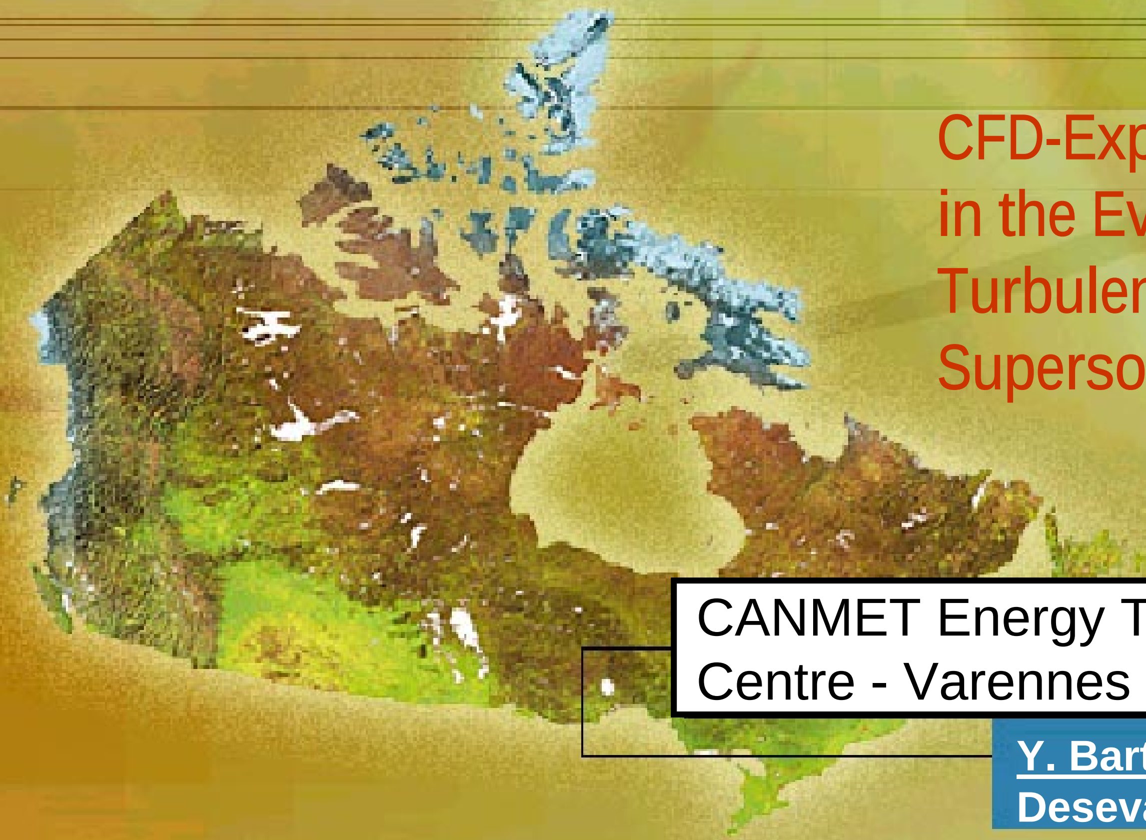
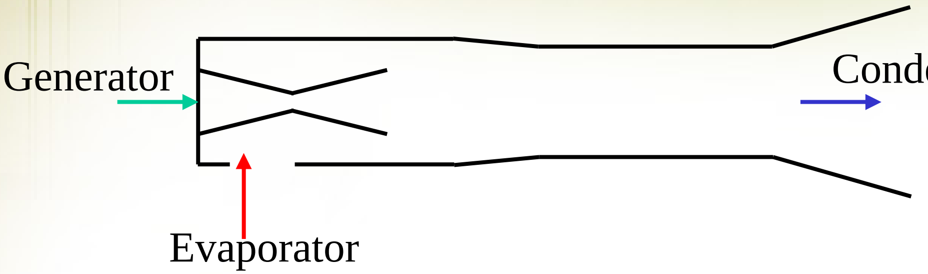


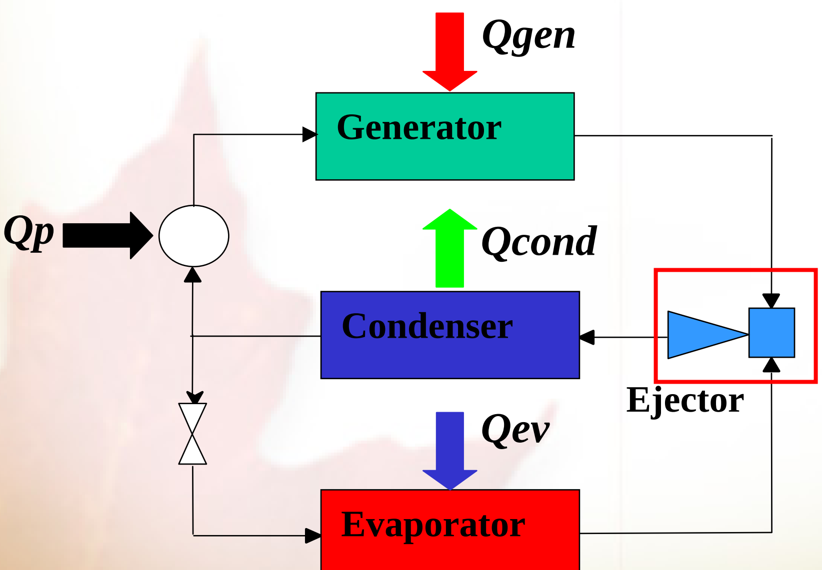
CFD-Experiments Integration in the Evaluation of Six Turbulence Models for Supersonic Ejectors Modeling

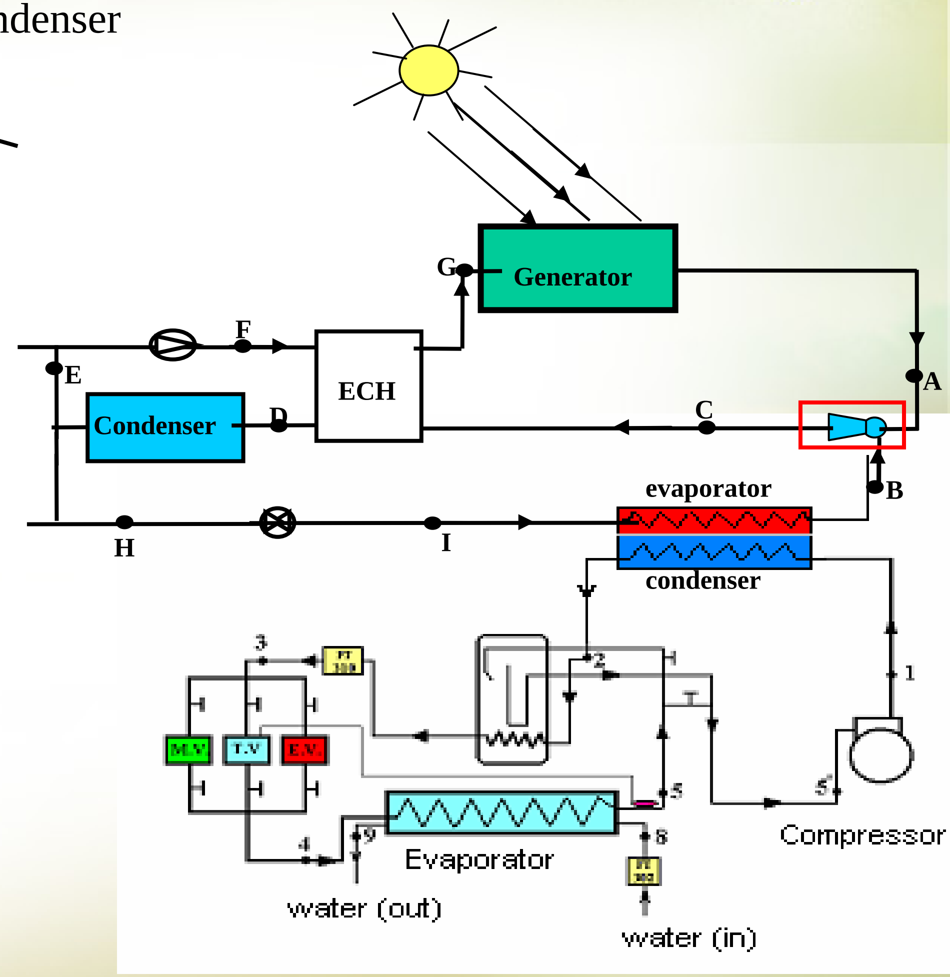
CANMET Energy Technology Centre - Varennes

Y. Bartosiewicz, Z. Aidoun, P. Desevaux, and Y. Mercadier

Supersonic ejectors in refrigeration







Main objectives of this study

Short term:

- Assess the **ability** of CFD to represent the operation range of a supersonic ejector in a **simple case**: single phase, known properties: Air

- Choose the best suited turbulence model among those giving **reasonable results** in comparison to the **computational cost**:

  - k-epsilon
  - Realizable k-epsilon
  - RNG
  - k-omega and k-omega-sst
  - RSM

  } Boussinesq hypothesis

- Correctly predict some **local** (shocks position…) and **global** (entrainment rate, pressure recovery) features

Long term:

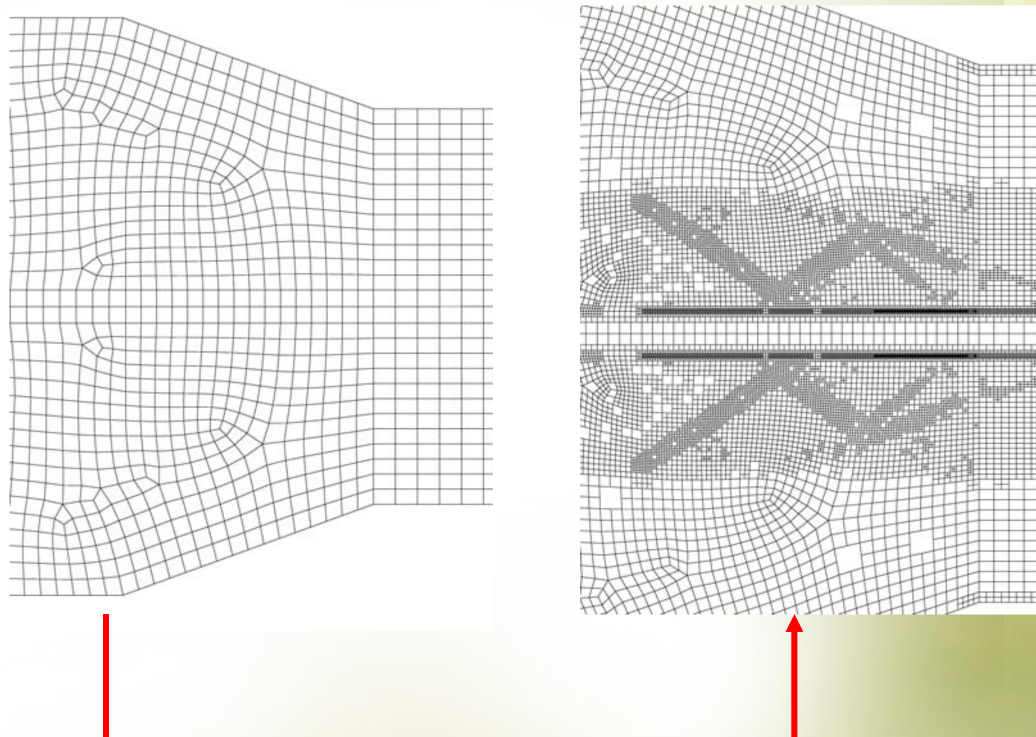
- Have a **better understanding** of involved phenomena (local physics, that 1-D models cannot provide)

- Set up a **reliable** tool for **geometrical design**

- Use CFD to model ejector in **refrigeration** with **refrigerants and two phase flow**

Numerical tools

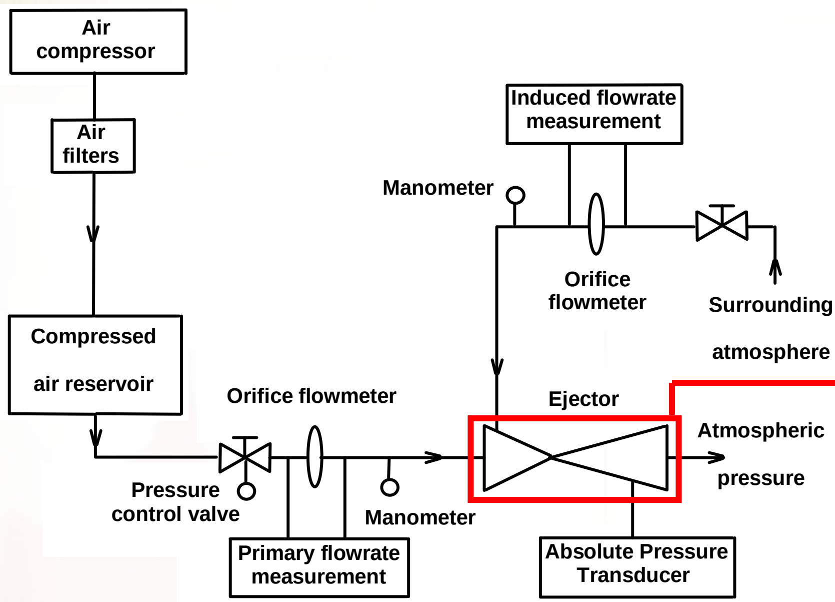
- CFD package FLUENT: F.V.
- Roe flux splitting for inviscid fluxes
- Time marching technique (implicit Euler)
- Time preconditioning (for low Mach)
- Algebraic multigrid solver (block Gauss - Seidel)
-Adaptative structured-unstructured mesh
- Standard (equilibrium) wall functions

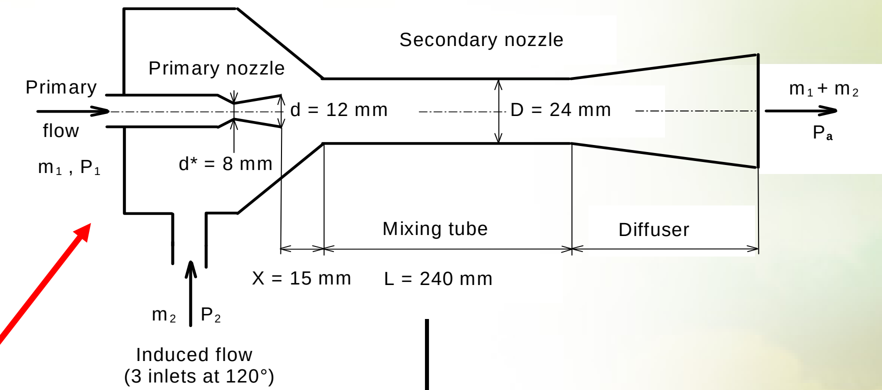


Adaptation following the pressure gradient, and y+ close to walls

Flow Facility (IGE*) – Computational domain

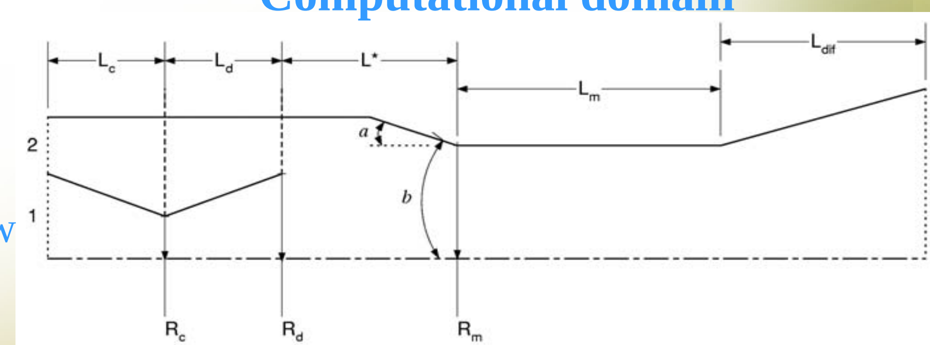
*: Institute of Applied Energy, CREST-CNRS, Belfort, France





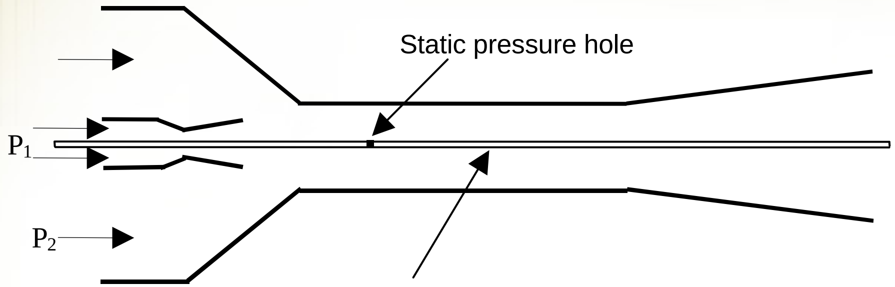
$m_2 = 0$ or constant

Computational domain



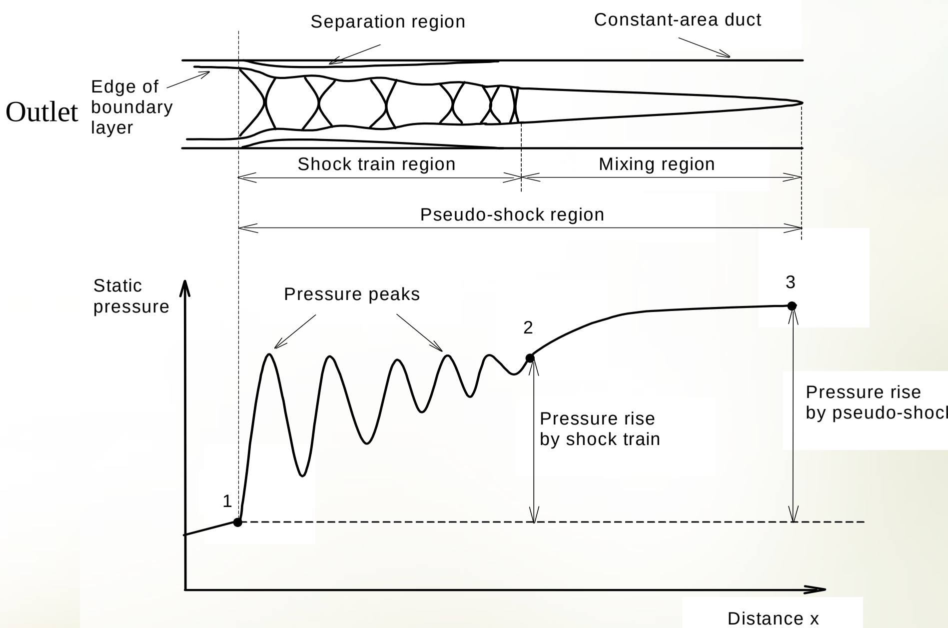
- **Axisymetric** computational domain
- **Equivalent cross section** for the secondary flow

Measurements (IGE): the centerline pressure



- Probe with 1 mm external diameter
- Hole diameter = 0.3 mm
- Pressure transducer

Flow physics

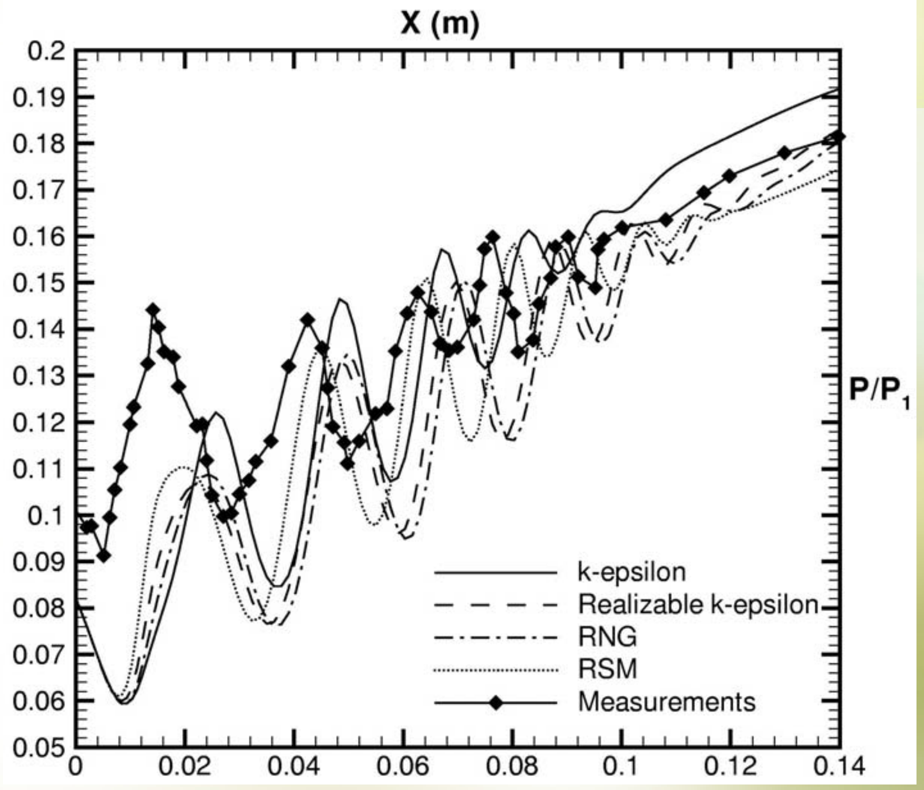


Comparison with experiments: Centerline pressure: without probe modeling (No secondary flow)

None of the turbulence models is able to completely reproduce shock reflections in terms of:

- Phase
- Strength

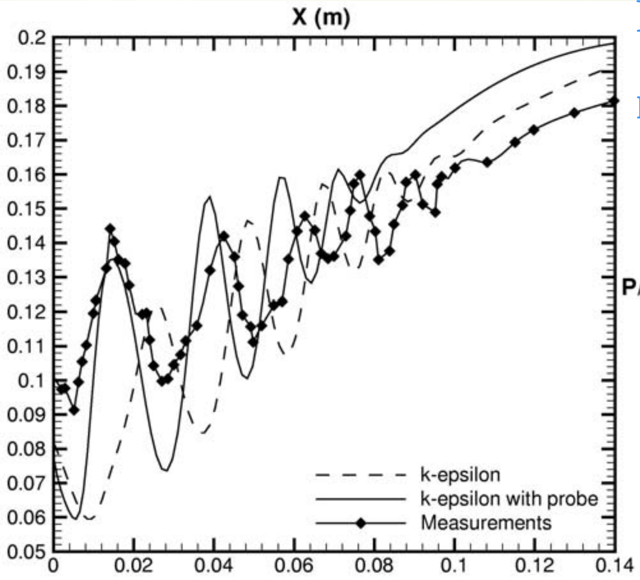
However the average pressure recovery is properly modeled.



P_1 = 5 atm

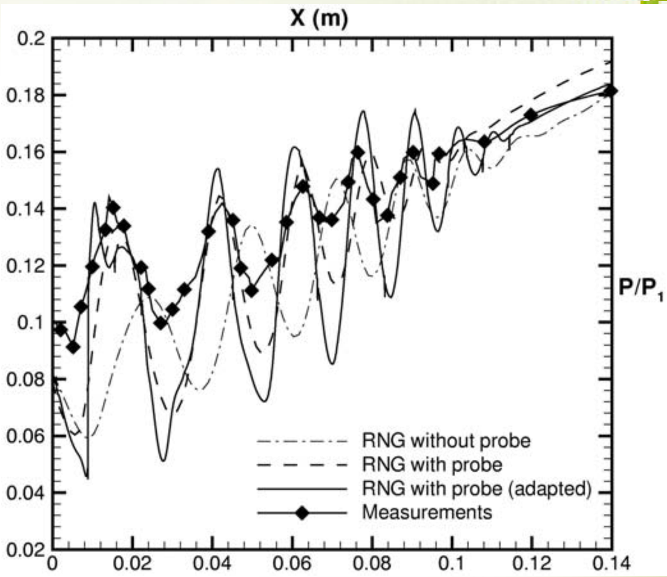
m_2 = 0. kg/s

Centerline Pressure: with probe modeling (No secondary flow)



$P_1 = 5$ atm

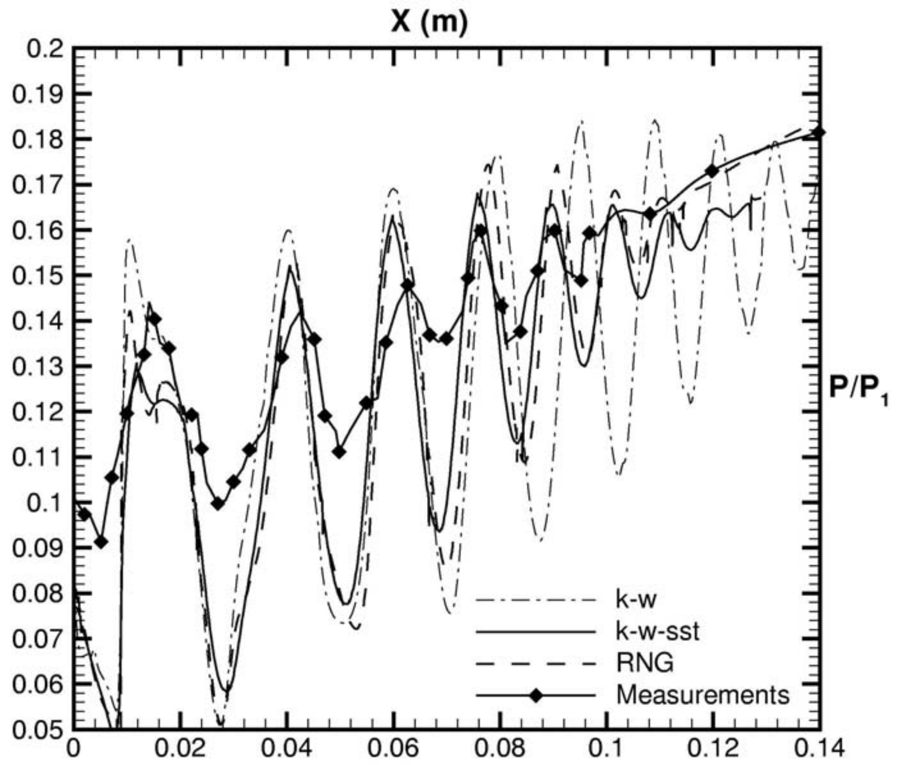
$m_2 = 0.$ kg/s



- The probe has a **significant effect** even though its size is small
- The numerical results are **all improved** with the probe modeling
- The **RNG** model gives the **best results among k-epsilon based models and RSM**
- The most important **discrepancy** is observed in **expansions** (35-50%) (**condensation)**
- In compressions, it is about 10%

Comparison between RNG and k-omega models
(No secondary flow)

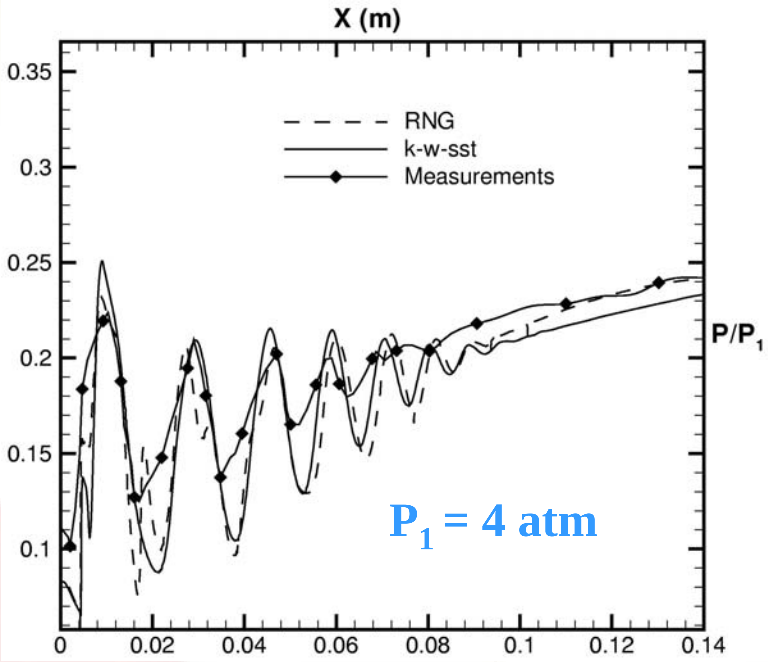
- The standard k-omega model **overpredicts** shocks downstream the fourth shock
- RNG and k-omega-sst results **comparable**
- Both models give the **same pressure recovery** value further downstream (not shown)

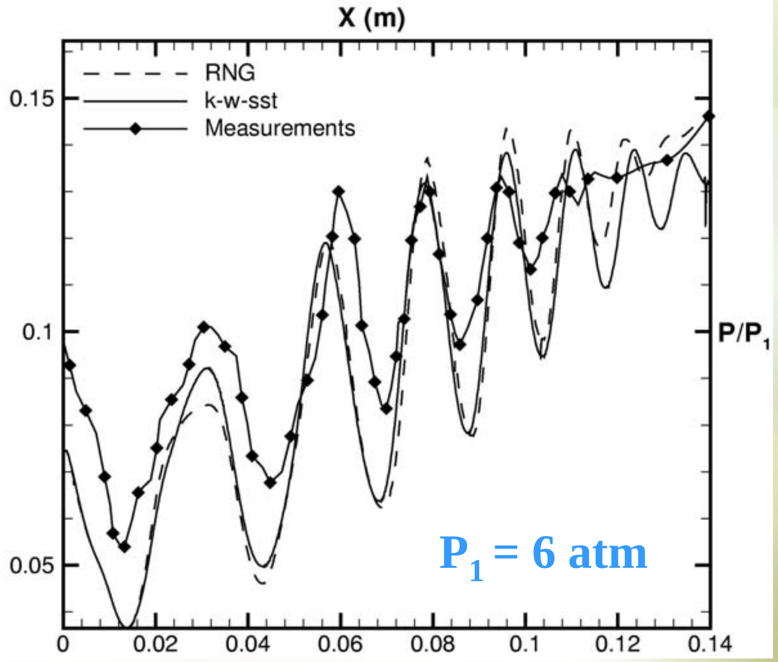


P_1 = 5 atm

m_2 = 0. kg/s

Other operation conditions

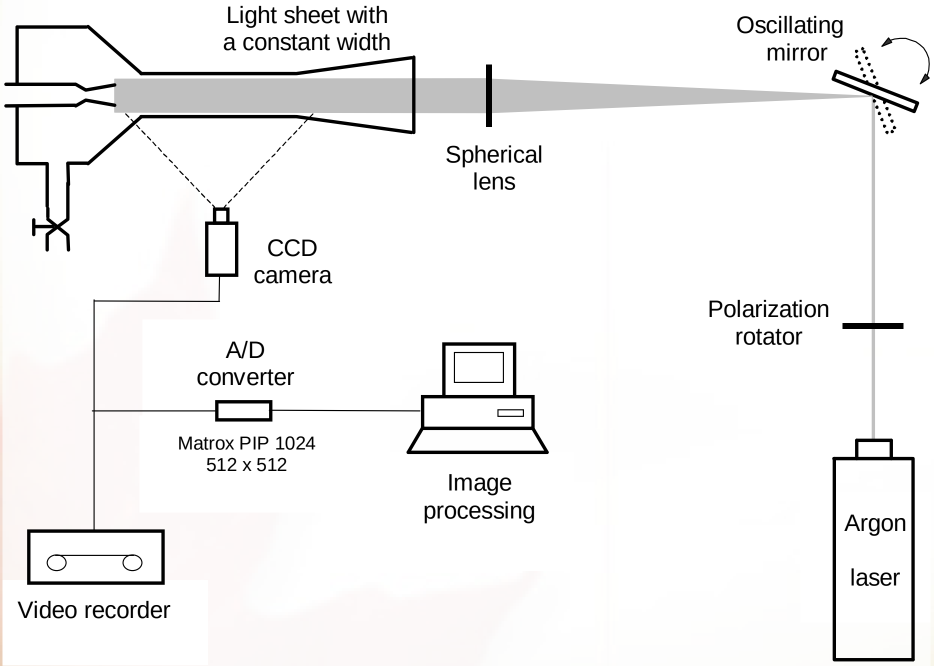




$m_2 = 0.\ kg/s$

Measurements (IGE): the non-mixing length

Laser Tomography



* Power:1.5 kW in the blue line

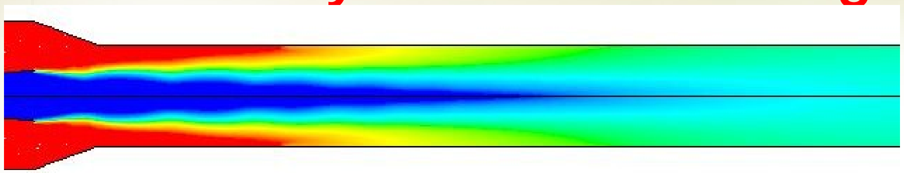
* F_{mirror} = 300 Hz

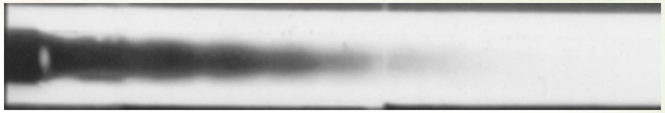
* Light sheet with parallel edges (thickness = 0.3 mm)

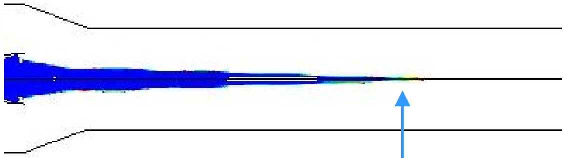
* Natural marker: water droplets issued from condensation (diameter = 0.1 μm)

* Additional markers: 1μm oil droplets

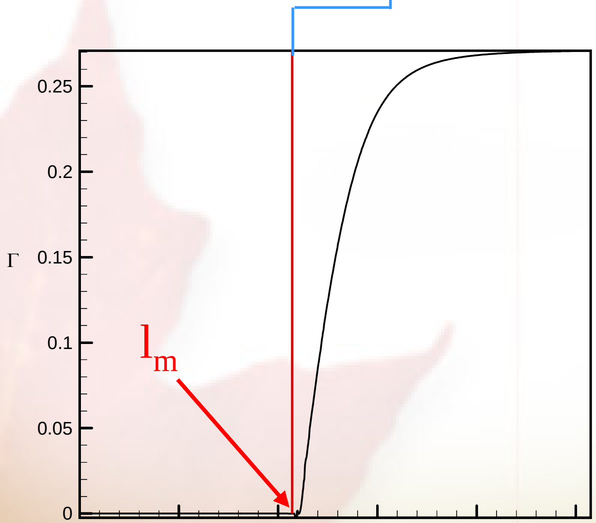
Supersonic ejector operating with a secondary flow: Non-mixing length







$\Gamma = 0$



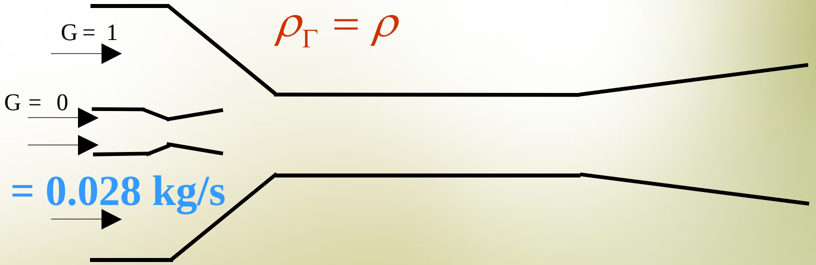
The laser tomography picture is treated by an image processing software to deduce l_m (Desevaux et al.)

Passive scalar equation

$$\frac{\partial \rho_\Gamma u_i \Gamma}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\mu_\Gamma \frac{\partial \Gamma}{\partial x_i} \right)$$

Ideal colorant: $\mu_\Gamma = \mu_l + \mu_t = \mu_{eff}$

$\rho_\Gamma = \rho$



m_2 = 0.028 kg/s

Non-mixing length results

P_1 (atm)	4	5	6
P_2 (measured) (atm)	0.78	0.68	0.4
P_2(computed) (atm)	0.61	0.52	0.4
L_m (measured) (m)	0.13	0.17	0.21
Measurements error (%)	15	12	9.5
Lm (computed) (m) k-omega	0.14	0.17	0.22
L_m (computed) (m) RNG	0.16	0.18	0.22
Error/measurement (%) (L_m) K-omega-sst	8	0	4.8
Error/measurement (%) (L_m) RNG	23	6	4.8

Concluding remarks

* Ejector with zero secondary flow:

- **RNG and k-omega-sst** models provide **good** and **comparable** results.
- More discrepancies in **expansions (condensation**?)

* CFD-experiments **integration**: CFD revealed that **intrusive** measurement systems should be **included** in models for supersonic flows

* **Preliminary** tests conducted with induced flow have shown that the **k-omega-sst model** accounts best for the mixing

⇒ A **wide range** of operating conditions needs to be modeled with **induced** flow: non-**shocked** to **shocked** ejector

⇒ + **More realistic** boundary conditions at the secondary inlet: total pressure

⇒ To check : - **entrainment ratio**: m2/m1 } To **ascertain** the selection of the

- **local profiles** } k-omega-sst model