Aalto-yliopisto

Measuring fuel particle velocities in a pilot-scale circulating fluidized bed riser

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Outline

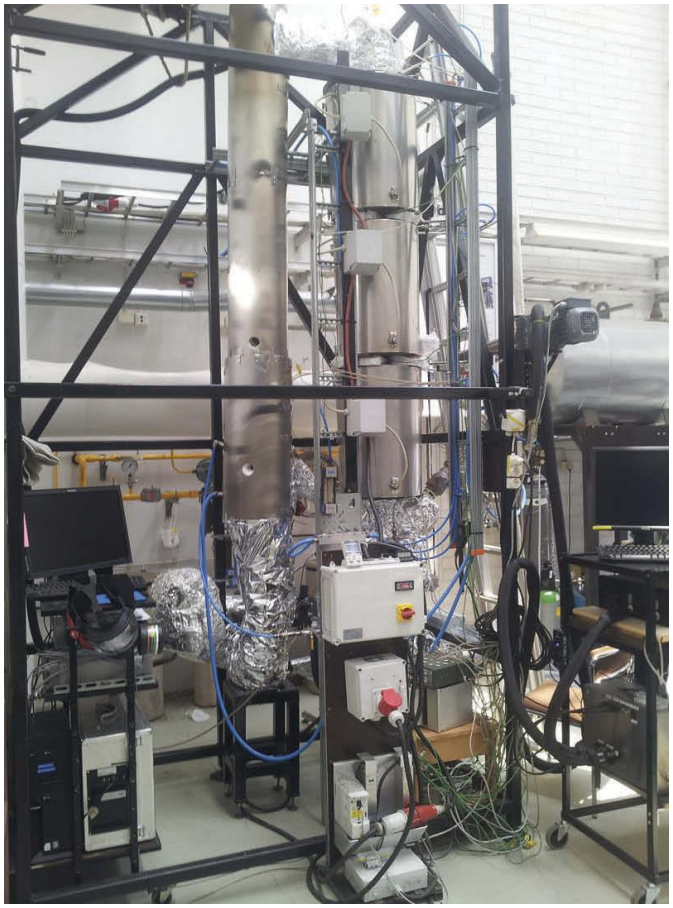
- Background and objective
- Equipment and experimental setup
- Method: image-based velocity measurement
  - Image processing
  - Forming Trajectories
- Results
- Conclusions and further research

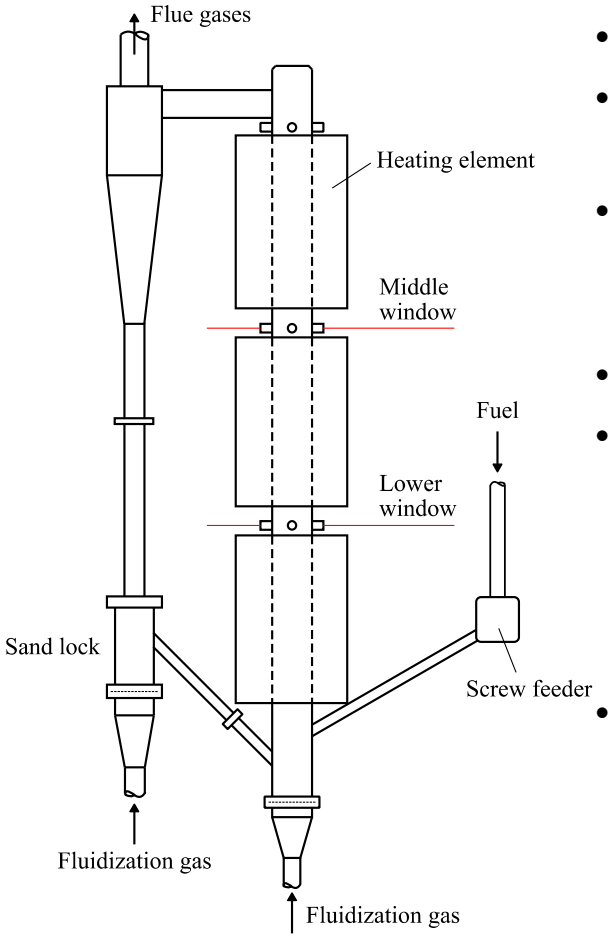
Background and objective

- CFBs extensively used in both industry and energy sector
- Complex multiphase flow
- Simulations/modeling ⇔ experimental methods/data
- Fuel particle movement affects performance
- Challenging conditions for direct optical measurement methods – still employed
- Interesting opportunity – hot conditions and thermal imaging!

- *“Develop a procedure, or set of algorithms, for measuring and calculating fuel particle displacements and velocities from thermographic recordings of combustion in a CFB riser.”*

Equipment: The CFB pilot





- Height 2.6 m
- Riser inner diameter 128 mm
- Temperature and pressure distributions
- Gas composition
- Inspection windows at three heights (diameter 21 mm)
- Supporting frame with movable mount for a camera

Equipment: Infrared Camera

- FLIR SC7600
- Mid-wavelength range (1.5 – 5.5 µm)
- Flame filter (3.97 – 4.01 µm)
- 50mm lens + 10mm extension tube

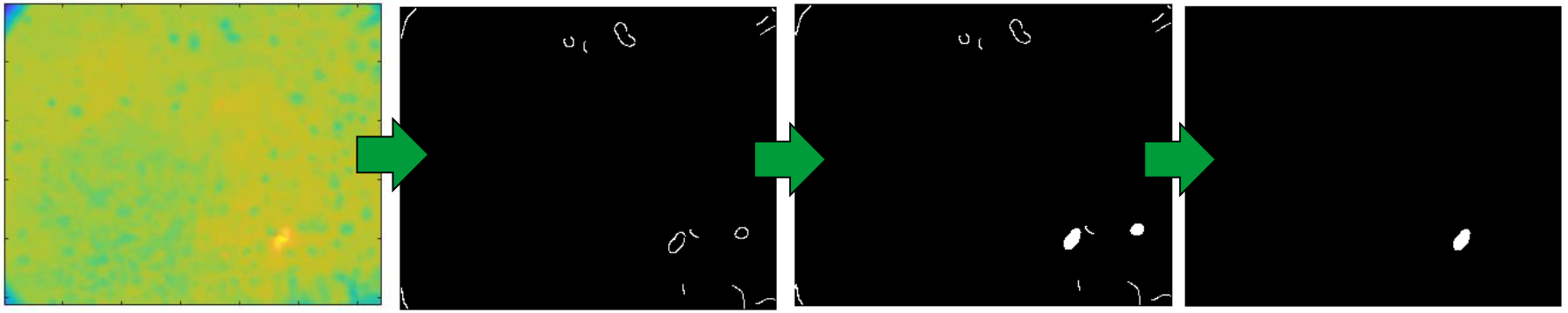
- Full resolution: 640x512 @ 100 Hz
- Sub-windowing: 320x256 @ 320 Hz
  160x128 @ 870 Hz

- File format compatible with Matlab

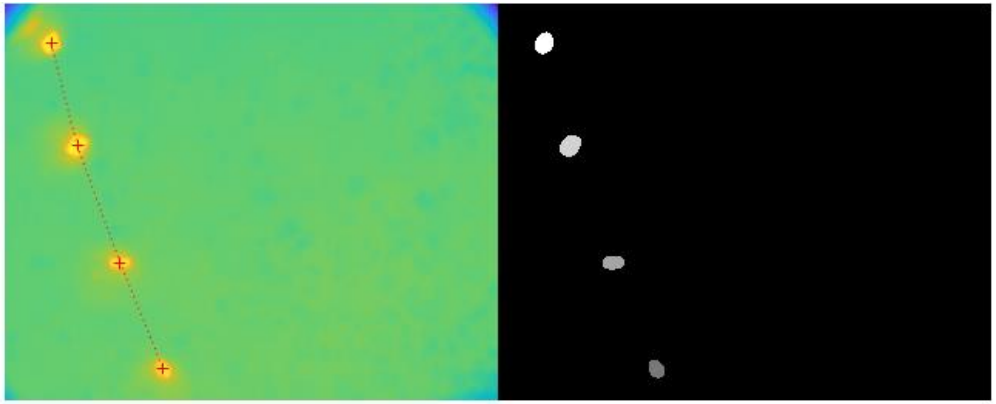
Experimental setup: Combustion

- Coal and peat fed separately over the span of 15 minutes
- Superficial gas velocity ~1.5 m/s
- Recorded at lower window (1.1 m above distributor plate)
- 128 recordings, automatically triggered (320 Hz, 1300 frames each)
- 10 processed recordings (spread throughout the test)

Calculating velocities: Main strategy



Identifying and segmenting fuel particles



Forming trajectories and calculating velocities

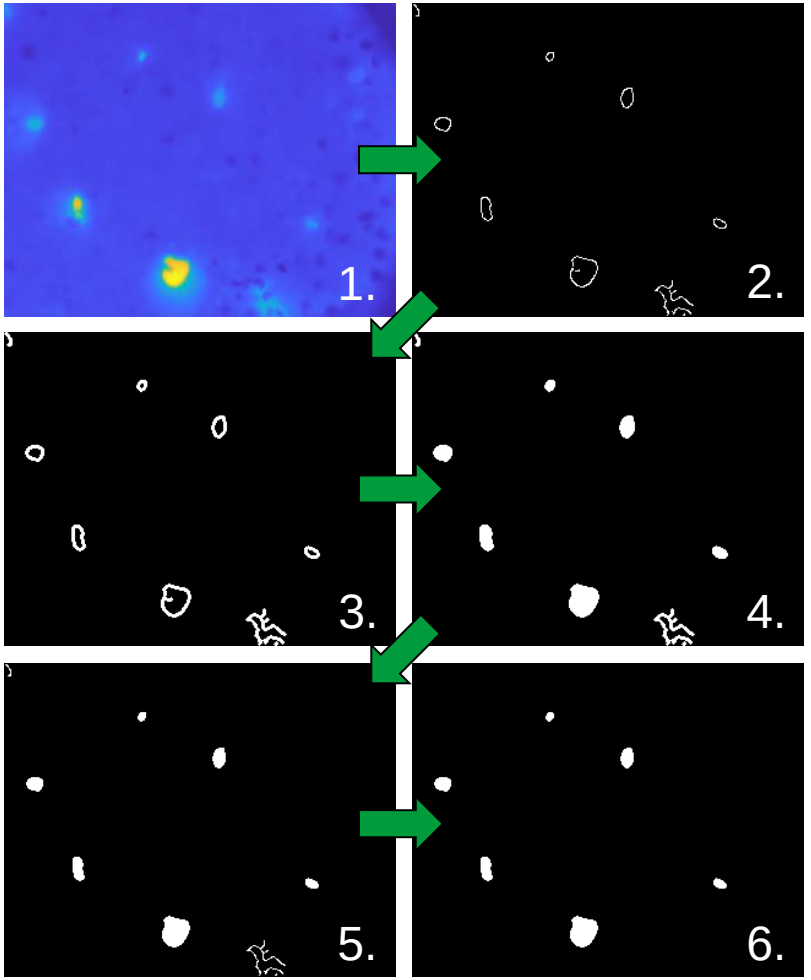
Calculating velocities: Segmentation

Some challenges

- Sand particles obstructing the view
- Different intensities (temperature)
- Non-uniform shape and size

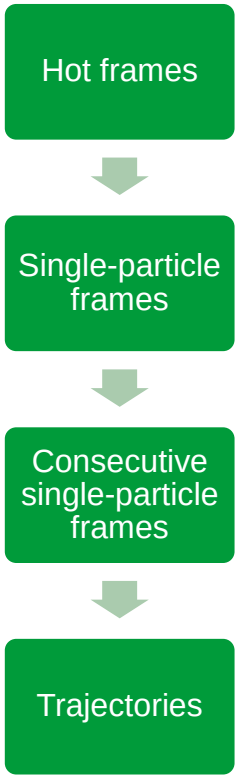
Approach

- Combination of edge-detection & intensity thresholding
- Edges are formed based on intensity gradient magnitudes, directions and connectivity
- Closed loops are filled and compared to a chosen temperature threshold
- Centroid mean of x- and y-coordinates

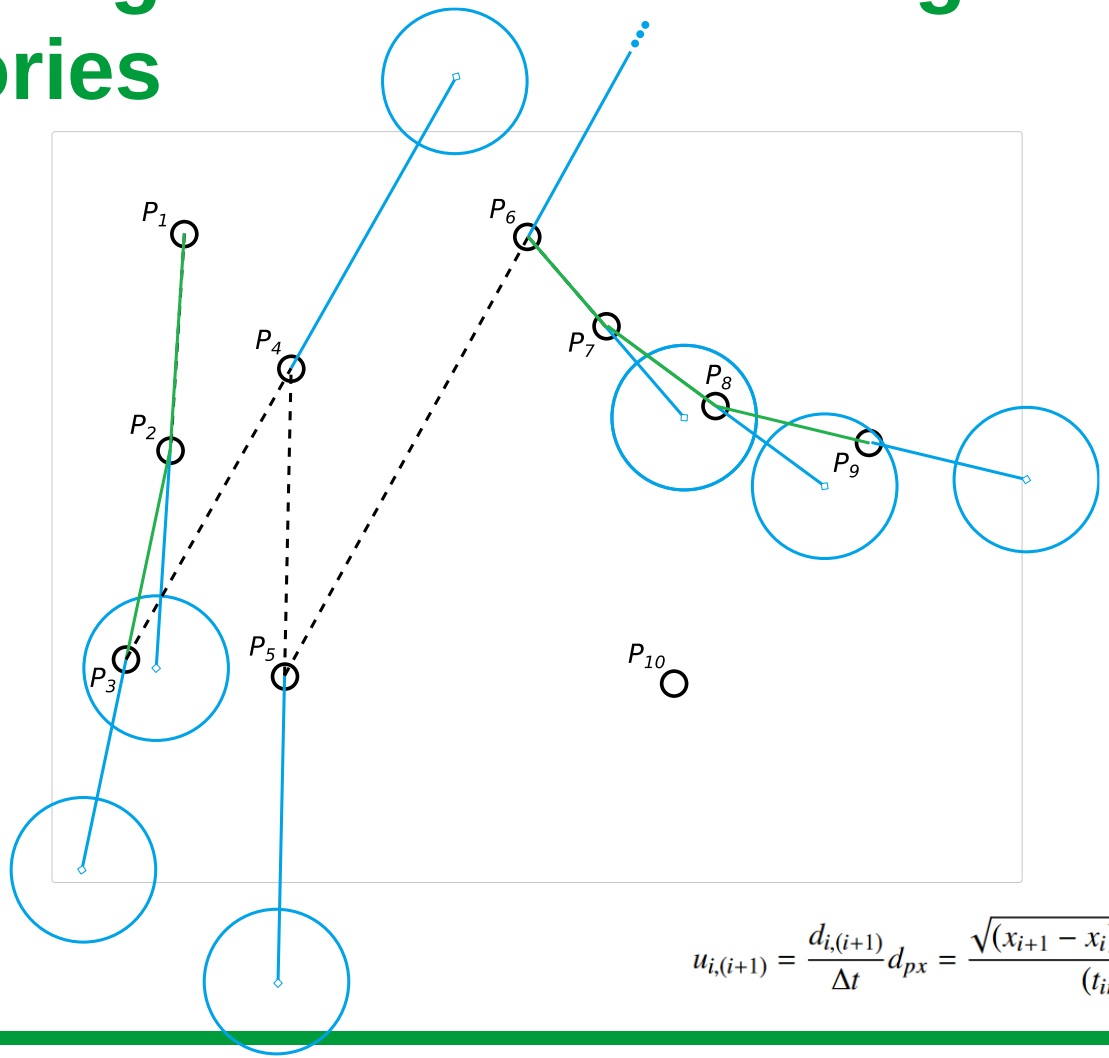


Calculating velocities: Forming trajectories

- Simplified approach (often large displacement compared to interparticle distances)
- Single-particle frames, grouped into sets of consecutives
- Searching for smooth trajectories within these sets
- Assuming somewhat *constant* velocity
- A trajectory can be valid only if a particle is apparent on three or more consecutive frames



Calculating velocities: Forming trajectories



$$u_{i,(i+1)} = \frac{d_{i,(i+1)}}{\Delta t} d_{px} = \frac{\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}}{(t_{int} + t_s)} d_{px}$$

Results: Segmentation

Table 7: Results of segmenting recordings 1-10

Rec_i	Hot frames	Segmented particles	Single-particle frames	Consecutives	Trajectories
1	105	101	82	32	8
2	299	338	179	92	19
3	512	755	269	125	24
4	981	1985	353	168	28
5	667	942	402	234	47
6	356	423	249	177	40
7	153	175	115	62	12
8	214	241	171	114	24
9	341	350	262	182	39
10	78	72	58	33	8

Results: Examples

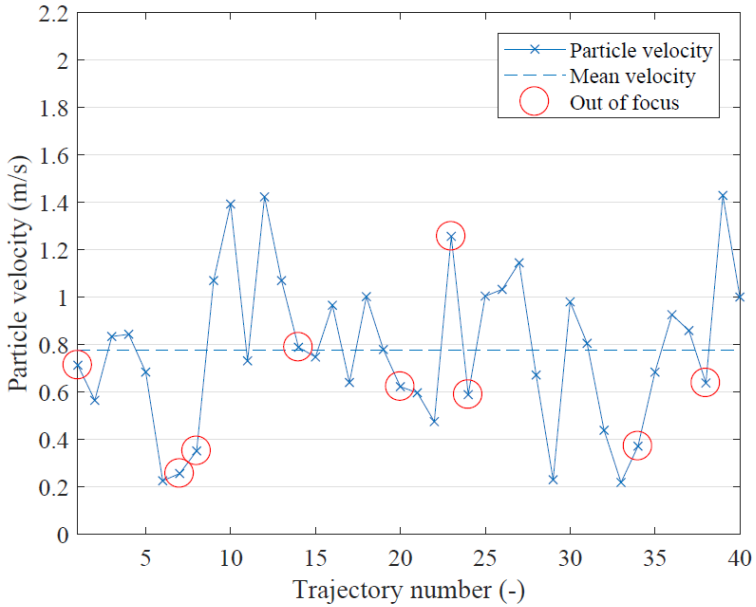


Figure 27: Velocities for the particle trajectories in Rec_6, U_0 = 1.52 m/s

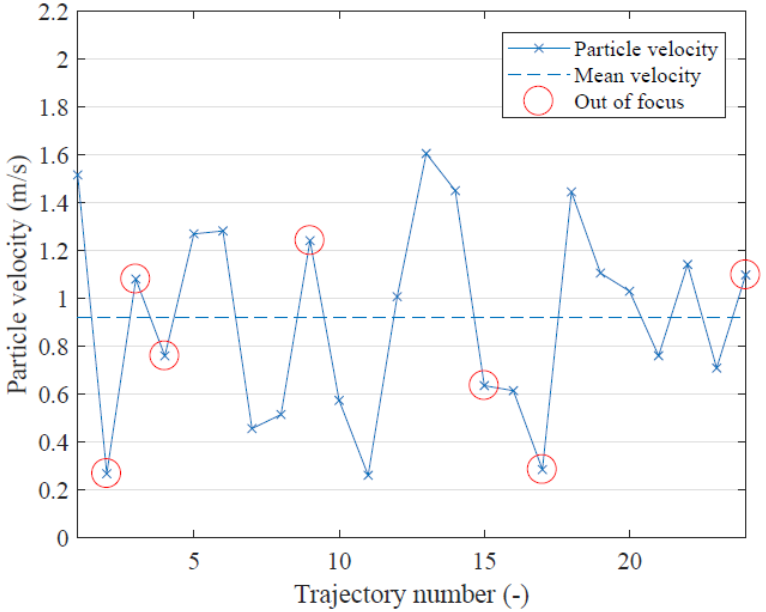


Figure 29: Velocities for the particle trajectories in Rec_8, U_0 = 1.53 m/s

Results: Examples

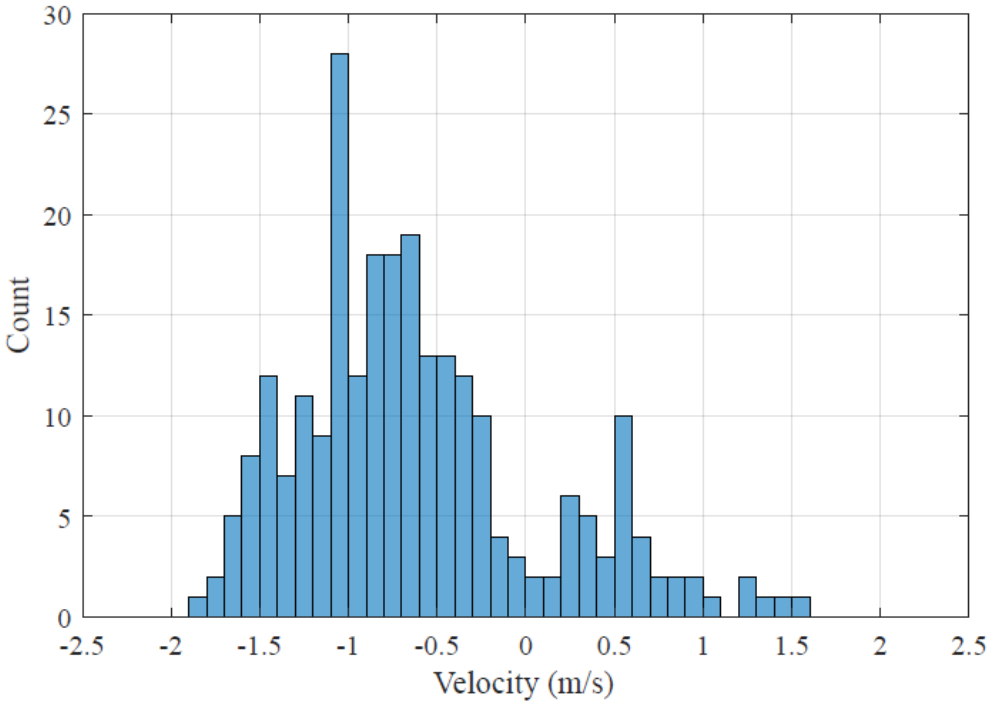
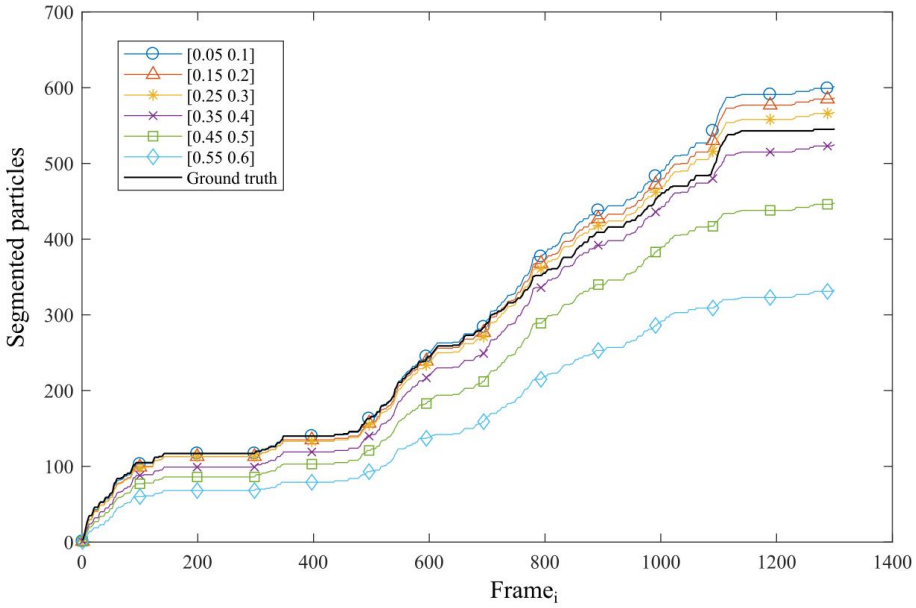


Figure 33: Velocity histogram for recordings 1-10. Negative values represent downwards moving particles.

Sources of uncertainty

- Calibration errors
- Incorrect segmentation
  - Particle focus
  - Particle mask ≠ fuel particle shape
  - Including wrong particles into calculation (e.g., cold sand particles in front of the hot glow of a fuel particle)
- z-axis motion



Conclusions and further research

- Objectives met with some simplifications
- Fuel particles could be identified and segmented, and centroids calculated
- For single-particle frames, trajectories were formed and used to compute particle velocities

Further research

- Intrusive tests (tubes/borescope)
- Further development of the segmentation procedure (and/or tracking)
  - Particle temperatures and temperature distributions (calibration!)
  - Size and/or shape distribution
  - Other information

Thank you!

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