CREALab

POLITECNICO MILANO 1863

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Experimental observation of non-ideal expanding flows of siloxane MDM vapor for ORC applications

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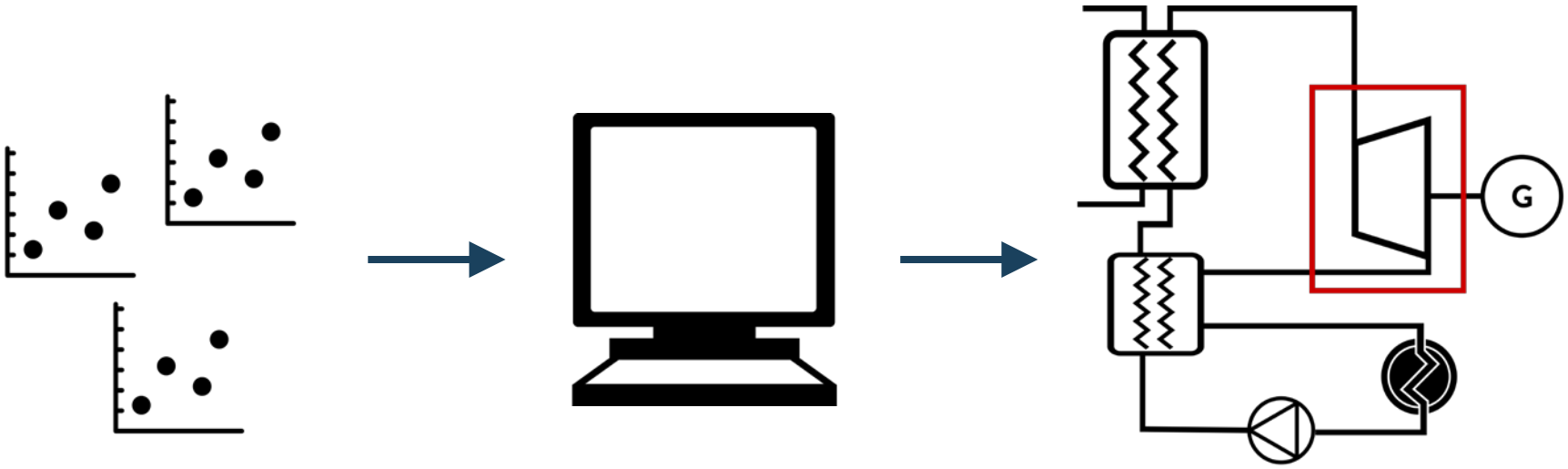
Motivation

Experimental data are needed to validate software tools

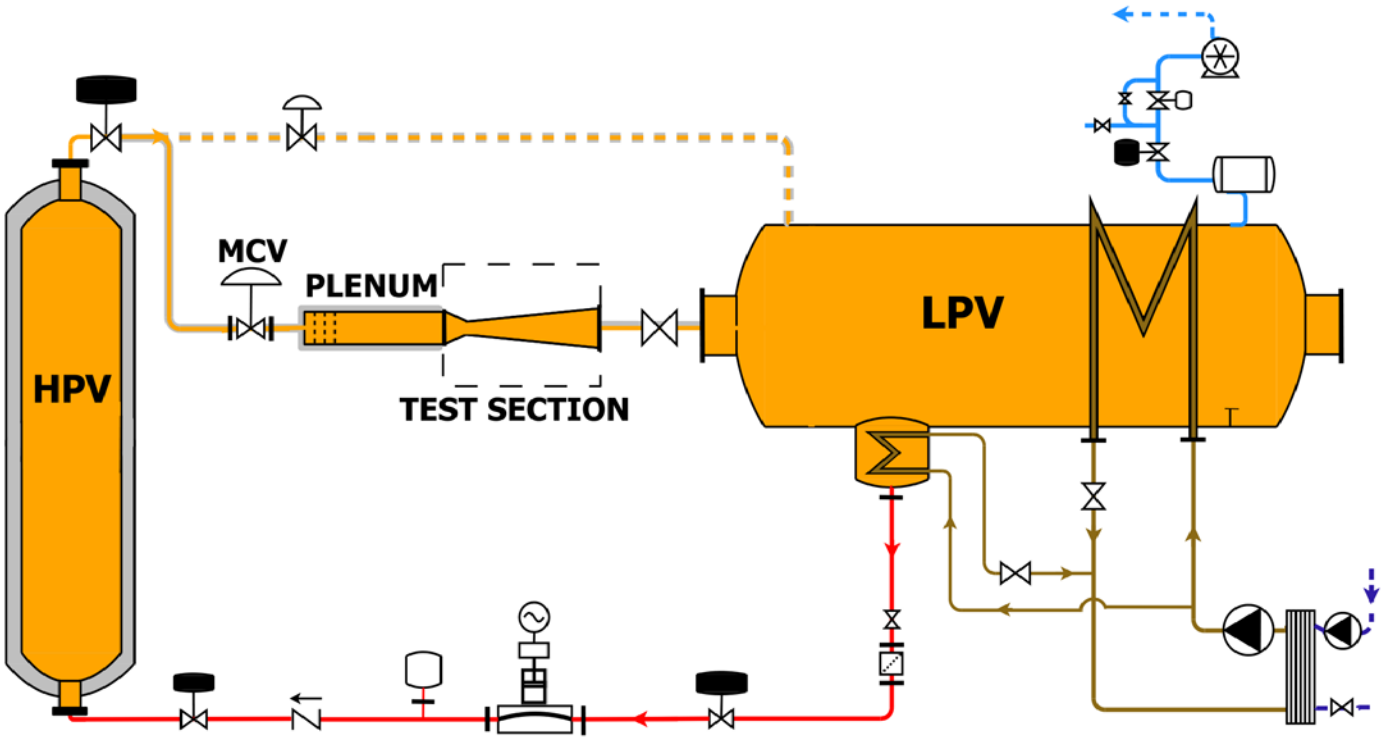


$pv \neq RT$

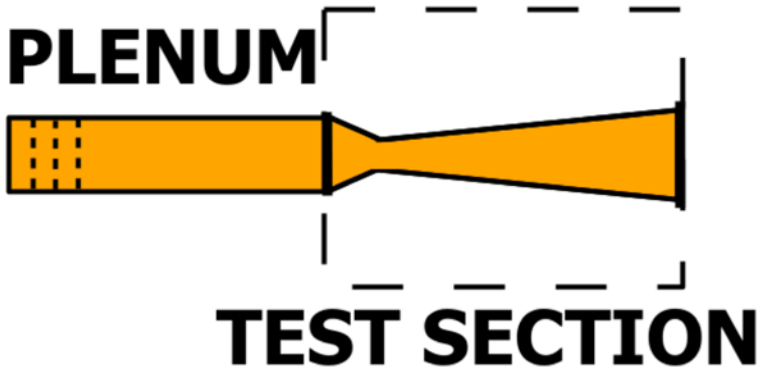
ORC expander

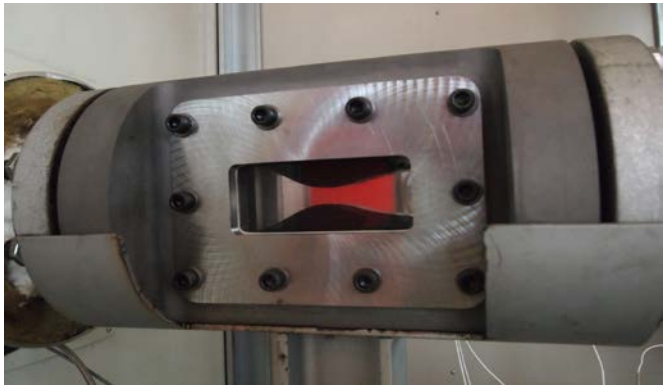
$\eta \uparrow$

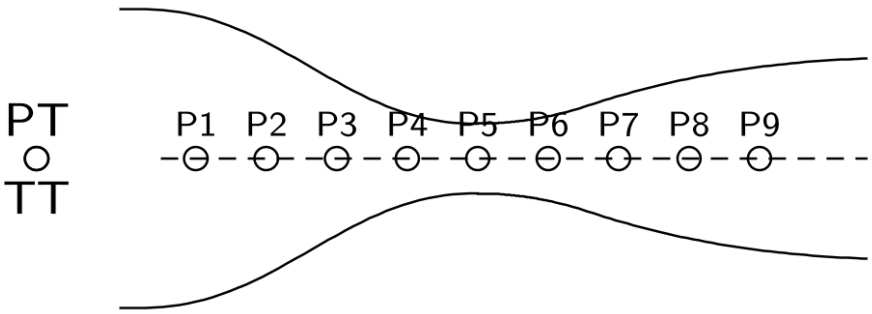
Test runs were performed on the TROVA blow-down wind tunnel



Measured quantities are: total pressure and temperature, and static pressures





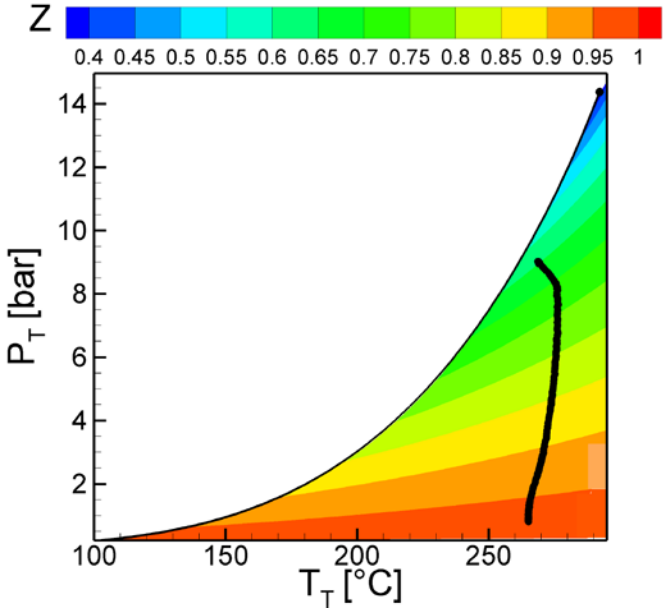


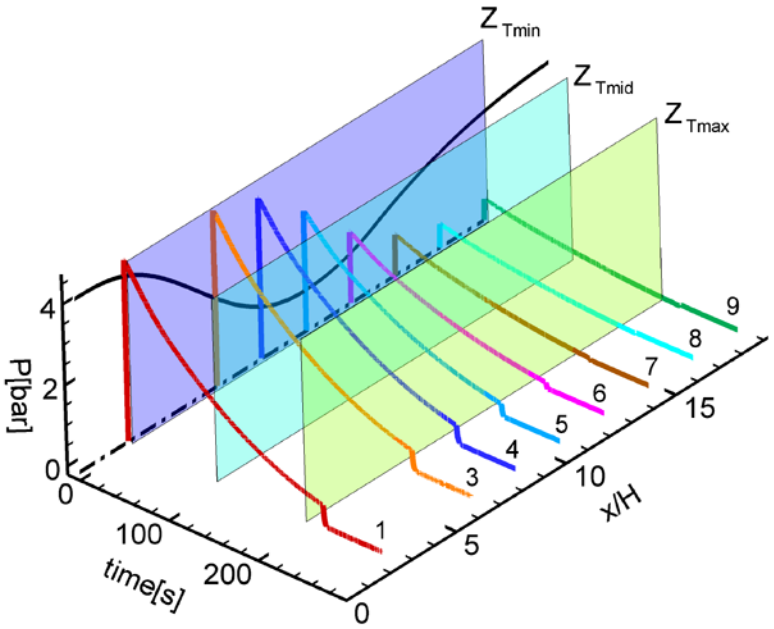
A steady state nozzle flow can be assumed at any given time

Evolution of total conditions during a test run

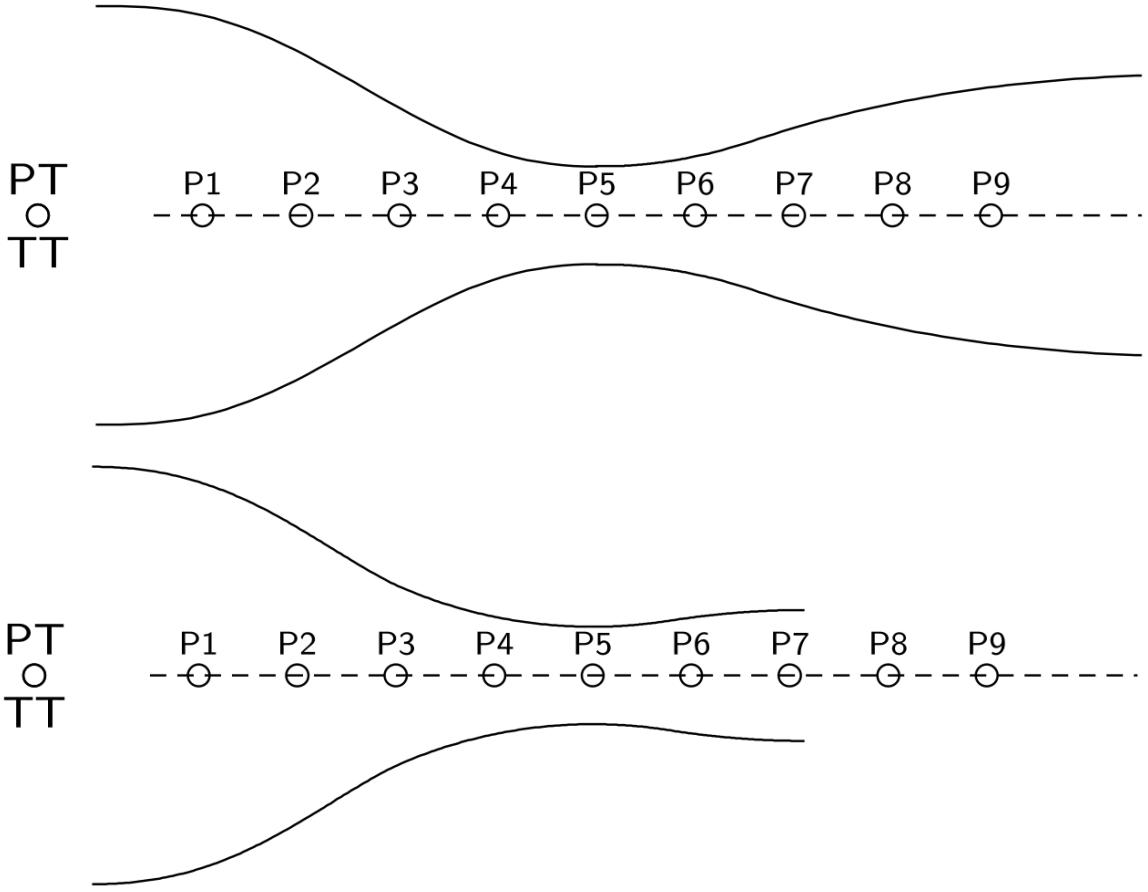
$$\tau_{nozzle\_relaxe} \ll \tau_{emptying_{LPV}}$$

$$f_{acq} = 1\ kHz$$





Two different nozzle geometries were tested using the siloxane MDM



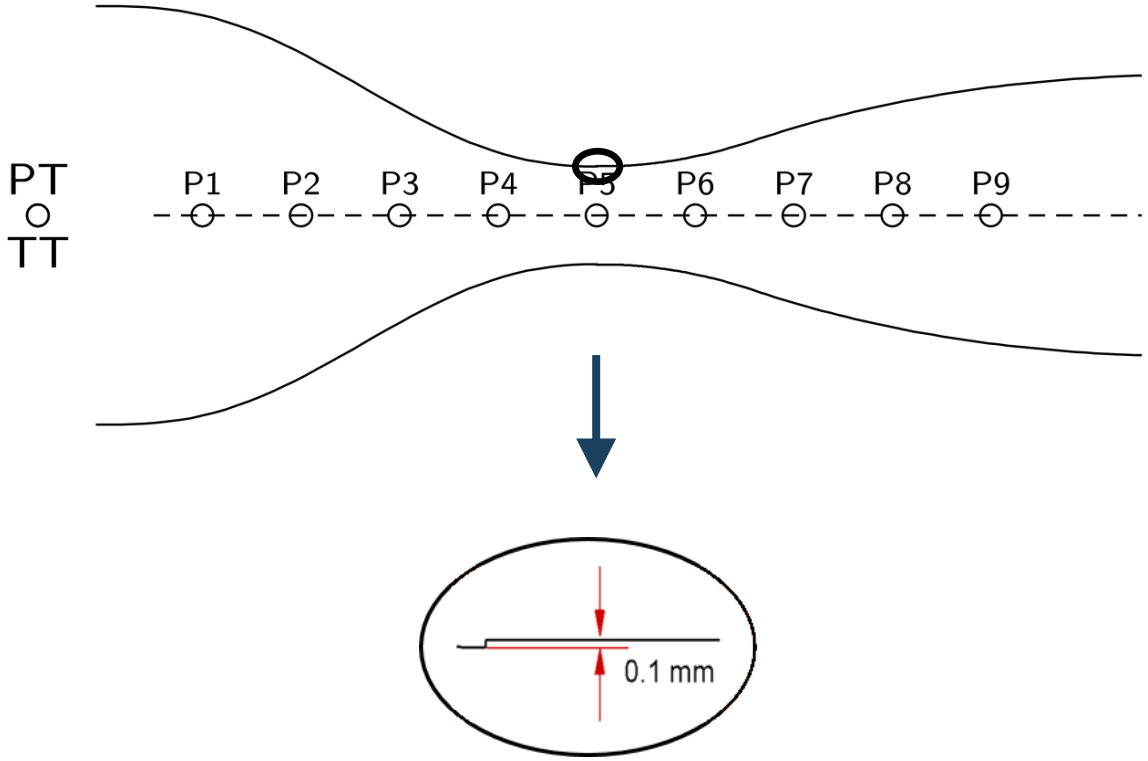
M2.0

$M_{exit} = 2$

M1.5

$M_{exit} = 1.5$

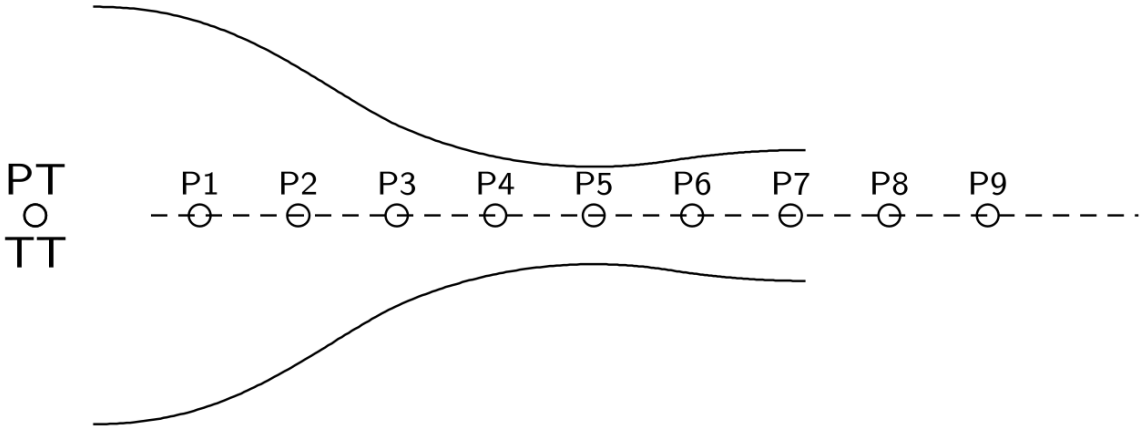
Nozzle M2.0 features a backward facing step at the geometrical throat



M2.0

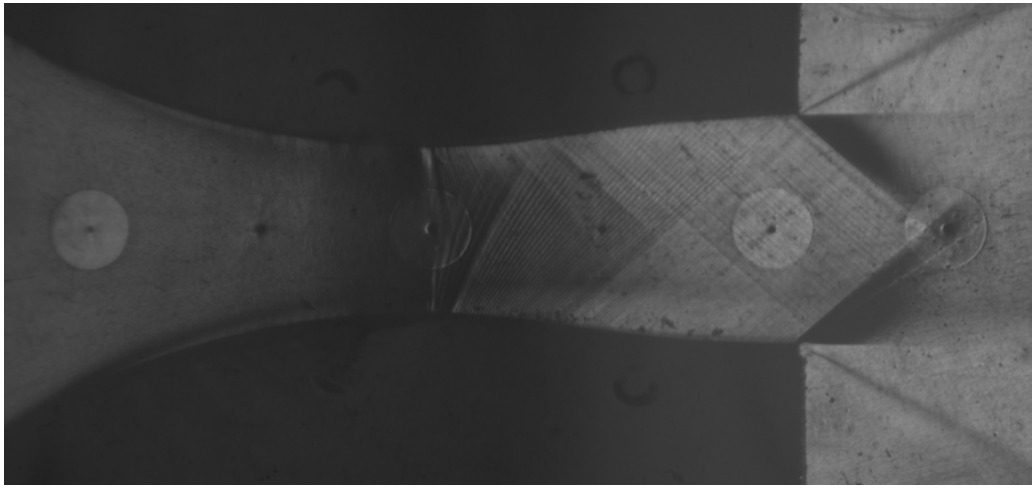
$M_{exit} = 2$

Nozzle M1.5 features an increased roughness at the walls

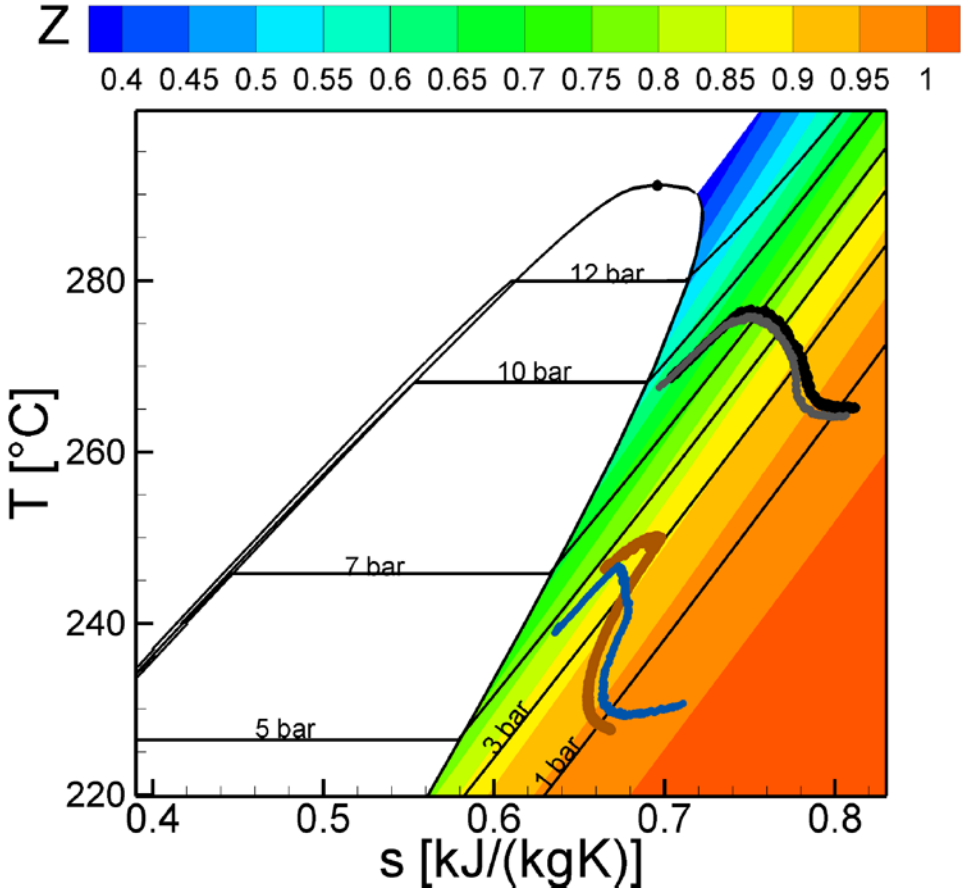


M1.5

$M_{exit} = 1.5$

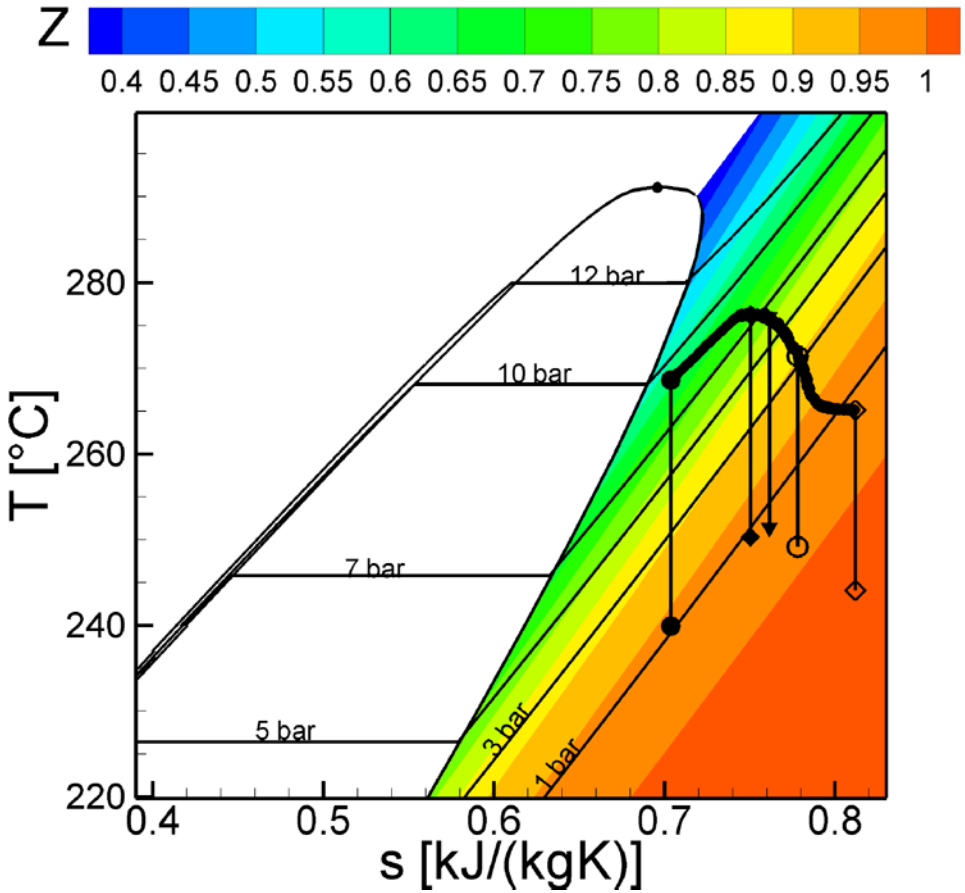


4 test runs will be presented



TEST	$P_{T,max}$ bar	$T_{T,max}$ °C	$Z_{T,min}$
M2.0L	4.58	247	0.82
M1.5L	4.59	239	0.81
M2.0H	9.02	269	0.65
M1.5H	9.20	268	0.63

5 steady state nozzle flows were extracted for each test

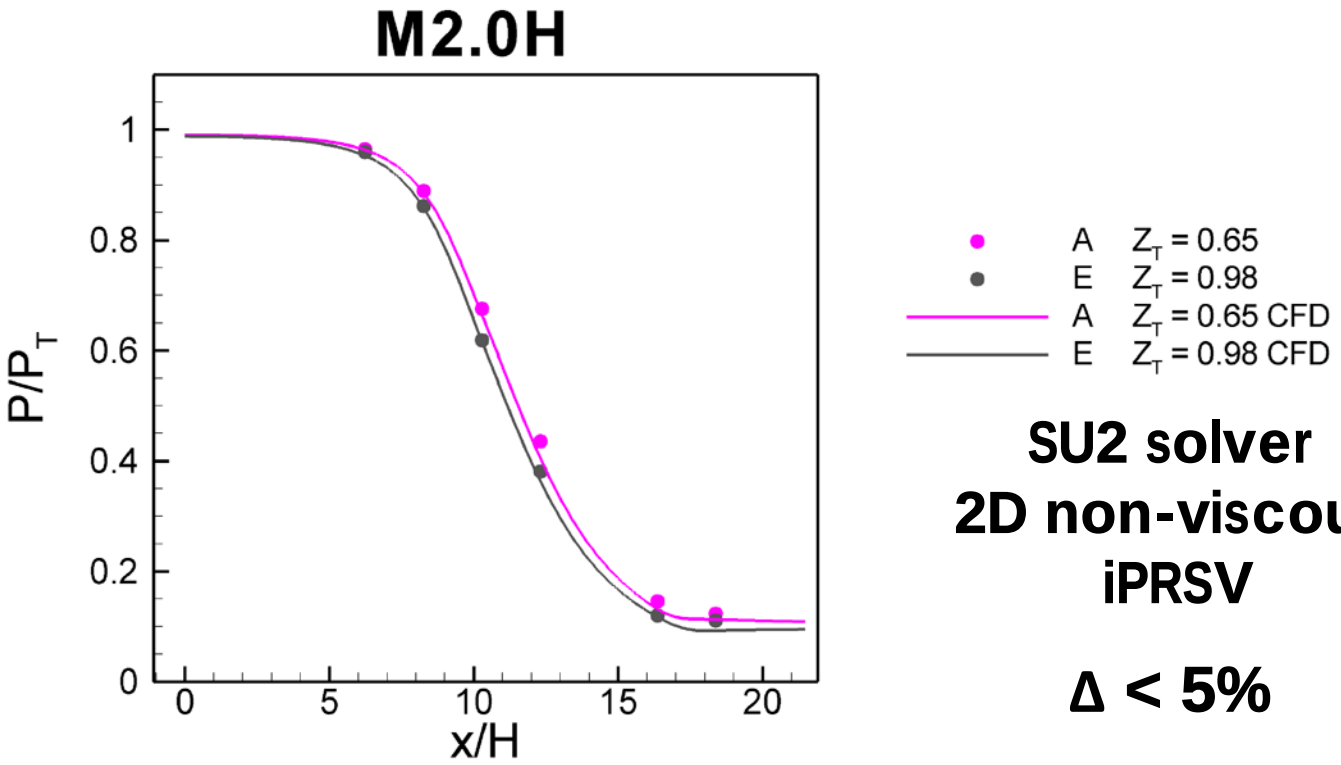


TEST M2.0H

Conditions extracted

		P_T bar	P_9 bar	T_T °C	Z_T
●	**A**	9.02	1.11	268.6	0.65
◆	**B**	7.52	0.92	276.2	0.75
▼	**C**	6.27	0.76	275.9	0.8
○	**D**	3.29	0.39	271.4	0.9
◇	**E**	0.80	0.09	265.1	0.98

Experimental data are in good agreement with CFD calculations



SU2 solver
2D non-viscous
iPRSV

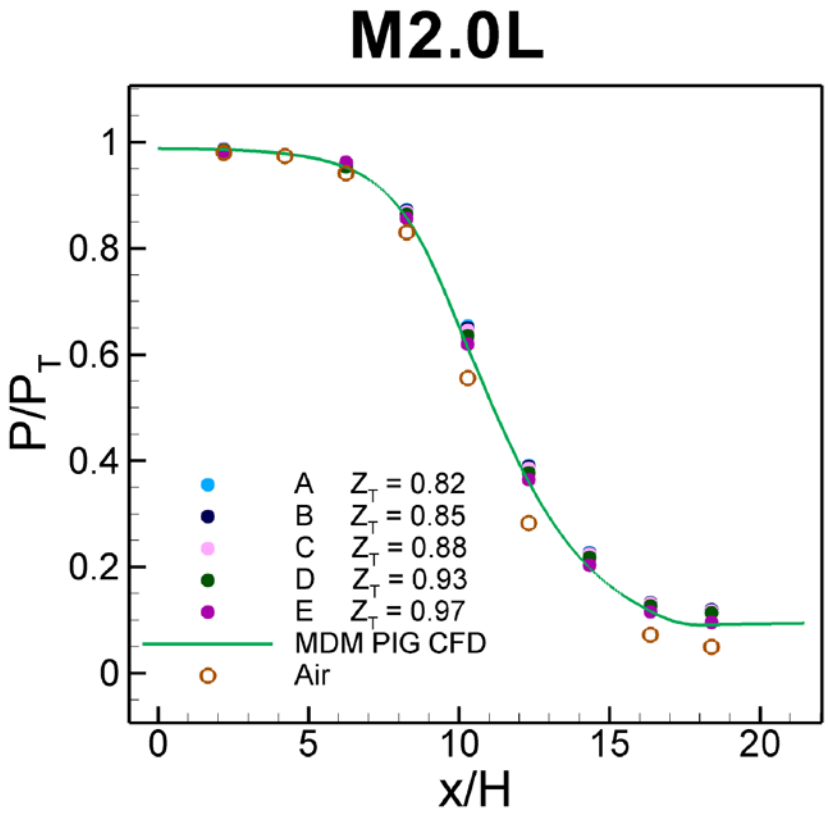
Δ < 5%

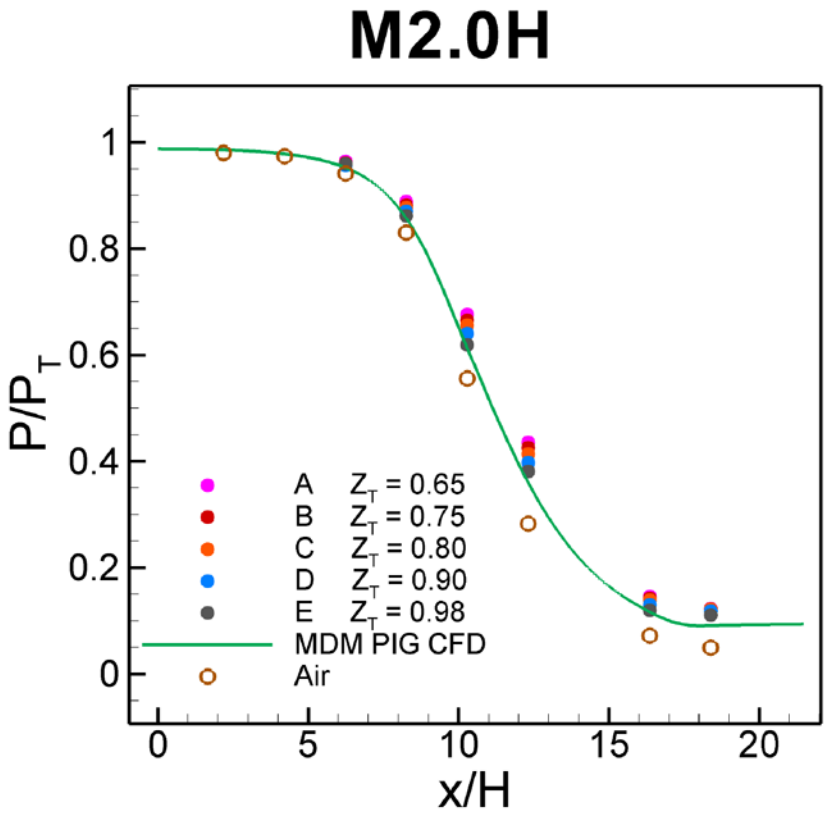
Ref. to '*Experimental assessment of the open-source SU2 CFD suite for ORC applications'*, G. Gori, M. Zocca, G. Cammi, A. Spinelli, A. Guardone
Speech: Wednesday session 3B 17:10

Results

Experimental data were compared with:

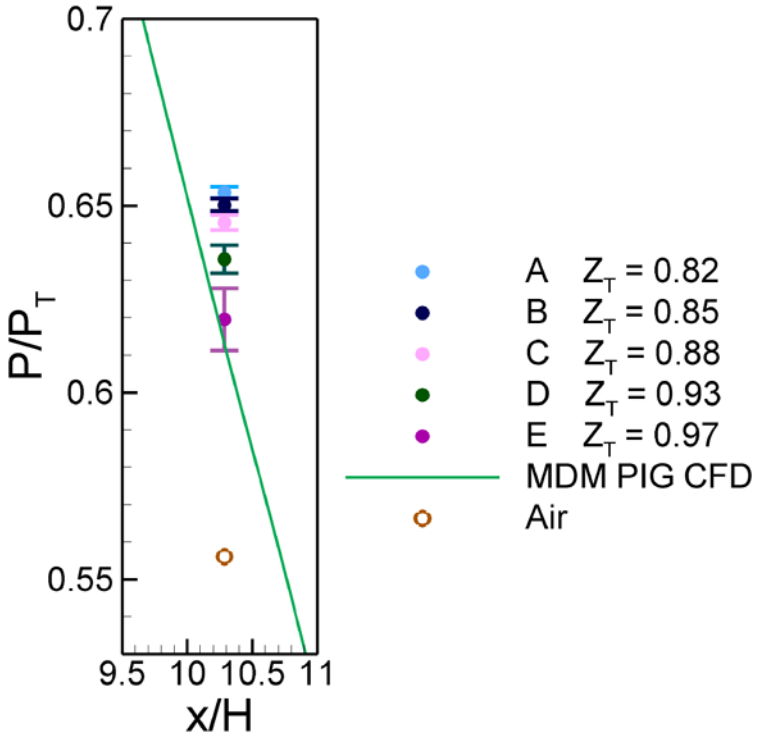
- experimental data of air flow
- CFD simulation of MDM treated as PIG



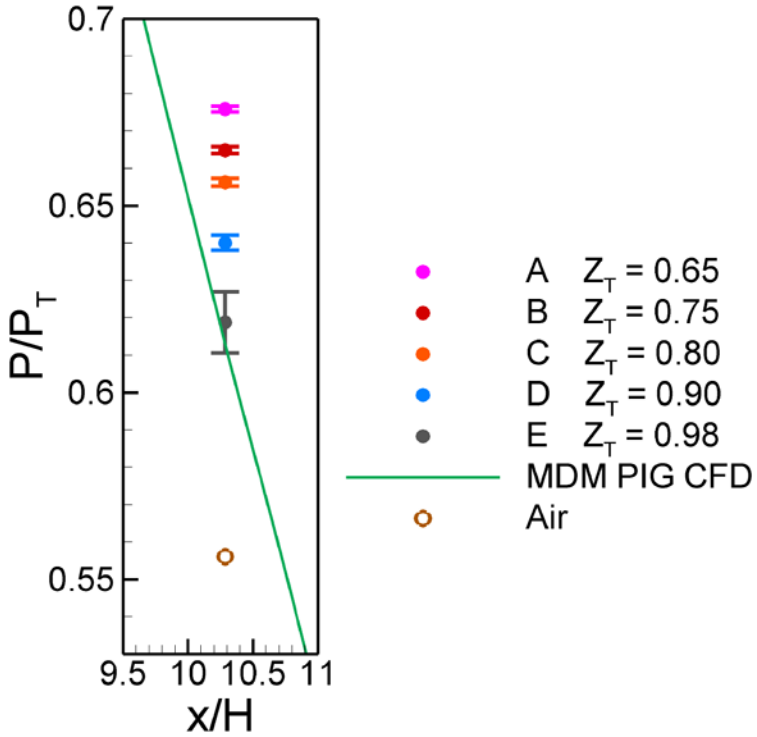


Non-negligible non-ideal effects detected

M2.0L Zoom at the Throat



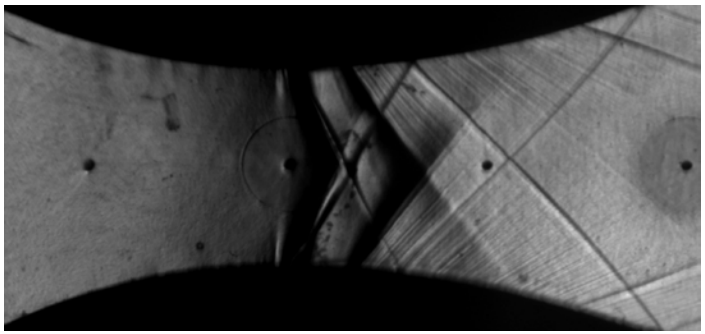
M2.0H Zoom at the Throat



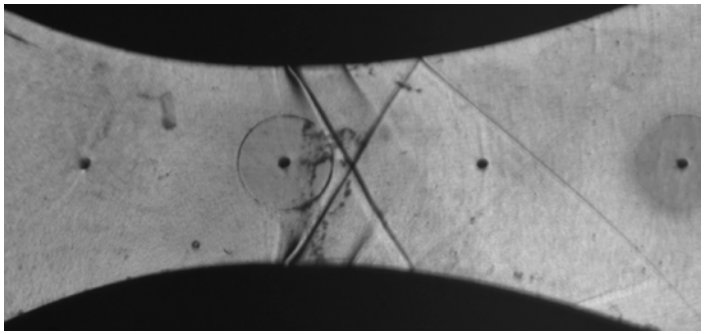
Δ from PIG assumption at $Z_T = 0.82$:
-6% on P/P_T, -20% on ρ, +16% on v_{flow}

Measuring range issues in Schlieren images

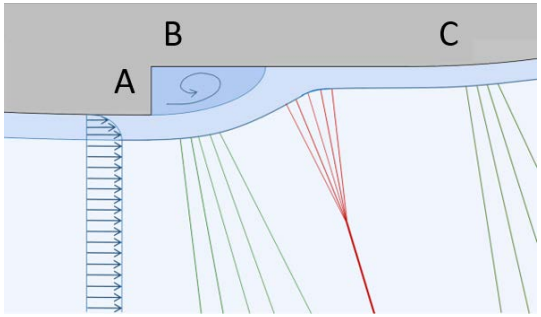
M2.0L A
P_T = 4.58 bar
Z_T = 0.82



M2.0L C
P_T = 3,39 bar
Z_T = 0.88



M2.0L E
P_T = 0.80 bar
Z_T = 0.98



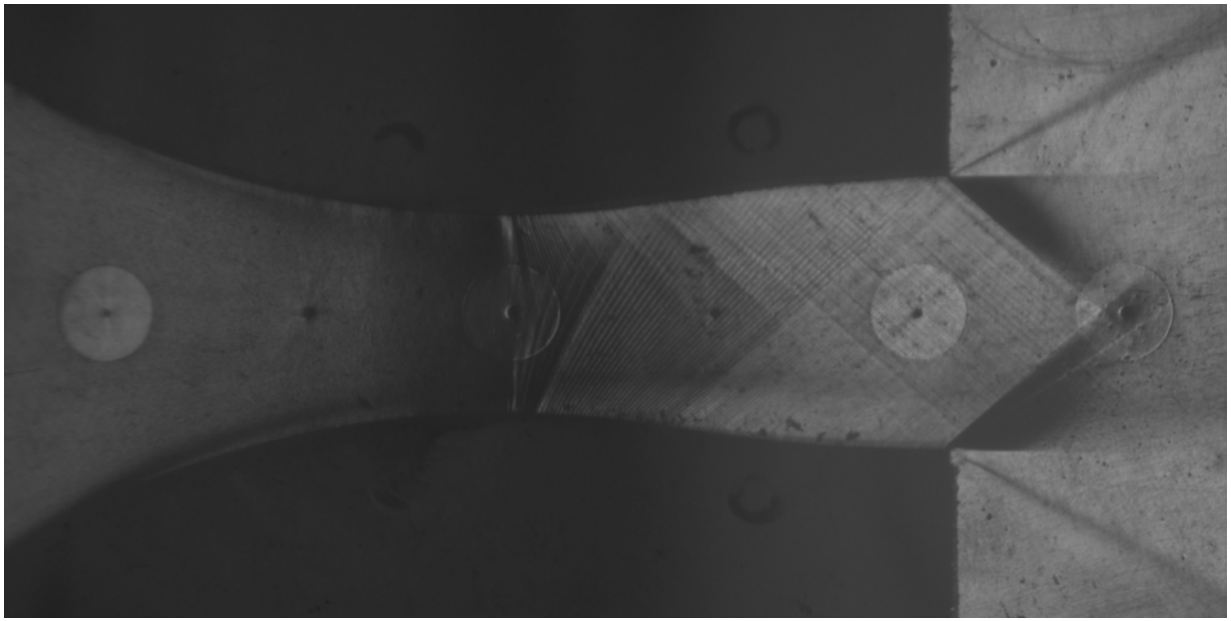
$$\frac{\partial n}{\partial x} = K \frac{\partial \rho}{\partial x}$$

$$\frac{\partial n}{\partial x} = K \frac{1}{c^2} P_T \frac{\partial (P/P_T)}{\partial x}$$

Ref. to Conti C, Spinelli A et al, *Schlieren visualization of non-ideal compressible fluid flows,* HEFAT2017

The local Mach number was measured from Schlieren images of M1.5 test runs

M1.5L A P_T = 4.59 bar, Z_T = 0.81

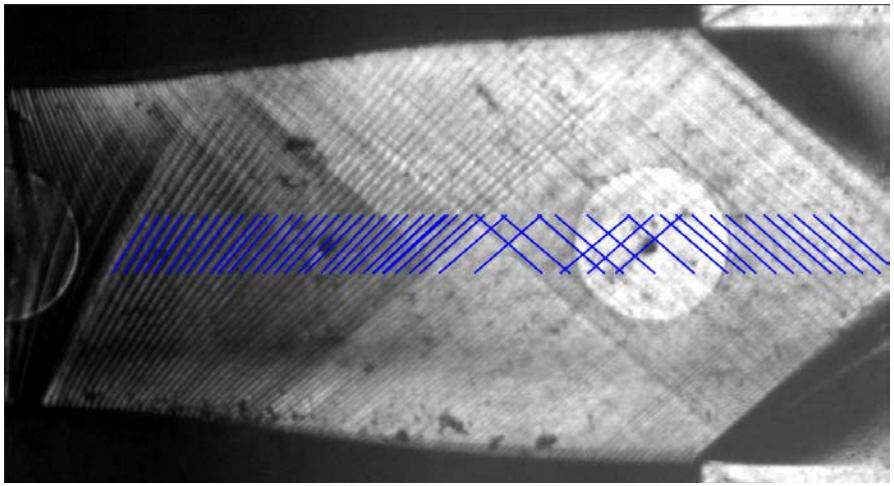


$$M = \frac{1}{\sin\theta}$$

Line detection techniques were used to detect Mach lines and directly measure the Mach number on the nozzle axis

M1.5L A

P_T = 4.59 bar, Z_T = 0.81



*****Lo RC, Tsai WH (1995) *Gray-scale hough trasform for thick line detection in grey-scale images,* Pattern Recognition 28:647–661

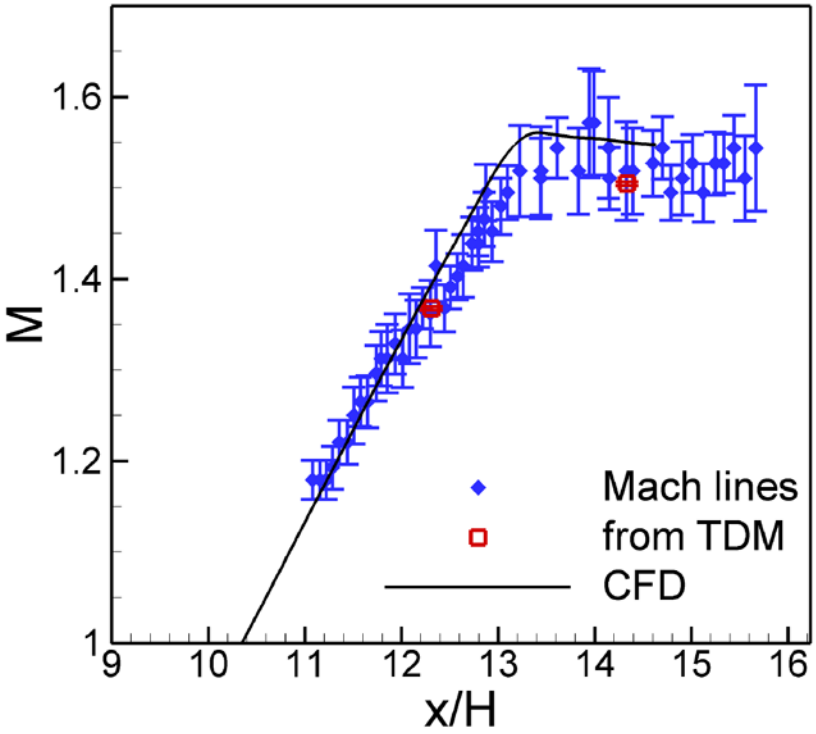
Line detection algorithm

- image cut and contrast enhancement
- binarization of the image
- Hough transform and peak detection
- computation of lines inclinations and positions*
- computation of Mach numbers and their uncertainties

Local M detected are in agreement with experimental data and CFD simulations

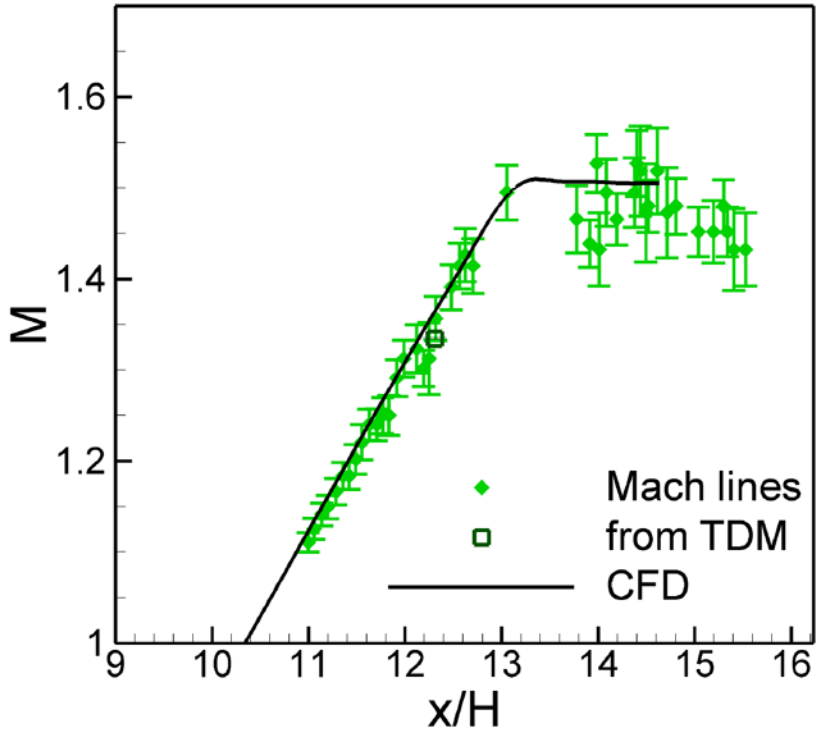
M1.5L

P_T = 4.59 bar, Z_T = 0.81



M1.5H

P_T = 9.04 bar, Z_T = 0.65

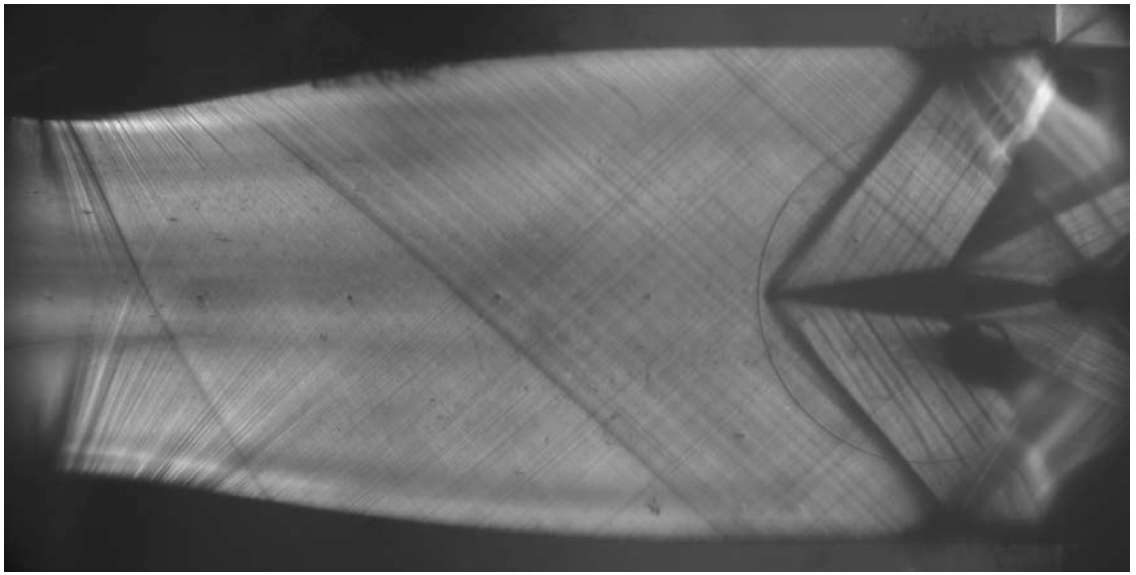


Conclusion

Nozzle expansions of complex vapor MDM were successfully characterize measuring:

- T_T
- P_T
- **Static Pressures along the axis**
- **Local Mach numbers**

Current work:



Future Developments

Following experimental campaigns will be performed aiming at:

- observing non-ideal flow features;
- investigating mixture flow fields

Visit our laboratory during the lunch break: information at the registration desk