AN OVERVIEW OF EXPERIMENTAL MEASUREMENTS IN A GENERIC CAN-TYPE GAS TURBINE COMBUSTOR

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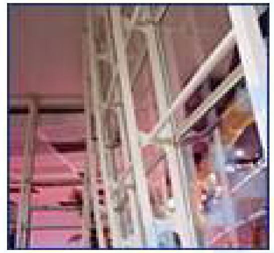
OVERVIEW

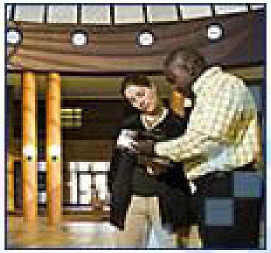
- INTRODUCTION
- EXPERIMENTAL SETUP
- EXPERIMENTAL PROCEDURE
- EXPERIMENTAL RESULTS
- CONCLUSION
- ACKNOWLEDGEMENTS

INTRODUCTION

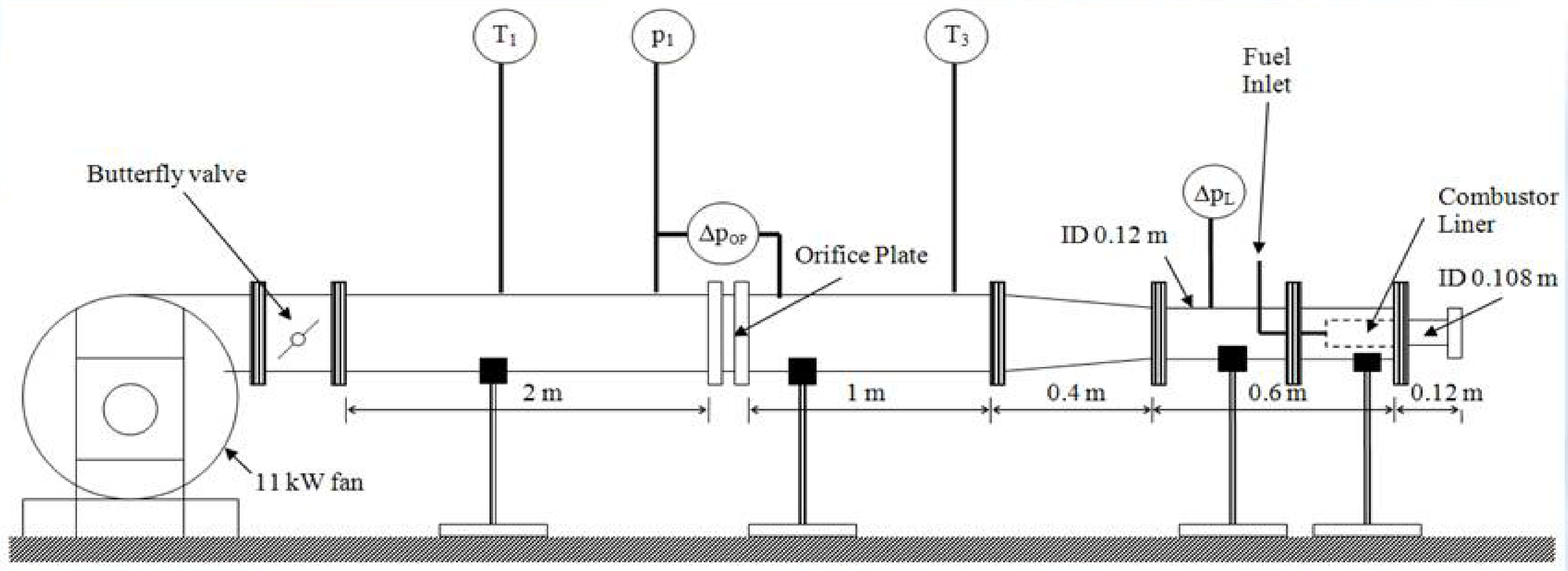


- The purpose of the study was to:
  - Create a combustor test case →comparison to computational fluid dynamics (CFD).
  - The Particle Image Velocimetry (PIV) results → non-reacting isothermal runs to test the applicability/validity of the turbulence models used.
  - Thermocouple measurements at outlet plane → combustion run comparisons
  - The combustor measured has all the features found in a gas turbine combustor i.e. swirler, primary holes, secondary holes, dilution holes, cooling rings

EXPERIMENTAL SETUP



- Test rig components:
  - 11 kW fan
  - Orifice plate with D and D/2 Pressure tapings
  - Can-type combustor liner
  - Exhaust to atmosphere

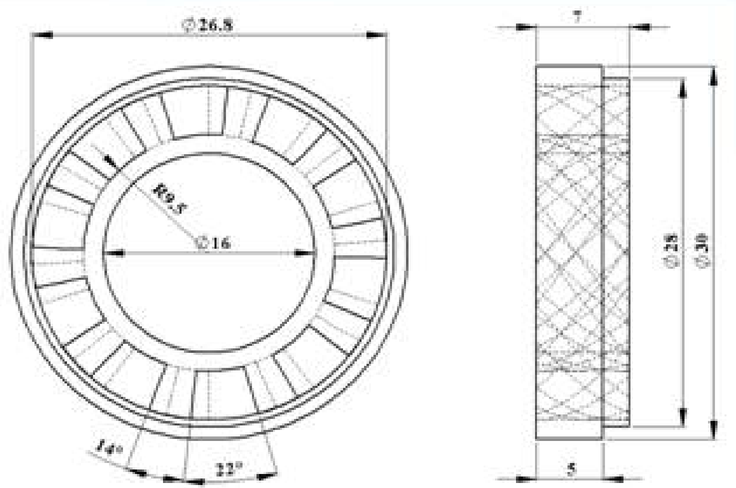


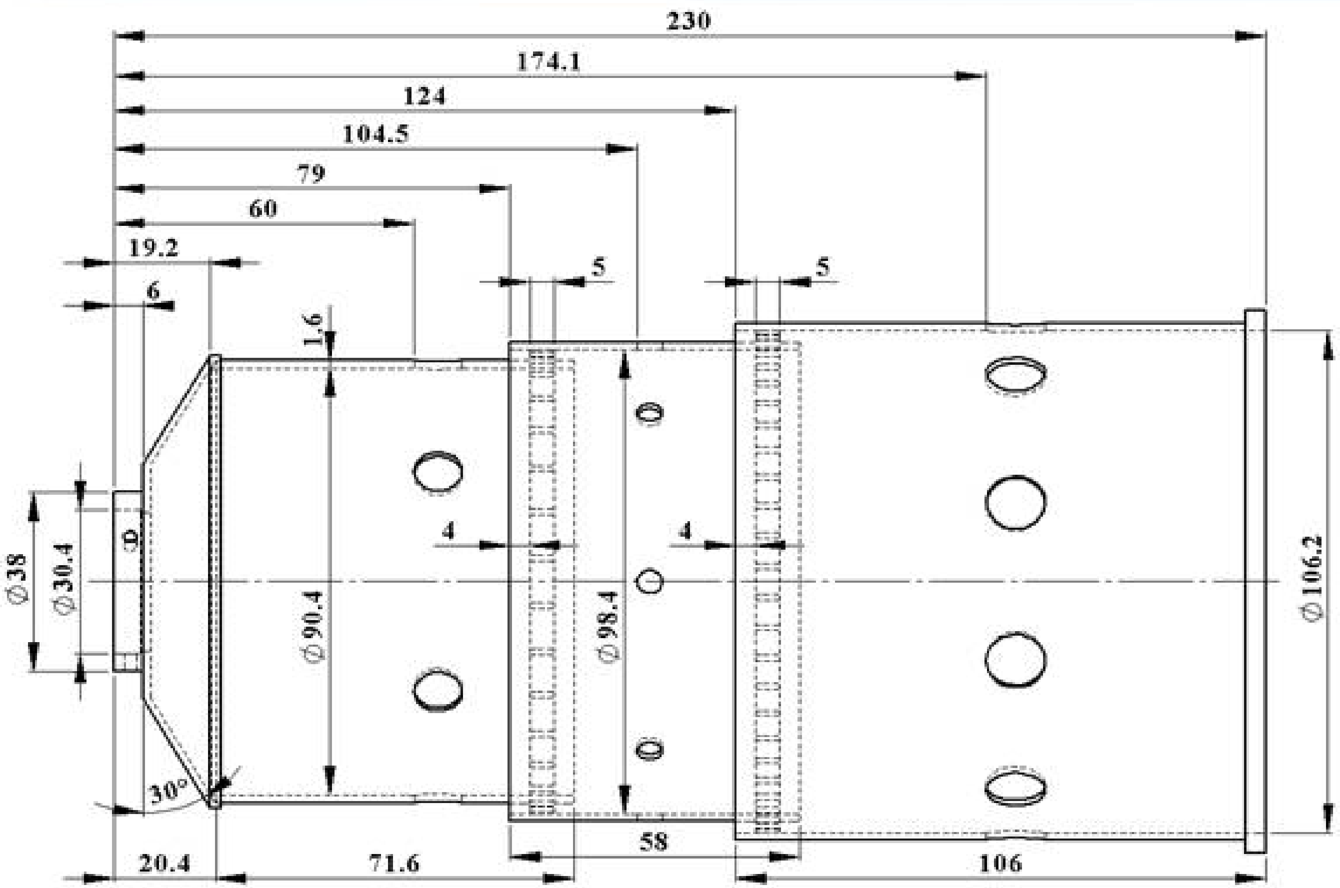
EXPERIMENTAL SETUP

- Combustor liner:
  - Replica of reacting test combustor
  - Material: Perspex
  - 230 mm long
  - Primary holes: 6 x Φ 9,5 mm
  - Secondary holes: 8 x Φ 5 mm
  - Dilution holes: 10 x Φ 11.8 mm
  - Nominal diameter of 98,4 mm
  - Primary cooling ring holes: 30 x 1,2 mm
  - Secondary cooling ring holes: 50 x 1,2 mm

EXPERIMENTAL SETUP

- Swirler
  - Annular swirler
  - Surrounds injector nozzle
  - 10 x flat vanes at 50° to inlet plane
  - 7mm deep
- Casing
  - Φ 121,2 mm





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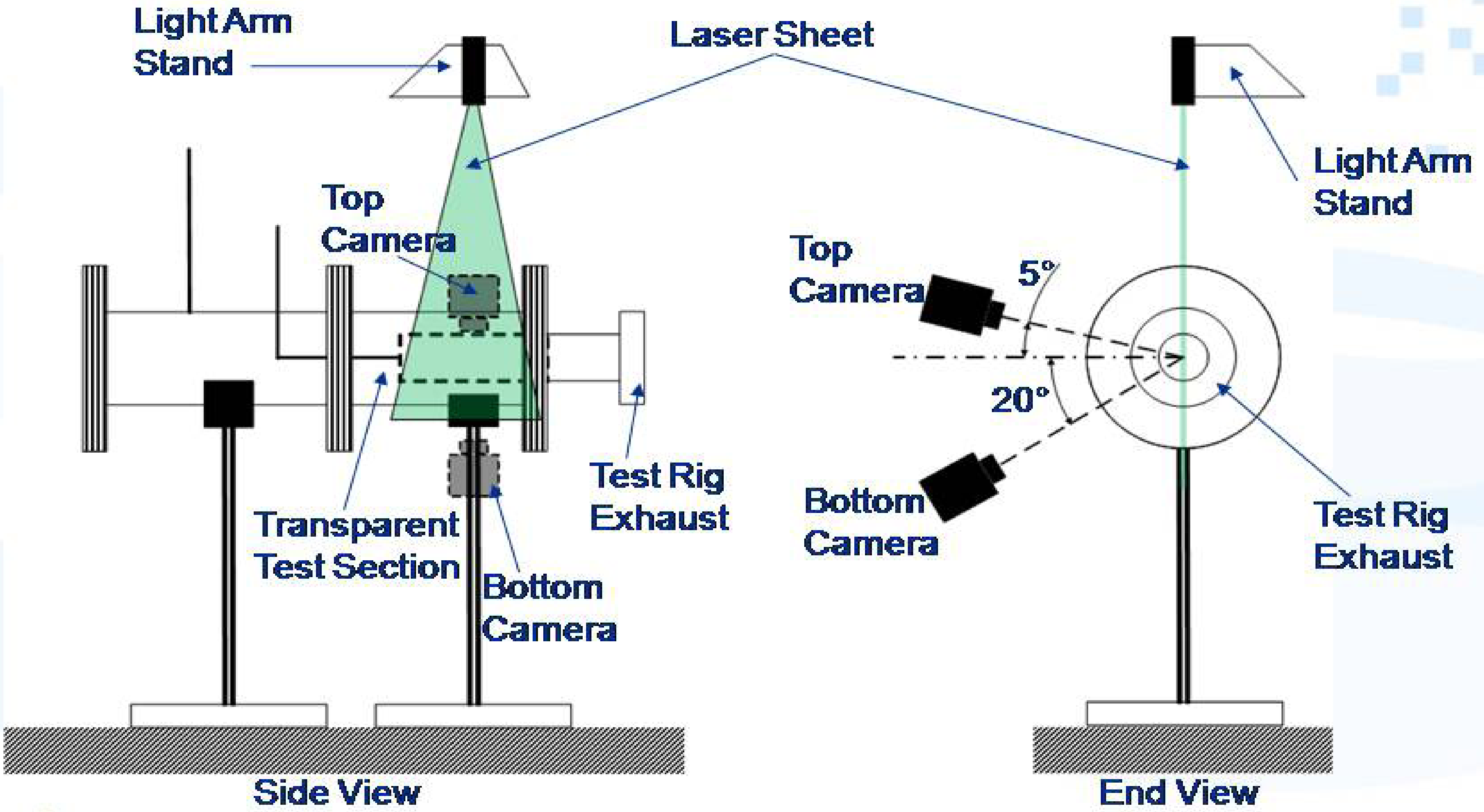
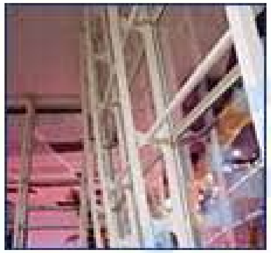
EXPERIMENTAL SETUP: THERMAL TESTS

- Outlet temperature plane → 5 thermocouple rake
- Outlet velocity profile → Pitot Tube

  → With & Without Combustion

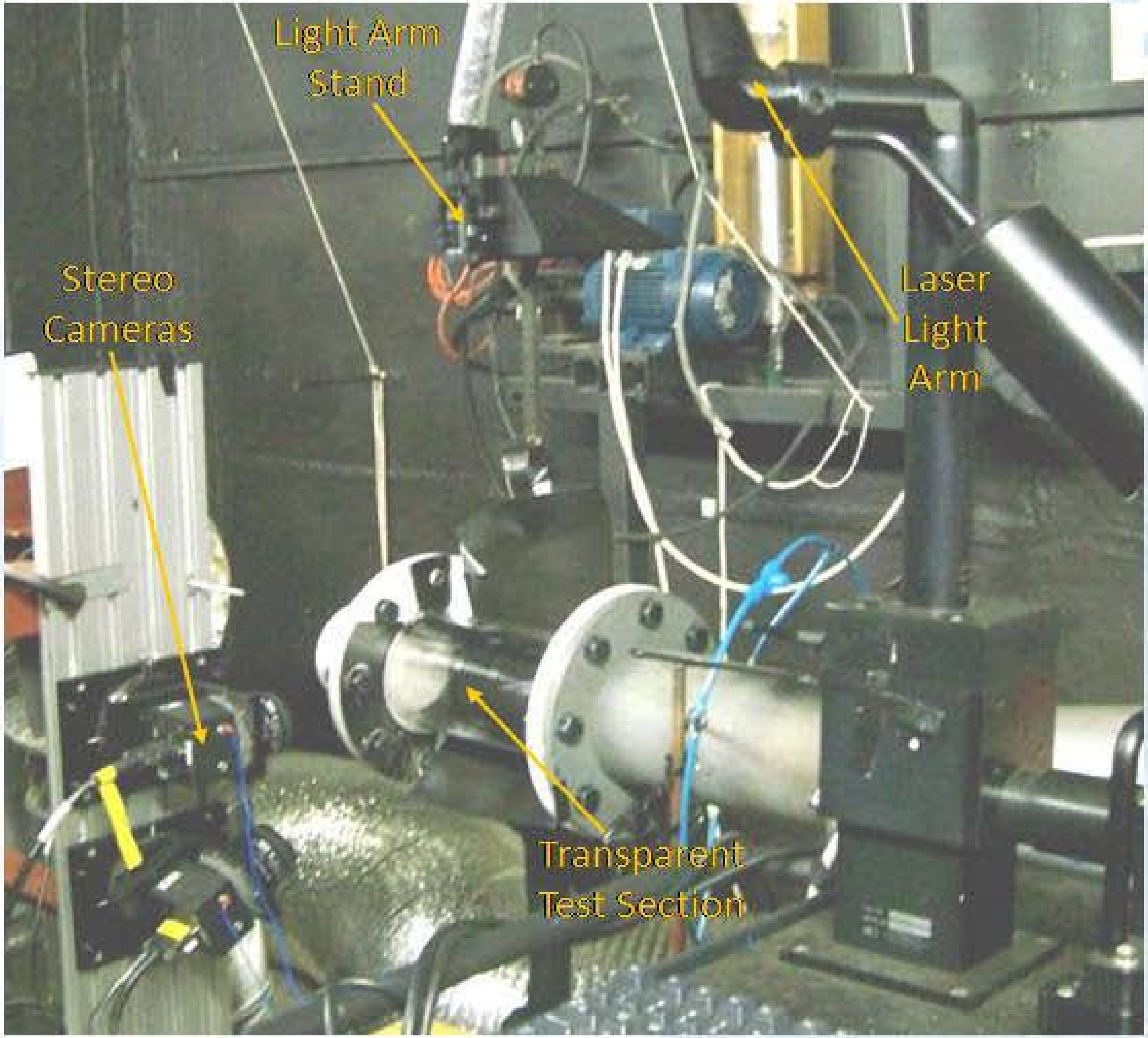
EXPERIMENTAL SETUP: PIV

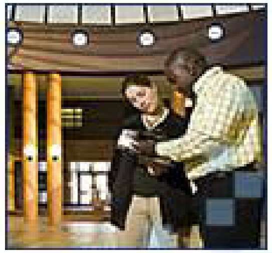




EXPERIMENTAL SETUP: PIV

- PIV system:
  - Dual laser heads
  - Q-switched
  - The laser sheet is in the axial plane entering from above
  - Laser light λ = 532 nm
  - Laser sheet thickness = 1 to 1,5 mm
  - 2 x 4MP CCD cameras
  - Seeding = Smoke from burning oil





EXPERIMENTAL PROCEDURE: THERMAL TESTS

- Air mass flow rate = 0,091 kg/s (372,6 kg/h)
- Thermal Characteristics:
  - Rotate thermocouple rake 360°
  - Measure every 10°
  - Normalized Temperature = $\frac{T_{4i} - \overline{T_3}}{\overline{T_{AFT}} - \overline{T_3}}$
  - Pattern factor = $\frac{T_{4max} - \overline{T_4}}{\overline{T_4} - \overline{T_3}}$
  - Profile Factor = $\frac{T_{4mr} - \overline{T_4}}{\overline{T_4} - \overline{T_3}}$
- Pressure characteristics:
  - Pressure loss factor = P_{34}/q_3
  - Overall Pressure loss = P_{34}/P_3 x 100
- Velocity Profile:
  - Measure outlet velocity profile with pitot tube at 5mm intervals across diameter of outlet

EXPERIMENTAL PROCEDURE: PIV

- Base case Air mass flow rate = 0,056 kg/s (201,6 kg/h)
- ΔT between Laser Pulses:
  - Primary zone = 15 µs
  - Secondary zone = 5 µs
  - Dilution zone = 5 µs
- Swirl Number = $Sn = \dfrac{2\int_{\frac{-D_{cs}}{2}}^{\frac{D_{cs}}{2}} |UWr^2|\, dr}{D_{cs}\int_{\frac{-D_{cs}}{2}}^{\frac{D_{cs}}{2}} |U^2 r|\, dr}$
- Runs performed in line with the holes and in between the holes of the respective sections.

EXPERIMENTAL PROCEDURE : PIV

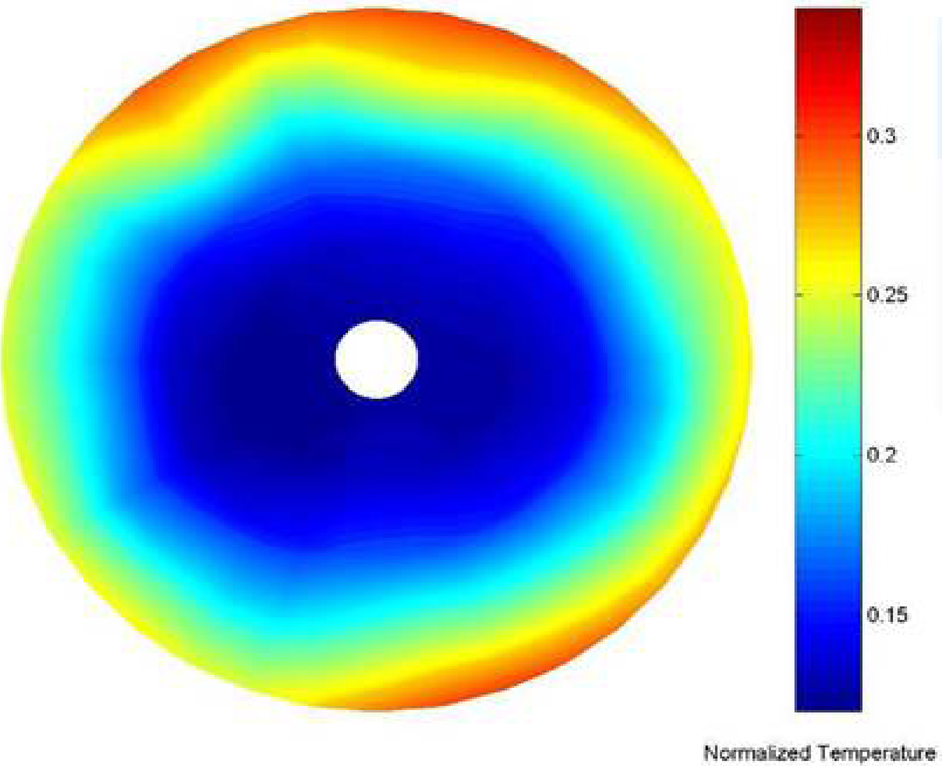
- Increase flow rate

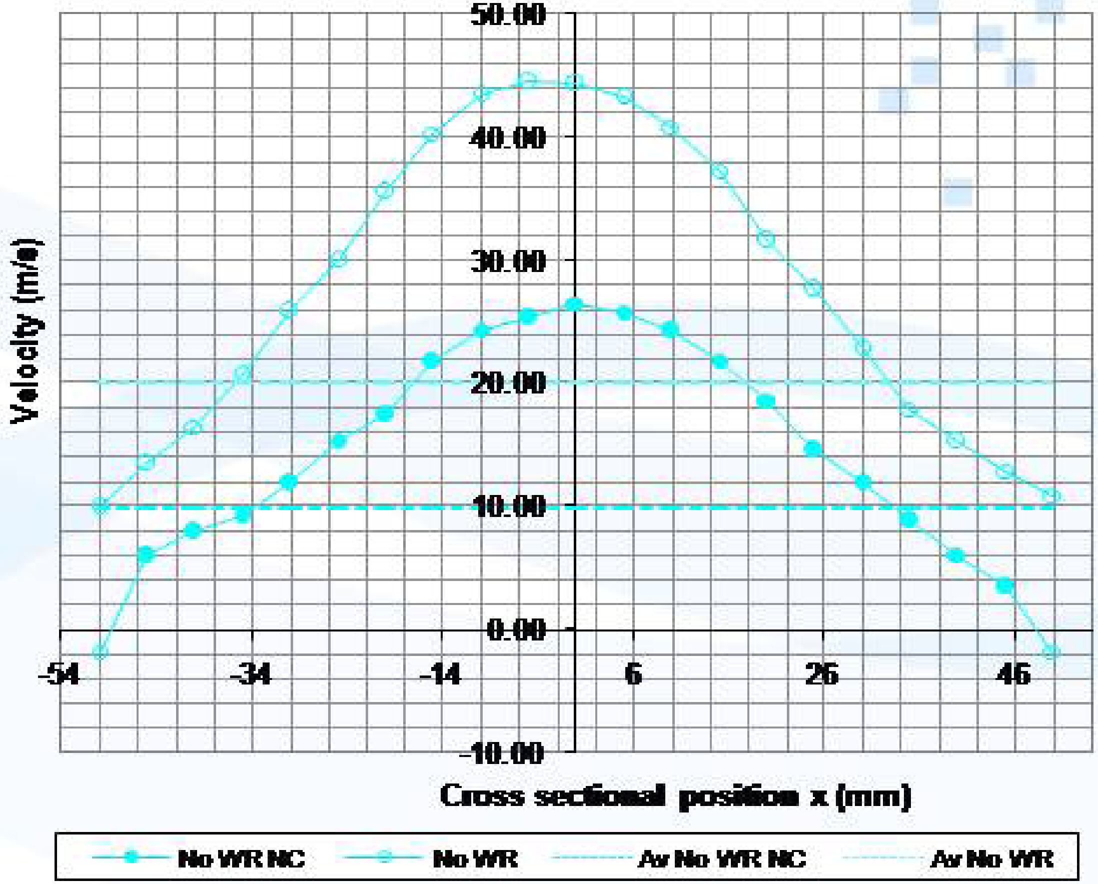
Pressure drop over orifice plate	Corresponding air mass flow rate	
[Pa]	[kg/s]	[kg/h]
1000	0.056	201.6
1100	0.059	212.4
1300	0.064	230.4
1600	0.070	252.0
2000	0.078	280.8
2600	0.091	327.6

- Temporal indication
  - Compare consecutive frames

EXPERIMENTAL RESULTS: THERMAL TESTS

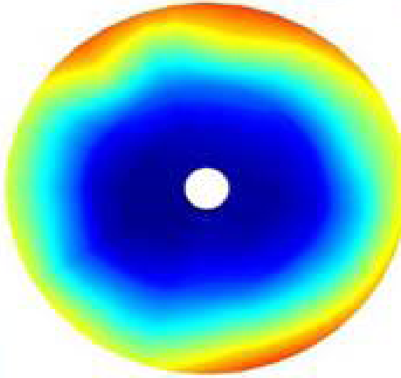
- T_{max}= 817 K
- T_{min}= 501 K
- Pattern factor = 0.70
- Profile factor = 0.54
- Overall pressure loss = 3.51%
- Pressure loss factor = 100.74

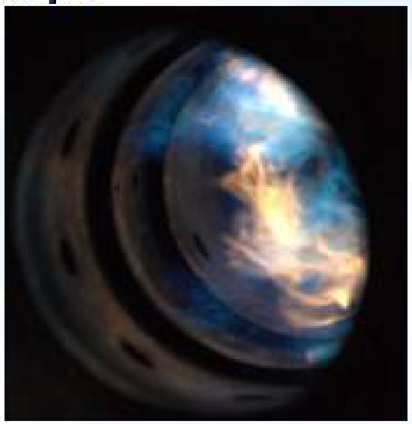


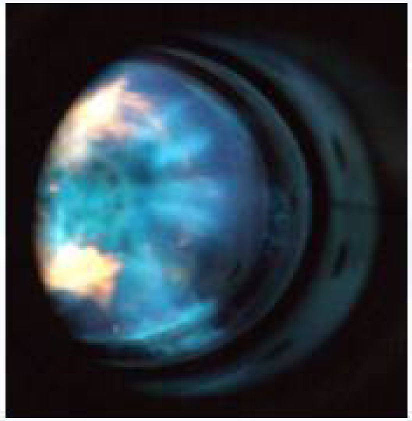


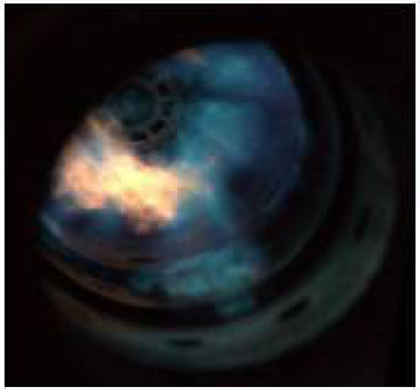
EXPERIMENTAL RESULTS: THERMAL TESTS

- Blue flames → Close to stochiometric
  → Stationary
- Orange flames → Off stochiometric
  → Likely rich
  → Contantly Moving and changing shape
- 135° to 225° no flame visible
- Top & bottom flame tongues present till secondary cooling ring
- Right flame tongue present till primary cooling ring

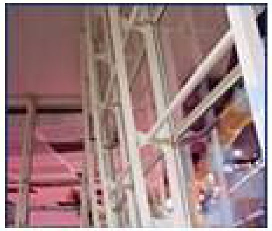


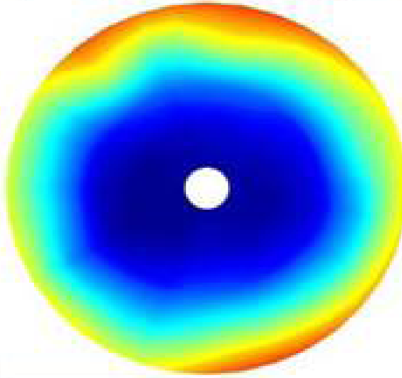






EXPERIMENTAL RESULTS: THERMAL TESTS



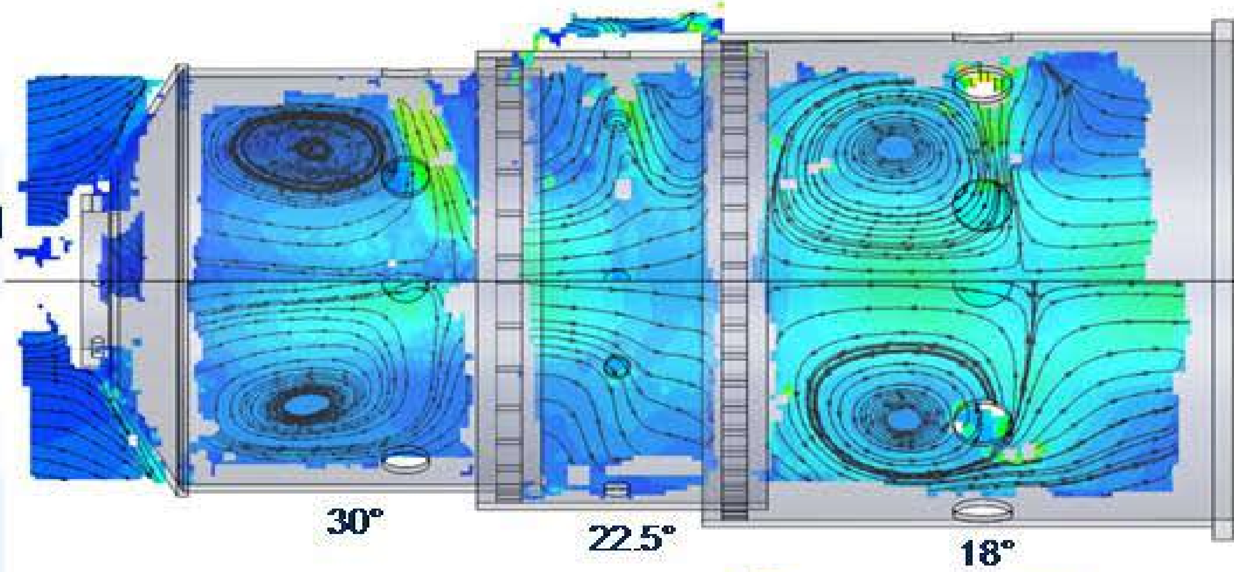


- Dome: Uneven carbon pattern → indicates skewed combustion already in the primary zone
- Bottom, top and right: Burned away carbon → corresponds to flame tongues
- Left: carbon is not present but it is not known why.

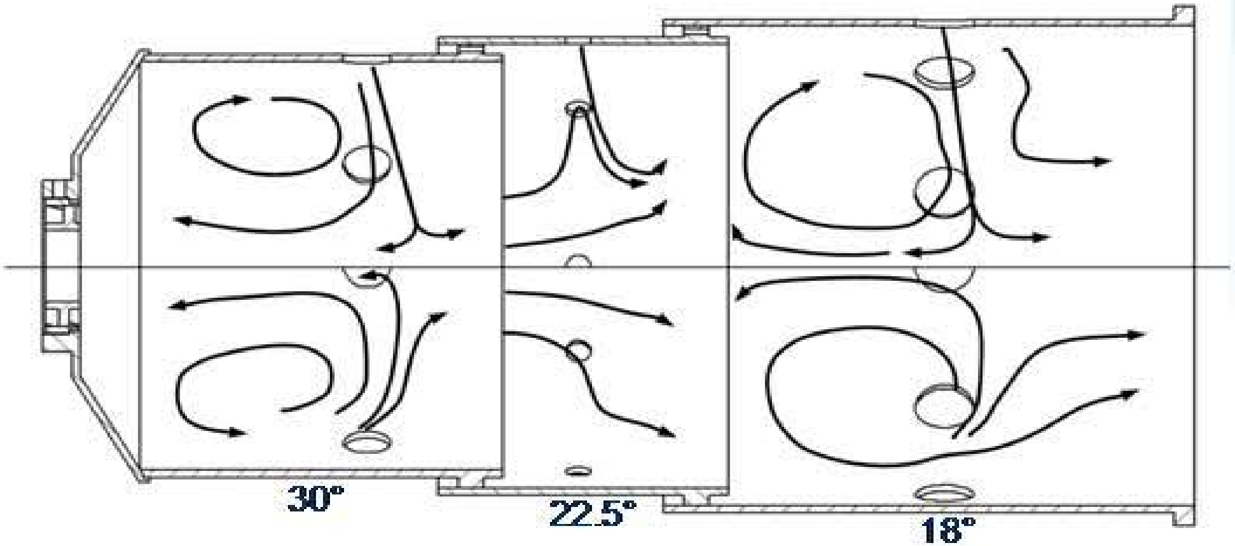
  Perhaps → just the correct temperature and air combination → A non-visible flame present

EXPERIMENTAL RESULTS: PIV BASE CASE

- Velocity Magnitude contours with streamlines superimposed
- Top = in line with the holes
- Bottom = In between the holes

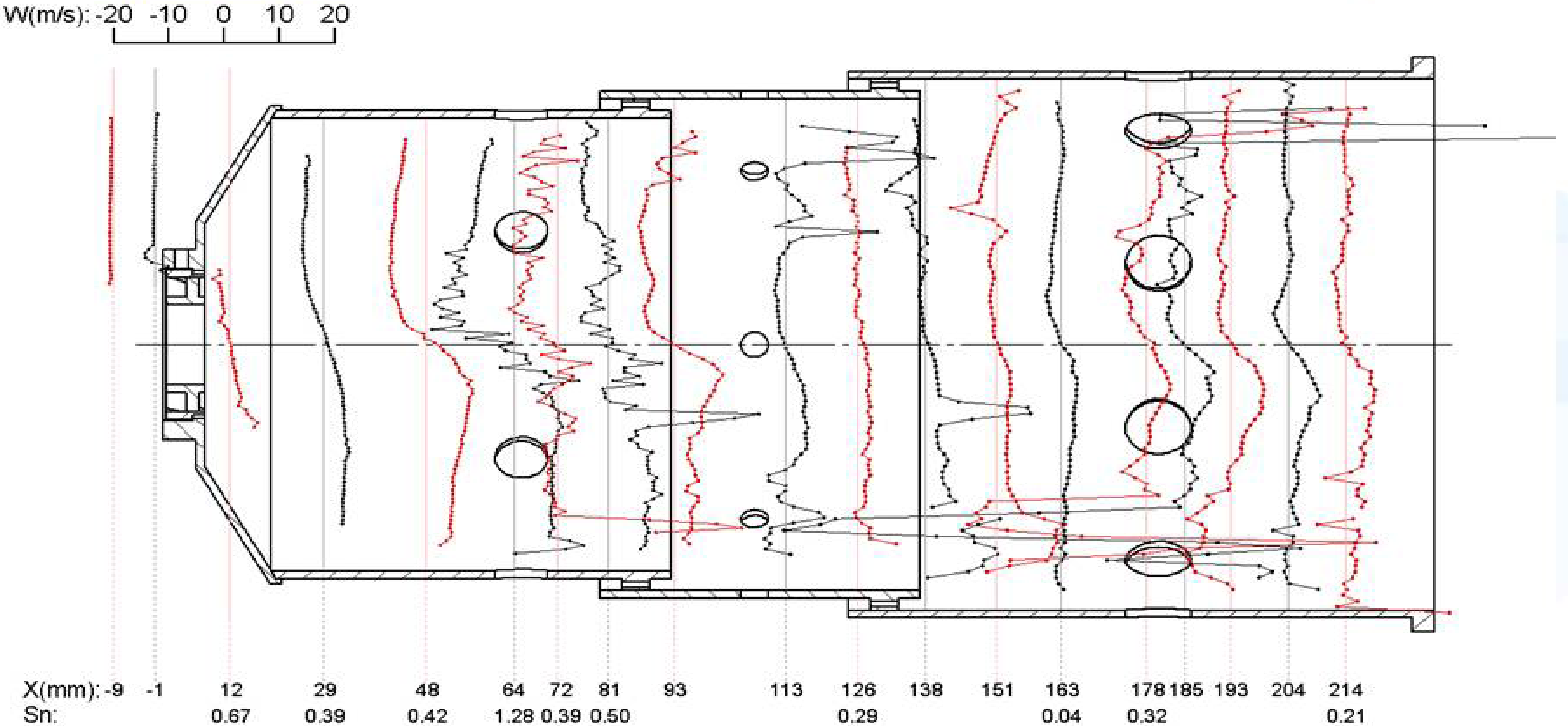


- Major feature streamline paths shown for comparison



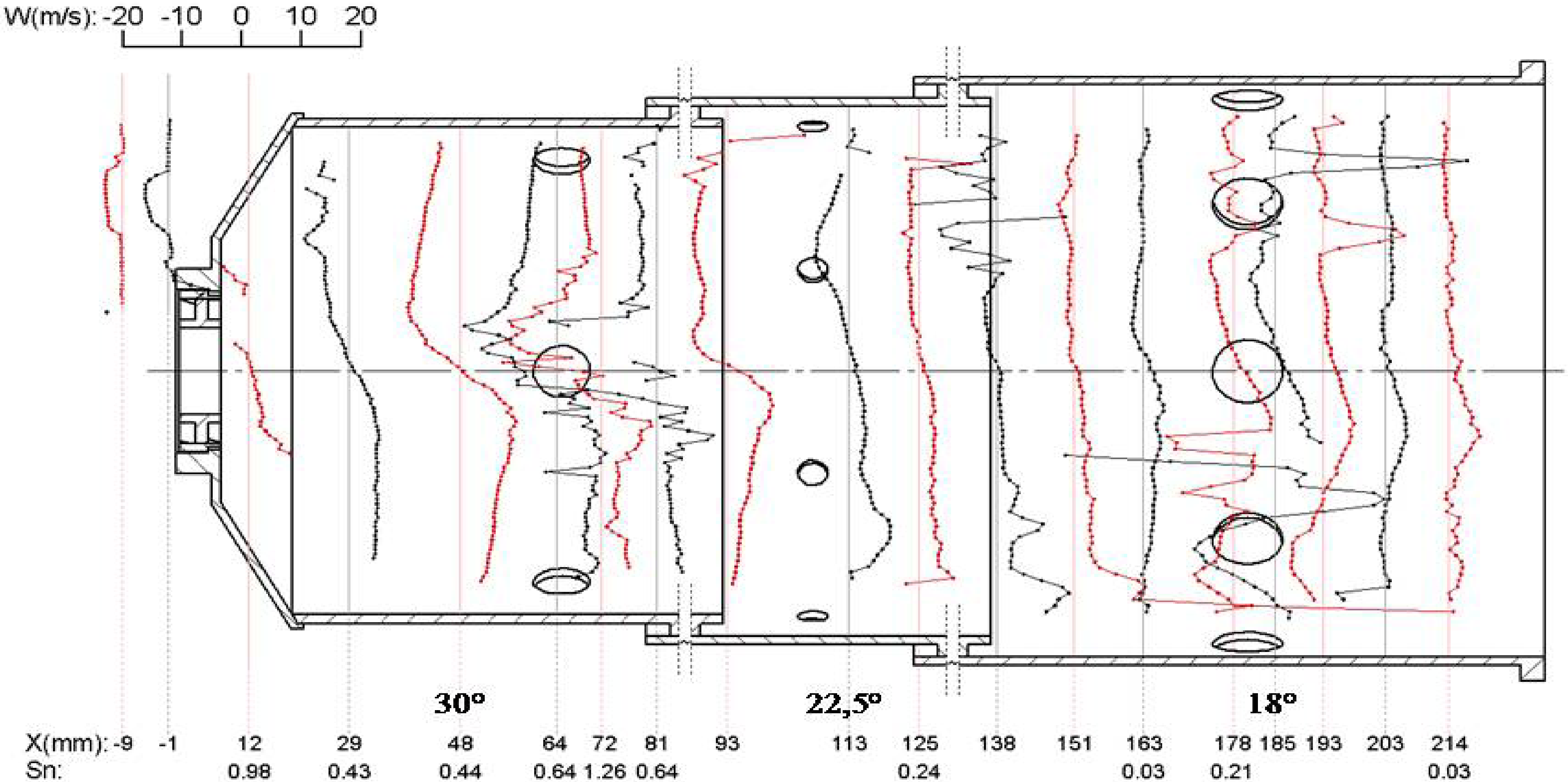
EXPERIMENTAL RESULTS: PIV BASE CASE

- The through plane velocity vector profiles at certain cross sections in line with the holes

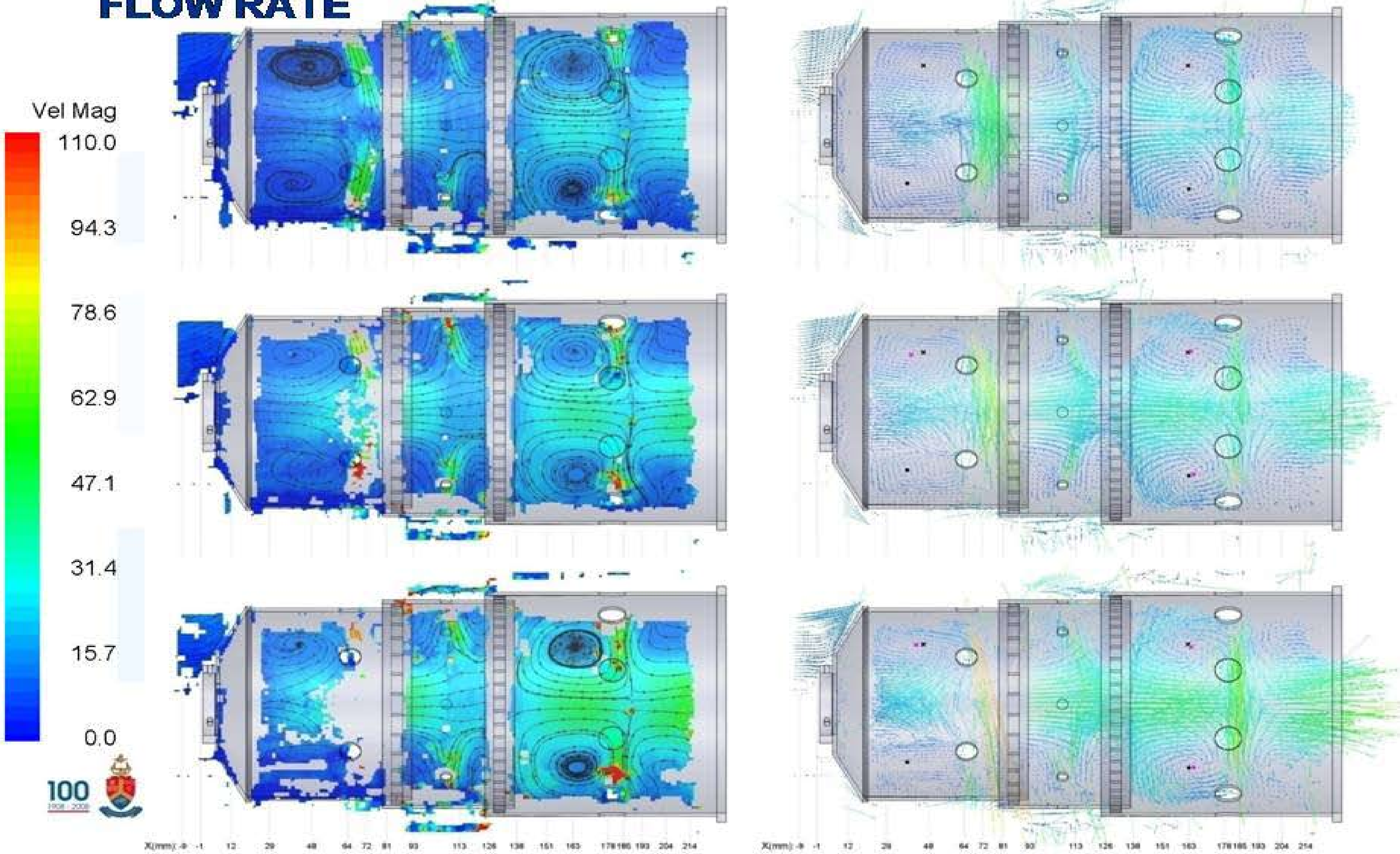


EXPERIMENTAL RESULTS: PIV BASE CASE

- The through plane velocity vector profiles at certain cross sections in between the holes



EXPERIMENTAL RESULTS: PIV INCREASING FLOW RATE



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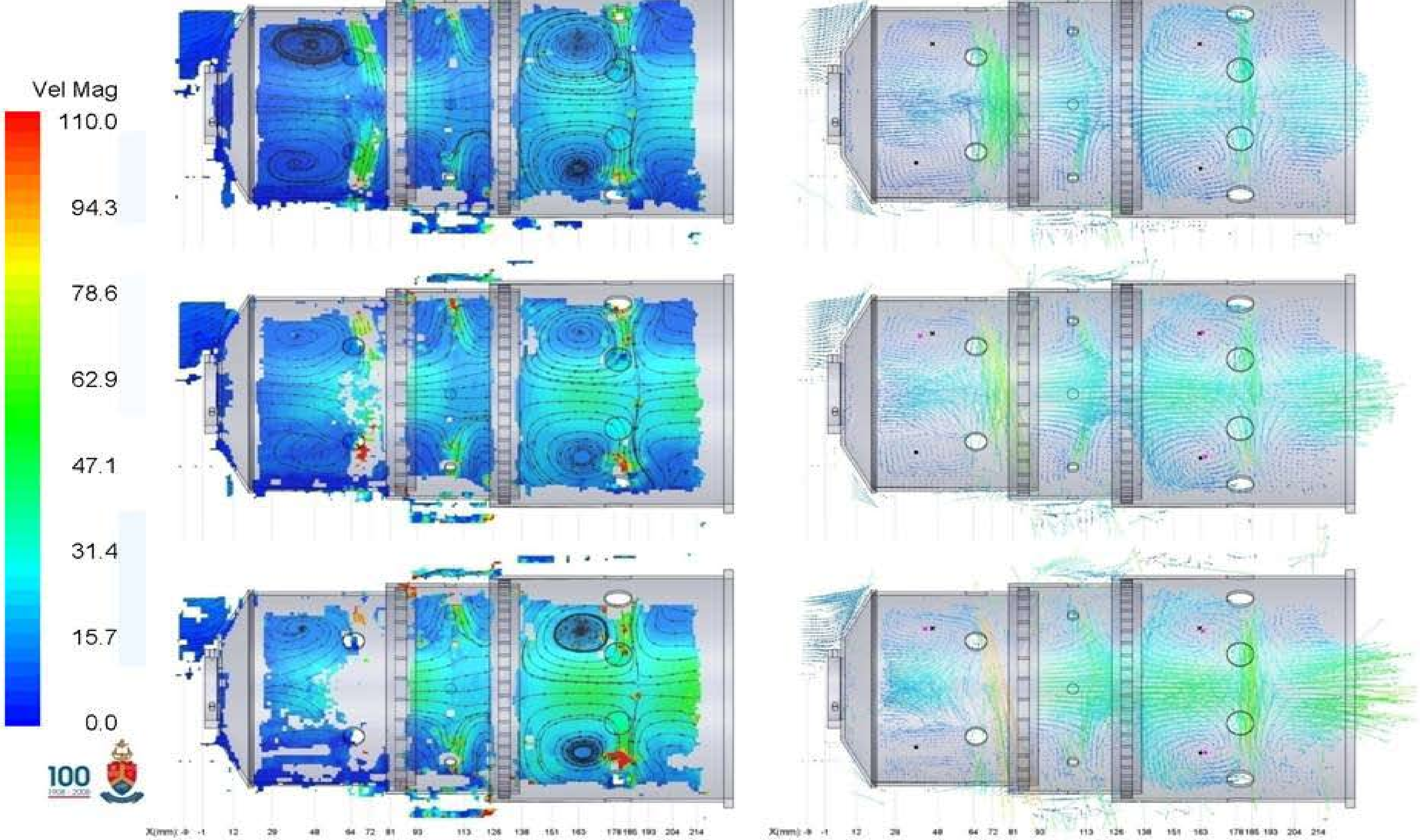

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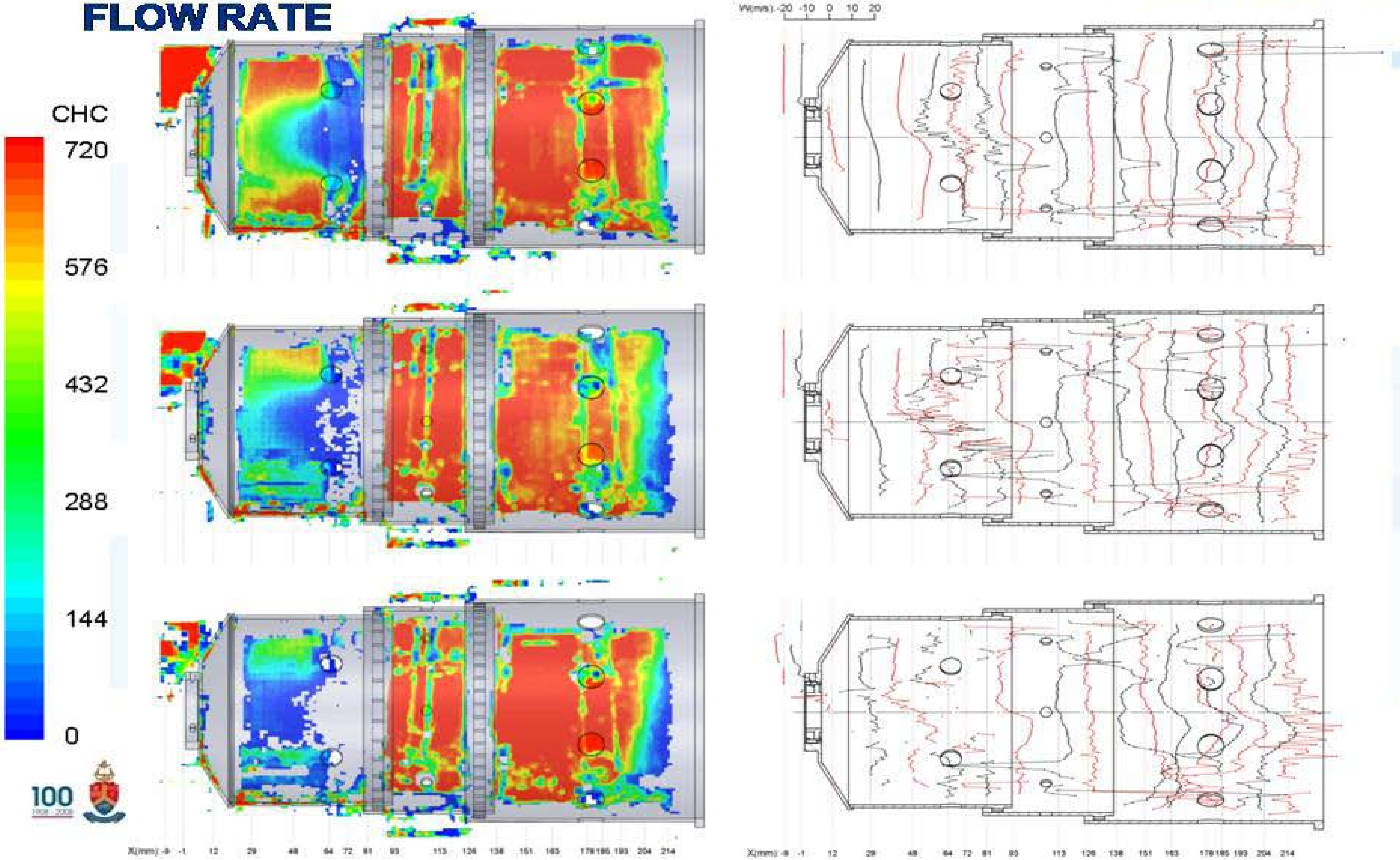
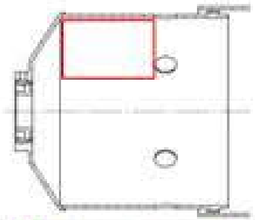


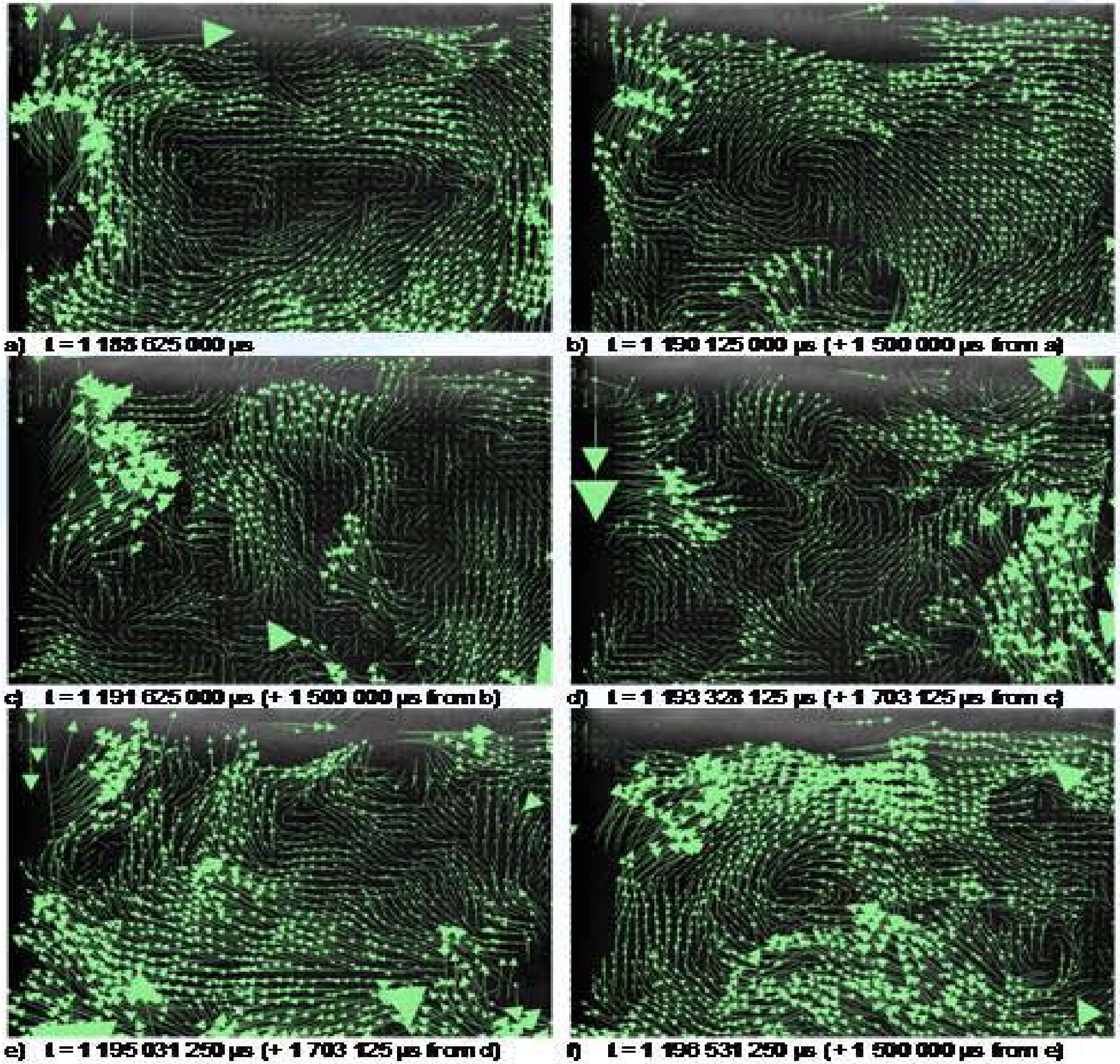
EXPERIMENTAL RESULTS: PIV TEMPORAL INDICATION



- Recirculation zone varies:

  Image a) → Rz is well defined

  Image d) → Rz broken down



a) t = 1 188 625 000 µs

b) t = 1 190 125 000 µs (+ 1 500 000 µs from a)

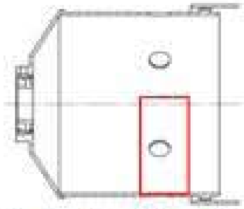
c) t = 1 191 625 000 µs (+ 1 500 000 µs from b)

d) t = 1 193 328 125 µs (+ 1 703 125 µs from c)

e) t = 1 195 031 250 µs (+ 1 703 125 µs from d)

f) t = 1 196 531 250 µs (+ 1 500 000 µs from e)

EXPERIMENTAL RESULTS: PIV TEMPORAL INDICATION



- The angle of the jet fluctuates between 16° to 27° with respect to the verticle

a) = 25°

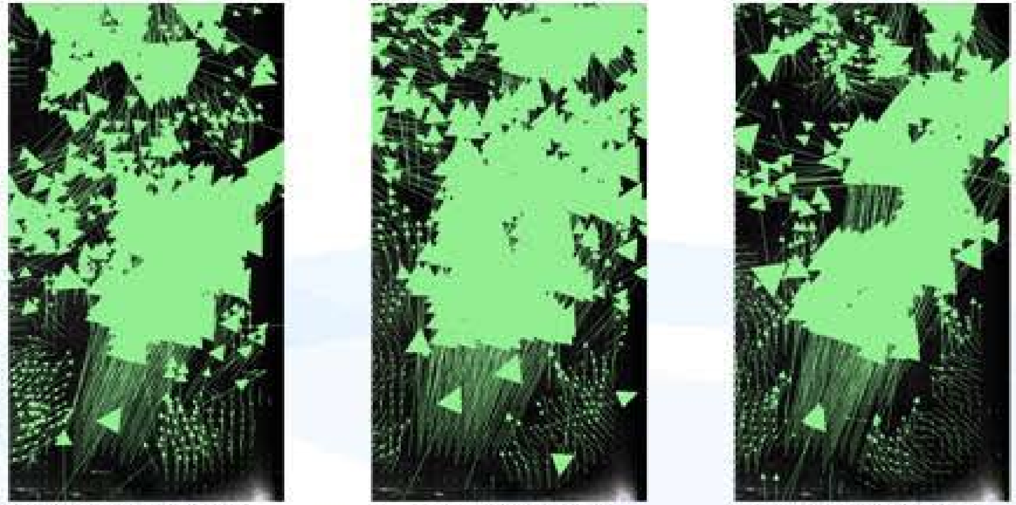
b) = 18°

c) = 20°

d) = 16°

e) = 27°

f) = 23°



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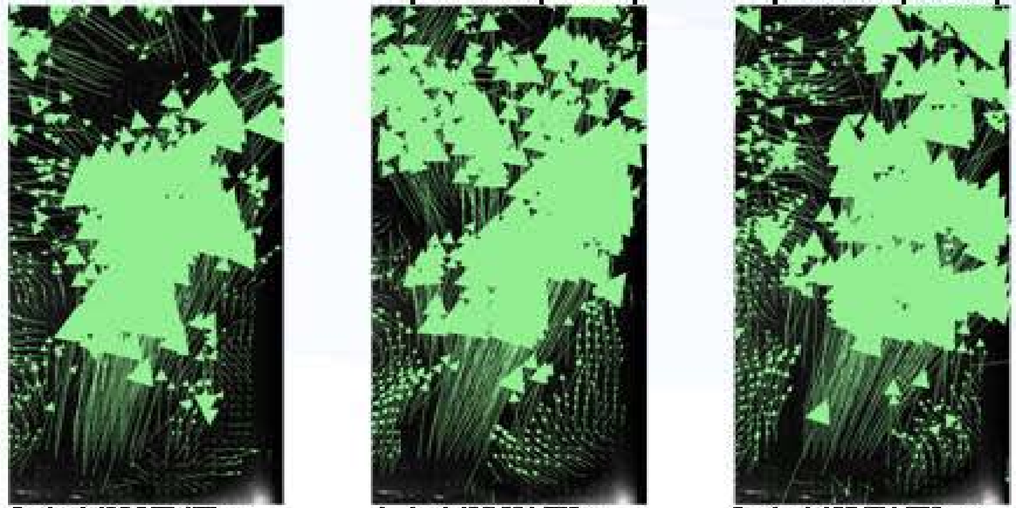

d) t = 1 193 328 125 μs (+ 1 703 125 μs fom c)

e) t = 1 195 031 250 μs (+ 1 703 125 μs fom d)

f) t = 1 196 531 250 μs (+ 1 500 000 μs from e)

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CONCLUSION

- Reacting Experiment
  - The outlet temperature profile is the most important feature to model correctly
  - The outlet temperature profile measured shows enough detail to compare to CFD
- Non-reacting Experiment
  - The PIV data has a large amount of detail
  - The primary recirculation zone size and position can be used to indicate how well the turbulence model is performing in simulating flow with both swirling and jet flow
  - The tangential flow measurements can be used to evaluate how well the swirling flow is modeled
  - The dilution recirculation zone is atypical and can thus be used to test how well the CFD captures real flow features
  - The flow data also yields the jet penetration depths which should also be modeled well because it influences the rate of mixing