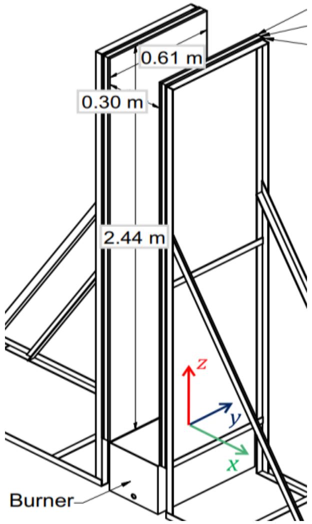
Flame Spread Experiments and Next Steps

Dushyant M. Chaudhari, Isaac T. Leventon and
Stanislav I. Stoliarov

2021 IAFSS Symposium Workshop: MaCFP Condensed Phase
April 23, 2021

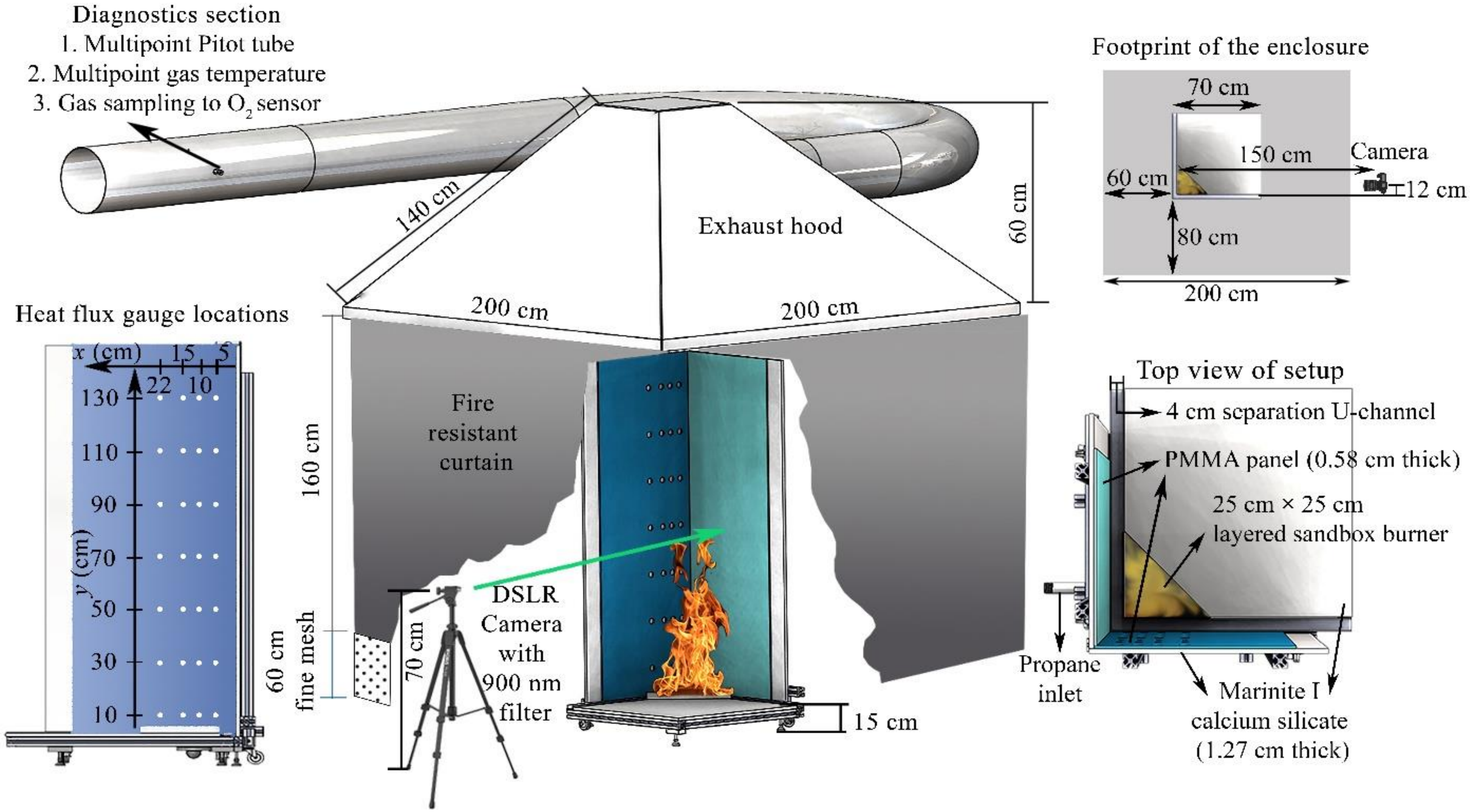
Large-scale experiments on the cast black PMMA that are currently in progress

- Flame spread on a corner wall formed by two 146×50 cm^2 panels of PMMA
- 7 tests were performed thus far at UNIVERSITY OF MARYLAND 1856; they are supported by FEDERAL AVIATION ADMINISTRATION



- Flame spread on parallel panels lined with 245×60 cm^2 sheets of PMMA
- 6 tests were performed thus far at NIST National Institute of Standards and Technology U.S. Department of Commerce

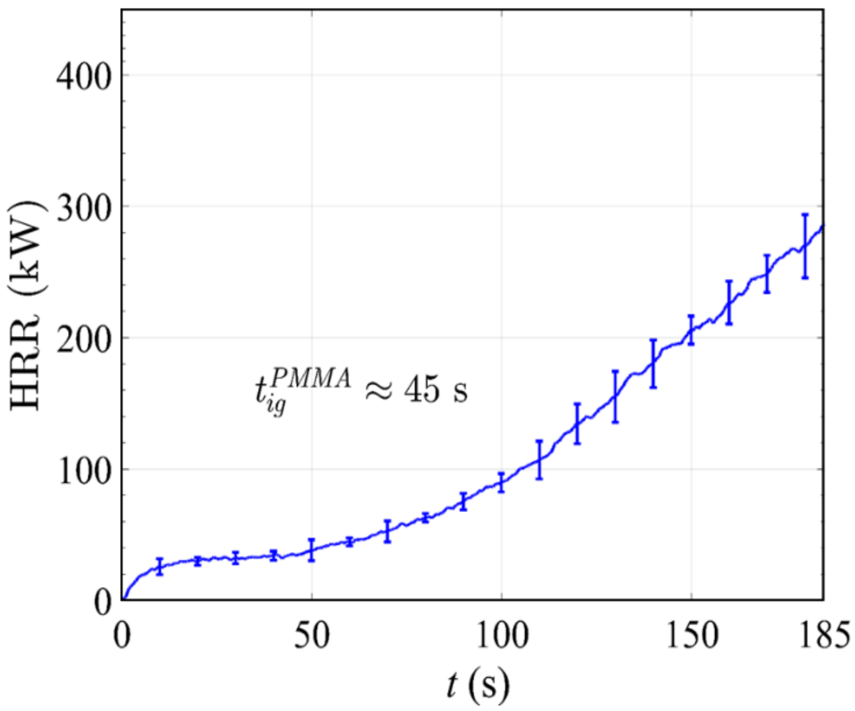
Experimental setup to study flame spread on a corner wall



Key Diagnostics:

1. Fast-response (13 s) heat release rate (HRR) measurement
2. Flame heat flux with water-cooled gauges positioned in 28 locations distributed over the PMMA surface
3. Monochromatic, 900 nm, video of the spreading flame using DSLR camera with a linear sensor response

Results of HRR measurements

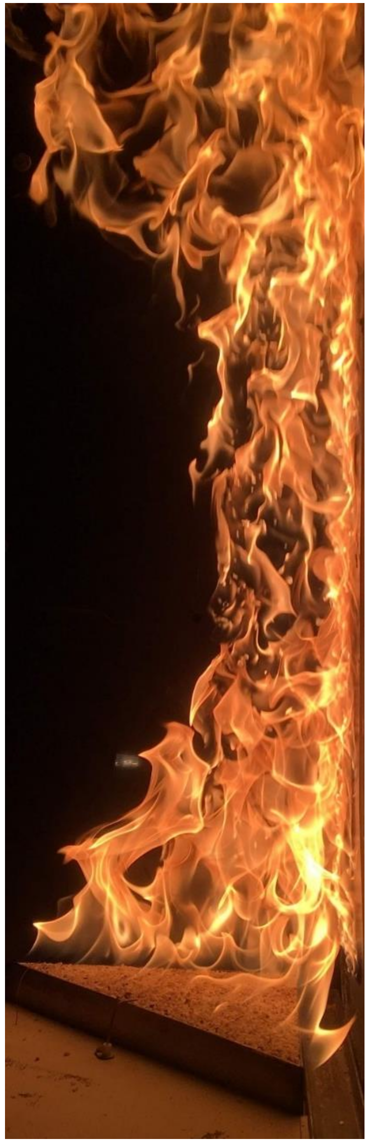


$$\mathrm{HRR} = E \cdot A \cdot C_f^e \left(2\Delta P\left(\frac{P_a M_e}{T_e R}\right)\right)^{0.5} \frac{M_{O_2}}{M_e}\left(\frac{X_{O_2}^{m,0}}{1+X_{O_2}^{m,0} r_{H_2O}^0} - X_{O_2}^t\right)$$

$$X_{O_2}^t = \frac{X_{O_2}^m}{1+\gamma\left(\frac{X_{O_2}^{m,0}}{\left(1-X_{O_2}^{m,0}\right)+X_{O_2}^m} - X_{O_2}^m\right)+r_{H_2O}^0 X_{O_2}^m}$$

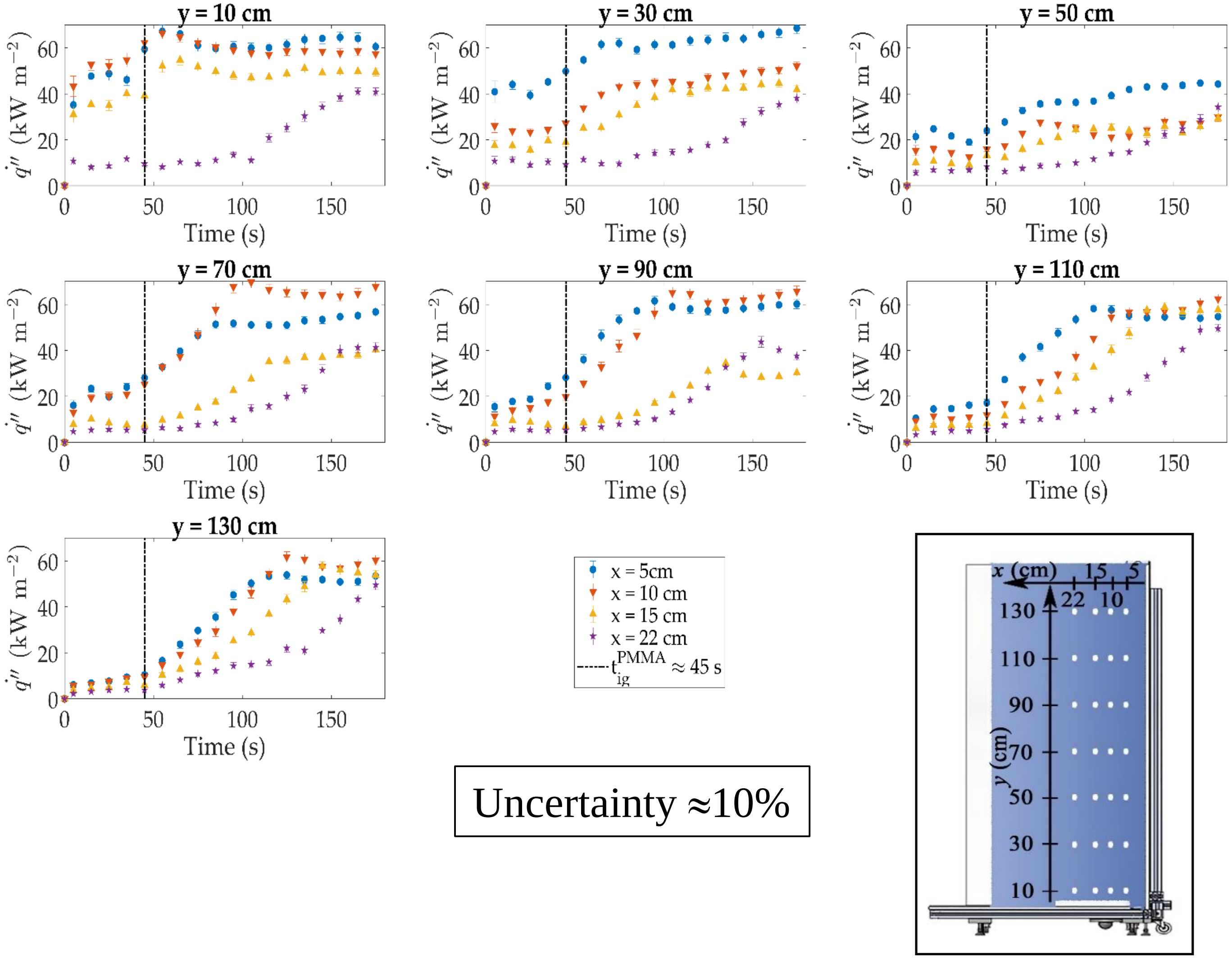
$$r_{H_2O}^0 = \left(\frac{P_a}{(RH^0/100)P_{H_2O}^v} - 1\right)^{-1} \frac{1}{X_{O_2}^{m,0}}$$

For details, see: https://doi.org/10.1016/j.polymdegradstab.2020.109433



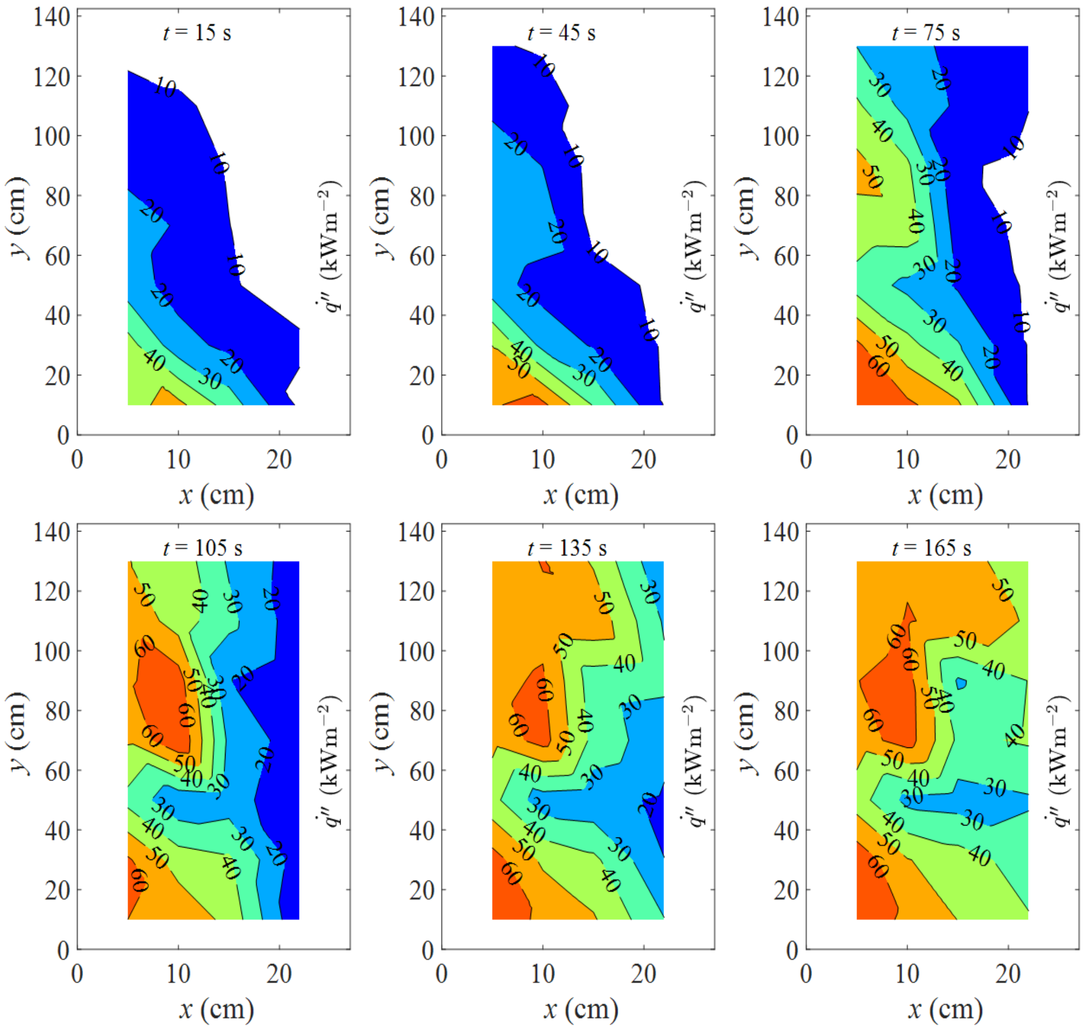
Results of flame heat flux measurements

Temporally resolved:



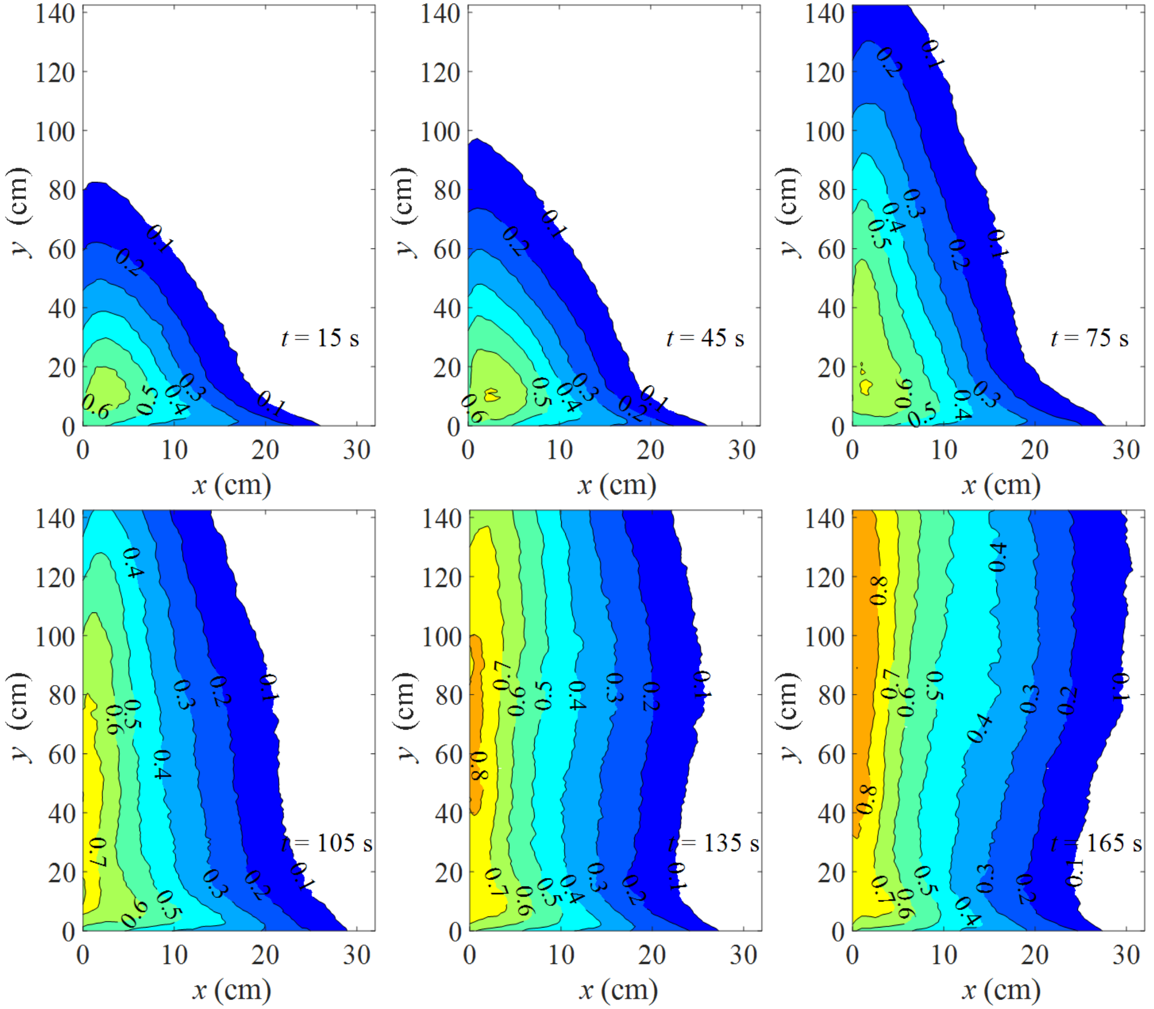
Uncertainty ≈10%

Spatially resolved:



Results of flame imaging

10 s averaged relative intensities of 900 nm flame emissions projected onto a PMMA panel surface



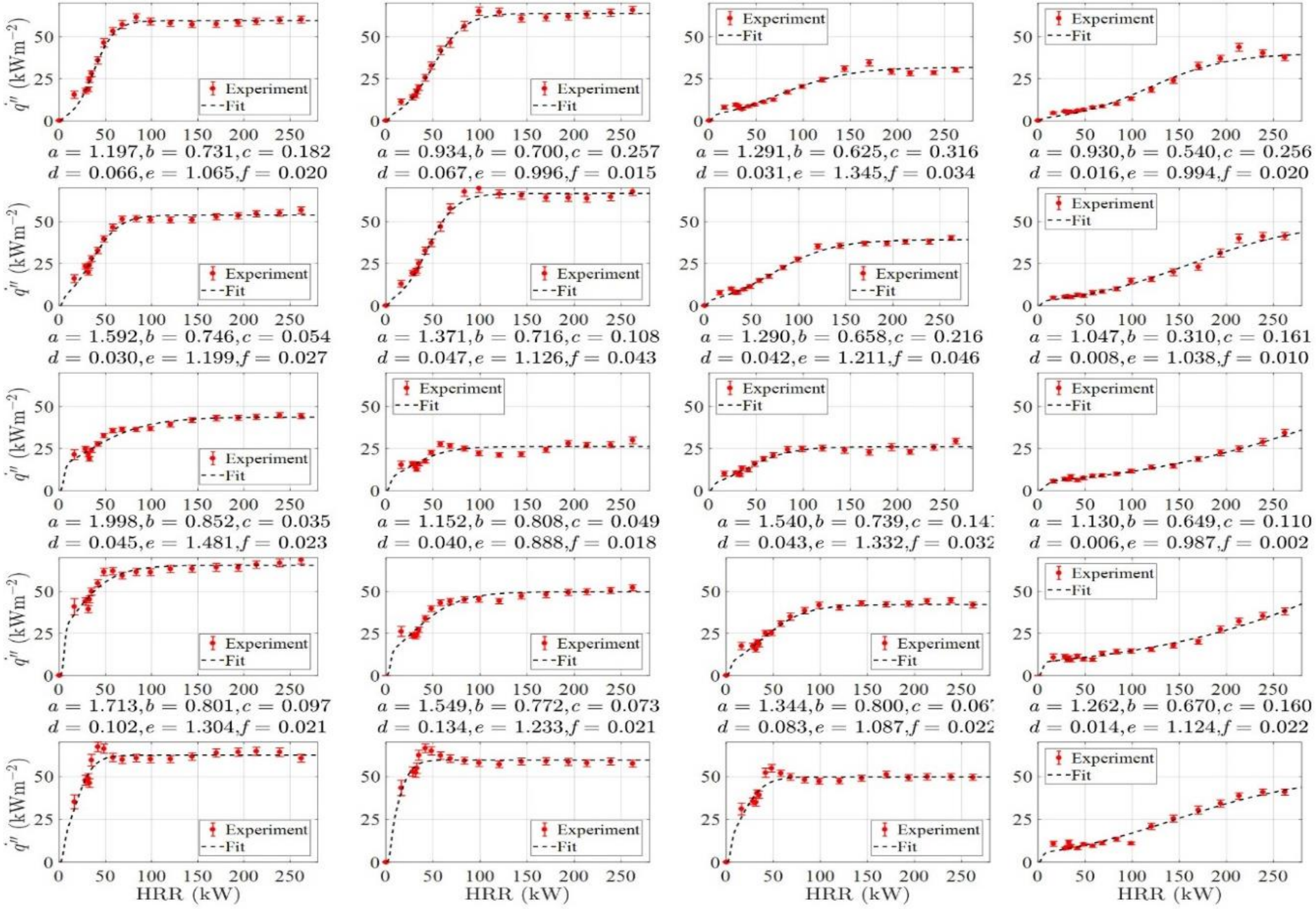
$$I^{cam}_{900\ nm}(x,y) \propto \int_s \left(k^{soot}_{900\ nm}(s) I^{b}_{900\ nm}(T) - k^{soot}_{900\ nm}(s) I_{900\ nm}(s) \right) ds$$

$$(x_s, y_s, z_s) = (x, y, 0) + \frac{s}{\sqrt{(12-x)^2+(70-y)^2+150^2}} \cdot (12-x, 70-y, 150)$$

$k^{soot}_{900\ nm}$ is the extinction coefficient that includes effects of absorption and scattering by soot and is related to the local soot volume fraction

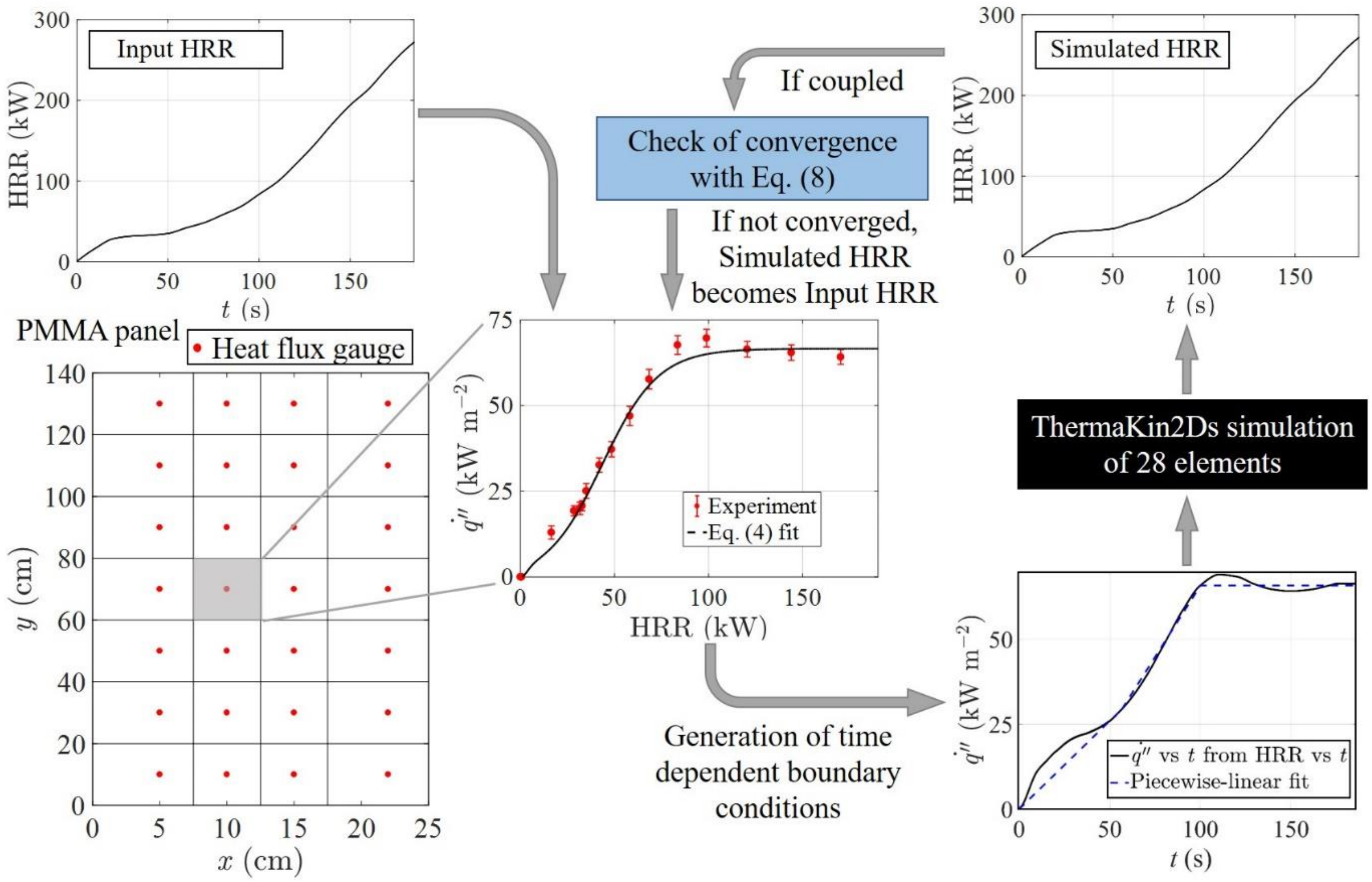
For details, see: https://doi.org/10.1016/j.polymdegradstab.2020.109433

Further analysis: relationship between flame heat flux and HRR



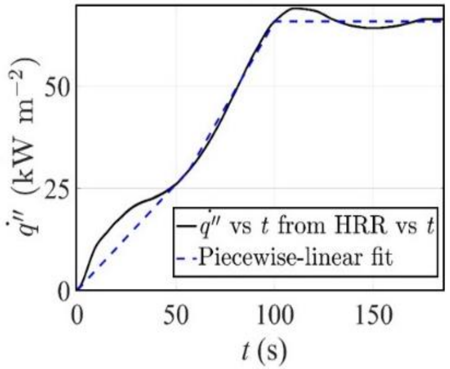
. . .

Further analysis: connection with pyrolysis model



Prediction of HRR

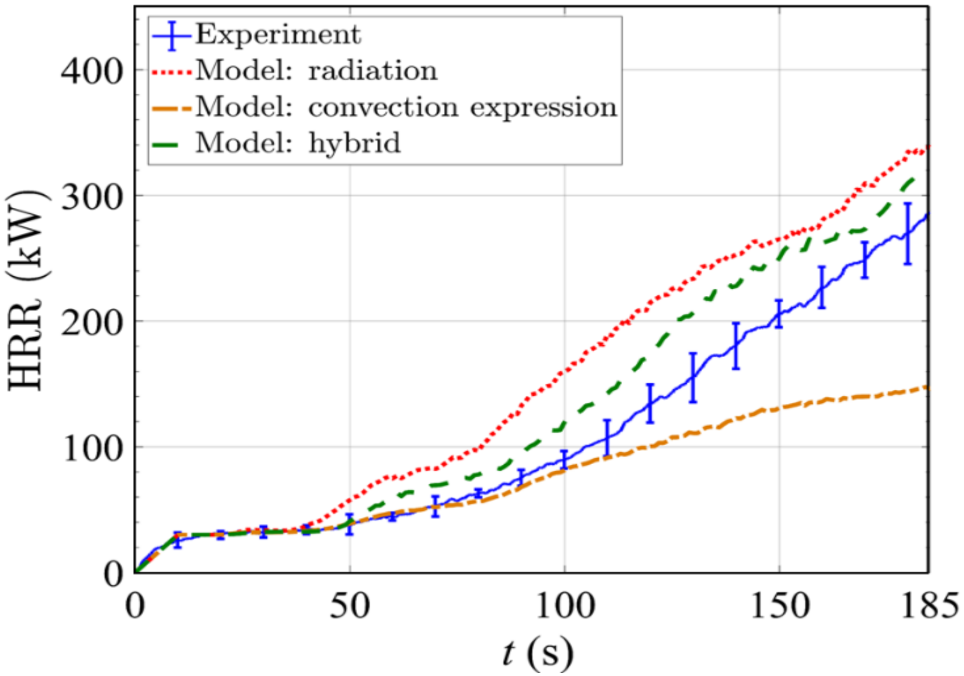
Front surface boundary conditions (two limiting cases):



Flame heat flux is radiative → $\dot{q}''_{net} = \varepsilon \dot{q}'' - \varepsilon\sigma\langle T_{solid}^4\rangle$ (averaged over absorption depth)

Flame heat flux is convective → $\dot{q}''_{net} = h\left(T_{flame} - T_{surf}\right) - \varepsilon\sigma\langle T_{solid}^4\rangle$ (averaged over absorption depth)

$$T_{flame}(t) = \frac{\dot{q}''}{h} + T_{gauge};\quad h = \frac{\dot{q}''_{\mathrm{MAX}}}{T_{flame}^{\mathrm{MAX}} - T_{gauge}}$$



For further details, see Poster 69 and https://doi.org/10.1016/j.polymdegradstab.2020.109433

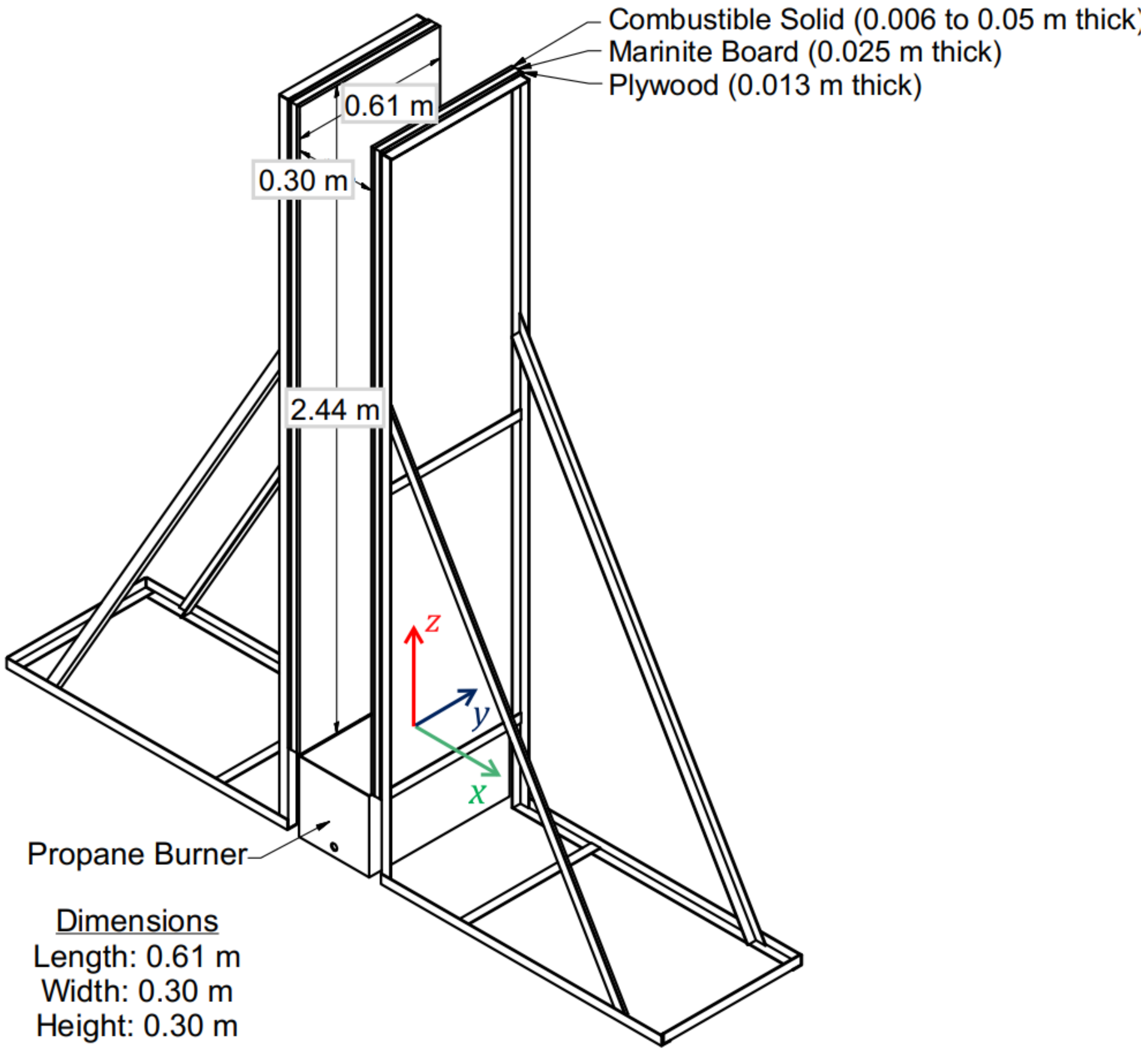
Future work: measurement of the radiative portion of flame heat flux

Parallel panel experimental setup

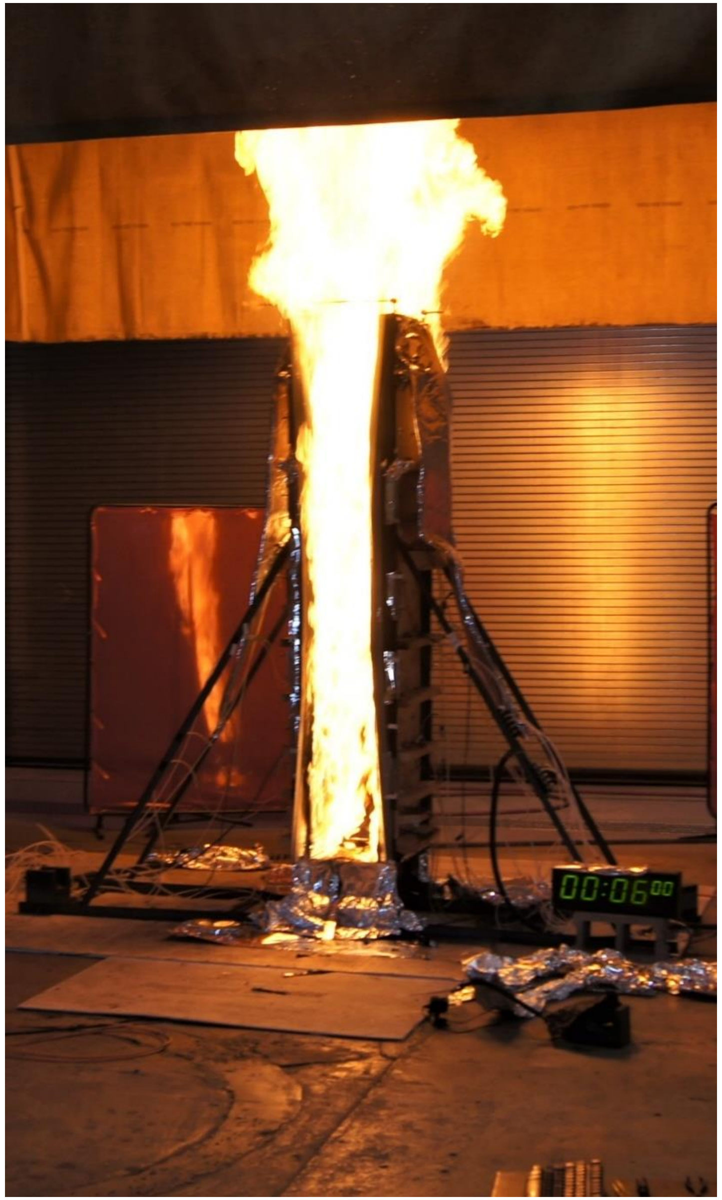
- Ignitability and flame spread
  - Sample size: 2.45 m tall, 0.6 m wide
  - Panel Separation: 0.3 m

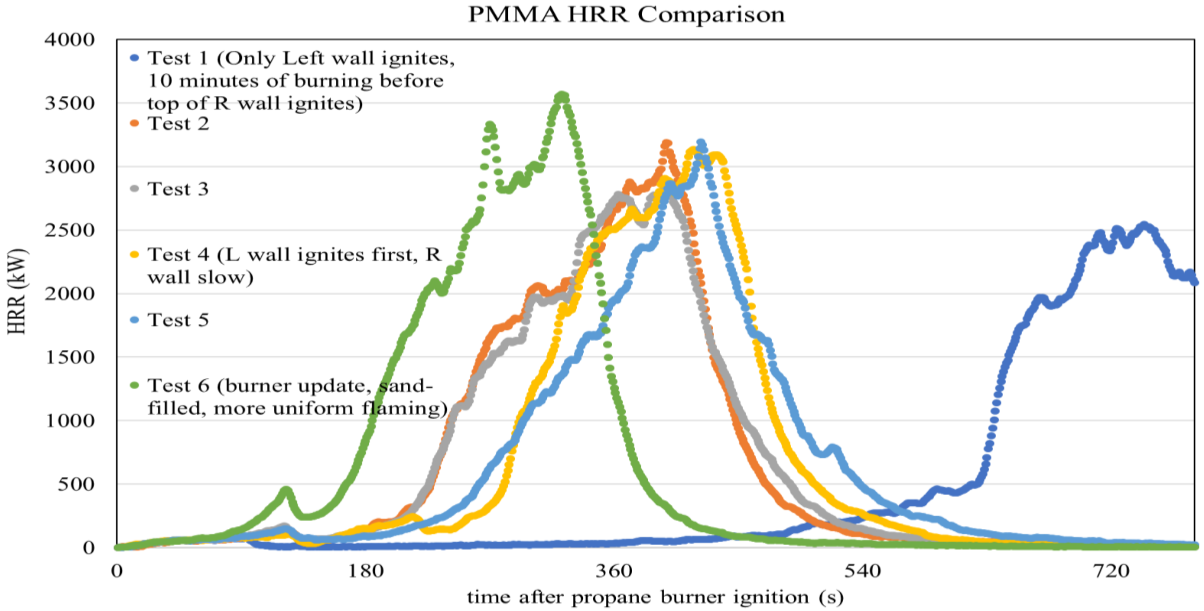
- Burner:
  - Fire Size: 60 kW
  - Dimensions: 0.6 m by 0.3m
  - Fill designed for uniform gas flow
    - Ceramic insulation blanket, 2.5 cm at top
    - Sand, 7.5 cm
    - Pea gravel, 20 cm base

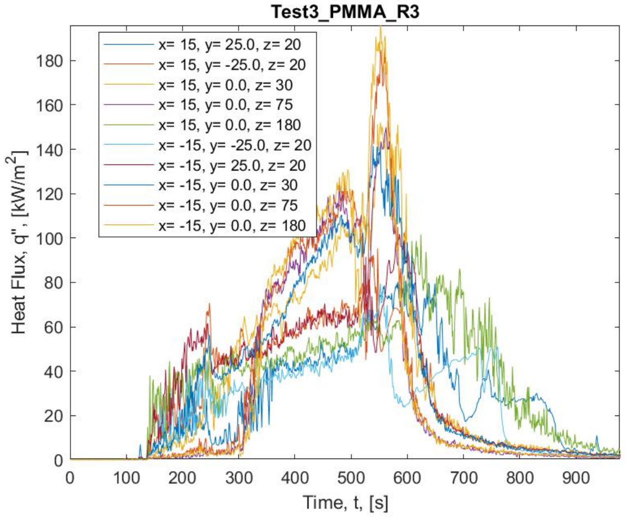
- Measurement Data
  - CO, CO_2, O_2, Soot and HRR
  - Flame to surface heat flux at 9 heights, 4 horizontal locations

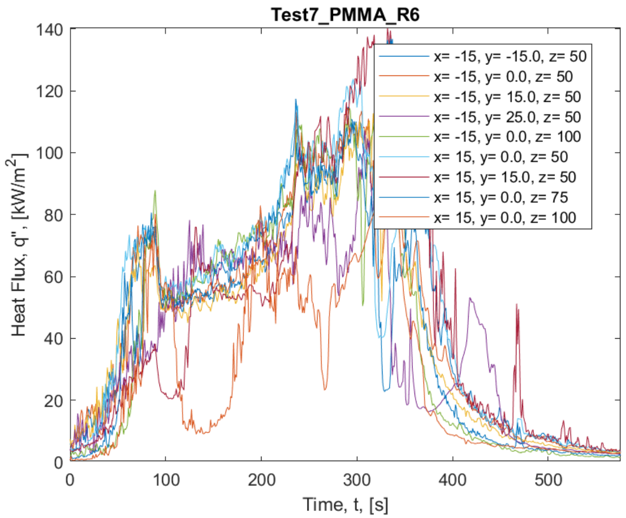


Results obtained thus far









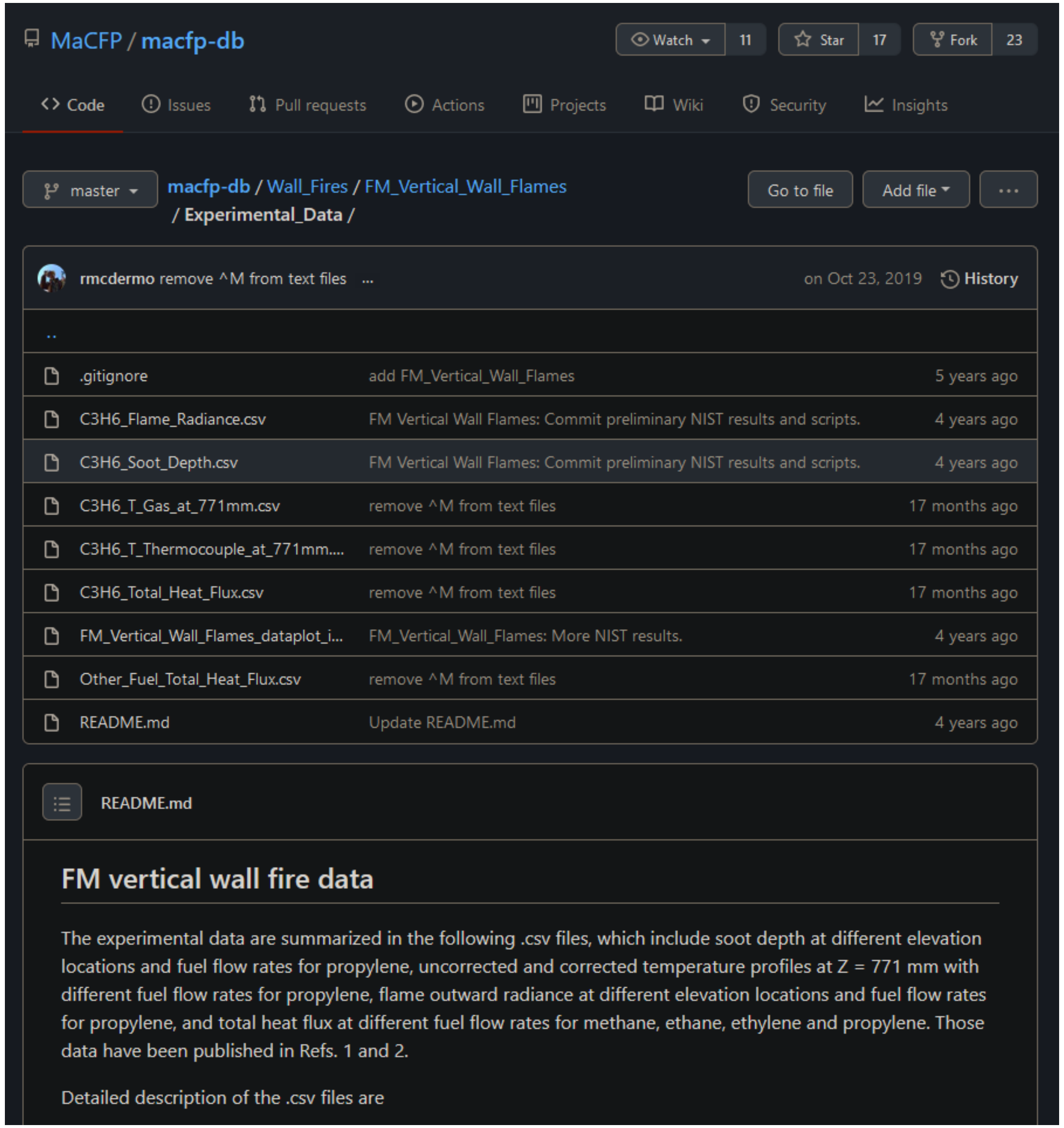
Measurements from the full-scale parallel panel experiments shown here were obtained by the National Institute of Standards and Technology (NIST), an agency of the US government, and are not subject to copyright in the USA. Not all of the measurement data presented here has been through a formal review process and it should therefore be considered as pre-decisional draft results.

National Institute of Standards and Technology
U.S. Department of Commerce

The Matl-db repository

- Processing /preparation for Github repository, Matl-db
    - Internal data review (NIST)
    - Evaluate ability to merge measurement data from unique tests

- Follow format of existing large-scale measurement data on macfp-db
    - README.md file
    - Global Measurements (time, HRR, Y_i)
    - Local Measurements (heat flux at location: x, y, z)



The Matl-db repository

- Example output file:
  - Global measurement quantities
  - Time-resolved data
  - Standard format
  - Quantified uncertainties

Time	HRR	Oxygen	CO2	CO	Ksmoke	Exhaust Mass Flow Rate
[s]	[kW]	[vol %]	[vol %]	[vol %]	[1/m]	[kg/s]
0	0.95	0.2094	0.0004	-9.00E-07	0	16.364
1	0.27	0.2094	0.0004	-9.00E-07	0	16.295
2	2.38	0.2094	0.0004	-1.40E-06	0	16.296
3	3.94	0.2094	0.0004	-1.20E-06	0	16.283
4	5.11	0.2094	0.0004	-1.00E-06	0	16.2
5	10.3	0.2094	0.0005	-8.00E-07	0	16.251
6	11.8	0.2094	0.0005	-5.00E-07	0	16.22
7	13.9	0.2094	0.0005	-6.00E-07	0	16.31
8	16.9	0.2094	0.0005	-7.00E-07	0	16.388
9	17.5	0.2094	0.0005	-8.00E-07	0	16.369
10	21.7	0.2094	0.0005	-9.00E-07	0	16.276
11	23.7	0.2093	0.0005	-5.00E-07	0.001	16.347
12	26.7	0.2093	0.0005	-7.00E-07	0.001	16.327
13	28.3	0.2093	0.0005	-1.00E-06	0	16.319
14	25.7	0.2093	0.0005	-1.00E-06	0.001	16.381
15	27.9	0.2093	0.0005	-1.20E-06	0.001	16.265
16	29.2	0.2093	0.0005	-7.00E-07	0.001	16.328
17	32.6	0.2093	0.0005	-9.00E-07	0.001	16.227
18	34.1	0.2093	0.0005	-8.00E-07	0.001	16.176
19	34.3	0.2093	0.0005	-6.00E-07	0.001	16.089
20	33.9	0.2093	0.0005	-7.00E-07	0.001	16.101
21	34.9	0.2093	0.0005	-8.00E-07	0.001	16.119
22	36.1	0.2093	0.0005	-7.00E-07	0.001	16.132
23	40.2	0.2093	0.0005	-5.00E-07	0.001	16.145
24	43.2	0.2093	0.0005	-5.00E-07	0.001	15.957
25	41.6	0.2093	0.0005	-4.00E-07	0.001	16.081
26	41.5	0.2093	0.0005	0	0.001	16.046
27	44.8	0.2093	0.0005	-2.00E-07	0.002	16.137
28	45.4	0.2093	0.0005	-6.00E-07	0.002	16.205
29	47.6	0.2093	0.0006	-4.00E-07	0.002	16.308
30	51	0.2092	0.0006	-8.00E-07	0.002	16.374