MODELLING OF TURBULENT FLOWS IN RECTANGULAR DUCTS OF CONSTANT SECTION USING OPENFOAM

Raquel Faria[a, b, *], Almerindo D. Ferreira[b], A.M.G. Lopes[b], Antonio C.M. Sousa [c]

[a] *Polytechnic Institute of Coimbra, ISEC, Department of Mechanical Engineering, Portugal*
[b] *ADAI-LAETA, Department of Mechanical Engineering, University of Coimbra, Portugal*
[c] *Department of Mechanical Engineering, University of New Brunswick, Canada*

**rfaria@isec.pt*

11th OpenFOAM® Workshop – 2016

2016 – 06 – 27

INTRODUCTION

Introduction

- Motivation?
  - Important technical applications (engineering practice)
    - Non-circular ducts
    - Turbulent flow
  - Improve equipment effectiveness
- Why?
  - Understanding and characterization
  - Most common ducts:
    - **Rectangular**
    - Triangular
    - Square

Results presentation

- Dimensionless parameters
  - Pressure and Friction coefficient

$$C_p = \frac{p - p_{ref}}{\frac{1}{2}\rho U^2}$$

$$C_f = \frac{D_h \frac{\partial p}{\partial x}}{\frac{1}{2}\rho U^2} = \frac{\tau_w}{\frac{1}{2}\rho U^2}$$

- Wall shear stress
  - *Preston* tube (Preston, 1954)
  - *Irwin* probes (Irwin, 1981)

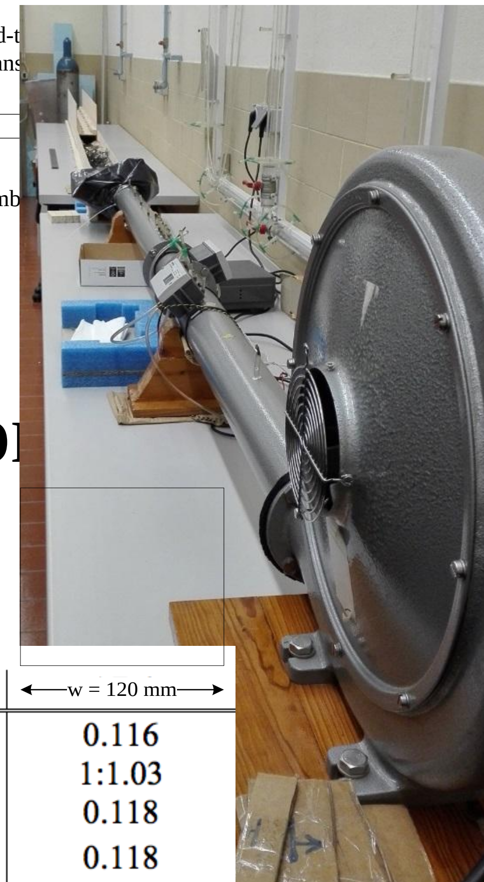
Work purpose

- Check the applicability of both *Preston* tubes and *Irwin* probes in ducts:
  - Constant section
  - Variable section
    - Convergent
    - Divergent

EXPERIMENTAL PROGRAM

Apparatus

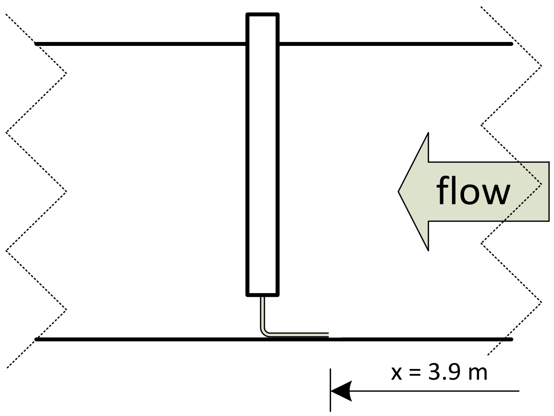
- Plywood rectangular duct:

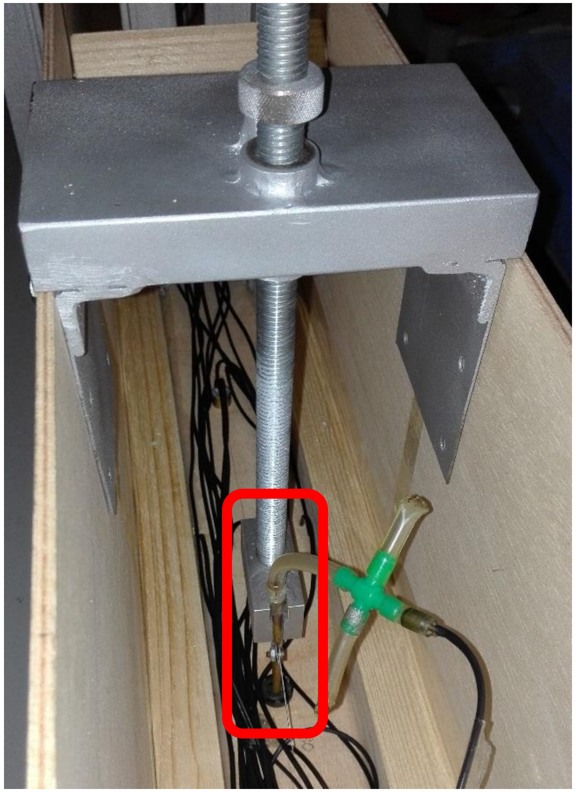


Case	AR1	AR2	AR3	← w = 120 mm →
Height [m]	0.030	0.045	0.060	0.116
Aspect Ratio (AR)	1:4.00	1:2.67	1:2.00	1:1.03
D_h *[m]*	0.048	0.065	0.080	0.118
$\sqrt{A}$ *[m]*	0.060	0.073	0.085	0.118
D_L *[m]*	0.042	0.062	0.081	0.133

Preston tube

- Geometry



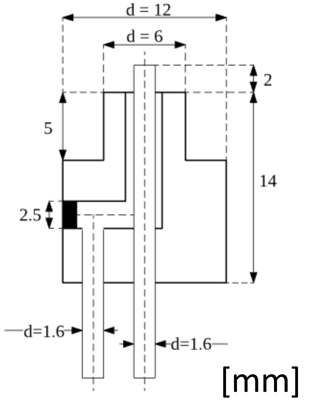


- Calibration
  - Patel (1965)
  - Bechert (1996)

$$\tau^{+} = \left[28.44\, \Delta p^{+^{2}} + (6.61 \times 10^{-6}) \Delta p^{+^{3.5}}\right]^{\frac{1}{4}}$$

Irwin probes

- Geometry



- Wall shear stress (τ_w)
  - Obtained by calibration (*Preston* tubes)

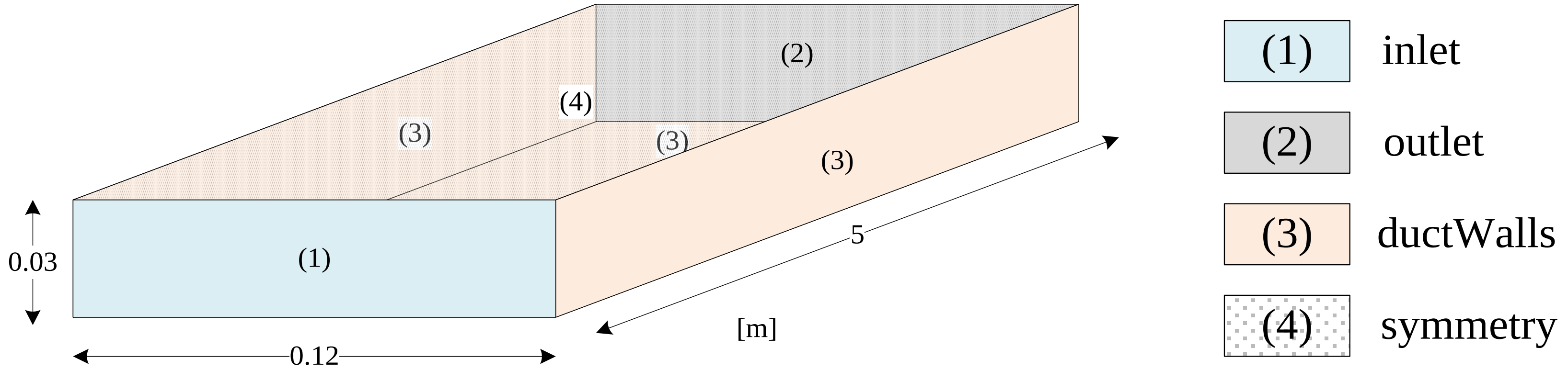
$$\tau_w = f(\Delta p_I)$$

[m]

NUMERICAL SETUP

Numerical simulations

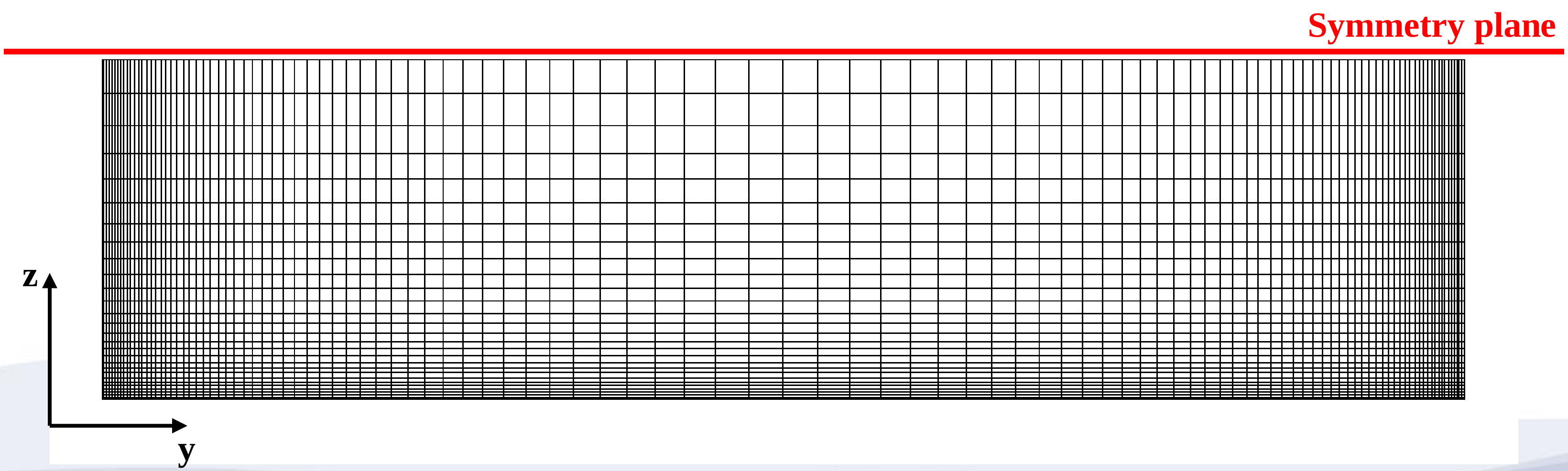
- **Computational domain**



- **CFD Package:**
  - OpenFOAM
  - ANSYS CFX

Mesh

- blockMesh
  - 2 blocks
  - simpleGrading (expansion outward the walls)
  - $0.5 < y^+ < 140$



Case Setup

- Steady state
- Incompressible flow
- Solver: **simpleFoam**
- Turbulence model: **kOmegaSST**
- Convergence criteria: **1E-5**

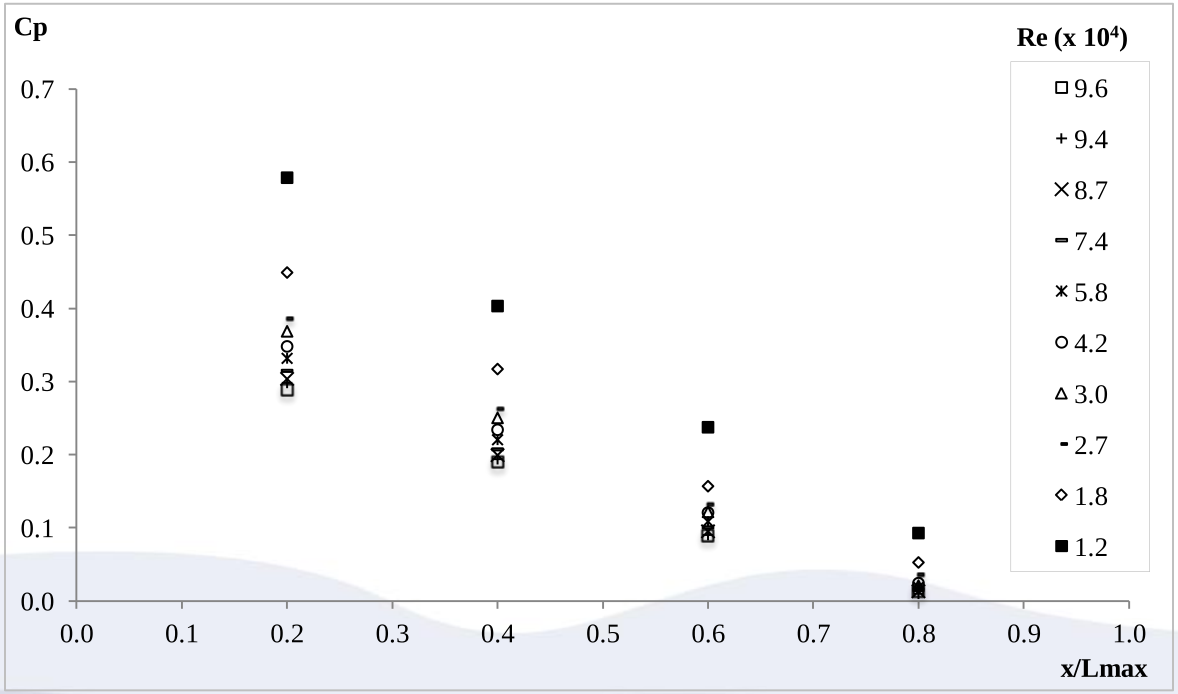
Boundary Conditions

- **inlet**
  - fixedValue (k, w, U)
- **outlet**
  - fixedValue (p)
- **ductWalls**
  - no slip condition
- **symmetry**
  - symmetry

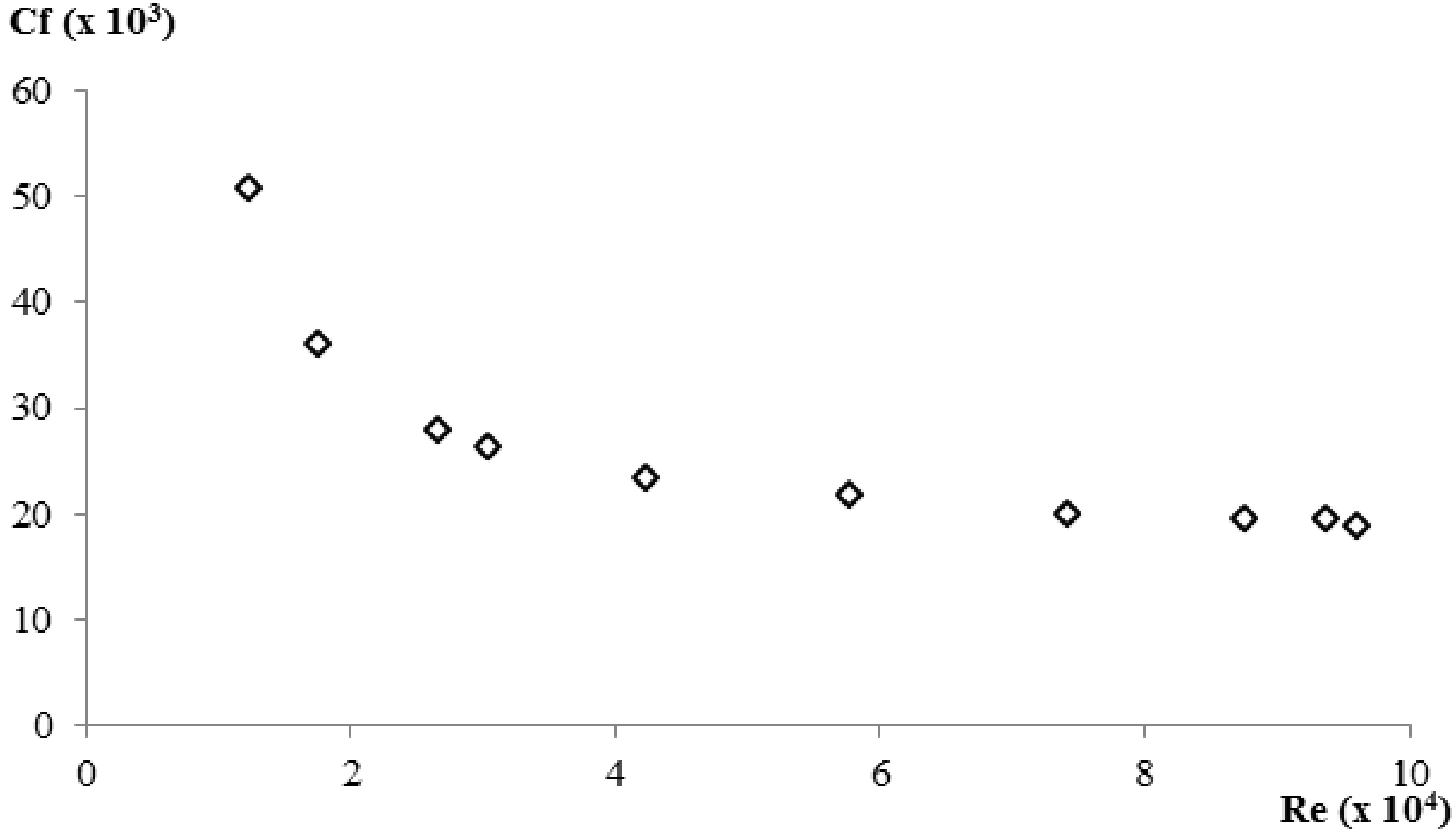
EXPERIMENTAL RESULTS

Pressure coefficient

- Distribution along the streamwise direction (Case AR3)



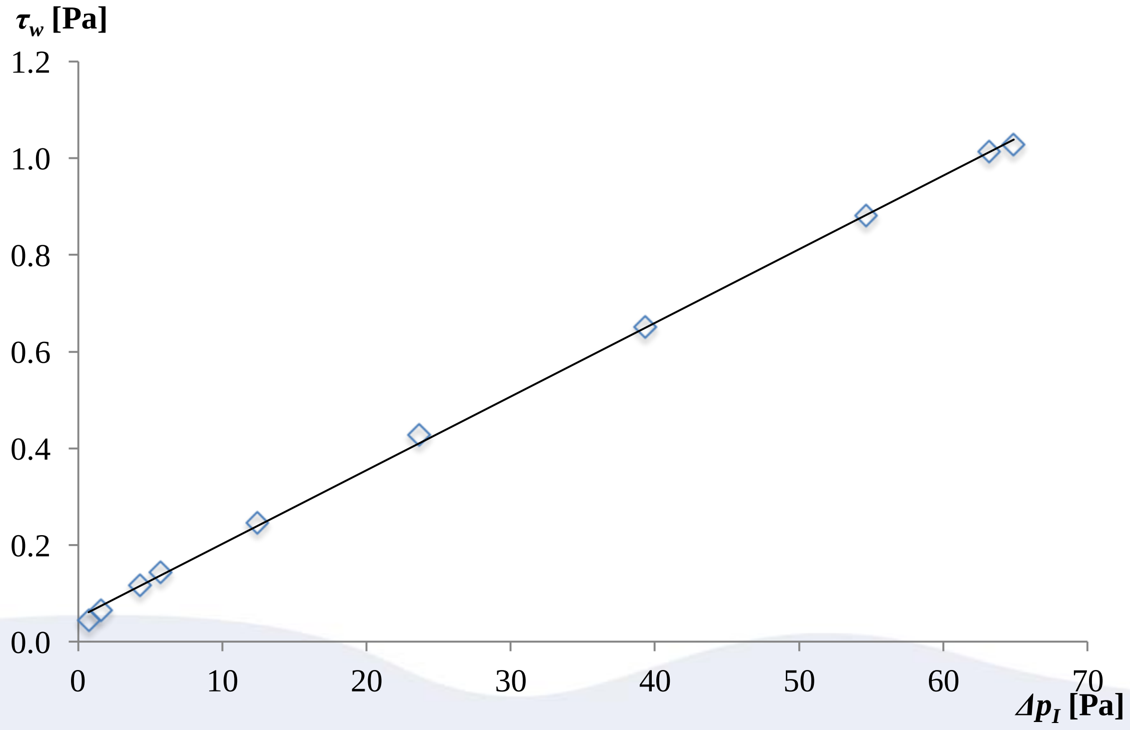
Friction coefficient



Irwin probes

- Calibration ($x/L_{max} =$ 0.56)

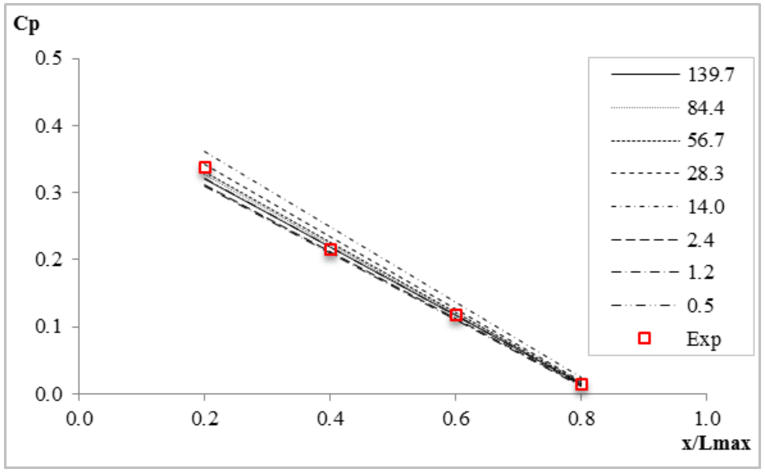
$$\tau_w = 0.0152\,\Delta p_I + 0.0498$$

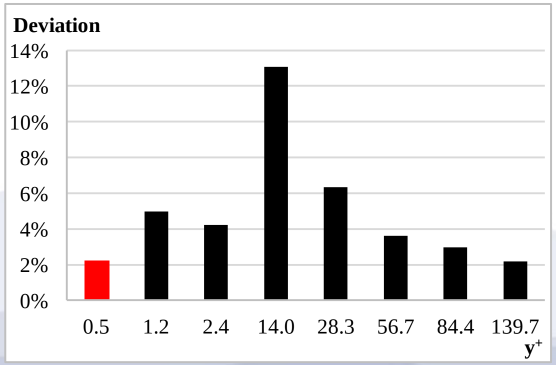


NUMERICAL RESULTS

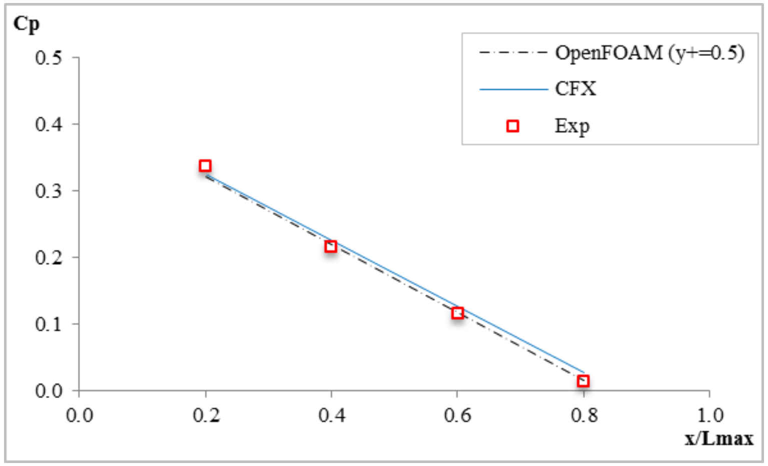
Pressure coefficient

Mesh study in OpenFOAM (various values of y^+)

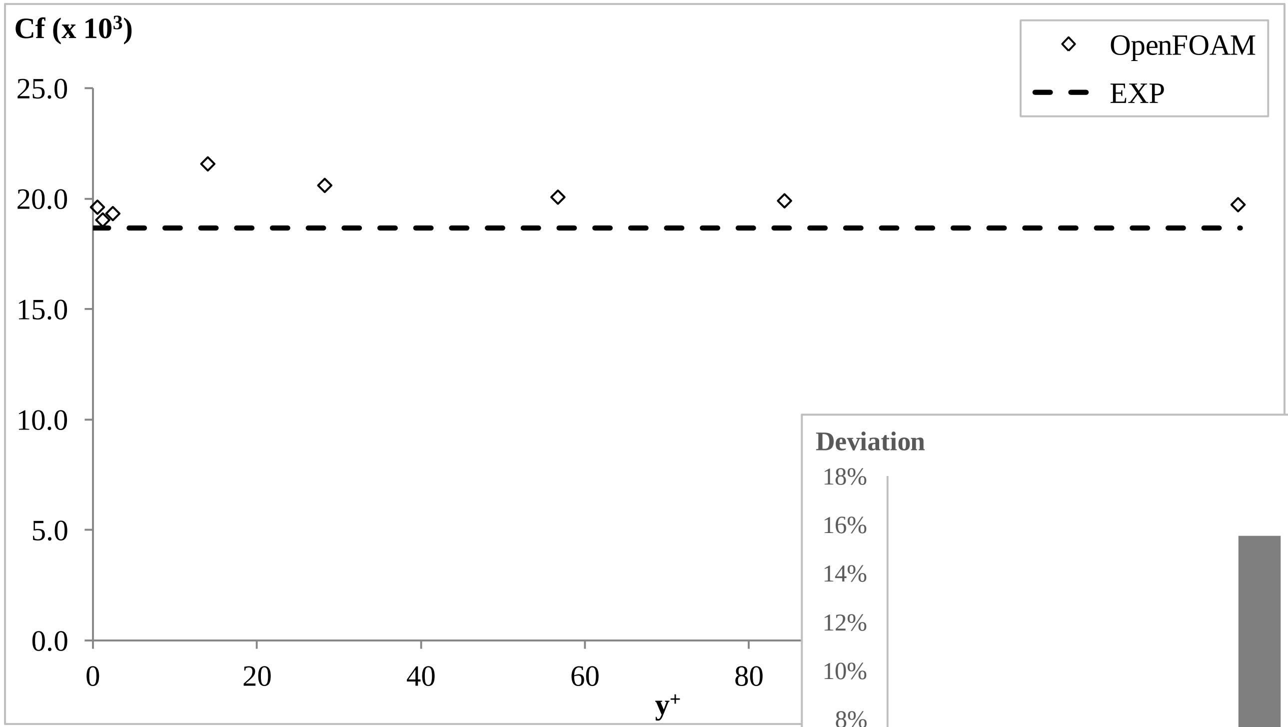


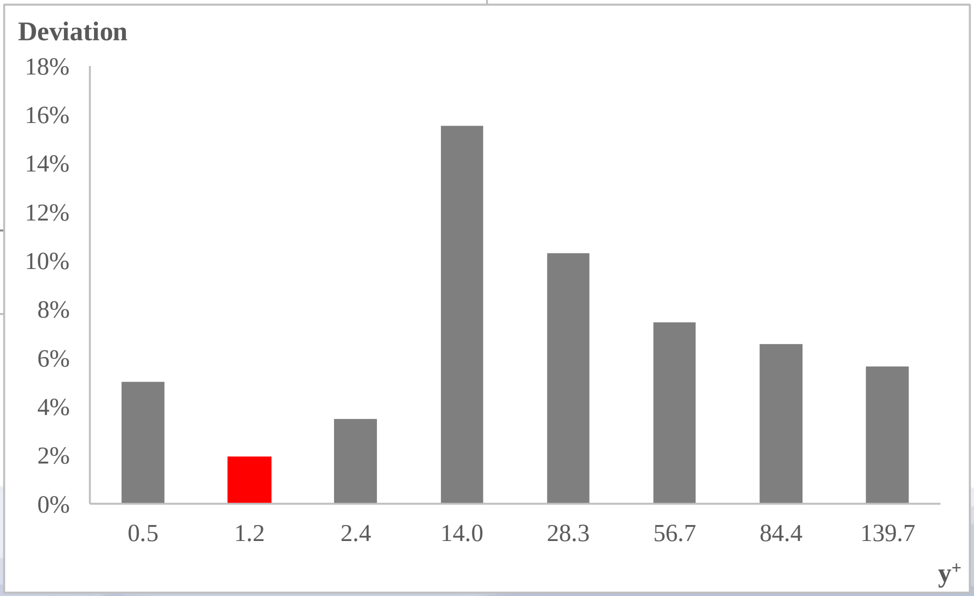


Experimental results vs OpenFOAM and CFX

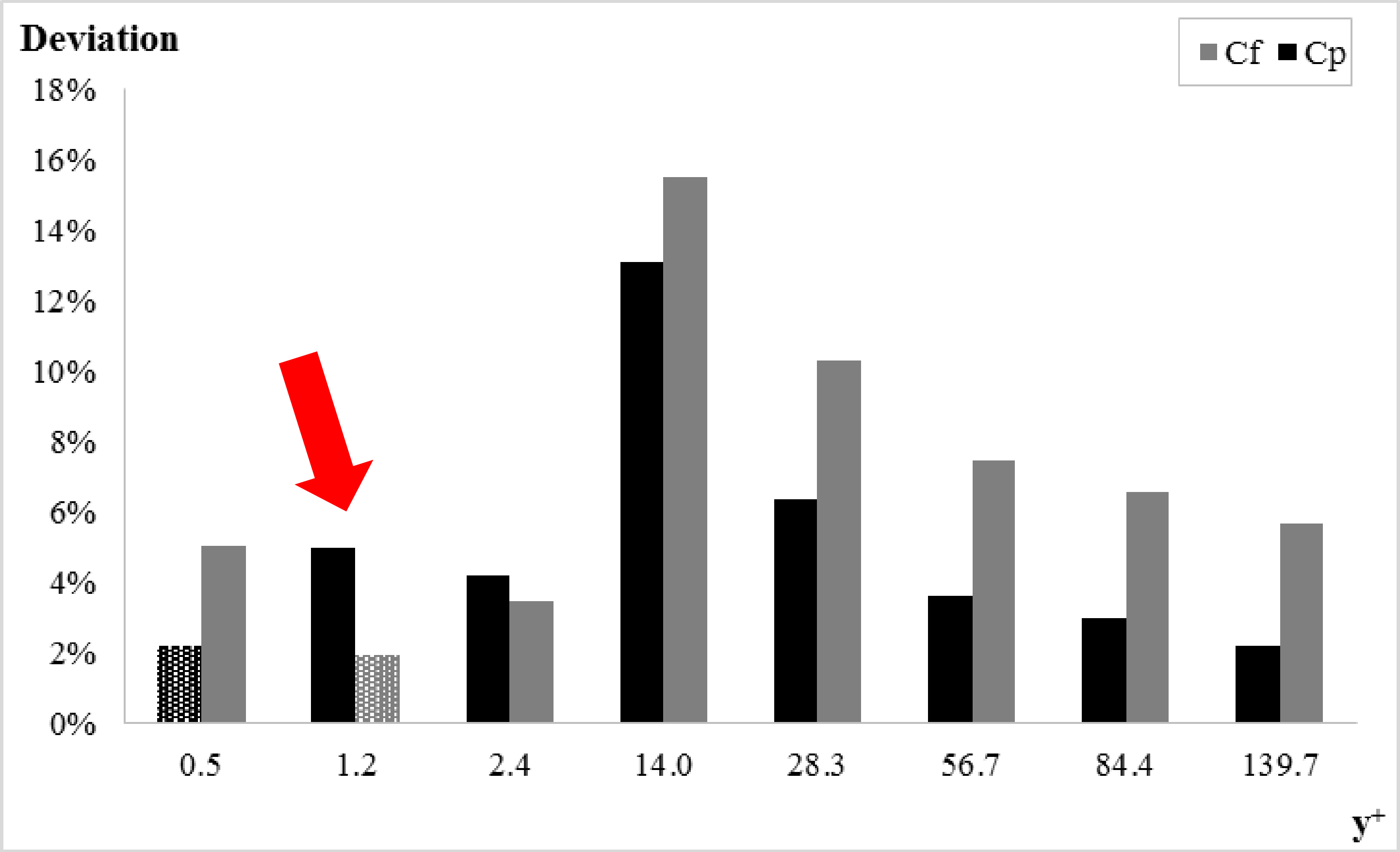


Friction coefficient ($x/L_{max} = 0.56$)



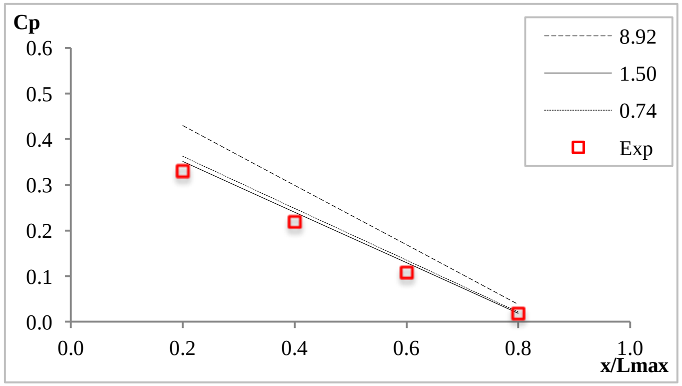


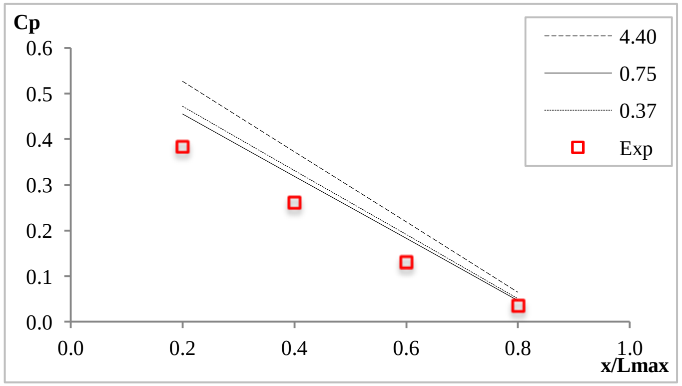
Overall performance

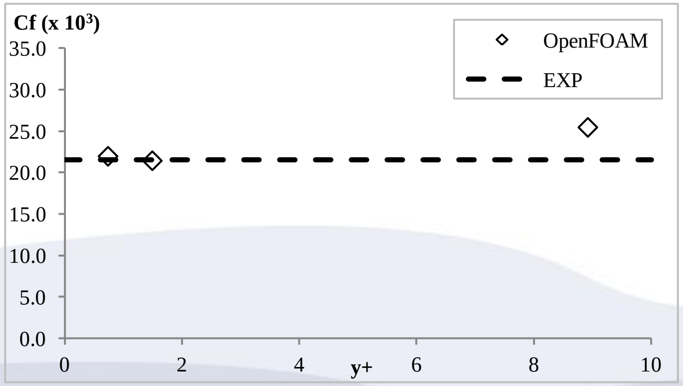


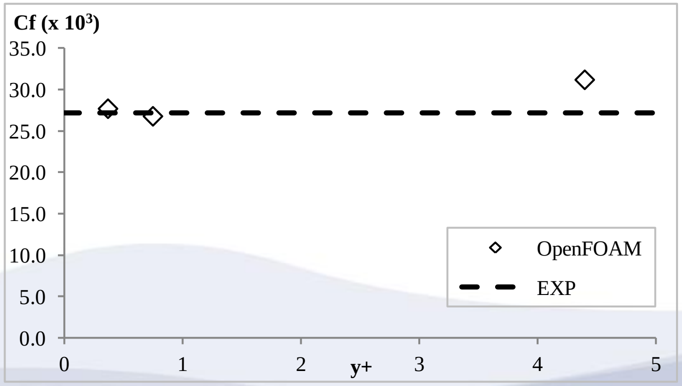
Velocity influence

0.6 U_{max}	0.3 U_{max}





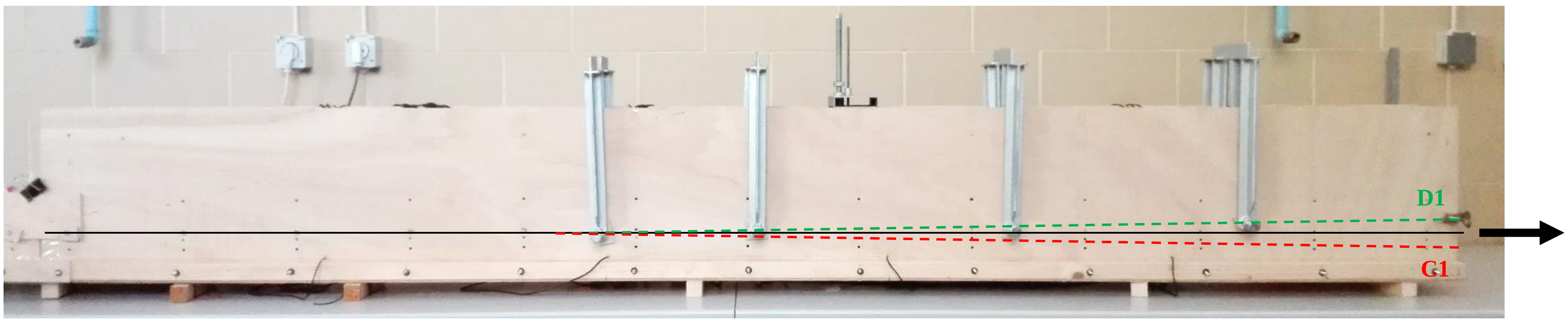


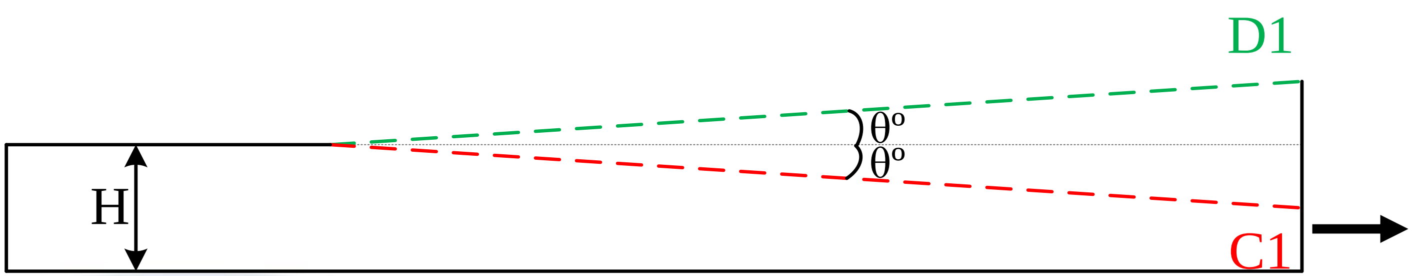


Recent Results…

DUCT WITH VARIABLE SECTION

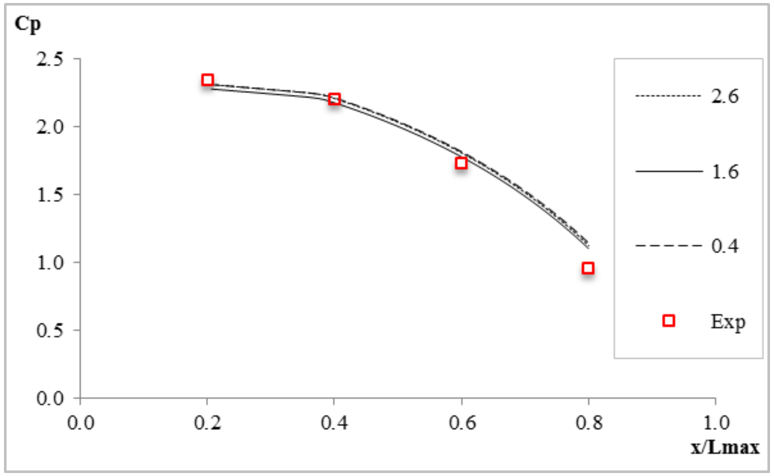
Apparatus

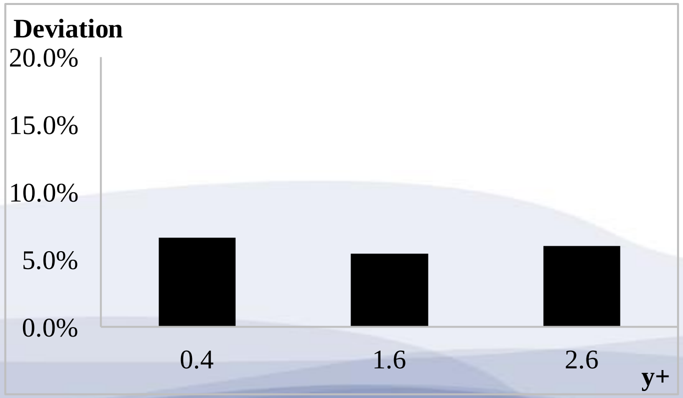




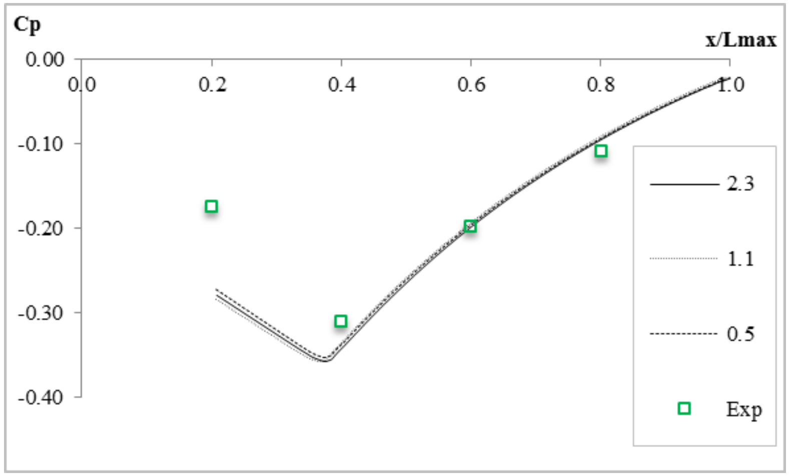
Pressure Coefficient

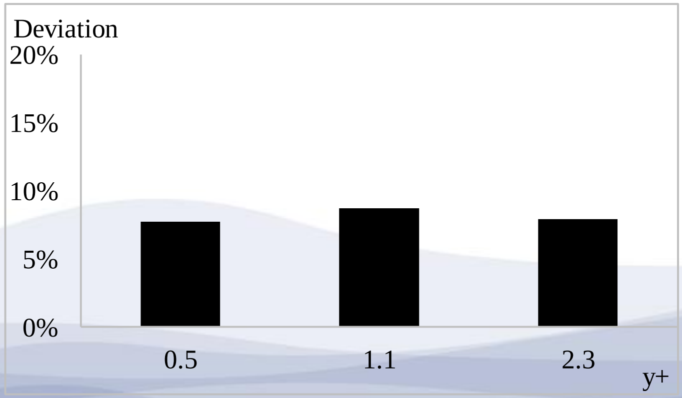
Convergent





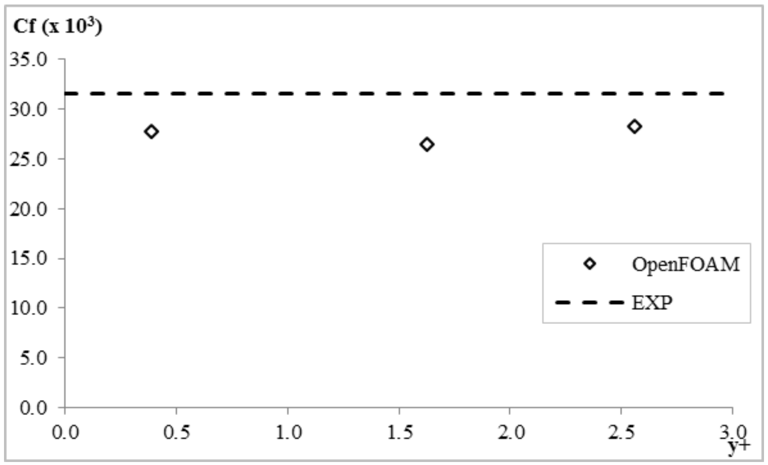
Divergent

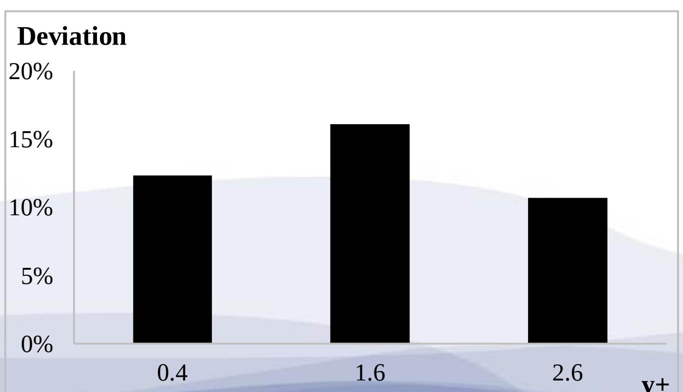




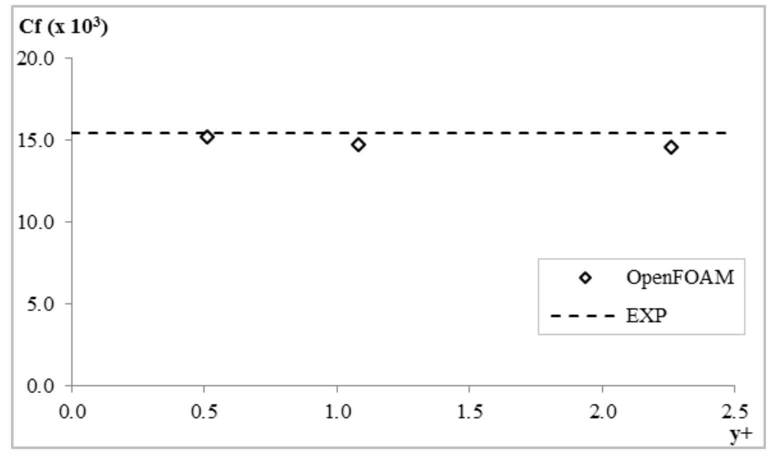
Friction Coefficient ($x/L_{max} = 0.56$)

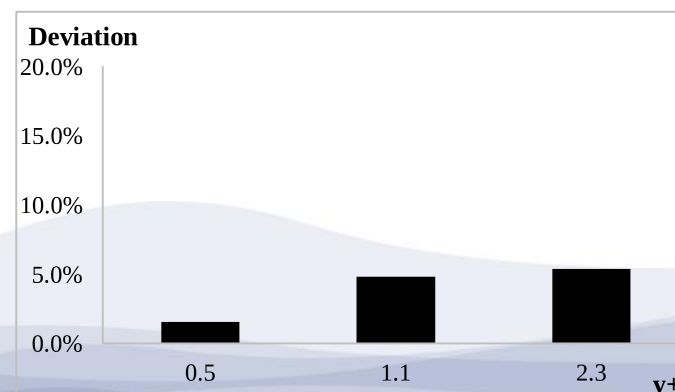
Convergent





Divergent





Patel (1965)

- *"… in both favourable and adverse pressure gradients the Preston tube tend to overestimate the skin friction…"*
- *"…in adverse and favourable pressure gradients the following limiting values of Δ are suggested if Preston tubes are to record τ_0, within the prescribed error range."*

(i) Adverse pressure gradients— **(Divergent)**

maximum error 3 %: $0 < \Delta < 0{\cdot}01$, $U_\tau d/\nu \leqslant 200$;

maximum error 6 %: $0 < \Delta < 0{\cdot}015$, $U_\tau d/\nu \leqslant 250$.

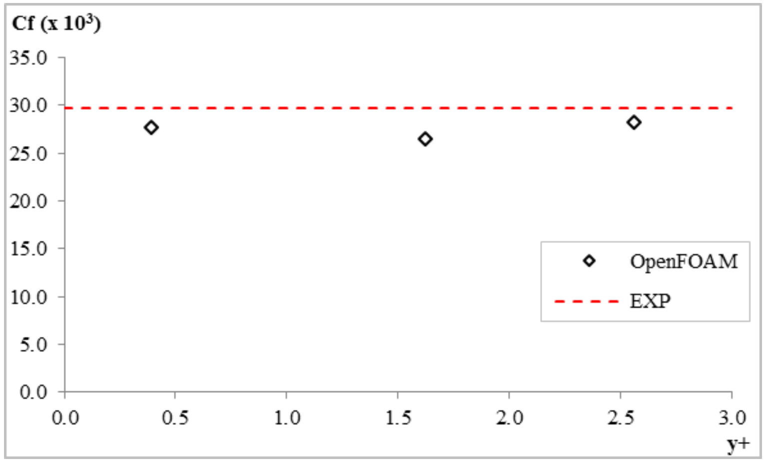
(ii) Favourable pressure gradients— **(Convergent)**

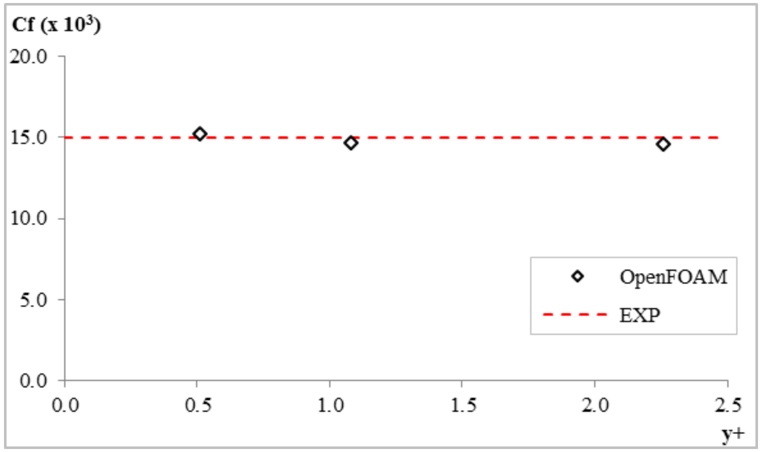
maximum error 3 %: $0 > \Delta > -0{\cdot}005$, $U_\tau d/\nu \leqslant 200$, $d/dx(\Delta) < 0$;

maximum error 6 %: $0 > \Delta > -0{\cdot}007$, $U_\tau d/\nu \leqslant 200$, $d/dx(\Delta) < 0$.

Friction Coefficient

Convergent	Divergent





CONCLUSIONS

Conclusions

- Applicability of both *Preston* tubes and *Irwin* probes in ducts of constant and variable section
- Rectangular ducts
  - AR = 1:2.00
  - $10^4 < Re < 9 \;\; 10^4$
- Fully developed flow - pressure decreases linearly towards the exit
- Wall shear stress - Reynolds independency
- *Irwin* probes calibration – linear approximation

Conclusions

- OpenFOAM - $0.4 < y^+ < 140$
- Constant section
  - **Pressure coefficient** – best agreement for $y^+ = 0.5$
  - **Friction coefficient** – best agreement for $y^+ = 1.2$
  - **Overall performance** – $y^+ \approx 1$
- Variable section
  - **Pressure coefficient** – good agreement for both cases
  - **Friction coefficient**
    - Best results for divergent section
    - Considering the limitations studied by Patel (1965), the comparison against the measured results have improved

MODELLING OF TURBULENT FLOWS IN RECTANGULAR DUCTS OF CONSTANT SECTION USING OPENFOAM

Raquel Faria *, Almerindo D. Ferreira, A.M.G. Lopes, Antonio C.M. Sousa

**rfaria@isec.pt*

11th OpenFOAM® Workshop – 2016

2016 – 06 – 27