Western Engineering

# A comparative study of plane and radial turbulent wall jets


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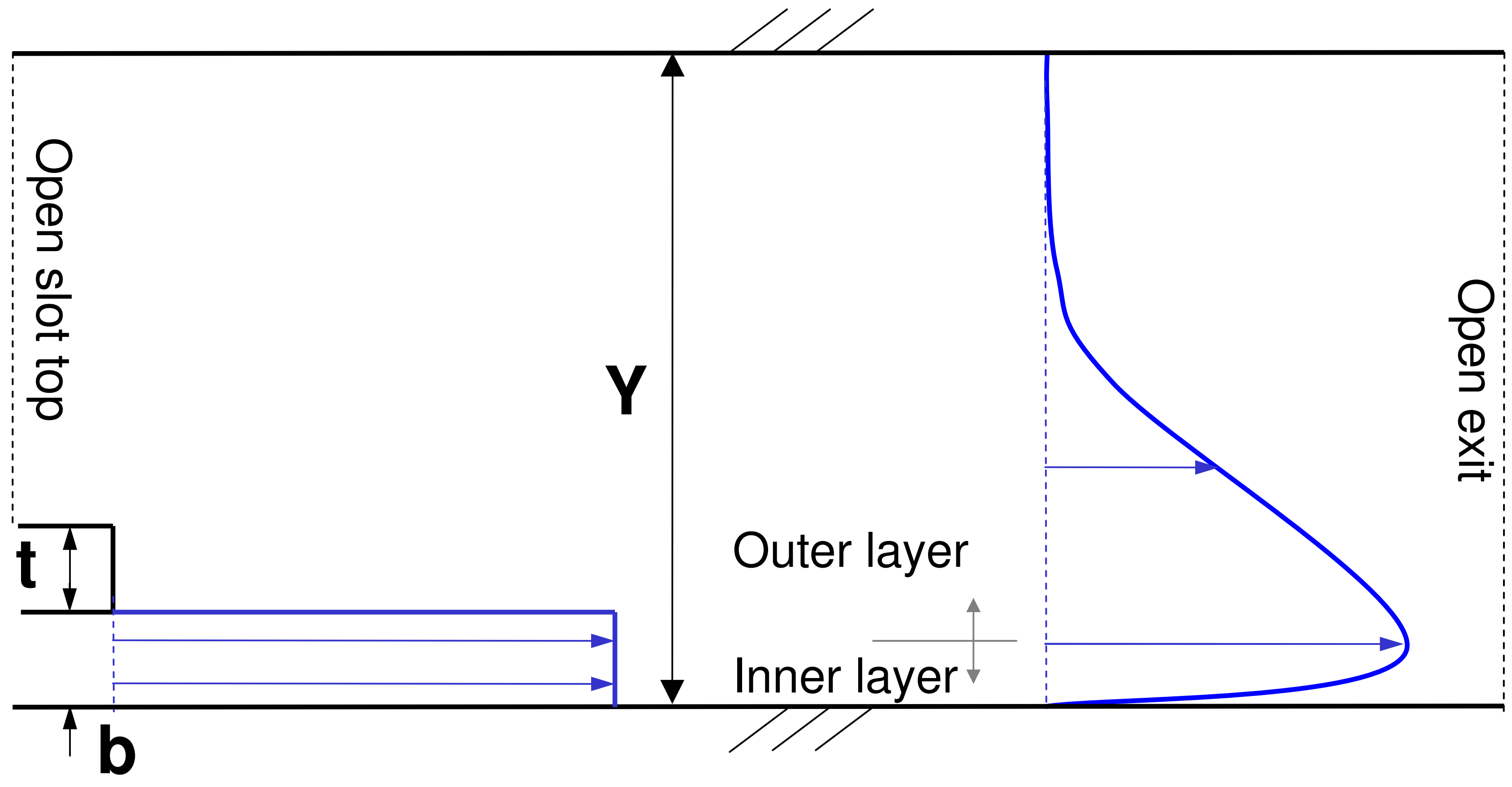
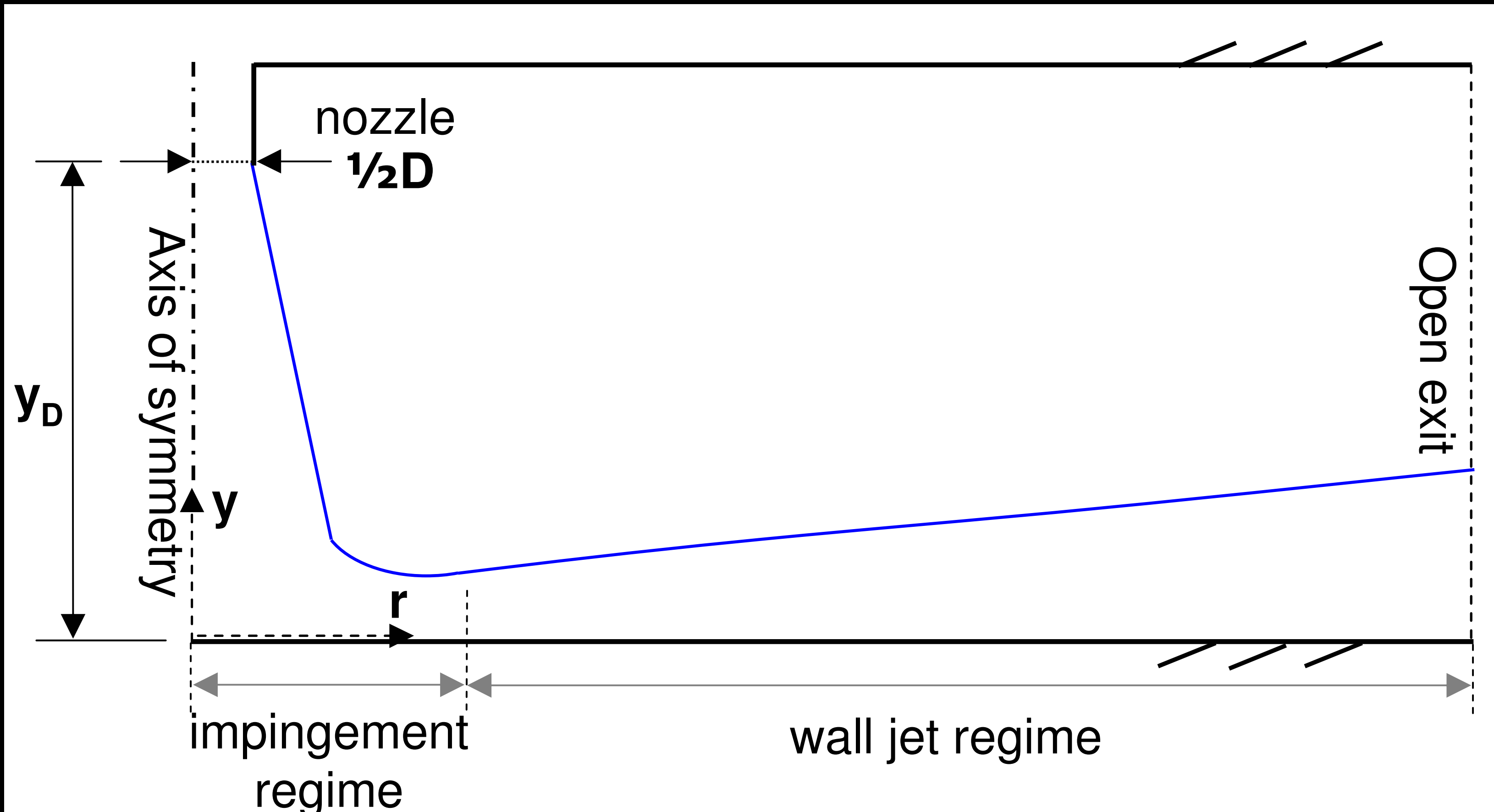
# Outline

1. Introductory remarks
   - Overview of two configurations
   - Motivation
   - Objectives
2. Plane wall jet velocity measurements
3. Comparison of plane and radial wall jets
4. Closing remarks

# Brief overview of the plane wall jet



# Brief overview of the radial wall jet



# Motivation

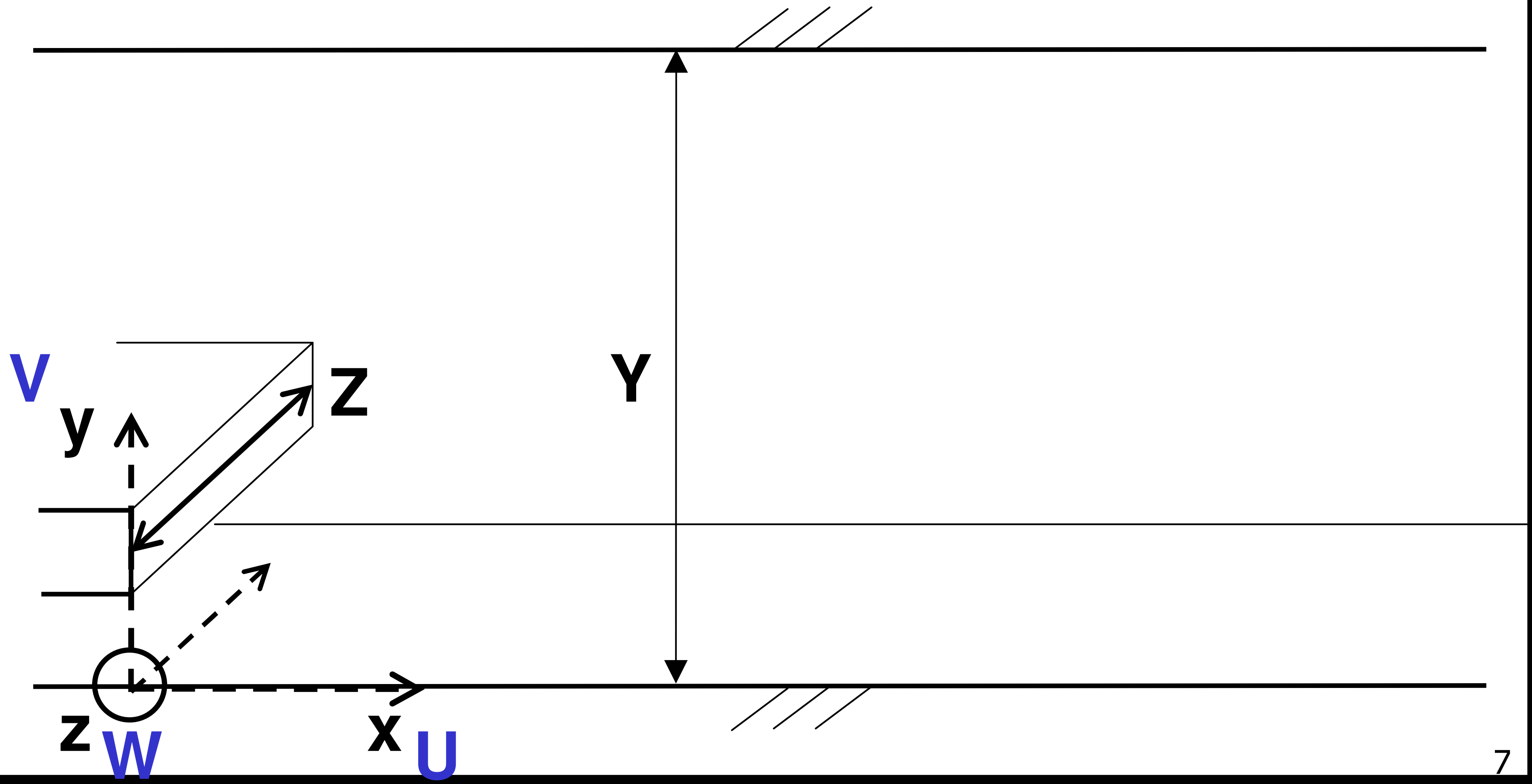
Applications:

- heating/cooling or drying/wetting
- removal or deposition of particles/films
- protective fluid layer
- modelling of storm outflows

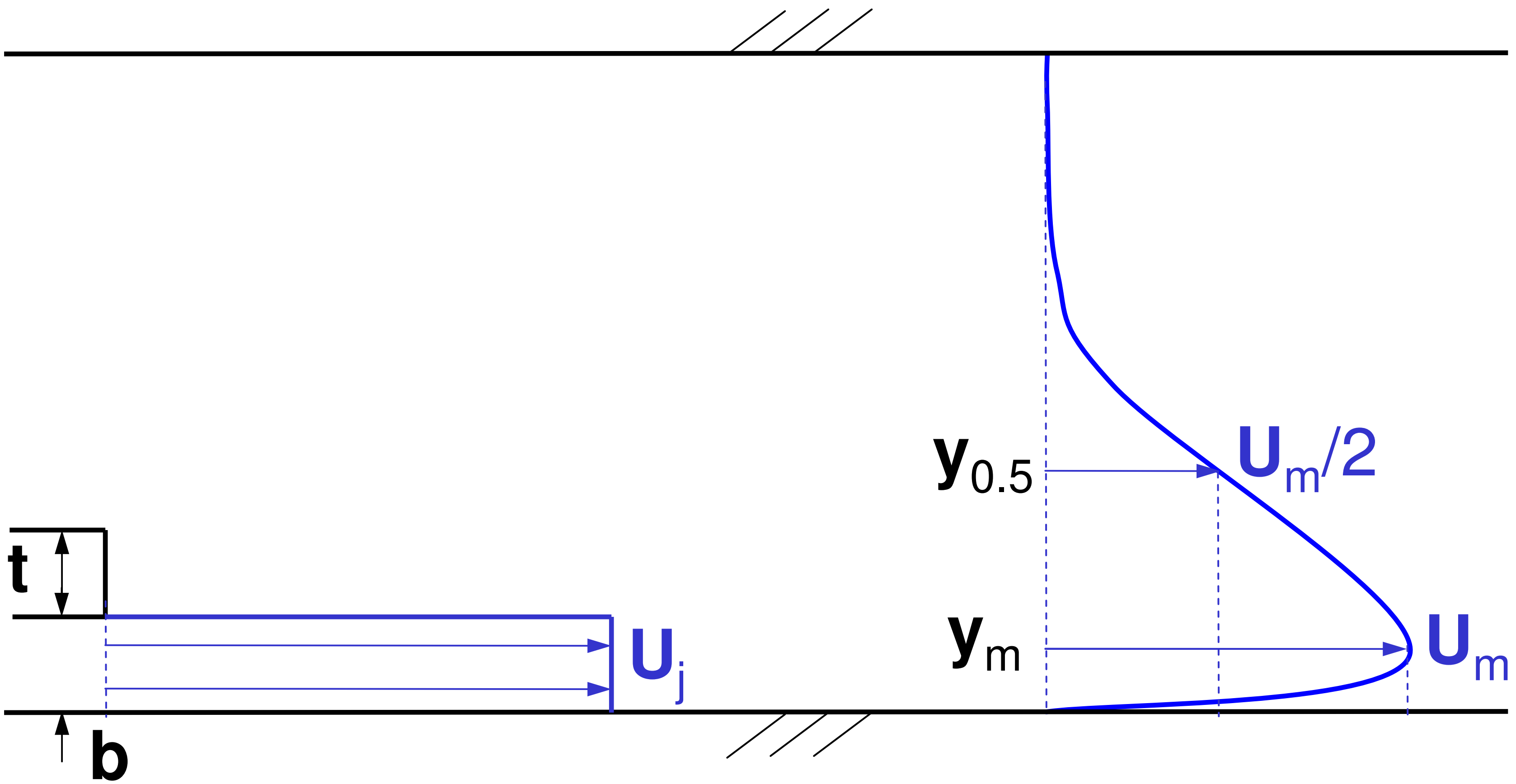
# Objectives

- To take velocity measurements of the plane turbulent wall jet
- To compare available experimental results from plane and radial wall jets.

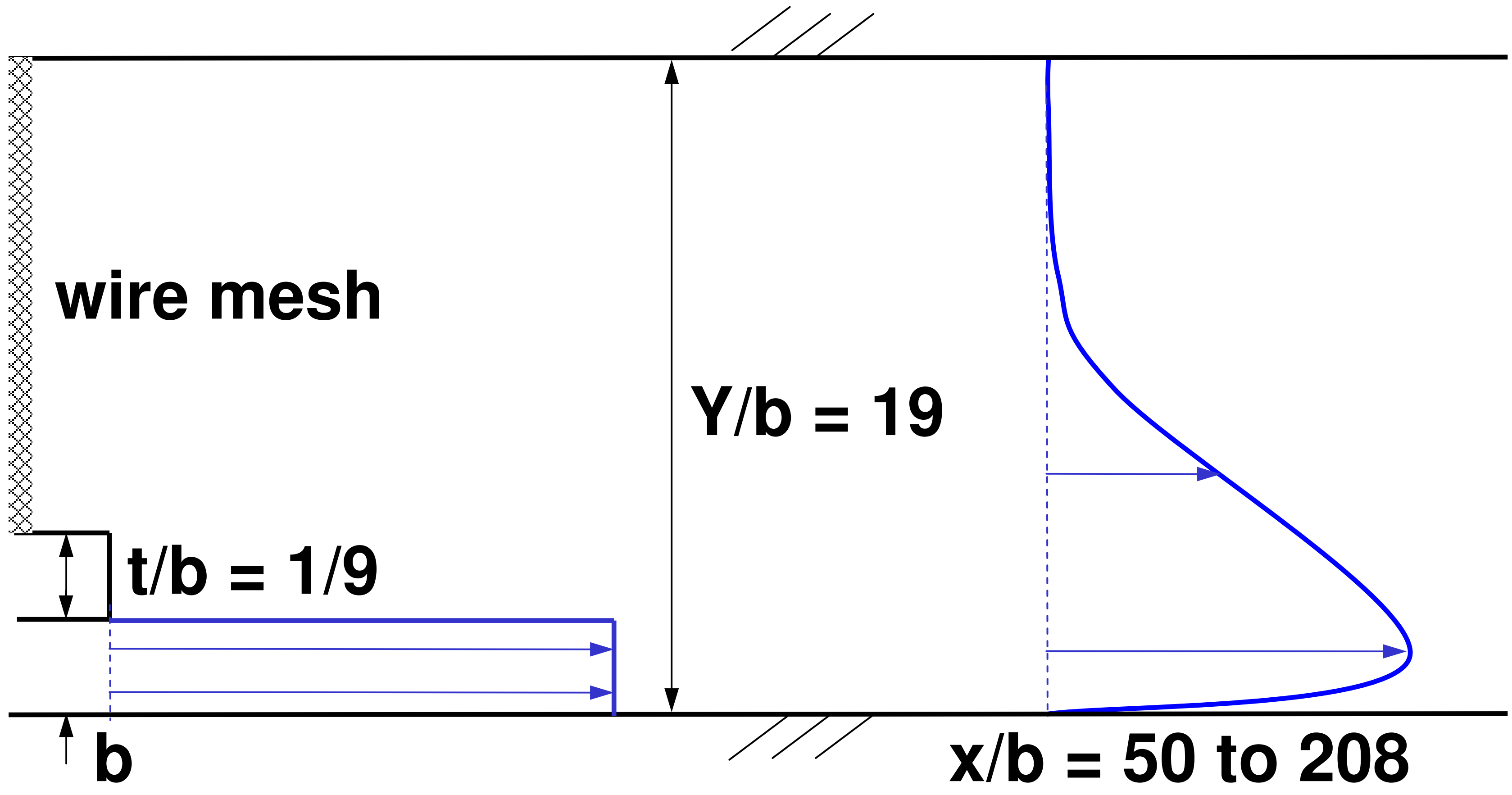
# Co-ordinate system



# Nomenclature



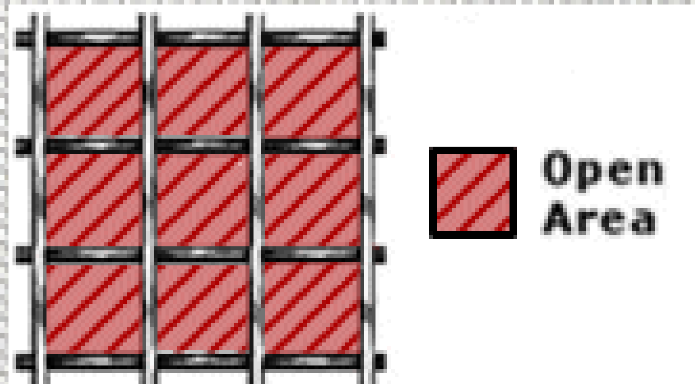
# Experimental set-up



# Experimental set-up

**Wire mesh**

- 16 x 16 openings/$in^2$
- $D_{wire}$ = 0.46 mm
- open area = 50.7%



# Measurement apparatus

## Dantec MiniCTA 54T30 system

- sampling frequency = 1 kHz

## 55P61 x-wire probe

- wire diameter = $5 \times 10^{-6}$ m
- wire length = $1.25 \times 10^{-3}$ m


## Calibration

- Pitot-static tube + U-tube manometer

## Traverse

- accuracy = $0.2 \times 10^{-3}$ m

## NI PCI-6071E card

- 12-bit resolution

# Uncertainty analysis

Propagation-of-uncertainties approach

(Wheeler & Ganji 1996)

U = f(A, B, C, ...)

$$\Delta U = \left[ \left( \frac{\partial U}{\partial A} \Delta A \right)^2 + \left( \frac{\partial U}{\partial B} \Delta B \right)^2 + \left( \frac{\partial U}{\partial C} \Delta C \right)^2 + \dots \right]^{1/2}$$

# Uncertainty analysis

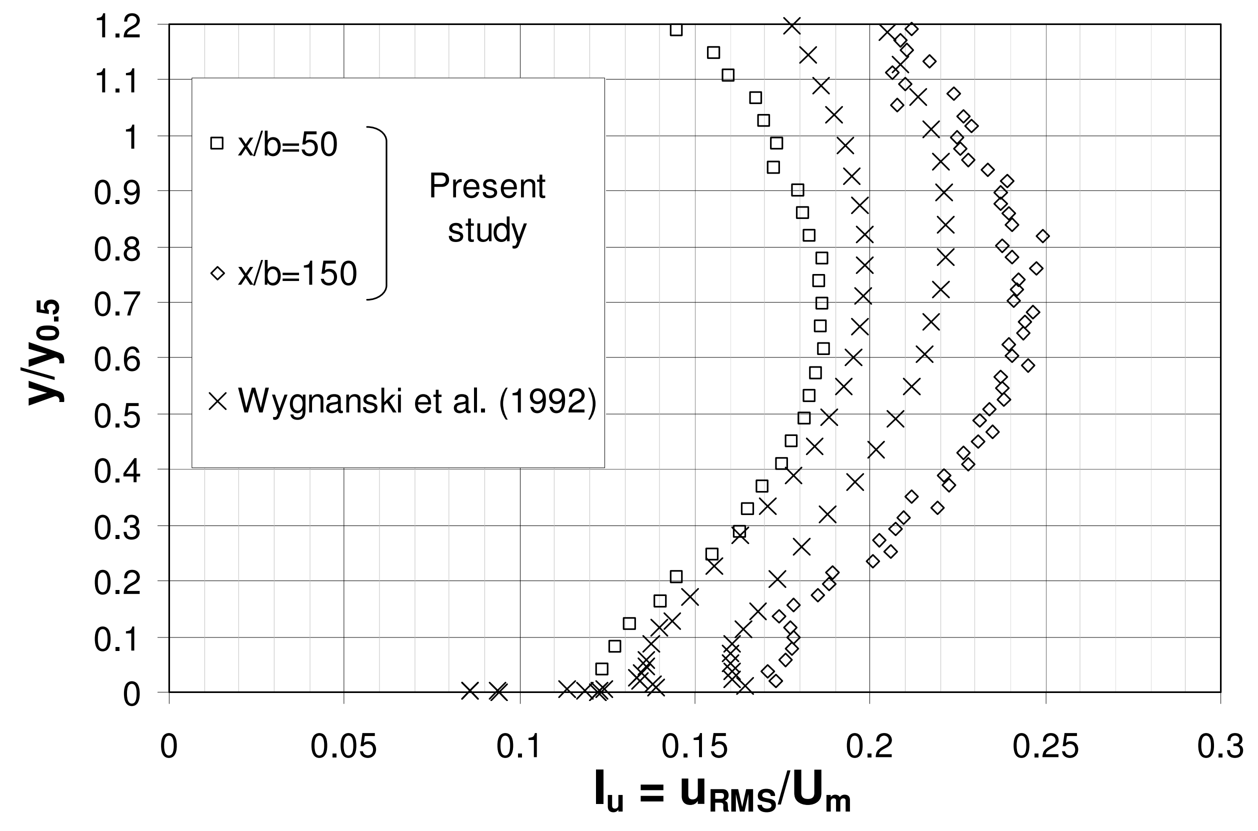
Sources of uncertainty considered:

- Random variation of the measurand
- Ambient temperature variations during measurements
- Potential x-wire probe misalignment (≤ 2°)
- Potential pitot-static tube misalignment (≤ 2°)
- A/D conversion uncertainties
- Scale readability limitation of the calibration manometer
- Calibration curve-fitting
- X-wire probe yaw coefficient uncertainties

# Uncertainty analysis

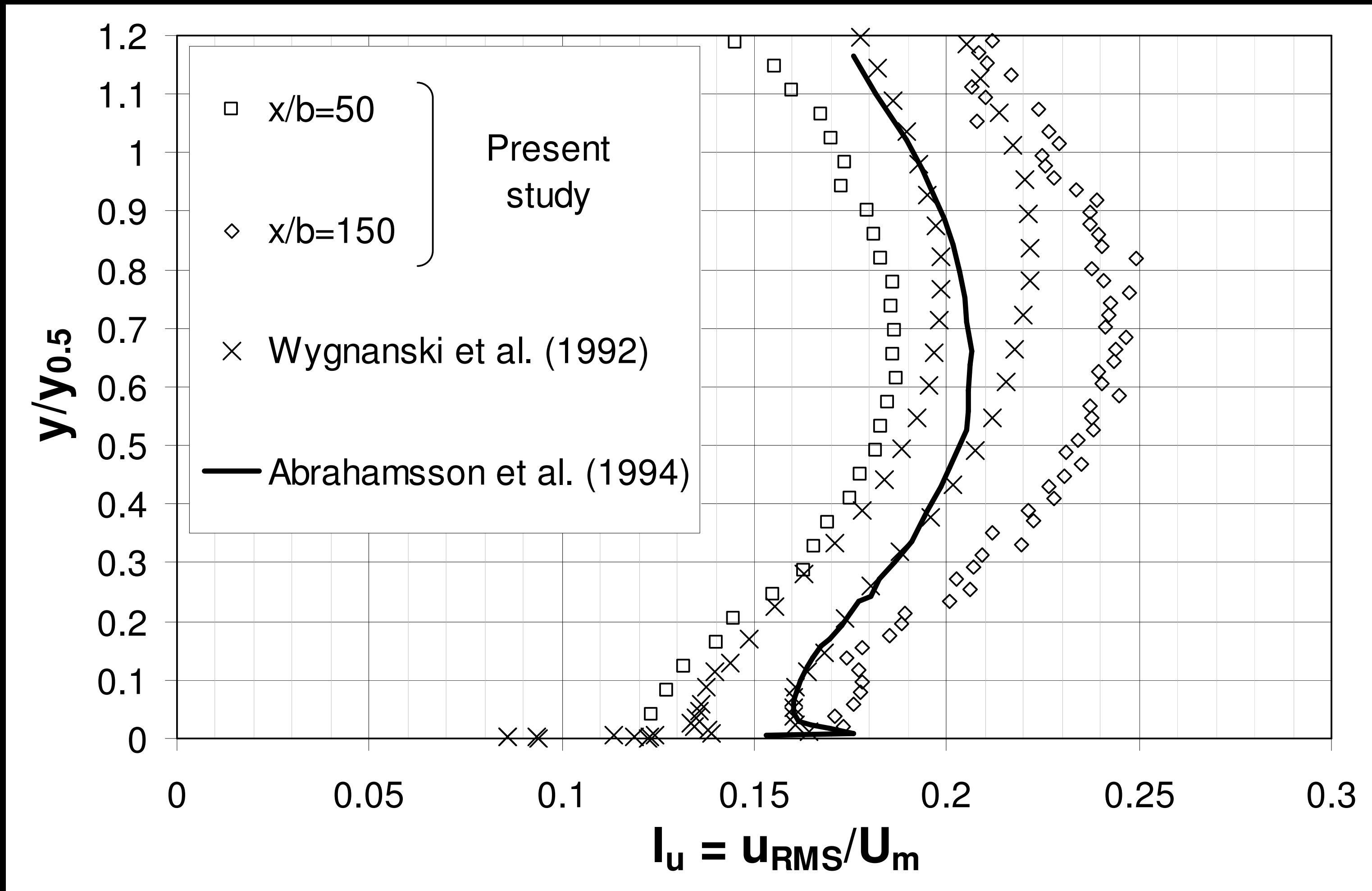
| U [m/s] | ±ΔU [%] |
|---|---|
| 41 | 3.2 |
| 37 | 3.3 |
| 31 | 3.4 |
| 28 | 3.5 |
| 24 | 3.7 |
| 20 | 4.1 |
| 15 | 4.3 |
| 12 | 4.8 |
| 7.9 | 6.1 |
| 5.0 | 8.4 |

# Plane wall jet velocity profiles




| Study | $Re_b$ | x/b | t/b | Y/b | similarity? |
|---|---|---|---|---|---|
| Present study | 4.0E+04 | 50, 150 | 0.1 | 21 | no |
| Wygnanski et al. (1992) | 1.9E+04 | 60 to 120 | <1 | 61 | no |

# Plane wall jet velocity profiles



# Plane wall jet velocity profiles

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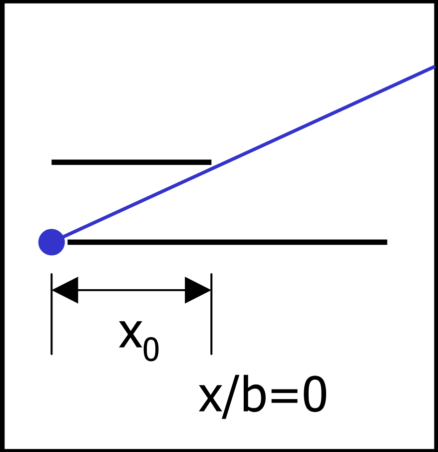
| Wygnanski et al. (1992) | 1.9E+04 | 60 to 120 | <1 | 61 | no |
| Eriksson et al. (1998) | 9.6E+03 | 40 to 150 | 107 | 108 | yes |
| Abrahamsson et al. (1994) | 1.0E+04<br>2.0E+04 | 70 to 150<br>125 to 150 | 239 | 240 | yes |

# Plane wall jet development

Jet spread

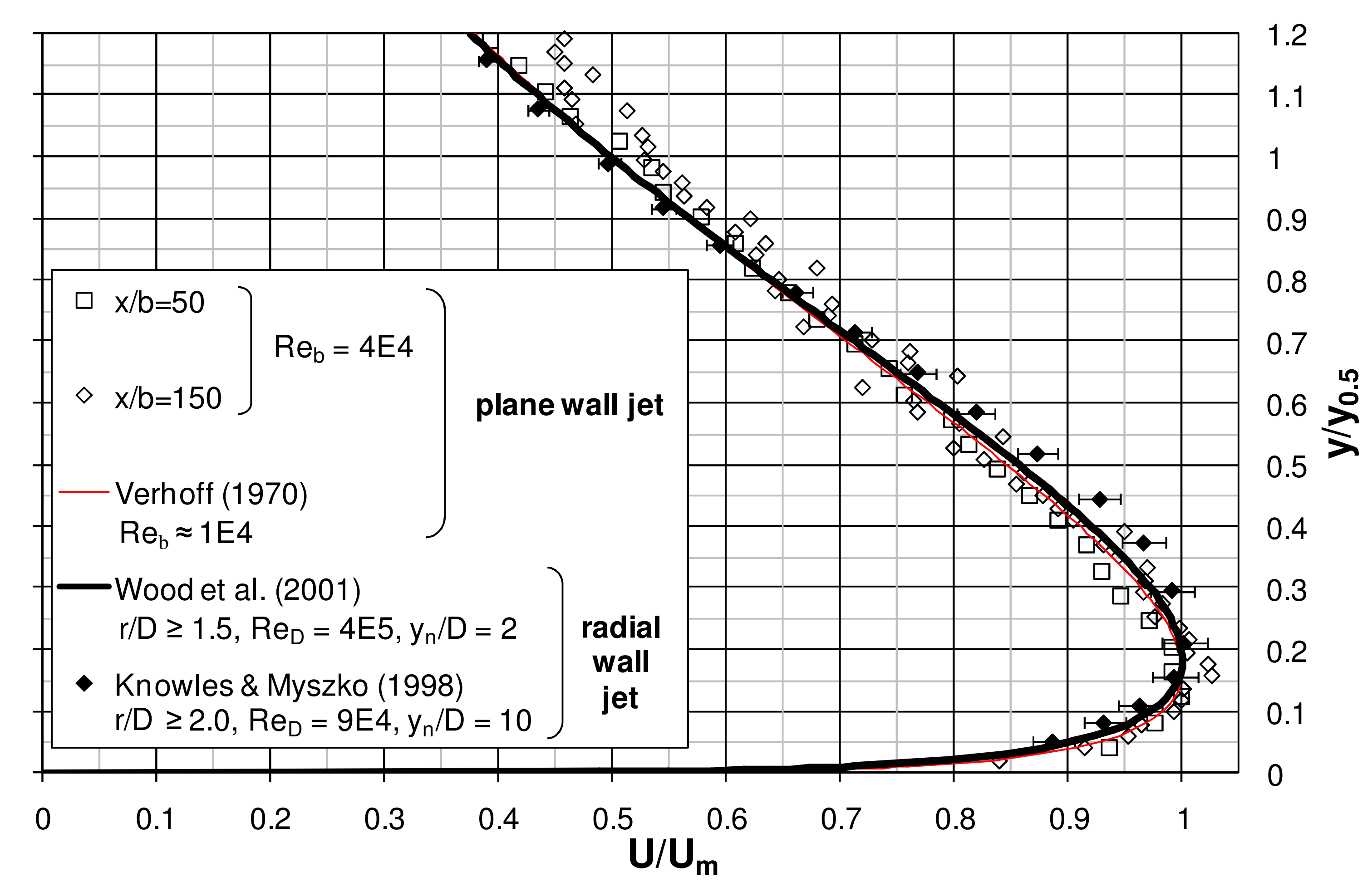
$$\frac{y_{0.5}}{b} = A\left(\frac{x + x_0}{b}\right)^m$$




m =1

(14 of 16 experiments)

# Velocity profile comparison



# Velocity profile comparison

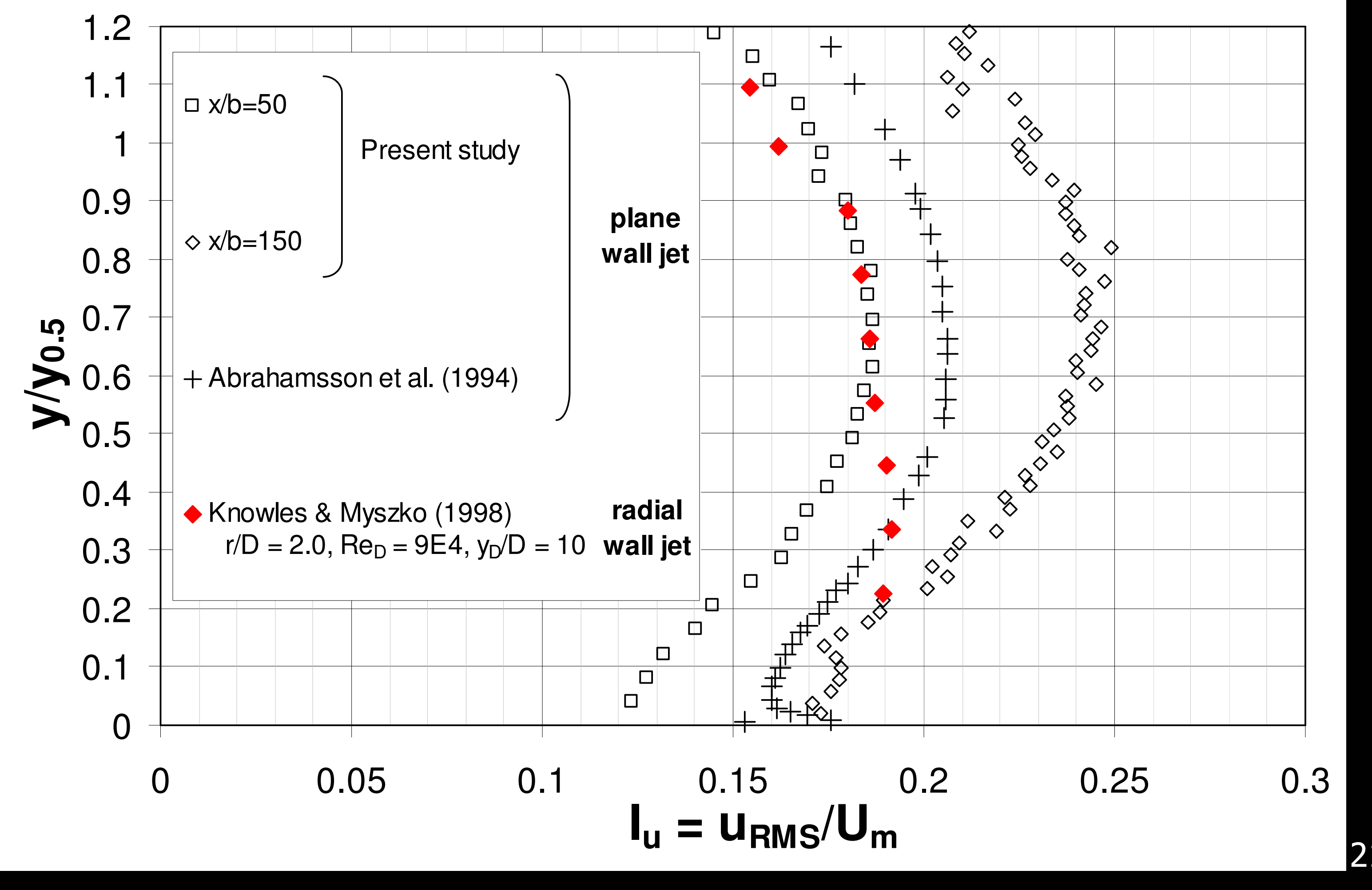
Plane wall jet (Verhoff 1970)

$$\frac{U}{U_m} = 1.48\left(\frac{y}{y_{0.5}}\right)^{1/7}\left(1 - erf\left(0.68\left(\frac{y}{y_{0.5}}\right)\right)\right)$$

Radial wall jet (Wood et al. 2001)

$$\frac{U}{U_m} = 1.55\left(\frac{y}{y_{0.5}}\right)^{1/6}\left(1 - erf\left(0.70\left(\frac{y}{y_{0.5}}\right)\right)\right)$$

# Velocity profile comparison



# Jet spread comparison

## Plane wall jet

| Authors | Data range x/b | $Re_b$ | Jet spread m | Jet spread A |
|---|---|---|---|---|
| Bradshaw & Gee [18] | 339 to 1459 | 6.0E+03 | 1 | 0.071 |
| Eriksson *et al*. [22] | 5.2 to 208 | 9.6E+03 | 1 | 0.078 |
| Wygnanski *et al.* [20] | 30 to 100 | 1.0E+04 | 0.88 | ? |
| Abrahamsson *et al.* [13] | 30 to 175 | 1.0E+04 | 1 | 0.081 |
| Verhoff [15] | 104 to 417 | 1.0E+04 | 1 | 0.082 |
| | 57 to 229 | 1.2E+04 | 1 | 0.077 |
| Schwarz & Cosart [14] | 24 to 42 | 1.4E+04 | 1 | 0.085 |
| Schneider & Goldstein [23] | 43 to 110 | 1.4E+04 | 1 | 0.077 |
| Abrahamsson *et al.* [13] | 30 to 175 | 1.5E+04 | 1 | 0.077 |
| Wygnanski *et al.* [20] | 30 to 140 | 1.9E+04 | 0.88 | ? |
| Abrahamsson *et al.* [13] | 70 to 175 | 2.0E+04 | 1 | 0.075 |
| Schwarz & Cosart [14] | 24 to 42 | 2.0E+04 | 1 | 0.069 |
| | | 3.0E+04 | 1 | 0.056 |
| Gartshore & Hawaleshka [16] | 18 to 124 | 3.1E+04 | 1 | 0.066 |
| Schwarz & Cosart [14] | 24 to 42 | 4.2E+04 | 1 | 0.061 |
| Förthmann [12] | 3 to 33 | 5.4E+04 | 1 | 0.082 |
| | | | arithmetic mean | 0.074 |
| | | | sample standard deviation | 0.008 |

## Radial wall jet

| Authors | Data range r/D | $Re_D$ | $y_D/D$ | Jet spread n | Jet spread B |
|---|---|---|---|---|---|
| Bakke [4] | 5 to 10.7 | 6.4E4 | 0.53 | 0.94 | ? |
| Cooper *et al.* [7] | 3 to 7 | 2.3E4 | 2 | 1 | 0.073 |
| | 3 to 6 | | 10 | 1 | 0.083 |
| Knowles & Myszko [8] | 2 to 9 | 9.0E4 | 2 | 1 | 0.091 |
| | 3 to 10 | | 10 | 1 | 0.109 |
| Bradshaw & Love [5] | 3.2 to 20 | 1.8E5 | 18 | 1 | 0.088 |
| | | | | arithmetic mean | 0.089 |
| | | | | sample standard deviation | 0.013 |

# Conclusions

- turbulence profile similarity dependency on slot top geometry
- profiles of time-averaged velocity for plane and radial wall jets match within experimental error
- linear spread rate of plane wall jet

  = 0.83 linear spread rate of radial wall jet

# Future work

- turbulence profile similarity dependency on slot top geometry
- investigation of the $Re_b$ dependency of the velocity decay parameters
- measurements in large plane wall jet facility (2.5 m x 2 m cross-section)

# Acknowledgements

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