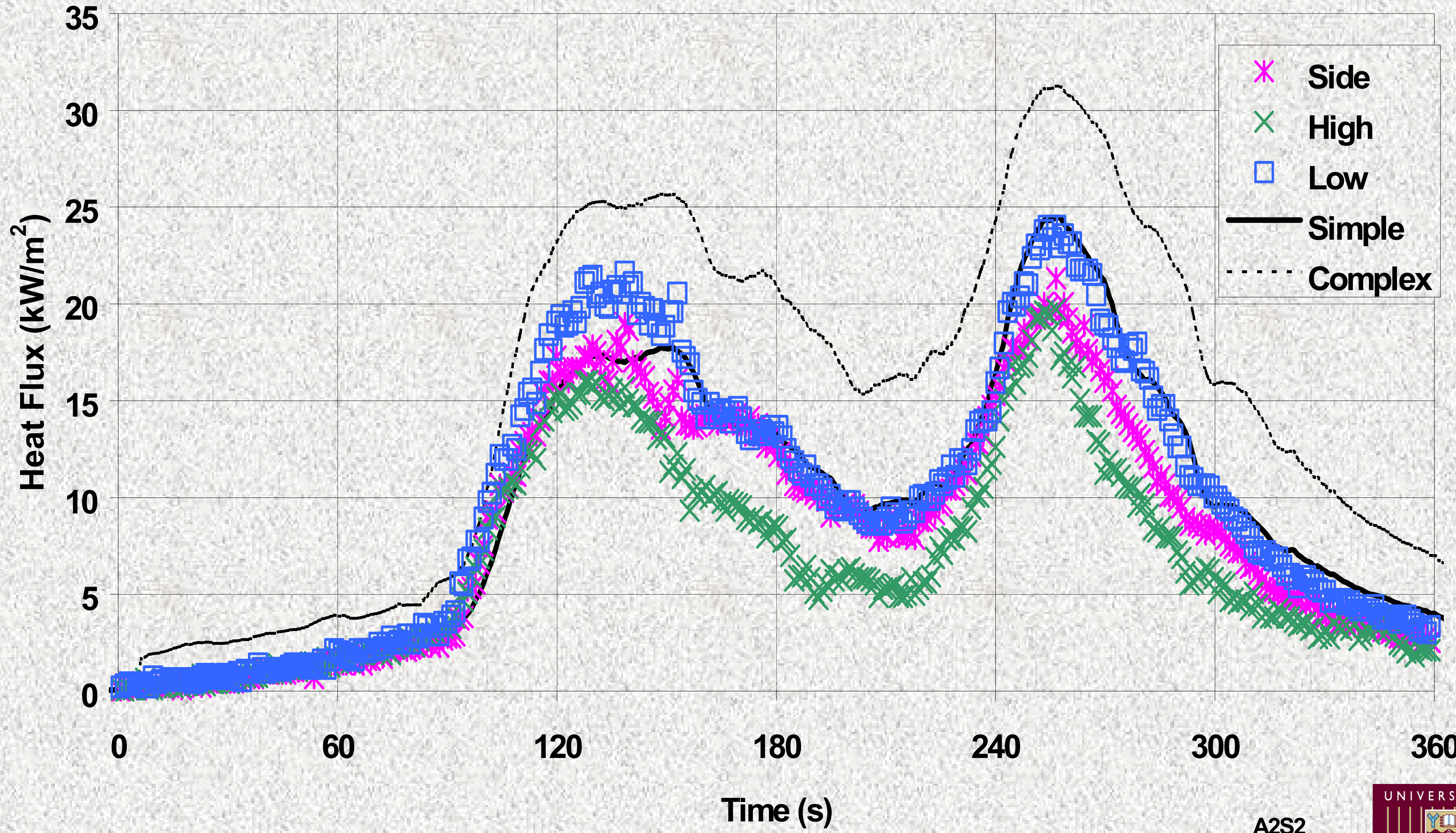
Two Seater Results



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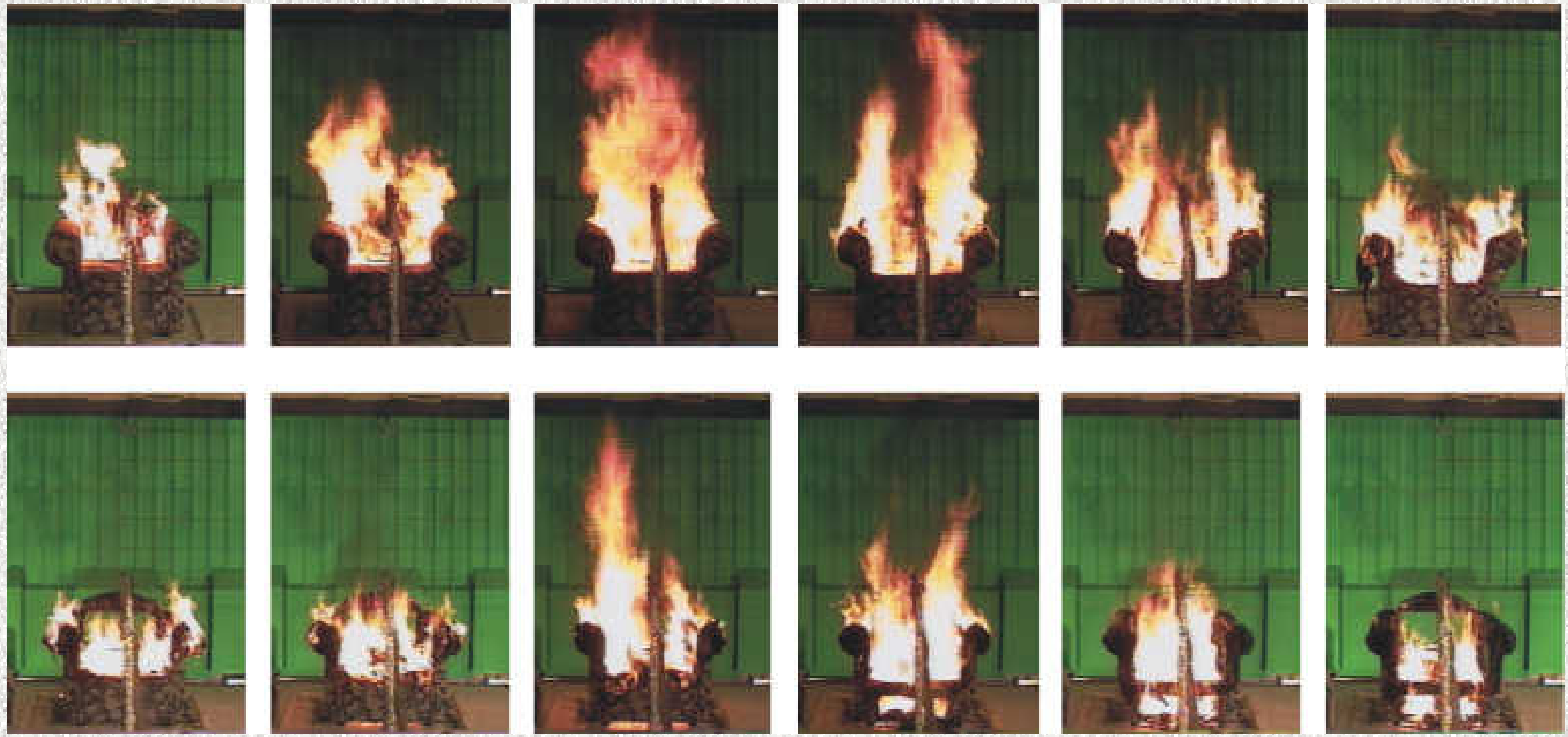
Furniture Flames



30 s after ignition to 360 s after ignition

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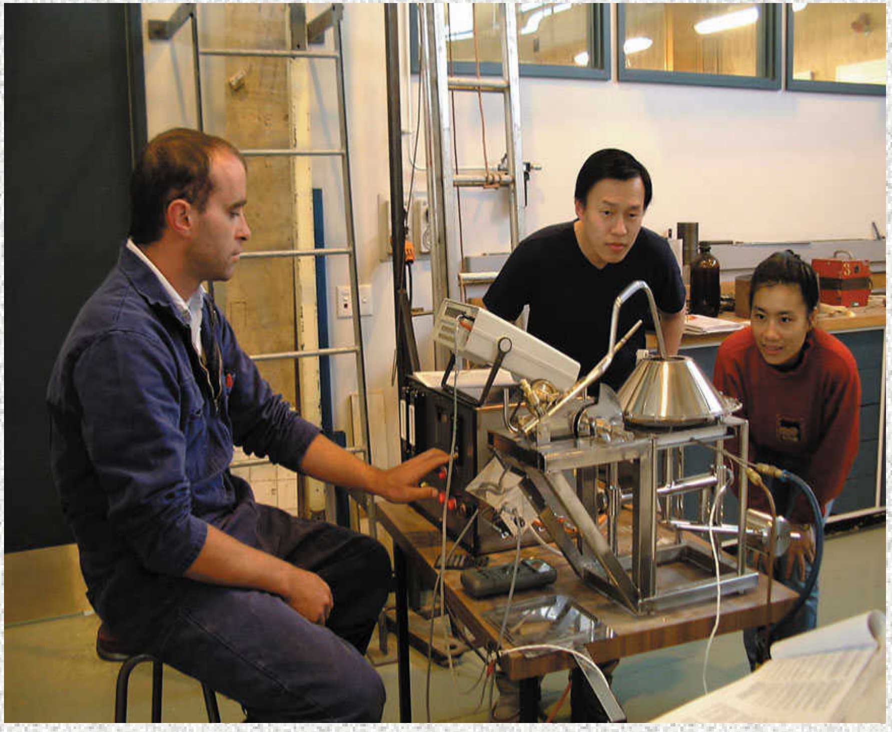
Radiant Ignition of Upholstered Furniture



- Experiments
- Results
- Analysis

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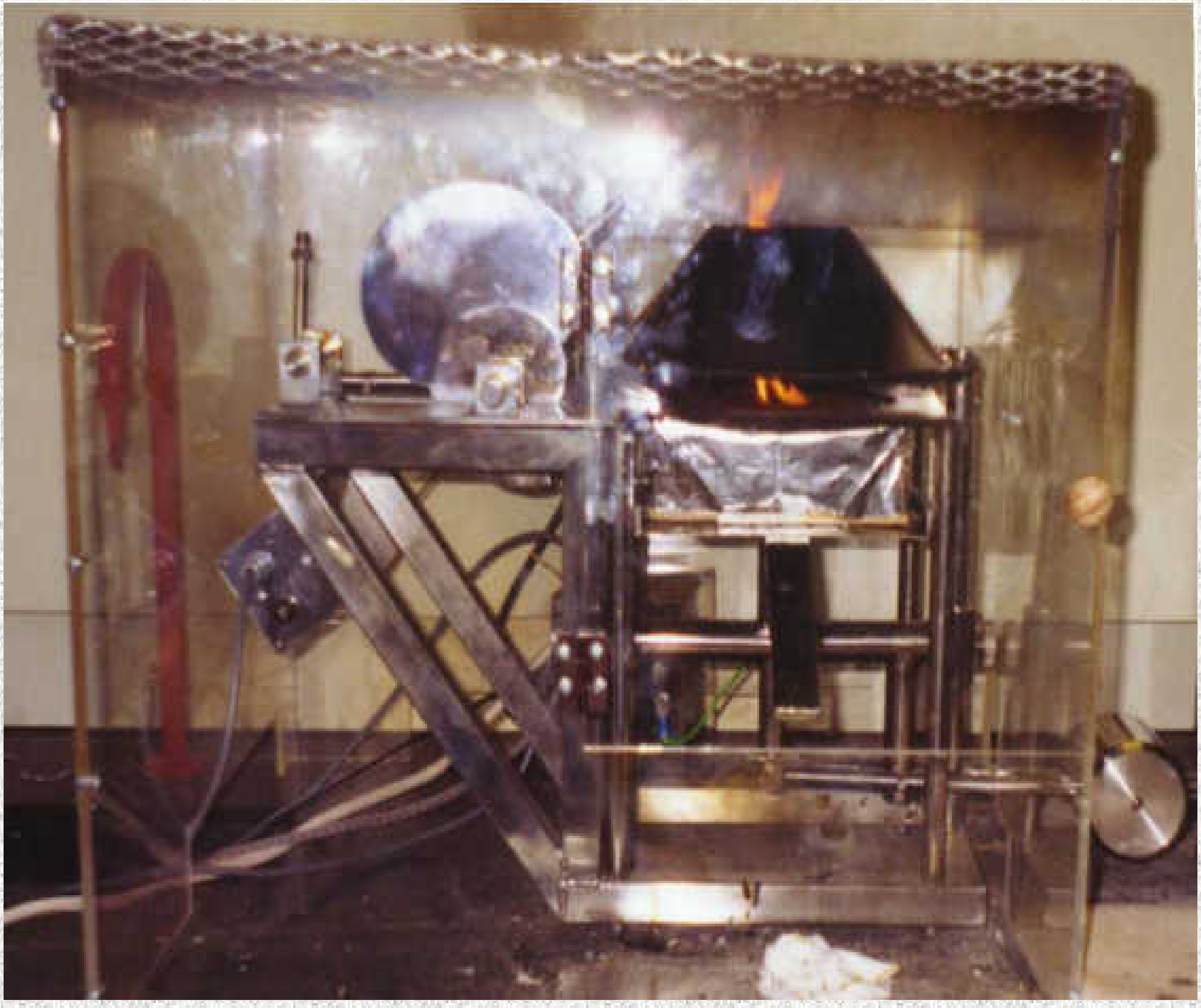
Ignition Apparatus



Radiant Ignition of Upholstered Furniture

- 14 NZ Fabrics
- 3 NZ Polyurethane Foam (Domestic, Commercial, Aviation)
- ISO Ignitability Apparatus w/electric arc
- q_e = 40, 35, 30, 25, 20, 15, 10 kW/m^2 + minimum heat flux levels
- 5 replicate samples at each heat flux
- Over 900 experiments were conducted

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Fabric Matrix

Color Code	Polypro-pylene	Polyester	Acrylic	Cotton	Olefin	Viscose	Nylon pile	Total
Pacific	100							100
Cement		100						100
Saffron			100					100
Azure					100			100
Gold							100	100
Dark red				100				100
Cadet		42	58					100
Blue		51		49				100
Sage		50			50			100
Navy		51				49		100
Forest	60	40						100
Denim		31	21	48				100
Spring		43	41		16			100
Taupe		39		40		21		100

* Fabric 28 is a fabric treated with fire retardant additive.

- Selected from over 350 fabrics
- Color was not a variable
- Pure fabrics chosen when possible

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Assumptions

- Ignition occurs when the surface reaches a material dependent temperature
- The material is opaque and inert
- The material has uniform thermal properties independent of T
- Thermal decomposition and associated changes are neglected
- Heat flow into the solid is 1-dimensional
- Heat loss from the surface is both convective and radiative with a constant convection coefficient

Time to ignition - thin solid

Approximate solution

$$\dot{q}''_{net} = \dot{q}''_e - \dot{q}''_{rr} = \tau \rho c_P \frac{dT}{dt}$$

Initial condition: $t = 0 \quad T = T_\infty$

Solution to simplified form:

Material dependent specific to ignition

$$t_{ig} = \tau \rho c_p \frac{(T_{ig} - T_0)}{(\dot{q}''_e - \dot{q}''_{crit})}$$

Approximation of surface heat loss

Thermally Thick - Time to Ignition

Approximate solution:

$$t_{ig} = \frac{\pi}{4} k\rho c \frac{\left(T_{ig} - T_o\right)^2}{\left(\dot{q}''_e - \dot{q}''_{crit}\right)^2}$$

Material dependent specific to ignition

Approximation of Net heat absorbed

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Critical versus Minimum Heat Flux

- Minimum heat flux for ignition $\dot{q}''_{\min}$ the heat flux below which ignition under practical conditions (in bench scale test or a real fire) cannot occur.

- Critical heat flux for ignition $\dot{q}''_{crit}$ is an estimate of $\dot{q}''_{\min}$ derived from a correlation of experimental data.

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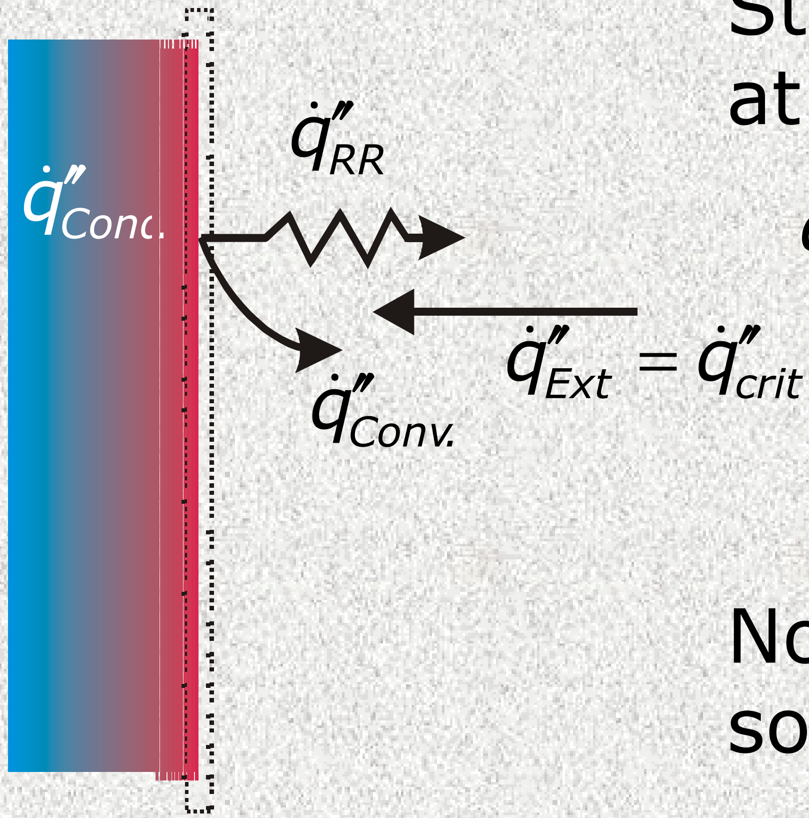
Estimating the Ignition Temperature



Steady State Energy Balance at Surface

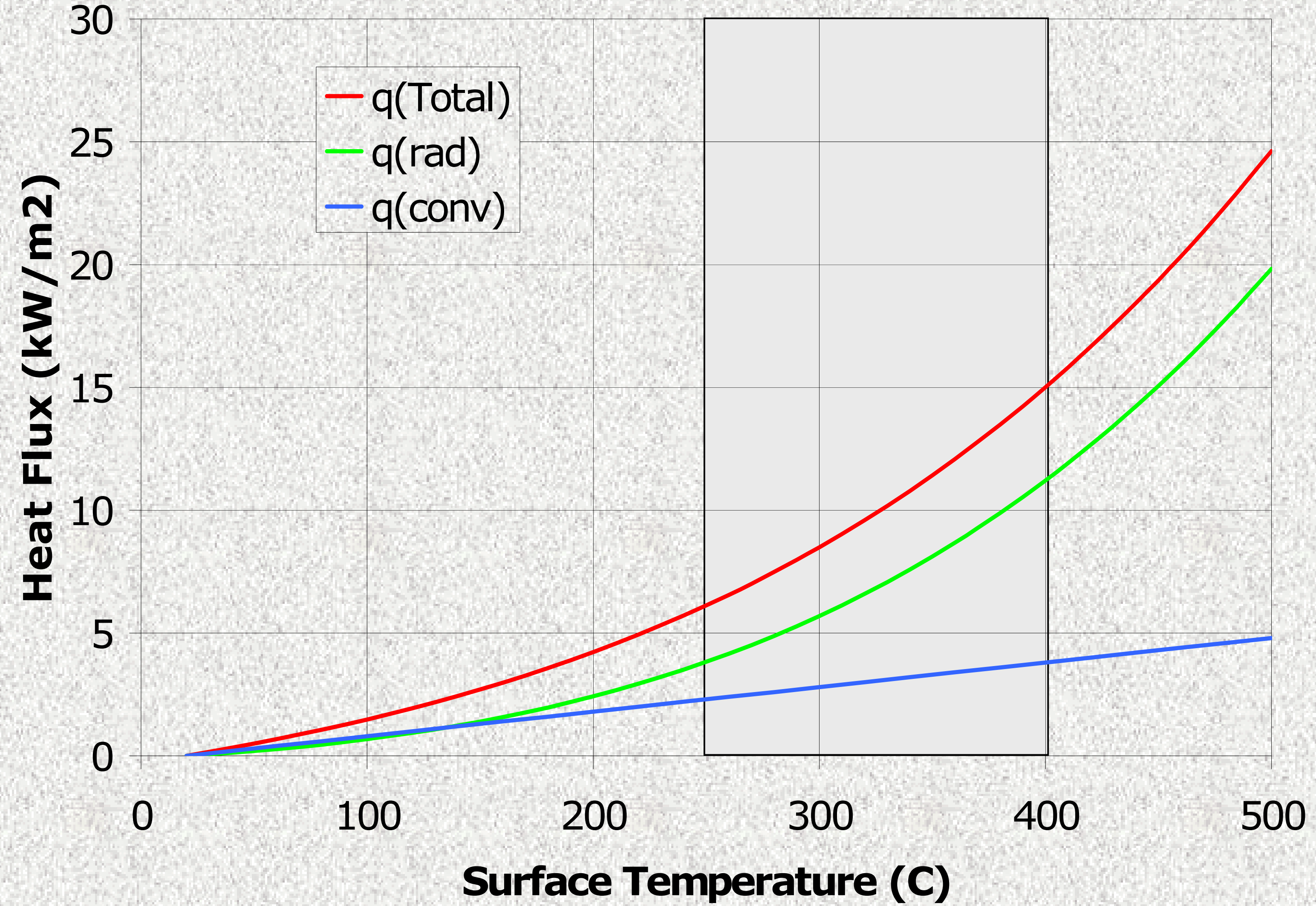
$$\dot{q}''_{crit} = \varepsilon\sigma\left(T_{ig}^4 - T_\infty^4\right) + h_c\left(T_{ig} - T_\infty\right)$$

Radiative losses

Convective losses

Nonlinear – interative solution

Components of Surface heat loss



Melting Fabric

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Melting Fabric

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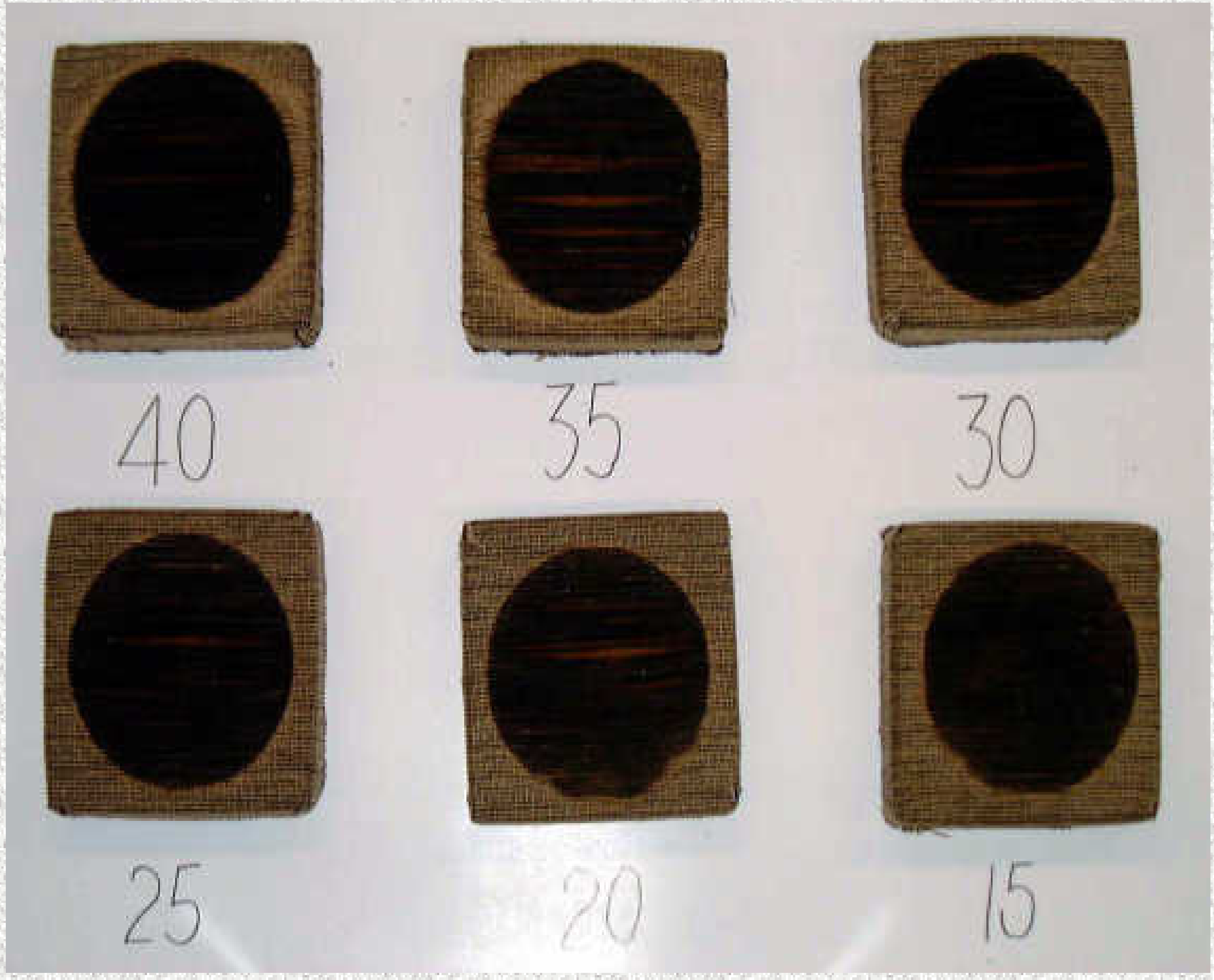
Charring Fabric



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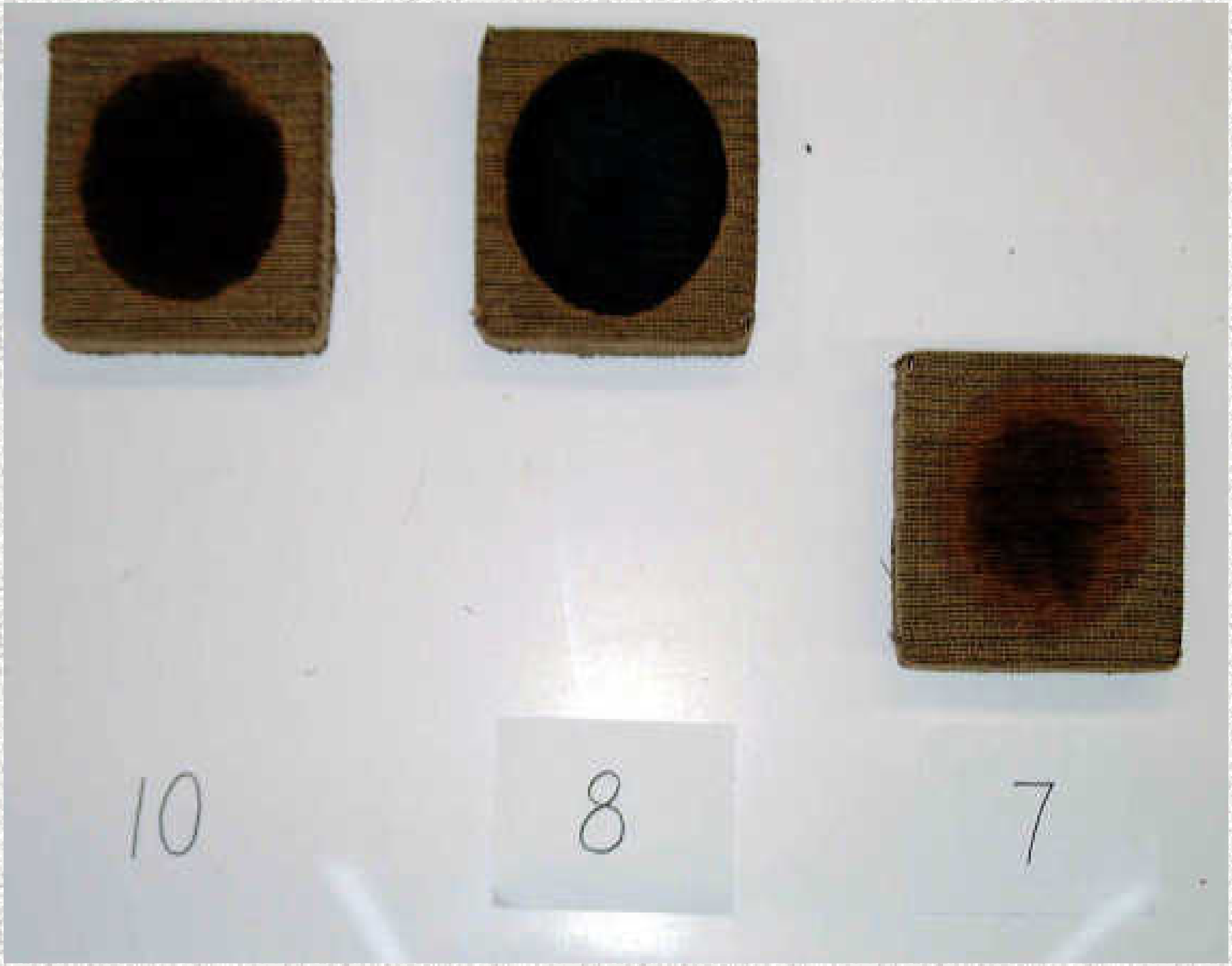
Charring Fabric



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Analysis

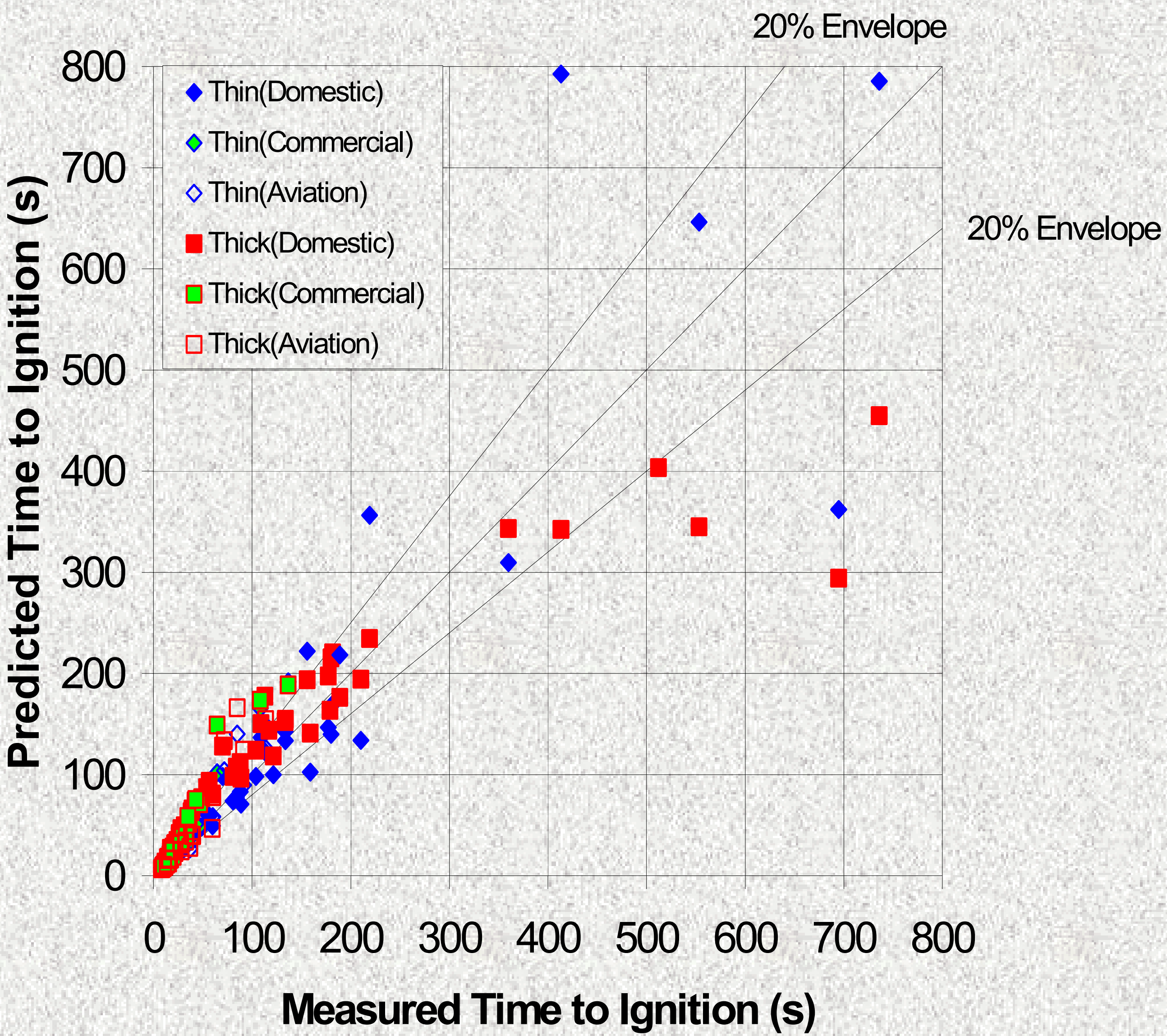
- Thermally Thin

$$t_{ig} = \rho\tau c \frac{(T_{ig} - T_0)}{(\dot{q}''_e - \dot{q}''_{crit})}$$

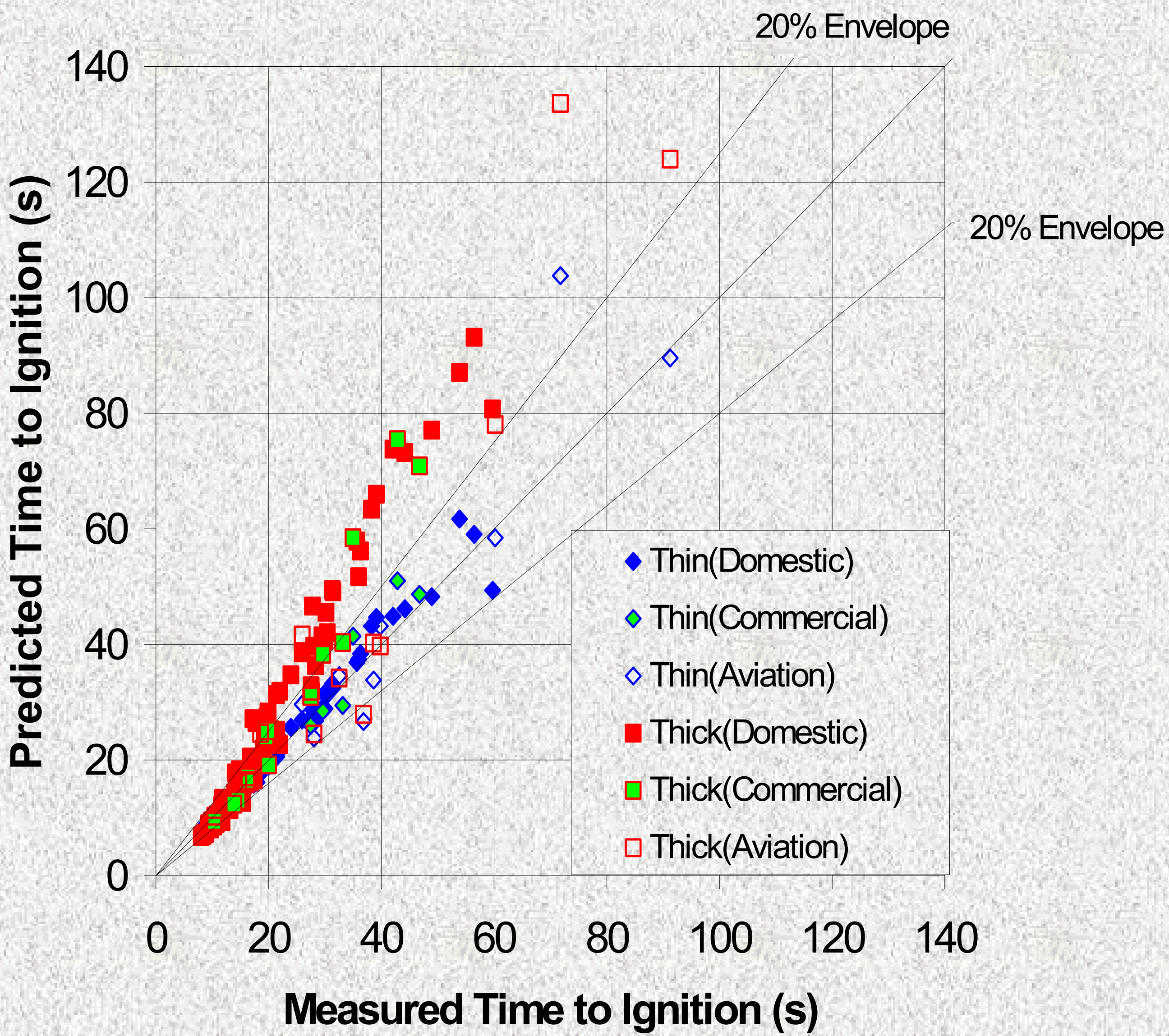
- Thermally Thick

$$\frac{1}{\sqrt{t_{ig}}} = \left(\frac{\pi}{4} k\rho c\right)^{-1/2} \frac{(\dot{q}''_e - \dot{q}''_{crit})}{(T_{ig} - T_o)}$$

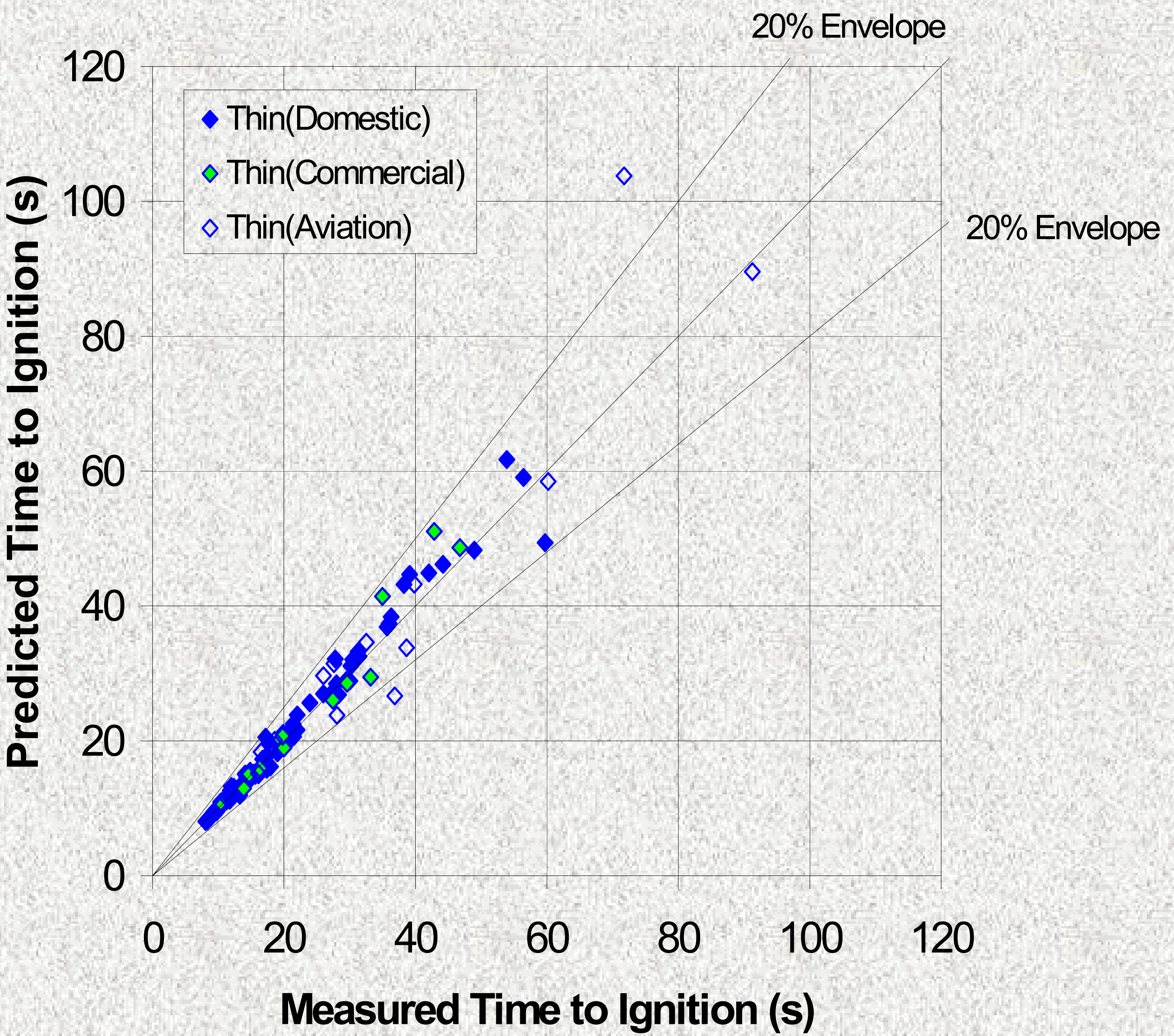
Results $7kW/m^2 \leq q''_e \leq 40kW/m^2$



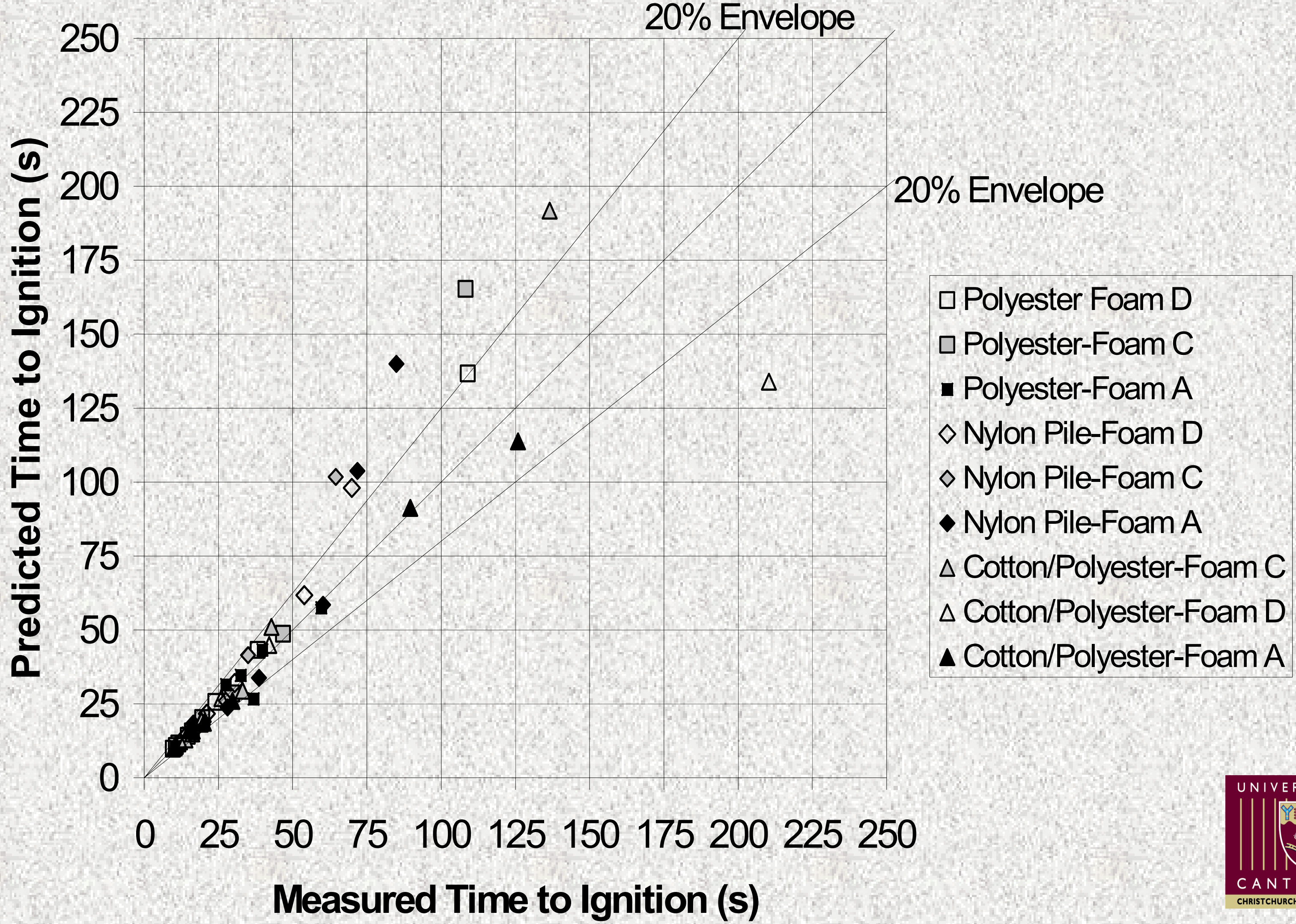
Results $15kW/m^2 \leq q''_e \leq 40kW/m^2$



Results 15kW/m² ≤ q″ₑ ≤ 40kW/m²



Fabric Effects



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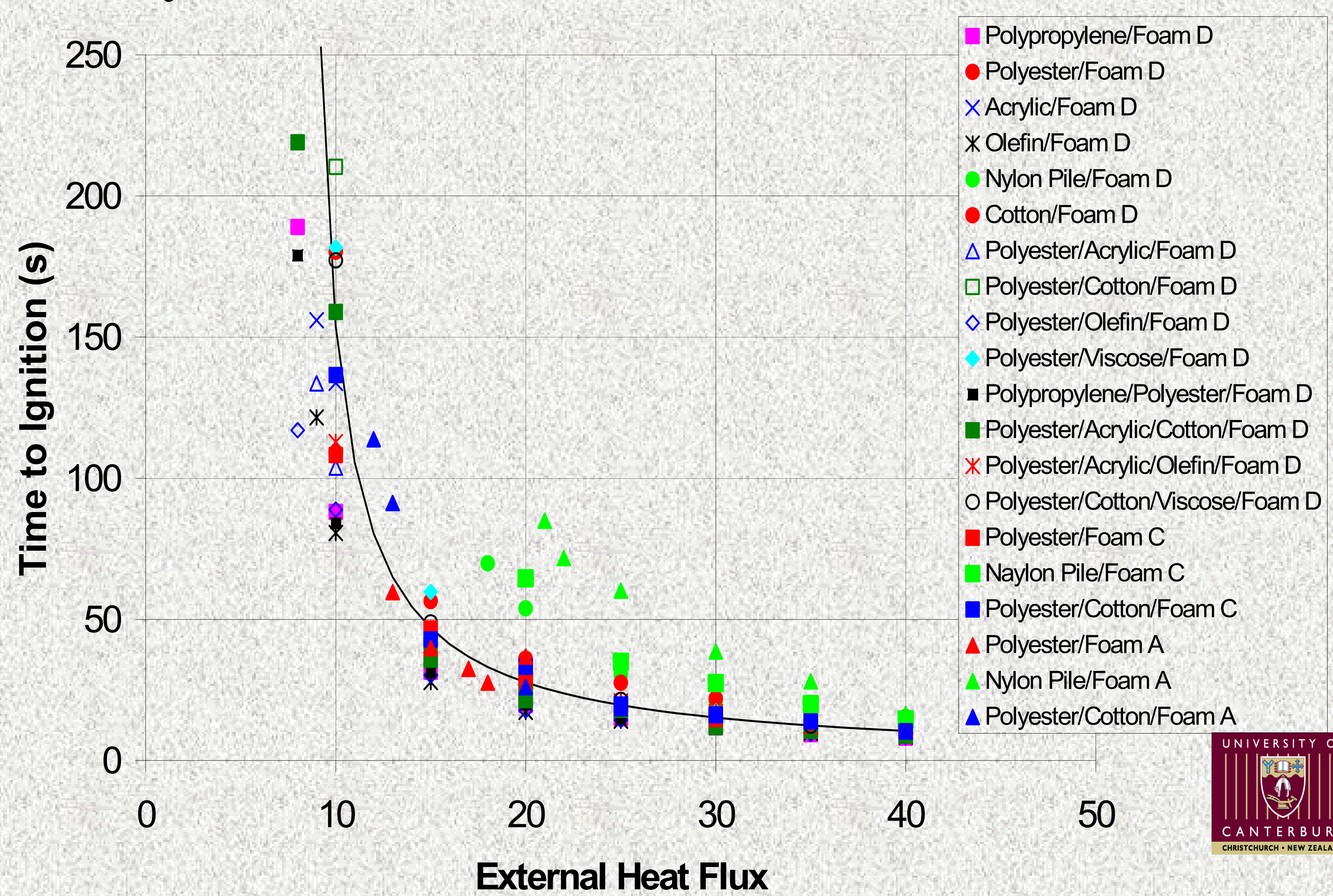
$$t_{ig} = \frac{338}{(\dot{q}''_e - 7.8)}$$

Generic Results



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Conclusions Radiant Ignition of Upholstered Furniture

- The results presented here show that upholstered furniture composites present a complex ignition problem.
- The melting of the foam and behaviour of the fabrics further complicates the problem.
- Ignoring these complications, the results show that when the fabric-foam composite is exposed to external radiation of 15 kW/m^2 or more, the time to ignition correlates well as a thermally thin solid
- When the external radiant heat fluxes are below 15 kW/m^2, i.e. approaching the minimum heat flux levels, neither the thermally thin or thermally thick correlations fit the data well.

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Conclusions - Radiation from the Source

- Due to the complex geometry of upholstered furniture flames it is difficult to model the radiation.
- Point source approximation give surprisingly accurate predictions for the flame radiation (At least at 1.5 m from burning chair)
- More complex is not always accurate.

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Further Research

- Improve the characterization of the flame shape using image processing of the video tape.

- Conduct additional experiments with more detailed heat flux measurements.

- Using the material properties from the steady state experiments to predict the ignition from a transient exposure and compare with new transient results.

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Flame Analysis with Image Processing

Paul Mason

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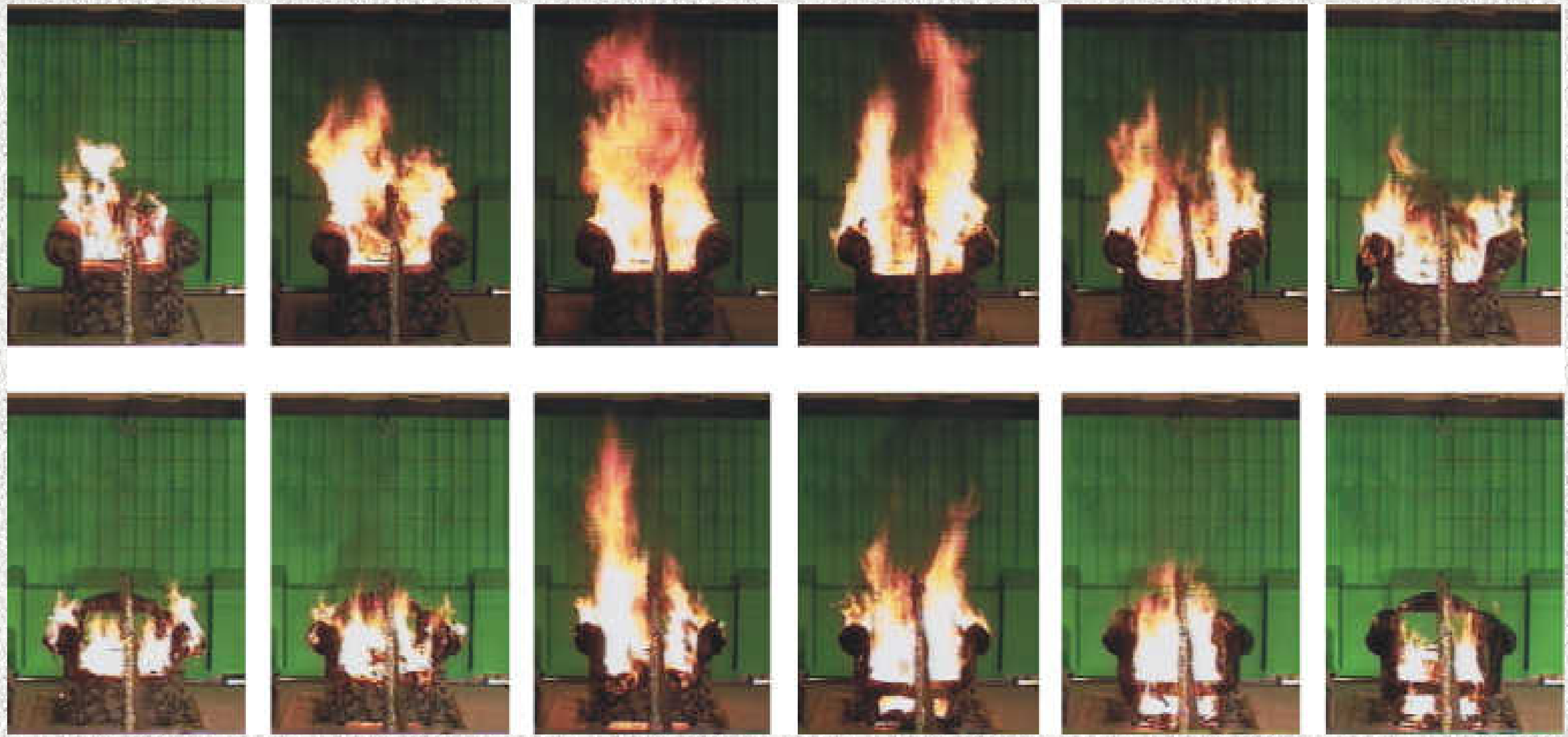
Furniture Flames



30 s after ignition to 360 s after ignition

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Motivation

- To identify and quantify the shape of a flame
- To effectively model flame shape (cylinder, truncated cone, double cone, etc.)
- To correlate flame shape with energy release rate
- To use multiple cameras to establish flame shape (3D)

Couch Fire

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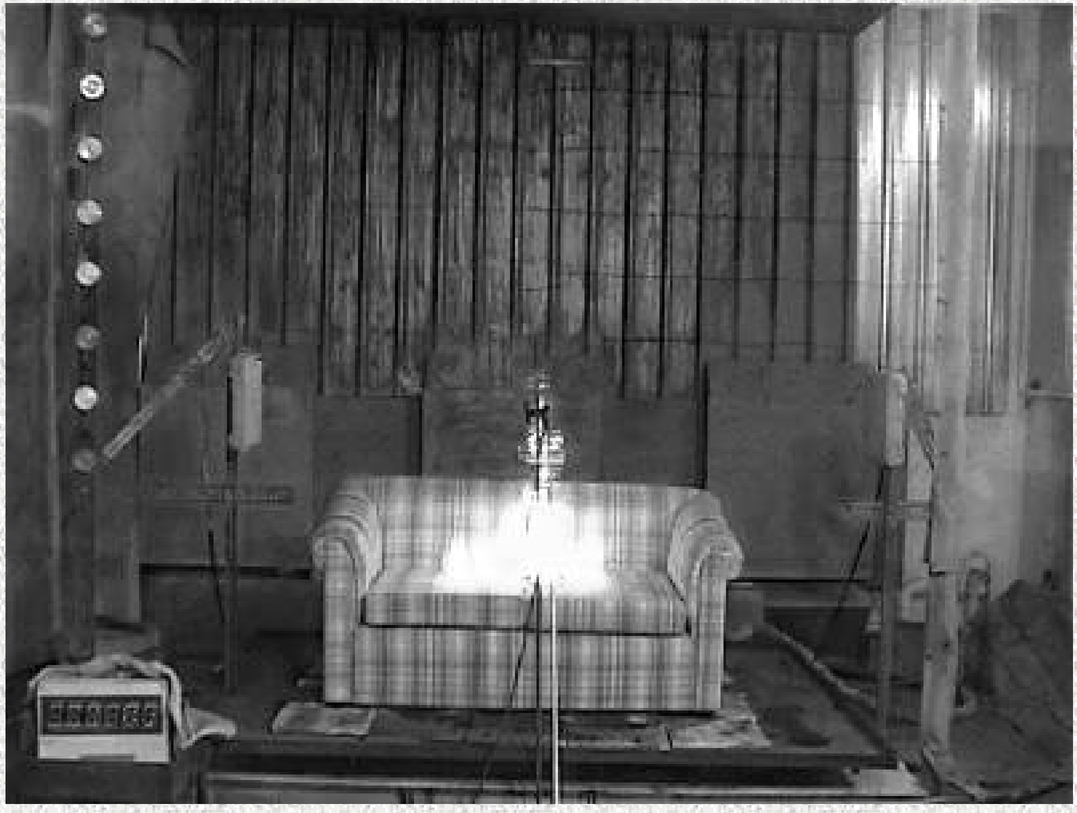
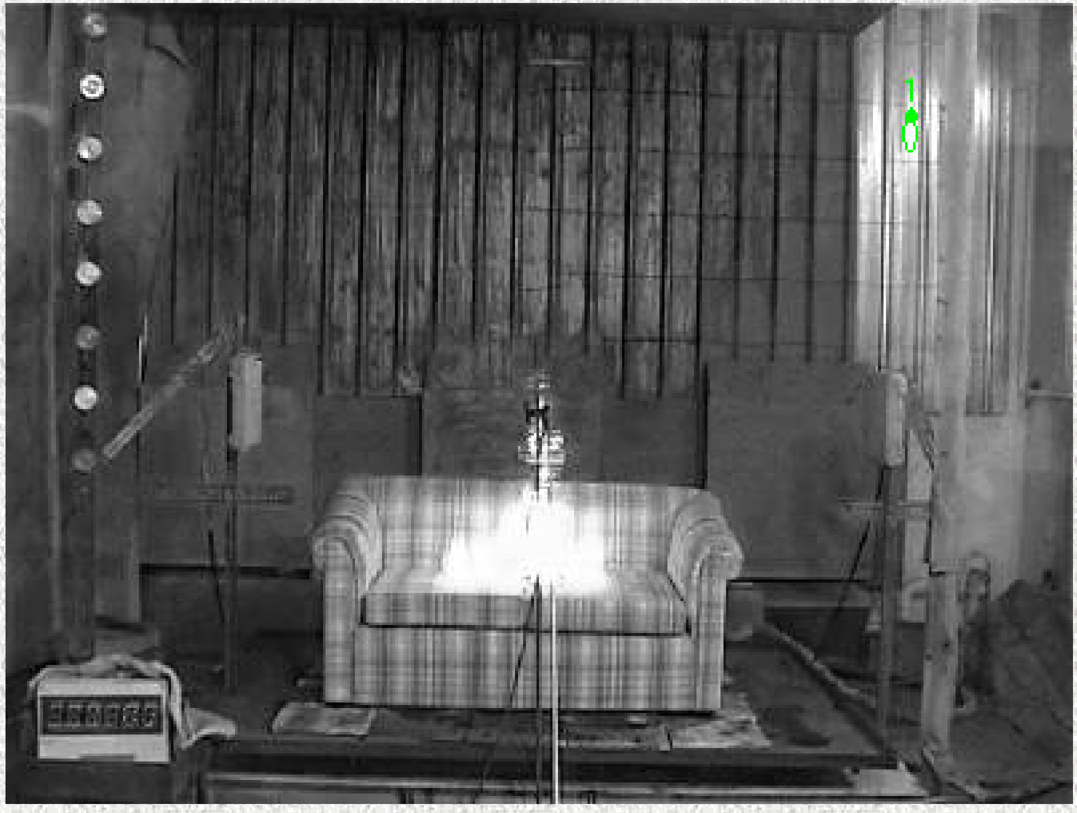
Algorithm

Extract blue color plane



Algorithm

Quantify



Maximal value: 255.00

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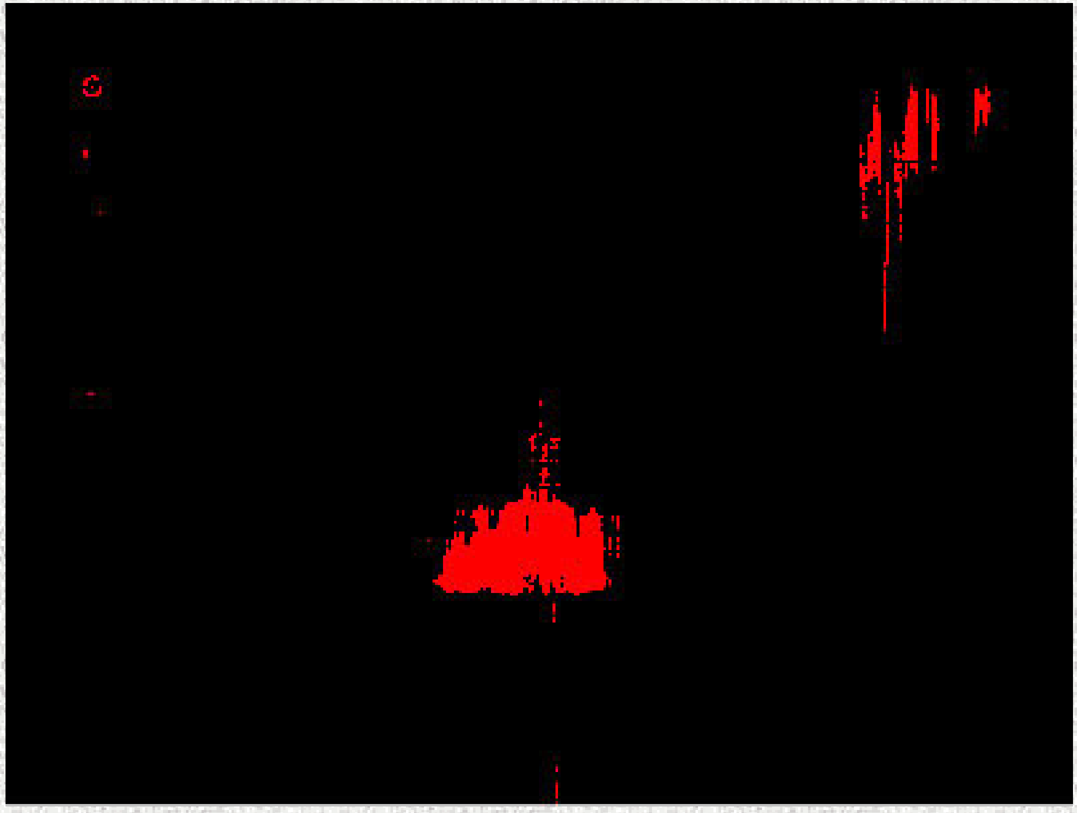
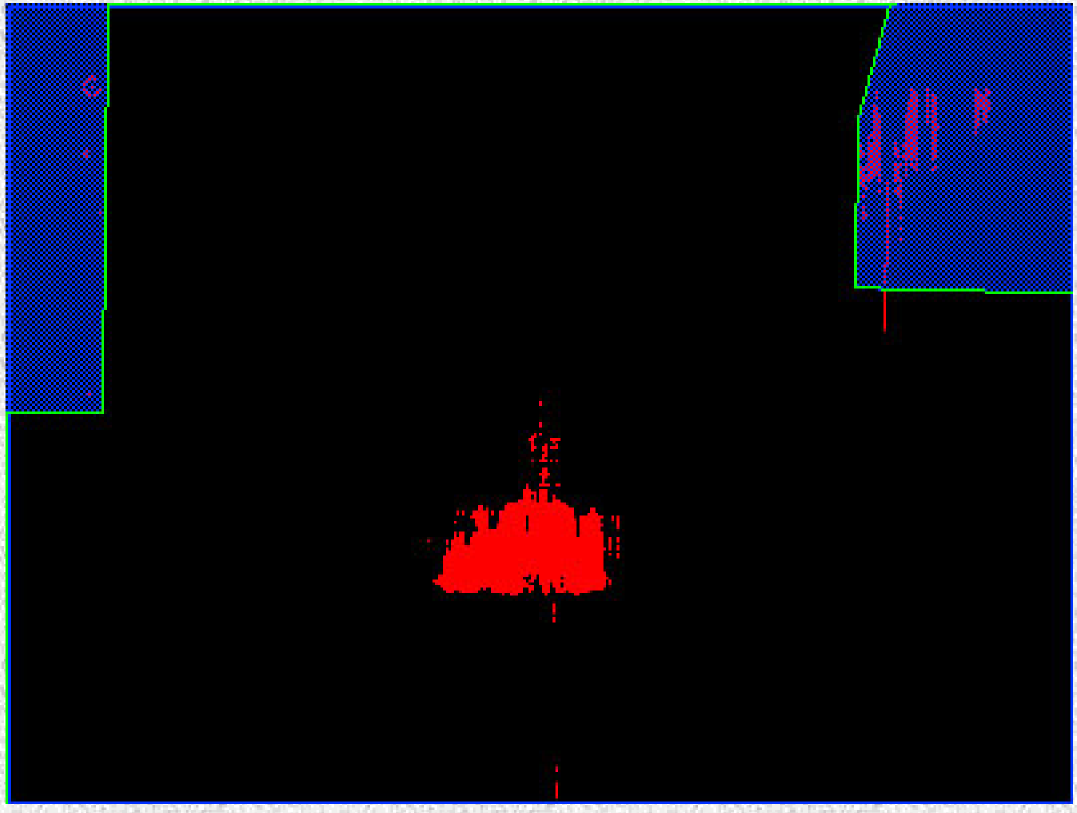
Algorithm

Threshold



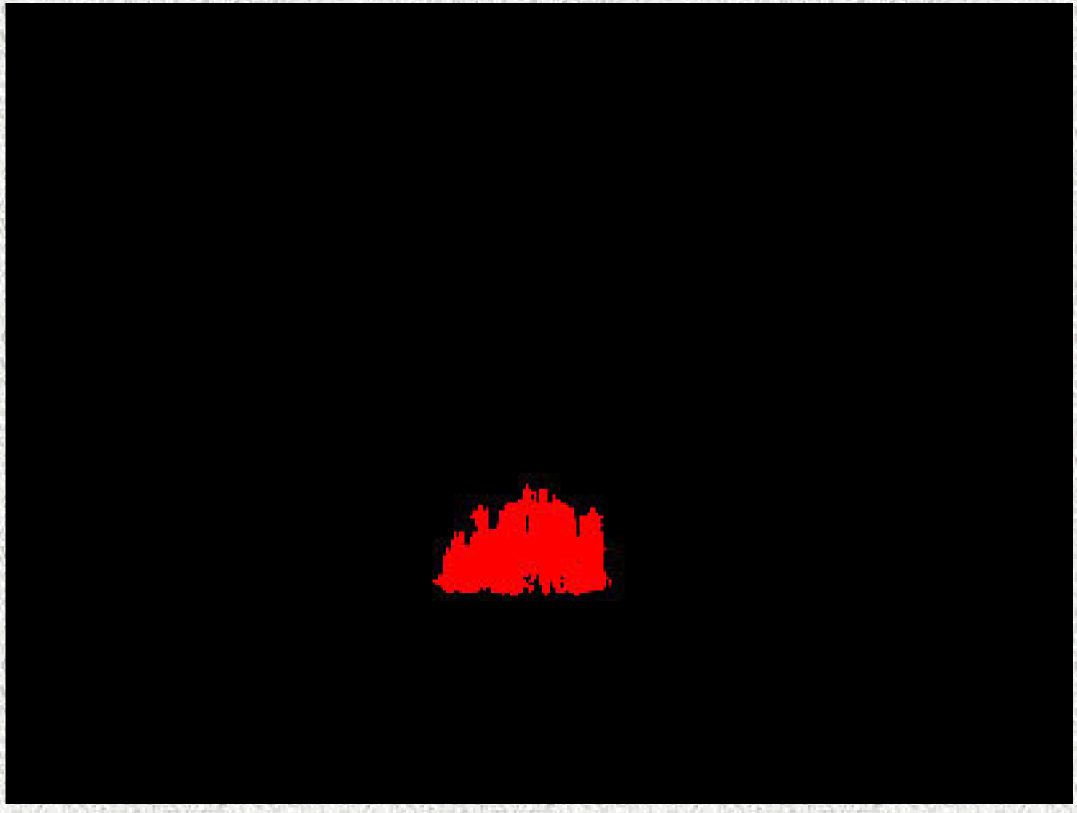
Algorithm

Image mask: from ROI



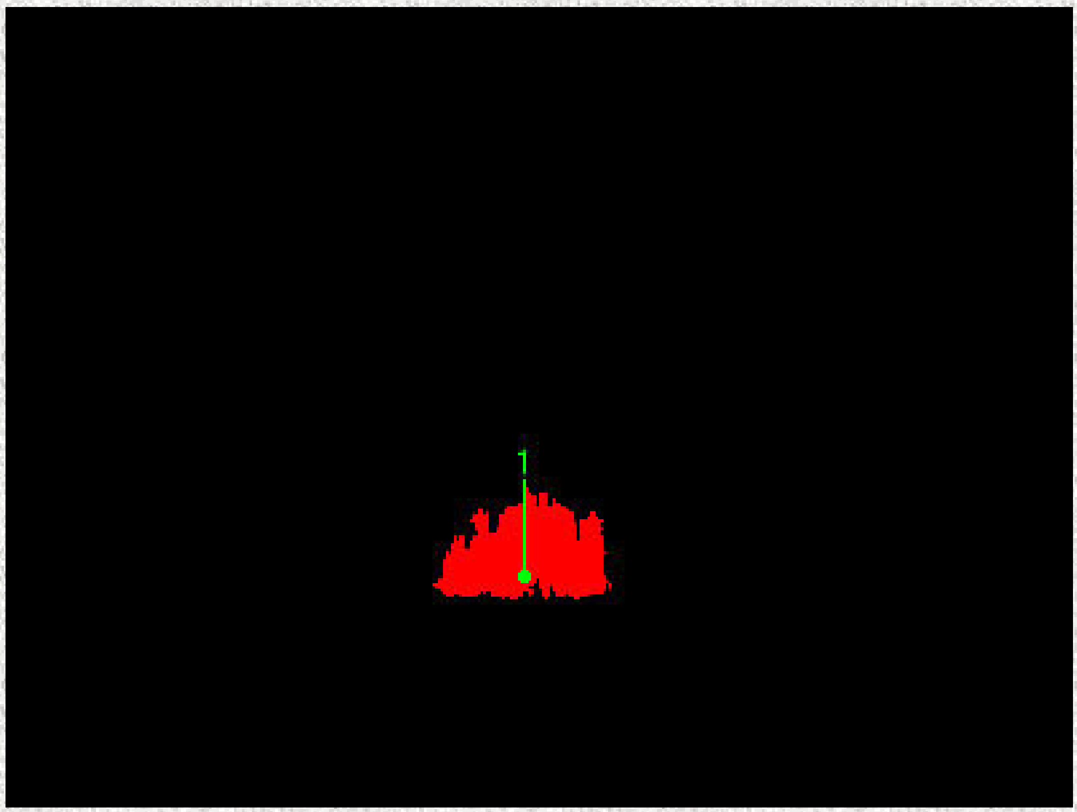
Algorithm

Remove small particles



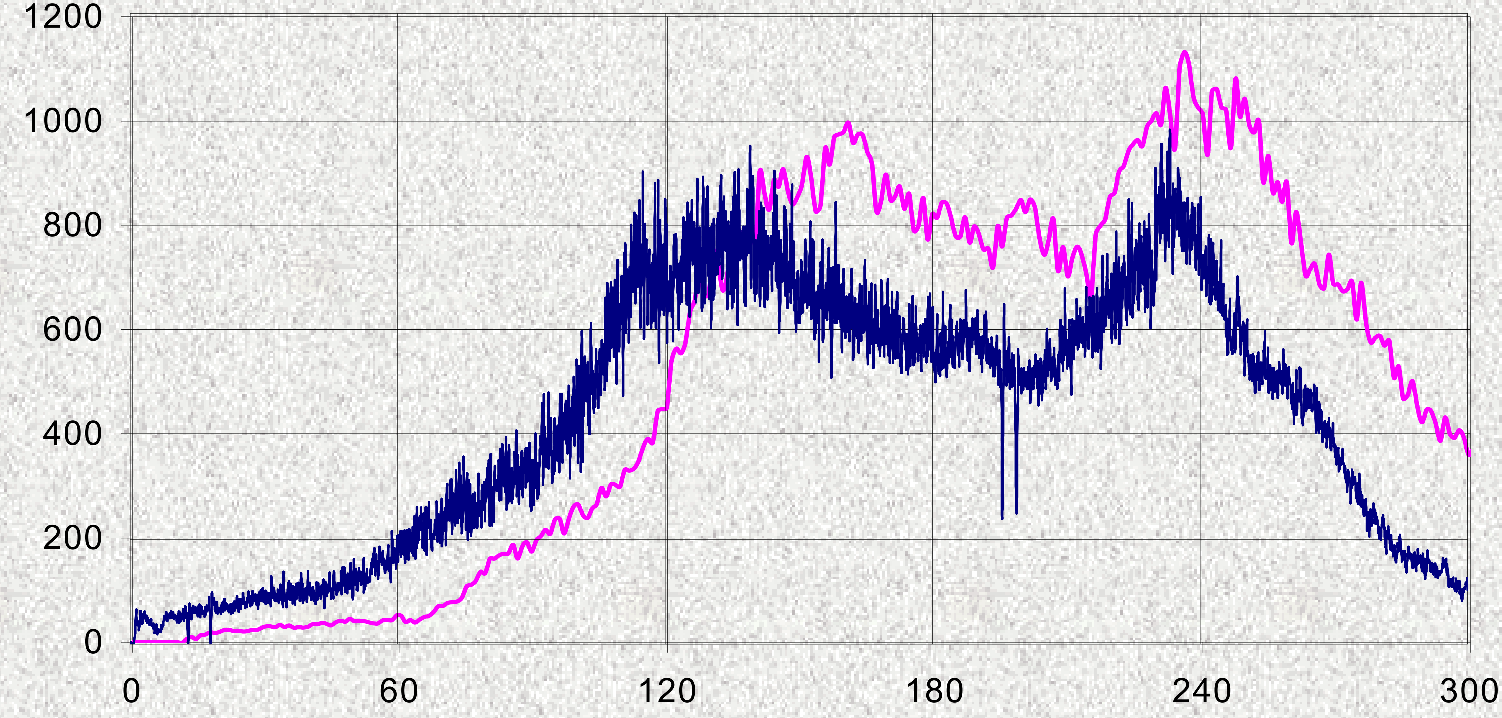
Algorithm

Particle Analysis: Area (pixels)



Results…	1
Area (unit)	1782

Data



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Future Efforts

- Minimize reflections
- Investigate smoke effects & video compression effects
- Average the flame – 100%, 50%, etc.
- Measure flame height & width
- Convert length & area from pixels to m^2
- Estimate flame volume (3D visualization)

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